Pacific Salmon Commission Run-size Estimation Procedures: An Analysis of the 1994 Shortfall in Escapement of Late-run Fraser River Sockeye Salmon

May, 1995

Pacific Salmon Commission
Technical Report No. 6

The Pacific Salmon Commission is charged with the implementation of the Pacific Salmon Treaty, which was signed by Canada and the United States in 1985. The focus of the agreement are salmon stocks that originate in one country and are subject to interception by the other country. The objectives of the Treaty are to 1) conserve the five species of Pacific salmon in order to achieve optimum production, and 2) to divide the harvests so each country reaps the benefits of its investment in salmon management.

Technical Reports of the Pacific Salmon Commission present results of completed or ongoing investigations carried out by the Pacific Salmon Commission that are deemed of sufficient interest to be made available to the scientific community and the public.

Pacific Salmon Commission staff wish to acknowledge contributions to this report made by members of the Joint Fraser River Technical Committee, Fraser River Panel members, and technical experts from Canada and the United States who attended and participated in the February 2-3, 1995 and April 26, 1995 workshops.

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TABLE OF CONTENTS

TABLE OF CONTENTS, continued

EXECUTIVE SUMMARY

1. The 1994 run of Fraser River sockeye salmon approached the Fraser River mainly through Johnstone Strait. This produced large abundances of fish in Canadian fishing Areas 11-16 where over 6 million fish were harvested, or approximately one-half of the commercial catch of all Fraser River sockeye in 1994. Escapements of late-run sockeye to the Strait of Georgia were fished in both Canadian and United States waters under regulations promulgated by the management agencies in the two countries. Catches of late-run sockeye salmon in the Strait of Georgia and lower Fraser River totalled 1,331,000 fish.

2. In late September, 1994, Pacific Salmon Commission staff identified a large shortfall in the gross escapement of late-run Fraser River sockeye salmon. After fisheries in the Strait of Georgia and lower Fraser River had closed for the season, the PSC staff estimate of the number of late-run sockeye available for gross escapement was 3,340,000 fish. Estimates of in-river Native fishery catches below Mission and Mission hydroacoustic estimates of escapement, however, resulted in an in-season gross escapement estimate of only 1,138,000. After completion of estimation programs in the Fraser watershed, Canada Department of Fisheries and Oceans post-season estimate was a total of 1,645,000 late-run sockeye in Native fishery catches and spawning ground escapements.

3. Canada and the United States approved the Pacific Salmon Commission plan for a bilateral review of run-size estimation procedures used in-season by PSC scientific staff. The review was led by PSC staff and included members of the Fraser River Panel Joint Technical Committee, experts from the two countries, members of the Fraser River Panel and members of the Fraser River Sockeye Public Review Board.

4. While late-run sockeye abundance was over-estimated in 1994, sockeye runs in 1993 were under-estimated and summer-run sockeye abundance in 1994 was also under-estimated by a small amount. Factors that may have led to the over-estimation of late-run sockeye in 1994 were identified at the first workshop on February, 2-3, 1995, and explored at the second workshop on April 26, 1995.

5. The methodology used by PSC staff for in-season run-size assessment was examined during the review. The three models that were used in-season provided similar estimates of late-run sockeye escapement to the Strait of Georgia and, thence, after subtraction of catch in the Strait of Georgia and the lower Fraser River, gave similar estimates of the number available for gross escapement. Post-season catch and racial analysis information used in the same models gave a greater range of estimates, but catch estimation errors and racial analysis imprecision did not fully explain the run-size estimation errors.

6. Analysis of post-season data showed that the large abundance of sockeye and the large purse seine fleet that fished in Johnstone Strait produced high harvest rates and record catches of late-run sockeye. Purse seine catch and CPUE models and the cumulative-normal model used in the assessments generated larger over-estimates of abundance using the post-season catch data than were obtained in-season. Extrapolation of the late-run regression models by applying 1994 data, which was much larger than the range of previous observation, may have been partly responsible for the over-estimation using purse seine models. A fundamental change in the Johnstone Strait purse seine harvest rates was identified as a major factor in the failure of the cumulative-normal model to correctly estimate the late-run abundance and number of fish available for gross escapement.

7. Harvest rates obtained in-season for summer-run sockeye were found to be substantially below those calculated using post-season estimates of catch and racial composition. During the 1994 fishing season, the error in summer-run harvest rate estimates led to the false conclusion that the use of 1983 harvest rates were appropriate for late-run sockeye. PSC staff did not adjust late-run harvest rates in the cumulative-normal model because of this finding. Also, when the low summer-run harvest rates were applied to late-run catch estimates, the exploitation rate model produced over-estimates of the number of late-run sockeye that entered the Strait of Georgia. Had correct catch and racial composition data been available in-season, higher harvest rates would have been used, thus lowering the in-season run size and escapement estimates from the cumulative-normal and exploitation rate models.

8. As a result of this investigation, the PSC will modify some assessment methodologies. First, the PSC will make changes to the purse seine catch and CPUE models. Second, Johnstone Strait purse seine harvest rates for recent years (1992-94) will be incorporated into the cumulative-normal model. In-season assessment of summer-run sockeye delay in the Strait of Georgia will be undertaken to avoid errors in summer-run exploitation rate models used for estimation of late-run escapement to the Strait of Georgia.

9. We recommend the establishment of a purse seine test fishery at the southeast end of the Johnstone Strait commercial fishing area, primarily to verify the arrival of expected numbers of fish at the commercial fishery boundary. Data on the rate of travel for sockeye salmon through the Johnstone Strait fishery area would also be obtained. Direct measurement of late-run sockeye escapement to the Strait of Georgia would be a future goal for this new test fishery.

10. We recommend that the area over which the Johnstone Strait fishery operates be reduced. This recommendation stems from the need to reduce harvest rates, stabilize the fishery in the future, improve manageability and provide high quality catch data for assessment of run sizes and measurement of escapement to the Strait of Georgia.

11. We recommend that methods for in-season and post-season catch estimation in Juan de Fuca and Johnstone Strait purse seine and gillnet fisheries be improved to provide more accurate and timely catch data for run-size assessment.

12. We recommend that emerging genetic (DNA) technologies be investigated, with the goal of improving the in-season racial identification of sockeye salmon stocks in the future. Improvements of stock composition estimates in catches used for assessment of run size is important to the scientific management of Fraser River sockeye salmon.

INTRODUCTION

Responsibility for management of Fraser River sockeye and pink salmon stocks is shared between the Government of Canada and the Pacific Salmon Commission (PSC) in accordance with the terms and conditions established by the August 13, 1985, exchange of diplomatic notes between the two governments party to the Pacific Salmon Treaty. The Fraser River Panel, a body of the PSC, is charged with the responsibility to meet annual objectives of escapement (set by Canada) and international catch sharing (set by agreement through the aegis of the PSC). The Panel meets its objectives through in-season regulation of United States and Canadian fisheries within an area defined as the "Fraser River Panel Area" (Figure 1).

In order to meet the major objectives of the Treaty, PSC scientific staff conduct in-season assessments of returning run size by stock group, arrival timing and routes of migration. These assessments are performed by PSC staff, using data provided by the management agencies of the two countries and collected directly through staff-conducted field and laboratory programs. In 1994, notwithstanding the fact that international catch-sharing arrangements were not agreed between the two countries, PSC staff conducted its regular programs and provided in-season analyses to the management agencies of the two countries.

Abundance estimates provided by PSC staff during the 1994 season, and the underlying technology and methodology used to generate those estimates, first became subject to wide public scrutiny in mid-September when the Canada Department of Fisheries and Oceans (DFO) announced that a serious discrepancy existed between summer-run sockeye escapement estimates generated by the PSC's Mission hydroacoustic program and DFO's upstream accounting. This situation resulted in establishment of the "Fraser River Sockeye Public Review Board" (FRSPRB), which published its report dealing primarily with this issue in early March, 1995. The Mission Hydroacoustic Facility Working Group concluded, and the Public Review Board concurred, that "...although the potential biases [in the methodology] raise some concerns, these are unlikely to lead to serious errors in escapement estimation" (FRSPRB 1995, p.85).

The second area of concern regarding the PSC's abundance estimation procedures became evident by late September, 1994, when the abundance of late-migrating sockeye stocks fell substantially short of in-season assessments. PSC staff made an in-season projection of 4,600,000 late-run sockeye that reached the Strait of Georgia. Catches removed by United States and Canadian fisheries in the lower portion of the Strait of Georgia totalled 1,260,000, leaving an estimated 3,340,000 sockeye for gross escapement. This figure was very close to Canada's adjusted gross escapement goal of 3,400,000 set September 2, 1994.

Hydroacoustic estimates at Mission, however, indicated that the actual late-run sockeye gross escapement totalled only 1,055,000 fish. Post-season revision of stock identification estimates placed the total, which includes Native fishery catches below Mission, at 1,138,000 sockeye. Later, the estimated spawning escapement plus the Fraser River Native fishery catch of these stocks, based on DFO's post-season accounting, totalled 1,645,000 sockeye. These totals were 1,695,000 to 2,202,000 fish short of the number projected to have remained in the Strait of Georgia, and therefore available for gross escapement, after all marine fisheries in both Canada and the United States had closed.

This situation led the Pacific Salmon Commission to announce on September 30, 1994, that it would conduct a bilateral review of run-size estimation procedures used in-season by the PSC's scientific staff. This review, while it was to be led by PSC staff, included the Fraser River Panel's Joint Technical Committee, which comprises representatives from both the United States and Canada, augmented by

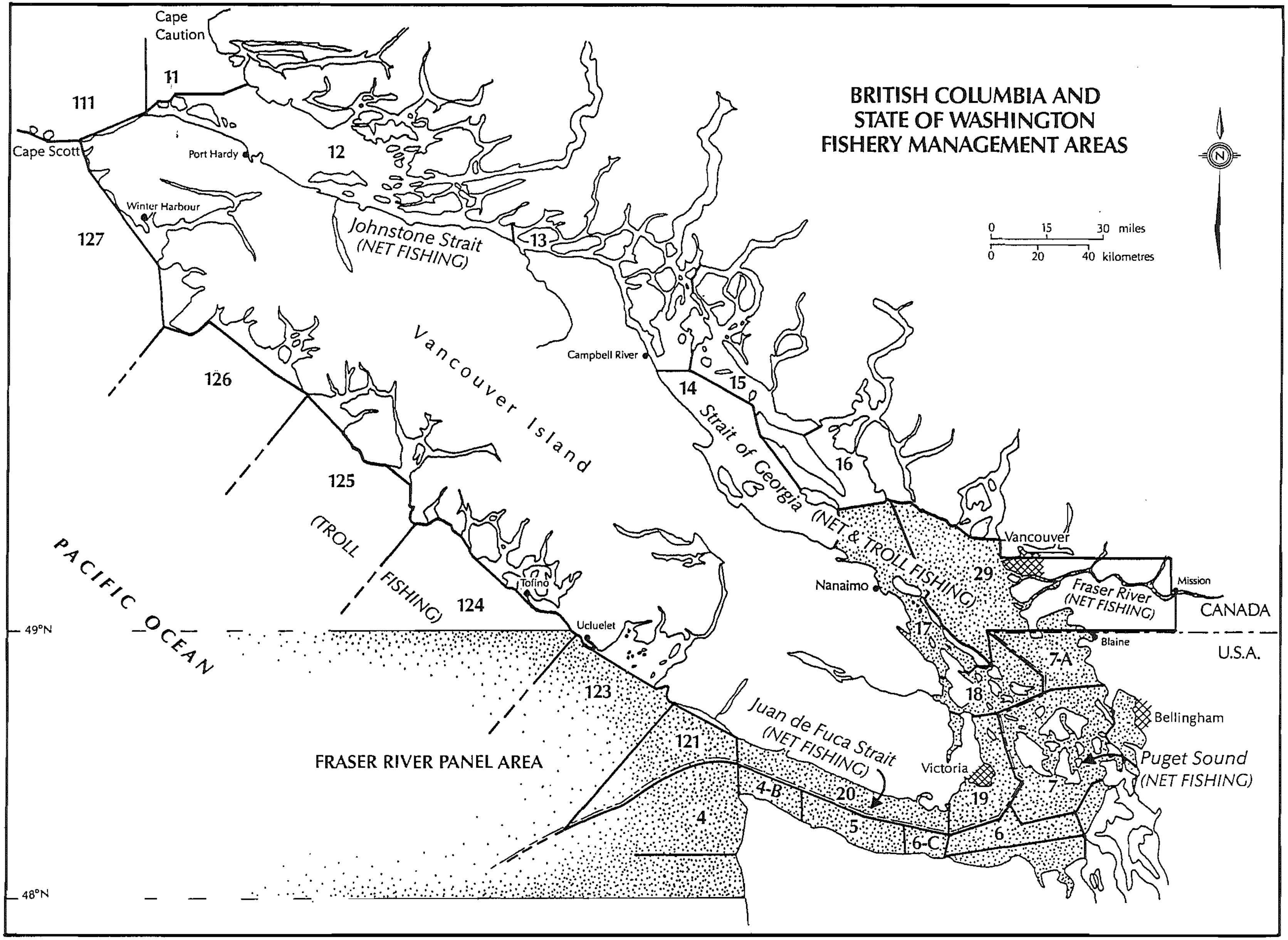

Figure 1. Fishery management areas and commercial gear used in the Fraser River Panel Area and Canadian south coast waters.

additional technical experts from the two countries, members of the Fraser River Panel, and members of the FRSPRB. A list of the participants in the two workshops conducted during this review is in Appendix A.

This report presents the analysis of data relevant to the 1994 shortfall of late-run sockeye escapements. We provide an assessment of the problem in terms of the essential elements that led to the error in estimation. As well, we attach appendices which contain detailed analyses of the possible impact that various factors may have had on the estimation process. Implementation of recommendations of the report, which include improvements to run-size estimation models, direct monitoring of escapement in lower Johnstone Strait and options for improved management, will reduce the likelihood of such large differences between estimates of late-run sockeye escapement in future years.

BACKGROUND

It is vital to understand the biology of late-run sockeye stocks and the process of escapement estimation in order to follow the analysis. The sockeye stocks which the Fraser River Panel has identified as "late-run stocks" for management purposes are: Birkenhead River, Adams River/Lower Shuswap River, Weaver Creek, Portage Creek, Cultus Lake and Harrison River stocks, plus a few minor stocks that spawn in lower Fraser River tributaries. Each stock has a unique production cycle with annual return abundances varying by up to three orders of magnitude (i.e., 1,000X). These stocks have their largest combined abundance on the 1994 cycle when the Adams/Lower Shuswap stock complex has its peak or "dominant" cycle line return. Returns in 1994 were primarily 4-year-old fish from the spawning in 1990. The pre-season forecast of total late-run abundance was 7,100,000 fish or about 37% of the expected total return of Fraser River sockeye in 1994 (Appendix B; Table 1).

Behaviour of late-run sockeye differs from other Fraser River sockeye stocks in several respects. These sockeye return later in the season than most "summer-run" stocks, generally peaking in mid to late August in Juan de Fuca and Johnstone Straits. More importantly, after arrival in the Strait of Georgia, late-run sockeye typically delay in deep water for variable periods before entering the lower Fraser River and proceeding upstream. Birkenhead sockeye delay 7-10 days but may hold for up to 3 weeks. Adams/Lower Shuswap sockeye spend approximately 3-4 weeks between peak arrival into the Strait of Georgia and the peak at the Cottonwood test fishing site in the lower Fraser. Weaver, Portage, Cultus and Harrison sockeye appear to delay from 3 to 6 weeks with variable timing of upstream movement, which on some cycles does not peak until the first half of October.

The delay behaviour of late-run sockeye stocks results in two main considerations in the management process. First, by the time these fish enter the lower Fraser River, the skin and flesh coloration has changed to the point that they are less desirable for fresh, frozen or canned use. Consequently, prices paid to fishermen for these fish are lower than prices paid for the same fish caught a few weeks earlier in migratory areas. Therefore, in the interest of optimizing the economic value of the fish, industry greatly prefers to catch the bulk of the harvest in marine migratory areas where fish are "silver-bright". The quality of late-run sockeye is highest in "outside" troll and Juan de Fuca and Johnstone Strait purse seine and gillnet fisheries in Canada, and Puget Sound purse seine, gillnet and reef net fisheries in the United States (Figure 1). "Inside" trollers fishing in the Strait of Georgia also catch high quality fish if openings are permitted soon after the fish arrive in the Strait. Late-run sockeye are not highly available to the Area 29 gillnet fleet until the fish begin to mature and press in toward the river mouth. At this time, catches can be large, but fish quality has begun to decline.

Second, the several-week delay in the Strait of Georgia means that by the time enough late-run fish reach Mission to allow a direct assessment of the total number available for gross escapement, the run through the marine migratory areas is essentially completed. Estimates of escapement at Mission simply come too late to allow the number reaching the Strait of Georgia to be adjusted upwards or downwards by modifying fishery regulations in marine areas.

Following is a list of terms that are used in this report to describe the abundance of late-run sockeye at various locations:

Pre-season forecast: The DFO pre-season expectation of sockeye salmon returns for a particular stock, stock group or for Fraser sockeye as a whole.

Run-size estimate: The in-season estimate of the abundance of a particular stock, stock group or the total Fraser sockeye run, obtained by use of mathematical "models" that are designed to produce accurate, precise estimates using data available from commercial and test fishery catches and from the Mission hydroacoustic program.

Total run: The total abundance of adult sockeye for a particular stock, stock-group or for Fraser sockeye as a group, for the year of return. Estimates of all catches, spawning escapements and en-route mortalities are included.

Escapement to the Strait of Georgia: The abundance of adult late-run sockeye that "escape" from fisheries in Johnstone Strait (Canadian Areas 11-16) and Juan de Fuca Strait (Canadian Area 20 and United States Areas 4B, 5, 6, 6C, 7 and 7A) into the Strait of Georgia. This number includes all catches in the terminal areas that occur thereafter, specifically Area 29 commercial fisheries, Strait of Georgia and Fraser River Native fisheries, sport and test fisheries and escapements to spawning grounds in the Fraser River watershed. United States Area 7A is a special case, where catches may include fish designated as "escapement to the Strait of Georgia" as well as catch of migrating fish.

Number of sockeye available for gross escapement: The estimate of late-run sockeye escapement to the Strait of Georgia (as above) minus all terminal area (Strait of Georgia and lower Fraser River) catch, except for the in-river Native fishery. This number is the in-season estimate of late-run fish available for in-river Native catch and spawning escapement.

Gross escapement based on Mission: The estimate of late-run sockeye escapement obtained at the Mission hydroacoustic site plus the Native fishery catch below Mission. This estimate is not available for in-season management because late-run sockeye delay in the Strait of Georgia.

Gross escapement based on upstream accounting: The sum of DFO late-run sockeye spawning ground escapement estimates, estimates of all catches by the in-river Native fishery and en-route mortality. This estimate is not available until mid-winter following the fishing season.

ESTIMATION METHODS

In-season assessments of returning run size and arrival timing by stock group and routes of migration (Figure 2) are conducted using data obtained by PSC staff through an integrated data collection program with four components (Woodey 1987): 1) catch estimation, 2) test fishing, 3) stock identification, and 4) escapement estimation. We estimate catches made in commercial fisheries in the Fraser River Panel Area (Figure 1) and obtain catch estimates from the two countries for fisheries

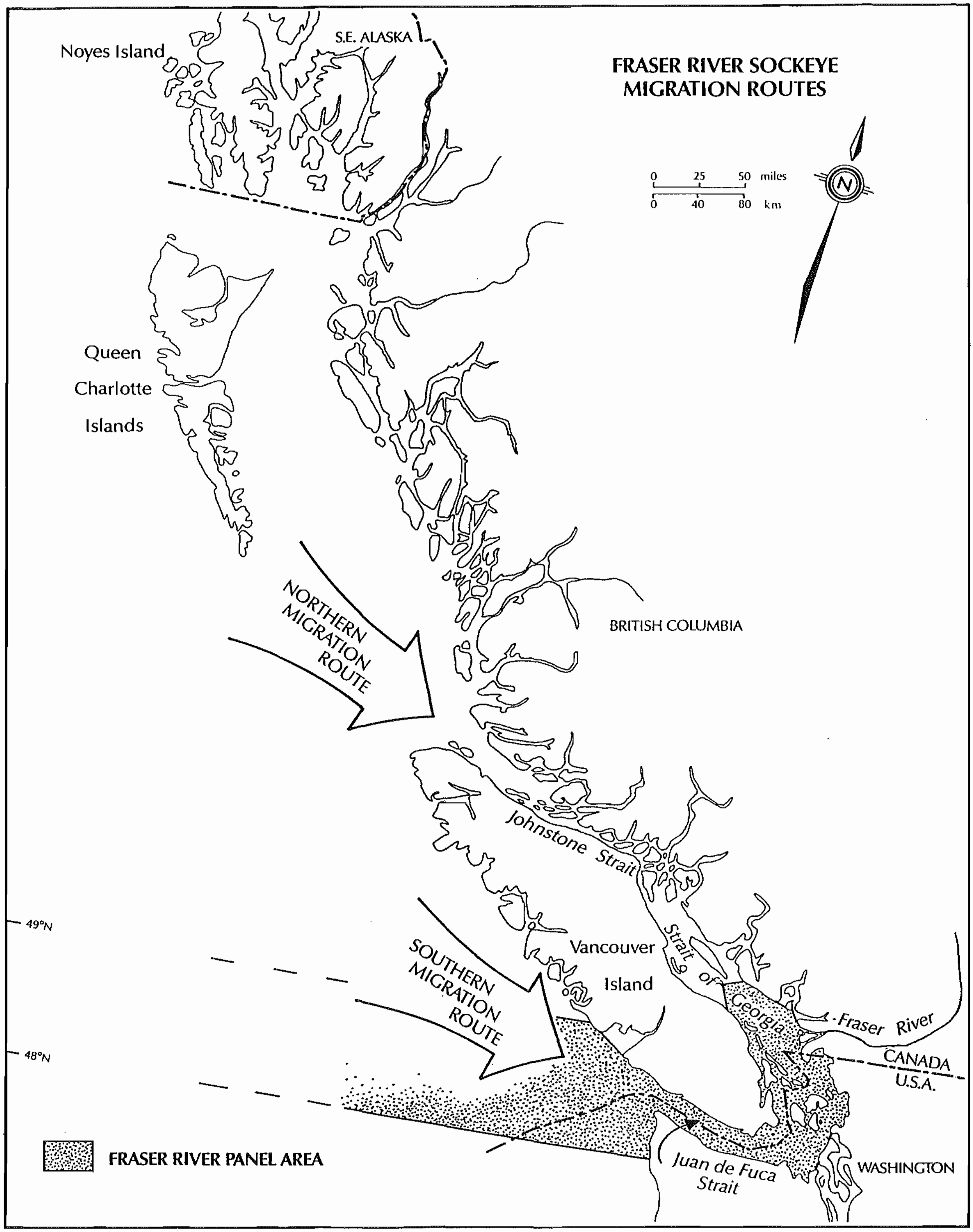

Figure 2. The northern (Johnstone Strait) and southern (Juan de Fuca Strait) routes for sockeye and pink salmon migrating to the Fraser River.

outside the Panel Area. During periods prior to and after the commercial fishing season and between openings within the season, test fishing is conducted to obtain indices of abundance and to provide biological samples for racial analysis. Scales and biological data obtained from samples of commercially caught sockeye and from test catches are analyzed in the PSC laboratory to estimate stock proportions (Gable and Cox-Rogers 1993). Daily escapements of sockeye salmon are estimated at Mission by a hydroacoustic estimation procedure (Banneheka et al. in press). These catch and escapement data by stock form the basis of the analyses used to estimate stock abundances, arrival timing and routes of migration as each stock appears on the coast and migrates through Juan de Fuca and Johnstone Straits toward the Fraser River.

Estimates of total run by stock group are based either on historical regression relationships that relate run size to catches or cumulative catch and escapement, or on estimates of catch in the current year divided by harvest rates obtained from the current or past years' data. Escapement to the Strait of Georgia is estimated by subtracting the estimated catch from the weekly or total run size. For summer runs, weekly gross escapement estimates can be cross-checked in-season based on estimates obtained from the Mission hydroacoustic program plus any catches that may occur within the Strait of Georgia or Fraser River. Such in-season feedback can also be used to modify the harvest rates that are used in run-size models. However, because of delay behaviour, estimates of gross escapement for late-run sockeye from the Mission program come too late to provide a useful cross-check on the projections of the number available for gross escapement. Furthermore, no in-season feedback is available on harvest rates for late-run stocks. Therefore, three alternative methods of estimating escapement of late-run sockeye to the Strait of Georgia have been developed with the goal that a comparison of the estimates from the three models could provide a form of cross-check.

Three run-size estimation models have been developed for estimating summer-run sockeye abundance. In the first type of model, Canadian Juan de Fuca and Johnstone Strait purse seine catch and catch per unit of effort (CPUE) data are used to obtain a total abundance estimate for each stock. In the second type of model, catches and escapements are adjusted to a common migration point to obtain daily abundances and cumulative abundance-to-date. Cumulative totals are then regressed on run size for the years of record to obtain a prediction model for use in future seasons. In the third method, these cumulative daily abundances are regressed on a series of cumulative-normal abundances obtained by varying the size and spread (variance) of normal curves. Maximization of the fit between the observed data and the generated normal distributions provides an estimate of abundance and timing of the run.

For estimating the run size of late-run sockeye, the purse seine catch and CPUE models are applied as for summer-run stocks. The escapement of late runs to the Strait of Georgia is then estimated by subtraction of migratory area catch from the run-size estimate. Cumulative passage models (second model above) cannot be applied to late-run stocks because the necessary escapement data are unavailable. However, the cumulative-normal model has been modified for use with late runs by the incorporation of historical harvest rates, which are applied to catch estimates in Juan de Fuca and Johnstone Straits net fisheries to obtain daily abundance estimates. These daily abundances are then treated the same way as for summer-run stocks, i.e., cumulative daily totals are regressed on the cumulative abundances from a suite of normal curves of varying run size and spread. Escapement of late-run sockeye to the Strait of Georgia is again obtained by subtraction of migratory area catch from the estimated run size. In addition to these two methods of projecting escapement of late runs, a third method has been developed which uses harvest rates estimated from catch and in-season escapement of co-migrating summer-run sockeye. Daily and weekly harvest rates in Juan de Fuca and Johnstone Straits migratory area fisheries are calculated during the season for summer-run stocks and applied to late-run catch estimates from these fisheries to obtain daily and weekly abundance estimates of the latter.

Escapements to the Strait of Georgia are then estimated by subtraction of the daily or weekly catch. Each of these methods is briefly explained below.

Commercial Purse Seine Models

Historically, regression of run size on peak week catch and CPUE for purse seine fisheries in Juan de Fuca and Johnstone Straits (Appendix C) was the major source of run-size information. In Area 20 and Areas 12 and 13, fish are confined to relatively narrow migration routes and are highly vulnerable to purse seine fisheries. These fisheries harvest sockeye which are from four to eight days' migration distance from the Strait of Georgia. Catch information from fisheries early in the week normally provide estimates for Friday Panel meetings and allow for the development of fishing plans in Panel Area and non-Area fisheries for the following week. These models require accurate estimates of total purse seine catch and gear count by area, and information on the duration of each fishery and area restrictions.

Purse seine catch models are particularly important for assessing late-run sockeye abundance, because they provide run-size estimates early enough to adjust outside fisheries to meet escapement and catch allocation goals. Purse seine catch and CPUE models can only confidently be used for data within the range of past experience. The relationships between catch or CPUE and run size that the models represent cannot be extended beyond previous limits without making additional assumptions. Consequently, when the catches, fleet sizes or fishery durations lie outside the range of previous experience, uncertainty in the resulting estimates increases. While the potential error on any estimate which is beyond the range of past observations will be quite large, but there may be no option **but** to use these estimates.

Pursuant to a recommendation from the 1993 PSC Workshop on run-size estimation, we developed methods to "adjust" the catches that were entered into the purse seine catch and CPUE models. The goal here was to compensate for unusually large catches taken in northern fisheries (Canadian Areas 1, 2W, 8, 101 and 142) that deform the arrival curve. To determine these "adjusted" catches, purse seine and troll catches taken in northern fisheries were incorporated into daily migration estimates to form a theoretical "unfished" arrival pattern in Area 12. Johnstone Strait purse seine catches of these fish that would have been taken had they not been intercepted in seaward fisheries were added to the observed catches to form an "adjusted catch" and "adjusted CPUE". These adjusted figures were used in in-season models.

Cumulative Passage Model

Regression models have been developed comparing the run size of summer-run stocks in past years to the reconstructed cumulative abundances of those stocks referenced to a common migration location, i.e., the Fraser River at Mission (Appendix D). Daily catches in all Panel and non-Panel Area fisheries and daily Mission hydroacoustic estimates of escapement for individual stocks are adjusted to common dates of migration and summed by day for the period of migration. The daily totals are then summed to give cumulative totals for each date and year. Regression of annual run sizes on cumulative abundances to a particular date then provides a means of assessing the current year run size at any date by using cumulative catch and escapement data in the current year. Two sets of regressions are calculated for each stock, one which uses only the accounted run to date, and a second which includes date of peak run timing for each year as an additional variable.

Annual reconstructions are performed in a given year for all uniquely identified summer-run stocks or stock groups. Models have not been developed for late-run stocks because the delay of these stocks in the Strait of Georgia means that escapement data are unavailable for the in-season reconstruction of daily abundances.

Cumulative-normal Models

PSC staff have developed techniques for run-size estimation based on the assumption that the migration of each returning stock approximates a normal distribution. In-season catches and escapements are adjusted to a common migration point and provide an estimate of the daily unfished abundance at that point. The cumulative daily estimates to each date are then regressed on expected values obtained from a set of normal curves with varying run size, timing and duration parameters (Appendix E). The abundance and timing parameters of the normal distribution scenario giving the best fit (highest r^2 value) to the observed data become the "best" estimates for the run. The model is updated periodically as additional days of catch and escapement data become available. The method relies upon high quality catch and escapement data and on the assumption that the speed of fish movement between areas is consistent between years. Particularly important is the determination of whether summer-run fish are delaying off the mouth of the Fraser River. Delay, if any, causes the escapement component to be inaccurately measured for particular blocks of the migration. The daily gross escapement estimates at Mission then do not reflect the actual escapements of sockeye associated with catches several days earlier in marine areas.

For summer-run sockeye, the method does not rely on historical data except for historical run distribution data that are used to develop scenarios for the model (i.e., the model uses a range of run durations observed in previous years). However, in order to use summer-run sockeye catches for the current week before the arrival of the escapement component at the Mission hydroacoustic site, historical daily harvest rates are used to project escapement from the catch data. These projections are replaced a few days later with Mission estimates.

The cumulative-normal model will provide an estimate of run size at any stage of the run, but the estimates stabilize only after the peak appears at Mission. Cumulative-normal models, in theory, provide a valid method to estimate run sizes beyond the range of previous experience as long as the basic assumptions of the model are met. However, simulation studies have shown that the model is sensitive to deviations from normality caused by skewness or bimodality.

Inputs to the cumulative-normal model for late-run sockeye cannot be estimated in the same manner as for summer-run sockeye because late-run escapements cannot be measured directly. However, an extension of the model has been developed wherein harvest rates for late-run stocks obtained from past years' data are applied to in-season catches in Juan de Fuca and Johnstone Straits fisheries to estimate the daily abundance (i.e., catch plus escapement). These estimated daily abundances are summed day by day during the season and the accumulated total is regressed on a range of cumulative-normal curves as for summer runs (Appendix E). The escapement of late-run sockeye to the Strait of Georgia can be estimated at any point in the season by subtraction of the catch from the estimate of abundance to date.

Johnstone Strait harvest rates from 1983 were used in the 1994 cumulative-normal model estimates of late-run sockeye abundance. The 1983 data were used because 1983 was the only high diversion year for late-run sockeye since 1978. However, summer-run harvest rates in 1993, which was a high diversion year but had few late-run sockeye, were higher than in 1983 and indicated that higher harvest rates may also occur in 1994. Therefore, to assess whether late-run harvest rates in 1994 were consistent with 1983 or with 1993 data, we assessed summer-run harvest rates during the 1994 fishing season. Harvest rates for migratory area fisheries and catches and gross escapements in the Strait of Georgia and Fraser River were calculated weekly. The migratory pattern of sockeye entering Johnstone Strait in 1994 was also monitored to determine if it was similar to that observed for summer runs in 1993. These data were assessed so that modifications to the harvest rates based on 1983 data could be made in-season if warranted.

In July, Canada provided a forecast of a high Johnstone Strait diversion rate for 1994. Since purse seine fishing times in Johnstone Strait had been reduced when high diversion rates occurred in 1992-93, we expected similarly short (single day) purse seine fishery openings in 1994. Due to the length of the Johnstone Strait fishing area (210 km), single day fisheries in Areas 12 and 13 impact five days of migrating fish leaving two days of migration per week for which no purse seine catch and harvest rate data are available to be used to estimate daily abundances. Although extended weekly fishing periods were provided for gillnets, the large variability in gillnet harvest rates did not allow their use to estimate abundance on those days. To provide estimates of migration abundance for those days, data from the purse seine test fishery in Area 12 were substituted, using estimated harvest rates for this vessel calculated from the reconstruction of abundance in the first two weeks of the 1994 season. Thus, the daily data used to generate estimates of late-run sockeye abundance using the cumulative-normal model was obtained from a mix of commercial and test purse seine fisheries.

In-season Summer-run Exploitation Rate Model

Due to the delay behaviour of late-run sockeye, daily escapements of these stocks to the Strait of Georgia cannot be measured by direct monitoring. Therefore, in-season harvest rates for summer-run stocks are applied to catches of Adams/Lower Shuswap sockeye in key migratory area fisheries to estimate the abundance of these latter stocks (Appendix F). Catches are then subtracted from the abundances to obtain the number of Adams/Lower Shuswap sockeye that escape into the Strait of Georgia.

Summer-run exploitation rates are estimated by reconstructing the current-year catches of unique (in terms of scale characteristics) summer-run stocks (e.g., Chilko or Chilko/Quesnel) from all fisheries between Area 20 and the Fraser River and Area 12 and the Fraser. The daily Mission hydroacoustic escapement profile for summer-run stocks is added to these catches to obtain a daily reconstruction of catch and escapement. From these data, both daily and weekly exploitation rates are estimated by dividing the catch by the catch plus escapement.

The migratory area catch profile for the Adams/Lower Shuswap stock group is assembled for the same fisheries as the Chilko or Chilko/Quesnel stock group. The migratory catches of Adams/Lower Shuswap sockeye are divided by the harvest rates calculated for summer-run stocks to obtain estimates of abundance. Migratory area catches of Adams/Lower Shuswap sockeye are then subtracted from the abundance estimate to obtain the number of fish that escape to the Strait of Georgia. Two estimates of Adams/Lower Shuswap escapement are derived, one using daily and the other using weekly exploitation rates. Finally, terminal area catches are subtracted to obtain the number of Adams/Lower Shuswap sockeye that remain in the Strait of Georgia for gross escapement. The number of all late-run sockeye that remain for escapement is estimated by dividing the Adams/Lower Shuswap escapement by the proportion of Adams/Lower Shuswap sockeye in the total late-run group.

Past performance of models

Three models, i.e., purse seine models, cumulative-normal model and summer-run exploitation rate models, have been used in previous years to estimate late-run sockeye escapement to the Strait of Georgia. These estimates can be compared to the post-season accounting of commercial and Native catches in the Strait of Georgia and the Fraser River, plus estimates of spawning escapements. However, the models vary in the number of years that each has been used. This makes direct comparisons of model performance difficult; however, each can be compared to the accounted total in the years of use (Table 1). The performance of the three basic models and their variants has been uneven. No one model has consistently outperformed the others. However, in four of five years of large late-run sockeye abundance for which estimates are available, most in-season estimates of escapement to the Strait of Georgia were lower than the post-season accounted total. A factor in the tendency of the models to produce low estimates of gross escapement is the in-season tendency for catch and CPUE in Juan de Fuca and Johnstone Strait purse seine fisheries to be under-estimated. Purse seine models have been developed with post-season data and, thus, when imprecise in-season data are applied, the models tend to produce low estimates. The cumulative-normal model and summer-run exploitation models are sensitive to in-season catch estimation errors, as well.

Table 1. Estimates of late-run sockeye escapement to the Strait of Georgia obtained in-season by various methods.

Year	Method Used in the Estimate				Accounted Total
	Purse Seine Models	Weekly Harvest Rate [1]	Daily Harvest Rate [2]	Summer-run Exploitation Rate	
1982		2.20-2.49		3.50-4.18	4.36
1986	4.31	(2.30)	4.26	3.41-3.91	4.95
1987		1.53	1.39	1.17	1.10
1990		4.50	4.93	3.74-5.59	5.14
1991	1.93	1.51	1.96	1.32	1.99
Average % Error					
Absolute	8%	30%	12%	17%	
Mean	-8%	-11%	+2%	-15%	

[1] Reconstructed catches divided by historical weekly harvest rates.

[2] Reconstructed catches divided by historical daily harvest rates.

Every run-size estimation model used by the PSC has limitations and variability. The estimates of abundance will differ from the true abundance to some degree. Even if the models are unbiased, imprecision will produce over-estimates in some years and under-estimates in others. By using multiple models, we can often detect problems with the data used in the models. For example, if the peak week purse seine catch and CPUE models are lower than other estimators, it may indicate that the actual peak of the run was missed by the fishery. A second consideration in the appreciation of model performance is that the larger the run size, the greater will be the potential numerical error or variability in estimates. While the rate of variation may be similar between years, a given percentage error will produce a larger numerical error on a larger run. **Because the projection of the number of late-run sockeye available for gross escapement is calculated as a subtraction of catch from run size in all three models, the entire variability or error in the run-size estimate is transferred directly to the escapement estimate.**

In the following analysis the estimate of late-run sockeye remaining for gross escapement into the Fraser River is compared to the gross escapement estimates obtained from sources within the river, both at the Mission hydroacoustic site and from the DFO accounting of in-river Native fishery catches and spawning escapements. These comparisons show the real problem. The number of late-run sockeye estimated to have entered the Strait of Georgia totalled 4,600,000 fish. Subsequent terminal area catches in Canada and the United States harvested 1,260,000 of these, leaving 3,340,000 theoretically available for gross escapement. Accounting using Mission hydroacoustic estimates of upstream migration totalled 1,138,000 fish, for a shortfall of 2,202,000. DFO's subsequent upstream accounting totalled 1,645,000, for a shortfall of 1,695,000. It is this range of discrepancy that is the subject of our analysis.

CHRONOLOGY OF THE 1994 SOCKEYE SEASON

Despite the lack of agreement between the countries on allocation of the total allowable catch (TAC) in 1994, PSC staff carried out all of their normal assessment functions and reported on the progress of the runs. Estimates of catches, escapements and racial composition and in-season projections of abundance, arrival timing and rate of northern (Johnstone Strait) diversion were provided to the national section managers for the United States and Canada at twice weekly meetings. All fishery regulations were promulgated by the management agencies within each country.

Prior to the 1994 fishing season, Canada provided the PSC with abundance forecasts for Fraser River sockeye by stock or stock group (Appendix B; Table 1). In addition, forecasts of run timing for major stocks and Johnstone Strait diversion rate (68%) were provided for PSC staff use in stock assessments.

Chronology of Sockeye Salmon Migrations

Early Stuart sockeye are the earliest to arrive of all Fraser stocks, arriving in the lower Fraser River from late June to late July. Abundance estimates from Area 20 test fishing and escapement estimates from the Mission hydroacoustic program indicated a lower run size than forecast, (Appendix B; Table 2) but with near normal arrival timing and diversion rate.

Overlapping the second half of the Early Stuart run are the early summer-run stocks. Early summer-run sockeye are a group of stocks which normally arrive in Juan de Fuca and Johnstone Straits from early July to mid August and peak in late July. In 1994, these stocks arrived a few days later than normal and their estimated abundance was lower than forecast. By the first week of August, the abundance estimates for these stocks had increased relative to earlier in-season estimates. The estimated migration via Johnstone Strait was approximately 50-60% of the total, indicating somewhat above average diversion.

Early summer and summer-run sockeye that reached the mouth of the Fraser River in late July behaved in an unusual fashion. Instead of migrating immediately up the river, some delayed for several days, possibly as a result of high river water temperatures. Although most of these sockeye then entered the Fraser in early August, an extended delay by some fish was apparent. Summer-run sockeye arriving in early to mid August apparently displayed similar unusual behaviour. The delay of summer-run sockeye was a critical aspect of the 1994 migration, in that it potentially added error to late-run estimates from models based on an orderly summer-run migration. Portions of the daily escapements in early to mid August were attributed to earlier migration periods to compensate for the delay.

Summer-run sockeye were estimated to be a week late in arriving in migratory fisheries and peaked in the second week of August. The abundances of the individual stocks in this run differed substantially from the pre-season forecasts, and the total was approximately 30% below forecast. Diversion rates progressively climbed from 50-60% in the first week of August to approximately 80% in the second week of August.

Late-run sockeye predominated in the catches beginning in the third week of August and continued to form the bulk of the catch until the end of the season. The peak timing of Adams/Lower Shuswap sockeye stocks was August 18 (relative to Area 20), which was four days earlier than normal for the dominant cycles of these stocks. The diversion rate of late runs reached approximately 90% and 95% in the third and fourth weeks of August, respectively.

Chronology of Run-size Estimates

Summer-run sockeye run-size estimates were based on methods outlined in the Estimation Methods section. The Early Stuart sockeye run was forecast at 400,000 fish in 1994 (Appendix B; Table 1). No non-Native commercial fishing took place while Early Stuart sockeye were present. Therefore, run-size estimates for this stock group were based on test fishing catches in Area 20 and on Mission hydroacoustic estimates of escapement. On July 15, the run size was estimated at 200,000 fish (Table 2). After all Early Stuart fish had passed Mission, the run-size estimate was reduced to 190,000 fish, which was the in-season total number of fish accounted in escapement, and in test fishing and Native catches below Mission. Using updated catch estimates and post-season racial analyses of catches and Mission escapements, the Early Stuart run size was estimated at 202,000 fish (Appendix B; Table 2).

Table 2. Comparison between 1994 in-season sockeye run-size estimates and post-season estimates based on Mission hydroacoustic estimates of escapement.

	In-season		Post-season
Run	Date	Estimate	Estimate
Early Stuart	July 15	200,000	
	July 29	190,000	202,000
Early Summer	August 5	800,000	
	August 19	850,000	1,267,000
Summer	August 19	7,000,000	7,363,000
Late	August 26	9,000,000	
	September 6	9,300,000	7,910,000
Total Fraser	September 6	17,500,000	16,742,000

Early summer runs were forecast at 1,117,000 fish. The major contributor was expected to be the Seymour/Scotch stock group. These fish rear in Shuswap Lake and are indistinguishable from Adams/Lower Shuswap sockeye in the scale-based racial analysis. However, Seymour/Scotch sockeye are early timed fish which normally enter the Fraser River upon arrival in the Strait of Georgia. We used the ratio of this group to summer-run stocks with unique scale characteristics (Chilko/Quesnel) in in-river commercial and test fishing samples to estimate their proportion in marine areas where they mix with Adams/Lower Shuswap sockeye. On August 5, the total abundance of early summer sockeye was estimated to be approximately 800,000 fish (Table 2), which was later revised to 850,000. The post-season abundance estimate increased greatly to 1,267,000 fish (Appendix B; Table 2), due to larger post-season estimates of catch and because revisions to the post-season stock composition ratios of Seymour/Scotch fish relative to the Chilko/Quesnel stock group in the river samples resulted in increased estimates of the proportion of the Seymour/Scotch group in marine area catches.

Chilko and Quesnel sockeye stocks were forecast to provide the bulk of the summer-run sockeye return in 1994 with Stellako and Late Stuart stocks to return in smaller numbers. A total return of 10,336,000 sockeye was expected for summer-run stocks (Appendix B; Table 1). The peak of abundance occurred in the second and third weeks of August in Johnstone Strait net fisheries. The run size was estimated to be 7,000,000 fish on August 19 (Table 2). The final accounting of abundance using Mission hydroacoustic estimates of escapement is 7,363,000 or 5.2% higher than estimated in-season.

Late-run abundances were forecast at 7,104,000 fish (Appendix B; Table 1). The Adams/Lower Shuswap component was expected to contribute 6,000,000 of this total. Estimates of late-run abundance were made weekly during the fishing period. The high diversion rate and characteristic delay of late-run sockeye resulted in the Johnstone Strait fishery providing the main information used for run-size estimation in 1994. Total late-run abundance was estimated at 9,000,000 fish on August 26 and updated on September 2 to 9,300,000 fish (Table 2). The post-season accounting of the catch and Mission escapement of late-run stocks was 7,910,000 fish or 14.9% less than estimated in-season (Appendix B; Table 2). However, the final run-size estimate was 800,000 fish larger than the pre-season forecast.

The total Fraser River sockeye run was estimated in-season at 17,500,000 fish compared to the pre-season forecast of 19,000,000. The post-season accounting using Mission hydroacoustic estimates of escapement is 16,742,000 sockeye. Larger post-season estimates of early summer and summer-run stocks partially offset the lower abundance of late-run sockeye, but the total run size estimated in-season was 4.5% higher than the post-season estimate.

Chronology of Fisheries

Fisheries on Fraser River sockeye entering Juan de Fuca Strait began July 19 when United States Treaty Indian gillnet fisheries commenced in Areas 4B, 5 and 6C. United States Areas 7 and 7A Treaty Indian and Non-Indian fisheries began on August 2. Canadian gillnet fishing in Area 20 opened July 31, outside troll fishing off the west coast of Vancouver Island commenced August 1 and purse seines in Area 20 began fishing on August 3. Catches in Juan de Fuca Strait and in Puget Sound (except at Point Roberts) were highest in the first ten days of August, after which the combined removals in troll and net fisheries seaward of each area and the progressively increasing diversion rate caused catches to decline.

Canadian fisheries in Johnstone Strait commenced for gillnets on August 1 and for purse seines on August 8. Large catches in the Area 12 and 13 purse seine fishery and declining abundances in Juan de Fuca Strait led to a shift in purse seine effort into Areas 12 and 13 on the August 15-16 fishery and again for the August 22 opening. The peak catch in the Johnstone Strait purse seine fishery of approximately 1,736,000 sockeye occurred on August 15-16. The August 22 catch was also very large, (1,049,000). The final Johnstone Strait purse seine fishery was conducted on August 31. By this time the abundance had fallen greatly and a catch of only 177,000 sockeye was made. Johnstone Strait fisheries in 1994 were notable for the very high purse seine effort, the shortness of the openings (three weekly fishing periods of 12 hours and one weekly period of 24 hours) and very large catches.

Sockeye fishing commenced in the Fraser River in early July. In-river Native fisheries targeted summer-run stocks but also continued into September on late-run sockeye. Non-Native commercial fisheries opened August 1 in the Strait of Georgia for trollers and August 7 in the Fraser River. The last non-Native commercial fishery for sockeye was on August 31.

During August, PSC staff reviewed the summer-run harvest rates for the first three Johnstone Strait fisheries to assess whether harvest rates were unusual. We examined the gross escapements and catches in Area 29 relative to catches in Juan de Fuca and Johnstone Straits. We concluded that harvest rate for the first Johnstone Strait fishery on August 8 was 29% or only 65% as effective as the 1983 harvest level and substantially less than observed in 1993. This low harvest rate appeared to be due to a concentrated migration through the closed portion of Area 12 along the mainland shore of Queen Charlotte Sound (Areas 12-7 and 12-13). This theory was supported by the rapid rise in purse seine catches in the Robson Bight (Area 12) test fishery after the commercial fishery closure. The weekly harvest rate for the August 15 fishery was estimated to be 55%. The final assessment of late-run sockeye estimated to have reached the Strait of Georgia was made on August 29 for fish that arrived from August 12 to 27. Summer-run harvest rates were estimated to be 40% for the period. As a result of these analyses, we concluded that the 1983 late-run harvest rates were the most appropriate rates to use in 1994.

Fisheries targeting late-run sockeye in the Strait of Georgia began in mid August and ended in early September. Canadian troll vessels licensed for both inside and outside waters harvested sockeye in Areas 11-13 and 29. Canadian Native fishing conducted in Johnstone Strait and Strait of Georgia harvested late-run sockeye, as well. United States gillnet and purse seines fishing near the International Boundary at Point Roberts operated daily until September 4, harvesting delaying late-run sockeye which had migrated to the Strait of Georgia primarily through Johnstone Strait. The total catch of late-run sockeye in the Strait of Georgia by fishermen of the two countries and the non-Native commercial catch in the lower Fraser was 1,331,000 fish.

Our analyses compare the projections of late-run sockeye that remained for gross escapement after the completion of commercial and Native fisheries to the estimates of numbers that entered the Fraser River and were either caught in the Native fishery or escaped to the spawning grounds. Two different estimates of the latter total exist. The first is the sum of the Mission hydroacoustic estimate of late-run sockeye escapement plus the DFO estimate of Native fishery catch below Mission. The in-season estimate of this total was 1,055,000 and, after revision of catch data and racial analyses, the post-season estimate increased to 1,138,000 late-run sockeye. The second estimate of river escapement was obtained using DFO estimates of spawning escapement and Native fishery catches in the Fraser River and tributaries. This total is 1,645,000 late-run fish.

ANALYTICAL APPROACH

Analyses of the discrepancy between in-season projections of the number of late-run sockeye available for gross escapement and the number that were estimated in the river catch and escapement proceeded along two major lines. The first line of investigation was to compare estimates of late-run abundance and numbers available for gross escapement that resulted from in-season to post-season changes in catch and racial estimates. The purpose here was to assess whether the estimation error observed in-season was due to inaccurate estimates of the models' inputs (catch and racial composition) and, if so, which of these inputs was most influential in creating the error.

Associated questions raised at the first workshop on the 1994 late-run escapement shortfall were examined, as they pertained to the treatment of data and assumptions of the purse seine models. We examined various options in the treatment of data such as logarithmic transformation and the use of single and combined-stock models, and looked for time trends and biases in the back-calculated estimates and data used in the development of the models.

Secondly, we conducted an extensive reconstruction of sockeye runs, by stock, for a number of recent years to obtain estimates of harvest rates in Johnstone Strait fisheries. Our purpose was to test whether harvest rates in the Johnstone Strait purse seine fishery had changed since 1983. As noted previously, harvest rates for 1983 were used in some in-season analyses because 1983 represented the only high diversion year for late-run stocks in recent years. Given the in-season catch, racial and escapement data, this assumption was supported. The question addressed here is whether the post-season data support the use of the 1983 harvest rates or the higher rates observed for summer-runs in recent years.

Since initial post-season analyses indicated that, in fact, harvest rates were higher than expected, we subsequently examined a number of possible causes of the change in harvest rate in Johnstone Strait purse seine fisheries. Factors associated with the operation of Johnstone Strait fisheries and behaviour of purse seine vessel operators are discussed along with fish travel speed and run distribution.

In-Season Versus Post-Season Data

Post-season estimates of commercial fishery catches for each sockeye stock/stock group differ from in-season estimates for two reasons: 1) post-season catch estimates are based on fish sales slips whereas in-season estimates in Canada are based on catch hails supplemented by partial landings data (often measured only by weight), and 2) post-season racial analyses are conducted using current year (i.e., 1994) spawning ground scale samples for the standards used in the discriminant function analysis (DFA) models as opposed to in-season analyses using standards developed from a combination of jack (age 3_2) spawning ground scale samples from the previous year and age 4_2 spawning ground samples from previous cycle years.

Final post-season catch data are not available for a year or more after the end of the season. Therefore, for the present analysis, we used preliminary DFO catch statistics from March 6, 1995, after an intensive review by PSC, DFO and J.O. Thomas (contractor) staff. This review became necessary when significant errors were found in earlier computer runs of "post-season" catch statistics. Preliminary post-season racial composition estimates were calculated using stock and stock group standards from 1994 spawning ground scale samples.

To assess the relative impact that changes in catch and racial composition estimates had on the projection of the number of late-run sockeye available for entry into the Fraser River, we conducted four analyses for each model using the following datasets: 1) in-season catch and in-season racial, 2) post-season catch and in-season racial, 3) in-season catch and post-season racial, and 4) post-season catch and post-season racial. Parameters in all run-size estimation models were the same as were used in-season in 1994.

We also examined the impacts of Mission versus upstream estimates of summer-run escapement on the calculation of late-run escapement. The summer-run exploitation rate model uses Mission hydroacoustic estimates of daily summer-run escapement to calculate daily and weekly harvest rates. These rates are then applied to the late-run catches; thus, in this analysis, we compared the projections of late-run sockeye available for gross escapement that were obtained using Mission estimates of summer-run escapement versus those obtained using upstream estimates of summer-run spawning escapements and in-river Native fishery catches. Similarly, we analyzed the error in run-size estimates and numbers of late-run sockeye available for entry into the river based on river abundances measured at Mission and accounted in in-river catch and spawning escapement.

Examination of Purse Seine Catch and CPUE Models

At the first workshop on run size and escapement estimation on February 2-3, 1995, questions were raised about the structure of purse seine catch and CPUE models and the impacts that violations of assumptions would have had on the estimates of late-run escapement in 1994. As a result, potential sources of error were examined. These analyses are presented in the Appendices I, J, K, L, M, and N and summarized in the Results.

With respect to the purse seine catch and CPUE models, many analyses were performed. We examined whether, in addition to catch and CPUE, effort and duration should be transformed into natural logarithms. Time trends in the dataset were examined by plotting the several variables (run size, catch, CPUE, effort, duration) against year (1970-1993). Residuals of the regression models were also plotted over year to determine whether run-size estimates were deviating in a systematic fashion in recent years. Third, the effect of bias in Johnstone Strait diversion rate estimates on run-size estimates was simulated. In addition, we examined a significant issue in 1994, that of estimating record Johnstone Strait late-run abundance using purse seine catch data that was substantially beyond the range of previous observation. For this, we compared estimates of late-run sockeye abundance and escapement obtained from single-stock models constructed for Adams/Lower Shuswap and other stocks with estimates from models constructed using data on catches and run sizes for all Fraser sockeye stocks in one large dataset (combined-stock models).

Examination of Harvest Rates

Estimates of late-run harvest rates in Juan de Fuca and Johnstone Straits fisheries are required for the cumulative-normal model to estimate late-run abundance. Since late-run harvest rates cannot be directly measured in-season, we used historical data to calculate stock-specific harvest rates from catch and escapement estimates. However, the escapement component can only be measured in the Fraser River where fish from the southern and northern routes intermingle and, because the abundance arriving from each route is unknown, unique harvest rates for Juan de Fuca and Johnstone Straits fisheries cannot be calculated. Therefore, we focus on years of very low or very high Johnstone Strait diversion for which harvest rates can be approximated for fisheries on the route having the major share of the migration. This is possible because of the relatively small error introduced into the calculations by uncertainty in the escapement estimates for the migration arriving via the minor route. Therefore, reliable harvest rate estimates for Johnstone Strait fisheries can only be obtained using data from years of high diversion. Since 1978, late-run harvest rates in the Johnstone Strait purse seine fishery were only available for 1983, which was a high diversion year when approximately 80% of Fraser sockeye migrated through that route. Estimates of harvest rate based on 1983 data were used in 1994.

Commercial fisheries in a geographical area harvest fish that arrive at any given point over one or more days. The rate of travel of sockeye through the area in question must be estimated to determine the number of days of migration which are vulnerable to the fishery. In short (63 km) areas such as Canadian Area 20, each day of fishing affects two days of migrating fish: fish that are in the area at the opening and fish that arrive during the day. The impact of net fisheries in Johnstone Strait on migrating sockeye is much more complex, due to the long geographical length (210 km) of the area. Approximations of travel speed have been made by comparing the peaks and valleys of migration during high diversion years and by use of a limited amount of radio-tagging data (Quinn and terHart 1987). These analyses indicate that one day of fishing in Johnstone Strait affects five days of the migration, although precise estimates of the rate of travel of sockeye through these areas are not available. Data from earlier tagging with disk tags (Verhoeven and Davidoff 1962) gave slightly slower rates of travel but could not assess the behavioral effect of the tagging which initially slows the progress of fish due to the trauma of tagging.

Since not all fish in a migration block are harvested in a fishery, algorithms are used in the reconstruction to apportion the catch in an area to the various daily migration blocks (Cave and Gazey 1994). Harvest rates can then be calculated for the removal of fish from those daily blocks. Weekly harvest rates can also be calculated from the daily harvest reconstructions.

Improved methods of run-reconstruction for Fraser River sockeye are currently under development by the PSC. These methods have been used to calculate stock-specific harvest rates for the major stocks in Johnstone Strait fisheries for years of high diversion: 1980, 1981, 1983, 1992, 1993 and 1994. Important in these analyses was the fact that, prior to 1994, reliable late-run harvest rates for Johnstone Strait fisheries were available only from 1983. Other than in 1983, major late runs in the 1980-1993 period arrived in low diversion years mainly via Juan de Fuca Strait (1982, 1986, 1990) or in years of intermediate diversion (1987 and 1991).

Examination of Factors That Affect Harvest Rate.

Variables that may have influenced 1994 calculated harvest rates in Johnstone Strait, include changes in fleet size, technology, fishing patterns, poaching, "laundering" of food fish catches, unusually fast or slow fish speed, a non-normal distribution of the late-run migration, en-route mortality and reliance on summer-run harvest rates in late-run estimation models. These potential influences on the 1994 harvest rates observed in Johnstone Strait were evaluated to the extent that they could be, given that data specific to these issues were not collected during the season.

RESULTS

In-Season Versus Post-Season Data

Every year the quality of in-season estimates of catch by stock varies between fisheries. At times the post-season estimates result in substantially different run sizes than were estimated in-season. To examine the impact of such changes in 1994, estimates of late-run sockeye abundance and escapement to the Strait of Georgia were calculated for each of the three models using in-season and post-season catch and racial composition data. We then compared the relative importance of catch updates versus racial composition updates in explaining the differences between in-season and post-season run-size estimates. The results from the various models were contrasted to discern the importance of each of these factors to the in-season estimates.

In-season estimates of purse seine and gillnet catches in the Johnstone Strait fishery were provided to the PSC by DFO, while catches in Juan de Fuca Strait fisheries were obtained in cooperative PSC/DFO programs. The in-season estimates were amended in the post-season period by the use of sales slip data in the DFO computer system (Table 3). In addition, estimates of Strait of Georgia and Fraser River commercial and Canadian Native fishery catches also changed (Appendix G).

The estimated Canadian purse seine catch in Johnstone Strait was 3,400,000 sockeye salmon (all stocks) during the fishing season, but was 3,868,000, or 13.8% higher, in the post-season period (Appendix H). Gillnet catches in the Areas 11-16 fishery also increased substantially, from 864,000 in-season to 1,172,000 post-season, a 35.6% increase. Catches in Area 20 increased by 165,000 (19.5%). Total outside troll catches were close to in-season estimates but the recorded Area 29 troll catch for the

Table 3. Comparison of in-season and post-season estimates of catches of Fraser River sockeye salmon in commercial and non-commercial fisheries in 1994.

	Fraser Catch	
Catch Area	**In-Season**	**Post-Season**
Canada		
Areas 1-10 Purse Seine	519,000	428,000
Areas 1-10 Gillnet	1,000	7,000
Areas 1-10 Troll	821,000	710,000
Areas 12-16 Purse Seine	3,401,000	3,868,000
Areas 11-16 Gillnet	864,000	1,168,000
Areas 12-16 Inside Troll	200,000	202,000
Areas 11-13 Outside Troll	506,000	804,000
Areas 121-127 Outside Troll	419,000	352,000
Area 20 Purse Seine	420,000	462,000
Area 20 Gillnet	261,000	384,000
Areas 17-29 Inside Troll	158,000	186,000
Areas 18-29 Outside Troll	255,000	166,000
Area 29 Gillnet	1,290,000	1,298,000
Areas 12-16 Native Fishery	100,000	97,000
Area 29 Native Fishery		85,000
United States		
Areas 4B,5,6C Treaty Indian	120,000	119,000
Areas 6,7,7B Treaty Indian	181,000	181,000
Areas 6,7,7B Non-Indian	136,000	136,000
Area 7A Treaty Indian	655,000	651,000
Area 7A Non-Indian	737,000	741,000
Alaska District 104 *	225,000	240,000

* District 104 estimates are both based on in-season racial identification models

August 29-30 fishery was approximately 90,000 less than the number estimated in-season. The cumulative post-season increase in Canadian commercial fishery catches was 920,000 Fraser River sockeye. United States fishery catches in Puget Sound were unchanged from the in-season estimate. Alaska District 104 catches increased by 15,000 to 240,000 Fraser River sockeye as a result of updated catch statistics. Appendix G contains an extensive discussion of catch estimation issues in 1994.

Post-season racial analyses using 1994 spawning ground scale samples produced altered stock composition estimates in all fisheries, including test fisheries in the lower Fraser River (Appendix G). Post-season estimates showed lower proportions of Chilko/Quesnel sockeye and Adams/Lower Shuswap and higher proportions of Scotch/Seymour and Stellako/Late Stuart than were estimated in-season.

The combined effects of changes in catch and racial composition estimates produced catches by stock in Juan de Fuca and Johnstone Strait fisheries and escapements at Mission (Appendix G; Table 5) that differed from those available for in-season management. Chilko/Quesnel catches increased by 201,000 fish (16%) in Johnstone Strait net fisheries but declined by 251,000 fish in the escapement at Mission. Revised Adams/Lower Shuswap catches were 173,000 (7%) higher in the post-season estimates of Johnstone Strait net catch, but catches in other areas declined slightly. Increases in the catch estimates for other late-run stocks resulted in an increase of the total late-run catch and accounted run size by 399,000 fish.

Commercial Purse Seine Models

Using in-season catch and racial data, purse seine catch and CPUE models projected that 2,879,000 (using northern catch-adjusted model) and 3,181,000 (using unadjusted model) late-run sockeye were available for entry into the river after terminal area catches had been removed (Table 4; also see Appendix C). Post-season catch and racial data generated comparative estimates of 3,108,000 and 3,060,000 late-run sockeye. In the adjusted model, the estimated total late-run sockeye abundance increased by 547,000. However, the larger post-season catches in the migratory areas reduced the difference between in-season and post-season estimates of the number available for escapement to 229,000 fish (i.e., 2,879,000 versus 3,108,000).

Examination of the relative importance of in-season catch estimation errors versus revisions to the racial analysis standards using spawning ground samples was conducted using the four combinations of in-season and post-season data (Appendix C). The analysis showed that post-season catch data caused the projected gross escapement of late-run sockeye and the magnitude of the discrepancy between

Table 4. Estimates of the 1994 late-run gross escapement (Mission hydroacoustic + Native catch below Mission) from the various run-size models used in-season, using in-season catch and racial data compared to when post-season data are used.

	Late-run Fish Available for Escapement	
Model	In-season Data	Post-season Data
Purse Seine		
Adjusted	2,879,000	3,108,000
Unadjusted	3,181,000	3,060,000
Cumulative -Normal	3,408,000	3,478,000
Summer-run Exploitation Rate		
Daily	3,830,000	2,572,000
Weekly	2,970,000	2,146,000
Range		
Minimum	2,879,000	2,146,000
Maximum	3,830,000	3,478,000

this number and the river abundance estimate to increase slightly, while the post-season racial data caused the number available and the discrepancy between estimates to decrease by a similar amount. Therefore, negligible changes occurred with the post-season data (Table 4). Neither of these factors reduced the post-season projections of number available for entry into the river to the degree necessary to approximate the estimated river abundance (1,138,000, based on Mission hydroacoustic estimates).

Cumulative-Normal Models

Changes in estimates of late-run sockeye available for gross escapement using in-season and post-season catch and racial data in the cumulative-normal model, as configured in-season, were similar to the purse seine catch models. Larger post-season catches in Juan de Fuca and Johnstone Straits produced larger estimates of total run sizes and, after subtraction of catch, slightly larger projections of gross escapement. The cumulative-normal model generated a total late-run estimate of 9,865,000 fish and 3,408,000 available for gross escapement in-season (Appendix E). Using post-season data the run-size estimate increased to 10,251,000 sockeye and the number available for river entry to 3,478,000 (Table 4).

In-season catch estimation errors tended to have greater importance in estimates of run size and projected number of late-run sockeye available for river entry from this model than did racial analysis revisions. The use of post-season catch estimates caused the numbers available for gross escapement to increase an average of 316,000 compared to the number obtained using in-season catch data. Conversely, post-season racial data gave a decrease of 246,000 compared to results using in-season data. As with the purse seine models, the use of accurate post-season catch and racial data did not reduce run-size estimates close to the gross escapement at Mission or accounted upstream. The results from adjustments to the 1983 harvest rates used in this model, had post-season racial data been available in-season, will be discussed.

In-Season Summer-run Exploitation Rate Models

Daily and weekly harvest rates for the combined Chilko and Quesnel stock complexes were used to obtain estimates of late-run sockeye escapement to the Strait of Georgia. The catch and escapement data for these two summer-run stock groups were combined because overlapping scale characteristics made it difficult to identify them. In-season, the use of daily harvest rates resulted in a substantially larger estimate of late-run sockeye available for gross escapement (3,830,000) than obtained using weekly harvest rates (2,970,000) (Appendix F). We decided to use the weekly harvest rate model estimates because of concerns that suspiciously large estimates of late-run escapement on a few days were produced by applying erroneously low harvest rates to large catches. The post-season estimates of late-run fish available for gross escapement using daily and weekly harvest rates were similarly divergent (2,572,000 versus 2,146,000) (Table 4). However, both were substantially smaller than those obtained in-season.

Analyses of the projected numbers of late-run fish available for gross escapement obtained from the two harvest rate models using in-season and post-season catch and racial data showed that in-season catch estimation errors played only a minor role in the error in escapement estimates. Estimates using post-season catch data decreased by an average of only 30,000 over those using in-season catch estimates. On the other hand, revised racial composition estimates in the post-season analysis affected the estimates dramatically. Late-run abundance estimates declined by an average of 887,000 fish with the post-season racial data. The large racial component in the difference between in-season and post-season estimates was traced to the effect of revised racial composition estimates on summer-run sockeye harvest rates. Chilko/Quesnel sockeye catches in Johnstone Strait fisheries increased substantially as a result of the larger post-season catch estimates and revised DFA models, whereas Mission escapement estimates declined. The combination of an increase in the Johnstone Strait catch and a decrease in escapement caused the post-season estimates of daily and weekly summer-run harvest rates to increase. Because run size was estimated as catch divided by harvest rate, the larger harvest rates resulted in smaller run-size estimates and smaller projections of late-run sockeye available for entry into the river.

Examination of Purse Seine Catch and CPUE Models

We examined the structure of the purse seine catch and CPUE models and the handling of data in order to determine if PSC procedures were appropriate for the estimation of late-run sockeye abundance and escapement. These studies are reported in detail in the Appendices as indicated.

Log Transformation of Effort and Duration

To estimate run size based on purse seine fishery data, the independent variables for the models that were used in 1994 were the natural log of catch and CPUE and the untransformed values of effort and duration. We compared the predictive performance of these models to ones in which effort and duration were also log transformed (Appendix I). This analysis shows that the latter is the more appropriate regression model. If such models had been used in 1994, the run-size estimates would have smaller to the extent that the discrepancy between in-season projections of the number of late-run sockeye available for gross escapement and post-season accounting would have been about half as large. Models using catches adjusted for northern area catches performed best.

Comparison of Catch-based and CPUE-based Models

A comparison was made between regression models using "catch" as the main independent variable and models using "CPUE" (Appendix J). When the regression models are formulated using log transformed values for catch, effort and duration, there are no differences between catch-based and CPUE-based models, as they provide identical estimates, residuals and R^2 values.

Time Trends in Fishery Data

Suggestions that changes have occurred in long-term harvest capacity in the Canadian purse seine fishery were examined (Appendix K). Harvest rates appear to be increasing since 1970 in Johnstone Strait but not in Juan de Fuca Strait. There are clear time trends for Johnstone Strait in terms of run size (increasing), diversion rate (increasing), catch (increasing), CPUE (increasing), effort (increasing) and weekly fishery duration (decreasing) (Figure 3). Quantification of the causes of the harvest rate trend in Johnstone Strait fisheries is masked because all the factors are varying simultaneously.

Time Trends in Regression Residuals

The question of whether regression models based on data from the 1970's and 1980's could be used in the 1990's was approached by examination of the differences between predicted and observed values in the regressions over time (Appendix L). We found no compelling evidence of time trends in the residuals of the regressions that are also consistent with the events of 1994. While late-run abundance was over-estimated in 1994, summer-run stocks were under-estimated. Therefore, the larger error in late-run sockeye estimates seen in 1994 could be due to the random error that is expected from a regression model. Such an error could be large simply because of the large run-size estimate, but also because of estimating a run size well beyond previous records.

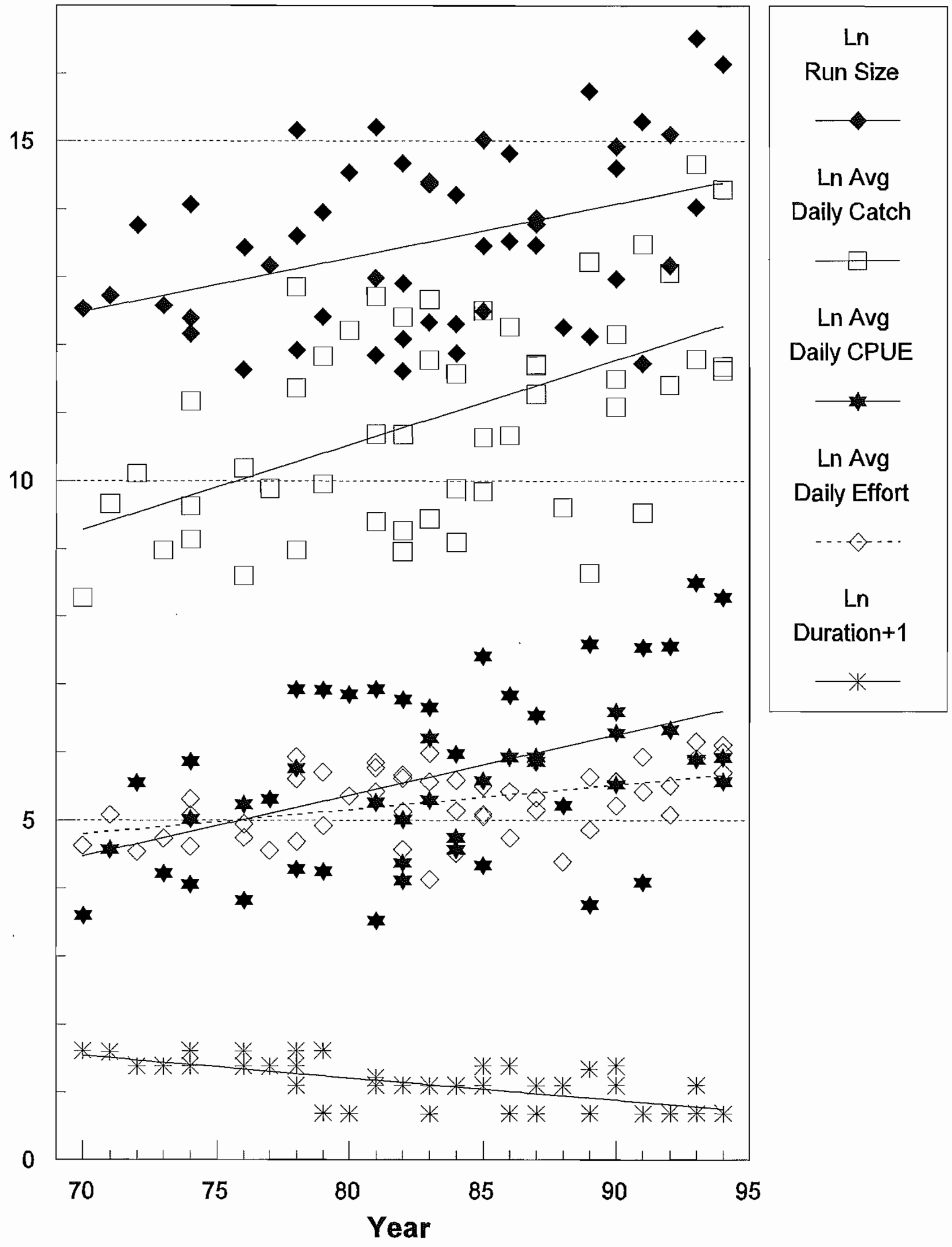

Figure 3. Run size, average daily catch, average daily CPUE, average daily effort and fishery duration versus year for purse seine fisheries in Johnstone Strait between 1970-94. The data are from the regression dataset, and so represent only peak-week fisheries for summer- and late-run stocks.

Bias in Diversion Rate Estimates

An analysis was conducted to assess the impact of potential biases in the historical diversion rate estimates (Appendix M). Our intent was simply to bound the magnitude of the impact of such a bias, assuming it was between a range of values. Diversion rate biases were simulated through a range of -30% to +30%. The results of the simulation indicated that a negative bias in diversion rate estimates (i.e., use of a lower estimate of diversion rate than the true value in run-size models) would result in under-estimates of Johnstone Strait and total run sizes, and a positive bias would result in over-estimates. Evidence of a systematic bias in diversion rate estimates would also be expected to show up as a bias in run-size estimates in past years. There is, however, no evidence of this occurring.

Impact of Data Outside Historical Range

The 1994 Johnstone Strait migration of late-run sockeye was the largest on record, exceeding the previous maximum run by about 30% and maximum daily catch by approximately 200%. We examined the potential error in the run-size estimation procedure associated with applying regressions to data outside the previous range (Appendix N). The use of a combined-stock model (Adams, Quesnel and Late Stuart combined) to estimate the abundance of late-run sockeye in Johnstone Strait in 1994 resulted in a projected gross escapement that was much closer to the post-season gross escapement estimate than obtained using the single-stock models. Thus, if estimates of the combined-stock model had been used in-season instead of estimates from the single-stock models, then the late-run abundance estimates would have been much closer to the actual total than they were. Instead, during the in-season period, the estimates from the single-stock and combined-stock models were pooled (weighted according to each models mean square error), but the pooled estimate was closer to the single-stock estimate.

The reason that the combined-stock model performed better than the one-stock model may be related to higher harvest rates in recent years. If harvest rates are higher than usual, then a regression model based on data from years with normal harvest rates would tend to overestimate run size, because it would project that the catch resulted from a larger run. However, if data from high harvest rate years are added to the regression dataset, and these additional data are very influential in determining the relationship, then the resulting model would tend to produce a more accurate estimate. To relate this hypothetical situation to the Adams/Lower Shuswap run in 1994, the most influential datum in the dataset for the Adams/Lower Shuswap model is the moderately sized run in 1990, which was 75% as large as the 1994 run and produced a peak week average daily catch only 33% of the 1994 catch. If we consider that the 1994 run exceeded the previous range of data and the harvest rate was also higher, it is not surprising that the run-size estimate was not close to the observed. However, the combined-stock model included the 1993 data for the Quesnel (largest run by far in Johnstone Strait) and Late Stuart runs (third largest), and the 1989 datum for the Quesnel run (largest Johnstone Strait run until the 1993 run). These very influential data not only extended the range of the data to include the magnitudes of catch, effort and run size of the 1994 Adams/Lower Shuswap run, but also occurred at the current high harvest rates, with the result that the estimates from this model were much closer to the observed.

Another important point here is that the 1994 late-run estimate is the largest positive deviation from the post-season accounted-for number for any stock in the 1970-94 period. The other very large stock group in 1994 (Chilko/Quesnel), which also returned in very large abundances through Johnstone Strait, was estimated with reasonable accuracy but was under-estimated, not over-estimated.

Examination of Harvest Rates

Reconstruction of sockeye abundances by stock in the six years of high diversion between 1980 and 1994 provided estimates of Johnstone Strait harvest rates for the major stocks each year (Appendix O). The data were grouped into an earlier dataset comprising 1980, 1981 and 1983 catches and escapements and a more recent set of years, 1992 to 1994, inclusive. We examined the data in the two sets of years to determine if the relationship between harvest rate and fleet size was consistent (Figure 4). The results indicated that both Area 12 and Area 13 harvest rates for the 1992-1994 period were significantly higher than harvest rates in the 1980-1983 period (Area 12: F=12.6; p<0.01; Area 13: F=10.6; p<0.01). In addition, effort level had a significant impact on harvest rate in Area 12 (F=19.5; p<0.01) but did not significantly affect harvest rate in Area 13. While late-run sockeye harvest rates in the recent period (1994) were generally higher than for summer-run stocks, the harvest rate to fleet size relationships were not significantly different (p>0.05) between summer-run and late-run stocks.

We examined the impact of recent-year Johnstone Strait harvest rate relationships on projections of late-run sockeye available for gross escapement after subtraction of catch from the total abundance estimate. Harvest rate data from 1992 and 1993 summer-run sockeye catches were regressed on fleet size to obtain a predictive relationship for use on 1994 fisheries. Fleet size for each 1994 fishery in Areas 12 and 13 was used to obtain predictions of harvest rates by area and week. These were applied to in-season and post-season catch estimates to obtain the escapement component of daily migrations. Purse seine test fishery harvest rates based on 1993 catches were applied to 1994 test fishery catch per set data to estimate abundance on days when no commercial purse seine catch was available. After subtraction of catch from the total abundance, we obtained projections of late-run sockeye available for entry into the river of 1,537,000 fish using in-season data and 1,518,000 sockeye using post-season data. These compare with estimates of escapement of 1,138,000 using Mission hydroacoustic estimates and 1,645,000 using DFO upstream estimates of Native catch and spawning escapement.

Examination of Factors Affecting Harvest Rate

Several factors may influence harvest rate estimates. These may be divided into biological factors and fishery factors. Below we discuss the effect of each identified factor assuming that they were in action in 1994.

Fish Migration Speed

The run reconstruction model assumes a particular rate of travel for sockeye salmon through the Juan de Fuca and Johnstone Straits migration routes. In the latter route, fish are assumed to migrate in daily blocks at approximately 56 km/day (35 mi/day). At this travel rate, four daily blocks of fish would be initially present in the Area 12/13 fishing area from the top of Area 12 (Hope Island) to the bottom of Area 13-7 (Deepwater Bay). Then, for each 24 hour fishery, one additional day of fish become vulnerable as they enter the top of Area 12. Travel rate estimates from radio tagged fish in Johnstone Strait (Quinn and terHart 1987) support this assumption. However, if fish speed varies within or between years, the number of daily blocks of fish vulnerable to the fishery may change. A slower migration rate would place a greater number of daily blocks of sockeye in the fishing area and potentially raise the weekly harvest rate although real elemental harvest rates may remain unchanged. Faster migrating fish would have the opposite effect. In a large area such as Johnstone Strait, small changes (<1 day) in migration time could have exaggerated impacts on weekly harvest rate (Appendix P). Because late-run sockeye delay in the Strait of Georgia, they do not appear in the escapement immediately after reaching the Fraser River, so their speed of travel cannot be directly assessed.

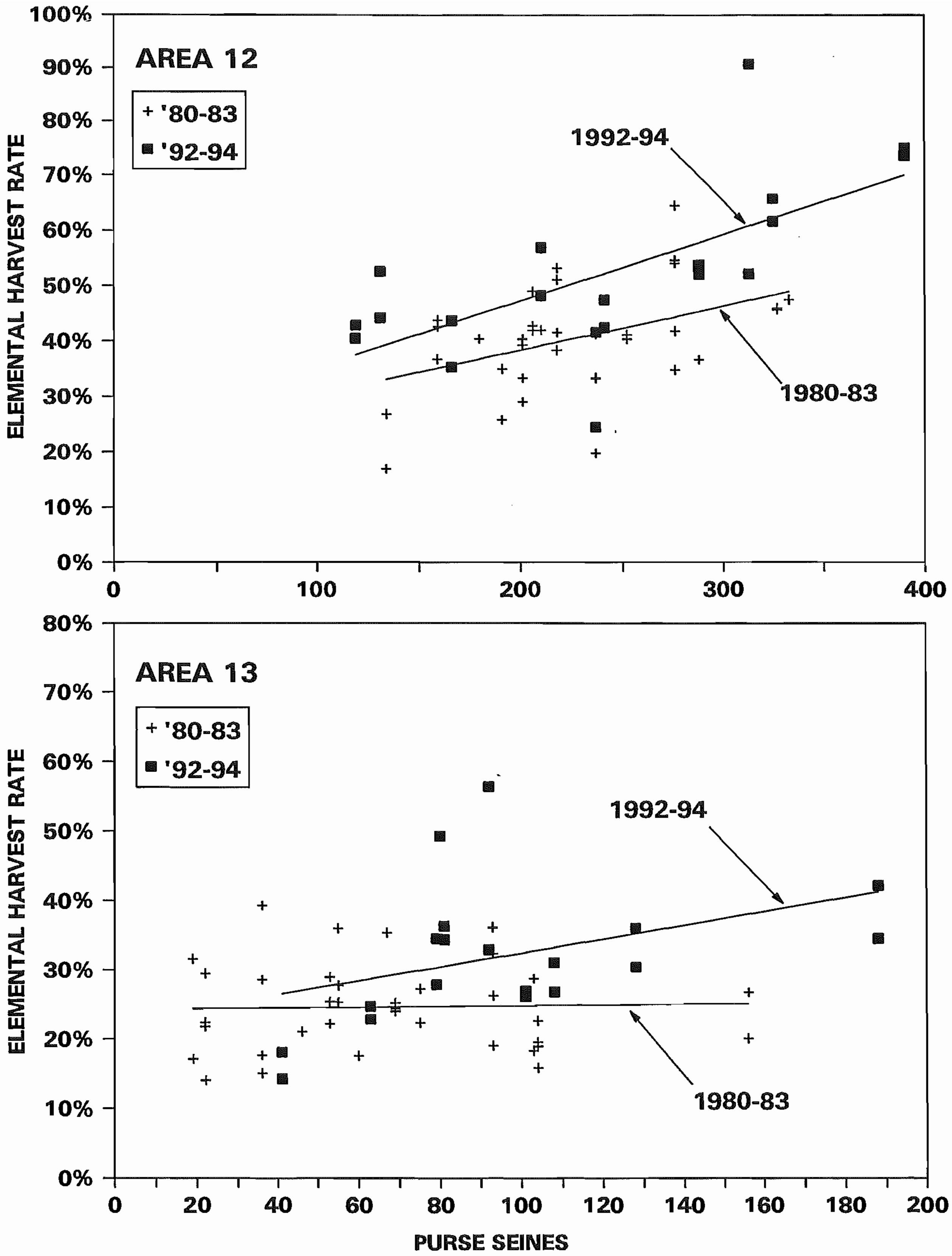

Figure 4. Relationship between harvest rate and fleet size for Area 12 and 13 purse seine fisheries. 1994 estimates were calculated using hydroacoustic estimates of gross escapement at Mission.

However, summer-run sockeye usually do not delay, so they provide data that may be analyzed for evidence of travel speed variation.

Summer-run sockeye migration patterns from the Johnstone Strait fishing area to the Fraser River in 1992-94 were analyzed for evidence of changes in travel rates between years. In 1994, a periodic lack of fit of terminal area abundance to migratory area fishery removals suggest that delay of summer-run sockeye occurred in late July and early August. However, the rate of travel of summer-run fish from the Areas 12 and 13 fishery to the Fraser River appeared to be normal during the period that late-run fish were co-migrating. While these data do not provide direct evidence regarding the possible deviation from a normal rate of travel for late-run sockeye in 1994, they do not support the theory that harvest rates in 1994 may have been higher than normal due to speed of travel variation.

Migration Distribution

Fish from each Fraser River sockeye salmon stock arrive at Juan de Fuca and Johnstone Straits over approximately a 30 day period. However, the distribution of daily abundances may vary interannually. Broad, flat distributions or short, highly peaked runs have both been observed, as have skewed and bi-modal runs. Deviations in distribution from the normal will affect all PSC methods of run-size estimation, especially models based on peak catch or CPUE data. Highly peaked runs would, on average, produce larger peak week catches than expected and would provide over-estimates of abundance. To examine migration distribution on the 1994 late-run sockeye estimation process, we plotted the first day purse seine catches of Adams/Lower Shuswap sockeye for past dominant cycle years and calculated the standard deviations of the distributions.

The data on the distribution of Adams/Lower Shuswap sockeye runs suggest that the 1994 run was slightly earlier than normal in its Johnstone Strait arrival. Standard deviations of the catch distribution with time did not indicate that the 1994 run duration or distribution departed from the pattern of other recent years.

Poaching

Illegal catch and sale of sockeye in the Area 12/13 purse seine fishery has been suggested as a potential cause for the higher harvest rates observed in 1994. While some poaching is generally accepted to have occurred, the anecdotal nature of the reports make it impossible for Pacific Salmon Commission staff to develop estimates of the numbers of fish involved. One form of illegal activity that has been suggested is one in which illegal catches from immediately prior to a legal fishery opening may have been delivered with catches from the legal fishery, resulting in inflated CPUEs. It is our conclusion, however, that such illegal activity was unlikely to have been sufficiently extensive by itself to inflate the purse seine CPUE enough to cause the magnitude of over-estimation of late-run sockeye abundance that occurred. First, the purse seine harvest rates that were calculated in the post-season run reconstructions were reasonable given the 1992 and 1993 data. Second, the illegal removal of fish immediately prior to a fishery may simply have shifted the area where most of those fish would otherwise have been caught. Such removals, if from migration blocks subsequently fished in the commercial opening, would also depress the actual CPUE, thus providing a compensatory effect. Escapement estimates would not be materially affected under this scenario. Poaching would have had to be selective for fish that were destined to escape to the Strait of Georgia for the harvest rate to have been artificially inflated to a substantial degree.

Laundering of Food Fish Catches

Examination of catch records for purse seines licensed by Native fishers versus those licensed by non-Native fishers indicated that 1994 catches were similar on a seasonal basis. This pattern was consistent with the comparison of catches in 1987-93. While some illegal activity may have occurred, it is unlikely that food fish catches being laundered into commercial fishery catches could have elevated CPUE data to the extent required to cause the over-estimate of late-run abundance.

En-Route Mortality

No data were available or could be developed to assess the possible selective mortality of late-run sockeye between Johnstone Strait and the Strait of Georgia. Natural and fishery induced mortalities undoubtedly occur each year but no unusual circumstances were reported that would lead to significantly increased mortalities in 1994. Increased troll fishing effort was suggested as a possible cause of mortality but no evidence was developed to support this theory. The marine dinoflaggelate *Heterosigma* has been implicated in net pen and confined inlet mortalities in recent years, but data collected in 1994 indicated that this species was not abundant in the Strait of Georgia during the residency of late-run sockeye (Appendix Q).

Use of Erroneous Data on Summer-run Harvest Rates

An hypothesis was put forward at the February 2-3 workshop that harvest rates used in the summer-run exploitation rate model may have been erroneous because of over-estimation of summer-run escapement at Mission. This hypothesis was tested by reconstruction of the in-river Native fishery catches and arrivals of sockeye at the spawning grounds and at other locations downstream of the spawning grounds (Appendix R). Recorded weekly upstream abundances were added to the reported catches in commercial and Native fishery catches below Mission. Using the upstream accounting estimates of summer-run sockeye abundance (no en-route mortalities) the total summer-run abundance would have been approximately 417,000 lower than obtained using the Mission hydroacoustic estimates in-season. However, discrepancies between Mission and upstream estimates of summer-run sockeye escapements were lower for the August 4-September 10 period, which was the period used to generate in-season estimates for co-migrating late-run stocks. Comparing the resulting estimates of late-run gross escapement using Mission data for summer-run harvest rates (2,970,000) versus upstream data (2,348,000), the difference was 622,000 fish. This latter number is still 1,210,000 higher than the in-season gross escapement estimate (1,138,000) and is 703,000 higher than the post-season accounted estimate (1,645,000).

DISCUSSION

In-Season Versus Post Season Data

While the use of post-season catch and racial data in the three run-size models (using the same parameters as were used in-season) generated somewhat different projections of late-run gross escapement than obtained using in-season data, we conclude that the differences between in-season and post-season estimates were not simply due to errors in the in-season catch and racial data. Use of these models with post-season data provided projections of late-run sockeye available for entry into the river that were still 1,008,000 to 2,430,000 larger than the in-river gross escapement as measured by the Mission hydroacoustic program and 501,000 to 1,923,000 larger as measured by DFO's upstream accounting.

If the actual Johnstone Strait purse seine catches been known at the time, the total abundance and escapement estimates using all three models would have been higher, leading to a slightly different perception of the numbers available for harvest in the Strait of Georgia. Using the in-season models and post-season racial analyses, all estimates would have been lower. But only the estimates of escapement to the Strait of Georgia from the summer-run exploitation rate models would have been substantially lower than estimated in-season.

However, had post-season racial data been available in-season, the higher summer-run harvest rates that would have been obtained in the in-season monitoring would have indicated that the use of 1983 late-run harvest rates was inappropriate. The subsequent substitution of higher harvest rates in the cumulative model would have generated lower estimates of late-run abundance and escapement to the Strait of Georgia. Thus, if post-season racial data had been available in-season, it would have provided a broader, but much lower range of estimates for Adam/Lower Shuswap and other late-run stock escapements into the Strait of Georgia.

During the fishing season, the close agreement (2,970,000 to 3,481,000) between projections of late-run sockeye available for entry into the river from the three models provided false confidence that the run size and escapement to the Strait of Georgia had been correctly estimated. The range likely would have been substantially lower with correct catch and racial data because the evaluation of summer-run harvest rates would have led to the use of higher late-run harvest rates in the cumulative-normal model, thus lowering the estimate of late-run abundance and the number available for gross escapement. During the fishing season, late-run abundance estimates from the cumulative-normal model were given greater weight because of the concurrent assessment of summer-run harvest rates and because this model has had the best average performance in past years. This model gave the highest estimates in-season, leading PSC staff to use a value at the upper end of the estimation range. Had the estimates from this model been lower, we would have used lower estimates of late-run abundance and escapement to the Strait of Georgia.

A major factor in run-size estimation for late-run sockeye stocks is that the entire error in run-size estimate is transferred to the projection of the number available for gross escapement because this number is computed by subtraction of catch from total abundance. For example, if the run size was estimated at 9,000,000 with a prediction interval of 7,000,000 to 11,000,000 (i.e., ± 2,000,000) and the catch was 6,000,000, this catch would be simply subtracted leaving an escapement of 3,000,000 (i.e., 9,000,000 minus 6,000,000) with a prediction interval of 1,000,000 to 5,000,000. Thus, even acceptable precision in the run-size estimate can lead to very imprecise estimates of escapement.

The use of DFO accounting of late-run sockeye escapement into the Fraser River would reduce the discrepancy between model results and accounted totals. The DFO data provided an estimate of in-river abundance of 1,645,000 late-run sockeye compared to the Mission hydroacoustic plus Native fishery catch below Mission total of 1,138,000 fish. The difference of 507,000 fish in escapement does not compensate fully for the apparent error of estimation in our post-season analysis.

Examination of the Structure of Run-size Estimation Models

The results of analyses addressing concerns regarding the structure and data used in purse seine catch and CPUE models indicated that the most appropriate model was the option in which all independent variables were log transformed. Estimates of late-run abundance in 1994 would have been approximately 1,000,000 fish lower using these models, halving the discrepancy between the projections of late-run sockeye available for gross escapement (2,042,000) and the gross escapement estimate at Mission (1,138,000) (Appendix I). The estimate would have been only 397,000 higher than the late-run escapement using DFO estimates of in-river catch and spawning escapement. Further work on these models is required to assess their general applicability for use on all stocks, but clearly they would have provided superior estimates of late-run abundance and escapement in 1994.

While time trends were evident in the Johnstone Strait catch and effort data (Figure 3), there was no compelling evidence of time trends in the residuals from regression models that were consistent with the over-estimate of late-run abundance as occurred in 1994. In 1993, the most recent year of high diversion, the same models under-estimated the abundance of the major summer-run stocks. Also, since summer-run abundances were under-estimated in 1994, it is unlikely that time trends in the residuals of the regressions were factors in the over-estimation of late-run abundance and escapement.

PSC staff have debated the validity of model results where the data used as inputs to the model fall outside the range of previous experience. Late-run sockeye catches in 1994 exceeded previous maxima and the fleet size at the peak of the run was near the upper limit experienced to date. Errors can occur in estimates based on extension of the regression line beyond the historical data, partly because the size of potential errors increase at larger run sizes, but also because the precise relationship at high abundance cannot be well defined if only low abundance years are used to formulate the models. An alternative method is to use data from other stocks that have experienced the higher catch and effort levels in conjunction with the data from the single-stock models. However, errors can also occur in this situation if regression relationships vary among stocks. In an attempt to minimize these potential errors in-season, we combined estimates from a single-stock model for Adams/Lower Shuswap with estimates from combined-stock models by weighting the estimates by the mean square error (MSE) of the regressions. When so combined, the combined-stock models had little influence because of the greater variance associated with these models, so the resulting combined estimates were still too high. When the combined-stock models with northern catch adjustments were used solely, they resulted in a small discrepancy between projections of late-run sockeye available for gross escapement and the gross escapement based on Mission hydroacoustic estimates. Our conclusion is that combined-stock models should be given more weight when catches for an individual stock are much larger than in previous experience. However, the criteria for deciding when to apply the combined-stock models and the methods for pooling estimates from the single-stock and combined-stock models require further consideration.

Examination of Harvest Rates

Reconstructions of catches and escapements by stock in the six high diversion years, 1980-1983 and 1992-1994, were conducted to determine the harvest rates which exist in the Johnstone Strait fishery. We analyzed the data from the two periods in order to determine if the assumption of consistent harvest rates over time was correct. The results showed that sockeye harvest rates have increased significantly in the ten years between the two periods of high diversion rates. That increase is related only partially to the larger purse seine fleet fishing in Johnstone Strait Areas 12 and 13 in 1993 and 1994. A change to the elevation of the regression line relating elemental harvest rate to purse seine fleet size in the 1992-1994 period compared to the 1980-1983 period must be associated with changes in gear efficiency, changes in fishing patterns, or effects associated with regulations. However, the effects of each factor cannot be quantified since no data have been collected to analyze progressive changes in harvest rates.

As noted earlier, in-season monitoring of summer-run harvest rates in 1994 failed to detect substantial deviation from 1983 levels which were used in the cumulative-normal model. Had reconstruction of 1980-83 and 1992-93 catches and escapements been conducted prior to the 1994 season, the assumption of 1983 harvest rates may have been modified, Also, had post-season catch and racial data been available, the consistency between summer-run harvest rates in 1994 and in 1992-93 would have been evident. This latter analysis failed due to in-season racial analysis imprecision and catch estimation errors.

Examination of Factors Influencing Harvest Rate

Gear efficiency in salmon fisheries has increased rapidly in recent years with the advent of new technology and innovative fishing techniques. The probability that changes in technology have increased the effectiveness of individual purse seine vessels fishing in Johnstone Strait cannot be ignored. However, it seems unlikely that gear improvements could effect the magnitude of change identified in the harvest rates between 1980-83 and 1992-94.

The shorter durations (e.g., 12 or 24 hours in 1994) of Johnstone Strait purse seine fisheries in recent years of high diversion rates may have affected the behaviour of fishermen leading to increased harvest rates in the available open period. We understand, in fact, that fishermen do fish more intensively (i.e., more sets per unit time) when time is limited. The need to pace themselves is absent such as would be the case with multiple day fisheries, and the opportunity to change location does not exist. Also, with the larger fleet, the shorter duration fisheries do not allow purse seines to wait in line for preferred tie-off spots, but new technology advances permit more effective open setting offshore. This allows each vessel to make more sets in a given opening. Competition within the large purse seine fleet operating in Johnstone Strait during recent years of high diversion may now be causing fishing to shift more into the northwestern portion of Area 12, leading to increased harvest of the portion of the migration that had been less vulnerable to the fleet in earlier years. The fleet may, therefore, well be able to exert increased harvest rates even in short duration fisheries.

Increasing skill level in the fleet may also be important to the change in harvest rates. Fishermen are becoming more organized in the sharing of information between vessels. There is an attempt to increase individual opportunity and efficiency by acting in a coordinated fashion. By finding and concentrating effort on the larger schools or abundances, individual catches increase and harvest rates increase over time.

While we have discussed possible causes, little evidence was available to PSC staff which would help explain the apparent increase in Johnstone Strait harvest rates in the recent period (1992-1994) of high diversion of Fraser River sockeye. Events which may be advanced to explain the occurrence in 1994 must also accommodate the high reconstructed harvest rates in 1992 and 1993. Fish migration speed and arrival spread or distribution analyses did not appear to provide insight into the harvest rate increases. Technological change and behaviour of vessel operators in response to shortened openings may be the most likely source of the increase in harvest rates observed in recent years. Larger fleet size has had an impact, as well, in producing higher harvest rates near the peak periods of Fraser River sockeye when run sizes are large as in several recent years.

CONCLUSIONS

Elevated harvest rates in the 1994 Johnstone Strait purse seine fishery for late-run sockeye appears to have affected abundance and escapement estimation in the models. High harvest rates during weekly 12-hour or 24-hour purse seine fisheries in Areas 12 and 13 produced larger catches than expected from a run of the magnitude observed in 1994. These catches, in turn, caused the purse seine catch and CPUE models to over-estimate late-run sockeye abundance and the number that were available for gross escapement after catches in the Strait of Georgia were removed. At the same time, the in-season under-estimate of Johnstone Strait catch and imprecision in the estimated proportions of key summer-run stocks in the catch and escapement by the in-season racial identification models caused summer-run harvest rates to be underestimated. The summer-run exploitation rate model consequently over-estimated the numbers of late-run sockeye available for entry into the river. As well, the under-estimate of summer-run harvest rates convinced PSC staff that the use of 1983 late-run harvest rates was appropriate for the cumulative-normal model estimates of late-run sockeye abundance.

That the purse seine catch and CPUE models over-estimated the late-run abundance and projected gross escapement may be due, in part, to the use of sub-optimal models. When log transformation of all independent variables was tested, the resulting models had improved fits to the data and provided closer projections of late-run gross escapement for 1994. Secondly, the use of the regression models to make estimates for data that were substantially beyond previous observations contributed to the inaccurate estimates. When we used combined-stock purse seine models exclusively, the estimates of abundance dropped to levels near the accounted totals. This was due to the presence of 1993 and 1989 Quesnel and 1993 Late Stuart data in the dataset for the combined-stock models which provided the highest catches and CPUEs and largest Johnstone Strait runs in the entire dataset. These data points, therefore, heavily influenced the combined-stock regressions, which then provided a reasonably accurate estimate of late-run abundance in 1994. The fact that the 1993 data for Quesnel and Late Stuart were the most influential data in the regressions and also represent high harvest rate years probably also contributed to the accuracy of these models when applied to late-run data.

If reconstructions of sockeye runs in previous high diversion years had been undertaken after the 1993 season, the likelihood of an error of the magnitude observed in 1994 would have been reduced. Unfortunately, even if this analysis had been completed prior to the 1994 season, projections of the number of late-run sockeye available for gross escapement, based on models which use harvest rate, would have still been high relative to the gross escapement estimated at Mission. Also, we probably would have used lower rates because the in-season data suggested that harvest rates were lower in 1994 than 1993. In addition, it is not likely that we would have exclusively used combined-stock purse seine catch and CPUE models since the MSE of these models was substantially greater than for single-stock models. Therefore, the following scenario would have been generated in-season: high escapement estimates from purse seine models; low estimates from cumulative-normal models; and intermediate estimates from the in-season summer-run exploitation model. The dilemma of greatly differing late-run escapement estimates would have undoubtedly generated additional caution as to run size and escapement, but all projections would have exceeded the in-river assessment of escapement. Thus, while there would have been a lower discrepancy between the in-season estimate and the post-season accounting, a sizable difference would have remained.

Examination of the possible factors which may have affected harvest rates did not explain the high harvest rates in 1994. The similarity of the reconstructed harvest rates in 1992, 1993, and 1994 suggest that there has been a fundamental change in the capability of the Johnstone Strait purse seine fleet to harvest the fish present in the area on the 12 or 24 hour openings which have become typical in high diversion years. We consider these higher rates to now be the "normal" situation and recommend that future planning acknowledge this fact.

The high reconstructed harvest rates for late-run stocks in 1994 obtained using the Mission escapement estimate indicated that Mission estimates may have been low. Use of the higher DFO spawning escapement plus Fraser River Native fishery catch estimates in the analysis resulted in reduced harvest rates.

RECOMMENDATIONS

Run-size Estimation Models

We will incorporate 1992-94 Johnstone Strait purse seine harvest rates into the reconstructions used for the cumulative-normal model. The recent years' harvest rates are the best estimates available and most representative of the current fisheries in Johnstone Strait. Differences between recent harvest rates and data from 1980-1983 strongly suggest that real changes have occurred in the fundamental relationships between harvest rate and fleet size. The use of 1992-1994 harvest rates will produce a risk averse escapement estimate if in-season catch estimates continue to be slightly below the final post-season statistics. Historical experience indicates that projections of the number of late-run sockeye available for entry into the Fraser River have been underestimated by approximately 10%, when runs arrive primarily via the Juan de Fuca Strait route. In years of high diversion through Johnstone Strait, the models have been more prone to over-estimate abundance. By increasing the Areas 12 and 13 harvest rates in the reconstructions for the cumulative-normal model, we will reduce the potential for over-estimation. In addition, reconstruction of catches and escapements should be conducted each year in order to assess changes in Johnstone Strait harvest rates and to incorporate the most current estimates into the cumulative-normal model.

The experience of 1994 suggests that purse seine catch and CPUE models should use natural log transformation of effort and duration variables, in addition to the log of catch and CPUE used in the past. It is our intention to adopt this approach in 1995. Additional modifications, such as developing criteria to determine when single-stock and/or combined-stock models should be used, will be developed prior to the 1995 season. The inclusion of the 1994 data in the regression datasets should improve the performance of late-run models, since it was a high diversion and high harvest rate year, and will define the upper end of the late-run regression relationships.

PSC staff will also investigate Bayesian models and other run-size estimation techniques for their application to Fraser River sockeye salmon run-size assessment. Bayesian models objectively incorporate the uncertainty inherent in the various estimation techniques. Thus, the use of these Bayesian models will provide an assessment of the uncertainty surrounding estimates of run-size.

PSC staff will make the assessment of summer-run harvest rates a primary focus of the summer-run exploitation rate models. Only the weekly harvest rate model will be used in years when summer-run delay is identified or suspected. Summer-run sockeye harvest rate models were shown to be sensitive to racial analysis imprecision in the 1994 estimation of late-run sockeye escapement to the Strait of Georgia. The summer-run exploitation rate model was further compromised in 1994 by short-term a delay exhibited by summer-run stocks.

Monitoring Activities

We recommend that monitoring of the escapement of sockeye through the Johnstone Strait fishery be developed by establishing purse seine test fishing sites near the southeastern end of Area 13. We further recommend that this test fishery, beginning in 1995, be conducted each day that the commercial fishery is closed during the migration of summer-run and late-run sockeye. Application of this methodology, beginning in 1995, should provide valuable in-season data on the speed of travel of sockeye through Johnstone Strait and, hence, improve in-season estimates of harvest rate in the fisheries. In the future, this test fishery could provide direct estimates of late-run sockeye escapement to the Strait of Georgia.

We also recommend that the purse seine test fishery in the Robson Bight sector of Area 12 be expanded to a minimum of four days per week when the commercial fishery is of one-day duration.

Fishery Management

We recommend a reduction of the Johnstone Strait purse seine and gillnet fisheries to a geographical area equivalent to the distance that sockeye salmon travel in two days migration (i.e., approximately 113 km). This would allow harvest of three days of migration on each day of fishing: two days of fish that are in the area on the opening and one day of fish that enter during the fishery. Evidence from the review of 1994 Johnstone Strait purse seine harvest rates shows that the fishing power of the purse seine fleet has become so large that real risks to conservation are inherent in the continued management of the fishery on the basis of weekly openings in the current area (from the northwest end of Area 12 to the southeast boundary of Area 13-7, i.e., 210 km). Two options are available to the managers of this fishery to control harvest rate: 1) reduction in the frequency of fisheries, and 2) reduction in the length of the gauntlet open for harvest by purse seines. The latter option is more viable from a management perspective for two reasons. First, it would permit weekly openings, which would provide the crucial catch data required for the in-season run-size models. Second, during high diversion years, short openings in a restricted geographical area would expose fewer daily blocks of fish to the fishery, thereby reducing weekly harvest rates. Fishery managers would consequently have greater flexibility to extend fisheries to longer openings, if required. In practice, the fishery would become more similar to the Area 20 fishery which is highly manageable in this regard. If the recommended Area 13 test fishery provides the data expected on escapements, it could also be used to govern extension or re-opening of fisheries. In the shorter term, changes to the fishing area will disrupt the harvest rate relationship referred to earlier. This underscores the need for extensive purse seine test fishing to assist in monitoring escapement from the Johnstone Strait fishery.

We recommend that purse seine and troll interceptions in migratory areas seaward of the Area 12 purse seine fishery be reduced. Data for definitive in-season run-size estimation can only be obtained from Juan de Fuca and Johnstone Straits purse seine fisheries, supplemented by purse seine test fishing in those areas. The Canadian management regime which is designed to harvest late-run stocks in outside fisheries results in a large fraction of the total allowable catch (TAC) being harvested before in-season run-size estimation can occur. The removal of fish from the migration seaward of the assessment points, in particular in the Queen Charlotte Island purse seine and troll fisheries, can affect the assessment of run size by changing the peak abundance and form of the migration curve of the run entering the purse seine fisheries. Also, as occurred in 1993, reaching purse seine allocation goals early in the season may prevent further fishing, leading to the consequent loss of the fishery information used to estimate escapements.

Catch Estimation

We recommend that DFO devise practical methods for obtaining more accurate temporal and spatial resolution of catches. Also, fish tickets should be modified to accommodate the splitting of catches between fishing areas, and the DFO catch database should be modified to accept and process such data. The apportionment of purse seine catch to the proper statistical areas was not correct when vessels fished in more than one area during a given week in 1994.

Accurate in-season catch estimates are required from all commercial fisheries for assessment and allocation requirements. This is especially true for the purse seine and gillnet fisheries operating in Juan de Fuca and Johnstone Straits where catches form the basis of Fraser River sockeye run-size estimation.

The accuracy of in-season purse seine and gillnet catch estimates in Canadian Areas 11-16 and of gillnet catch estimates for fisheries in Area 20 have been problem areas and should receive attention.

Post-season catch data gathering and reconciliation should also be upgraded. DFO has implemented revised estimation procedures for the troll fishery which has improved the accuracy and speed of catch verification. Application of these techniques to the Canadian net fishery is warranted. Implementation of a catch estimation system based on rapid collection and processing of fish sales slip information such as the Washington Department of Fisheries "soft system" is desirable from a management point of view.

Racial Analysis

We recommend that PSC and DFO scientists review the genetically-based stock identification techniques, including DNA analysis, to determine the potential for applying newly emerging technology to the problem of obtaining accurate in-season analyses of stock composition. In-season racial analyses in 1994 provided imprecise estimates of stock composition in critical Johnstone Strait and Fraser River commercial and test fishing catches due to reliance on adult sockeye scale collections from previous years. This problem has arisen in recent years because the preferred source of scales, jack sockeye from the preceding year, have been returning in much reduced abundances. Consequently, scales from adult sockeye from previous cycle years must be used instead, even though they are not as effective as jack scales. In the short term, racial composition estimates should be assessed in-season by incorporation of scale data collected early in each run from in-river locations that are upstream of mixed-stock catch areas, provided that scales collected early in the season by DFO can be quickly provided to PSC staff.

Summary

In summary, improving the quality of in-season catch and racial data, stabilizing the fisheries, and improving the run-size models will reduce the likelihood of such large estimation errors as were experienced in 1994. We urge the adoption of the view that fisheries serve two important purposes. One is to provide the economic gains derived from harvesting the fish. The second is to provide the data that is necessary to manage the fisheries with enough precision to meet both spawning escapement and catch goals without compromising the conservation of the stocks.

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APPENDICES

TABLE OF CONTENTS

Appendix A: List of Participants At the Workshops

Workshop on February 2-3, 1995:

D. Anderson
A. Chapman
R. Conrad
C.C. Graham
M. Grayum
L. HopWo
A. Macdonald
M. Medenwaldt
R. Routledge
P. Ryall
W. Saito
M. Stocker
T. Tynan
C. Walters

Workshop on April 26, 1995:

A. Cass
A. Chapman
B. Conrad
B. Gazey
J. Giard
M. Grayum
L. HopWo
A. Lill
A. Macdonald
K. McGivney
S. McKinnell
M. Medenwaldt
R. Routledge
P. Ryall
W. Saito
M. Staley
T. Tynan
L. Wick

Participation in the workshops does not imply that all attendees are in full agreement with the conclusions and recommendations in this report.

Workshop on February 2-3, 1995:

PSC Staff:

I. Todd
J. Cave
J. Gable
I. Guthrie
M. Lapointe
J. Woodey

PSC Staff:

I. Todd
J. Cave
J. Gable
I. Guthrie
M. Lapointe
J. Woodey

Appendix B: Statistical Tables for Fraser River Sockeye Fisheries in 1994.

Table 1. Return forecasts and escapement targets for the 1994 run of Fraser River sockeye .

Run	Stock	Forecast Return	1994 Escapement Target
Early Stuart		408,000	200,000
Early Summer		1,117,000	400,000
Summer	Horsefly	1,172,000	585,000
	Chilko	7,268,000	825,000
	Late Stuart/Stellako	1,896,000	600,000
	Sub-total	10,336,000	2,010,000
Late	Birkenhead	682,000	290,000
	Adams/Lower Shuswap	5,976,000	2,350,000
	Misc. Late	446,000	140,000
	Sub-total	7,104,000	2,780,000
Total Adults		18,965,000	5,390,000
Total Jacks		35,000	19,000
Total		19,000,000	5,409,000

Table 2. Estimates of actual run size by stock/stock group in 1994 (estimates of gross escapement from Mission hydroacoustic program).

Run and Stock / Stock Group	Catch	Escapement	Total
Early Stuart	4,000	198,000	202,000
Early Summer	753,000	515,000	1,268,000
Summer			
Quesnel	2,251,000	1,090,000	3,341,000
Chilko	1,733,000	840,000	2,573,000
Late Stuart/Stellako	864,000	584,000	1,448,000
Sub-total	4,848,000	2,514,000	7,362,000
Late			
Birkenhead	464,000	105,000	569,000
Adams/Lower Shuswap	5,788,000	927,000	6,715,000
Misc. Late	521,000	105,000	626,000
Sub-total	6,773,000	1,137,000	7,910,000
Total	12,378,000	4,364,000	16,742,000

Table 3. In-season and post-season estimates of catches of Fraser River sockeye salmon in 1994.

Area	In-season Fraser Catch	Post-season Fraser Catch	Difference (post-season - in-season)	% Difference (post-season - in-season)
Canada				
Area 1 net	59,556	96,415	36,859	61.9%
Area 2W net and troll	774,028	809,799	35,771	4.4%
Area 8	222,210	163,960	-58,250	-35.5%
Area 111 and 8 troll	792,461	878,929	86,468	9.8%
Area 12	3,044,900	3,595,265	550,365	15.3%
Area 13	1,097,800	1,293,459	195,659	15.1%
Area 16	121,600	147,631	26,031	17.6%
Area 20	681,253	846,486	165,233	19.5%
Area 29A (outside troll)	255,000	165,555	-89,445	-54.0%
Area 29B	807,818	828,749	20,931	2.5%
Area 29D	482,298	469,174	-13,124	-2.8%
Upper Georgia Strait troll	199,396	201,940	2,544	1.3%
Lower Georgia Strait troll	158,234	186,092	27,858	15.0%
Areas 125-127 troll	161,601	118,964	-42,637	-35.8%
Areas 123-124 troll	257,250	232,549	-24,701	-10.6%
Total Canadian Commercial Catch	**9,115,405**	**10,034,967**	**919,562**	**9.2%**
United States				
Treaty Ceremonial fisheries	0	0	0	0.0%
Area 7A	1,392,461	1,392,452	-9	0.0%
Area 7	316,502	316,489	-13	0.0%
Areas 4B, 5 and 6C	120,190	119,424	-766	-0.6%
Alaska District 104 *	225,000	240,000	15,000	6.3%
Total U.S. Commercial Catch	**2,054,153**	**2,068,365**	**14,212**	**0.7%**
Total Catch **	**11,323,491**	**12,377,940**	**1,054,449**	**8.5%**

Notes:

* Alaska District 104 catch of Fraser sockeye is based on in-season stock identification.

** In addition to catches shown in table, total catch includes in-season non-commercial catch of 153,933 and post-season non-commercial catch 274,608.

Table 4. Comparison of catch and harvest rate in migratory and terminal areas for summer-run and late-run stock groups. All estimates are from post-season analyses.

	Summer Runs		Late Runs	
	Chilko/ Quesnel	Stellako L.Stuart	Adams/ Shuswap	Misc. Late Runs
Total Run	5,913,298	1,447,800	6,714,948	1,196,291
Outside Area Catches	564,836	132,508	1,515,901	292,456
Total Run Entering Inside Waters	5,348,462	1,315,292	5,199,047	903,835
Migratory Area Catches				
Canadian Waters	2,006,126	367,126	2,956,800	467,179
U.S. Waters	378,035	88,288	183,152	27,010
Total Migratory Area Catch	2,384,161	455,414	3,139,952	494,189
Migratory Area Harvest Rate	44.6%	34.6%	60.4%	54.7%
Total Run Entering Georgia Strait	2,964,301	859,878	2,059,095	409,646
Terminal Area Catches				
Canadian Waters	858,095	247,299	387,858	111,804
U.S. Waters (7A Delay)	177,231	28,368	744,099	86,946
Total Terminal Area Catch	1,035,326	275,667	1,131,957	198,750
Terminal Area Harvest Rate	34.9%	32.1%	55.0%	48.5%
Gross Escapement (Into River)	1,928,975	584,211	927,138	210,896
(Mission Esc. + IF Catch Below)				

Appendix C: Compare Estimates From Commercial Purse Seine Models Using In-season and Post-season Catch and Racial Data

Objective

To assess whether the overestimate in late-run escapement to the Strait of Georgia could be attributed to discrepancies between in-season and post-season estimates of the model inputs, specifically, catch and racial composition. If yes, then which of these data contributed most to the overestimate. Also, to compare estimates that incorporate adjustments of Johnstone Strait catches to compensate for large northern removals, which was done in-season, to estimates made without such adjustments.

Methods

Description and Use of Models

The commercial purse seine models used multiple regression techniques and data from commercial purse seine openings in Juan de Fuca and Johnstone Straits to estimate the abundance of runs that migrated through these approaches. In the following paragraphs we describe the data and methods used to derive and apply the models.

The regression data had two main components. First, the dependent variables, the annual Juan de Fuca and Johnstone Straits runs by stock group, were calculated by subtracting the catches in northern areas (Alaska and Canadian Areas 1-10) from the total run to obtain the run to the northern end of Vancouver Island. This number was multiplied by the estimate of diversion rate for each year to estimate the number of fish that migrated through Johnstone Strait. The west coast Vancouver Island catch of the remaining fish (i.e., Cape Caution run minus Johnstone Strait run) was then subtracted to estimate the Juan de Fuca run. Preliminary data were used for years when final data were not yet available.

The independent variables, average daily catch, average daily catch per unit effort (CPUE), daily effort (gear count) and duration (number of days fishery was open),were primarily from two sources. Final catch data (based on sales slips) and gear counts were provided by DFO. Racial data for splitting the total catch into catch by stock data were from the PSC. Preliminary data were used for years when final data were not yet available. Models for estimating Juan de Fuca runs were based on commercial purse seine fishery data from Area 20, whereas Johnstone Strait models were based on data from Areas 12 and 13.

Once the historical data were compiled, the peak average daily catch for each stock and for each year was determined. This is called the "peak week catch". We then attempted to weed out years when the peak week catch did not occur on the peak of the run or when the fishery was unusual. For example, years when no fisheries occurred on the peak or when industry strikes occurred during the major runs were removed. The remaining data were merged with the run size data to create the dataset used in the regressions. A natural log transformation was then applied to the run size, catch and CPUE values.

These data are then used to calculate regression parameters by approach and by run. The resulting models had the forms:

$$Run\ Size = Exp\ (a + b_1(\ln\ Catch\ ) + b_2 Effort + b_3 Duration\ )$$

and

$$Run\ Size = Exp\ (a + b_1(\ln\ CPE\ ) + b_2 Effort + b_3 Duration\ )$$

where either catch or CPUE were included in all models, but effort and duration were included only if the adjusted R^2 and Mallows C_p statistic indicated the model was improved if they were included.

In-season, these models were used to provide estimates of run size based on the available estimates of catch, effort, duration and racial composition. Catch estimates for a given fishery were initially based on DFO hails, and later replaced by estimates derived from information collected by phone from fish packers and processors. Generally, the PSC estimates catches in Area 20 while DFO estimates catches in Areas 12 and 13. Effort data were collected by overflights or by on-water estimates by DFO personnel. Information about fishery durations were available from the regulations. Finally, racial composition data were derived from racial analyses of scale samples collected by DFO and PSC from each fishery, using standards from jack returns in 1993 and age 4_2 returns in 1990.

After each fishery, the data were analyzed to determine which fishery represented the peak week catch for each stock group. The data from these fisheries were then entered into the run size models to generate run size estimates. Estimates for each stock group were then pooled to provide a single estimate for each stock group, using the mean square error (MSE) of each model to weight the individual estimates.

In addition to the models shown above, we used two other types of models in-season in 1994 and in previous years to generate run size estimates. These are considered to be secondary models and so are not included in the analyses presented in this document. However, they are described briefly for the sake of completeness. First, we developed models that used the peak week catch from the two fisheries with the highest average daily catch. These models were applied after the peak of the run had passed. Second, the regression data were combined to provide models based on combinations of stocks, specifically, summer-run, late-run and all-stocks combined models. The summer- or late-run models were used when no stock-specific model was available, such as for the Early Stuart run through Juan de Fuca Strait, and generally as a verification of the estimates from the one-stock models. The all-stocks combined model was used when the peak week catch for a stock exceeded the previous maxima for all the stocks in the run, such as for the Adams run through Johnstone Strait in 1994. The estimates from these models were pooled with the estimates from the models shown above, using the MSE of each model to weight the individual estimates. However, generally the one-stock peak week models shown above had the lowest MSEs, so they were given more weight than estimates from the models presented in this paragraph.

Analysis

Using the same regression models that were used in-season to generate estimates of run size through Juan de Fuca (JdF) and Johnstone Straits (JS), the in-season and post-season catch and racial data were entered in four combinations (Table 1) to produce a series of parallel estimates. This was done using both the adjusted and unadjusted catches. Fishery catches in inside areas were then removed from the estimates of total run size through the two straits to estimate the escapement to the Strait of Georgia and to Mission. Catches in Areas 1-11 were also removed when adjusted catches were used.

Table 1. Combinations of data that were evaluated to assess the effect of in-season and post-season data on run size estimates in 1994.

Catch Adjustments	Catch	Racial
Adjusted	in-season	in-season
"	in-season	post-season
"	post-season	in-season
"	post-season	post-season
Unadjusted	in-season	in-season
"	in-season	post-season
"	post-season	in-season
"	post-season	post-season

The resulting estimates of escapement to Mission were then compared to the escapement estimate derived from summing the Mission hydroacoustic estimate and estimated Native catch below Mission.

Although the "Catch" and "Racial" blocks in Table 1 are self evident, the "Catch Adjustments" block requires some explanation. This block refers to additions to Johnstone Strait (Areas 12 and 13) purse seine catches to compensate for unusually large catches in northern areas (Areas 2W, 8 and 11), which deform the run entering Johnstone Strait. Such deformation of the run would cause the catch models to underestimate run size, so run reconstruction techniques were used to estimate what catches in Areas 12 and 13 would have been if the northern fisheries had not occurred. The application of this method during the 1994 season was the outcome of a workshop held to investigate the underestimation of escapement in 1993. The specific adjustments are summarized in Table 2.

Table 2. Adjustments to Areas 12 and 13 purse seine catches that were applied in 1994 to compensate for unusually large catches in northern areas in 1994.

		Fishery	Adjustments		
Catch	Racial	Date	Summer	Late	Total
In-season	In-season	Aug 15	67,000	144,000	211,000
		Aug 22	74,000	328,000	402,000
		Aug 31	2,000	31,000	33,000
			143,000	503,000	646,000
In-season	Post-season	Aug 15	69,000	133,000	202,000
		Aug 22	92,000	310,000	402,000
		Aug 31	6,000	27,000	33,000
			167,000	470,000	637,000
Post-season	In-season	Aug 15	60,000	202,000	262,000
		Aug 22	101,000	480,000	581,000
		Aug 31	4,000	55,000	59,000
			165,000	737,000	902,000
Post-season	Post-season	Aug 15	68,000	185,000	253,000
		Aug 22	127,000	460,000	587,000
		Aug 31	13,000	47,000	60,000
			208,000	692,000	900,000

Results

Table 3 shows a detailed accounting by run of run size estimates, catches in various areas, and calculated escapements to the Strait of Georgia and to Mission, for the combinations described above. Table 4 summarizes the differences between the various estimates of gross escapement and the hydroacoustic estimates (Mission hydroacoustic plus Native catch below Mission).

For the scenarios using adjusted catches, the in-season catch and racial data (in:in) produced a larger difference for early summer and summer runs, and smaller difference for late runs and the total run compared to when post-season data (post:post) were used. Based on the relative size of the differences, the primary source of the discrepancy between in:in and post:post results were in-season to post-season changes in racial data for early summer runs, and changes in catch data for summer runs, late runs and the total run. Thus, the major source of differences between in-season and post-season run size and escapement estimates are post-season updates to the in-season catch estimates.

The results are similar in most respects for the unadjusted catch scenario. However, one difference is that for summer runs the effects of post-season updates to catch and racial data essentially cancelled out. Another difference is that for late runs, the in:in discrepancy is larger than the post:post discrepancy and the primary source of the change are updates to racial estimates.

Comparing the adjusted and unadjusted catch scenarios, the estimates are only moderately different. For example, discrepancies between the in:in estimates are 12,000, 76,000, 302,000 and 390,000 for early summer, summer, late and total runs, respectively. Equivalent discrepancies for the post-post estimates are 25,000, 149,000, 48,000 and 126,000. For early summer and summer runs, the unadjusted catch scenario produced more accurate estimates in 1994. For late runs, the adjusted in:in estimate and unadjusted post:post estimates were closest, while for the total run the adjusted scenario produced the most accurate estimates.

Conclusions

When adjusted catches were used (as was done in-season), most of the discrepancies between in-season and post-season estimates in 1994 were due to post-season updates of catch data. The result was mixed when unadjusted catches were used, with catch and racial updates having an equal effect for summer runs, racial updates having a larger effect for late runs and catch updates having a larger effect for the total run.

The most accurate estimates for early summer and summer runs were based on post-season estimates of catch and escapement. However, the use of in-season catch and racial data resulted in the best estimates of late-run and total abundance when adjusted catches were used (as they were in-season). When unadjusted catches were used, post season data provided better estimates for late runs and poorer estimates for the total run.

If in-season data are used, unadjusted catches provided slightly better estimates of early summer-and summer-run escapement, while adjusted catches resulted in better estimates of late-run and total escapement. If post-season data are used, the same pattern holds for early summer, summer and total runs, but unadjusted catches resulted in only a marginal improvement in the estimate of late-run escapement.

Based on the above analysis, the overestimation of late-run escapement to Mission could not have been avoided in-season, either by having perfect information (i.e., post-season catch and racial data) or by using unadjusted catch data instead of adjusted catch data. In fact, the discrepancy would have been larger if post-season data had been available. The best and the worst estimates, from all of the various scenarios and permutations evaluated, deviated from the actual escapement by amounts that were of the same order of magnitude (1,600,000 to 2,300,000).

Adjusted catches performed better than unadjusted catches for late runs and the total run, but not for early summer and summer runs. Therefore, this analysis does not indicate a clear advantage to using adjusted versus unadjusted catches.

Table 3. Comparison of estimates of run size and escapement using adjusted versus unadjusted catches, and in-season versus post-season catch and racial estimates.

Run	Run Size Excluding WCVI Catch	Areas 1-11 Catch	JdF + JS Run Size	Inside Catch *	Strait of Georgia Esc.	Terminal Area Catch **	Available Gross Esc.	Actual Gross Esc. ***	Difference
Adjusted Catch Data									
In-season Catch and Racial Data									
E.Summ	709,000	12,000	697,000	241,000	456,000	146,000	310,000	516,000	(206,000)
Summer	5,888,000	401,000	5,487,000	2,409,000	3,078,000	1,383,000	1,695,000	2,623,000	(928,000)
Late	8,961,000	1,434,000	7,527,000	3,388,000	4,139,000	1,260,000	2,879,000	1,055,000	1,824,000
Total	15,558,000	1,847,000	13,711,000	6,038,000	7,673,000	2,789,000	4,884,000	4,194,000	690,000
In-season Catch and Post-season Racial Data									
E.Summ	1,048,000	36,000	1,012,000	461,000	551,000	188,000	363,000	515,000	(152,000)
Summer	6,056,000	625,000	5,431,000	2,457,000	2,974,000	1,304,000	1,670,000	2,513,000	(843,000)
Late	8,327,000	1,202,000	7,125,000	3,126,000	3,999,000	1,288,000	2,711,000	1,138,000	1,573,000
Total	15,431,000	1,863,000	13,568,000	6,044,000	7,524,000	2,780,000	4,744,000	4,166,000	578,000
Post-season Catch and In-season Racial Data									
E.Summ	755,000	12,000	743,000	272,000	471,000	144,000	327,000	516,000	(189,000)
Summer	6,545,000	313,000	6,232,000	2,784,000	3,448,000	1,386,000	2,062,000	2,623,000	(561,000)
Late	10,203,000	1,608,000	8,595,000	3,943,000	4,652,000	1,304,000	3,348,000	1,055,000	2,293,000
Total	17,503,000	1,933,000	15,570,000	6,999,000	8,571,000	2,834,000	5,737,000	4,194,000	1,543,000
Post-season Catch and Post-season Racial Data									
E.Summ	1,135,000	25,000	1,110,000	533,000	577,000	185,000	392,000	515,000	(123,000)
Summer	6,727,000	489,000	6,238,000	2,838,000	3,400,000	1,311,000	2,089,000	2,513,000	(424,000)
Late	9,508,000	1,435,000	8,073,000	3,634,000	4,439,000	1,331,000	3,108,000	1,138,000	1,970,000
Total	17,370,000	1,949,000	15,421,000	7,005,000	8,416,000	2,827,000	5,589,000	4,166,000	1,423,000
Unadjusted Catch Data									
In-season Catch and Racial Data									
E.Summ			709,000	241,000	468,000	146,000	322,000	516,000	(194,000)
Summer			5,563,000	2,409,000	3,154,000	1,383,000	1,771,000	2,623,000	(852,000)
Late			7,829,000	3,388,000	4,441,000	1,260,000	3,181,000	1,055,000	2,126,000
Total			14,101,000	6,038,000	8,063,000	2,789,000	5,274,000	4,194,000	1,080,000
In-season Catch and Post-season Racial Data									
E.Summ			1,048,000	461,000	587,000	188,000	399,000	515,000	(116,000)
Summer			5,716,000	2,457,000	3,259,000	1,304,000	1,955,000	2,513,000	(558,000)
Late			7,272,000	3,126,000	4,146,000	1,288,000	2,858,000	1,138,000	1,720,000
Total			14,036,000	6,044,000	7,992,000	2,780,000	5,212,000	4,166,000	1,046,000
Post-season Catch and In-season Racial Data									
E.Summ			755,000	272,000	483,000	144,000	339,000	516,000	(177,000)
Summer			6,246,000	2,784,000	3,462,000	1,386,000	2,076,000	2,623,000	(547,000)
Late			8,618,000	3,943,000	4,675,000	1,304,000	3,371,000	1,055,000	2,316,000
Total			15,619,000	6,999,000	8,620,000	2,834,000	5,786,000	4,194,000	1,592,000
Post-season Catch and Post-season Racial Data									
E.Summ			1,135,000	533,000	602,000	185,000	417,000	515,000	(98,000)
Summer			6,387,000	2,838,000	3,549,000	1,311,000	2,238,000	2,513,000	(275,000)
Late			8,025,000	3,634,000	4,391,000	1,331,000	3,060,000	1,138,000	1,922,000
Total			15,547,000	7,005,000	8,542,000	2,827,000	5,715,000	4,166,000	1,549,000

* Catches in Canadian Areas 12-16, 18-20, and U.S. Areas 4B, 5, 6C, 6, and 7, and portion of the catch in Area 7A.

** Catches in Canadian Areas 17 and 29, but excluding IF catch below Mission.

*** Mission hydroacoustic estimate of escapement plus IF catch below Mission.

Table 4. Differences between estimated and actual gross escapements (Mission escapement + Native catch below Mission) by run, for adjusted versus unadjusted catches, and in-season versus post-season catch and racial estimates.

	Adjusted Catches			**Unadjusted Catches**		
		Catch			**Catch**	
	Racial %	In-seas	Post-seas	**Racial %**	In-seas	Post-seas
Early Summer	In-seas	(206,000)	(189,000)	In-seas	(194,000)	(177,000)
	Post-seas	(152,000)	(123,000)	Post-seas	(116,000)	(98,000)
		Catch			**Catch**	
	Racial %	In-seas	Post-seas	**Racial %**	In-seas	Post-seas
Summer	In-seas	(928,000)	(561,000)	In-seas	(852,000)	(547,000)
	Post-seas	(843,000)	(424,000)	Post-seas	(558,000)	(275,000)
		Catch			**Catch**	
	Racial %	In-seas	Post-seas	**Racial %**	In-seas	Post-seas
Late	In-seas	1,824,000	2,293,000	In-seas	2,126,000	2,316,000
	Post-seas	1,573,000	1,970,000	Post-seas	1,720,000	1,922,000
		Catch			**Catch**	
	Racial %	In-seas	Post-seas	**Racial %**	In-seas	Post-seas
Total	In-seas	690,000	1,543,000	In-seas	1,080,000	1,592,000
	Post-seas	578,000	1,423,000	Post-seas	1,046,000	1,549,000

Appendix D: Cumulative Passage Models

Model Description

Cumulative passage models are developed from stock specific historical reconstructions referenced to a common migratory location, the Fraser River at Mission. Reconstructions for individual stocks, using a daily time step, are developed from Mission escapement data and from catches in Panel and non-Panel area commercial fisheries. Regression based estimates of the total return for a stock of interest are derived by comparing the total number of fish accounted for in catch and escapement at specific dates throughout the season, to the number of fish observed historically at the same date, and the total run size for that year. Two sets of regressions are run for each stock, one which includes individual year run timing as a variable, and one which uses only run accounted for to date.

Annual reconstructions are performed in a given year, for all uniquely identified stocks or stock groups, through the summer-run time period. Historically, models have been developed for the following stocks or stock groups: Early Stuart, Early Summer-runs, Chilko, Horsefly, Late Stuart and Stellako. Models have not been developed for late-run stocks because of the delay behaviour they exhibit prior to migrating into the Fraser River.

Assumptions

A variety of assumptions must be met for the cumulative passage models to provide unbiased estimates of run size. Violations of these assumptions may result in directional bias and cause run size estimates to be systematically high or low. A list of the assumptions include:

- the assumptions inherent to linear regression applications are not being violated,
- the historical reconstructions are accurate (ie. the speed of migration between areas is known, there is no significant racial identification bias, the post season catch and escapement data are accurate),
- the in-season catch and escapement data by stock are accurate and complete,
- the migrational distribution of the run in the current year is similar to historical patterns,
- for regression models which incorporate run timing as a variable, that run timing can be accurately assessed in-season.

Data Sources

The data sources required for the construction of the cumulative passage models include post-season catch and racial data for the construction of the historical data sets, in-season catch and racial data for development of the in-season reconstructions, and in-season run timing data.

In Canada, post-season catch data are tabulated by week-ending period by DFO from fish sales slips collected from all registered fish buyers in the province. In the United States, daily catch data are tabulated from fish tickets. Post-season discriminant function analysis models are derived from stock specific spawning ground scale data collected each year. Commercial catches are separated into stock specific components using discriminant function analysis. Stock specific Mission escapement data are combined with the catch data, adjusted to a Mission timing date, and post-season reconstructions are developed.

In-season catch data are derived from gear counts, in conjunction with estimates of catch and CPUE data from hails and fish buying companies. In-season racial analyses are conducted in a similar manner to the post-season analyses. However, the baseline standards are developed from prior year scales, preferably with jack sockeye scales from the same cohort, but often using previous years adult sockeye scales from the same age class. These baseline standards are less accurate than the standards constructed for the post-season analyses, and consequently, there is likely to be more bias associated with in-season stock identification assessments relative to the post-season analyses.

In-season run timing estimates for individual stocks are initially obtained from pre-season forecasts developed by DFO. These forecasts are replaced using in-season data derived from the cumulative-normal model once the process of generating in-season run size estimates is initiated. Early in a run, timing estimates from the cumulative-normal model are unreliable. They become more accurate as the run builds towards a peak in the primary assessment fisheries in Area 20 and Johnstone Strait.

Data Available for Individual Stocks

As mentioned above, cumulative passage models have been developed for the following stocks or stock groups: Early Stuart, Early Summer runs, Chilko, Horsefly, Late Stuart and Stellako. However, depending on the spatial distribution of the mean discriminant scores in the in-season baseline standards, in some years it is not possible to uniquely separate all of the stocks outlined above. For example, in 1994, Chilko and Horsefly were grouped together and the Late Stuart stock was grouped with Stellako. The years for which historical reconstructed run size data are available include:

- Early Stuart (1973 - 1977, 1979 - 1993),
- Early Summer runs (1974 - 1993),
- Chilko (1974 - 1993),
- Horsefly (1974,1975,1977,1978,1981,1982,1985,1986,1989 - 1991,1993),
- Stellako (1974 - 1976, 1978 - 1980, 1982 - 1984, 1986 - 1988, 1990 - 1992).

Computational Methods

The cumulative passage models were developed with two objectives in mind: to produce minimum run size updates of pre-season forecasts prior to the peak of the run passing Mission, and to produce revised run size updates of pre-season forecasts closer to the peak of the run. They are regression based models, which are easy to assess, and they can provide reasonably accurate estimates of run strength prior to the peak of the run, providing run timing can be estimated. Total run for a stock in a particular year (ln Y) is regressed against the reconstructed run at Mission for a given date (ln X1) in a simple linear regression. A separate regression is available for each day that the reconstructed run is present at Mission. Multiple regression models are the primary method used. The multiple regressions incorporate run timing (the date at which 50% of the cumulative reconstructed run has past Mission) as the second variable (ln X2).

Examples of the two forms of regression equations used to generate estimates of run size for individual stocks or stock groups are provided below:

- Simple Regressions: Total Run(Stock 1) = a + (Run Accounted(Stock 1,Day n))(X1) + E

- Multiple Regressions: Total Run(Stock 1) = a + (Run Accounted(Stock 1,Day n))(X1) + (Run Timing(Stock 1))(X2) + E

To help in assessing the precision of the cumulative passage models, 80% confidence intervals and prediction intervals are provided for each assessment that is made during the in-season management period, along with the point estimates. The R2 values for the multiple regressions, and the confidence and prediction intervals, are calculated assuming that in-season run timing is measured without error.

Discussion of Historical Data

As described above, for early timed and summer-run Fraser River sockeye stocks, daily regression equations exist which allow the total run to be estimated throughout the course of the each stocks migration. The variance around individual point estimates generated for the stock specific regressions is high early in the season, and is reduced on successive days as more of the run is accounted for in catch and escapement. The variance is particularly high in the simple regressions, when run timing is not used as an independent variable.

The historical data sets allow for run timing to be accurately assessed. Run size predictions which incorporate run timing as a second independent variable allow us to forecast the total return for a given stock with a reasonable degree of precision approximately one week prior to the cumulative 50% point of the run reaching Mission. To understand the change in the relative precision of the regression models through the course of a run, adjusted R squared values from the cumulative passage models are provided for selected Mission dates for each of the stocks for which regression equations have been developed. For each stock, the adjusted R squared value at the historical 50% cumulative passage date at Mission is reported in Table 1, along with the adjusted R squared values one week before and one week after the peak date. When considering the adjusted R squared values from the multiple regressions listed in Table 1, it is important to recognize that the values for the multiple regressions are generated using post-season run timing estimates. These post-season run timing estimates are accurate, assuming the run reconstructions are accurate. During the in-season management period, run timing estimates are less accurately estimated. Consequently, the run size predictions which are generated from post-season data sets, using in-season data, will provide optimistic assessments of model performance. From Table 1 three points are evident:

- it is possible to estimate the run size for individual stocks or stock groups at least one week prior to the cumulative 50% passage date at Mission, provided run timing can be predicted,
- without assessing run timing it is unlikely that precise estimates of run strength will be generated **prior to** the 50% point of the run, but with run timing reasonably precise estimates can be generated,
- run timing is less important one week after cumulative 50% point of the run has been observed, but it still improves the predictive capabilities of the model.

In summary, the cumulative passage models are important in that they provide in-season estimates of run strength by stock, independently of other methods used by the PSC. The models are easy to assess, and can provide reasonably accurate and precise estimates of run strength prior to the peak of the run, **providing run timing can be assessed**. Also, because these methods are based on complete reconstructions, referenced to a Mission timing date, catches taken in northern migratory areas can be incorporated into the run size assessments. It is important, however, to recognize some of the weaknesses inherent in using the in-season catch and racial data to assess run strengths. Changes to in-season catch and escapement data are made continually throughout the in-season period. These changes, in conjunction with in-season racial identification bias, can have significant effects on run size estimates. With this in mind, the 1994 run size assessments for the key summer-run stocks are reviewed below.

Analysis of 1994 Estimation Results (In-season Versus Post-season Estimates)

In 1994, in-season discriminant function analysis allowed for the estimation of two distinct summer-run stock groups, the Chilko/Horsefly stock group and the Late Stuart/Stellako stock group. The discussion of the relative in-season and post-season performance of the cumulative passage models will be confined to these two stock groups. Changes in total run size estimates for each of the two stock groups, using in-season versus post-season data sets, are due to a combination of changes which occurred in both the catch and the racial analysis in the post-season.

In assessing the performance of the cumulative passage models, actual in-season estimates as presented on specific dates are used. Dates on which run size estimates were made using the cumulative passage model include August 12, August 18 and August 23. The post-season estimate for the Chilko/Horsefly stock group is 5,907,000 fish, with a cumulative 50% passage date at Mission of August 16. In hindsight, the August 12 in-season estimate was based of data available four days prior to the eventual 50% cumulative passage date, while the August 18 and 23 estimates incorporated data from two and seven days after the peak, respectively (Table 2).

On August 12, the in-season assessment of run timing was for a peak at Mission on August 18. This number was used to provide the best estimate of the Chilko/Horsefly run size, which was 5,296,000. This number was 611,000 or 10.3% below the current post-season estimate of 5,907,000 (Table 2). Using post-season catch and racial data, the projected total run, assuming an August 18 peak passage date, was 5,816,000. This projected number is 91,000 or 1.5% below the current post-season estimate.

By August 18, two days after the cumulative 50% date, the in-season run timing estimate was correctly identifying the peak cumulative passage date for the Chilko/Horsefly stock group as August 16. The cumulative passage model, updated to include the new timing date, and incorporating all available catch and escapement data through to August 18, was predicting a total run of 6,000,000 fish. This was 93,000 or 1.6% above the current best estimate for the stock group. With post-season data replacing the in-season data, the cumulative passage model predicts a total run of 5,609,000, or 298,000 (5.0%) below the total return for the stock group (Table 2).

A final run size update from the cumulative passage model was provided on August 23. At that time, the run timing estimate was August 15, and the total run estimate for the stock group was 5,965,000, or 58,000 (1.0%) above the post-season return. If an August 16 peak passage date had been used, the run size estimate would have been 6,126,000, or 219,000 (3.7%) above the post-season return. Regardless of the timing date used, the model was very accurate in assessing the total return strength for the stock group. Similarly, using post-season data, and an August 16 peak passage date, the run size prediction was 5,818,000, or 89,000 (1.5%) below the current estimate for the stock group (Table 2). In conclusion, whether using in-season or post-season data, the cumulative passage model performed well in 1994 for the Chilko/Horsefly stock complex.

With regard to the Late Stuart/Stellako stock complex, the same three dates were used to assess the performance of the cumulative passage model, namely August 12, 18 and 23. The post-season estimate for the Late Stuart/Stellako stock group complex is 1,451,000 fish, with a cumulative 50% passage date at Mission of August 13. Therefore, run size predictions for the Late Stuart/Stellako stock group, using the cumulative passage model, were made one day before, and five and ten days after the peak. During the in-season period the run timing assessment for this stock group was not estimated to be August 13, but was initially projected to be August 16, and subsequently August 14 (Table 3). Consequently, no run size estimates are available from the in-season period with the August 13 timing date.

On August 12, a peak timing date of August 16 was used. With this date, the cumulative passage model predicted a total run of 1,025,000 for the Late Stuart/Stellako stock group. This was 426,00, or 29.4% below the current post-season estimate. Using post-season catch and racial data, and an August 16 peak timing estimate, the run size for the stock group was estimated to be 1,853,000. If the actual 50% cumulative passage date of August 13 is used, the run size estimate is 1,333,000, or 8.1% below the post-season estimate (Table 3).

On August 18, the in-season run timing estimate was August 14. this generated a run size estimate of 1,172,000, which was 279,000 or 19.2% below the post-season estimate. With the post-season data incorporated into the cumulative passage model, and an August 14 peak cumulative passage date, the run size estimate was 1,527,000, or 76,000 (5.2%) above the post-season estimate. If a cumulative 50% date of August 13 is substituted into the model, the run size estimate is 1,425,000, or 26,000 (1.8%) below the post-season number (Table 3).

Finally, the August 23 run size estimate from the cumulative passage model, using the in-season catch and racial data, was 1,110,000. This was 341,000, or 23.5% below the post-season accounted for number. Using post-season data, the model projects either 1,429,000 fish for the stock group (50% date at Mission of August 14), or 1,371,000 fish (50% date of August 13). These two estimates are 22,000 or 1.5%, and 80,000 or 5.5%, below the post-season estimate of total run for the Late Stuart/Stellako stock group (Table 3).

In conclusion, the Late Stuart/Stellako cumulative passage model performed significantly better using post-season data than it did with the in-season data. The explanation for this is the in-season versus the post-season discriminant function models. As described in Appendix G, due to a bias in the in-season discriminant function analysis models, the Late Stuart/Stellako stock group was systematically underestimated. Therefore, not surprisingly, the in-season cumulative passage models underestimated this stock group. Once the post-season catch and racial data were used in the models, the estimates were reasonably precise, providing the correct run timing estimate was used.

Table 1. Stock specific adjusted R^2 values (Mission passage dates).

Stock / Stock Group	Regression Type		1 Week Prior To 50% Date	Adj R Sq Value	Cumulative 50% Date	Adj R Sq Value	1 Week After 50% Date	Adj R Sq Value
Early Stuart	Simple Regression	(ln v ln)	(July 2)	65.3%	(July 9)	87.3%	(July 16)	98.6%
	Multiple Regression	(ln v ln)	(July 2)	81.4%	(July 9)	97.7%	(July 16)	99.7%
Early Summers	Simple Regression	(ln v ln)	(July 26)	54.5%	(Aug 2)	76.0%	(Aug 9)	91.6%
	Multiple Regression	(ln v ln)	(July 26)	70.0%	(Aug 2)	93.4%	(Aug 9)	96.2%
Chilko	Simple Regression	(ln v ln)	(Aug 6)	39.4%	(Aug 13)	74.1%	(Aug 20)	94.0%
	Multiple Regression	(ln v ln)	(Aug 6)	93.3%	(Aug 13)	97.3%	(Aug 20)	98.9%
Horsefly	Simple Regression	(ln v ln)	(Aug 5)	65.8%	(Aug 12)	84.4%	(Aug 19)	95.1%
	Multiple Regression	(ln v ln)	(Aug 5)	96.7%	(Aug 12)	98.4%	(Aug 19)	99.4%
Stellako	Simple Regression	(ln v ln)	(Aug 5)	32.8%	(Aug 12)	52.1%	(Aug 19)	78.5%
	Multiple Regression	(ln v ln)	(Aug 5)	74.5%	(Aug 12)	88.3%	(Aug 19)	96.9%

Table 2. In-season projections of the Chilko/Horsefly cumulative passage model on August 12, 18 and 23, 1994.

		Historical Passage Data In-season Data (Mission Timing)		Historical Passage Data Post-season Data (Mission Timing)	
Chilko/Horsefly Stock Group	**AB Peak Timing Estimate**	**Run Size Estimate**	**% Error**	**Run Size Estimate**	**% Error**
Run Accounted for to Aug 12	16-Aug (2)	4,414,000	-25.3%	4,848,000	-17.9%
Run Accounted for to Aug 12	18-Aug (1)	5,296,000	-10.3%	5,816,000	-1.5%
Run Accounted for to Aug 18	16-Aug (1) (2)	6,000,000	1.6%	5,609,000	-5.0%
Run Accounted for to Aug 23	15-Aug (1)	5,965,000	1.0%	5,665,000	-4.1%
Run Accounted for to Aug 23	16-Aug (2)	6,126,000	3.7%	5,818,000	-1.5%

(1) In-season Estimate of Peak Timing on Date of Analysis

(2) Post-season Estimate of Peak Timing

* Current Estimate of Chilko/Horsefly Total Run = 5,907,000

Table 3. In-season projections of the Late Stuart/Stellako cumulative passage model on August 12, 13 and 23, 1994.

		Historical Passage Data In-season Data (Mission Timing)		Historical Passage Data Post-season Data (Mission Timing)	
Late Stuart/Stellako Stock Group	**AB Peak Timing Estimate**	**Run Size Estimate**	**% Error**	**Run Size Estimate**	**% Error**
Run Accounted for to Aug 12	13-Aug (2)	NA		1,333,000	-8.1%
Run Accounted for to Aug 12	16-Aug (1)	1,025,000	-29.4%	1,853,000	27.7%
Run Accounted for to Aug 18	13-Aug (2)	NA		1,425,000	-1.8%
Run Accounted for to Aug 18	14-Aug (1)	1,172,000	-19.2%	1,527,000	5.2%
Run Accounted for to Aug 23	13-Aug (2)	NA		1,371,000	-5.5%
Run Accounted for to Aug 23	14-Aug (1)	1,110,000	-23.5%	1,429,000	-1.5%

(1) In-season Estimate of Peak Timing on Date of Analysis
(2) Post-season Estimate of Peak Timing
* Current Estimate of Late Stuart/Stellako Total Run = 1,451,000

Appendix E: Estimation of Run-Size of Summer and Late Sockeye Stocks and Late-Run Escapement to the Strait of Georgia Using In-season Run Reconstructions and Cumulative-normal Models

Introduction

Estimates of abundance, timing and route of travel of the different returning stocks are vital to management of Fraser sockeye during the fishing season. While estimates of the total returning abundance of stocks are vital for determining the total allowable catch (TAC), the timing and route of travel (i.e. the proportion of fish migrating via the southern and northern approaches) are important for scheduling fisheries on the stocks. A general procedure for estimating these parameters involves reconstructing the daily abundance of the migrating stocks, and comparing these reconstructions to normal distributions of varying peak timing and spread. Since the procedure involves comparing the cumulative migration to date by day with cumulative-normal distributions, the method has been called the "Cumulative-normal Model".

Run-reconstruction based methods require both catch and escapement data. For early Stuart, early summer-run and summer-run populations, the escapement data are obtained from hydroacoustic estimates at Mission. Late-run stocks (i.e. Birkenhead, Adams/lower Shuswap and Weaver Creek populations) pose a problem to management in that they do not migrate immediately upstream upon arrival but delay in the Strait of Georgia near the mouth of the Fraser River for 3-6 weeks prior to their upstream migration. Since estimates of river escapement are entirely unavailable during the periods that the migratory area fisheries have access to these sockeye, information on expected escapement must be determined by various indirect methods. For in-season reconstruction of late-run sockeye abundance, estimates of harvest rate by daily migration block are applied to the catch from that block to estimate the abundance of fish. Escapement is then calculated by subtracting catch from daily abundance. Thus unlike earlier timed sockeye stocks where estimates of escapement are measured directly, estimates of late-run escapement are entirely dependent on estimates of harvest rate and catch.

Harvest rates used in computations for late-run sockeye were developed using data from prior years where fisheries have been assessed for the catch and escapement of these stocks. Data from 1983 were used in the Johnstone Strait portion of the run-reconstruction model because it was the only year that late-run stocks migrated via the northern approach.

In 1994, returning Fraser River sockeye migrated predominantly via the northern approach. During mid to late August, we evaluated the in-season information available on the harvest rates on the late-run stocks. This was necessary because 1983 is the only recent year where late-run sockeye predominantly migrated via the northern route. Therefore 1983 harvest rates were used and modified using feedback information on 1994 summer-run harvest rates.

Estimates of late-run sockeye abundance and escapement to the Strait of Georgia obtained via run-reconstruction and the cumulative-normal model proved to be substantially larger than the post-season estimate. For obvious reasons, underestimates of harvest rate have been implicated in this over-estimate. Below, the in-season assessments of summer-run sockeye harvest rate are reviewed. In order to determine the relative effects of errors in stock identification and catch, four scenarios are examined using the in-season run reconstruction methodology: 1) in-season racial and catch data, 2) post-season racial and catch data, 3) post-season racial and in-season catch data and 3) in-season racial and post-season catch data. These scenarios are examined with the same harvest rates (h_k; see below) used in-season.

Methodology

Run Reconstructions

Run-reconstruction procedures can be used both in-season and post-season. In-season methods follow a "forward" approach, (i.e. commencing at the beginning of the season at the first fishing area) and are "incomplete" until the fish from any given migration block pass the Mission hydroacoustic site. Post-season methods do not suffer from this "incompleteness" and involve using a backwards procedure.

The purpose of in-season run-reconstruction methods is to rebuild the migration referenced to a specific location (usually Area 20). This involves tabling catches by stock, date and area. Escapements are similarly added to the daily "block". These data are lagged so that they can be referenced to a "common" date of travel. For example, fish which may have entered Area 12 on August 1 if not caught would be expected to enter Area 13 on August 4, Area 16 on August 6 and Area 29 B (Below Pattullo Bridge) on August 8. Likewise, fish which entered Area 20 on August 3 would have entered Area 4 on August 4, Area 7 on August 5, Area 7A on August 7 and Below Bridge on August 8. These fish area said to belong to a common migration block ("box car" in some literature). The procedure becomes more complex with fishing areas that contain more than several days of migration. Catches in these areas must be allocated to the constituent migration blocks.

Harvest Rates

Harvest rates are used in two situations. As mentioned above, in the case of late runs, they serve as the principal input for determining escapement to the Strait of Georgia:

$$E_k=\frac{C_k}{h_k}-C_k \tag{1}$$

where E_k is the escapement on migration block k, C_k is catch and h_k is harvest rate on block k. In the case of Summer runs, harvest rates are used to predict escapement to the Strait of Georgia but are subsequently replaced by more accurate estimates based on the catch in Area 29 plus estimates of escapement from the hydroacoustic program at Mission.

There is no opportunity to estimate late-run harvest rates during the season, except from what can be inferred from co-migrating summer-run stocks. In this situation, estimates of terminal catch plus escapement for summer-runs, can be used in the back-calculation of harvest rates of the principal migratory approach, given assumptions about harvest rate in the secondary migratory area. Thus, if the major part of the migration is from Johnstone Strait, then given historical estimates of harvest rates for the southern approach fisheries, we can subtract the estimated southern escapement to the river from the total abundance according to the following procedure:

$$E_{ks}=\frac{C_{ks}}{h_{ks}}-C_{ks} \tag{2}$$

where E_{ks} is escapement from the south for migration block k, C_{ks} is total southern catch, and h_{ks} is the estimated southern historical harvest rate; and:

$$E_{kn}=E_{kt}-E_{ks} \tag{3}$$

where E_{kn} is escapement from the north on block k and E_{kt} is total terminal escapement. Then:

$$h_{kn}=\frac{C_{kn}}{C_{kn}+E_{kn}} \tag{4}$$

where h_{kn} is harvest rate and C_{kn} is catch on block k from the north. Harvest rate can be evaluated for any fishery. Catchability q [catch-per-set/ $(C_{kn} + E_{kn})$] in the Area 12 purse seine test fishery was similarly evaluated during the season. We emphasize that h_{kn} and h_{ks} represent the cumulative harvest rate on a migration block, from the respective approaches. These should not be confused with u, or elemental harvest rate, of which h is a function. The subject of elemental harvest rates is reviewed in the document dealing with the reconstruction of marine area harvest rates. Further, exploitation rate is considered to be an annual statistic and has little application in the situation described here.

For the purpose of estimating late-run escapement to the Strait of Georgia, Equation (1) can then be rewritten for the northern approach:

$$E_{kn}=\frac{C_{kn}}{h_{kn}}-C_{kn} \tag{5}$$

As mentioned above, we were concerned about the accuracy of harvest rates (i.e. h_{kn}'s) that were to be applied to the in-season run reconstructions. This was less critical for summer-run stocks, where timely escapement data afforded opportunity to incorporate escapements measured at Mission to improve run-size assessments. In the case of late-run stocks, true harvest rates could not be accurately estimated until upstream escapements could be determined. Therefore, there was no opportunity for additional feedback of corrected harvest rates on late-run stocks during the season.

The reconstructed harvest rates on summer-run sockeye in 1993 were higher than for 1983. In order to insure that run-size estimation error did not occur in 1994, due to higher harvest rates, examination of summer-run harvest rates was conducted periodically. During the season, harvest rates were examined in the manner described above on three separate occasions: August 16, August 24-25 and September 1. While these analyses can be made only on summer-run stocks, the assumption was made that these harvest rates would be applicable to co-migrating late-run stocks. While situations occur where late-run harvest rates are different than for summer-run stocks, these situations are usually in gillnet fisheries where late-run harvest rates are lower than for summer-run stocks. In situations where there was no opportunity to estimate harvest rates, the 1983 harvest rates were used because there was no indication that the harvest rates differed from the 1983 situation.

During the 1994 fishing season tables of in-season run-reconstructions were prepared and the cumulative migration by day was used as input to the cumulative-normal model. Because of the high diversion rate, the critical fishing areas of concern were Areas 11-16. In the case of late runs, estimates of catch by daily migration block were divided by harvest rate to calculate total abundance and escapement by migration block.

Low harvest rate and a high degree of variability in the harvest rates is apparent in the gillnet-only fisheries in Area 11-12. We decided to substitute data from the Area 12 (Robson Bight purse seine test fishery) for days of migration where no purse seine harvest was taken. The expansion line (1/q) and catch-per-effort in Robson Bight test fishery was used to estimate daily abundance on those blocks.

These periods were critical, as they represent the main periods of escapement during each week. The cumulative run by day was then calculated for use in the cumulative-normal model.

Cumulative-normal Model

The cumulative-normal model is used to estimate the total run, by regressing the cumulative daily abundance of the run-to-date, against cumulative-normal distributions truncated to the most recent day of information. The procedure used is analogous to a logistic regression method. The "observed" cumulative-run-by-day data are regressed against the "expected" cumulative-run-by-day and model of best fit is determined by varying timing and spread of the cumulative-normal models (Figure 1). The timing and spread of the model of best fit is assumed to match the actual run. The run-size R_s is described by the equation for the simple regression:

$$R_s = aR_m + b \tag{6}$$

where, R_m is the run-size of the cumulative-normal model and a and b are the slope and intercept parameters of the model of best fit. This method is unique as it provides an objective assessment of timing.

The cumulative-normal model is constrained by the quality and timing of the in-season reconstructions of daily abundance of the migrating sockeye stocks. In particular, it is sensitive to changes in catch data, particularly at the peak of the run. The method is not robust to severe deviations from normality (i.e. bimodal, or severely peaked or skewed migrations are estimated with bias). For example, outside area fishery removals may deform the run and there is uncertainty as to the reconstruction of the catch in these fisheries on the migration. Since the difficulties encountered in 1994, and in particular the uncertainty surrounding the escapement of late-run stocks to the Strait of Georgia, indicate a problem with data inputs (i.e. harvest rates, catches and racial estimates) the focus in the Results and Discussion sections will be on data quality and harvest rate parameters, rather than the cumulative-normal model.

Results

In-season Assessment of the Return Abundance of Summer-run Stocks

The pre-season expectation of peak timing of summer-run stocks was August 18 (Area 20 date). On August 4, because of stronger than expected abundance of summer-run stocks to date, the cumulative-normal model predictions indicated that an August 18th timing was unlikely. We speculated that the peak timing of the summer-run return would be August 12 in Area 20. The first estimate of the return abundance of summer-run stocks was made on August 11: 5.0 million fish and peak timing of August 7. This was based in part on calculations of available fish from harvest rates applied to catches on daily migration blocks in the Area 12-13 fishery. By August 16, the estimate of abundance was revised to 7.0 million, well less than the expected summer-run return of 10.3 million, with return timing of August 10. The cumulative-normal model was having some difficulty with what was apparently a non-normal migration. On August 23rd the cumulative-normal estimate of summer-run abundance had dropped to 6.5 million and we speculated that the final estimate would fall in the 6.5-7.0 million range. The comments on August 25 analyses were that the cumulative-normal model was underestimating the summer-run run size (6.4 million) because the migration was flatter than expected at the peak for a normal distribution. Such a flat distribution could be caused by differences in peak dates for the multiple stocks in the summer-run complex. To adjust for this non-normality, a larger estimate of 6.5-6.9 million was suggested as being more appropriate. The final in-season estimate of the summer-run return was 7.1 million fish. The post-season catch and racial data indicated a total return of 7.4 million.

In-season Assessment of Harvest Rates in the Area 12-13 Commercial Fisheries and Robson Bight Purse Seine Test Fishery

On August 16, the escapement situation for summer-run stocks during the previous 5 day period was examined and the harvest rate for the August 8 fishery in Area 12 and 13 was reviewed. The back calculated weekly harvest rate in this fishery was estimated to be approximately 29%, or about 65% of historical values (1983 situation) and substantially less than observed in 1993. This conclusion was made even after terminal abundance was adjusted for an evident delay and subsequent high migration for the migration blocks in question. The theory advanced at the time was that the low catches in the Gordon Island and Queen Charlotte Strait areas (Sub-areas 12-8 to 12-12) were due to a concentrated migration down the closed areas (Sub-areas 12-7 and 12-13) on the mainland side of Queen Charlotte Strait. This theory was supported by a faster than usual recovery in the purse seine test fishery in Robson Bight, 36 hours after the fishery closure. Similarly, the catchability in this test fishery on August 3-5 was estimated to be about 0.64%, or about 75% of the estimate for 1993 at 0.87%. Subsequent adjustments to the catchability in the purse seine test fishery could not be made in later weeks because of the uncertainty in the relative proportions of summer-run and late-run stocks due to possible sampling bias. A *q* of 0.64% in the seine test fishery was used at this time.

Prior to assessments of the Area 12-13 fishery on August 15th, we increased the Area 12 harvest rate by 10% (over the 1983 values) because of the very high gear count in the area. The summer-run harvest rates in this fishery were evaluated on August 24th and August 25th. The back-calculated weekly harvest rate for Areas 12-13 (including all gillnet harvest) was 54% as compared with the expected 55%. This analysis was made based on the assumption of no delay of summer runs. This adjustment was not done for the August 22 fishery on the basis that this fishery was only 12 hours as compared to the 24 hour fishery on August 15.

On August 29, analyses were made to determine the late-run escapement to the Strait of Georgia on the basis of the re-examination of the harvest rates on summer runs. The assumptions in the analysis were 1) equal harvest rates for summer and late runs and 2) that delay of summer runs, (violation of the order-of-movement assumption) which would put the catch out of sync from the migratory area catch, had been properly taken into account. A gross comparison of Area 11-16 catch with total terminal abundance from August 12-27 (Below Bridge timing) would have indicated a summer-run harvest rate of 40%. This acknowledges that some of the terminal abundance would have come from the southern approach. However, due to the intensities of the southern fisheries and high diversion, this was perhaps a reasonable gross analysis. On August 30, a formal estimate of 3.466 million late-run sockeye available for gross escapement was made using the harvest rate analysis. On September 1, we determined that the terminal abundance of summer-run sockeye was higher than the exploitation rates in the Area 12-13 fishery for the August 22 fishery would have indicated. The conclusion was made that while some of the contribution of summer runs may have migrated prior to the period of concern (i.e. affected by delay) their presence indicated a lower harvest rate for the 2-week period in Johnstone Strait. This would indicate higher terminal abundance of late-run stocks. A decision was made to decrease the catchability in the Robson Bight test fishery to 0.625% from 0.64%.

Estimation of Run-size and Escapement to the Strait of Georgia of Late-run Fraser Sockeye

As indicated above, the critical difference in the estimation of run-size and escapement of late-run sockeye from the procedure for summer-run sockeye concerns the lack of direct estimates of escapement on late-run sockeye during the period of active management of the migratory area fisheries. To estimate the potential escapement of late-run sockeye, measures of harvest rate are used, and these assessments for 1994 are described above. The estimates of run-size and escapement then follow directly from equation 2.

The first estimate of the total return of late-run sockeye (9.0 million) was made August 18. This decreased to 8.5 million on August 23 because of concerns about the degree of certainty in the harvest rate estimates. At this time we estimated that there would be 2.0 million fish in the Strait of Georgia, although this would be reduced by future terminal catch. Such terminal catch was understood to include United States Area 7A, as we had identified a contribution of "blow-back" fish in the catches in that area. On August 25, the abundance of late runs remained stable at 8.4 million, and the anticipated escapement to the gulf was predicted to be 3.0 million by August 31. On August 26, the estimate of the total late run increased to 9.2-9.4 million. This decreased to 8.5+ million on August 30, based on weakness in the Johnstone Strait test fishery. At this time, the available gross escapement was estimated at 3.25-3.5 million, to arrive by September 5. Reworking all estimates on September 1, the total return of late runs was estimated at 9.4 million, with an expected escapement to the gulf by year-end of 3.65 million. Estimates stabilized during the assessments in September, with the last estimate of 3.5 million available for gross escapement prior to the major upstream escapement being made September 12.

At the end of the Mission escapement period on October 13, considerably fewer late-run sockeye had migrated upstream than were expected based on the in-season assessments. The total late-run abundance was estimated at 7.592 million with 1.055 million fish passing Mission. Re-working the estimates with post-season catch and racial data, the total late-run abundance was estimated at 7.911 million with 1.138 million fish passing Mission (using Mission hydroacoustic estimates). Using post-season catch and racial data and estimates of up-stream accounting, the total return is 8.418 million with an upstream accounting estimate of 1.645 million.

Re-evaluation of In-season Methods, using Combinations of In-season and Post-season catch and Racial Analysis

Clearly, considerably fewer late-run sockeye had migrated upstream in 1994 than were expected. In order to tease out the effects of harvest rate from errors in stock identification and catch, 4 scenarios are examined using the in-season run reconstruction methodology: 1) in-season racial and catch data, 2) post-season racial and catch data, 3) post-season racial and in-season catch data and 3) in-season racial and post-season catch data. These scenarios are examined with the harvest rates (h_k's) used in-season and are shown in Table 1. All 4 scenarios would indicate between 3.2-3.8 million late-run sockeye available for gross escapement, and total returns of between 9.2 and 11.0 million. These results indicate that in-season catch and racial data were not directly responsible for the overestimate of late-run gross escapement in 1994. However, the results suggest a shift in summer-run harvest rates between the in-season and post-season scenarios as a result of shifts in the catch and racial data.

Post-season Review of Harvest Rates used to Estimate Escapement of Late-run Sockeye to the Strait of Georgia

The late-run escapement to the Strait of Georgia in 1994 has 4 components: 1) a portion derived from commercial harvest rates, 2) a portion derived from the Robson Bight seine test fishery, 3) a portion including escapements estimated prior to commercial fisheries and 4) a portion of the escapement relating to "holes" thought due to uncertainty in harvest rates. The relative proportions of this escapement are shown in Table 2. While estimates of escapement were derived using catch-per-effort from the Robson Bight test fishery, we could have used the estimates of harvest rate in the Area 12 commercial gillnet fishery. If these estimates were used instead, the estimates of escapement to the gulf would have decreased by 348,000 using the in-season catch and racial data, and by 68,000 using the post-season catch and racial data. Use of the gillnet harvest rates would have resulted in a lower estimate of escapement to the Strait of Georgia during the season, however, the catch estimation error in this fishery and timeliness still result in a problems with the use of this data during the season.

The harvest rate estimated on August 29 for the period August 12 to August 27 (Below Bridge timing) was **39.6%** (Table 1). The calculations for this harvest rate have been re-examined and verified. It is very important to understand that this was the best information that we had at that time. With this information we made our estimates of escapement of late runs to the Strait of Georgia using the methods described. An interesting shift emerges when the post-season catch and racial data are examined, as the harvest rate for this same period increases to 44.8%. However, on this date the effects of the August 22 Area 12 fishery on terminal area catch and escapement of summer-run sockeye could not be evaluated. The co-migrants to this fishery would not have reached the Below Bridge area until August 31 and the hydroacoustic estimates on this group of fish would not have been available until September 2. Using in-season data, the harvest rate for the 2 peak weeks was estimated to be 49.1%. This estimate increases to 55.1% using in-season procedures and post-season data. The final re-evaluation of summer-run harvest rates on September 1 did not indicate a dilemma concerning summer-run harvest rates. While changes in both the catch and racial data combined to shift the peak 2 week harvest rates, evidently, the catch data resulted in the biggest shift in the harvest rate.

The question is: what would the escapement of late-run sockeye have been if the post-season catch and racial data were available during late August? If a harvest rate of 55.1% is substituted for the peak 2 weeks of fishing on late-run stocks in Areas 11-12 for the post-season racial and catch data scenario, the expected escapement to the Strait of Georgia would be 3.95 million with an expected 2.34 million being available for gross escapement. This compares with post-season estimates of 2.70 million and 1.09 million respectively, using Mission estimates of gross escapement, and 3.26 million and 1.65 million, respectively, using upstream accounting estimates of gross escapement.

Clearly, all aspects of gross escapement estimation become suspect in 1994, not just the harvest rates contained in the 2 peak weeks. For this reason, a last evaluation is made using the relationship between harvest rate and fleet size for the Area 12-13 seine fishery. These were determined from backward reconstruction of harvest rates for 1992 and 1993. Also used were the 1993 estimates of catchability in the Robson Bight test fishery, since in-season estimates of catchability could only be estimated during the early part of the season. We investigated 2 scenarios: 1) in-season racial and catch data, 2) post-season racial and catch data. The results are summarized in Table 3. Both these scenarios are very similar, indicating approximately 1.52-1.54 million fish available for gross escapement. The harvest rate and test fishery components of these estimates are shown in Table 4.

General Discussion

The approach to the assessment of harvest rates in-season was: "What are the summer- run harvest rates telling us about the possible harvest rates on late-run stocks?" Clearly this approach failed us during 1994. In examining the analyses made during the season, we followed the general approach of examining the "what if" scenarios that might have been asked during the season and solved with information that would have been available during the season. Additionally, we examined scenarios which addressed the differences in the quality of the in-season and post-season estimates of catch and stock identification. It makes little sense to examine the scenario of "what if we knew what the harvest rates were during the season?" For this reason, there is no point in examining a scenario using the post-season estimates of harvest rate using the backwards reconstruction. The results of these reconstructions are contained in a companion document on this subject.

Revisions to catch and racial data in the post-season resulted in higher harvest rates than were estimated during the season. However, we are not certain how the changes in harvest rate could have been anticipated during the season, particularly when the timing of updates to harvest rate would have been too late to affect fishing opportunities at the end of August.

The in-season analyses were made with the assumption that the gillnet and troll fisheries did not remove fish from the escapement profile. For example, during the major weekly escapement period in Area 12, the Robson Bight seine test fishery was used for escapement. We assumed that the gillnet catch was removed prior to that test fishery. Whether this assumption was met in reality is unknown and remains in the realm of conjecture. However, the continuous nature of both the gillnet and troll fisheries does raise a question on this assumption.

In the final scenario, we examined the results of using the 92-93 relationships of harvest rate verses fleet size to predict the harvest rates for each fishery. These would have got us much closer to the escapement estimates that were realized at the end of the season. We could be criticised for not using this "historical data". However, if we had used only historical data for 1993, the escapement to the gulf would have been grossly underestimated during that year. It was with this understanding that we tried to use in-season assessments of harvest rate for 1994.

Table 1. Scenarios examined using the in-season run reconstruction methodology and the harvest rates used in-season: 1) in-season racial and catch data, 2) post-season racial and catch data, 3) post-season racial and in-season catch data and 4) in-season racial and post-season catch data.

Scenario	Peak 2 Week Summer-run Harvest Rate(1)	Peak 2 Week Late-Run Harvest Rate(2)	August 12-27 Harvest Rate(3)	Gross Terminal Georgia Strait Late-Run Escapement(4)	Available for Gross Escapement(5)	Total Late-Run Return(6)
1	49.1%	42.7%	**39.6%**	4,933,000	3,408,000	9,865,000
2	55.1%	45.2%	44.8%	5,088,000	3,478,000	10,251,000
3	51.2%	42.9%	40.9%	4,733,000	3,191,000	9,183,000
4	52.9%	44.8%	43.5%	5,340,000	3,753,000	10,983,000

1) The peak two weeks include the August 15 and August 22 fisheries in Area 11-16. The value is calculated as Johnstone Strait catch divided by (Johnstone Strait catch plus terminal abundance). This calculation treats all terminal area escapement as migrating from the north (>95% in post-season reconstructions). Scenarios 1 and 4 use the in-season terminal area escapement data.

2) Harvest rate calculation is the same as for summer runs except the daily late-run gross escapements to Georgia Strait are used for estimates of terminal abundance. These change in each scenario (i.e. a function of variation in late-run catch in the migratory areas). In-season harvest rates by daily migration blocks ($h_k s$) are maintained throughout all scenarios.

3) Calculation that was made on August 29 that brackets the Below Bridge period of August 12 - 27.

4) Estimated late-run escapement available for upstream escapement prior to removal of terminal catch.

5) Estimated late-run escapement available for upstream escapement after removal of all terminal catch, except for all in-river Native fishery catches

6) Estimated late-run escapement available for upstream escapement plus late-run catch according to method indicated.

Table 2. Components of in-season escapement estimates of late-run sockeye to the Strait of Georgia. This includes all terminal area catches.

Derived from Harvest Rates in Commercial Fisheries:	2,777,000	56.3%
Derived from Robson Bight Seine Test Fishery:	1,771,000	35.9%
Escapement prior to Major Commercial Fishing:	185,000	3.8%
Escapement adjustment on Migration Holes:	200,000	4.1%
	4,933,000	100.0%

Table 3. Scenarios examined using the in-season run reconstruction methodology, the harvest rates predicted from the 1992-93 harvest rate-fleet size regressions and the catchabilities from the 1993 Robson Bight test fishery: 1) in-season racial and catch data, 2) post-season racial and catch data.

Scenario	Peak 2 Week Late-Run Harvest Rate(1)	Gross Terminal Georgia Strait Late-Run Escapement(2)	Available for Gross Escapement(3)	Total Late-Run Return(4)
1	53.5%	3,062,000	1,537,000	7,994,000
2	56.4%	3,128,000	1,518,000	8,291,000

1) The peak two weeks include the August 15 and August 22 fisheries in Area 11-16 and the value is calculated as Johnstone Strait catch divided by (Johnstone Strait catch plus terminal abundance). This calculation treats all terminal area escapement as migrating from the north (>95% in post-season reconstructions). The daily late-run gross escapements to Georgia Strait are used for estimates of terminal abundance. These change in each scenario (i.e. a function of variation in late-run catch in the migratory areas).
2) Estimated late-run escapement available for upstream escapement prior to removal of terminal catch.
3) Estimated late-run escapement available for upstream escapement after removal of all terminal catch, except for all in-river Native fishery catches
4) Estimated late-run escapement available for upstream escapement plus late-run catch according to method indicated.

Table 4. Components of escapement to the Strait of Georgia for scenarios examined using the in-season run reconstruction methodology, the harvest rates predicted from the 1992-93 harvest rate-fleet size regressions and the catchabilities from the 1993 Robson Bight test fishery: 1) in-season racial and catch data, 2) post-season racial and catch data. This includes all terminal area catches.

	Scenario 1		**Scenario 2**	
Derived from Harvest Rates in Commercial Fisheries:	1,708,000	55.8%	1,774,000	56.7%
Derived from Robson Bight Seine Test Fishery:	1,169,000	38.2%	1,169,000	37.4%
Escapement prior to Major Commercial Fishing:	185,000	6.0%	185,000	5.9%
Escapement adjustment on Migration Holes:	0	0.0%	0	0.0%
	3,062,000	100.0%	3,128,000	100.0%

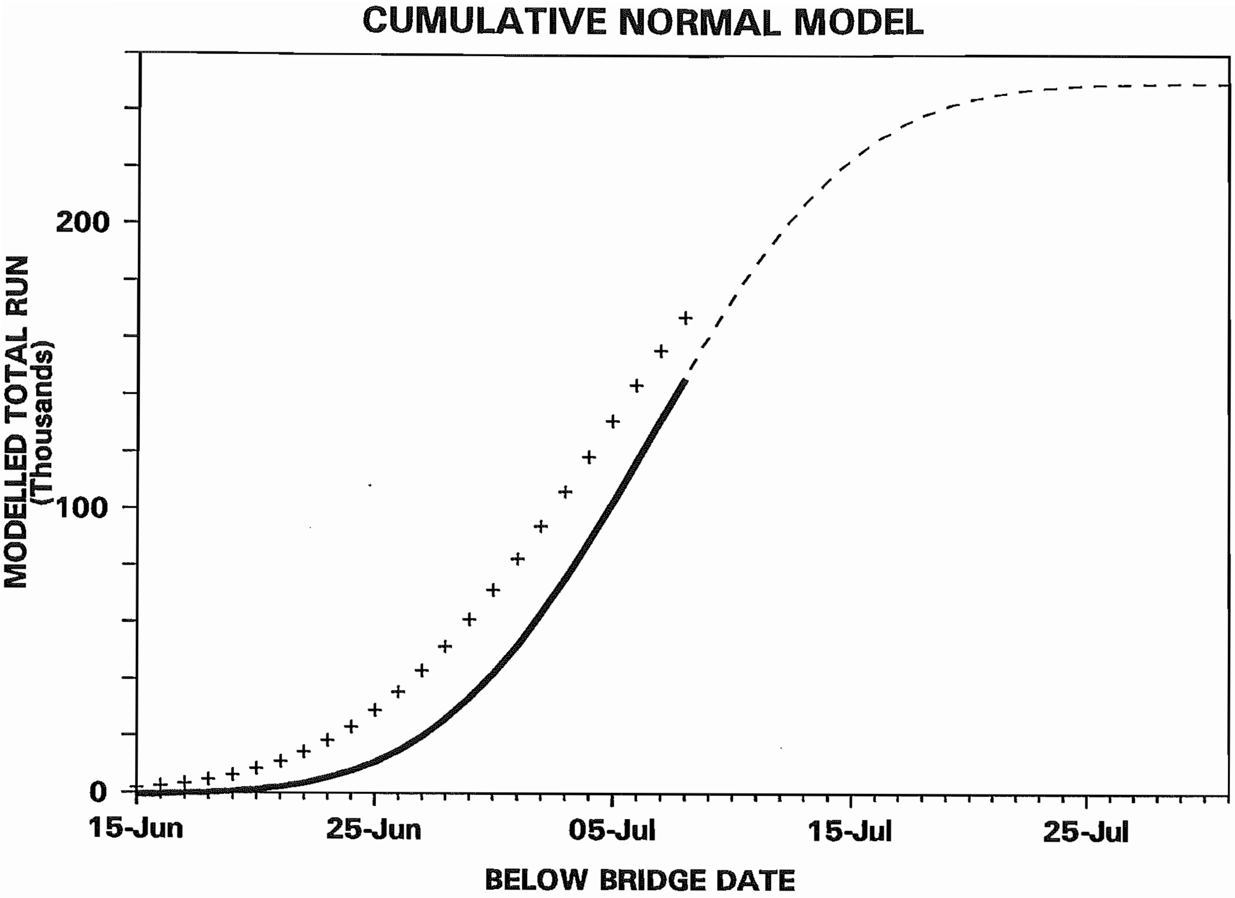

Figure 1. Schematic representation of the cumulative-normal model. The "observed" cumulative-run-by-day is regressed against the "expected" cumulative-run-by-day and model of best fit is determined by varying timing and spread of the cumulative-normal models.

Appendix F: Escapement to the Strait of Georgia (Summer-run Exploitation Rate Methods)

Model Description

Indirect estimation of late-run sockeye escapements to the Strait of Georgia is made necessary by the delay behaviour of these stocks off the mouth of the Fraser River. Late-run stocks, typified by the behaviour of Adams/Lower Shuswap River sockeye, delay off the mouth of the Fraser River for approximately three to six weeks prior to entering the river, unlike earlier timed stocks which migrate into the river with little or no delay. In order to estimate the abundance of the Adams/Lower Shuswap stock group accumulated in the Strait of Georgia prior to their movement into the Fraser River, methods using exploitation rates for co-migrating summer-run stocks have been developed. The summer-run exploitation rates, calculated from catch and escapement data, are then applied to the catch of Adams/Lower Shuswap sockeye in key migratory area fisheries to obtain total abundance.

Summer-run exploitation rates are estimated by reconstructing the current years migratory catch of a uniquely identified summer-run stock (eg. Chilko River) from all fisheries between Areas 20 and 12 and the Fraser River. These catches are lagged to correspond to a Mission date. The daily Mission escapement profile for the summer-run stock group is added to the migratory catch to obtain a daily reconstruction of catch and escapement. From this data set both daily and weekly exploitation rates are generated.

The migratory area catch profile for the Adams/Lower Shuswap stock group is put together for the same areas as the Chilko River stock group. The catch profile is lagged to correspond to a Mission timing date. The exploitation rates calculated for the summer-run stocks are applied to the migratory catches of Adams/Lower Shuswap sockeye. Two estimates of Adams/Lower Shuswap escapement into the Strait of Georgia are derived, one using daily and the other using weekly exploitation rates. Finally, any catch of the Adams/Lower Shuswap stock group which has been removed in terminal area fisheries is subtracted from the total escapement estimate, as is any upstream escapement of Adams/Lower Shuswap sockeye, to produce the number of Adams/Lower Shuswap sockeye remaining in the Strait of Georgia.

Assumptions

A number of key assumptions are made when using the Summer-run Exploitation Rate model. Violations of some or all of these assumptions in a given year could result in directional bias and cause run size estimates to be systematically high or low. A list of the assumptions is provided below.

It is assumed that:

- the in-season racial analysis of summer-run and late-run stocks is unbiased,
- the in-season catch and escapement data are accurate,
- the speed of migration between adjacent migratory areas is the same for both summer-run and late-run stocks,
- the availability and the vulnerability of summer-run and late-run stocks is the same in migratory fishing areas,
- the migrational distributions of the summer-run and late-run stocks are highly overlapped.

Data Sources and Available Data

The only data sources required for the Summer-run Exploitation Rate model are in-season catch and racial data. The methodology for deriving in-season catch data and for conducting in-season racial analyses is outlined in Appendix G.

In putting together the historical performance of this technique in estimating late-run escapement to the Strait of Georgia, there were no in-season data records available for many of the earlier years. Consequently, post-season catch and escapement data were used to assess estimates of late-run escapements in the years 1974, 1978, 1982, 1983, and 1986. In-season data were available for the years 1987, 1990, and 1991. In each of these years the Chilko River stock group has been used as the summer-run stock in the Summer-run Exploitation Rate models.

The relative accuracy and precision of the point estimates of late-run escapement for the years of available data are measured using the mean percent error and the mean absolute percent error between the number of Adams/Lower Shuswap sockeye estimated during the in-season management period, and those accounted for in terminal area (Strait of Georgia, Fraser River) catches and spawning ground escapement estimates. Since the years prior to 1987 have been constructed using post-season data, they are likely to provide an optimistic assessment of the accuracy of the technique.

Computational Methods

The Summer-run Exploitation Rate model provides weekly estimates of the escapement of the Adams/Lower Shuswap stock group into the Strait of Georgia. Daily and weekly exploitation rates of the Chilko River stock are used as surrogates, to assess exploitation rates for the Adams/Lower Shuswap stock group.

First, as described above, in-season estimates of the mean daily and weekly exploitation rate for a specific summer-run stock (Chilko River) are calculated for all migratory area fisheries seaward of Area 29. Second, the daily and weekly catches of Adams/Lower Shuswap sockeye in migratory areas outside of Area 29, and the corresponding exploitation rates calculated for a co-migrating summer-run stock, are used to estimate the total number of Adams/Lower Shuswap sockeye migrating into both Area 12 and Area 20 prior to any fishery removals. These estimates are available on a daily and a weekly time step, and are calculated sequentially throughout the season. To estimate the number of the Adams/Lower Shuswap stock group escaping the migratory area fisheries, and entering the Strait of Georgia, the migratory area catch is subtracted from the total number of Adams/Lower Shuswap sockeye entering the migratory areas. Third, all catches of the Adams/Lower Shuswap stock group in Area 29, as well as any recorded escapement of the Adams/Lower Shuswap stock, are subtracted from the total daily or weekly escapement numbers, leaving an estimate of the Adams/Lower Shuswap fish which have entered and remain in the Strait of Georgia (Area 29A).

A summary of the equations used to generate the estimate of Adams/Lower Shuswap escapement to the Strait of Georgia is provided below:

- Equation 1. (C4) = (C1) / (C1 + C2 + C3)
    - Summer-run Exploitation Rate (C4) = (Chilko&Quesnel Migratory Area Catch (C1)) / (Chilko&Quesnel Migratory Area Catch (C1) + Chilko&Quesnel Terminal Area Catch (C2) + Chilko Gross Escapement (C3))

- Equation 2. (A5) = (A1) / (C4)
  - Adams/Lower Shuswap Run Entering Migratory Areas (A5) = (Adams/LShus Migratory Area Catch (A1)) / (Summer-run Exploitation Rate (C4))

- Equation 3. (A2 + A3) = (A5 - A1)
  - Adams/LShus Gulf Escapement, prior to terminal catch & escapement (A2 + A3) = (Adams/LShus Run Entering Migr Areas (A5)) -(Adams/LShus Migr Area Catch (A1))

Discussion of Historical Data

Estimates of the escapement of the Adams River stock group into the Strait of Georgia are available for eight years prior to 1994, including both dominant and sub-dominant Adams River return years (1974, 1978, 1982, 1983, 1986, 1987, 1990 and 1991). For each of these years, three estimates generated from the exploitation rate model are available for comparison with the actual number of the Adams River stock group accounted for in the post-season. The three annual estimates are based on the "daily exploitation rate model", the "weekly exploitation rate model" and an average of the daily and weekly models (Table 1).

The percent error of the daily and weekly exploitation rate model results, for each of the eight years of data, are summarized in Figure 1. The daily exploitation rate model overestimated the Adams/Lower Shuswap stock group, relative to the post-season accounted number, in five of the eight years, while the weekly model overestimated the Adams/Lower Shuswap stock group in four of the years.

In 1978 and 1983, the models overestimated the Gulf escapement by an average of 28.5% and 46.4% respectively (Table 1). These years were both high diversion rate years (58% and 80%). The models have tended to perform better in years of low Johnstone Strait diversion. However, with the relatively small data set it is difficult to say whether this is coincidental.

It is of interest to assess which of the two models performs more accurately in predicting the Adams/Lower Shuswap stock group escapement to the Strait of Georgia, or whether an average of the results from the two models produces more accurate results. To assess this, the mean percent error and the absolute mean percent error, as well as the standard deviation of the mean percent errors, were calculated (Table 2). There is little difference in the average mean percent error from the three estimates, 5.81%, 4.34% and 5.07% respectively. However, the standard deviation of the mean percent error shows that the daily exploitation rate model tends to produce more precise estimates than the weekly model (Table 2). Similarly, the results from the absolute mean percent errors show that the daily model tends to be more accurate and precise than the weekly model.

The estimate of the mean performance of the weekly exploitation rate model is heavily weighted by its' poor performance in one year, 1983. In most other years the daily and weekly models perform with about the same degree of accuracy (Figure 1).

There are logistical reasons to continue to use the weekly exploitation rate model, in conjunction with the daily exploitation rate model, even though the limited data set indicates that the daily model has performed better. A key reason is that the daily model is sensitive to any short term delay behaviour of the Chilko River stock between the migratory catch areas and the Fraser River. Short term delay uncouples the lagged daily migratory catches of Chilko sockeye with subsequent Mission daily escapements. This could result in errors in the calculation of summer-run exploitation rates, and subsequently, errors in Adams/Lower Shuswap escapement estimates to the Strait of Georgia. The weekly exploitation rate model is more robust to short term delay behaviour in summer-run stocks.

Analysis of 1994 Estimation Results

In-season Summer-run Exploitation Rate Models

In 1994, the Summer-run Exploitation Rate models overestimated the escapement of the Adams/Lower Shuswap stock group into the Strait of Georgia. The daily model predicted an escapement of 4,544,000 fish, while the weekly and combined estimates were 3,787,000 fish and 4,166,000 fish, respectively. The post-season Gulf escapement estimate, generated from Mission echo sounding escapements and terminal area catches, was 2,059,000 fish. The discrepancies between the post-season accounting and the daily, weekly and combined exploitation rate estimates were 120.7%, 83.9% and 102.3%, respectively (Table 3).

The model predictions in 1994, relative to the post-season accounting of Adams/Lower Shuswap terminal area catch and escapement, was the worst on record. In 1983, the year of the poorest model performance prior to 1994, the discrepancies between the model predictions and post-season escapement estimates to the Strait of Georgia were 24.4%, 68.6%, and 46.4% (Table 1).

During the 1994 management season, estimates from the weekly exploitation rate model were used in management decision making, rather than estimates from the daily or combined models. The decision to use estimates from the weekly model was taken because of some "suspiciously high" daily Adams/Lower Shuswap escapement estimates generated from the daily model. Specifically, Adams/Lower Shuswap escapement estimates of 743,000 on August 17 & 18 (Table 4). The higher than expected escapement estimates on these days may have been caused by a delay induced uncoupling of Chilko stock group escapements and migratory area catches (i.e., fish from the Chilko stock group that had been delaying from a prior period may have entered the Fraser River on August 17 & 18). This behaviour would cause the daily summer-run exploitation rates, associated with prior Chilko migratory area catches, to be incorrectly calculated. Specifically, the calculated exploitation rates would be too high on days when the fish delayed, and too low when the accumulated pool migrated into the Fraser River to be counted as escapement. Since the Adams/Lower Shuswap escapement to the Strait of Georgia is subsequently calculated using summer-run exploitation rates, the Adams/Lower Shuswap escapement estimates would be biased. As previously mentioned, the weekly exploitation rate model is more robust to short term delay behaviour of the Chilko stock group. Consequently, the decision was made to use the estimates from the weekly exploitation rate model in-season. Even so, the weekly exploitation rate model estimated a total Adams/Lower Shuswap escapement to the Strait of Georgia of 3,787,000 fish, which was 1,728,000 (83.9%) higher than the post-season accounting (Table 3).

During the in-season management period the Adams/Lower Shuswap run size estimate was expanded to include all late runs. An expansion factor of 13.6% was used. This was based on in-season racial analysis of Area 29 troll samples. The daily, weekly, and average late-run escapement estimates were 5,161,000, 4,301,000, and 4,731,000, respectively. By comparison, the accounted late-run escapement into the Strait of Georgia, using Mission gross escapement data, was 2,469,000. (*Note: The terminal area catch of late-run sockeye, not including Native catch below Mission, was 1,331,000. Therefore, by subtraction the models generated projections of the number of late-run fish available for river entry of 3,830,000, 2,970,000 and 3,400,000).

Adams/Lower Shuswap Gulf Escapement Estimates Using Four Combinations of Catch and Racial Data

Potential reasons for the large numerical discrepancy between the exploitation rate model results, and post-season accounting estimates, include in-season racial identification bias, errors in the in-season catch reporting data, the violation of some of the general model assumptions listed earlier, and finally, bias in the post-season accounting of terminal area abundance of the Adams/Lower Shuswap stock group. It is important to note that the performance of the models for all past years of data was assessed using post-season terminal area abundance, estimated from spawning ground net escapements, in-river Native fishery catches, and post-season estimates of terminal area catch. At this time, we prefer to use the 1994 Mission estimate of Adams/Lower Shuswap escapement in part because it provides a "worst-case" scenario. Therefore, Mission escapement estimates were used in place of spawning ground net escapements and Native fishery catches upstream of Mission, in calculating the terminal area escapement for the Adams/Lower Shuswap stock group. The two estimates of upstream escapement (net escapement and Native catch versus Mission escapement), are substantially different. If Mission data are used the total terminal area Adams/Lower Shuswap stock group escapement is estimated to be 2,059,000 fish. If upstream catch and net escapement data are used, the terminal area escapement is estimated to be 2,634,000 fish. The performance of the models relative to the Mission based terminal area accounting is discussed below. Their performance, relative to DFO upstream accounting data, is discussed later in the appendix.

To test the extent that in-season racial identification bias and errors in catch reporting contributed to the discrepancy in the Adams/Lower Shuswap escapement estimates to the Strait of Georgia, four different scenarios were investigated. The data sets include: in-season catch and racial data, post-season catch data and in-season racial data, in-season catch data and post-season racial data, and post-season catch and racial data.

The results of the four comparisons are summarized in Table 3. Scenario One, for which in-season data were used, resulted in large differences between the post-season accounted numbers and the model based estimates, as previously discussed. Scenario Two, in which the in-season catch estimates were replaced with post-season data to test for the effect of catch reporting error, did not significantly change the Adams/Lower Shuswap escapement estimates to the Strait of Georgia. The discrepancies between the daily, weekly and combined exploitation rate models and estimates of terminal area abundance were 119.6%, 87.0% and 103.3% respectively. In Scenario Three the exploitation rate models were run with post-season racial data and in-season catch data. This resulted in significant reductions in the discrepancies between model results and the post-season accounting estimate of the Adams/Lower Shuswap escapement to the Strait of Georgia. However, the Adams/Lower Shuswap escapement was still significantly overestimated. The daily, weekly and combined exploitation rate model estimates exceeded the post-season terminal area escapement estimates by 71.7%, 51.7% and 61.7%, respectively. Finally, in Scenario Four, post-season racial and catch data were used. Additional, but small improvements in the discrepancy between models results and accounted Adams/Lower Shuswap escapement numbers resulted. The numerical predictions for the Adams/Lower Shuswap stock group from the daily, weekly and average model results, using post-season data, were 3,436,000, 3,061,000, and 3,249,000, respectively. Hence, in percentage terms the exploitation rate models exceeded the post-season estimate of terminal area abundance by 66.9%, 48.7% and 57.8%. Once post-season catch and racial data are incorporated, the 1994 model performances are similar to the model results documented in 1983. However, the discrepancies between the 1994 model predictions and the post-season accounting of Adams/Lower Shuswap terminal area escapement are larger than for any other year on record (Table 1). As was done with the in-season data, these post-season results were expanded to include all late runs by incorporating a 13.6% expansion factor. The expansion factor reflects the relative percentage of miscellaneous late-run stocks to the Adams/Lower Shuswap stock in the Area 29 troll fishery. The numerical predictions of late-run escapement to the Strait of Georgia, incorporating post-season catch and racial data, and the 13.6 percent expansion factor for miscellaneous late runs, were 3,903,000, 3,477,000, and 3,690,000. (*Note: The terminal area catch of late-run sockeye, not including Native catch below Mission, was 1,331,000. Therefore, by subtraction the models generated projections of the number of late-run fish available for river entry of 2,572,000, 2,146,000 and 2,359,000).

Based on the results of the above scenario's, it appears that the exploitation rate models performed poorly during the in-season management period partly due to imprecision in the in-season racial identification analyses, and partly due to other unassessed biases. A comparison of Scenario Three versus Scenario One shows that, on average, the discrepancy between the combined exploitation rate models and the post-season accounted for escapement of Adams/Lower Shuswap sockeye was reduced from 102.3% to 61.7% with the addition of post-season racial data (Table 3). A comparison of Scenario Four versus Scenario Three demonstrates that when the in-season catch data were replaced with post-season catch data, very little additional improvement resulted. The discrepancy between the combined exploitation rate model and the post-season accounting of escapement to the Strait of Georgia was reduced from 61.7% to 57.8% (Table 3).

In 1994, the daily exploitation rate model results may have been compromised by short-term delay behaviour exhibited by the Chilko River stock group. The weekly exploitation rate model, being more robust to short term delay behaviour, consistently outperformed the daily model in all four scenario's tested (Table 3). The delay of the Chilko River stock, and the resulting affect this has on marine area exploitation rates, may be a partial explanation for the remaining discrepancies between 1994 model predictions and the best estimate of post-season terminal area abundance.

Interpretation of Adams/Lower Shuswap Gulf Escapement Estimates Using DFO Upstream Accounting Estimates

In this section, the Adams/Lower Shuswap post-season terminal area escapement to the Strait of Georgia is calculated using DFO net escapement data and in-river Native catch data plus terminal area commercial catches. Using these data, the Adams/Lower Shuswap post-season escapement estimate to the Strait of Georgia is 2,634,000 fish.

The Chilko River exploitation rate model results, using four combinations of in-season and post-season catch and racial data, are the same as those presented in Section (ii). The performance of the model results, as measured by the percent deviation of the model estimates relative to the post-season accounting estimate of 2,634,000, are presented in Table 5.

Under Scenario's One and Two (using in-season catch and racial data, and post-season catch and in-season racial data) the model estimates of the Adams/Lower Shuswap escapement to the Strait of Georgia are significantly higher than the post-season accounting of terminal area Adams/Lower Shuswap escapement. Specifically, the average of the daily and weekly model estimates under these scenarios overestimates the Adams/Lower Shuswap escapement estimate by 58.1% and 58.9%, respectively (Table 5). These deviations are larger than any previously observed in the historical data set (Table 1).

With Scenarios Three and Four (using in-season catch and post-season racial data, and post season catch and racial data) the average deviations, compared to the post-season accounting estimate, were reduced to 26.4% and 23.3%, respectively (Table 5). The model results using post-season catch and racial data were not significantly different from the results observed in the historical data set. When post-season data were used, the average deviation of the daily and weekly models (23.3%) was lower than the average deviation observed in three of the eight years for which estimates are available, specifically for the years 1978, 1983 and 1986. The deviation observed in 1994 was higher than those observed in 1974, 1982, 1987, 1990 and 1991 (Table 1). The weekly exploitation rate model with post-season data was just 16.2% above the accounted total using upstream catch and escapement estimates (Table 5).

Late-Run Gulf Escapement Estimates Using a Pooled Stock Group Approach

As discussed above, racial identification bias, specifically during the in-season management period, was a partial cause of the overestimate of Adams/Lower Shuswap escapement to the Strait of Georgia. It is possible that racial identification bias could be reduced by pooling stocks. For example, catch and escapement estimates for individual summer-run stocks could be pooled, and exploitation rates calculated for the group. That way mis-allocation bias between the individual summer-run stock groups would be cancelled out. Similarly, migratory catch estimates for individual late-run stocks could be pooled. This approach does not eliminate mis-allocation bias between summer-run and late-run stocks. In fact, mis-allocation bias between summer-run and late-run stocks could be increased using a pooled approach, depending on the classification accuracies between the different stock complexes involved.

Exploitation rate models were developed using pooled summer-run and late-run stock complexes to test the assumption that racial identification bias would be reduced in 1994 using a pooled stock approach. Migratory catch and terminal area catch and escapement estimates were tabulated for the Chilko/Quesnel stock group and the Late Stuart/Stellako stock group. The data were pooled and exploitation rates, both daily and weekly, were tabulated for the combined stock complex. Similarly, individual migratory area catch estimates were tabulated and combined for the following late-run stock groups: Birkenhead, Adams/Lower Shuswap and Weaver/Portage. Four scenario's of late-run escapement estimates were generated using the same four data sets as described above for the Chilko and Adams/Lower Shuswap estimates; namely, using in-season catch and racial data, post-season catch and in-season racial data, in-season catch and post-season racial data, and using post-season catch and racial data (Table 6).

The results summarized in Table 6 show that when using in-season data the exploitation rate models performed better using pooled stock data (86.8% average deviation, Table 6) than with the Chilko and Adams/Lower Shuswap stock groups alone (102.3% average deviation, Table 3). However, when using post-season data, the pooled stock models generated estimates with slightly higher deviations (58.4% average deviation, Table 6) than the Chilko and Adams/Lower Shuswap models (57.7% average deviation, Table 3). These results indicate that in 1994, stock identification bias was not significantly improved using a pooled stock approach. For example, during the in-season management period, the single stock weekly exploitation rate model, when expanded by 13.6 percent to include miscellaneous late runs, forecast a total late-run escapement to the Strait of Georgia of 4,301,000 fish. Had a pooled stock model been used, the estimate would have been reduced by 115,000, to 4,186,000 fish.

Table 1. Estimates of Adams/Lower Shuswap escapement to the Strait of Georgia using Chilko exploitation rates.

	Method of Estimation	Adams/Lower Shuswap Strait of Georgia Escapements			Diversion Rate
		#	%		
1974	Strait of Georgia Escp (Daily Expl Rate Calc)	2,174,570	20.4%	Post-season Data	28%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	1,757,499	-2.7%		
	Ave of the two Expl Rate Estimates	1,966,035	8.9%		
	Post-season St of Georgia Escapement Estimate	1,806,000			
1978	Strait of Georgia Escp (Daily Expl Rate Calc)	2,969,147	26.7%	Post-season Data	58%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,052,057	30.3%		
	Ave of the two Expl Rate Estimates	3,010,602	28.5%		
	Post-season St of Georgia Escapement Estimate	2,343,000			
1982	Strait of Georgia Escp (Daily Expl Rate Calc)	3,509,036	-1.5%	Post-season Data	22%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,617,770	1.5%		
	Ave of the two Expl Rate Estimates	3,563,403	0.0%		
	Post-season St of Georgia Escapement Estimate	3,563,000			
1983	Strait of Georgia Escp (Daily Expl Rate Calc)	473,924	24.4%	Post-season Data	80%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	641,958	68.5%		
	Ave of the two Expl Rate Estimates	557,941	46.4%		
	Post-season St of Georgia Escapement Estimate	381,000			
1986	Strait of Georgia Escp (Daily Expl Rate Calc)	3,179,460	-20.3%	Post-season Data	22%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	2,776,144	-30.4%		
	Ave of the two Expl Rate Estimates	2,977,802	-25.3%		
	Post-season St of Georgia Escapement Estimate	3,989,000			
1987	Strait of Georgia Escp (Daily Expl Rate Calc)	743,264	4.8%	In-season Data	37%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	788,073	11.2%		
	Ave of the two Expl Rate Estimates	765,669	8.0%		
	Post-season St of Georgia Escapement Estimate	709,000			
1990	Strait of Georgia Escp (Daily Expl Rate Calc)	5,325,988	10.5%	In-season Data	25%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,658,214	-24.1%		
	Ave of the two Expl Rate Estimates	4,492,101	-6.8%		
	Post-season St of Georgia Escapement Estimate	4,818,000			
1991	Strait of Georgia Escp (Daily Expl Rate Calc)	1,220,806	-18.6%	In-season Data	40%
	Strait of Georgia Escp (Weekly Expl Rate Calc)	1,206,356	-19.6%		
	Ave of the two Expl Rate Estimates	1,213,581	-19.1%		
	Post-season St of Georgia Escapement Estimate	1,500,068			

Table 2. Percentage error in historical in-season estimates versus post-season accounted run size.

Year	Daily Expl Rate	Weekly Expl Rate	Average of Daily & Weekly Expl Rates
1974	20.4%	-2.7%	8.9%
1978	26.7%	30.3%	28.5%
1982	-1.5%	1.5%	0.0%
1983	24.4%	68.5%	46.4%
1986	-20.3%	-30.4%	-25.3%
1987	4.8%	11.2%	8.0%
1990	10.5%	-24.1%	-6.8%
1991	-18.6%	-19.6%	-19.1%
Mean	5.8%	4.3%	5.1%
Standard Deviation	18.3%	32.7%	23.8%

Year	Absolute Daily Expl Rate	Absolute Weekly Expl Rate	Average of Daily & Weekly Expl Rates
1974	20.4%	26.9%	8.9%
1978	26.7%	30.3%	28.5%
1982	1.5%	1.5%	0.0%
1983	24.4%	68.5%	46.4%
1986	20.3%	30.4%	25.4%
1987	4.8%	11.2%	8.0%
1990	10.5%	24.1%	6.8%
1991	18.6%	19.6%	19.1%
Mean	15.9%	26.6%	17.9%
Standard Deviation	9.2%	19.7%	15.2%

Table 3. Summary of Adams/Lower Shuswap escapement into the Strait of Georgia, estimated using migratory area exploitation rates for the Chilko/Quesnel stock group and with Mission hydroacoustic estimates used as the source of escapement data for post-season numbers.

Year	Estimate	Adams Group Escapement Estimates	Discrepancy		
			#	%	
1994	Post-season Strait of Georgia Escp Estimate *	2,059,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	4,544,000	2,485,000	120.7%	In-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,787,000	1,728,000	83.9%	In-season Racial Data
	Ave of the two exploitation rate estimates	4,165,500	2,106,500	102.3%	
1994	Post-season Strait of Georgia Escp Estimate *	2,059,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	4,522,000	2,463,000	119.6%	Post-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,851,000	1,792,000	87.0%	In-season Racial Data
	Ave of the two exploitation rate estimates	4,186,500	2,127,500	103.3%	
1994	Post-season Strait of Georgia Escp Estimate *	2,059,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	3,536,000	1,477,000	71.7%	In-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,123,000	1,064,000	51.7%	Post-season Racial Data
	Ave of the two exploitation rate estimates	3,329,500	1,270,500	61.7%	
1994	Post-season Strait of Georgia Escp Estimate *	2,059,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	3,436,000	1,377,000	66.9%	Post-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,061,000	1,002,000	48.7%	Post-season Racial Data
	Ave of the two exploitation rate estimates	3,248,500	1,189,500	57.8%	

Post-season Strait of Georgia Escapement Estimate = PSC Mission Escapement, Native Catch Below Mission, Strait of Georgia Native Catch, Area 29 Catch, Lower Georgia Strait Troll Catch, Terminal Area Test Fishing Catch, and the Delay Component of the Area 7A Catch.

Table 4. Single-stock analysis, using in-season catch and racial data.

		Adams Group Escapement Estimates	Discrepancy		
Year	Estimate		#	%	
1994	Post-season Strait of Georgia Escp Estimate *	2,634,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	4,544,000	1,910,000	72.5%	In-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,787,000	1,153,000	43.8%	In-season Racial Data
	Ave of the two exploitation rate estimates	4,165,500	1,531,500	58.1%	
1994	Post-season Strait of Georgia Escp Estimate *	2,634,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	4,522,000	1,888,000	71.7%	Post-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,851,000	1,217,000	46.2%	In-season Racial Data
	Ave of the two exploitation rate estimates	4,186,500	1,552,500	58.9%	
1994	Post-season Strait of Georgia Escp Estimate *	2,634,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	3,536,000	902,000	34.2%	In-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,123,000	489,000	18.6%	Post-season Racial Data
	Ave of the two exploitation rate estimates	3,329,500	695,500	26.4%	
1994	Post-season Strait of Georgia Escp Estimate *	2,634,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	3,436,000	802,000	30.4%	Post-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,061,000	427,000	16.2%	Post-season Racial Data
	Ave of the two exploitation rate estimates	3,248,500	614,500	23.3%	

Post-season Strait of Georgia Escapement Estimate = DFO Net Escapement, Fraser River Native Catch, Strait of Georgia Native Catch, Area 29 Catch, Lower Georgia Strait Troll Catch, Terminal Area Test Fishing Catch, and the Delay Component of the Area 7A Catch.

Table 5. Summary of Adams/Lower Shuswap escapement into the Strait of Georgia, estimated using migratory area exploitation rates for the Chilko/Quesnel stock group and with DFO upstream accounting estimates used as the source of escapement data for post-season numbers.

	Chilko/Quesnel					Method A		Method B
BB Date	Total Migr Catch	Area 29 Catch & Escp	Daily Exploit Rate	Weekly Exploit Rate	Adams Total Migr Catch	Daily Late Run Escp into St of Georgia	Cummul Late Run St of Georgia Delay	Cummul Late Run St of Georgia Delay
01-Aug								
02-Aug								
03-Aug								
04-Aug	30,684	176,051	14.8%		529	3,035	3,035	
05-Aug	41,779	148,469	22.0%		617	2,193	5,228	
06-Aug	47,257	105,800	30.9%		1741	3,898	9,126	
07-Aug	47,391	119,357	28.4%	23.3%	3588	9,037	18,164	21,300
08-Aug	41,177	81,048	33.7%		9344	18,392	36,556	
09-Aug	97,781	25,263	79.5%		47563	12,289	48,844	
10-Aug	68,760	112,150	38.0%		31461	51,314	100,158	
11-Aug	55,656	137,717	28.8%		38199	94,521	194,679	
12-Aug	65,228	227,600	22.3%		41474	144,715	339,394	
13-Aug	162,627	164,469	49.7%		90042	91,062	430,456	
14-Aug	120,328	146,280	45.1%	40.6%	64005	77,809	508,266	492,420
15-Aug	185,183	161,493	53.4%		182179	158,873	667,139	
16-Aug	198,358	170,017	53.8%		204354	175,156	842,295	
17-Aug	14,459	151,572	8.7%		28438	298,111	1,140,406	
18-Aug	17,103	139,894	10.9%		54388	444,867	1,585,273	
19-Aug	13,476	75,376	15.2%		16617	92,944	1,678,217	
20-Aug	76,763	90,365	45.9%		120468	141,815	1,820,032	
21-Aug	71,692	61,315	53.9%	40.4%	103478	88,500	1,908,532	1,538,209
22-Aug	172,002	65,629	72.4%		463208	176,742	2,085,274	
23-Aug	172,128	40,795	80.8%		466787	110,629	2,195,903	
24-Aug	2,858	48,309	5.6%		13740	232,248	2,428,151	
25-Aug	5,323	35,727	13.0%		19990	134,177	2,562,328	
26-Aug	5,810	74,084	7.3%		22312	284,521	2,846,849	
27-Aug	44,368	31,984	58.1%		151951	109,538	2,956,387	
28-Aug	43,764	38,774	53.0%	57.1%	149429	132,391	3,088,778	2,505,538
29-Aug	41,420	84,178	33.0%		134615	273,579	3,362,357	
30-Aug	41,420	24,647	62.7%		134615	80,103	3,442,460	
31-Aug	41,420	39,406	51.2%		134615	128,070	3,570,529	
01-Sep	2,895	69,684	4.0%		13236	318,597	3,889,126	
02-Sep	2,895	61,047	4.5%		13236	279,108	4,168,234	
03-Sep	1,312	24,534	5.1%		5576	104,270	4,272,503	
04-Sep	1,312	14,449	8.3%	29.4%	5576	61,408	4,333,912	3,563,491
05-Sep	5,467	11,479	32.3%		30276	63,576	4,397,488	
06-Sep	5,467	9,100	37.5%		30276	50,400	4,447,888	
07-Sep	5,163	4,887	51.4%		38209	36,164	4,484,051	
08-Sep	5,163	4,268	54.7%		38209	31,583	4,515,635	
09-Sep	5,163	2,882	64.2%		38209	21,327	4,536,961	
10-Sep	1,000	1,056	48.6%	44.9%	7000	7,392	4,544,353	3,787,183

Escapement to the Strait of Georgia prior to terminal area catch amd escapement

Table 6. Summary of late-run escapement into the Strait of Georgia, estimated using migratory area exploitation rates for summer-run stocks and with Mission hydroacoustic estimates used as the source of escapement data for post-season numbers.

Year	Estimate	Late Run Escapement Estimates	Discrepancy		
			#	%	
1994	Post-season Strait of Georgia Escp Estimate *	2,469,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	5,038,000	2,569,000	104.1%	In-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	4,186,000	1,717,000	69.5%	In-season Racial Data
	Ave of the two exploitation rate estimates	4,612,000	2,143,000	86.8%	
1994	Post-season Strait of Georgia Escp Estimate *	2,469,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	5,060,000	2,591,000	104.9%	Post-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	4,254,000	1,785,000	72.3%	In-season Racial Data
	Ave of the two exploitation rate estimates	4,657,000	2,188,000	88.6%	
1994	Post-season Strait of Georgia Escp Estimate *	2,469,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	4,122,000	1,653,000	67.0%	In-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,489,000	1,020,000	41.3%	Post-season Racial Data
	Ave of the two exploitation rate estimates	3,805,500	1,336,500	54.1%	
1994	Post-season Strait of Georgia Escp Estimate *	2,469,000			
	Strait of Georgia Escp (Daily Expl Rate Calc)	4,142,000	1,673,000	67.8%	Post-season Catch &
	Strait of Georgia Escp (Weekly Expl Rate Calc)	3,679,000	1,210,000	49.0%	Post-season Racial Data
	Ave of the two exploitation rate estimates	3,910,500	1,441,500	58.4%	

Post-season Strait of Georgia Escapement Estimate = PSC Mission Escapement, Native Catch Below Mission, Strait of Georgia Native Catch, Area 29 Catch, Lower Georgia Strait Troll Catch, Terminal Area Test Fishing Catch, and the Delay Component of the Area 7A Catch.

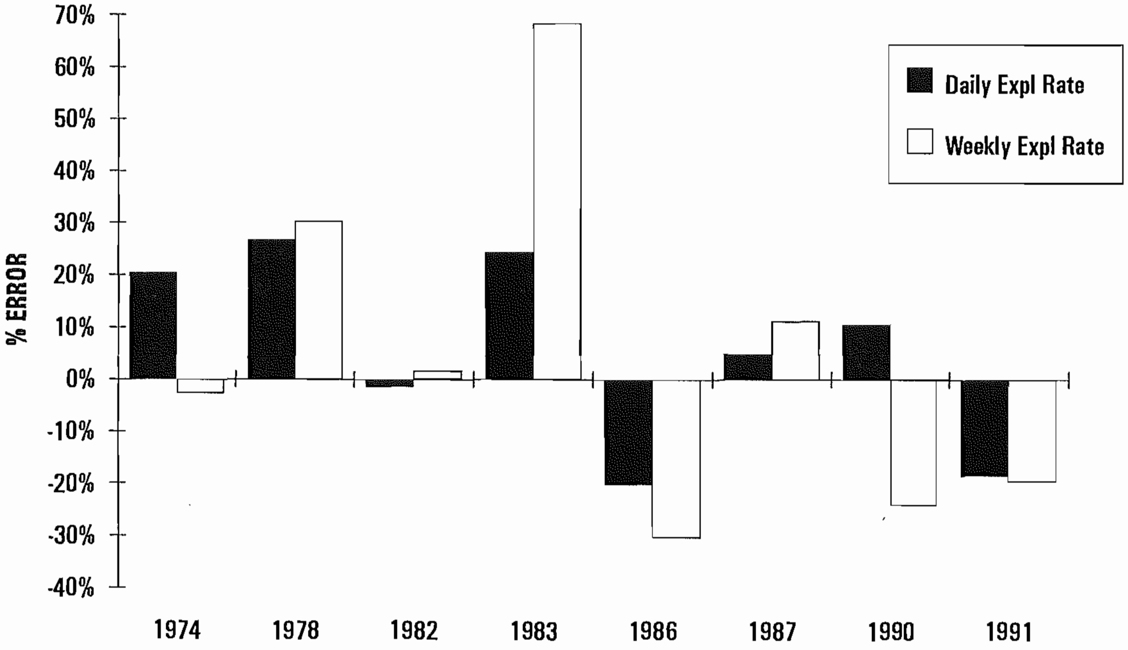

Figure 1. Percentage error in historical estimates of Adams escapement to the Strait of Georgia.

Appendix G: 1994 Catch and Racial Data Review

Introduction

In-season run size assessments are based on two sources of data: abundance to date, comprised of catch and escapement components, and racial analysis of the catch and escapement data. Stock-specific catch and escapement profiles are continually updated throughout the in-season management period as additional data become available. However, at the end of the management season the catch data and racial analyses remain preliminary for two reasons. First, stock proportions must be re-estimated using post-season models (see 1994 Post-season Models, below). Second, final catch data are derived from sales slips which must be obtained from processors and entered into a computer database (see Catch Data Overview, below). Thus, in a typical year, final catch and racial data are not available until several months to a year or more after the end of the fishing season.

1994 Racial Analysis Overview

The PSC is responsible for estimating proportions of Fraser River sockeye stocks or stock-groups in all catches, in order to facilitate the achievement of stock-specific catch and escapement objectives. The PSC uses discriminant function analysis (DFA) to estimate the proportions of individual stocks or stock groups in mixed stock fishery samples. The stock identification methodology, including the development of in-season and post-season models, and general management applications of the methodology, are reviewed in detail by Gable and Cox-Rogers (1993). In-season stock identification models are developed and applied to samples obtained from commercial and test fishing catches on an ongoing basis throughout the management season. Post-season stock identification models are developed, and the post-season racial analysis is conducted, once final catch data and spawning ground scale samples become available after the close of the season. Application of both in-season and post-season DFA models follows the same four steps: (i) discriminant functions are estimated using the baseline standards, (ii) these models are then used to classify each fish in the baseline in a cross-validation procedure which generates a classification matrix containing the expected rates of misclassification for each stock, (iii) individual fish in the mixture samples are classified using the discriminant functions, and initial estimates of stock proportions are generated, (iv) the classification matrix generated in step (ii) is used to correct the initial stock proportion estimates for the expected rates of misclassification resulting in nearly unbiased estimates of stock proportions (i.e., Cook and Lord's (1978) bias correction procedure).

1994 In-season Models

The key element in the construction of in-season models is the selection of baseline standards for each stock that accurately represent the scale characters (e.g. freshwater circuli counts and distance measures) of the returning adults. Unrepresentative baseline standards can result in bias in both the initial estimates and nearly unbiased estimates of stock proportions, because they would result in errors in both the individual classifications and in the expected rates of misclassification. The 1994 in-season discriminant function analysis models were constructed using stock-specific baseline standards from two sources: i) prior year spawning ground scales from fish with the same freshwater residency period (eg. 3_2 jack scales in 1993 used in 1994 age 4_2 models), ii) past years' spawning ground scales from the same age class (eg. 4_2 adult scales from 1990 used in 1994 age 4_2 models; Table 1).

For most of the period of active commercial fishing in 1994, one of two categories of in-season models was used: i) models with early-summer-run and summer-run stock complexes, ii) models with summer-run and late-run stock complexes. A list of the 4_2 stock groups, baseline standards, and expected classification matrices of the models used in 1994, are presented in Table 1. The classification matrices printed in Table 1 have two components. First, the diagonal elements are the expected rates of correct classification for each stock, or classification accuracies (assuming the baseline standards accurately reflected the scale characters of the returning 4_2 adults). Second, the off-diagonal elements represent the expected rates of misclassification due to overlap in scale characters among the baseline stocks. The matrices showed that misclassifications could be expected among the summer-run stocks. For example, the Late Stuart/Stellako group was expected to be misclassified to the Birkenhead group at a rate of 16-18%. Misclassification rates of 27-34% were expected among the Chilko and Quesnel stocks. Pooling the Chilko and Quesnel stocks was considered, but differences in pre-season forecasts of abundance and escapement goals for these two co-migrating stocks, forced an attempt to obtain separate estimates. In order to assist in this process, data on the presence or absence of the brain parasite, *Myxobolus articus*, was collected from key fishery samples during the season. From past years' samples the Quesnel stock was known to be infected with *Myxobolus*, while the parasite is absent from Chilko and other co-migrating stocks. A revised Quesnel standard for the in-season models was constructed using scales from fish in mixture samples that had the parasite (Table 1). Despite misclassifications among the summer-run stocks, there was little misclassification between summer and late-run stocks. The key stock group in the late run, Adams/Lower Shuswap, was expected to be accurately distinguished from other late-run and summer-run stocks (except Scotch/Seymour, see below).

In addition to the potential for misclassifications among stocks described above, the separation of the Scotch/Seymour stock group from the Adams/Shuswap stock group was of particular concern in 1994. Both these stock groups rear in Shuswap Lake and therefore are indistinguishable by their freshwater scale characteristics. However, differences in behaviour exhibited by the two stocks provide a means by which they can be estimated in marine areas. The Scotch/Seymour group is an early summer-run stock with an average peak timing of July 28 in Area 20, and of August 3 in Area 29. The Scotch/Seymour group does not typically delay off the mouth of the Fraser River prior to its' upstream migration. In contrast, the Adams/Shuswap group is a late-run stock with an average peak timing of August 18 in Area 20. Adams River fish delay for a period three to four weeks off the mouth of the Fraser River prior to migrating upstream. Consequently, while the Scotch/Seymour and Adams/Shuswap stock groups are jointly intercepted in outside migratory area fisheries, their timing does not overlap in the Fraser River.

The differences in behaviour were used to generate separate estimates for the Scotch/Seymour and Adams/Shuswap stock proportions in the following manner. For all Area 29 commercial and test fishery samples analyzed from mid-July through to the end of August, the percentages of the Scotch/Seymour and the Chilko/Quesnel stock groups were identified. The Chilko/Quesnel group was used in 1994 rather that the Chilko group as in past years, because of the expected overlap in the scale patterns of the Chilko and Quesnel stock groups (Table 1). The ratio of the Scotch/Seymour stock group to the Chilko/Quesnel stock group was then calculated. In marine area fisheries, the contribution of the Chilko/Quesnel stock group was estimated, as was the contribution of the Seymour/Adams stock group complex. Using appropriate lag times, the Area 29 Scotch/Seymour to Chilko/Quesnel ratio was used to estimate the Scotch/Seymour stock component of the Seymour/Adams stock group complex in marine area fisheries. The Adams/Shuswap stock group was assigned the remaining portion of the Seymour/Adams complex.

1994 Post-season Models

Post-season models were constructed using revised baseline standards, with scales collected from individual spawning ground streams throughout the Fraser River watershed (Table 2). A list of the 4_2 stock groups, baseline standards, and expected classification matrices of the post-season models used in 1994 are presented in Table 2. Post-season models had generally higher classification accuracies (diagonals of matrices) than expected from in-season models (Tables 1 and 2). No attempt was made to separate the Chilko and Quesnel stocks in post-season models because of highly overlapped scale characters. The Late Stuart/Stellako group was misclassified to the Birkenhead group and the Chilko/Quesnel group. As was the case with the in-season models, the key late-run stock group, Adams/Shuswap, was well separated from other late-run and summer-run stocks (except Scotch/Seymour, see below).

The method used to separate the Scotch/Seymour stock group from the Seymour/Adams stock group complex, was the same in the post-season analysis as in the in-season analysis. In other words, the daily ratio of Scotch/Seymour to Chilko/Quesnel in Area 29 was used to estimate the Scotch/Seymour stock component of the Seymour/Adams stock complex in marine area fisheries. The daily ratio of Scotch/Seymour to Chilko/Quesnel in Area 29 was substantially higher in the post-season however, largely due to a reduction in the daily estimates of the Chilko/Quesnel stock group in Area 29. The reasons for the stock composition changes from in-season to post season analyses are discussed below.

Comparison of "Realized" Classification Accuracies of the In-season and Post-season Models

Simulations were performed whereby in-season and post-season models were applied to mixtures based on post-season spawning ground scales to compare how the models performed. Specifically, the models were tested on pure 1994 spawning ground mixtures comprised of one stock or stock group. The results from the series of simulations conducted using the in-season and post-season models are summarized in four classification matrices as follows: (i) the early summer/summer-run model based on the in-season standards used during the 1994 management season, (ii) the summer/late-run model based on the in-season standards used during the 1994 management season, (iii) the early-summer/summer-run model based on the post-season standards used for the post-season analysis, (iv) the summer/late-run model based on the post-season standards used for the post-season analysis (Table 3).

The elements of each matrix presented in Table 3 are the means of nearly unbiased estimates of stock proportions from 100 simulated mixtures created using 115 post-season, spawning ground scales from the stock or stock group listed at the top of each column. For example, the first column of Matrix 1, contains the mean proportions identified as the stocks in each row when the model was given a mixture of 100% Scotch/Seymour group scales. In this example, the model estimated stock proportions of 97.3% for the Scotch/Seymour group, and 2.7% for the Chilko group. The matrices presented in Table 3 are termed the "realized" classification matrices, and the diagonal elements are the "realized" classification accuracies. The off-diagonal elements of the matrices represent the bias remaining after initial estimates are corrected for expected rates of misclassification based on the corresponding expected classification matrices presented in Tables 1 and 2.

When the in-season model for summer/late runs (matrix 2) was given simulated mixtures of 100% Chilko/Quesnel group, only 0.2% were misclassified to the Late Stuart/Stellako group (Table 3). However, when simulated pure mixtures of 100% Late Stuart/Stellako group were run, 21.5% were misclassified to the Quesnel group. This discrepancy is caused by the changes in the scale characters from in-season to post-season standards. Both the early-summer/summer-run and summer/late-run post-season models, detailed in Matrices 3 and 4, performed well, as would be expected. Although even with bias correction, there is still some misclassification of the Chilko/Quesnel group to the Late Stuart/Stellako group, and of the Late Stuart/Stellako group to Birkenhead. Most misclassification problems were relatively minor, with the exception that a significant proportion of Late Stuart/Stellako group was misclassified to the Quesnel group when the in-season models were used, as describe above. The misclassification of the Late Stuart/Stellako group to the Quesnel group resulted in significant changes in the allocation of catches to stock-groups (see In-season and Post-season Estimates of Catch and Exploitation Rate By Stock and Area, below).

In summary, due to changes in scale characters of the in-season and post-season standards the following shifts in stock allocations in mixed stock fishery samples are expected from the simulation results (gains and losses of fish are for the post-season relative to results of in-season models):
(i) Scotch/Seymour and Adams/Shuswap stock groups - will gain small numbers of fish from the Chilko/Quesnel group;
(ii) Chilko/Quesnel group - will lose significant numbers of fish to the Late Stuart/Stellako group and small numbers of fish to the Scotch/Seymour and Birkenhead groups;
(iii) Late Stuart/Stellako group - will gain a significant number of fish from the Chilko/Quesnel group and loose a small number of fish to the Birkenhead group and;
(iv) Birkenhead group - will gain small numbers of fish from the Chilko/Quesnel and Late Stuart/Stellako groups.

One final shift in stock allocations resulted indirectly from the changes documented above. Since the Scotch/Seymour stock group increased slightly from the in-season to the post-season results, and the Chilko/Quesnel group lost significant numbers of fish, the Scotch/Seymour to Chilko/Quesnel ratio was significantly higher in the post-season. Since this ratio is used to estimate the Scotch/Seymour stock component of the Seymour/Adams stock complex, the proportion of Scotch/Seymour in the migratory area fisheries will increase in the post-season and the proportion of the Adams/Lower Shuswap stock group will decline.

Catch Data Overview

The PSC has the responsibility for estimating in-season catch by gear type in Panel area waters, while DFO provides in-season catch estimates for non-Panel area catches in Canada, with the exception of troll fisheries where DFO estimates the catch in both Panel and non-Panel area waters. Catch monitoring, through contacts with major fish buyers and on-water hail data, provides the initial estimate of catch for individual fisheries while the fisheries are ongoing. Immediately following the close of a fishery, more complete estimates of catch are derived from gear counts, in conjunction with estimates of catch and catch per delivery from fish buying companies. These estimates are updated on a weekly basis once the companies have processed and summarized the catch for each fishery. In-season estimates of total catch are usually within ten to fifteen percent of the final sales slip catch numbers, but in-season and post-season estimates for individual fisheries can differ by larger amounts.

In Canada, post-season catch data are tabulated by week-ending period by DFO from fish sales slips collected from all registered fish buyers in British Columbia. In addition, any private sales for which sales slips are made out and sent in to DFO are included in the commercial catch summaries. In the United States, post-season catch data are summarized on a daily basis from fish tickets sent in to The Washington Department of Fish and Wildlife (WDFW). In fact, in Washington State, fish buying companies are required to send in their tickets to WDFW immediately after the close of each fishery, and the catch data base is updated continually throughout the in-season management period. Consequently, in-season projections are replaced with computer run fish ticket data approximately one week after the close of a fishery. This system results in little change occurring in catch numbers between the in-season and the final, post-season catch estimates, which are available some months after the close of the season. A small catch of Fraser sockeye also occurs off southeast Alaska where total sockeye catches are estimated by the Alaska Department of Fish and Game using a similar system to that used by WDFW.

1994 In-season and Post-season Catch Data

The final in-season catch estimates, along with the current "preliminary" post-season catch estimates, are presented in Table 4. The total 1994 in-season Canadian commercial catch for all areas was 9,115,000 fish. The current post-season total is 10,035,000 fish, or a 920,000 fish (9.2%) increase above the in-season number. Virtually all (911,000, or 99%) of the increase in Canadian catch is accounted for by three statistical areas: Areas 12 (increase of 550,000 or 15.3%),13 (196,000, 15.1%) and 20 (165,000, 19.5%; Table 4). It is important to note that catches in each these areas are key inputs in the PSC's in-season run size models. The changes in other Canadian catch areas were much smaller in numerical terms, but not necessarily in terms of percentage change (Table 4). For reasons outlined previously, the United States post-season number (2,068,000) is virtually unchanged from the in-season number (2,054,000).

In-season and Post-season Estimates of Catch and Exploitation Rate By Stock and Area

Run size models ultimately rely on a combination of catch and racial data for their input parameters. Therefore, it is important to look at the combination of changes in both the catch and racial estimates in assessing in-season run size model accuracies in 1994. In-season estimates of catch by stock and area were derived using the actual DFA models used during the 1994 in-season management period and catch data available at the end of October. The in-season gross escapement estimates were derived from in-season estimates of Mission daily escapements by stock group, plus Native fishery catches below Mission. Post-season estimates of catch by stock and area were derived using post-season DFA models and post-season catch data available from computer runs at the end of February. The post-season gross escapement estimates were derived from post-season estimates of Mission daily escapements by stock group, plus Native fishery catches below Mission. Annual exploitation rates were estimated by dividing the catches for each stock and area by the total run size.

Post-season changes to catch and racial data, resulted in significant changes in the catch and exploitation rate estimates for the key stock group complexes(Table 5). For example, the Area 29 post-season net catch of 1,298,000 is not substantively different from the in-season net catch of 1,290,000 (Table 5). However, there are some significant changes in the catch by stock group estimates. For example, catch and exploitation rates attributed to the early-summer, Late Stuart/Stellako and Adams/Lower Shuswap stock groups increased, while the catch and exploitation rate of the Chilko/Quesnel stock group decreased significantly. Similar shifts in stock composition estimates are expected in all catch areas as identified by the results of simulation analyses presented above (in Comparison of "Realized" Classification Accuracies of the In-season and Post-season Models).

Catches and exploitation rates of the early-summer stock group (primarily the Scotch/Seymour component) increased significantly in the migratory area fisheries, due in part to a general increase in total catch, but largely because of increases in the Scotch/Seymour to Chilko/Quesnel ratios in Area 29 samples. The revised ratios increased the proportion of the Scotch/Seymour component in Seymour/Adams stock complex as discussed above. The total catch in all areas for the early-summer stock group increased from 419,000 (33% annual exploitation rate) during the in-season to 753,000 (59% annual exploitation rate) in the post-season (Table 5).

The total catch in all areas for the Chilko/Quesnel stock group in the post-season was 3,984,000 (67% annual exploitation rate), up from in-season estimate of 3,794,000 (64% annual exploitation rate; Table 5). The increases in catch and exploitation rate for this stock group were primarily due to increases in total catch. Post-season estimates of the proportion of the Chilko/Quesnel stock group in mixed stock fishery samples were smaller than in-season estimates for reasons discussed above (in Comparison of "Realized" Classification Accuracies of the In-season and Post-season Models). The decrease in estimates of stock proportions of the Chilko/Quesnel stock group also caused a decrease in the estimated gross escapement from 2,180,000 during the in-season to 1,929,000 in the post-season period.

The total catch of Late Stuart/Stellako stock group increased from 650,000 during the in-season to 864,000 in the post-season. The gross escapement also increased from 443,000 to 584,000 (Table 5). These changes are due to both increases in overall catch, and to changes in the DFA post-season standards as previously discussed (in Comparison of "Realized" Classification Accuracies of the In-season and Post-season Models). The total annual exploitation rate was essentially unchanged from in-season (59.4%) to post-season (59.6%).

In contrast to the other stock groups, catch estimates for the Adams/Shuswap stock group decreased slightly from the in-season estimate of 5,791,000 to the post-season estimate of 5,788,000. (Table 5). The classification accuracies of the in-season and post-season models were high for the Seymour/Adams stock group complex. The drop in catch was due to an increase in the Scotch/Seymour stock group at the expense of the Adams/Shuswap stock group as described above.

Using in-season data, the total run in 1994 was estimated to be 15,705,000 fish, including 191,000 Early Stuart, 935,000 early-summers, 5,974,000 Chilko/Quesnel, 1,093,000 Late Stuart/Stellako, 6,711,000 Adams/Lower Shuswap, and 801,000 Birkenhead, Weaver and other miscellaneous late runs (Table 5). Using post-season data, the total run was estimated to be 16,742,000 fish, including 202,000 Early Stuart, 1,268,000 early-summers, 5,913,000 Chilko/Quesnel, 1,448,000 Late Stuart/Stellako, 6,715,000 Adams/Lower Shuswap, and 1,196,000 Birkenhead, Weaver and miscellaneous late runs (Table 5).

In-season and post-season estimates of catch and harvest rate in migratory and terminal areas for summer and late-run stock groups are compared in Table 6. The shift in total catch by stock group from in-season to post-season in migratory areas is due mainly to post-season revisions to catch estimates; post-season catches are larger than in-season catches for each of the stock groups. In contrast the shift in total catch by stock group from in-season to post-season in the terminal areas is due mainly changes in estimates of stock proportion resulting from the application of DFA models based on post-season spawning ground standards; catch of Late Stuart/Stellako increased at the expense of Chilko/Quesnel, catch of Adams/Shuswap decreased (while the Scotch/Seymour group increased [not shown]), and the catch of Birkenhead, Weaver and other miscellaneous late runs increased, primarily due to Birkenhead gaining small number of fish from the Chilko/Quesnel and Late Stuart/Stellako stock groups. In-season and post-season harvest rates were very similar in both the migratory and terminal areas for each of the stock groups with one exception (Table 6). First, the Chilko/Quesnel harvest rate in the migratory area increased in the post-season due to the combined effect of increased post-season catch and decreased post-season escapement. Late-run harvest rates were consistently and significantly higher than summer-run harvest rates in both migratory and terminal areas regardless of whether in-season or post-season data were used (Table 6).

The changes in stock group catches and escapements and exploitation rates from the in-season to the post-season documented above were due to a combination of : (i) increases in total catch and (ii) changes in the estimates of stock proportions resulting from the application of DFA models based on post-season spawning ground standards. The implications of these changes for in-season run size model predictions, and the relative importance of the change in catch versus the change in DFA models is explored in Appendices G, E and F.

References

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Table 1. Summary of 1994 in-season stock groups and classification matrices of in-season models.

Stock-Group	Run	Stock-Group Abbreviation	In-season Baseline Standards	no. of scales per stock	Total Scales for Group
Early Summer-run and Summer-run Model					
1. Scotch/Seymour	Early	ScSeAn	1987 Scotch Creek 4/2's	18	100
/Anstey	Summer		1986 Seymour River 4/2's	61	
			1986 Anstey River 4/2's	21	
2. Chilko	Summer	Chilko	1993 Chilko River 3/2's	100	100
3. Quesnel	Summer	Quesnel	1994 Returning 4/2's based on myxobolus positive fish in early samples *	*67	*67
4. Late Stuart/Stellako	Summer	LStSte	1993 Stellako River 3/2's	33	100
			1990 Middle &Tachie River 4/2's	67	
5. Birkenhead	Summer	Birken	1993 Birkenhead River 3/2's	100	100
Summer-run and Late-run Model					
Stock-Groups 2, 4 and 5 above and					
6. Quesnel	Summer	Quesnel	1994 Returning 4/2's based on myxobolus positive fish in early samples *	*83	*83
7. Adams/Shuswap	Late	Adams	1993 Lower Adams River 3/2's	71	100
			1993 Lower Shuswap River 3/2's	29	
8. Weaver	Late	Weaver	1993 Weaver Creek 3/2's		100

Expected Classification Matrices based on In-season Standards

Early Summer-run and Summer-run Model

		FROM				
		ScSeAn	Chilko	Quesnel	LStSte	Birken
	ScSeAn	88.0%	5.0%	11.9%	1.0%	2.0%
	Chilko	2.0%	63.0%	34.3%	2.0%	1.0%
TO	Quesnel	8.0%	27.0%	53.7%	4.0%	2.0%
	LStSte	0.0%	1.0%	0.0%	75.0%	16.0%
	Birken	2.0%	4.0%	0.0%	18.0%	79.0%

Summer-run and Late-run Model

		FROM					
		Chilko	Quesnel	LStSte	Adams	Birken	Weaver
	Chilko	60.0%	33.7%	1.0%	1.0%	1.0%	0.0%
	Quesnel	34.0%	63.9%	5.0%	4.0%	3.0%	0.0%
TO	LStSte	0.0%	0.0%	70.0%	0.0%	13.0%	10.0%
	Adams	3.0%	2.4%	0.0%	95.0%	2.0%	0.0%
	Birken	3.0%	0.0%	16.0%	0.0%	66.0%	13.0%
	Weaver	0.0%	0.0%	8.0%	0.0%	15.0%	77.0%

NOTES * By August 12, 1994, the pre-seaon Quesnel standard based on 1990 4/2 scales was replaced with scales from fish with Myxobolus in 1994 mixture samples . The Early Summer/Summer Run model was based on a standard with 67 scales. An additional 16 scales were available for the Quesnel Standard used in the Summer/Late-run model.

Table 2. Summary of post-season stock groups and classification matrices of post-season models.

Stock-Group	Run	Stock-Group Abbreviation	Post-season Baseline Standards (all 1994 4/2's)	no. of scales per stock	Total Scales for Group	Expected Classification Matrices based on Post-season Standards						
			Early Summer-run and Summer-run Model									
1. Scotch/Seymour	Early Summer	ScoSey	Scotch Creek	79	150							
			Seymour River	71								
									FROM			
2. Chilko/Quesnel	Summer	ChrQue	Chilko River	82	201							
			Lower Horsefly River	27				ScoSey	ChrQue	LStSte	Birken	
			Upper Horsefly River	70			ScoSey	96.0%	0.5%	0.0%	0.0%	
			Upper McKinley Creek	0			ChrQue	4.0%	94.5%	11.5%	4.0%	
			Mitchell River	22		**TO**	LStSte	0.0%	5.0%	77.0%	10.0%	
							Birken	0.0%	0.0%	11.5%	86.0%	
3. Late Stuart/Stellako	Summer	LStSte	Middle River	24	200							
			Tachie River	39								
			Stellako River	137								
4. Birkenhead	Summer	Birken	Birkenhead River	150	150							
			Summer-run and Late-run Model									
										FROM		
Stock-Groups 2, 3, 4 above and												
								ChrQue	LStSte	Adams	Birken	Weaver
							ChrQue	95.0%	11.5%	1.0%	4.0%	0.0%
5. Adams/Shuswap	Late	Adams	Lower Adams River	140	200		LStSte	4.5%	73.5%	0.0%	10.7%	2.0%
			Lower Shuswap River	53		**TO**	Adams	0.5%	0.0%	98.5%	0.0%	1.0%
			Middle Shuswap	7			Birken	0.0%	9.5%	0.5%	79.3%	12.0%
							Weaver	0.0%	5.5%	0.0%	6.0%	85.0%
6. Weaver	Late	Weaver	Weaver Creek	100	100							

Table 3. Realized classification matrices for 1994 in-season and post-season models.

In-season Models Applied to Post-season standards

1. Early Summer/Summer-run Model

		FROM (Post-season standards)			
		ScoSey	ChrQue	LStSte	Birken
TO (In-season standards)	ScSeAn	97.3%	0.0%	0.0%	0.0%
	Chilko	2.7%	57.2%	0.3%	2.3%
	Quesnel	0.0%	42.7%	23.2%	0.1%
	LStSte	0.0%	0.1%	76.6%	1.6%
	Birken	0.0%	0.0%	0.0%	96.0%

2. Summer/Late-run Model

		FROM (Post-season standards)				
		ChrQue	LStSte	Adams	Birken	Weaver
TO (In-season standards)	Chilko	62.9%	0.1%	0.4%	2.3%	0.0%
	Quesnel	36.9%	21.5%	0.1%	0.0%	0.0%
	LStSte	0.2%	78.4%	0.0%	1.6%	0.0%
	Adams	0.0%	0.0%	99.5%	0.0%	0.0%
	Birken	0.0%	0.0%	0.0%	95.8%	0.0%
	Weaver	0.0%	0.0%	0.0%	0.2%	100.0%

Post-season Models Applied to Post-season standards

3. Early Summer/Summer-run Model

		FROM (Post-season standards)			
		ScoSey	ChrQue	LStSte	Birken
TO (Post-season standards)	ScoSey	99.4%	1.0%	0.0%	0.1%
	ChrQue	0.6%	95.8%	0.8%	0.1%
	LStSte	0.0%	3.2%	96.8%	0.2%
	Birken	0.0%	0.0%	2.3%	99.6%

4. Summer/Late-run Model

		FROM (Post-season standards)				
		ChrQue	LStSte	Adams	Birken	Weaver
TO (Post-season standards)	ChrQue	95.7%	0.8%	0.8%	0.1%	0.0%
	LStSte	3.4%	96.8%	0.0%	0.2%	0.4%
	Adams	0.9%	0.0%	99.1%	0.1%	0.0%
	Birken	0.0%	1.3%	0.1%	98.3%	0.6%
	Weaver	0.0%	1.1%	0.0%	1.3%	99.0%

Table 4. In-season and post-season estimates of catches of Fraser River sockeye salmon in 1994.

Area	In-season Fraser Catch	Post-season Fraser Catch	Difference (post-season - in-season)	% Difference (post-season - in-season)
Canada				
Area 1 net	59,556	96,415	36,859	61.9%
Area 2W net and troll	774,028	809,799	35,771	4.4%
Area 8	222,210	163,960	-58,250	-35.5%
Area 111 and 8 troll	792,461	878,929	86,468	9.8%
Area 12	3,044,900	3,595,265	550,365	15.3%
Area 13	1,097,800	1,293,459	195,659	15.1%
Area 16	121,600	147,631	26,031	17.6%
Area 20	681,253	846,486	165,233	19.5%
Area 29A (outside troll)	255,000	165,555	-89,445	-54.0%
Area 29B	807,818	828,749	20,931	2.5%
Area 29D	482,298	469,174	-13,124	-2.8%
Upper Georgia Strait troll	199,396	201,940	2,544	1.3%
Lower Georgia Strait troll	158,234	186,092	27,858	15.0%
Areas 125-127 troll	161,601	118,964	-42,637	-35.8%
Areas 123-124 troll	257,250	232,549	-24,701	-10.6%
Total Canadian Commercial Catch	**9,115,405**	**10,034,967**	**919,562**	**9.2%**
United States				
Treaty Ceremonial fisheries	0	0	0	0.0%
Area 7A	1,392,461	1,392,452	-9	0.0%
Area 7	316,502	316,489	-13	0.0%
Areas 4B, 5 and 6C	120,190	119,424	-766	-0.6%
Alaska District 104 *	225,000	240,000	15,000	6.3%
Total U.S. Commercial Catch	**2,054,153**	**2,068,365**	**14,212**	**0.7%**
Total Catch **	**11,323,491**	**12,377,940**	**1,054,449**	**8.5%**

Notes:

* Alaska District 104 catch of Fraser sockeye is based on in-season stock identification.

** In addition to catches shown in table, total catch includes in-season non-commercial catch of 153,933 and post-season non-commercial catch 274,608.

Table 5. In-season and post-season estimates of catch and annual exploitation rate by stock and area, and total catch, gross escapement and total run by stock for Fraser sockeye in 1994.

		Early Stuart		Early Summers		Chilko/Quesnel		Stellako/L.Stuart		Adams/Shuswap		Misc. Late Runs		Totals	
		In	Post	In	Post	In	Post	In	Post	In	Post	In	Post	In	Post
Canadian Waters:															
Area 1-2W Net & Troll	Catch	0	0	3,203	15,700	141,958	212,580	28,151	29,207	609,376	553,382	50,896	95,345	833,584	906,214
	Expl. rate	0.0%	0.0%	0.3%	1.2%	2.4%	3.6%	2.6%	2.0%	9.1%	8.2%	6.4%	8.0%	5.3%	5.4%
Area 8-111 Net & Troll	Catch	0	0	9,240	9,306	199,403	192,588	31,964	55,085	681,617	640,897	92,447	145,013	1,014,671	1,042,889
	Expl. rate	0.0%	0.0%	0.7%	0.7%	3.3%	3.3%	2.9%	3.8%	10.2%	9.5%	11.5%	12.1%	6.5%	6.2%
Area 121-127 Troll	Catch	0	0	20,018	9,909	132,497	93,668	40,475	33,216	198,717	191,622	27,144	23,098	418,851	351,513
	Expl. rate	0.0%	0.0%	1.6%	0.8%	2.2%	1.6%	3.7%	2.3%	3.0%	2.9%	3.4%	1.9%	2.7%	2.1%
Area 11-16 Net	Catch	0	0	106,264	305,752	1,274,313	1,475,704	189,864	239,488	2,431,352	2,604,115	262,507	411,296	4,264,300	5,036,355
	Expl. rate	0.0%	0.0%	8.4%	24.1%	21.3%	25.0%	17.4%	16.5%	36.2%	38.8%	32.8%	34.4%	27.2%	30.1%
Area 11-16 Inside Troll	Catch	0	0	5,820	8,379	47,642	39,669	10,845	13,328	123,903	116,557	11,186	24,007	199,396	201,940
	Expl. rate	0.0%	0.0%	0.5%	0.7%	0.8%	0.7%	1.0%	0.9%	1.8%	1.7%	1.4%	2.0%	1.3%	1.2%
Area 17,18 & 29 Inside Troll	Catch	0	0	11,948	19,629	59,445	43,070	27,560	48,918	53,771	67,011	5,510	7,464	158,234	186,092
	Expl. rate	0.0%	0.0%	0.9%	1.5%	1.0%	0.7%	2.5%	3.4%	0.8%	1.0%	0.7%	0.6%	1.0%	1.1%
Area 29 Outside Troll	Catch	0	0	0	0	20,400	15,959	2,550	681	193,800	123,464	38,250	25,451	255,000	165,555
	Expl. rate	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%	0.2%	0.0%	2.9%	1.8%	4.8%	2.1%	1.6%	1.0%
Area 20 Net	Catch	0	0	48,788	106,698	332,431	431,800	50,516	99,600	227,776	185,155	21,742	23,233	681,253	846,486
	Expl. rate	0.0%	0.0%	3.8%	8.4%	5.6%	7.3%	4.6%	6.9%	3.4%	2.8%	2.7%	1.9%	4.3%	5.1%
Area 29 Net	Catch	0	0	113,062	144,204	916,395	782,886	139,320	195,654	92,066	111,897	29,273	63,282	1,290,116	1,297,923
	Expl. rate	0.0%	0.0%	8.9%	11.4%	15.3%	13.2%	12.7%	13.5%	1.4%	1.7%	3.7%	5.3%	8.2%	7.8%
Total (Canada)	**Catch**	**0**	**0**	**318,343**	**619,577**	**3,124,484**	**3,287,924**	**521,245**	**715,177**	**4,612,378**	**4,594,100**	**538,955**	**818,189**	**9,115,405**	**10,034,967**
	Expl. rate	**0.0%**	**0.0%**	**25.1%**	**48.9%**	**52.3%**	**55.6%**	**47.7%**	**49.4%**	**68.7%**	**68.4%**	**67.3%**	**68.4%**	**58.0%**	**59.9%**
U.S. Waters:															
Areas 4B, 5, 6C	Catch	441	441	20,452	23,174	62,519	63,759	15,799	17,446	20,109	12,017	870	2,587	120,190	119,424
	Expl. rate	0.2%	0.2%	1.6%	1.8%	1.0%	1.1%	1.4%	1.2%	0.3%	0.2%	0.1%	0.2%	0.8%	0.7%
Area 7 & 7A	Catch	0	0	71,057	91,621	498,036	491,507	86,911	99,210	965,477	915,234	87,482	111,369	1,708,963	1,708,941
	Expl. rate	0.0%	0.0%	5.6%	7.2%	8.3%	8.3%	7.9%	6.9%	14.4%	13.6%	10.9%	9.3%	10.9%	10.2%
Alaska District 104	Catch	0	0	0	0	62,000	66,000	14,000	15,000	122,000	130,000	27,000	29,000	225,000	240,000
	Expl. rate	0.0%	0.0%	0.0%	0.0%	1.0%	1.1%	1.3%	1.0%	1.8%	1.9%	3.4%	2.4%	1.4%	1.4%
Total (United States)	**Catch**	**441**	**441**	**91,509**	**114,795**	**622,555**	**621,266**	**116,710**	**131,656**	**1,107,586**	**1,057,251**	**115,352**	**142,956**	**2,054,153**	**2,068,365**
	Expl. rate	**0.2%**	**0.2%**	**7.2%**	**9.1%**	**10.4%**	**10.5%**	**10.7%**	**9.1%**	**16.5%**	**15.7%**	**14.4%**	**11.9%**	**13.1%**	**12.4%**
Total Non-Commercial Catch	Catch	3,087	3,087	9,329	18,923	46,805	75,133	11,858	16,756	71,165	136,459	11,689	24,250	153,933	274,608
	Expl. rate	1.5%	1.5%	0.7%	1.5%	0.8%	1.3%	1.1%	1.2%	1.1%	2.0%	1.5%	2.0%	1.0%	1.6%
Grand Total Catch	**Catch**	**3,528**	**3,528**	**419,181**	**753,295**	**3,793,844**	**3,984,323**	**649,813**	**863,589**	**5,791,129**	**5,787,810**	**665,996**	**985,395**	**11,323,491**	**12,377,940**
	Expl. rate	**1.7%**	**1.7%**	**33.1%**	**59.4%**	**63.5%**	**67.4%**	**59.4%**	**59.6%**	**86.3%**	**86.2%**	**83.2%**	**82.4%**	**72.1%**	**73.9%**
Gross Escapement (into river) (Mission Esc. + IF Catch below)		**187,862**	**198,202**	**515,704**	**514,767**	**2,179,822**	**1,928,975**	**443,465**	**584,211**	**919,632**	**927,138**	**134,926**	**210,896**	**4,381,411**	**4,364,189**
Total Run		**191,390**	**201,730**	**934,885**	**1,268,062**	**5,973,666**	**5,913,298**	**1,093,278**	**1,447,800**	**6,710,761**	**6,714,948**	**800,922**	**1,196,291**	**15,704,902**	**16,742,129**

Table 6. In-season and post-season estimates of catch and harvest rate in migratory and terminal areas for summer- and late-run stock groups, and gross escapement and total run by stock for Fraser sockeye in 1994.

	Summer Runs				Late Runs			
	Chilko/Quesnel		Stellako/L.Stuart		Adams/Shuswap		Misc. Late Runs	
	In-season	Post-season	In-season	Post-season	In-season	Post-season	In-season	Post-season
Total Run	**5,973,666**	**5,913,298**	**1,093,278**	**1,447,800**	**6,710,761**	**6,714,948**	**800,922**	**1,196,291**
Outside Area Catches								
Area 1-2W Net & Troll	141,958	212,580	28,151	29,207	609,376	553,382	50,896	95,345
Area 8-111 Net & Troll	199,403	192,588	31,964	55,085	681,617	640,897	92,447	145,013
Area 121-127 Troll	132,497	93,668	40,475	33,216	198,717	191,622	27,144	23,098
Alaska District 104:	62,000	66,000	14,000	15,000	122,000	130,000	27,000	29,000
Total Run Entering Inside Waters	**5,437,808**	**5,348,462**	**978,688**	**1,315,292**	**5,099,051**	**5,199,047**	**603,435**	**903,835**
Migratory Areas Catches: Canadian Waters								
Area 11-16 Net	1,274,313	1,475,704	189,864	239,488	2,431,352	2,604,115	262,507	411,296
Area 11-16 Inside Troll	47,642	39,669	10,845	13,328	123,903	116,557	11,186	24,007
Area 20 Net	332,431	431,800	50,516	99,600	227,776	185,155	21,742	23,233
Non-commercial Catch	38,860	58,953	10,163	14,710	62,244	50,973	10,415	8,643
U.S. Waters								
Areas 4B, 5, 6C	62,519	63,759	15,799	17,446	20,109	12,017	870	2,587
Areas 6,7, 7B	148,544	151,999	25,063	33,165	106,391	82,058	11,102	12,988
7A (migratory)	170,631	162,277	33,219	37,677	87,193	89,077	11,383	11,435
Total Migratory Area Catch	**2,074,940**	**2,384,161**	**335,469**	**455,414**	**3,058,968**	**3,139,952**	**329,205**	**494,189**
Migratory Area Harvest Rate	**38.2%**	**44.6%**	**34.3%**	**34.6%**	**60.0%**	**60.4%**	**54.6%**	**54.7%**
Total Run Entering Georgia Strait	**3,362,868**	**2,964,301**	**643,219**	**859,878**	**2,040,083**	**2,059,095**	**274,230**	**409,646**
Terminal Area Catches: Canadian Waters								
Area 17,18 & 29 Inside Troll	59,445	43,070	27,560	48,918	53,771	67,011	5,510	7,464
Area 29 Outside Troll	20,400	15,959	2,550	681	193,800	123,464	38,250	25,451
Area 29 Net	916,395	782,886	139,320	195,654	92,066	111,897	29,273	63,282
Sport, Area 29 IF and Testfishing	7,945	16,180	1,695	2,046	8,921	85,486	1,274	15,607
U.S. Waters								
7A (delay)	178,861	177,231	28,629	28,368	771,893	744,099	64,997	86,946
Total Terminal Area Catch	**1,183,046**	**1,035,326**	**199,754**	**275,667**	**1,120,451**	**1,131,957**	**139,304**	**198,750**
Terminal Area Harvest Rate	**35.2%**	**34.9%**	**31.1%**	**32.1%**	**54.9%**	**55.0%**	**50.8%**	**48.5%**
Gross Escapement (Mission Esc. + IF Catch below)	**2,179,822**	**1,928,975**	**443,465**	**584,211**	**919,632**	**927,138**	**134,926**	**210,896**

Appendix H: Johnstone Strait Catch Estimation

Paul Ryall[1]

The primary source of post-season salmon catch information within Canada is obtained from the DFO's sales slip database. However, the existing sales slip program was not designed to deal with the problem of obtaining catch information in the short time frame required for in-season fishery management. Consequently, an alternative catch data collection system is employed in-season. The program in 1994 was designed to survey landing information of the major fish buying companies in Johnstone Strait. Both purse seine and gillnet catches were estimated during the in-season management period. The description of the purse seine estimation program is outlined below.

Purse seine landing information was received from the fish buying companies via Fax machine two to three days following the close of each commercial fishery. Sales slips (DFO Catch Statistics Database) from the years 1987 through 1993 were used to identify the companies which have been the "major" buyers in past years. The companies identified as "major" buyers were contacted on a weekly basis in 1994. From each company contacted, information was obtained on the total landings for the week, in pounds, and the number purse seine vessels which delivered to the company. From these landing data, and the number of vessels which delivered fish to the company, the catch per purse seine vessel (CPUE) was calculated. Separate CPUE averages were estimated for statistical areas 12 and 13. A post-season evaluation was conducted, using the post-season sales slip landings, and it was determined that the in-season purse seine catch data obtained from the surveyed companies comprised approximately 70 to 90 percent of the total purse seine catch for a particular week.

To estimate the total purse seine catch for the fishery, the average CPUE was multiplied by the total effort count for the fishery. A weekly estimate of total effort was obtained from a DFO overflight of the purse seine and gillnet fishing area conducted on the morning that the purse seine fishery opened. The effort counts were tabulated separately for statistical areas 12 and 13, as were the CPUE data as outlined above, thereby allowing area specific catch estimates to be generated.

The estimation of the gillnet catch for Johnstone Strait was conducted in a similar fashion. Fish buying companies are surveyed to provide information on total landings and CPUE. As the gillnet fishery in 1994 extended over four to five days each week, with the exception of a one day fishery in the first week of fishing, additional fishing effort data were obtained from on-water gear counts. These on-water gear counts were provided by DFO patrol vessels and charter patrol vessels.

Accurate in-season catch estimates are a necessity to meet both stock assessment and allocation requirements. A comparison of the annual 1994 in-season catch estimates versus the 1994 post-season sales slip data is provided in Table 1. It is clear from the data that during the in-season management period, catches in Johnstone Strait were underestimated. The purse seine catch was underestimated by 12.1 percent, while the gillnet catch was underestimated by 26.0 percent.

There are two possible causes of the underestimation of weekly catch in 1994; either the number of vessels actively fishing during the opening was underestimated, or the average CPUE calculated from the company landing data was too low. Data are not available to allow for an assessment of which of

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these factors caused the gillnet catch to be underestimated. However, for the purse seine fleet, weekly effort and CPUE data are available.

The cumulative effect of these two sources of error are reflected in the discrepancies observed in the weekly comparisons of in-season versus post-season catch estimates (Table 2). In each week during the in-season management period, the purse seine catch was underestimated. The percentage difference between the in-season and post-season catch estimates range from 10.1 to 13.8 percent, with the largest catch week (W/E August 20) having the largest numerical and percentage discrepancy.

Consistent weekly trends are apparent in the effort and catch data (Table 2). DFO overflight data consistently underestimated purse seine effort, when in-season effort counts were compared to unique purse seine vessel landing data obtained from the sales slip database. The largest discrepancy occurred in the peak catch week of August 20, when the effort was underestimated by 9.4 percent, or 42 vessels. The lowest discrepancy was observed in the week-ending period September 3, when the in-season effort was underestimated by 4.2 percent, or 19 vessels. The company based average CPUE data were also chronic underestimates compared to the CPUE's calculated from the post-season database. The CPUE was underestimated by 4.3 to 6.2 percent during the course of the season, with the largest discrepancy occurring during the week-ending period August 27.

Analysis of the in-season data suggest that improvements could be made to the in-season catch estimation program. First, the number of pieces landed is estimated by dividing the total weight landed by an estimate of average sockeye weight. Consequently, the values used for average weight are very important. To obtain average estimates of sockeye weight that are within 0.1 pounds at a 95 percent confidence limit requires sampling about 400 sockeye for purse seine gear, and 300 for the gillnet gear. In some 1994 fisheries it appears that sample sizes for estimating average weights were too small. Second, comparisons between in-season overflight gear counts and post-season sales slip effort tallies show that in-season effort counts were underestimated. With respect to improving gear counts for future years, DFO is planning additional weekly overflights with two observers on-board the aircraft. Also, under consideration is the trial use of remote sensing equipment during night flights in order to improve gillnet gear counts.

Research is also needed to determine if factors other than incorrect average weights were involved in the in-season CPUE estimates being underestimated in 1994. For example, are individual companies underestimating their in-season landing poundage each week, relative to the poundage reported in the post-season sales slip database? What are the average CPUE 's for boats delivering to companies not being phoned in-season, relative to the CPUE's for the boats delivering to companies which are being phoned as part of the in-season catch estimation program? It is also recommended that research be conducted to determine if in-season CPUE's have been consistently underestimated in past years. If so, the reasons for the underestimates should be assessed.

Finally, additional steps which could be taken to improve the in-season catch estimation program include: an on-going verification of weekly catch estimates throughout the season, similar to the verification system currently in place in the Canadian troll fishery.

Table 1. Comparison of in-season and post-season estimates of catches of Fraser River sockeye salmon in commercial and non-commercial fisheries in 1994.

	Fraser Catch	
Catch Area	**In-season**	**Post-season**
Canada		
Areas 1-10 Purse Seine	519,000	428,000
Areas 1-10 Gillnet	1,000	7,000
Areas 1-10 Troll	821,000	710,000
Areas 12-16 Purse Seine	3,401,000	3,868,000
Areas 11-16 Gillnet	864,000	1,168,000
Areas 12-16 Inside Troll	200,000	202,000
Areas 11-13 Outside Troll	506,000	804,000
Areas 121-127 Outside Troll	419,000	352,000
Area 20 Purse Seine	420,000	462,000
Area 20 Gillnet	261,000	384,000
Areas 17-29 Inside Troll	158,000	186,000
Areas 18-29 Outside Troll	255,000	166,000
Area 29 Gillnet	1,290,000	1,298,000
Areas 12-16 Native Fishery	100,000	97,000
Area 29 Native Fishery		85,000
United States		
Areas 4B,5,6C Treaty Indian	120,000	119,000
Areas 6,7,7B Treaty Indian	181,000	181,000
Areas 6,7,7B Non-Indian	136,000	136,000
Area 7A Treaty Indian	655,000	651,000
Area 7A Non-Indian	737,000	741,000
Alaska District 104 *	225,000	240,000

* District 104 estimates are both based on in-season racial identification models.

Table 2. In-season and post-season estimates of catch and CPUE in purse seine and gillnet fisheries in Canadian Areas 11-13.

Area 12 & 13 Purse Seine Catch Estimates

W/E Date	In-Season Catch Est's	Post-Season Catch Est's	% Difference
06-Aug	0	0	0
13-Aug	785,000	880,000	10.8%
20-Aug	1,496,000	1,736,000	13.8%
27-Aug	932,000	1,049,000	11.2%
03-Sep	160,000	178,000	10.1%

Area 11 - 13 Gill Net Catch Estimates

W/E Date	In-Season Catch Est's	Post-Season Catch Est's	% Difference
06-Aug	83,000	83,000	0.0%
13-Aug	285,000	304,000	6.3%
20-Aug	200,000	357,000	44.0%
27-Aug	123,000	205,000	40.0%
03-Sep	79,000	92,000	14.1%

Area 12 & 13 Purse Seine Effort Estimates

W/E Date	In-Season Effort Est's	Post-Season Effort Est's	% Difference
06-Aug	0	0	0
13-Aug	300	322	6.8%
20-Aug	405	447	9.4%
27-Aug	451	476	5.3%
03-Sep	429	448	4.2%

Area 12 & 13 Purse Seine CPE Estimates

W/E Date	In-Season CPE Est's	Post-Season CPE Est's	% Difference
06-Aug	0	0	0
13-Aug	2,617	2,733	4.3%
20-Aug	3,694	3,884	4.9%
27-Aug	2,067	2,204	6.2%
03-Sep	373	397	6.1%

Appendix I: Log Transformation of Effort and Duration in Commercial Purse Seine Models

Objective

To determine whether the independent variables representing fishing effort (daily gear count and fishery duration) should be transformed to their natural logarithms when generating the regression models and estimating run sizes.

Introduction

The practice of using catch and effort data to estimate run size is based on the first equation below, which can be algebraically transformed into the subsequent equations:

$$C_t = q\, f_t^{\alpha}\, N_t^{\beta}$$

$$C_t = q\, (E_t D_t)^{\alpha}\, N_t^{\beta}$$

$$\ln C_t = \ln q + \alpha \ln (E_t D_t) + \beta \ln N_t$$

$$\ln C_t = \ln q + \alpha \ln E_t + \alpha \ln D_t + \beta \ln N_t$$

$$\beta \ln N_t = \ln q + \ln C_t + \alpha \ln E_t + \alpha \ln D_t$$

$$\ln N_t = \frac{\ln q + \ln C_t + \alpha \ln E_t + \alpha \ln D_t}{\beta}$$

where C_t = total catch during time interval t (i.e., total catch during the peak fishery),
q = catchability (i.e., fraction of the population taken by 1 unit of fishing effort),
f_t = total fishing effort during time interval t (i.e., total boat days for a fishery),
N_t = population abundance (i.e., run size),
E_t = average daily effort (i.e., average number of boats fishing per day), and
D_t = duration of fishery (i.e., number of days fishery was open).

The regression model that corresponds to the above is:

$$N = \exp\,[a + b_1(\ln C) + b_2(\ln E) + b_3(\ln D)]$$

Thus, from a theoretical point of view the independent variables used in the regression models should be the natural log transformed values for catch, effort and duration. However, to date, the practice has been to transform catch, but not effort and duration. The impact of this potential oversight on the estimates is investigated below.

Methods

To compare the models that would result from inclusion of the transformed versus the untransformed effort and duration, a jackknife procedure was performed. For each area and stock, each year was sequentially removed from the dataset and the parameters for the full regression model were estimated, which were then used to estimate the run size for the year that was removed. The result was a vector of run size estimates with an entry for each area, stock and year. This process was performed for both models being evaluated:

$$N = \exp\left[a + b_1(\ln C) + b_2 E + b_3 D)\right]$$ **Model 1**

versus

$$N = \exp\left[a + b_1(\ln C) + b_2(\ln E) + b_3(\ln D)\right]$$ **Model 2**

The performance of these alternative models was assessed using four indicators: 1) untransformed residuals, 2) absolute untransformed residuals, 3) percentage of years that estimates that were larger than actual run sizes, and 4) coefficient of determination R^2. Because R^2 values from ln:ln regressions may be misleading, I calculated the R^2 of the untransformed actual and predicted run sizes, as follows:

$$R^2 = \frac{SS_{regression}}{SS_{total}} = \frac{SS_{total} - SS_{residual}}{SS_{total}}$$

$$= \frac{\Sigma Y_i^2 - \Sigma(Y_i - \hat{Y}_i)^2}{\Sigma Y_i^2}$$

where Y_i = observed run size in year i, and
$\hat{Y}_i$ = predicted run size in year i.

In addition, in-season and post-season catch data were used with Model 1 and 2 to generate escapement estimates for 1994 that were compared against each other and post-season estimates.

Results

The results of comparing the performance of the two models using jackknife techniques are summarized in Figure 1. Figure 1a shows that the R^2 values of Models 1 and 2 are similar in most cases. However, the R^2 values for Model 2 are notably higher for Late Stuart sockeye in Juan de Fuca Strait (JdF) and Quesnel sockeye in Johnstone Straits (JS). Figure 1b shows that both models tend to overestimate run size through JdF and underestimate run size through JS, although the magnitude of the biases are small compared to the mean run sizes shown in Figure 1c. Figure 1c shows that the absolute mean residual is proportional to the mean run size, and that differences between the two models are generally small. The largest difference is for the Quesnel run through JS, where Model 2 achieved an absolute mean residual about 200,000 less than Model 1. Both models tended to underestimate run size more often than they overestimate (Figure 1d), however, the majority of models were within 10% of the 50% point (i.e., number of overestimates = number of underestimates). The largest differences between the two models were for Adams and Late Stuart sockeye in JS.

For comparison, the relative performance of the two models when the full dataset was used are shown in Figure 2. Generally, use of the full dataset resulted in higher R^2 values, smaller mean residuals and mean absolute residuals, and no change to the percentage of years when run sizes were overestimated.

Table 1 shows the estimates for 1994 using Model 1 and 2, adjusted and unadjusted catches and in-season and post-season data. Table 2 shows the differences between the various estimates of gross escapement and the hydroacoustic estimates (Mission hydroacoustic plus Native catch below Mission). Model 1 is the same as the model evaluated in the last section, so Model 1 results for in:in and post:post scenarios appear on Tables 3 and 4 in Appendix C and in Tables 1 and 2 in this Appendix.

Compared to the estimates from Model 1, the estimates from Model 2 are much closer to the hydroacoustic estimates for all scenarios of summer and late runs, but deviates more for post-season estimates of early summer runs. The effect on the total deviation is to reduce the difference substantially. The catch adjustments to compensate for northern removals had a small effect on the early summer and summer-run estimates, but reduced the difference for late runs by about 480,000 using the in-season data, and 230,000 using the post-season data. The affect of in-season versus post-season data was to substantially reduce the differences for summer runs, but to have only a relatively small affect on late-run estimates.

Conclusions

Although differences between the performance of models that used untransformed (Model 1) versus transformed (Model 2) effort and duration were generally small (Figure 1), the notable exceptions (Late Stuart in JdF and Quesnel in JS) suggest that the latter models are more robust. Table 2 shows that Model 2 provided more accurate estimates in 1994, although this support must be tempered by the recognition that patterns observed in 1994 cannot be assumed to recur in other years.

In spite of the smaller differences that would have occurred had Model 2 been used in 1994, late-run escapement would still have been overestimated in 1994. However, the size of the discrepancy would be almost half (990,000) of the observed (1,820,000) difference if adjusted catches were used, as they were in-season. In-season use of adjusted catches and Model 2 would have resulted in differences that would have been slightly greater for early summer runs, and about 50% smaller for summer runs and the total run.

Based on the above results, I tentatively recommend using Model 2 (i.e., ln catch, ln effort and ln duration) in the future. This recommendation should be reviewed when the 1994 data point is included in the regression dataset, because of the very important role that 1994 has in substantially extending the range of the dataset.

Table 1. Comparison of estimates of run size and escapement using Models 1 and 2, adjusted versus unadjusted catches, and in-season versus post-season catch and racial estimates.

Run	Run Size Excluding WCVI Catch	Areas 1-11 Catch	JdF + JS Run Size	Inside Catch *	Strait of Georgia Esc.	Terminal Area Catch **	Available Gross Esc.	Actual Gross Esc. ***	Difference
Model 1 and Adjusted Catch Data									
In-season Catch and Racial Data									
E.Summ	709,000	12,000	697,000	241,000	456,000	146,000	310,000	516,000	(206,000)
Summer	5,888,000	401,000	5,487,000	2,409,000	3,078,000	1,383,000	1,695,000	2,623,000	(928,000)
Late	8,961,000	1,434,000	7,527,000	3,388,000	4,139,000	1,260,000	2,879,000	1,055,000	1,824,000
Total	15,558,000	1,847,000	13,711,000	6,038,000	7,673,000	2,789,000	4,884,000	4,194,000	690,000
Post-season Catch and Post-season Racial Data									
E.Summ	1,135,000	25,000	1,110,000	533,000	577,000	185,000	392,000	515,000	(123,000)
Summer	6,727,000	489,000	6,238,000	2,838,000	3,400,000	1,311,000	2,089,000	2,513,000	(424,000)
Late	9,508,000	1,435,000	8,073,000	3,634,000	4,439,000	1,331,000	3,108,000	1,138,000	1,970,000
Total	17,370,000	1,949,000	15,421,000	7,005,000	8,416,000	2,827,000	5,589,000	4,166,000	1,423,000
Model 1 and Unadjusted Catch Data									
In-season Catch and Racial Data									
E.Summ			709,000	241,000	468,000	146,000	322,000	516,000	(194,000)
Summer			5,563,000	2,409,000	3,154,000	1,383,000	1,771,000	2,623,000	(852,000)
Late			7,829,000	3,388,000	4,441,000	1,260,000	3,181,000	1,055,000	2,126,000
Total			14,101,000	6,038,000	8,063,000	2,789,000	5,274,000	4,194,000	1,080,000
Post-season Catch and Post-season Racial Data									
E.Summ			1,135,000	533,000	602,000	185,000	417,000	515,000	(98,000)
Summer			6,387,000	2,838,000	3,549,000	1,311,000	2,238,000	2,513,000	(275,000)
Late			8,025,000	3,634,000	4,391,000	1,331,000	3,060,000	1,138,000	1,922,000
Total			15,547,000	7,005,000	8,542,000	2,827,000	5,715,000	4,166,000	1,549,000
Model 2 and Adjusted Catch Data									
In-season Catch and Racial Data									
E.Summ	715,000	12,000	703,000	241,000	462,000	146,000	316,000	516,000	(200,000)
Summer	6,412,000	401,000	6,011,000	2,409,000	3,602,000	1,383,000	2,219,000	2,623,000	(404,000)
Late	8,124,000	1,434,000	6,690,000	3,388,000	3,302,000	1,260,000	2,042,000	1,055,000	987,000
Total	15,251,000	1,847,000	13,404,000	6,038,000	7,366,000	2,789,000	4,577,000	4,194,000	383,000
Post-season Catch and Post-season Racial Data									
E.Summ	956,000	25,000	931,000	533,000	398,000	185,000	213,000	515,000	(302,000)
Summer	7,213,000	489,000	6,724,000	2,838,000	3,886,000	1,311,000	2,575,000	2,513,000	62,000
Late	8,459,000	1,435,000	7,024,000	3,634,000	3,390,000	1,331,000	2,059,000	1,138,000	921,000
Total	16,628,000	1,949,000	14,679,000	7,005,000	7,674,000	2,827,000	4,847,000	4,166,000	681,000
Model 2 and Unadjusted Catch Data									
In-season Catch and Racial Data									
E.Summ			715,000	241,000	474,000	146,000	328,000	516,000	(188,000)
Summer			6,019,000	2,409,000	3,610,000	1,383,000	2,227,000	2,623,000	(396,000)
Late			7,174,000	3,388,000	3,786,000	1,260,000	2,526,000	1,055,000	1,471,000
Total			13,908,000	6,038,000	7,870,000	2,789,000	5,081,000	4,194,000	887,000
Post-season Catch and Post-season Racial Data									
E.Summ			956,000	533,000	423,000	185,000	238,000	515,000	(277,000)
Summer			6,823,000	2,838,000	3,985,000	1,311,000	2,674,000	2,513,000	161,000
Late			7,257,000	3,634,000	3,623,000	1,331,000	2,292,000	1,138,000	1,154,000
Total			15,036,000	7,005,000	8,031,000	2,827,000	5,204,000	4,166,000	1,038,000

* Catches in Canadian Areas 12-16, 18-20, and U.S. Areas 4B, 5, 6C, 6, and 7, and portion of the catch in Area 7A.

** Catches in Canadian Areas 17 and 29, but excluding IF catch below Mission.

*** Mission hydroacoustic estimate of escapement plus IF catch below Mission.

Table 2. Differences between estimated and actual gross escapements (Mission escapement + Native catch below Mission) by run, for Model 1 versus Model 2, adjusted versus unadjusted catches, and in-season versus post-season catch and racial estimates.

	Model 1			**Model 2**		
		Catch Adjustments			**Catch Adjustments**	
	Data	Adjusted	Unadjusted	**Data**	Adjusted	Unadjusted
Early Summer	In-seas	(206,000)	(194,000)	In-seas	(200,000)	(188,000)
	Post-seas	(123,000)	(98,000)	Post-seas	(302,000)	(277,000)
		Catch Adjustments			**Catch Adjustments**	
	Data	Adjusted	Unadjusted	**Data**	Adjusted	Unadjusted
Summer	In-seas	(928,000)	(852,000)	In-seas	(404,000)	(396,000)
	Post-seas	(424,000)	(275,000)	Post-seas	62,000	161,000
		Catch Adjustments			**Catch Adjustments**	
	Data	Adjusted	Unadjusted	**Data**	Adjusted	Unadjusted
Late	In-seas	1,824,000	2,126,000	In-seas	987,000	1,471,000
	Post-seas	1,970,000	1,922,000	Post-seas	921,000	1,154,000
		Catch Adjustments			**Catch Adjustments**	
	Data	Adjusted	Unadjusted	**Data**	Adjusted	Unadjusted
Total	In-seas	690,000	1,080,000	In-seas	383,000	887,000
	Post-seas	1,423,000	1,549,000	Post-seas	681,000	1,038,000

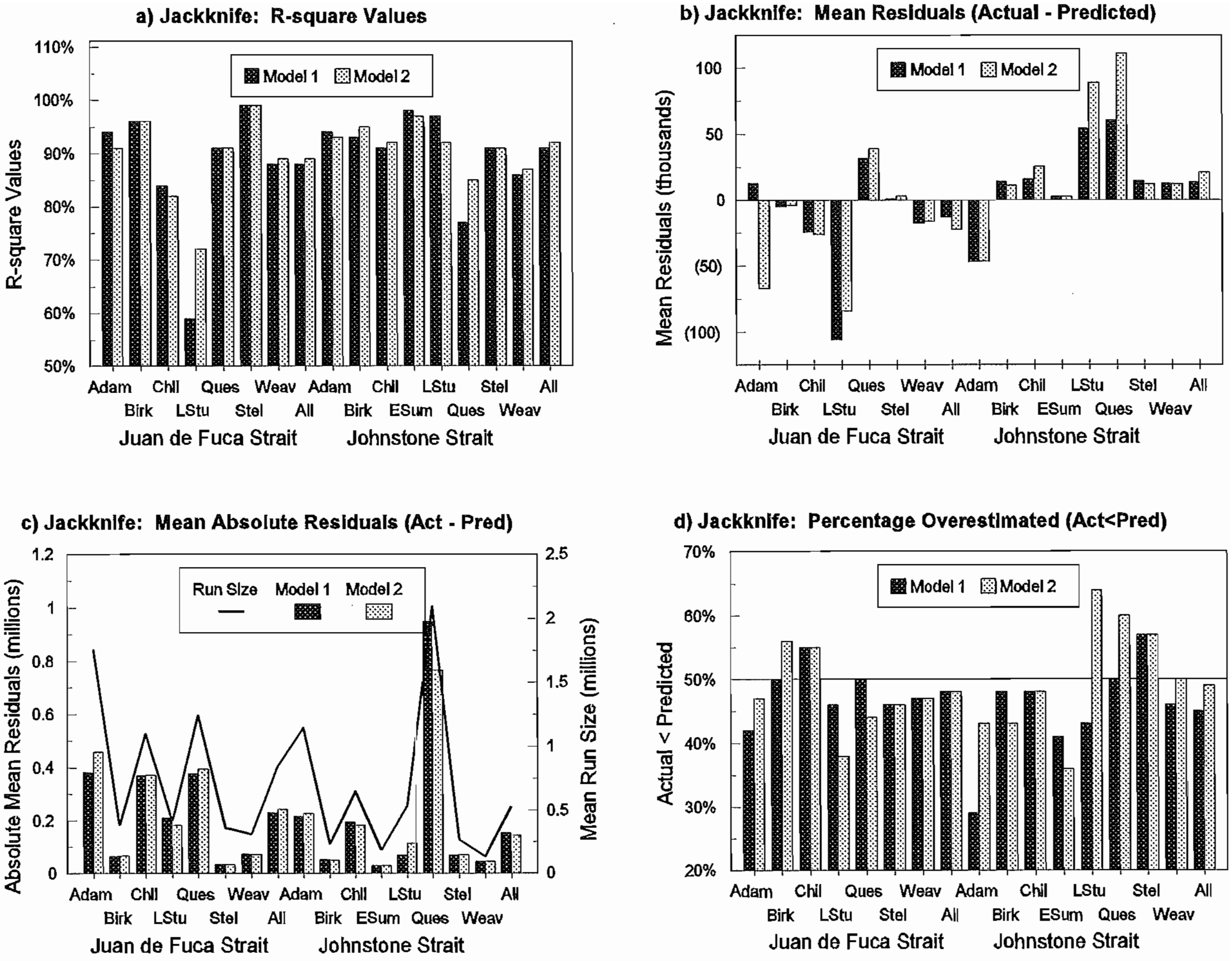
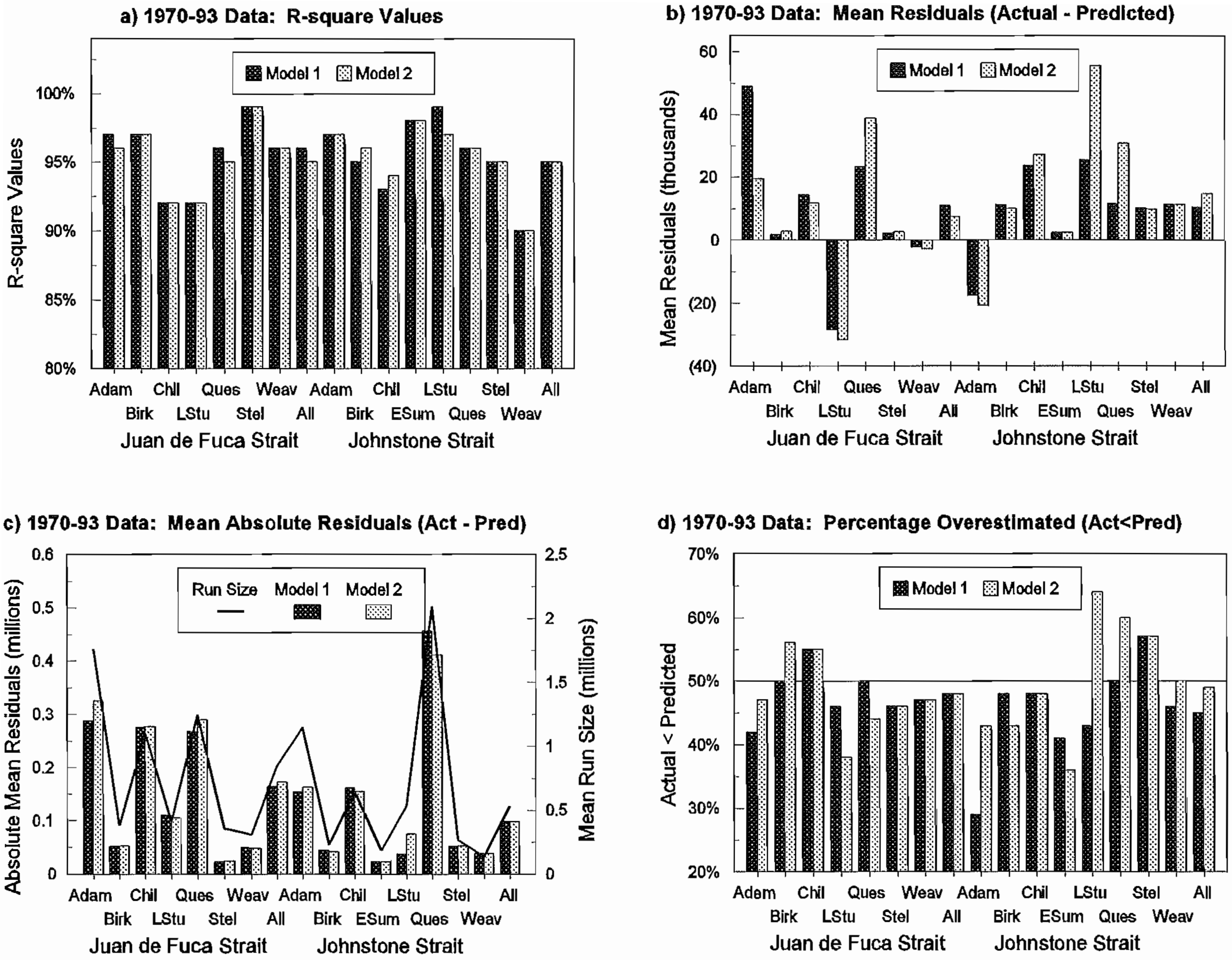


Figure 1. Results of jackknife analyses showing performance comparisons of Model 1 versus Model 2: a) R^2, b) mean residuals (actual - predicted run size), c) absolute mean residuals (actual - predicted run size), and d) percentage of years when the prediction was an overestimate (i.e., actual > predicted).



a) 1970-93 Data: R-square Values

b) 1970-93 Data: Mean Residuals (Actual - Predicted)

c) 1970-93 Data: Mean Absolute Residuals (Act - Pred)

d) 1970-93 Data: Percentage Overestimated (Act<Pred)

Figure 2. Results of analyses using complete 1970-93 dataset, showing performance comparisons of Model 1 versus Model 2: a) R^2, b) mean residuals (actual - predicted run size), c) absolute mean residuals (actual - predicted run size), and d) percentage of years when the prediction was an overestimate (i.e., actual > predicted).

Appendix J: Compare Catch-based and CPUE-based Commercial Purse Seine Models

Objective

In the context of the suggestion by Dr. Walters that CPUE (Catch Per Unit Effort) models should not be used for estimating run size, compare catch- and CPUE-based regression models.

Introduction

In Appendix I, we showed how effort and duration should be transformed into their natural logarithms. Thus, the catch- and CPUE-based regression models should be:

$$N = \exp[a + b_1(\ln C) + b_2(\ln E) + b_3(\ln D)] \qquad \textbf{Model 1}$$

and

$$N = \exp[a + b_1(\ln C_e) + b_2(\ln E) + b_3(\ln D)] \qquad \textbf{Model 2}$$

where N = run size,
C = average daily catch for the peak fishery,
C_e = average daily CPUE for the peak fishery (i.e., C/E),
E = average daily effort (i.e., average number of boats fishing per day), and
D = duration of fishery (i.e., number of days fishery was open).
The performance of these models are compared below.

Methods

Similar to Appendix I, regressions were performed using a jackknife technique and using the complete 1970-93 dataset. In addition, post-season catch data were used to generate estimates for 1994 that were compared against each other and post-season accounted run sizes.

Results

The estimates, residuals and R^2 values from Model 1 and 2 are identical.

The estimates for 1994 are the same as Model 2 results in Appendix I ("Log Transformation of Effort and Duration").

Conclusions

Models 1 and 2 are essentially different faces of the same model and provide the same estimates from the same data. Therefore, it is necessary to use only one of them in the future.

Appendix K: Time Trends in Fishery Data for Commercial Purse Seine Models

Objective

A potential weakness of run size models based on catch and CPUE data is that year-to-year increases in the ability if fishing vessels to catch fish (catchability) may be unrecognized and unaccounted for in the models. This is less of a problem for species such as salmon, because the ability to compare estimates from run size models with reasonably accurate catch and escapement estimates provide annual feedback on how well the models are performing. However, in the case of purse seine models used to estimate the run size of returning Fraser River stocks, on-going changes in the characteristics of both fisheries and fish behaviour have raised the concern that time trends in the easily measured data (catch, effort, duration) may be obscuring changes in less easily measured data such as catchability. Such undetected changes can compromise the ability of the models to accurately estimate run size. The objective of this section is to perform exploratory analyses of trends in fishery data, diversion rate and run size to evaluate the likelihood of such unaccounted-for changes to the predictive relationships.

Methods

The analysis consists of the following data plots:

1. Run size, average daily catch, average daily CPUE, average daily effort, and fishery duration plotted against year, for JdF and JS separately (Figure 1 and 2). For these plots, the regression dataset containing peak-week catch data was condensed by fishery. Therefore, for run size, catch and CPUE, each data point represents the total for all the stocks whose peak-weak catch occurred during the fishery. To be consistent with the correct formulation of the model discussed in Appendix I, a natural log transformation was applied to each plotted variable.
2. Combined JdF and JS run size (all stocks combined) and JS diversion rate plotted against year, showing trend line (Figure 3).

Results

Figure 1 shows that purse seine fisheries in JS between 1970-94 experienced significant evolution in the number of fish available to catch (increasing run size), the average daily catch (increasing), the average daily CPUE (increasing), the number of vessels fishing (increasing effort) and the duration of fisheries (decreasing). The situation was substantially different in JdF (Figure 2), with no significant discernable trends in any of the plotted variables except a possible slight decreasing trend for CPUE and slight increasing trend for effort.

Figure 3 presents the relationship between total run size, diversion rate and time, showing strong positive trends in total run size (combined JS + JdF) and JS diversion rate for summer- and late-run stocks since 1970. Thus, an increasing number of Fraser River sockeye were returning and an increasing proportion of these were migrating through JS.

Conclusions

Increasing run strengths combined with increasing diversion rates (Figure 3) explain the observation that JS runs were increasing while JdF runs experienced no such trend (Figures 1 and 2). The increasing effort can reflect the response of fishermen to the larger availability of fish in JS, but may also be a consequence of increases in the coastwide number of purse seines fishing for sockeye or of changes in fishing regulations, such as how openings in various fisheries are staggered. The increasing catch and CPUE likely reflect an interaction between the larger number of fish available and the larger number of vessels attempting to catch the fish. The decreasing trend in fishery duration is due entirely to changes in regulations.

The trends noted above may provide evidence of increasing harvest rates in JS. Simply put, the higher slope of the average daily catch line compared to the run size line in Figure 1 suggests that each day of fishing in JS harvests an increasing proportion of the JS run over time. Alternatively, part or all of this difference may be due to the combined effect of shorter fishery openings and the tendency for shorter fisheries to have higher average daily catches because more fish are available in the first day compared to succeeding days. However, it is also likely that the increasing harvest rate is partially due to the increasing effort. Another possible cause of the apparent increase in harvest rate includes trends in variables that are not easily assessed, such as changes in gear efficiency, which presumably must be increasing due to technological advances, improvements in fishing strategies and other factors. Such effects would be included in the increasing trend displayed by average daily CPUE, but would not be discernable from the effects of increasing availability of fish, increasing number of vessels fishing and decreasing duration. There is no evidence of increasing harvest rates in JdF in the above data. Although a direct link between harvest rate and catchability cannot be shown here, one interpretation of the above data is that catchability may have increased in JS, but not in JdF.

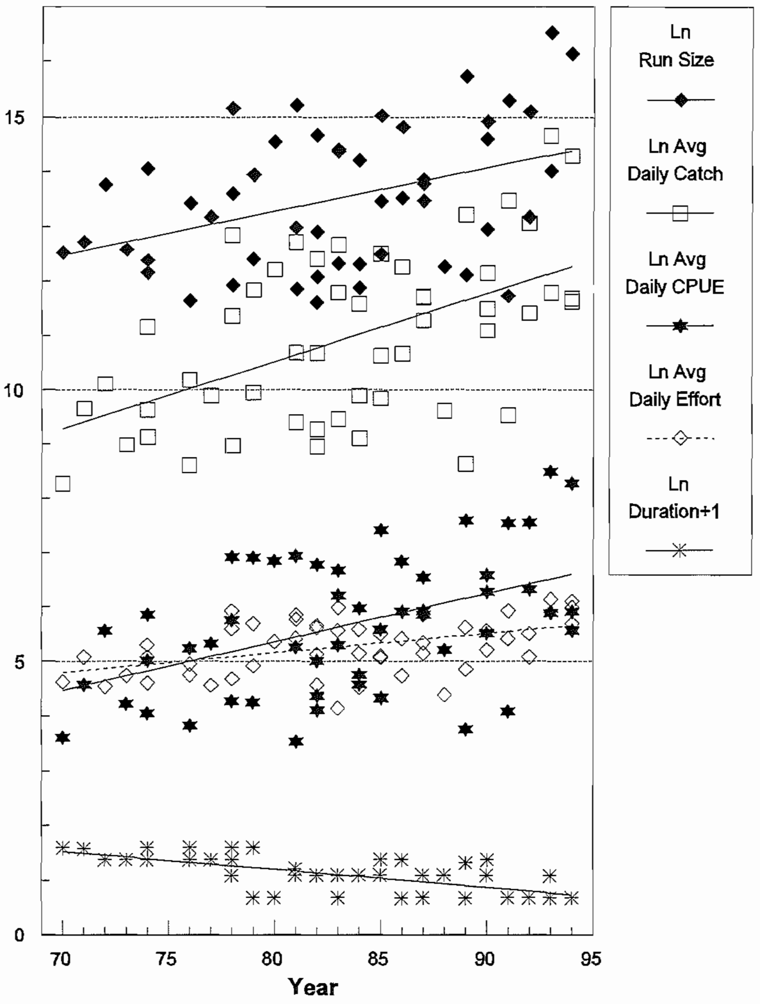


Figure 1. Run size, average daily catch, average daily CPUE, average daily effort and fishery duration versus year for purse seine fisheries in Johnstone Strait between 1970-94. The data are from the regression dataset, and so represent only peak-week fisheries for summer- and late-run stocks.

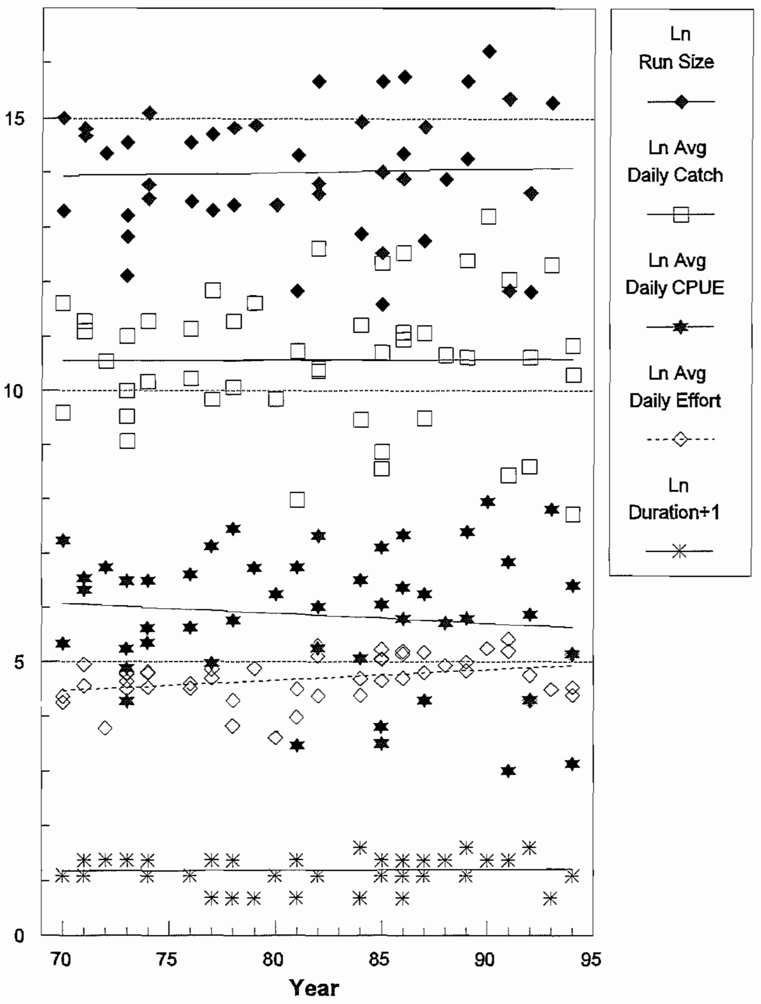


Figure 2. Run size, average daily catch, average daily CPUE, average daily effort and fishery duration versus year for purse seine fisheries in Juan de Fuca Strait between 1970-94. The data are from the regression dataset, and so represent only peak-week fisheries for summer- and late-run stocks.

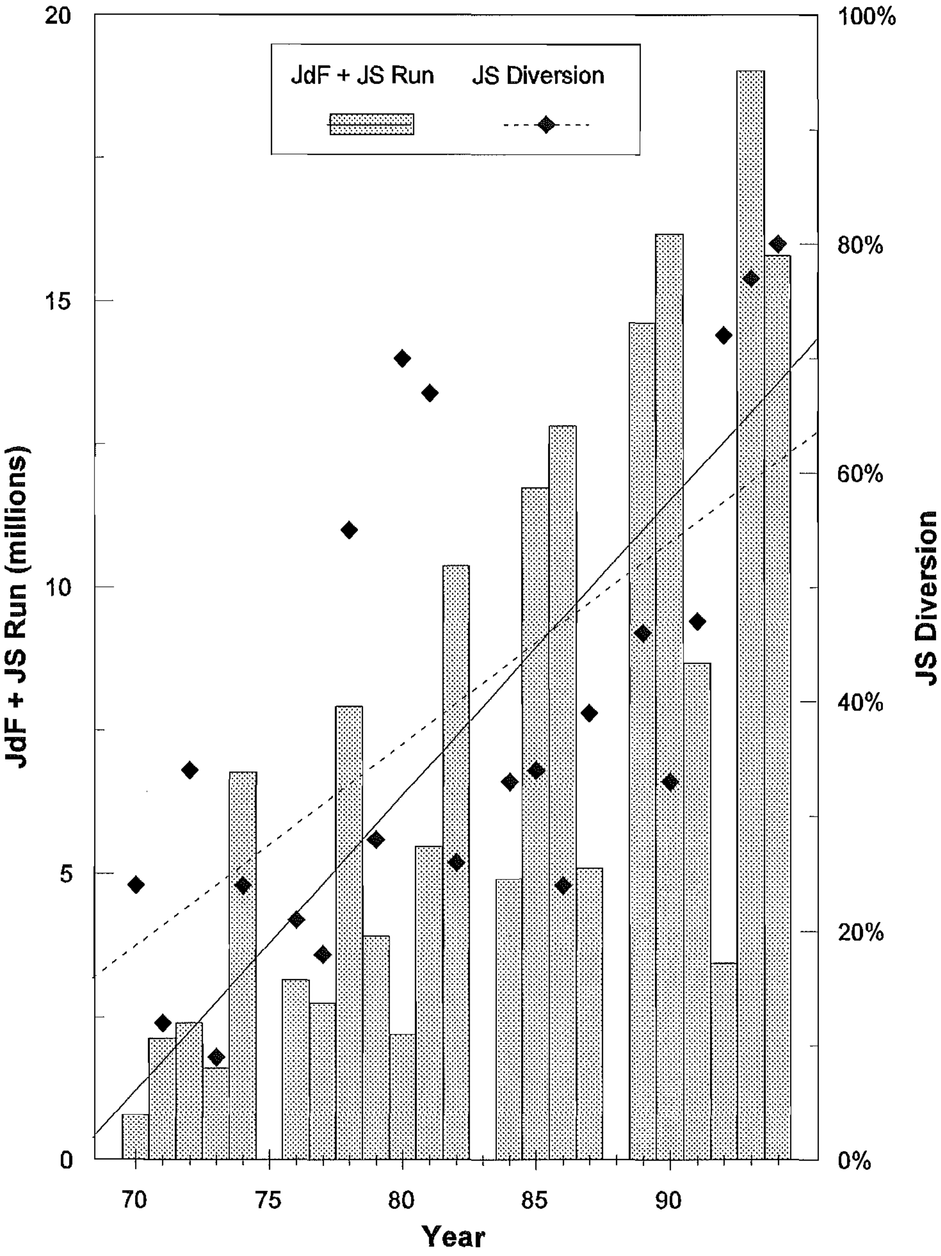


Figure 3. Total combined run (Johnstone Strait + Juan de Fuca Straits) and diversion rate versus year for summer- and late-run stocks between 1970-94, showing the trend line (linear regression) for each.

Appendix L: Time Trends in Residuals of Commercial Purse Seine Regressions

Objective

Another method of assessing whether time trends in fisheries or fish behaviour have affected model performance is to plot residuals from the regressions against year. If such trends have occurred, then the residuals will not show a normal scatter around the zero residual line.

Methods

Regressions were performed for each area and stock group using the model:

$$N = \exp[a + b_1(\ln C) + b_2(\ln E) + b_3(\ln D)]$$

Residuals (observed - predicted run size) were calculated two ways: 1) using the log transformed residuals as output from the regression package, and 2) using the untransformed observed and predicted run sizes to calculate the residuals. The residuals were then plotted against year.

Results

Figures 1 and 2 show the residual plots for JS and JdF, respectively. The left-hand plots show the residuals taken directly from the regression package, and so are measured in terms of the difference between the log-transformed actual run size minus the predicted run size. The right-hand plots, show residuals in terms of untransformed values. These plots show that for most stocks there is no compelling evidence of time trends in the residuals for JS (Figure 1) and JdF (Figure 2). However, there are two aspects of these plots that require further discussion.

First, the 1993 data points for stocks (Late Stuart, Quesnel, Stellako, Birkenhead, Weaver) in JS (Figure 1) are consistent in being well above the zero residual line, showing that actual JS run sizes in 1993 were considerable higher than historical relationships between purse seine catch and run size would suggest. This result could stem from natural variability in the relationship, but could also be due to unusual circumstances in 1993 that resulted in a lower-than-usual harvest rate.

Second, the residuals for Late Stuart and Adams runs through JS may show evidence of a different relationship since about 1977. In these plots the post-1977 residuals appear to have an upward time trend. However, the other stocks do not show this trend and the trend is much less evident in the plots of the untransformed residuals (right-hand plots) than in the plots of the transformed residuals (left-hand plots).

The above patterns are not evident in the JdF plots.

Conclusions

The observation that the runs of some stocks through JS in 1993 would have been underestimated by an unusually large amount could be interpreted as evidence that the relationship between catch and run size may have changed suddenly. However, the fact that run sizes in 1994 were estimated fairly accurately for summer-runs and overestimated by a large amount for late-runs conflict with this conclusion. A more likely explanation may be that we are simply seeing larger-than-usual random error in 1993 and 1994. This could simply be an outcome of the larger numerical error that is associated with estimates of large runs and of estimating run sizes that were well in excess of previous record runs though JS. These runs are pushing the relationships into new ranges, which is an essential part of improving the model for future years, but means the benefits of these large runs must be paid for by temporarily larger errors in run size estimation.

The possible time trends in the Late Stuart and Adams residuals for JS are difficult to interpret. For the Late Stuart run, this is because there are too few data points to draw firm conclusions. For the Adams run, most of the apparent time trend disappears when the untransformed residual plot is considered. Inclusion of the 1994 data in the analysis would discount the apparent time trends, since the events in 1994 directly contradict what would be expected if the trends were real. Namely, instead of underestimating run sizes in 1994, the summer-runs were fairly accurately estimated and the Adams run was considerably overestimated.

There is no evidence of time trends in the JdF relationships.

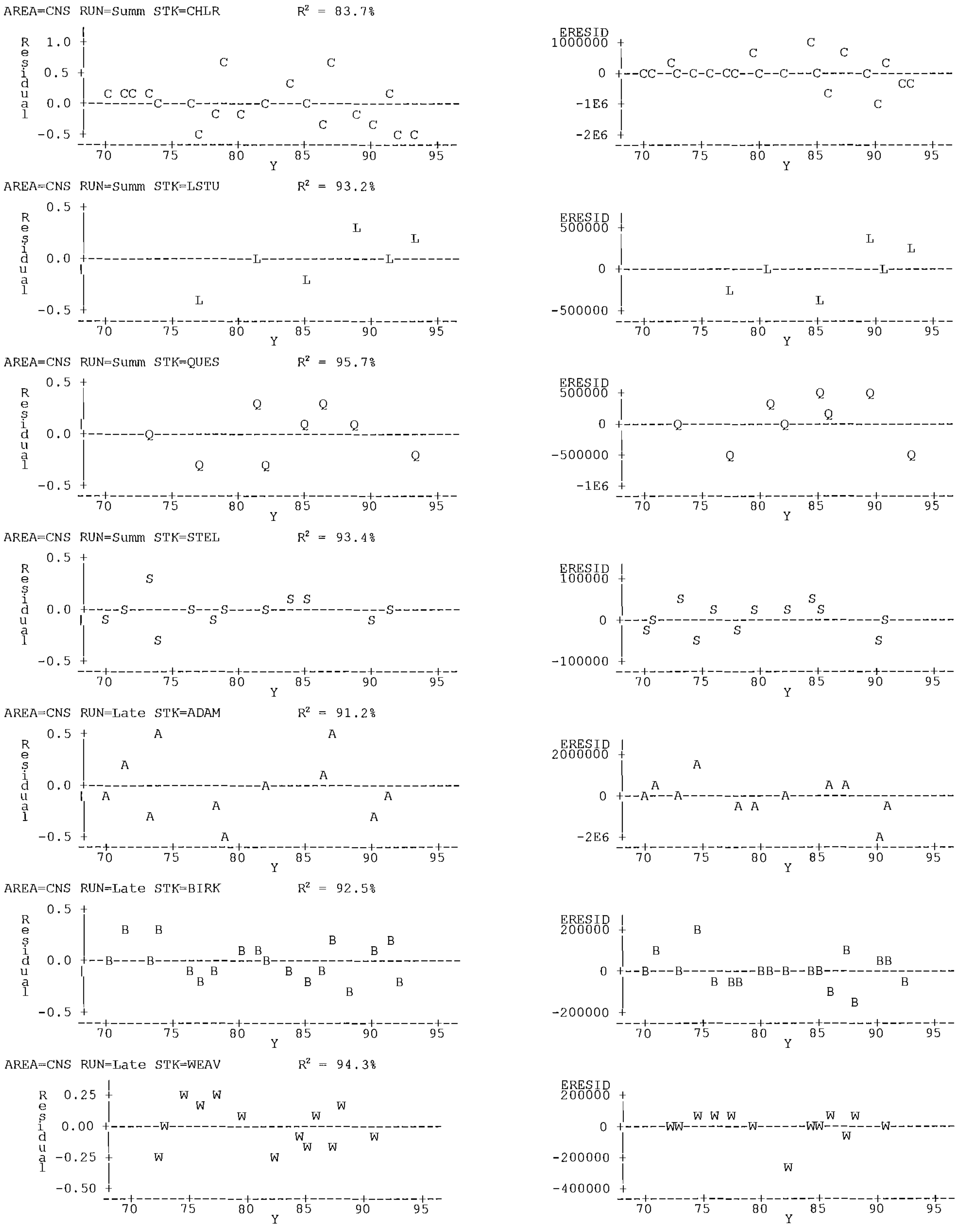


Figure 1. Residuals (actual - predicted) from run size regressions for JdF . The left-hand plots show residuals calculated using log-transformed actual and predicted run sizes, compared to residuals calculated using untransformed values.

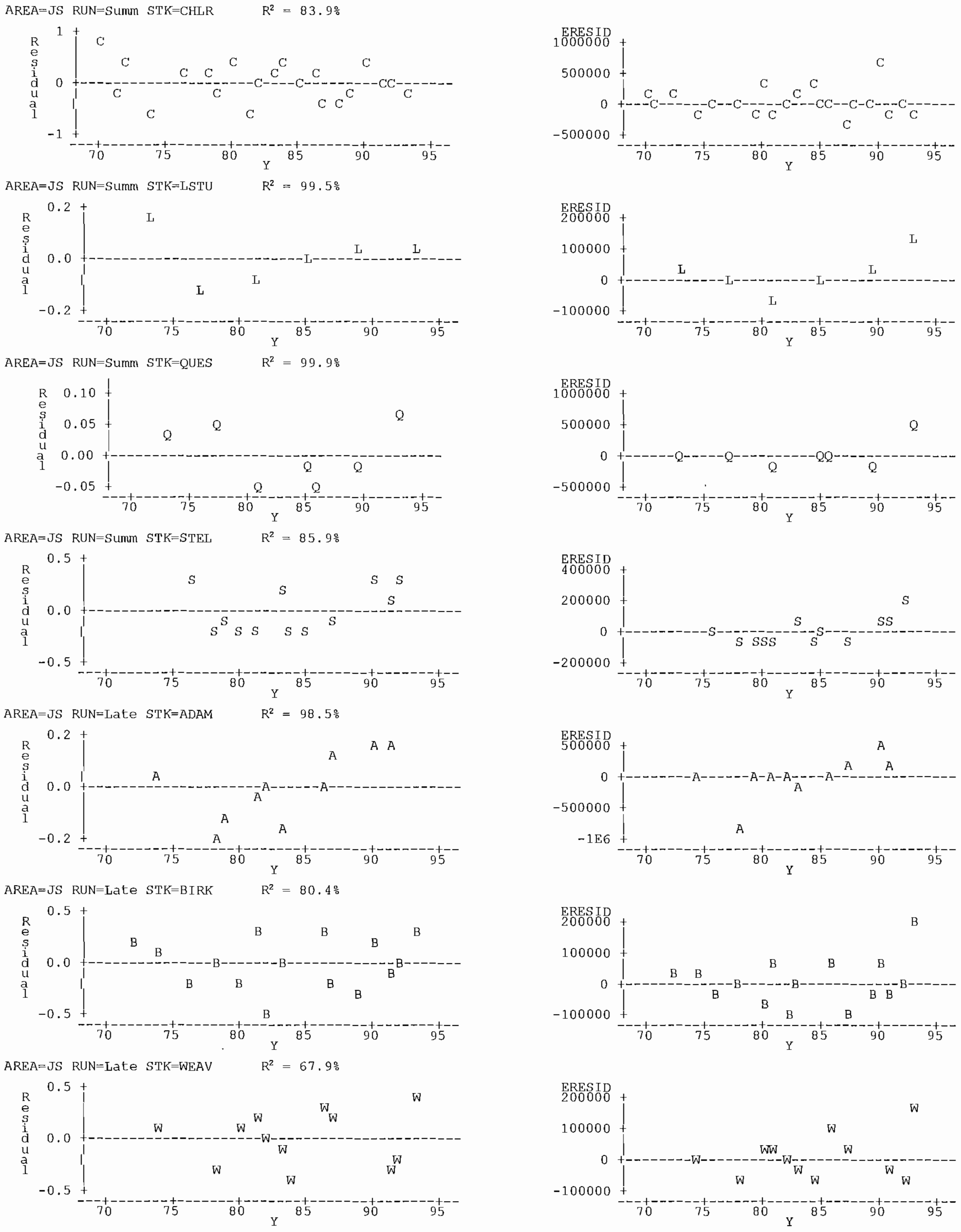


Figure 2. Residuals (actual - predicted) from run size regressions for JS. The left-hand plots show residuals calculated using log-transformed actual and predicted run sizes, compared to residuals calculated using untransformed values.

Appendix M: Effect of Potential Bias in Diversion Rate Estimates on Run Size Estimates from Commercial Purse Seine Models

Objective

Dr. Walters suggested that historical JS diversion rates may be systematically overestimated. If this were true, then the true JS runs would be lower than estimated. Such a bias would cause the run size models to overestimate JS runs and underestimate JdF runs. The effect of this potential biases on the estimates from the JS and JdF run size models are assessed further in this section.

Methods

A sensitivity analysis was performed in which diversion rate biases were varied from -30% to +30% in 10% increments. In the analysis, the "true" diversion rate was calculated:

$$D_t = D_e\,(1 - B)$$

where D_t = "true" JS diversion rate,
D_e = estimated JS diversion rate, and
B = bias.

The corresponding calculation of numerical bias was $R_{JS}B$, and the "true" JS and JdF runs were calculated:

$$R_{JSt} = R_{JSe} - (R_{JSe}B)$$

and

$$R_{JFt} = R_{JFe} - (R_{JSe}B)$$

where R_{JSt} = "true" JS run size,
R_{JSe} = estimated JS run size,
R_{JFt} = "true" JdF run size, and
R_{JFe} = estimated JdF run size.

For example, if the estimated JS diversion rate was 70% and the bias was +10%, then the true diversion rate would be 63%. Further, if the JS and JdF runs were 700,000 and 300,000, respectively, then the numerical bias would be 70,000, the "true" JS run would be 630,000 and the JdF run 370,000.

For each iteration, the ambient bias value was used to recalculate JS and JdF run sizes for all years in the regression dataset, which was then used to re-generate regression parameters using the model:

$$N = \exp\left[a + b_1(\ln C) + b_2(\ln E) + b_3(\ln D)\right]$$

These parameters were then applied to the 1994 post-season estimates of purse seine catch, effort and duration for the peak-week fishery of each stock group through each approach to estimate the run through JS and JdF and the total run. These data were grouped by run and the results plotted.

Results

Figure 1 shows the results of the analysis for the largest stock groups (Adams, Chilko, Late Stuart and Quesnel). For all stocks, as the bias in historical diversion rates increased from -30% to +30%, estimates of the true run size through JS decreased and for JdF increased, as expected. However, the offsetting changes were not of equal size: the decrease in JS runs was much larger than the increase in JdF runs, so the total run size decreased. This effect was most pronounced for the Adams stock.

Conclusions

If historical diversion rates are subject to systematic error, then the estimates of run size through JS and JdF from the purse seine models would also be biased, as would the estimate of total run size. A negative bias in diversion rate estimates would result in underestimates of JS and total run size. A positive bias would result in JS and total runs being overestimated.

In 1994, although it is possible that the overestimation of late-run escapement could be partly due to positively biased diversion rates in the historical record, there has been no evidence presented that such a bias is in fact happening. Furthermore, such a bias would have created similar discrepancies between in-season and post-season estimates in past years, and this has not been shown to exist.

In summary, although Dr. Walters hypothesis is certainly possible, we have not established that a bias in historical diversion rate estimates is anything more than conjecture. Therefore, these results are not supporting evidence for the hypothesis, they only an attempt to bound the effect of such biases.

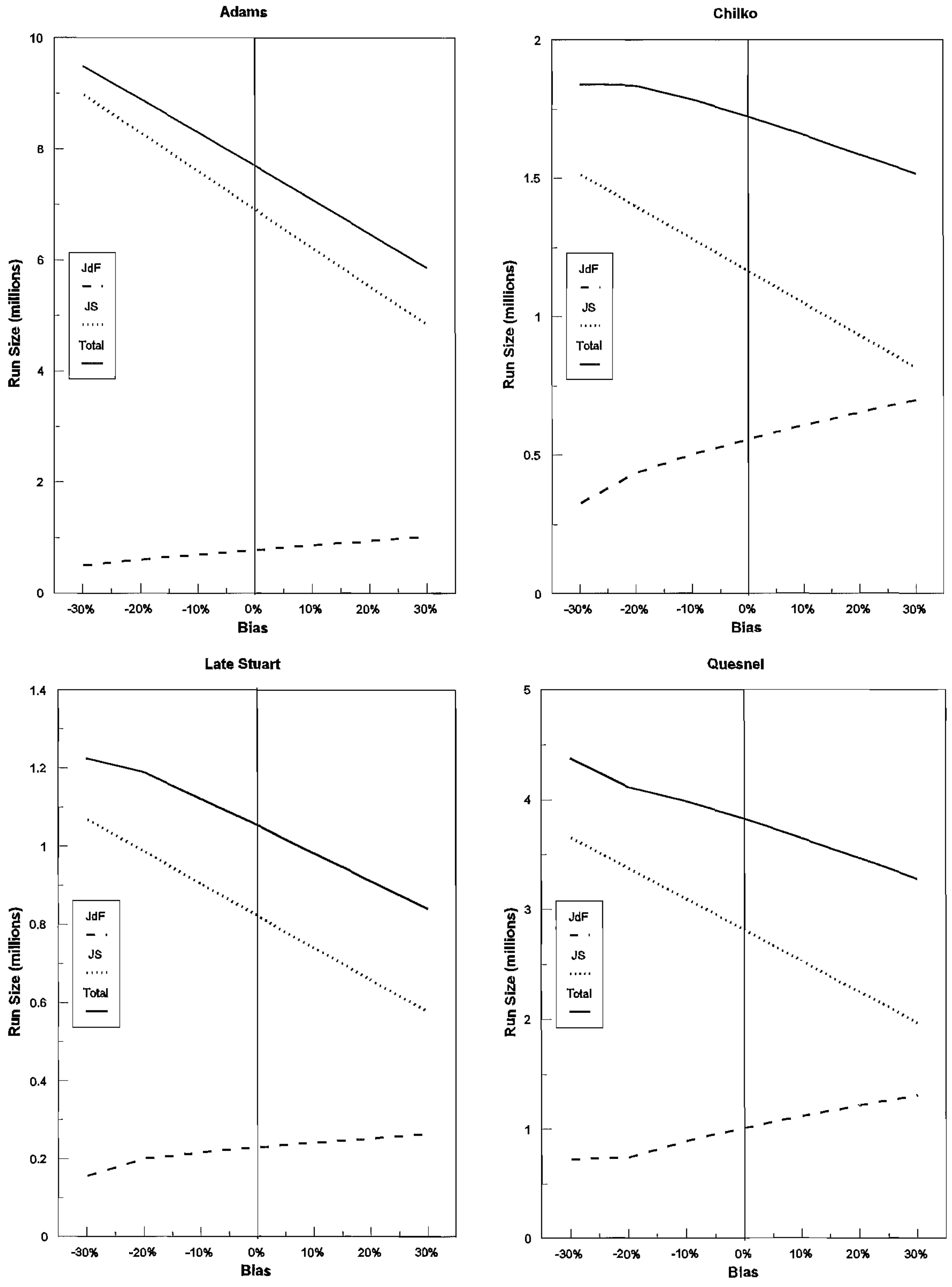


Figure 1. Results of sensitivity analysis on the effect of bias in historical diversion rate estimates on run size estimates in 1994.

Appendix N: Data Outside Previous Range for Commercial Purse Seine Models

Objective

When regression models are used to make estimates for data ranges that substantially exceed the range of the data used to construct the models, there is a risk that large errors can occur in the estimates. This was the situation in 1994 with respect to the estimation of the Adams run through Johnstone Strait. The peak average daily catch was 950,000 compared to the previous high of 350,000 (a 171% difference) in 1978, and the run size was 4,900,000 (preliminary) compared to the previous record of 3,700,000 (a 32% difference, Figure 1). Figure 2 shows that the fishery duration of 1 day has occurred several times in the dataset, although primarily in recent years. Figure 3 shows that the gear count during the peak Adams and Chilko/Quesnel fisheries in 1994 (405 boats) was equal to the second highest observed and moderately less than the highest count (471 boats), which occurred in 1993.

One way to reduce the risk of large errors is to expand the dataset, so data for runs that have had catches and run sizes of the required magnitude are pooled with the original data. Implicit to this method is the assumption that the underlying relationships between run size and catch, effort, and duration are similar for the pooled stocks.

In Johnstone Strait since 1970, only the 1993 Quesnel run has been larger than the 1994 Adams run, while both the 1989 Quesnel and 1993 Late Stuart runs were of approximately the same size. Thus, these stocks are candidates for creating a pooled dataset for estimating the 1994 Adams run through Johnstone Strait. A potential problem with pooling these stocks relates to the assumption noted above. Both the Quesnel and Late Stuart are summer-run stocks while the Adams is a late-run stock, and so could be subject to differences in fisheries and fish behaviour and to differences in their relationships. In fact, we normally assume that sufficient differences exist among the stocks to justify having unique models for each major stock group. However, there are a limited number of data points at high run size levels on which to base firm conclusions. Also, with the exception of the Adams run in 1994, which is the subject of this review, there are no substantive differences visible in plots of run size versus catch (Figure 1) or observed versus predicted run sizes (Figure 4) for Adams, Quesnel and Late Stuart stock groups in Johnstone Strait.

Under the assumption that the Adams, Quesnel and Late Stuart relationships between run size and catch, effort and duration are sufficiently similar to counterbalance the potential error from using a one-stock model outside of its previous range, the pooled model is evaluated below. Specifically, would such a model have produced a more accurate estimate for the Johnstone Strait run of Adams sockeye in 1994.

As an aside, such models were used in-season but not at the exclusion of the Adams one-stock models. The estimates from the various one-stock and combined-stock models were combined in the usual fashion (using the mean square error (MSE) of each model to weight the individual estimates) to produce a pooled estimate. This pooled estimate was closer to the estimates from the one-stock models than to the estimates from the combined-stock models, because the MSE was considerably higher for the former models.

Methods

The regression datasets for the Adams, Quesnel and Late Stuart runs through Johnstone Strait were combined and regression parameters were generated for the model:

$$N = \exp\left[a + b_1(\ln C) + b_2(\ln E) + b_3(\ln D)\right] \qquad \textbf{Model 1}$$

The resulting regression equation was used to estimate the Adams run through Johnstone Strait using the 1994 peak-week catch, duration and effort for this stock. Four catch scenarios were evaluated: in-season adjusted catch, in-season unadjusted catch, post-season adjusted catch and post-season unadjusted catch. These scenarios are consistent with those evaluated in Appendix I. Thus, the estimates from the combined-stock model were compared to the estimates from the one-stock model that were provided previously in the named section.

Results

Table 1 shows a detailed accounting by run of run size estimates, catches in various areas, and calculated escapements to the Strait of Georgia and to Mission. The differences between the estimates of gross escapement and the hydroacoustic estimates (Mission hydroacoustic plus Native catch below Mission) are summarized in Table 2. The results shown for the one-stock models are the same as for Model 2 in Tables 1 and 2 in Appendix I.

Because the difference examined here is the effect of using a one-stock versus a combined-stock model for the Johnstone Strait run of only Adams sockeye, the right and left sides of the early summer and summer-run sections of Table 2 are identical. Regarding the effect on late-run estimates, the combined-stock model obtained substantially smaller differences than the one-stock model, especially when adjusted catches were used. The use of post-season data resulted in smaller differences than when in-season data were used. The lowest difference (101,000) was for post-season adjusted catches.

In terms of total differences for all stocks, the use of the combined-stock model had a variable impact compared to the use of one-stock models. For one-stock models, the differences were always positive, indicating a tendency to overestimate run size in 1994. In contrast, the result of using combined-stock models for the Adams estimate were differences that were both positive and negative, and considerably smaller in magnitude. The lowest difference (-139,000) was observed when post-season adjusted catches were used.

Conclusions

In considering the above results, it is important to consider that the error for the 1994 late run is the largest for any stock in the 1970-94 period (Figure 4). However, the other very large stock in 1994 (Chilko/Quesnel), which also returned in very large abundances through Johnstone Strait, was estimated with reasonable accuracy but was underestimated instead of overestimated.

The use of a combined-stock model clearly resulted in a more accurate estimate of the Adams run through Johnstone Strait in 1994 than the one-stock model, and the use of adjusted catches provided the most accurate estimate of all the scenarios. The conclusion from these results is that when the run of a stock is expected to exceed its previous range by a significant amount, a combined-stock model should be used in place of the one-stock model.

Although it is tempting to extend this conclusion to other situations, the analysis is not extensive enough and the conclusion not strong enough to do this. For example, some of the questions that remain are:

1. When the run is expected to be near or slightly exceed the previous maximum, should the estimate from the one-stock model be used, or a pooled estimate from the one-stock and combined-stock models.

2. When the run is expected to be well within the previous range, but the sample size (and degrees of freedom) for a regression is small, should a one-stock model be used, or a pooled estimate from the one-stock and combined-stock models.

These questions relate more to the criteria used to select which models to apply, than to problems or shortcomings with the modelling methodology or data.

Regarding the use of adjusted versus unadjusted catches, the adjusted catches provided the best estimate for late-run stocks but made little difference for summer-run stocks. Thus, no firm conclusion can be drawn about whether adjusted or unadjusted catches should be used.

Similarly, the use of post-season catch estimates resulted in the most accurate estimates for summer-run and late-run stocks. However, the differences are relatively small.

Table 1. Comparison of estimates of run size and escapement, for one-stock versus combined-stock Adams models, using adjusted versus unadjusted catches, and in-season versus post-season catch and racial estimates.

Run	Run Size Excluding WCVI Catch	Areas 1-11 Catch	JdF + JS Run Size	Inside Catch *	Strait of Georgia Esc.	Terminal Area Catch **	Available Gross Esc.	Actual Gross Esc. ***	Difference
One-stock Models and Adjusted Catch Data									
In-season Catch and Racial Data									
E.Summ	715,000	12,000	703,000	241,000	462,000	146,000	316,000	516,000	(200,000)
Summer	6,412,000	401,000	6,011,000	2,409,000	3,602,000	1,383,000	2,219,000	2,623,000	(404,000)
Late	8,124,000	1,434,000	6,690,000	3,388,000	3,302,000	1,260,000	2,042,000	1,055,000	987,000
Total	15,251,000	1,847,000	13,404,000	6,038,000	7,366,000	2,789,000	4,577,000	4,194,000	383,000
Post-season Catch and Post-season Racial Data									
E.Summ	956,000	25,000	931,000	533,000	398,000	185,000	213,000	515,000	(302,000)
Summer	7,213,000	489,000	6,724,000	2,838,000	3,886,000	1,311,000	2,575,000	2,513,000	62,000
Late	8,459,000	1,435,000	7,024,000	3,634,000	3,390,000	1,331,000	2,059,000	1,138,000	921,000
Total	16,628,000	1,949,000	14,679,000	7,005,000	7,674,000	2,827,000	4,847,000	4,166,000	681,000
One-stock Models and Unadjusted Catch Data									
In-season Catch and Racial Data									
E.Summ			715,000	241,000	474,000	146,000	328,000	516,000	(188,000)
Summer			6,019,000	2,409,000	3,610,000	1,383,000	2,227,000	2,623,000	(396,000)
Late			7,174,000	3,388,000	3,786,000	1,260,000	2,526,000	1,055,000	1,471,000
Total			13,908,000	6,038,000	7,870,000	2,789,000	5,081,000	4,194,000	887,000
Post-season Catch and Post-season Racial Data									
E.Summ			956,000	533,000	423,000	185,000	238,000	515,000	(277,000)
Summer			6,823,000	2,838,000	3,985,000	1,311,000	2,674,000	2,513,000	161,000
Late			7,257,000	3,634,000	3,623,000	1,331,000	2,292,000	1,138,000	1,154,000
Total			15,036,000	7,005,000	8,031,000	2,827,000	5,204,000	4,166,000	1,038,000
Combined-stock Model for Adams Run and Adjusted Catch Data									
In-season Catch and Racial Data									
E.Summ	715,000	12,000	703,000	241,000	462,000	146,000	316,000	516,000	(200,000)
Summer	6,412,000	401,000	6,011,000	2,409,000	3,602,000	1,383,000	2,219,000	2,623,000	(404,000)
Late	7,366,000	1,434,000	5,932,000	3,388,000	2,544,000	1,260,000	1,284,000	1,055,000	229,000
Total	14,493,000	1,847,000	12,646,000	6,038,000	6,608,000	2,789,000	3,819,000	4,194,000	(375,000)
Post-season Catch and Post-season Racial Data									
E.Summ	956,000	25,000	931,000	533,000	398,000	185,000	213,000	515,000	(302,000)
Summer	7,213,000	489,000	6,724,000	2,838,000	3,886,000	1,311,000	2,575,000	2,513,000	62,000
Late	7,639,000	1,435,000	6,204,000	3,634,000	2,570,000	1,331,000	1,239,000	1,138,000	101,000
Total	15,808,000	1,949,000	13,859,000	7,005,000	6,854,000	2,827,000	4,027,000	4,166,000	(139,000)
Combined-stock Model for Adams Run and Unadjusted Catch Data									
In-season Catch and Racial Data									
E.Summ			715,000	241,000	474,000	146,000	328,000	516,000	(188,000)
Summer			6,019,000	2,409,000	3,610,000	1,383,000	2,227,000	2,623,000	(396,000)
Late			6,595,000	3,388,000	3,207,000	1,260,000	1,947,000	1,055,000	892,000
Total			13,329,000	6,038,000	7,291,000	2,789,000	4,502,000	4,194,000	308,000
Post-season Catch and Post-season Racial Data									
E.Summ			956,000	533,000	423,000	185,000	238,000	515,000	(277,000)
Summer			6,823,000	2,838,000	3,985,000	1,311,000	2,674,000	2,513,000	161,000
Late			6,662,000	3,634,000	3,028,000	1,331,000	1,697,000	1,138,000	559,000
Total			14,441,000	7,005,000	7,436,000	2,827,000	4,609,000	4,166,000	443,000

* Catches in Canadian Areas 12-16, 18-20, and U.S. Areas 4B, 5, 6C, 6, and 7, and portion of the catch in Area 7A.

** Catches in Canadian Areas 17 and 29, but excluding IF catch below Mission.

*** Mission hydroacoustic estimate of escapement plus IF catch below Mission.

Table 2. Differences between estimated and actual gross escapements (Mission escapement + Native catch below Mission) by run, for one-stock versus combined-stock Adams models, adjusted versus unadjusted catches, and in-season versus post-season catch and racial estimates.

	One-stock Adams Model			Combined-stock Adams Model		
		Catch Adjustments			Catch Adjustments	
	Data	Adjusted	Unadjusted	Data	Adjusted	Unadjusted
Early Summer	In-seas	(200,000)	(188,000)	In-seas	(200,000)	(188,000)
	Post-seas	(302,000)	(277,000)	Post-seas	(302,000)	(277,000)
		Catch Adjustments			Catch Adjustments	
	Data	Adjusted	Unadjusted	Data	Adjusted	Unadjusted
Summer	In-seas	(404,000)	(396,000)	In-seas	(404,000)	(396,000)
	Post-seas	62,000	161,000	Post-seas	62,000	161,000
		Catch Adjustments			Catch Adjustments	
	Data	Adjusted	Unadjusted	Data	Adjusted	Unadjusted
Late	In-seas	987,000	1,471,000	In-seas	229,000	892,000
	Post-seas	921,000	1,154,000	Post-seas	101,000	559,000
		Catch Adjustments			Catch Adjustments	
	Data	Adjusted	Unadjusted	Data	Adjusted	Unadjusted
Total	In-seas	383,000	887,000	In-seas	(375,000)	308,000
	Post-seas	681,000	1,038,000	Post-seas	(139,000)	443,000

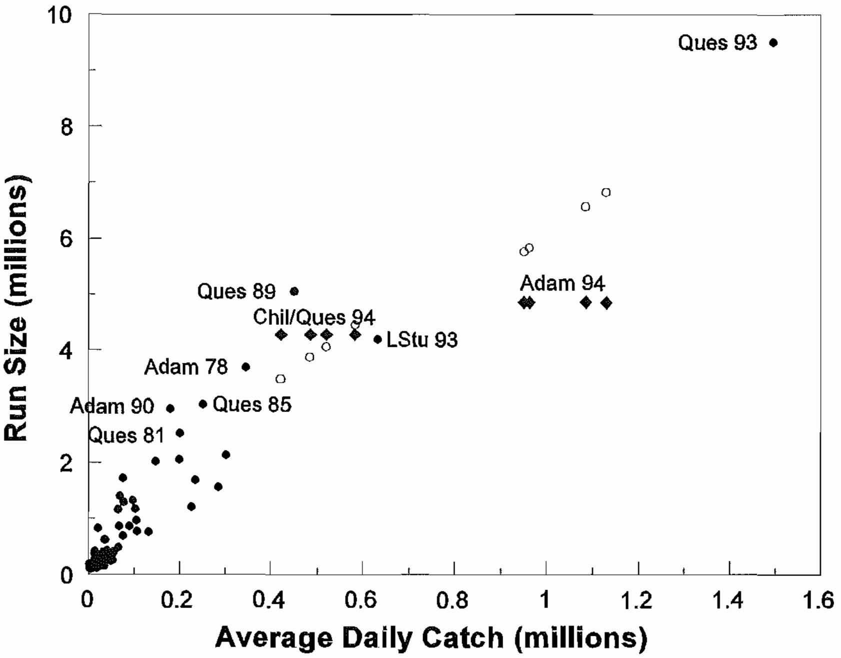


Figure 1. Observed run size versus average daily catch during peak-week purse seine fisheries in Johnstone Strait. The largest historical runs in the regression dataset are identified by stock and year, as are the range of catch estimates (in-season versus post-season, adjusted versus unadjusted) for Adams and Chilko/Quesnel groups in 1994.

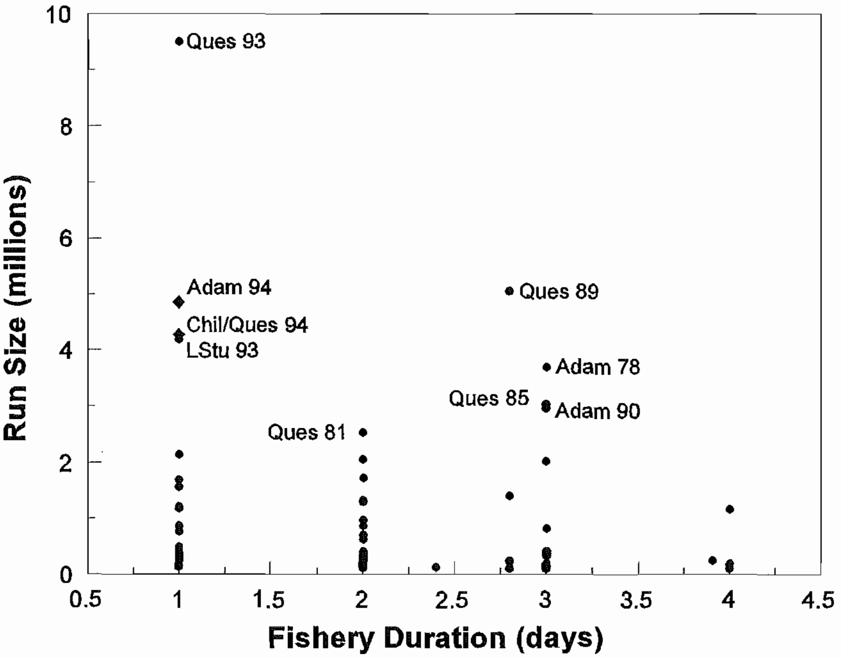


Figure 2. Observed run size versus fishery duration for peak-week purse seine fisheries in Johnstone Strait. The largest historical runs in the regression dataset are identified by stock and year, as are the fishery durations for Adams and Chilko/Quesnel groups in 1994.

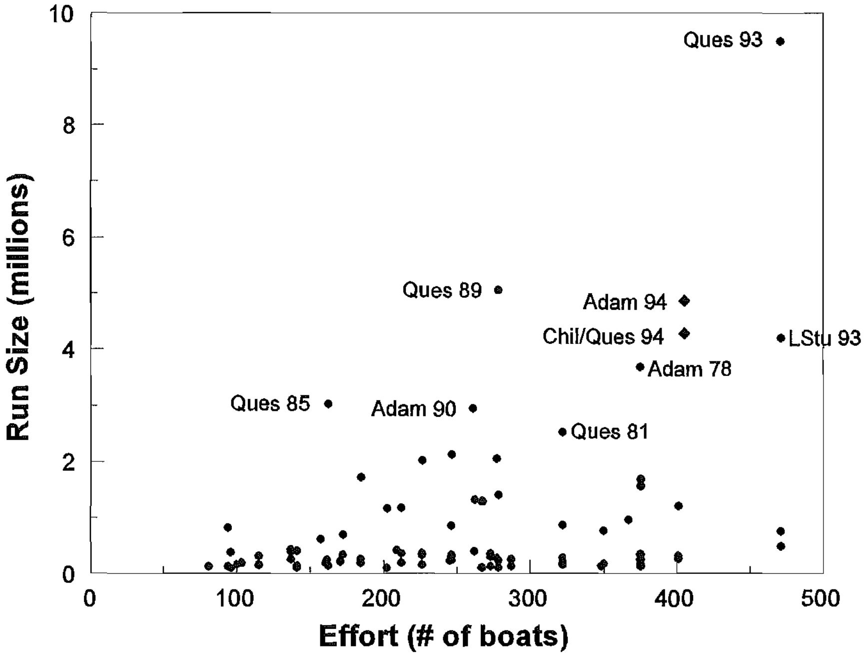


Figure 3. Observed run size versus average daily effort during peak-week purse seine fisheries in Johnstone Strait. The largest historical runs in the regression dataset are identified by stock and year, as are the effort estimates for Adams and Chilko/Quesnel groups in 1994.

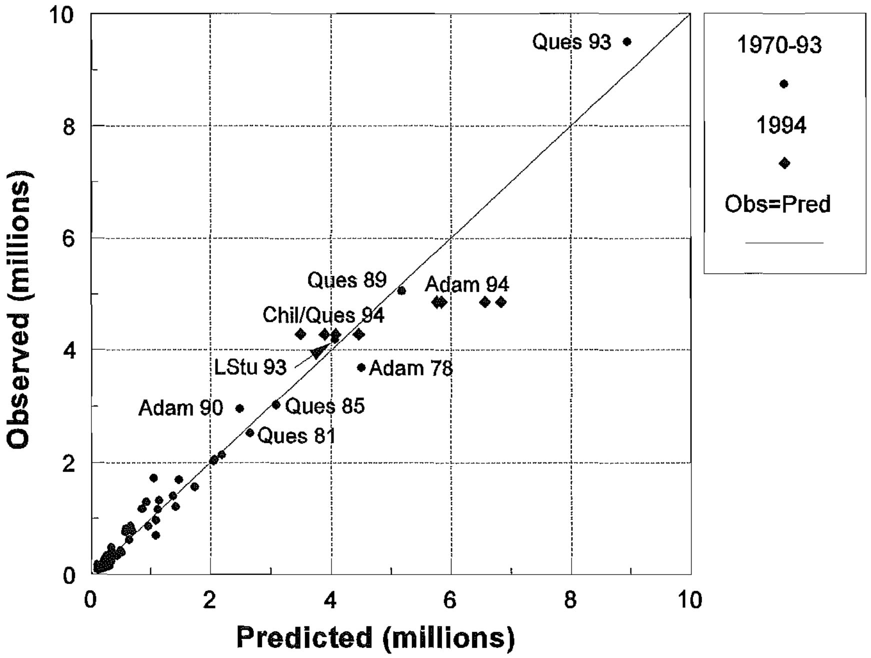


Figure 4. Observed versus predicted run size for Johnstone Strait. The largest historical runs in the regression dataset are identified by stock and year, as are the estimates for Adams and Chilko/Quesnel groups in 1994.

Appendix O: Reconstruction of Marine Area Harvest Rates and Timing-Abundance Curves

Introduction

In 1994, returning Fraser River sockeye migrated predominantly via the northern approach. During late August, considerable attention was directed to application of appropriate harvest rates on the late-run stocks and this is reviewed in Appendix D ("Estimation of run-size of summer and late sockeye stocks and late-run escapement to the Strait of Georgia using in-season run reconstructions and cumulative-normal models"). The 1983 harvest rates were used and modified using feedback information on the 1994 summer-run harvest rates. The main issue concerning the 1994 late-run migration concerns the overestimation of the run-size of late-run sockeye and in particular the component represented by the escapement to the Strait of Georgia. Use of incorrect harvest rates has been presumed responsible for this overestimate.

The examination of historic information from fisheries on migrating salmon typically involves run-reconstruction methods. "Backwards run reconstruction" is a procedure by which a salmon run is reconstructed backwards in time and space using catch-by-area-stock-and-date and escapement-by-stock-and-date information, to estimate the abundance-by-area-and-date that was present prior to any fishing. The purpose of the technique is to estimate timing-abundance curves by stock and to estimate area and stock specific harvest rates. Area specific harvest rates are vital inputs to the forward fishery model used for pre-season planning and for in-season run-reconstructions which serve as inputs to the cumulative-normal model that is used to make in-season estimates of timing and run-size. Although this procedure has been in use for many years, recent advances in the availability of computers has prompted some refinements and formalization in the methodology.

Starr and Hilborn (1988) described a run-reconstruction methodology for migratory salmon. Following the procedure described, Starr and Hilborn reconstructed estimates of harvest rate and catch by stock for Fraser River sockeye. However, Starr and Hilborn's notation does not provide for migration of fish into and out of fishing areas during the course of the fishery, nor does it provide for the distribution of the fleet in fishing areas. This omission is not insignificant, because it results in a bias in the estimation of harvest rates: Catch for a three day fishery includes fish which were resident in the area during the opening of the fishery, but also includes fish which entered during the second and third day. However, the escapement on which the catch is reconstructed, is confined to a "half-weekly" block, which is the finest resolution of time-step by which Starr and Hilborn define a fishery. This does not allow for daily increments of escapement to be considered in the calculation of harvest rate. The result is that harvest rates may be overestimated, although, as discussed below, there may be some compensatory bias that occurs as well.

Cave and Gazey (1994) described methodology to allow for migration of fish into and out of fishing areas during the course of the fishery. Further, they attempted to take into account the distribution of the fleet in the fishing areas. Although the principal emphasis of Cave and Gazey was to document a forward model used for pre-season planning, a refinement is described which provides for the unbiased backward reconstruction of harvest rates. In this method, catch for any period (e.g. daily, weekly) can be apportioned to daily migration block, even though escapement is maintained at a daily resolution. However, by incorporating this flexibility, the assumption is that harvest rate is constant for the period of catch.

The pre-season planning model described by Cave and Gazey (1994) requires detailed input information such as timing and spread of a migrating stock, as well as fishery specific harvest rate parameters. To this end, a backward run-reconstruction model was developed to evaluate historical information on fisheries. This model was built to estimate inputs for the fishery planning model currently in use. Therefore, when output from the planning model is used as input to the reconstruction model, output is produced identical to the input for the planning model. Extensive de-bugging was used to check for this requirement. A working version of this model was available by January, 1994, however, detailed run-reconstructions were not made until after the 1994 fishing season. These reconstructions were completed in order to more fully understand events which led up to the overestimation of late-run sockeye to the Strait of Georgia. The model uses the PSC estimates of catch-by-stock, rather than calculate estimates of stock composition based on the reconstruction. This allows us to relax the assumption (implicit in the Starr-Hilborn model) of equal vulnerability in harvest rates across stocks for a fishery-time stratum.

The focus of the reconstructions in this paper are the high diversion years and in particular, the harvest rates in the Johnstone Strait fisheries. These include 1980, 81, 83, and 92-94. Below, we describe the reconstruction model, and the assumptions and input data required for analysis. Second, we flag a problem in the analysis: violation of the "order of movement assumption", one of the critical assumptions in the model and provide evidence for its violation and an approach to address this effect. Finally, we provide estimates of the reconstructed harvest rates and timing abundance curves.

Methods

The concept of Harvest Rate

There are several ways of considering harvest rate in a fishery. First, annual harvest rates (typically called exploitation rates) can be calculated but these are considered less useful in the management of a fishery. Second, the weekly harvest rates can be examined. These are useful in determining the overall harvest of a weekly fishery, but do not provide information on the pattern of harvest within a fishery opening. Third, the elemental harvest rate, "u" can be examined. The elemental harvest rates describe the harvest rate on a migration block as it enters the fishing area. The total harvest rate on a migration block for a given fishery is a function of "u" and can be described by polynomial equation. Since the elemental harvest rate is assumed to be independent of the duration of a fishery, relationships between u and effort can be examined directly.

Algorithm

The program calculates, by stock, the elementary daily harvest rate and entering run size given catch, escapement and movement information. Stocks are assumed to approach from either the north (through Johnstone Strait) or the south (through the Strait of Juan de Fuca) and join together in the Strait of Georgia just before entering area 29. Therefore, conceptually, there are 3 distinct sets of fisheries: (1) Fraser River (29A, 29B, 29D), (2) the south (UVI, LVI, 20, U4B, U7, U7A) and (3) the north (11, 12, 13, 14 16). For each fishery, daily or weekly catch statistics are required. The computational algorithm for one of these sets for any one stock is given below in "pseudo-code", assuming that catch has a daily resolution:

```
1. Let $N_t = E_t$ for all $t$

2. Let $j = J$
```

3. Let $w = 1$

4. Let $f = O_j$

5. Let $t = T$

6. Solve $C_{ft} = \sum_{k=0}^{r_f} \frac{h_{ftk}}{1 - h_{ftk}} N_{t+w+k}$ for u_{ft}

7. Let $N_{t+w+k} = \frac{N_{t+w+k}}{1 - h_{ftk}}$ for $k = 0, 1, 2, ..., r_f$

8. Let $t = t - 1$

9. If $t > 0$ then go to step (6).

10. Let $w = w + r_f$

11. Let $j = j - 1$

12. if $j = 0$ then finished; otherwise, go to step 4

where,

$$\begin{aligned} h_{ftk} &= p_{ftk}u_{ft} + p_{ft,k-1}u_{ft}(1 - p_{ftk}u_{ft}) && \textit{if } 0<k<r_f \\ &= p_{ftk}u_{ft} && \textit{otherwise} \end{aligned}$$

and the notation is as follows:

Indices

f - fishery
j - fishery referenced in sequence
k - migration block of fish available to a fishery
m - time period consisting of more than one day (e.g., week)
t - time (day)

Variables

C_{ft} - catch in fishery f during the t'th day
E_t - escapement during the t'th day
h_{ftk} - harvest rate of fishery f on the k'th migration block during the t'th day
J - last fishery through which fish migrate common to all stocks
N_t - available population representing the run which would have escaped during the t'th day (i.e., the escapement if there were no fishing allowed)
O_j - fishery identifier as any stock migrates through the j'th area
p_{ftk} - weight given to fishing intensity in fishery f on the k'th migration block during the t'th day
p_{ftk} - standardized weight given to fishing intensity in fishery f on the k'th migration block during the t'th day
r_f - residence (days) in fishery f
T - number of days in the season
u_{ft} - elementary harvest rate of fish entering or leaving fishery f during the t'th day
w - travel time (days) from leaving a fishery to escapement

Step (1) of the algorithm copies the escapement into a vector which will be expanded in subsequent steps to represent the entering run size. Step (2) sets the fishery reference to the last fishery through which fish pass prior to escapement and the travel time from that fishery to escapement is set in step (3). The iterative part of the algorithm starts in step (4) with the identification of the current fishery. Step (5) initiates the time (day) counter to the last day in the season. Step (6) solves the catch equation for the elemental harvest rate using a bisection algorithm and the run size is expanded by the survival rate in step (7). The time counter is decreased in step (8) and tested in step (9) for the finish of the season. Step (10) increments the travel time to escapement by the length (travel time) of the fishery for which calculations have just been completed. Finally, step (11) decreases the fishery reference and step (12) tests if all the fisheries have been processed.

For fisheries which accumulate catch by a week, we simply replace step (6) with the following:

$$solve \quad C_{fm} = \sum_{t \subset m} C_{ft} = \sum_{t \subset m} \sum_{k=0}^{r_{sf}} \frac{h_{ftk}}{\prod_{t \subset m} (1 - h_{ftk})} N_{t+w+k} \quad for \quad u_{fm}$$

and the run size is updated for all days (*t)* fished in week *m* in step (7).

Data and Other Inputs

The reconstruction model requires a substantial amount of data and other information. The schematic in Figure 1 shows the type of information required to run the model. These fall into the following categories: catch-by-stock data for each stock identified in the program (Files: YRSTCK.DAT), escapement data for each stock (File: MESC-YR.DAT and/or GESC-YR.DAT), program control (File: HEADERS.PRN), timing and routing information (File: TIMING.PRN), standardized fishing intensity weights for each of the migration block within a fishery (For a description, see Gazey and Cave 1994) (File: POINTERS.PRN), fishery regulations (File: REGULATI.PRN). All of the previously described .PRN files are produced and exported by an overall front-end file (File: FRONTYR.WK3)

Catch data can originate from either the PSC database or from the in-season working files (lotus files: .wk1) produced by the PSC staff. Likewise, the Mission escapement data by stock can originate from either the database or in-season lotus files. As indicated below, the Mission escapement data is not required for reconstructions. GESC-YR.DAT is a special case file and is however, required for the reconstruction. It is produced following several steps described below.

Procedure

The current version of the run-reconstruction model has the option of starting the run-reconstruction either from Mission or from the Strait of Georgia, where the migrations from the northern and southern approaches meet. Reconstructions from Mission require the escapement data by day and by stock at Mission and Area 29 catch by stock and fishery type (e.g. troll, gillnet). Reconstructions starting from the Strait of Georgia require annual terminal catch and escapement by stock.

Timing-abundance curves of fish escaping to the Strait of Georgia from each of the two approaches have to be created. For example, the Mission escapement data for any day include fish from both routes. There is no independent measurement of this proportion of fish from the two approaches. Therefore, assumptions have to be made on the harvest rates on one of the two approaches: historical harvest rates are used on the approach which has the smaller migration in order to estimate the proportion entering the Strait of Georgia from that approach. The balance of the migration is considered to be from the other approach and reconstructed harvest rates should be representative of fisheries for that approach. Since these terminal abundances have been affected by fisheries, we have taken the approach that the forward model should be used, together with the fishery regulations, and posteriori estimates of run-size, timing and diversion, to determine **the relative proportions of each daily block** of fish that migrated from each approach. In the case of reconstructions starting at Mission, only the proportions, north and south, are used to determine the route of fish. In the case of reconstructions starting at the Strait of Georgia, the timing abundance curves entering the Strait of Georgia are weighted using the annual terminal catch and escapement data and are normal distributions with catch by migration block removed. Calculations in both instances are done by major stock. The circularity of this kind of approach should be acknowledged: harvest rates have been used to generate these profiles for both approaches.

Bias: Violation of the "Order of Movement" Assumption

There is possible bias in reconstructed harvest rates due to uncertainty in escapement profiles entering the Strait of Georgia. One of the central assumptions in run reconstruction procedures is that fish maintain a rigid order of movement: i.e. that fish contained within a days migration into an area (so-called, daily migration block) remain with their co-migrants within that block, as they migrate from one area to the next. This is called the "order-of-movement" assumption. Of course, we believe that this is rarely true in observation: fish do jumble themselves up during their migration, and move from one migration block to the next. The most obvious place that this occurs is at the mouth of the Fraser River, where fish may delay from anywhere from 1 to 28 days. In the case of Adams and Weaver stocks, this compromises the Mission daily escapement data to the point that it cannot be used for these stocks. However, even for summer-run stocks, this may be a problem, as was the case in 1994. Even if delay is very limited, a slow down of 1 day, for even 25% of the population, is a concern and this may not be detectable with the monitoring systems we currently have in place. The analogy we could give is digging a ditch in dry sand at the beach: the sand from the high spots fill in the trench. This is like a fishery bite into several days of a migration: the fish on either side of the impacted migration move into the days of removal. In the case of delay this may almost completely cover up a hole, but in the case of no delay, it may still be a factor. When we consider the situation where we may want to estimate the harvest rate for a particular fishery or date, this introduces a potentially serious negative bias: catch is reconstructed onto a "hole" that has been partially filled.

The potential bias that violation of this assumption might contribute, prompted us to design the model so that it could be run either from the Strait of Georgia or from Mission. The difference between the two methods is that the Mission method uses actual escapement data while the "Strait of Georgia" option uses a escapement-to-the-Strait profile which is created using the forward model, generated by the forward model. The Mission escapement profiles may be affected to a greater or lesser extent by violation of the order-of-movement assumption, depending on the year and stock. The result is that the harvest rates are underestimated. When the model is started from the Strait of Georgia, using the escapement profiles generated by the forward model, we reconstruct the catch on top of the "holes" in the migration caused by the fishery. In other words, we have used "best guess" harvest rates to create the holes on which we add the catch onto the entering run and by which we estimate the harvest rate. This is circular but **may** be preferable to the clear (negative) bias caused by filling. The main problem with starting the model in the Strait of Georgia is in situations where the run deviates from the normal distribution, for example 1993 was a clearly bimodal run. In this situation, reconstruction error of the harvest rates would be increased and potentially biased.

Examples of bias in estimates of harvest rate due to violation of the order-of-movement assumption can be easily simulated, but the argument becomes more compelling when it can be demonstrated with actual data. 1993 was a "high Johnstone Strait Diversion" year where sockeye apparently did not delay at any time during their return migration to the Fraser River. A peak in the Area 11 troll test fishery August 21 was confirmed by the Area 12 (Robson Bight) purse seine test fishery on August 25 and in the Area 29B (Cottonwood) test fishery on August 29. The reconstruction uses a daily time-step and the half-daily elemental harvest rates are calculated accordingly, however we can also look at the daily reconstructed migration, and accumulate the catch and abundance data for a week period to calculate the weekly harvest rate. A weekly harvest rate calculated in this manner should be robust to violation of the order of movement assumption, since the escapement data is accumulated over a week. These can be compared to the predicted weekly Area 12-13 seine harvest rates as derived from the elemental harvest rates, which may be susceptible to violation of this assumption. This comparison is shown in Figure 2 with the 1:1 line. All points are shown below the line, indicating an average negative bias of 7.6%.

In order to address this bias, and for the purpose of estimating harvest rates, the model was run using the Strait of Georgia option. The procedure involves examining the reconstructed runs for severe deviations of normality and comparing the back-calculated weekly Area 12-13 seine harvest rate as derived from the elemental harvest rates with the estimated weekly harvest rates from the timing-abundance curves. If these differ by more than 5% from one another, the forward model is re-run with adjusted harvest rates, the Strait of Georgia-profile is regenerated and the reconstructions re-run until the differences between the estimates of weekly harvest rates generated by the two methods are minimized. We examined the reconstructed elemental harvest rates for possible bias by the previously described method of predicting the weekly harvest rates from the elemental rates and comparing these with the estimated weekly harvest rates derived from the accumulated catch and abundance data for a week period. This relationship with the accompanying 1:1 line is shown in Figure 3. The even distribution of the points about the line indicates that bias in the reconstructed elemental harvest rates is not evident.

Results

Two scenarios were reconstructed for 1994: 1) annual gross escapement of sockeye past Mission, as determined by the hydroacoustic program at Mission and 2) annual gross escapement of sockeye past Mission, as concluded by the Fraser River Sockeye Public Review Board findings (i.e. the total of DFO net escapement estimates plus Native fishery catches and en-route mortality).

1994 Timing Abundance Curves

The timing abundance curves estimated from the run reconstructions for 1994 are shown in Figures 4-6. Examination of this output is useful as the run reconstructions are carried out as they may indicate problems with either the timing and shape of the Strait of Georgia escapement profiles, or with the catch by stock data. For example the non-normal distributions shown for both the Scotch Creek-Seymour River and the Late Stuart-Stellako stock group are suspicious (Figure 4). The timing of the Strait of Georgia escapement profiles were adjusted in attempts to create a more normally distributed entering run, without success. In these situations, the stock composition estimates for this complex of stocks is suspect and this will be reviewed when the final racial estimates are prepared. However, this does not necessarily indicate problems with the other stocks as these groups are small relative to the size of the major stock groupings (Chilko-Horsefly and Adams-late run).

Figure 5 shows the comparison between the timing curves for the summer-run and late-run stock groups (reconstructions calculated using annual gross escapement of sockeye past Mission, as determined by the hydroacoustic program at Mission). Visually, the harvest of summer-run stocks in the first Area 12-13 fishery (August 8) is shown to be considerably less than the following fisheries.

Very intense fisheries are shown for the 2 peak fisheries (August 15 and August 22) on the late-run stocks. The comparison indicates the bias that would result if annual harvest rates of summer-run fish were applied to the management of late-run stocks. Application of annual harvest rates of summer-run stocks to catches of late-run stocks would cause a severe over-estimate of escapement. The skewed distributions of the profiles shown indicate the effects of the Area 11 and 2W troll and net fisheries on the latter part of these migrations. These effects may cause bias in the seine catch and CPUE based models. Figure 6 shows the reconstructed timing curve for late runs using the annual gross escapement of sockeye past Mission, as concluded by the Fraser River Sockeye Public Review Board findings. Comparison of the reconstructions of the late-run migration indicate different harvest rates in the Johnstone Strait fisheries, particularly for the peak (August 15) fishery. The elemental and weekly harvest rates for this fishery were more easily reconciled for the "up-stream accounting" based reconstruction than for the hydroacoustic based reconstruction. The implications of this are discussed below.

Area 12-13 Purse Seine Harvest Rates

The most intense fishery directed on the migration of sockeye through the northern approaches is the Area 12-13 purse seine fishery. The magnitude of the harvest rates in this fishery was re-evaluated several times during the 1994 season.

The elemental harvest rates for the seine fisheries are shown in Table 1. The only situations shown are those for stocks of significant proportion in the fishery. In addition, only "All-Area 12" fisheries are shown, although all of the "Lewis Point" type fisheries were reconstructed. Figures 7-8 show the scatter-plots of elemental harvest rate versus fleet size. The arrows indicate the base harvest rates (48% for Area 12 and 28% for Area 13) which are currently used in the forward planning model and which served as a guide to estimating the abundance of late-run stocks entering the Strait of Georgia from the northern approach in 1994.

Analysis of covariance (ANCOVA, General Linear Model) was used to determine if there was any justification to treat the data in subsets of stock and period: Are the relationships between harvest rate and fleet size different in 1992-1994 from the situation in 1980-83 and do summer-run and late-run stocks follow different relationships? A significant main effect of period was shown for both Areas 12 and 13 (Table 2, $p<0.05$). The main effect of stock was not found to be significant for either area. The response of harvest rate on effort was significant for Area 12 but was not significant for Area 13. These results are consistent, regardless of the origin of the escapement statistics for 1994. The main effect of period was not found to be significant when only single day fisheries are examined.

The harvest rates shown in Table 1 and examined in the ANCOVA analyses summarized in Table 2 were based on our understanding that the gross escapements at Mission for years 1980-83 were best assessed using the upstream accounting estimates. Concerns were raised that the different methodologies of escapement estimation could have been responsible for the significant effect of period on the relationship between harvest rate and fleet size. Therefore, the ANCOVA analyses were reexamined with the reconstructed harvest rates based on hydroacoustic estimates of gross escapement at Mission for all years (Table 3). The conclusions did not change from those indicated in Table 2: 1) A significant main effect of period was shown for both Areas 12 and 13: 2) the main effect of stock was not found to be significant for either area; 3) the response of harvest rate on effort was significant for Area 12 but was not significant for Area 13; 4) the main effect of period was not found to be significant when only single day fisheries are examined.

The simple linear regressions of harvest rate versus fleet size are shown in Figures 9-10. The reconstructed harvest rates are higher for a given fleet size for the years 92-94, when compared to 80-83. Figure 11 shows the relationship between elemental harvest rate and fleet size for 92-93, together with the observations of reconstructed harvest rates for 1994 derived using the Mission hydroacoustic based estimates. Stock specific differences are evident, with the harvest rate at a given fleet size for late-run stocks for the peak week being substantially greater than for summer-run stocks (Figure 11). Considerable effort was made to reconcile these differences by adjusting timing of the stocks in question, however results were unsuccessful. The same relationship is shown in Figure 12, except the estimates of harvest rate are reconstructed using the annual gross escapement of sockeye past Mission as concluded by the Fraser River Sockeye Public Review Board findings. In this situation, stock specific differences in relationship are less apparent, and the 1994 data show less deviation from the 1992-93 regression line.

The weekly harvest rates for the entire Area 12-13 fishery (all-gear) for 1994 are shown in Table 4. The harvest rates first fishery on August 8 were lower than expected. This is believed due to a concentrated migration down the closed areas (Sub-areas 12-7 and 12-13) on the mainland side of Queen Charlotte Strait. However, because this is the beginning of the late-run migration, there is additional uncertainty in the reconstruction of harvest rates, either weekly or elemental. This uncertainty also pertains to fisheries at the end of the migration. Consequently, such fisheries may cloud the judgement of the overall fishery if overemphasised. The two fisheries of greatest importance are the fisheries of August 15 and August 22. The summer-run harvest rates for the 2 week period are considerably lower than for Adams. This is true for both situations that were reconstructed for 1994, although the differences between the summer-run and late-run harvest rates are less for the reconstructions using the up-stream accounting estimates of gross escapement. The differences in the summer-run and late-run harvest rates may be real, or may indicate a problem with the data, with either the summer-run estimate of escapement being too high or the late-run estimate of escapement being too low. The reconstructions do not provide conclusive evidence as to which of these possible causes is correct.

Area 11-12 Gillnet Harvest Rates

Prior to these analyses, gillnet harvest rates had been developed for the combined Area 11-12 fishery, and were only applicable to the gillnet fisheries scheduled following the combined seine-gillnet fishery. Harvest rates were considered to be significantly less than the combined-gear fishery, and highly variable. For this reason, we were reluctant to use catches in these fisheries as indicators of stock status.

Gillnet harvest rates are summarized in Table 5. Considerable variability is evident in the relationship between gillnet harvest rate and fleet size (Figure 13). Part of this variance is undoubtably due to error in reconstruction, and low harvest rates are particularly subject to this source of measurement error. Also, while some interannual variability is evident, there is no clear time-trend: relatively high harvest rates are shown in 1993, but these moderate somewhat in 1994 for both summer and late-run stocks. Although the annual gillnet catch in these areas may approach 1.5 million fish, there is little opportunity to assess run strength from analysis of this catch data, as a result of this high level of uncertainty. This is particularly disconcerting, as these fisheries have the greatest impact on the major escapement periods in the weekly migration as gillnets continue to fish following the seine fishery. Also, as a result of the uncertainty in reconstructed harvest rates, the expected catch in these fisheries from a pre-season planning perspective will be highly inaccurate.

Area 11-12 Harvest Rates Outside Trollers

Area 11 troll harvest rates for 1994 are shown in Table 6. Comparisons between harvest rate and fleet size are invalid as the extent of the fishing area was increased several times during the season to increase the availability of sockeye to the fleet. This is shown in the harvest rates, which increase throughout the season. The harvest rates do not give information on how the fish were affected during the fishery, as the temporal resolution of the catches used for this fishery is weekly. Presently there is no provision in the model to use both weekly and daily catch data for the fishery, although both statistics are available. Without this finer resolution, we cannot determine if this troll fishery adversely affected the escapement profile and removed fish from projected escapement. The non traditional aspects of this fishery make this scenario a real possibility.

General Discussion

The reconstructions for 1994 clearly indicate high harvest rates for late-run stocks in the Area 12 and 13 purse seine fisheries, relative to what was measured for summer-run stocks and applied to late-run stocks during the management season. The attempt to use the in-season estimates of harvest rates for summer-run stocks and to apply these to late-run stocks was not valid, in hindsight. This was not because the "true" or "accurate" summer run harvest rates were different from late runs, but because the in-season data were providing incorrect estimates of harvest rates due to a combination of catch underestimation and in-season racial analysis bias. This is particularly troubling, as we strongly felt that this procedure would improve the accuracy of estimates of escapement to the Strait of Georgia. While the high harvest rates on Horsefly and Late Stuart sockeye in 1993 are clearly evident during the management of those stocks, the same feedback mechanisms were misleading in 1994.

Should a regression of harvest rate versus fleet size (for Area 12 and 13 seine) be used to estimate input harvest rates for pre-season planning and in-season assessments of run-size? The alternative is to use an average of harvest rates across all years. A regression would seem to be more appropriate, given the relationships presented in Figures 10-11. Statistical justification is provided for Area 12 as regression slopes are significant. In Area 13 the slopes are not significant, so an argument could be made to use the mean. However, given that fleet sizes are increasing and harvest rates are increasing with fleet size, it would be more prudent to use the regression line for Area 13 as well. If a mean is used, then we need to decide which data (periods) should be used to construct the mean.

The results of the ANCOVAs (Tables 2-3) are interesting for a number of reasons. A statistically significant period effect is indicated when all levels of fishing were considered but this becomes not significant when the analysis is restricted to single-day fisheries. This may be due to combinations of any of the following reasons. First, fewer data points result in a weaker power test for the analysis of the one-day fisheries (there were only 3 one day fisheries in the earlier period). Second, there may be a bias in the reconstruction of harvest rate for multiple day fisheries, resulting in underestimates of harvest rate for the multiple day fisheries in the earlier period and apparent significant differences between periods. If there is bias in the reconstructed harvest rates for multiple day fisheries (possible underestimate of elemental harvest rates), then reconstructions of fisheries for the early 1980's would provide biased information, because of the predominance of multi-day fisheries during that time. Third, there may be differences in fleet or fish behaviour (in relation to the fleet) between multiple day versus single day fisheries. Fourth, there may be real differences in vessel power between the two periods. Certainly, there have been several improvements in fishing technology since that time (e.g. sounder technology, improved use of running lines, stern ramps).

Regardless of which of the above processes are responsible, there are several important facts. First, putting the statistical significance question aside, harvest rates have been higher in recent years than in the period from 1980-83, and they appear to increase in relation to fleet size. Second, the duration of fisheries has been shortened in recent years. Only 3 one day fisheries were scheduled in the early years, and only two fisheries longer than one day was scheduled in the recent years. These clearly indicate different approaches to management of these fisheries. Third, there are time trends in other factors in the Johnstone Strait fisheries (see Appendix L, Figure 1). Given these facts, we would conclude that harvest rates are higher in recent years and that they appear to increase in relation with effort. Further, these relationships between harvest rate and effort are different (higher) for the 1992-94 period than they are for the 1980-83 period. Therefore the 1992-94 harvest rate versus effort relationships should be used for pre-season planning and in-season assessment of run-size. If a mean harvest rate is used for Area 13 instead of a harvest rate versus effort relationship, the average for the 1992-94 period should be used.

The second interesting result from the ANCOVAs is that stock specific differences in the relationship are not evident. We believe this may be due to the error in the reconstructions being greatest at the beginning and end of a migration which would result in lack of resolution of any stock specific differences of harvest rate. Also, stock specific differences may be real for a specific fishery but show no consistency in pattern between fisheries. However, as indicated above, we believe there is evidence of small stock specific differences in harvest rate in 1994 (Table 1).

Two scenarios were reconstructed for 1994: 1) annual gross escapement of sockeye past Mission, as determined by the hydroacoustic program at Mission and 2) annual gross escapement of sockeye past Mission, as concluded by the Fraser River Sockeye Public Review Board findings (i.e. the total of DFO net escapement estimates plus Native fishery catches and en-route mortality). The above analyses of the reconstructions indicate that the second scenario may be more valid for late-run stocks. First, the reconstructed timing-abundance curves appear to be more "normal" and the elemental and weekly harvest rates are more easily reconciled. Second, the observations of reconstructed harvest rates for 1994 show less deviation from the 1992-93 relationship between elemental harvest rate and fleet size (Figure 12) stock specific differences in the relationship are less apparent for this scenario. Finally, the differences between "2-peak-week" summer and late-run harvest rates are less for this scenario. However, there is no evidence from the 1994 reconstructions for a systematic bias in historical estimates of gross escapement of summer-run stocks as determined by the hydroacoustic program at Mission.

References

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Table 1. Summary of elemental harvest rates of purse seine fisheries from run reconstructions of years of high Johnstone Strait diversion.

AREA	GEAR	DATE	STOCK	AREA 12 H.R.	EFFORT	DAYS FISH	AREA 13 H.R.	EFFORT	ACTUAL WEEKLY H.R.	PROJECT WEEKLY H.R.	
12	PS	28-Jul-80	CHLR	26.75%	134	1	31.54%	19	28.60%	32.97%	
12	PS	28-Jul-80	STEL	16.92%	134	1	17.10%	19	26.80%	20.42%	
12	PS	05-Aug-80	BIRK	42.54%	159	1	28.95%	53	42.56%	40.10%	
12	PS	05-Aug-80	CHLR	36.70%	159	1	22.16%	53	34.40%	34.13%	
12	PS	05-Aug-80	STEL	43.73%	159	1	25.41%	53	38.50%	39.15%	
12	PS	11-Aug-80	BIRK	45.90%	327	3	22.40%	75	74.80%	75.00%	
12	PS	11-Aug-80	CHLR	45.57%	327	3	27.30%	75	81.10%	77.61%	
12	PS	19-Aug-80	BIRK	25.69%	191	2	26.71%	156	52.20%	49.81%	
12	PS	19-Aug-80	CHLR	34.83%	191	2	20.05%	156	56.90%	51.94%	
12	PS	27-Jul-81	HORS	40.36%	180	2	21.06%	46	0.00%	55.87%	
12	PS	03-Aug-81	BIRK	47.96%	210	2	36.00%	55	50.30%	67.19%	
12	PS	03-Aug-81	HORS	41.93%	210	2	25.37%	55	61.60%	59.18%	
12	PS	03-Aug-81	LSTU	56.63%	210	2	27.76%	55	62.10%	66.85%	
12	PS	10-Aug-81	BIRK	41.53%	218	2	22.63%	104	48.30%	57.42%	
12	PS	10-Aug-81	HORS	51.02%	218	2	18.92%	104	53.10%	59.94%	
12	PS	10-Aug-81	LSTU	38.30%	218	2	15.87%	104	48.20%	51.38%	
12	PS	10-Aug-81	WEAV	53.13%	218	2	19.57%	104	49.70%	61.23%	
12	PS	17-Aug-81	BIRK	36.69%	288	2	17.57%	60	0.00%	51.52%	
12	PS	24-Aug-81	BIRK	41.13%	252	2	28.78%	103	61.80%	60.59%	
12	PS	24-Aug-81	WEAV	40.32%	252	2	18.24%	103	51.80%	54.11%	
12	PS	01-Aug-83	ADAM	40.32%	201	2	21.78%	22	60.20%	56.27%	
12	PS	01-Aug-83	BIRK	39.26%	201	2	29.49%	22	47.20%	59.96%	
12	PS	01-Aug-83	CHLR	29.00%	201	2	22.44%	22	51.60%	49.55%	
12	PS	01-Aug-83	STEL	33.38%	201	2	14.04%	22	47.20%	46.95%	
12	PS	08-Aug-83	ADAM	33.26%	237	3	39.33%	36	67.70%	77.27%	
12	PS	08-Aug-83	BIRK	24.33%	237	3	15.12%	36	70.50%	54.88%	
12	PS	08-Aug-83	CHLR	33.42%	237	3	17.65%	36	66.40%	64.46%	
12	PS	08-Aug-83	STEL	19.75%	237	3	15.03%	36	65.00%	50.15%	
12	PS	08-Aug-83	WEAV	41.18%	237	3	28.61%	36	81.40%	76.20%	
12	PS	15-Aug-83	ADAM	54.59%	276	1	36.06%	93	58.20%	48.54%	
12	PS	15-Aug-83	BIRK	41.78%	276	1	18.97%	93	58.80%	35.29%	
12	PS	15-Aug-83	CHLR	54.02%	276	1	32.33%	93	52.60%	46.82%	
12	PS	15-Aug-83	STEL	34.77%	276	1	26.27%	93	46.10%	34.96%	
12	PS	15-Aug-83	WEAV	64.31%	276	1	36.19%	93	73.20%	52.56%	
12	PS	21-Aug-83	ADAM	42.69%	206	3	25.22%	69	71.70%	75.07%	
12	PS	21-Aug-83	BIRK	48.93%	206	3	24.31%	69	67.40%	77.46%	
12	PS	21-Aug-83	WEAV	41.84%	206	3	23.96%	69	69.60%	73.90%	
12	PS	29-Aug-83	ADAM	47.41%	333	2	35.35%	67	85.10%	66.67%	
12	PS	03-Aug-92	CHIR	40.51%	119	1	14.31%	41	34.30%	32.47%	(a)
12	PS	03-Aug-92	STLK	42.86%	119	1	18.09%	41	38.10%	35.44%	(a)
12	PS	10-Aug-92	CHIR	43.65%	166	1	49.30%	80	56.30%	48.72%	(a)
12	PS	10-Aug-92	STLK	35.28%	166	1	34.46%	80	42.00%	38.79%	(a)
12	PS	17-Aug-92	CHIR	48.22%	210	1	26.85%	108	40.20%	41.92%	(a)
12	PS	17-Aug-92	STLK	56.84%	210	1	31.04%	108	47.80%	47.52%	(a)
12	PS	10-Aug-93	HORS	53.68%	288	2	34.55%	79	71.20%	68.83%	(a)
12	PS	10-Aug-93	LSTU	52.02%	288	2	27.89%	79	74.30%	65.14%	(a)
12	PS	16-Aug-93	HORS	74.91%	390	1	34.40%	81	60.10%	55.77%	(a)
12	PS	16-Aug-93	LSTU	73.45%	390	1	36.32%	81	60.66%	55.96%	(a)
12	PS	01-Sep-93	HORS	44.13%	131	2	26.21%	101	60.20%	60.75%	(a)
12	PS	01-Sep-93	LSTU	52.51%	131	2	26.99%	101	67.30%	64.90%	(a)

AREA	GEAR	DATE	STOCK	AREA 12 H.R.	EFFORT	DAYS FISH	AREA 13 H.R.	EFFORT	ACTUAL WEEKLY H.R.	PROJECT WEEKLY H.R.	
12	PS	08-Aug-94	ADAM	41.58%	237	1	24.71%	63	40.74%	39.38%	(a)
12	PS	08-Aug-94	CHHY	24.43%	237	1	22.88%	63	29.03%	28.28%	(a)
12	PS	15-Aug-94	ADAM	90.66%	313	1	56.38%	92	69.45%	67.80%	(a)
12	PS	15-Aug-94	CHHY	52.04%	313	1	32.89%	92	47.15%	46.42%	(a)
12	PS	22-Aug-94	ADAM	65.63%	325	1	35.99%	128	51.85%	53.56%	(a)
12	PS	22-Aug-94	CHHY	61.60%	325	1	30.43%	128	48.49%	49.76%	(a)
12	PS	31-Aug-94	ADAM	42.42%	241	1	34.52%	188	38.52%	43.20%	(a)
12	PS	31-Aug-94	CHHY	47.44%	241	1	42.16%	188	45.61%	48.63%	(a)
12	PS	08-Aug-94	ADAM	33.32%	237	1	23.75%	63	37.36%	34.34%	(b)
12	PS	08-Aug-94	CHHY	24.06%	237	1	22.54%	63	28.80%	27.90%	(b)
12	PS	15-Aug-94	ADAM	74.01%	313	1	40.61%	92	61.88%	57.98%	(b)
12	PS	15-Aug-94	CHHY	58.50%	313	1	36.65%	92	50.59%	50.69%	(b)
12	PS	22-Aug-94	ADAM	61.24%	325	1	35.79%	128	50.04%	51.77%	(b)
12	PS	22-Aug-94	CHHY	65.59%	325	1	36.05%	128	51.93%	53.56%	(b)
12	PS	31-Aug-94	ADAM	28.67%	241	1	24.56%	188	27.76%	31.44%	(b)
12	PS	31-Aug-94	CHHY	46.47%	241	1	40.90%	188	45.07%	47.70%	(b)

(a) Reconstructions using annual gross escapement of sockeye past Mission, as determined by the hydroacoustic program at Mission.

(b) Reconstructions using annual gross escapement of sockeye past Mission, as determined by the findings of the Fraser River Sockeye Public Review Board.

Table 2. Summary of analyses of covariance (general linear model) on the response of harvest rate with effort (covariate). Main effects of period (years) and stock are examined.

	Covariate:		............Main Effects...........				Interaction	
Analysis	Effort		Stock		Period		Stk*Period	
	F	P	F	P	F	P	F	P
1	19.5	<0.01	1.3	0.27	12.6	<0.01	0.2	0.66
2	1.0	0.31	4.2	0.05	10.6	<0.01	0.3	0.57
3	22.7	<0.01	0.2	0.65	5.2	0.03	1.3	0.26
4	1.0	0.32	0.5	0.49	5.2	0.03	0.8	0.38
5	18.2	<0.01	1.5	0.24	1.6	0.22	0.1	0.78
6	2.9	0.10	0.6	0.45	0.7	0.41	0.1	0.74

Analyses:

1) Area 12 Harvest rates reconstructed using hydroacoustic estimates of gross escapement at Mission. All fisheries.

2) Area 13 Harvest rates reconstructed using hydroacoustic estimates of gross escapement at Mission. All fisheries.

3) Area 12 Harvest rates reconstructed using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission. All fisheries.

4) Area 13 Harvest rates reconstructed using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission. All fisheries.

5) Area 12 Harvest rates reconstructed using hydroacoustic estimates of gross escapement at Mission. One day only fisheries.

6) Area 13 Harvest rates reconstructed using hydroacoustic estimates of gross escapement at Mission. One day only fisheries.

Table 3. Summary of analyses of covariance (general linear model) on the response of harvest rate with effort (covariate). Harvest rates reconstructed using in-season estimates of gross escapement at Mission. Main effects of period (years) and stock are examined.

Analysis	Covariate: Effort		............Main Effects........... Stock		Period		Interaction Stk*Period	
	F	P	F	P	F	P	F	P
1	24.9	<0.01	0.7	0.42	17.7	<0.01	0.7	0.43
2	3.4	0.07	2.4	0.13	15.6	<0.01	1.1	0.31
3	20.7	<0.01	0.6	0.44	3.2	0.10	0.0	0.90
4	3.7	0.07	0.4	0.84	1.7	0.20	0.8	0.39

Analyses:

1) Area 12: All fisheries.

2) Area 13: All fisheries.

3) Area 12: One day fisheries only.

4) Area 13: One day fisheries only.

Table 4. Summary of weekly harvest rates (Areas 12-13, all catches) for summer- and late-run sockeye. The harvest rates for the 2 peak weeks combined are also shown.

Scenario: Harvest rates reconstructed using hydroacoustic estimates of gross escapement at Mission.

Fishery	Summer Run	Chilko/Horsefly	Late Run
August 8	36.5%	33.6%	46.4%
August 15	48.7%	51.2%	71.9%
August 22	53.2%	54.6%	57.1%
August 31	46.2%	49.5%	42.5%
August 15-22 (Combined)	50.0%	52.2%	64.5%

Scenario: Harvest rates reconstructed using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission.

Fishery	Summer Run	Chilko/Horsefly	Late Run
August 8	36.8%	33.5%	43.0%
August 15	52.6%	54.5%	64.7%
August 22	57.1%	58.1%	55.1%
August 31	46.1%	50.0%	31.2%
August 15-22 (Combined)	53.8%	55.5%	60.1%

Table 5. Summary of elemental harvest rates of gillnet fisheries from run reconstructions of years of high Johnstone Strait diversion.

AREA	DATE	STOCK	HARVEST RATE	GEAR	AREA	DATE	STOCK	HARVEST RATE	GEAR
11	11-Aug-80	BIRK	0.56%	27	12	28-Jul-80	CHLR	2.94%	134
11	11-Aug-80	CHLR	0.21%	27	12	28-Jul-80	STEL	8.80%	134
11	11-Aug-80	STEL	0.17%	27	12	05-Aug-80	BIRK	1.81%	239
11	19-Aug-80	BIRK	2.98%	36	12	05-Aug-80	CHLR	2.22%	239
11	19-Aug-80	CHLR	0.32%	36	12	05-Aug-80	STEL	5.10%	239
11	03-Aug-81	BIRK	0.50%	8	12	11-Aug-80	BIRK	1.40%	307
11	03-Aug-81	HORS	0.33%	8	12	11-Aug-80	CHLR	0.48%	307
11	03-Aug-81	LSTU	0.07%	8	12	11-Aug-80	STEL	0.43%	307
11	10-Aug-81	BIRK	0.41%	14	12	19-Aug-80	BIRK	5.46%	136
11	10-Aug-81	HORS	1.02%	14	12	19-Aug-80	CHLR	0.44%	136
11	10-Aug-81	LSTU	0.98%	14	12	03-Aug-81	BIRK	4.17%	201
11	10-Aug-81	WEAV	0.38%	14	12	03-Aug-81	HORS	3.92%	201
11	17-Aug-81	BIRK	0.73%	5	12	03-Aug-81	LSTU	0.76%	201
11	24-Aug-81	BIRK	0.26%	12	12	10-Aug-81	BIRK	2.94%	142
11	24-Aug-81	WEAV	0.23%	12	12	10-Aug-81	HORS	7.18%	142
11	01-Aug-83	ADAM	5.89%	140	12	10-Aug-81	LSTU	7.08%	142
11	01-Aug-83	BIRK	2.46%	140	12	10-Aug-81	WEAV	2.90%	142
11	01-Aug-83	CHLR	2.40%	140	12	17-Aug-81	BIRK	6.71%	184
11	01-Aug-83	STEL	1.83%	140	12	24-Aug-81	BIRK	2.40%	95
11	08-Aug-83	ADAM	0.18%	45	12	24-Aug-81	WEAV	2.28%	95
11	08-Aug-83	BIRK	0.16%	45	12	01-Aug-83	ADAM	4.60%	221
11	08-Aug-83	CHLR	0.26%	45	12	01-Aug-83	BIRK	1.86%	221
11	08-Aug-83	STEL	0.15%	45	12	01-Aug-83	CHLR	2.75%	221
11	15-Aug-83	ADAM	0.11%	6	12	01-Aug-83	STEL	1.83%	221
11	15-Aug-83	BIRK	0.11%	6	12	08-Aug-83	ADAM	1.62%	208
11	15-Aug-83	CHLR	0.05%	6	12	08-Aug-83	BIRK	1.37%	208
11	15-Aug-83	STEL	0.13%	6	12	08-Aug-83	CHLR	3.45%	208
11	21-Aug-83	ADAM	0.07%	8	12	08-Aug-83	STEL	2.40%	208
11	21-Aug-83	BIRK	0.11%	8	12	15-Aug-83	ADAM	3.01%	299
11	29-Aug-83	ADAM	0.03%	3	12	15-Aug-83	BIRK	3.12%	299
11	03-Aug-92	CHIR	4.29%	270	12	15-Aug-83	CHLR	2.05%	299
11	03-Aug-92	STLK	5.62%	270	12	15-Aug-83	STEL	7.82%	299
11	10-Aug-92	CHIR	14.47%	700	12	21-Aug-83	ADAM	2.01%	136
11	10-Aug-92	STLK	11.06%	700	12	21-Aug-83	BIRK	2.31%	136
11	17-Aug-92	CHIR	8.13%	107	12	29-Aug-83	ADAM	0.69%	105
11	17-Aug-92	STLK	12.85%	107	12	03-Aug-92	CHIR	5.36%	149
11	10-Aug-93	HORS	5.60%	203	12	03-Aug-92	STLK	6.03%	149
11	10-Aug-93	LSTU	5.94%	203	12	10-Aug-92	CHIR	10.84%	866
11	16-Aug-93	HORS	6.06%	233	12	10-Aug-92	STLK	7.99%	866
11	16-Aug-93	LSTU	7.34%	233	12	17-Aug-92	CHIR	18.45%	499
11	28-Aug-93	HORS	0.20%	1	12	17-Aug-92	STLK	25.67%	499
11	28-Aug-93	LSTU	0.18%	1	12	10-Aug-93	HORS	3.33%	315
11	29-Aug-93	HORS	0.12%	1	12	10-Aug-93	LSTU	3.27%	315
11	29-Aug-93	LSTU	0.15%	1	12	16-Aug-93	HORS	7.27%	396
11	02-Aug-94	ADAM	5.40%	203	12	16-Aug-93	LSTU	7.86%	396
11	02-Aug-94	CHHY	5.43%	203	12	28-Aug-93	HORS	7.39%	469
11	08-Aug-94	ADAM	2.12%	214	12	28-Aug-93	LSTU	5.26%	468
11	08-Aug-94	CHHY	2.86%	217	12	29-Aug-93	HORS	8.38%	284
11	16-Aug-94	ADAM	2.91%	101	12	29-Aug-93	LSTU	9.26%	284
11	16-Aug-94	CHHY	4.94%	101	12	02-Aug-94	ADAM	3.78%	570
11	22-Aug-94	ADAM	1.54%	31	12	02-Aug-94	CHHY	2.49%	570
11	22-Aug-94	CHHY	2.70%	31	12	08-Aug-94	ADAM	1.42%	342
					12	08-Aug-94	CHHY	1.73%	342
					12	16-Aug-94	ADAM	2.17%	282
					12	16-Aug-94	CHHY	2.81%	282
					12	22-Aug-94	ADAM	3.06%	303
					12	22-Aug-94	CHHY	3.76%	303

1993-1994 Reconstructions calculated using annual gross escapement of sockeye past Mission, as determined by the hydroacoustic program at Mission.

Table 6. Summary of elemental harvest rates by weekly period for Area 11 troll fisheries.

Scenario: Harvest rates reconstructed using hydroacoustic estimates of gross escapement at Mission.

Period	**Chilko/Horsefly**	**Adams/Late run**
August 11-13	0.1%	0.3%
August 14-20	4.9%	7.3%
August 21-27	13.5%	11.1%
August 28- September 1	37.5%	33.8%

Scenario: Harvest rates reconstructed using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission.

Period	**Chilko/Horsefly**	**Adams/Late run**
August 11-13	0.2%	0.3%
August 14-20	5.3%	7.1%
August 21-27	13.6%	9.2%
August 28- September 1	37.3%	25.4%

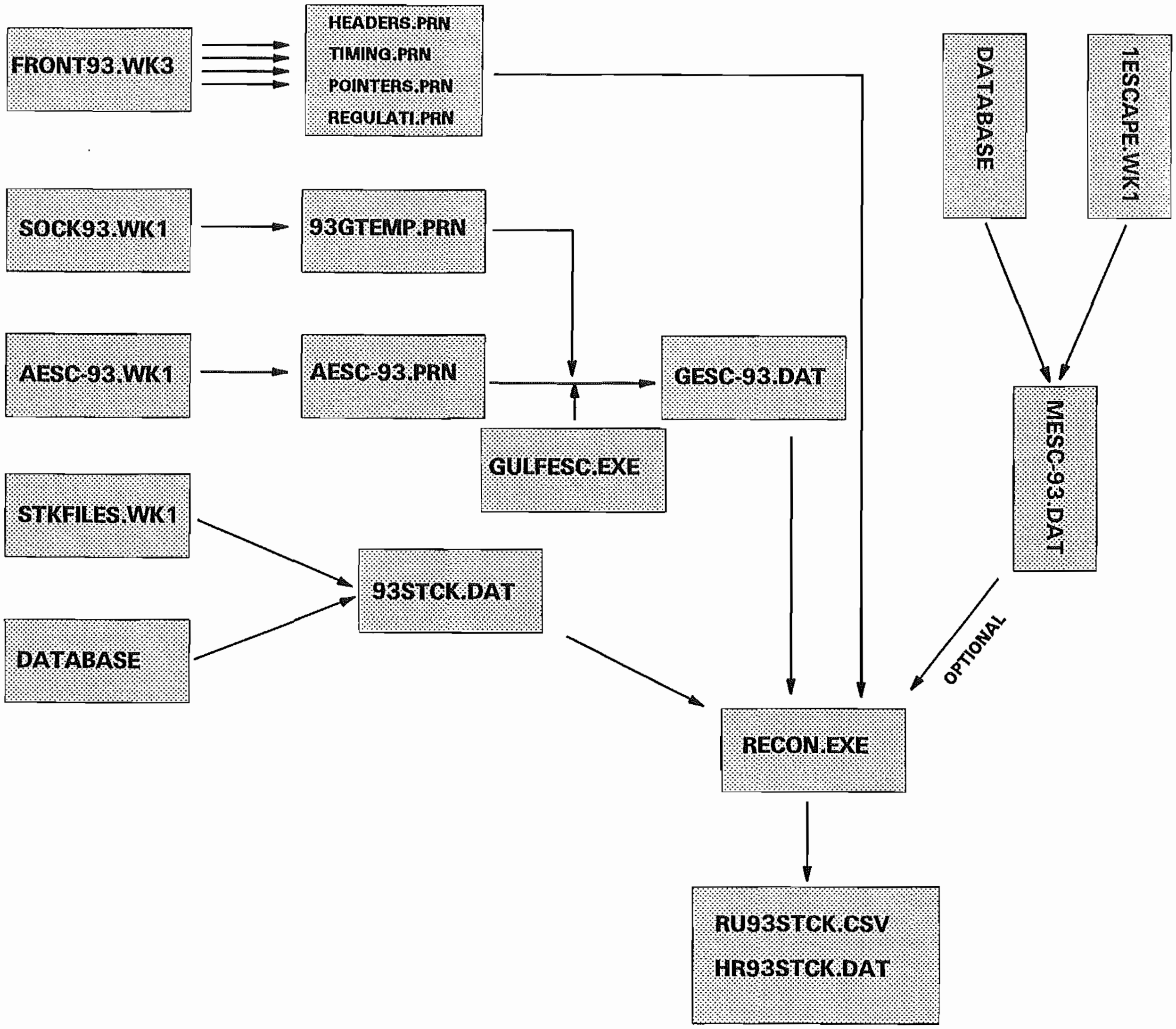

Figure 1. Schematic showing files and program control of backward reconstruction program.

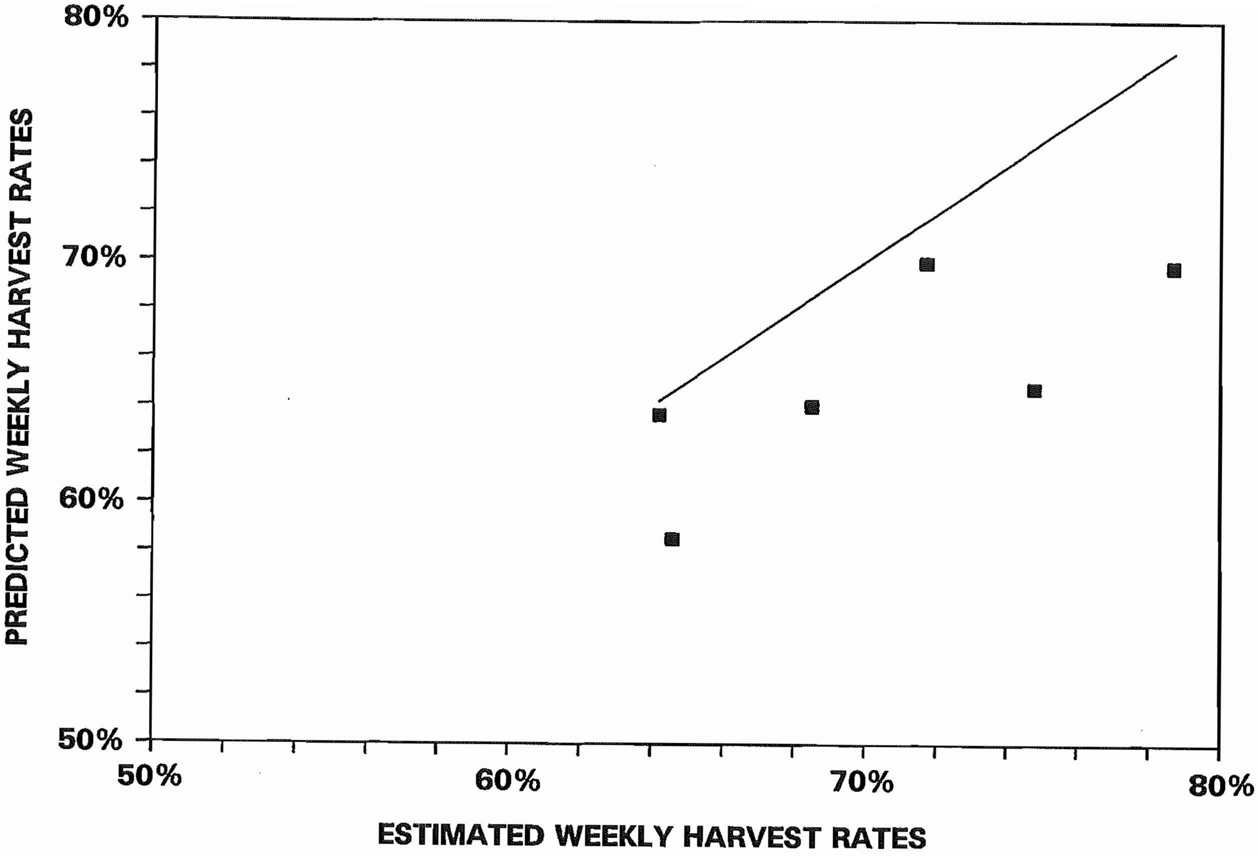

Figure 2. Relationship between the back-calculated weekly Area 12-13 seine harvest rate for 1993 as derived from the elemental harvest rates, and the estimated weekly harvest rates from the timing-abundance curves. Reconstructions are based on daily estimates of escapements at Mission. The 1:1 line is also shown. Points below the line indicate a negative bias.

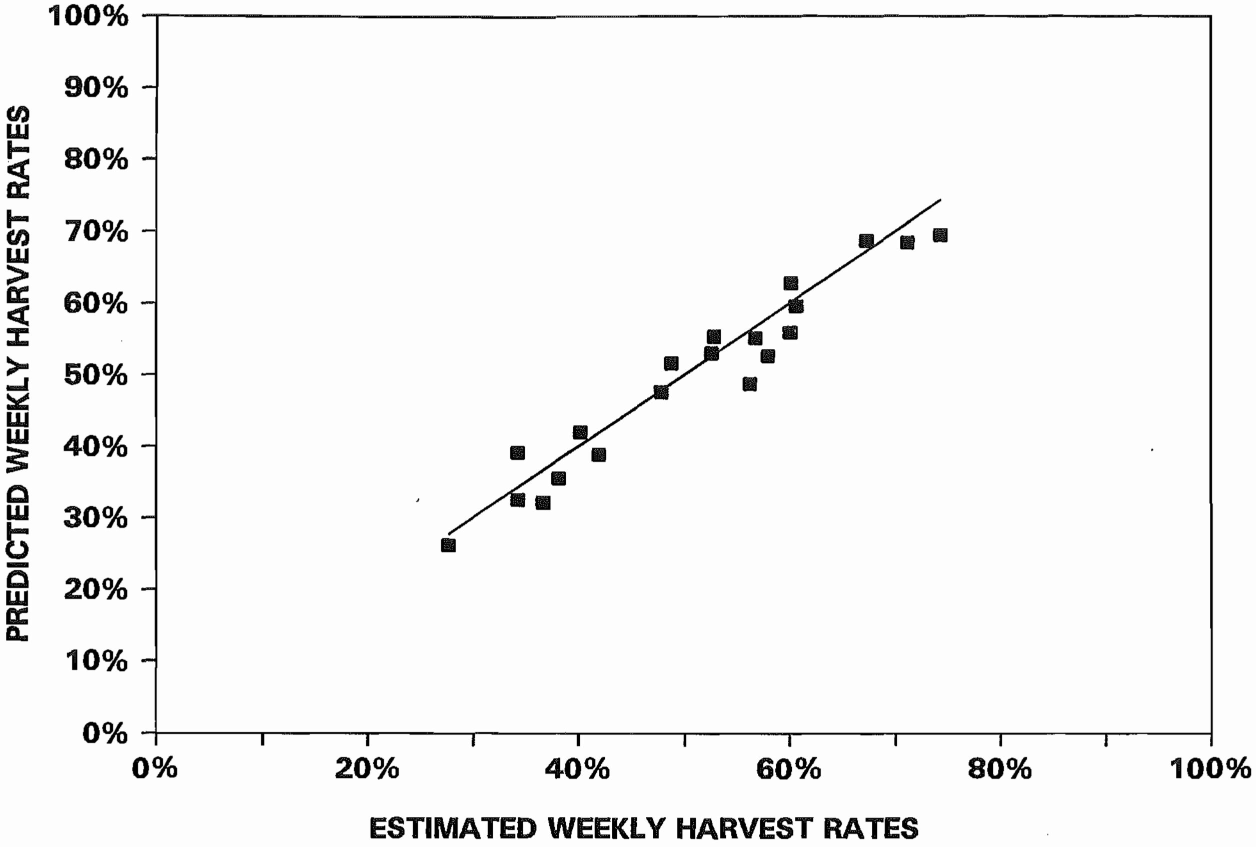

Figure 3. Relationship between the back-calculated weekly Area 12-13 seine harvest rate for 1992-94 as derived from the elemental harvest rates, and the estimated weekly harvest rates from the timing-abundance curves. Reconstructions are made using the "Strait of Georgia" option. The 1:1 line is also shown. Points below the line indicate a negative bias.

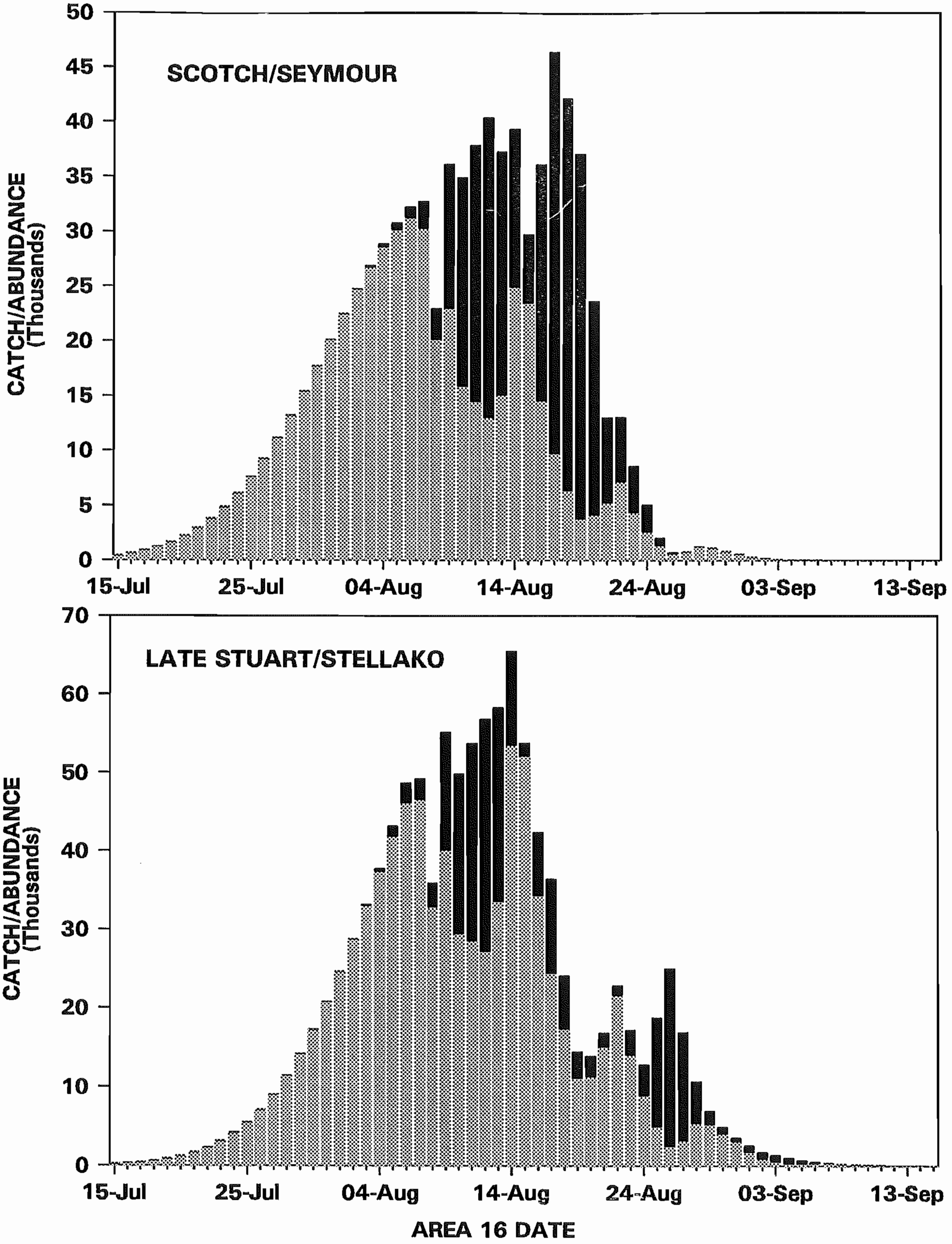

Figure 4. Reconstructed Scotch/Seymour and Late Stuart/Stellako migrations via Johnstone Strait for 1994 calculated using hydroacoustic estimates of gross escapement at Mission. The catch-by-migration-block-profiles (catch curves) are shown by the black bars and the escapement profile is shown by the light grey bars.

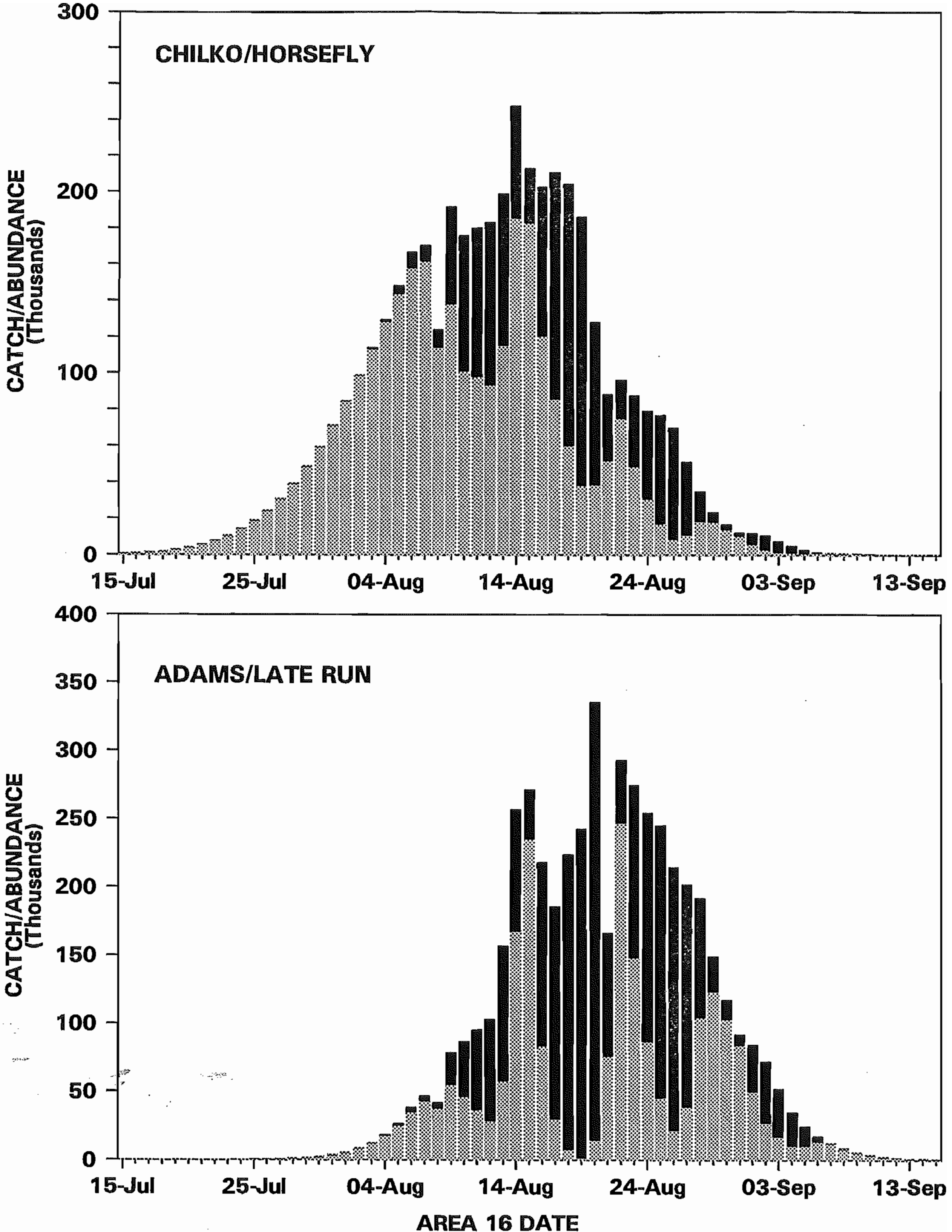

Figure 5. Reconstructed Chilko/Horsefly and Adams/Late-run migrations via Johnstone Strait for 1994 calculated using hydroacoustic estimates of gross escapement at Mission. The catch-by-migration-block-profiles (catch curves) are shown by the black bars and the escapement profile is shown by the light grey bars.

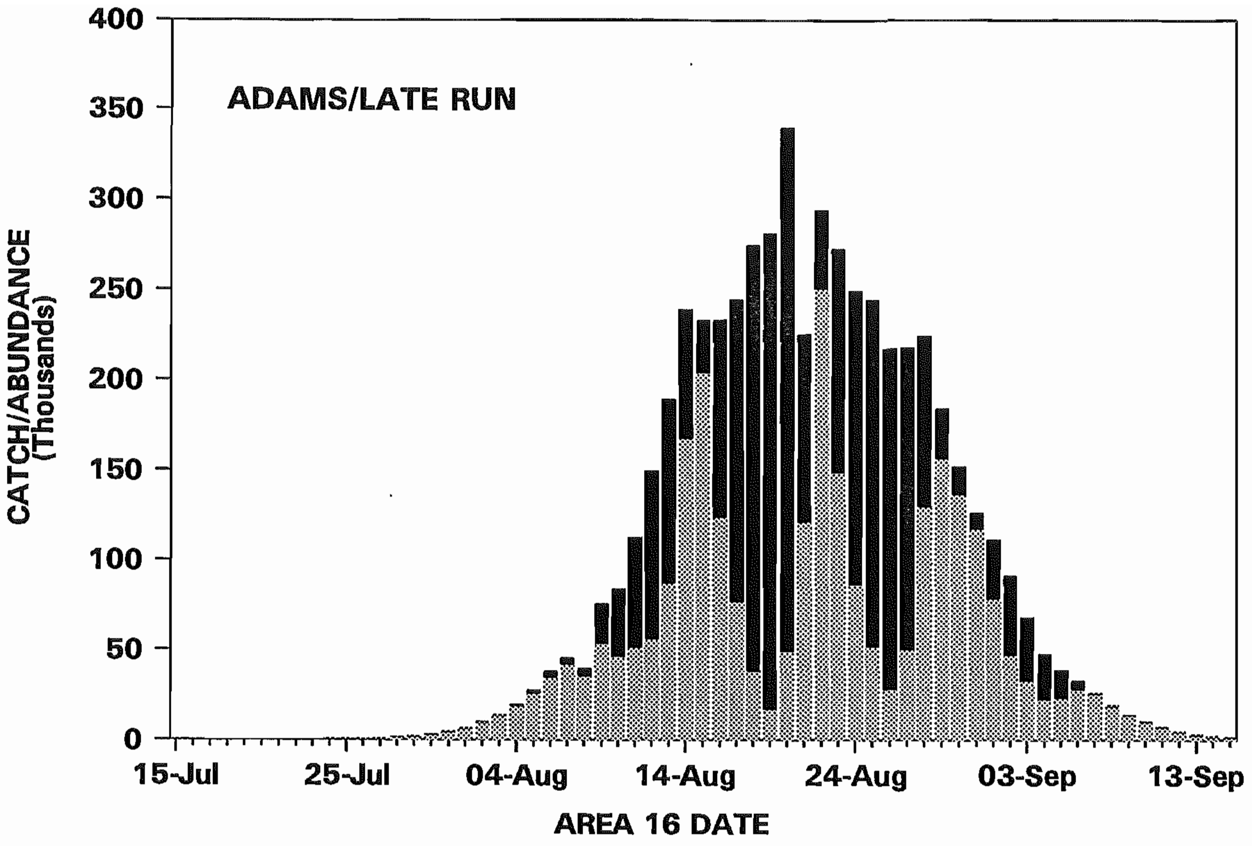

Figure 6. Reconstructed Chilko/Horsefly and Adams/Late-run migrations via Johnstone Strait for 1994 calculated using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission. The catch-by-migration-block-profiles (catch curves) are shown by the black bars and the escapement profile is shown by the light grey bars.

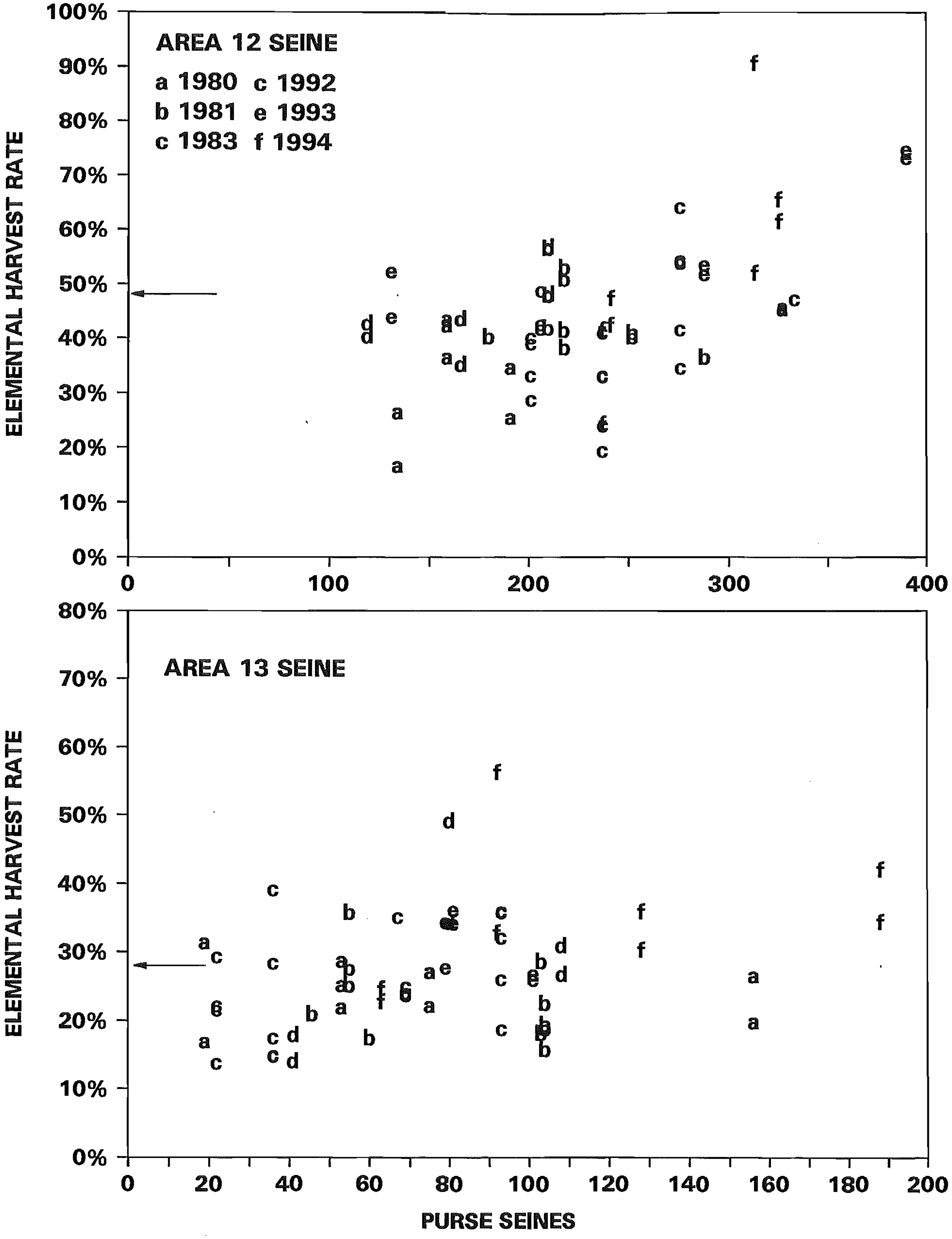

Figure 7. Scatter plot of reconstructed harvest rates for Area 12-13 seine fisheries. 1994 estimates were calculated using hydroacoustic estimates of gross escapement at Mission.

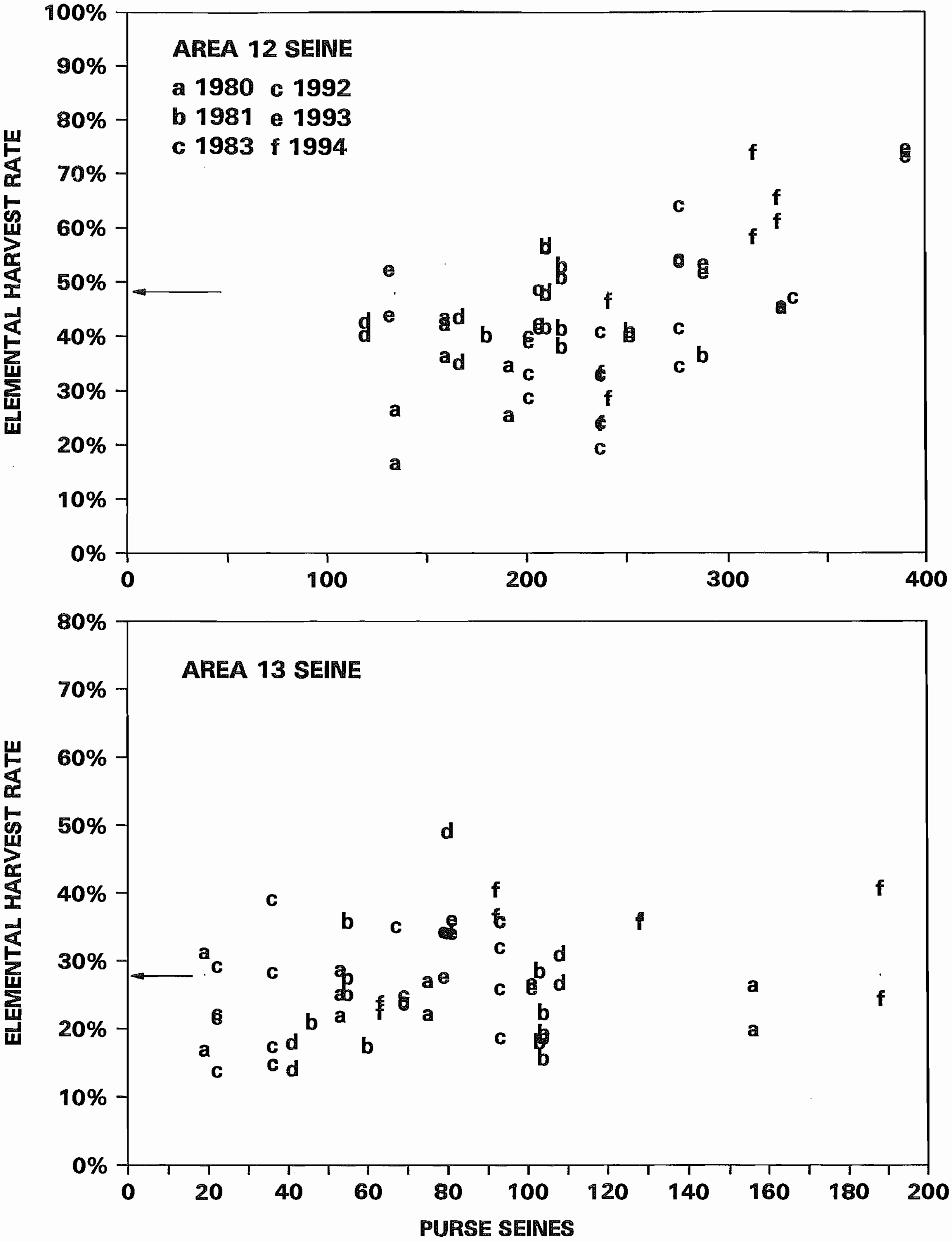

Figure 8. Scatter plot of reconstructed harvest rates for Area 12-13 seine fisheries. 1994 estimates were calculated using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission.

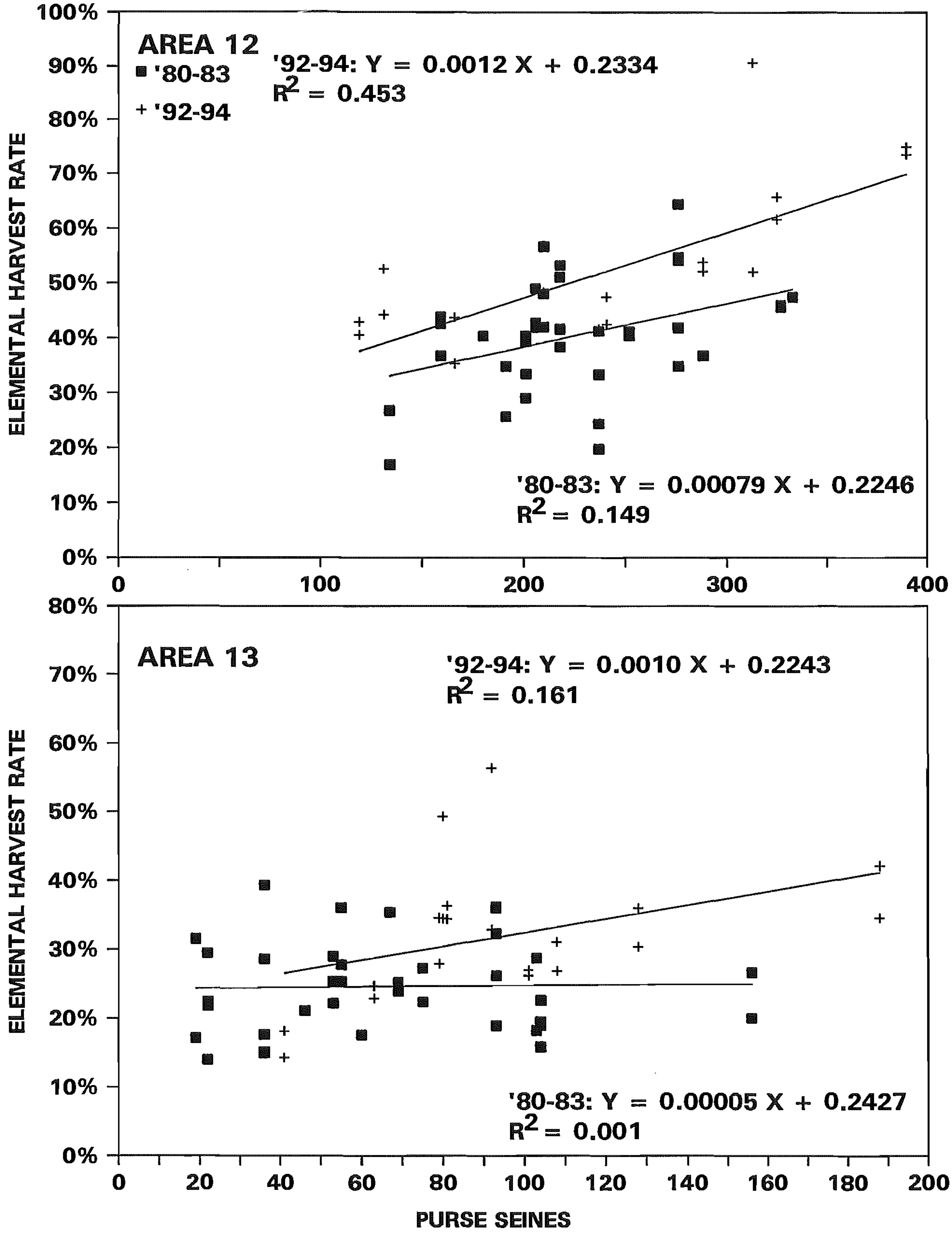

Figure 9. Relationship between harvest rate and fleet size for Area 12 and 13 purse seine fisheries. 1994 estimates were calculated using hydroacoustic estimates of gross escapement at Mission.

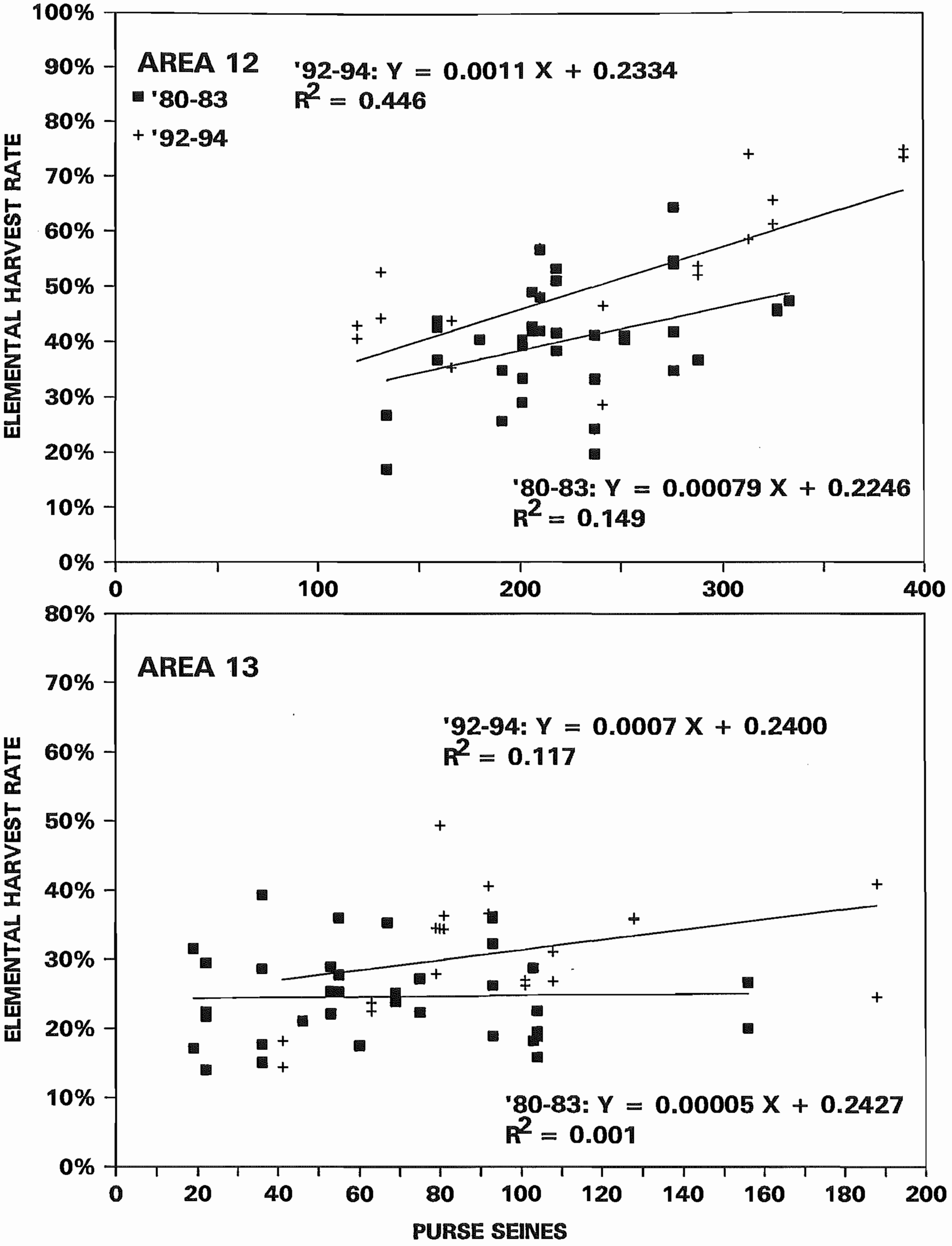

Figure 10. Relationship between harvest rate and fleet size for Area 12 and 13 purse seine fisheries. 1994 estimates were calculated using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission.

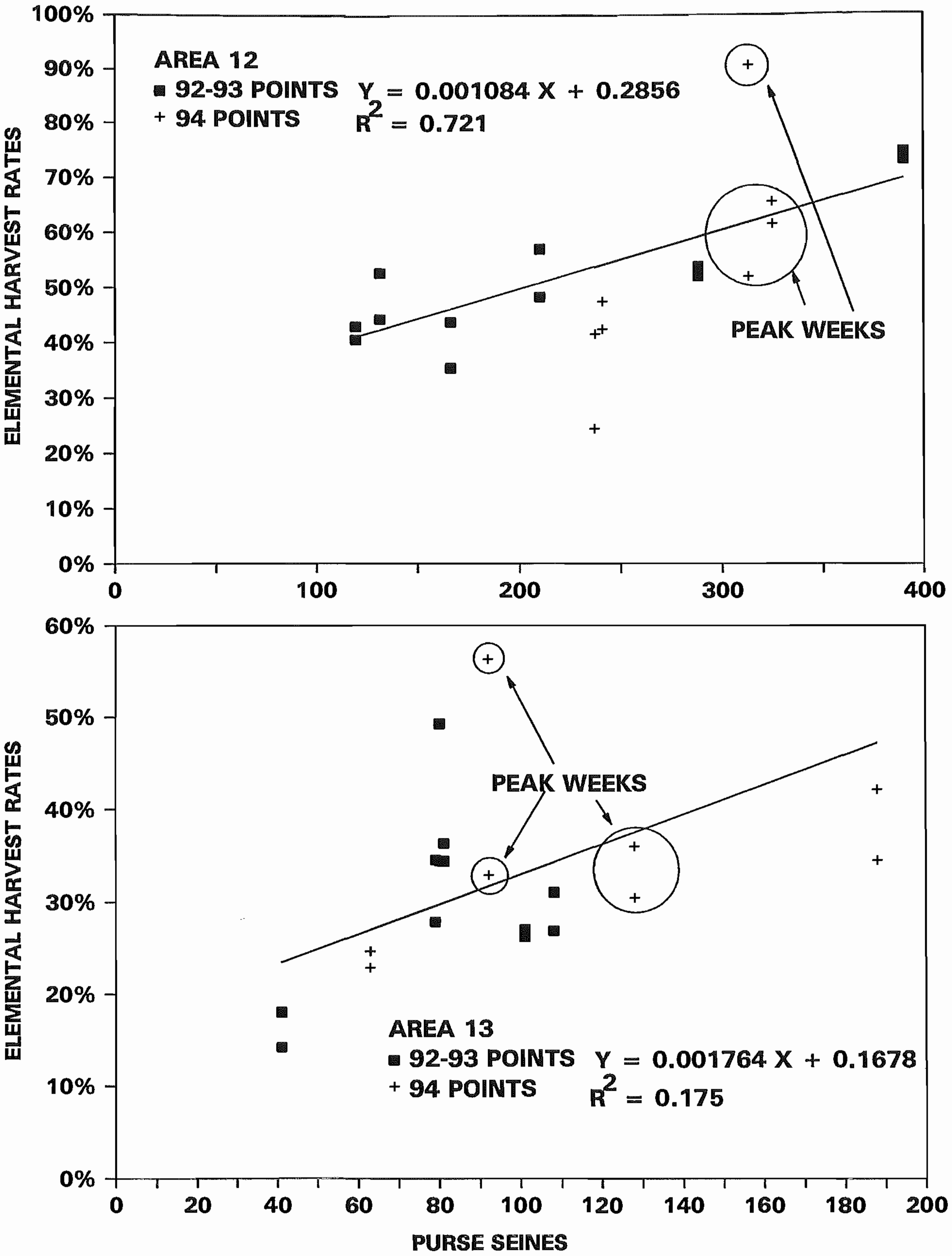

Figure 11. Relationship between harvest rate and fleet size for Area 12 and 13 purse seine fisheries for 1992-93 and comparison with the reconstructed harvest rates-fleet size estimates for 1994. The 1994 estimates were calculated using hydroacoustic estimates of gross escapement at Mission.

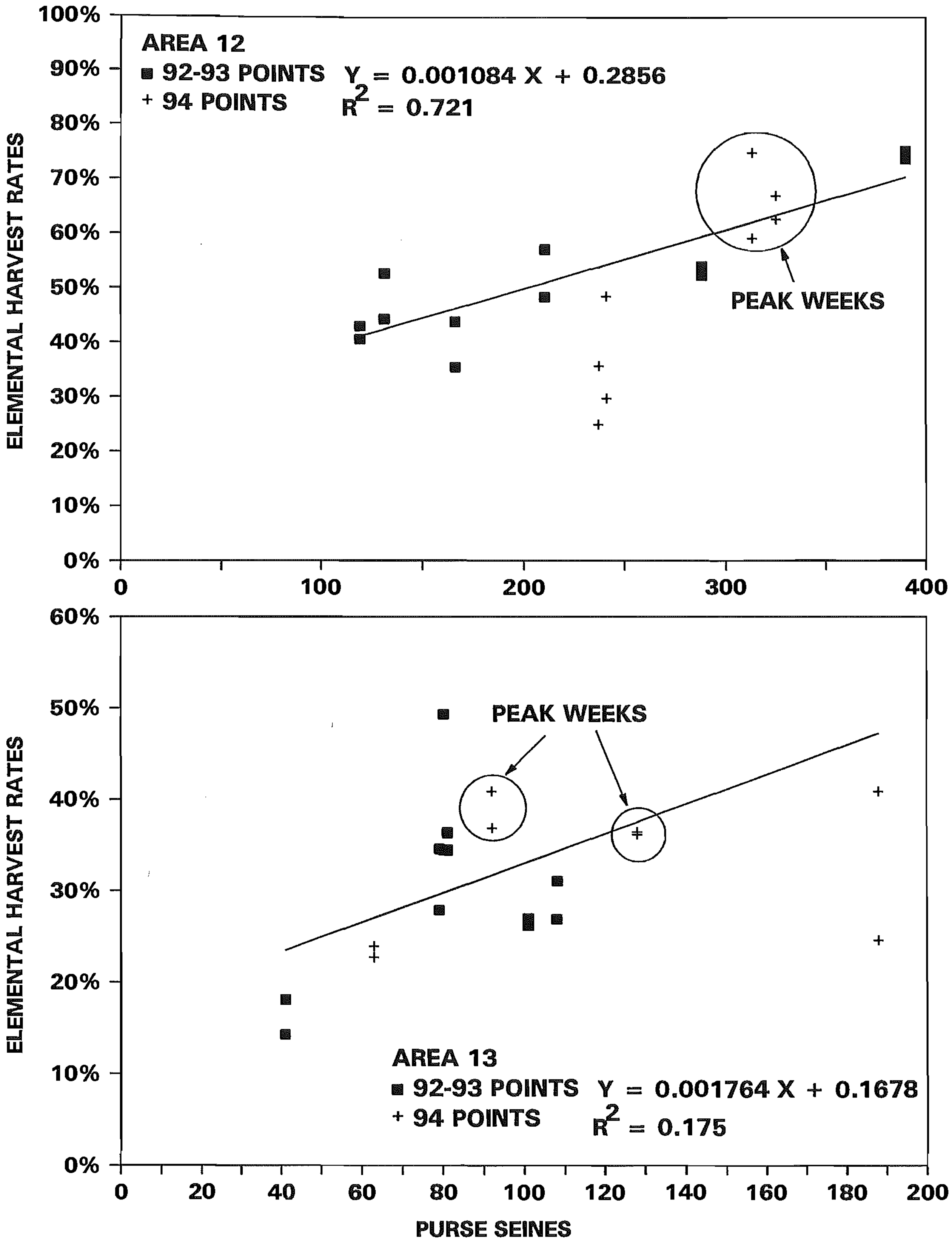

Figure 12. Relationship between harvest rate and fleet size for Area 12 and 13 purse seine fisheries for 1992-93 and comparison with the reconstructed harvest rates-fleet size estimates for 1994. The 1994 estimates were calculated using Fraser River Sockeye Public Review Board estimates of gross escapement at Mission.

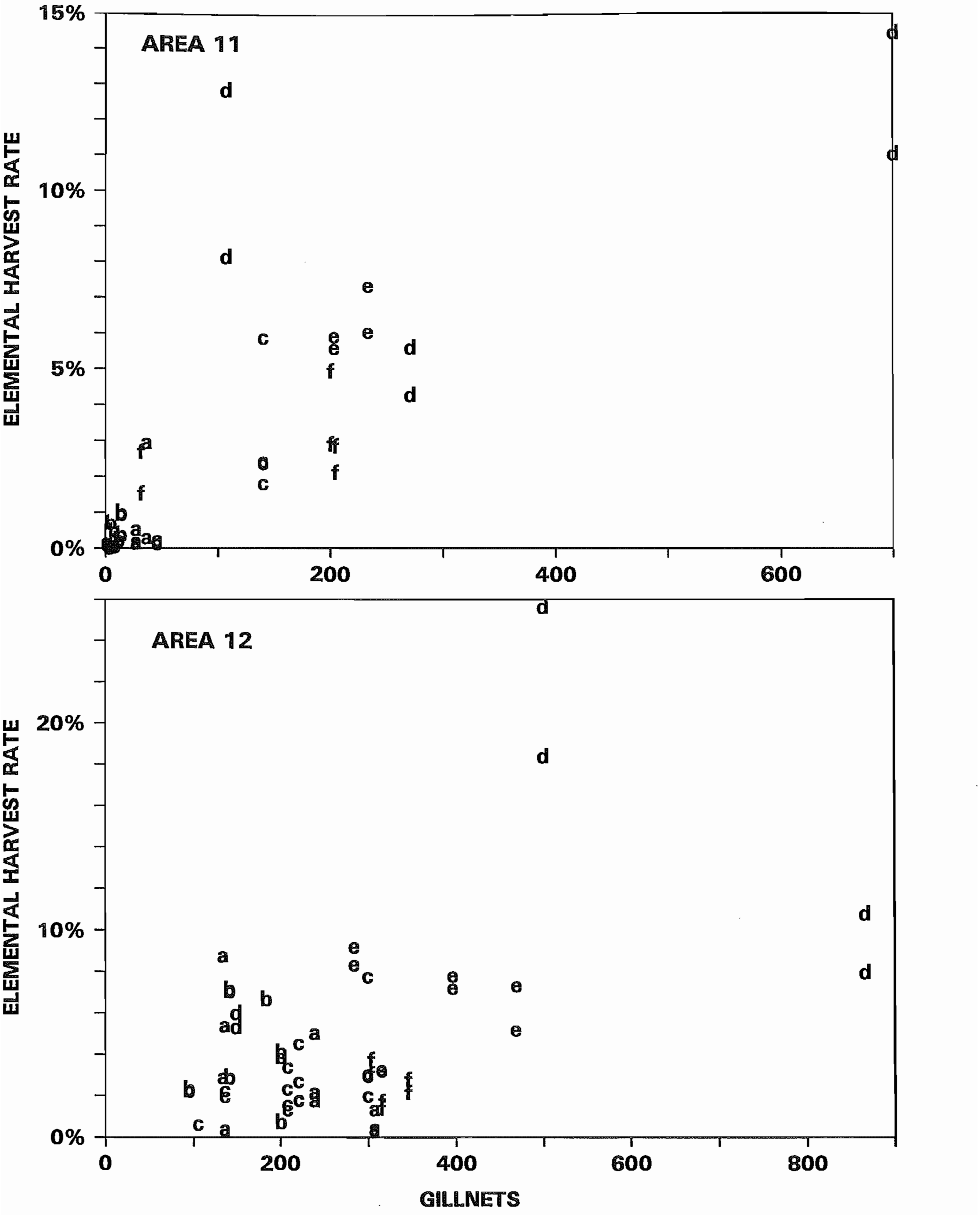

Figure 13. Scatter plots of harvest rates versus gillnet fleet size for Areas 11-12. The 1994 estimates were calculated using hydroacoustic estimates of gross escapement at Mission.

Appendix P: Migration Speed

PSC harvest rate based models of late-run abundance and escapement to the Strait of Georgia depend upon assumptions about migration speed between areas for different stocks. To investigate the potential impacts of assumptions about migration speed on our results we performed two types of analysis. First, we assessed migration speed between outside catch areas and the Fraser River by comparing catch and escapement profiles in the Fraser River (terminal area daily abundance) with identified catch removals in outside area fisheries. If the chronological order of daily migration blocks is maintained across areas, then fishery removals in outside area fisheries should be identifiable as "migration holes" in the terminal area abundance profile. In contrast, periods of lower migratory area catch should correspond to peaks in the terminal area abundance. A disruption in the chronological order of daily migration blocks, or significant delay off the mouth of the Fraser River, would cause a breakdown in the matching of peaks and valleys between the terminal area and outside migratory areas. Second, we simulated the effect of different migration rates through Johnstone Strait on estimated weekly harvest rates.

Historical Assessment of Migration Rates

Speed of migration for sockeye migrating via Johnstone Strait can only be assessed for years with high diversion rates. Therefore, data for recent high Johnstone Strait diversion years, 1992, 1993 and 1994 were assessed using run reconstructions as a means of comparing the migration profile of outside fishery removals to the migration profile of terminal area abundance. These reconstructions were performed using a daily time step. All catch and escapement data are lagged to a common below bridge timing date using historically developed speed of migration data (Gable and Cox-Rogers 1993). Thus, if peaks of catch correspond to valleys in escapement and vice versa, we can conclude that migrations speeds in the given year are consistent with assumed estimates based on historical data. The raw catch and escapement data are smoothed, using a 1-2-1 smoothing function, to compensate for artificial peaks and valleys introduced through inconsistencies in splitting weekly catch data into daily time steps. Speed of migration could only be examined in this manner for summer-run stocks because late-run stocks delay in the Strait of Georgia, prior to migrating up the Fraser River. This behaviour disrupts the chronological order of migration blocks and confounds the interpretation of migration rates.

1992 Summer-Run Migration

The Fraser River sockeye run in 1992 was comprised of, for the most part, summer-run sockeye stocks. In 1992, through most of the reconstructed summer-run migration, the migratory area catches were large relative to the terminal area abundance. This fact makes it difficult to match outside removals with daily terminal area escapement profiles, and few matching trends were evident (Figure 1). A small terminal area abundance peak occurred on August 7 (Below Bridge date), during a period of low migratory catch. Subsequently, migratory catch peaks on August 8 and 9 coincided with a drop in terminal area abundance. Following this early August period, migratory area catches were high throughout the season, while terminal area abundances tended to be relatively flat and stable (Figure 1).

In conclusion, due to the harvest patterns in 1992, the reconstructed summer-run migration curves do not provide evidence that the arrival patterns of escapement into the Fraser River were consistent with removal patterns in outside fisheries. The comparisons are made difficult by the fact that the migratory area catches during the peak two weeks of the summer-run migration, August 12 to August 24, were relatively constant. Therefore, the resultant migratory catch and terminal area escapement profiles were not highly variable.

1993 Summer-Run Migration

The 1993 summer-run was characterized by a strongly bi-modal migration profile. The first abundance peak occurred between August 16 and August 22 (Below Bridge dates), and the second peak between August 30 and September 2. The first series of peak abundances were heavily fished in outside migratory areas, resulting in a very flat terminal area abundance profile from early August through August 25. Subsequently, the migratory area fisheries were curtailed, and the terminal area abundance rapidly increased, coincidental with the second mode of summer-run abundance from August 27 to 31 (Figure 2). These patterns of migratory area harvests and terminal area escapements make it difficult to draw any conclusions about migration speeds.

However, some speed of migration data are available from the Area 12 purse seine test fishery, and subsequent arrival patterns in Area 29. Data presented in Figure 3 show consistent trends in the purse seine test fishery conducted at Robson Bight, and subsequent terminal area abundance. Therefore, for the second migration mode of summer-run fish in 1993, the speed of migration appeared to be consistent with our expectations based on historical data.

1994 Summer-Run Migration

During 1994, the reconstructed summer-run migration spanning from early August through August 25 provides evidence that high outside area catch resulted in drops in subsequent terminal area abundance, and that periods of reduced migratory area catch corresponded to increased terminal area abundance. For example, as outlined in Figure 4, migratory area catch peaks occurred on August 6, 12 to 15, and 19 to 21 (Below Bridge date). Generally, on these dates the terminal area abundance was low, relative to adjacent days. In contrast, the terminal area abundance was high, relative to adjacent periods, on August 4, 7, 10 to 11, 15 to 16, and 24 (Figure 4). These dates tended to coincide with periods of non-peak migratory area catches. These data provide evidence that the chronological order of summer-run migration was largely maintained between outside catch areas and the Fraser River, and that the speed of travel for the summer-run stocks was generally consistent with historical observations.

Independent evidence exists which indicates that a portion of summer-run fish delayed off the mouth of the Fraser River during the period from late July through early to mid-August (Appendix D). Consequently, the reconstructed terminal area abundance during this time period may be compromised.

Effect of Migration Rates on Weekly Harvest Rates and Run size Estimates in Johnstone Strait

We performed a simple simulation to determine the effects of differences in migration rates on weekly harvest rates and run size estimates in Johnstone Strait. We calculated weekly harvest rates for migration speeds through Areas 12 and 13 ranging from 3-7 days (our current assumption is 5 days) given a fixed "elemental" harvest rate of 50%. The elemental harvest rate, u, is defined as the harvest rate on a partially vulnerable migration block of fish (think of it as the harvest rate for a group of fish, just entering or leaving a fishing area at the start of a 24 hour fishery). The harvest rate, h, for the group of fish resident at the start of the fishery can be shown to equal $2u-u^2$ (Cave and Gazey 1994). Next we used these harvest rates to estimate the resulting run size estimates given a weekly catch of 1 million fish.

We illustrate how the elemental harvest rate is used to calculate weekly harvest rates for a migration time of 5 days, a single 24 hour fishery, and u=0.5 in Table 1. The value of 0.5 for u is not unreasonable; the estimate of u for Area 12 during the most recent year of high diversion with an abundant late run (1983, Adams subdominant year) is 0.48. Given a migration rate of 5 days, 4 daily migration blocks would be resident in areas 12 and 13, 1 migration block would be entering area 12 and 1 migration block would be leaving. With u=0.5, a 24 hour fishery would remove 50% of the migration blocks that are entering and leaving, and 75% (i.e. $2*.5 - (.5)^2$) of each of the 4 blocks that are resident. Thus, a total of 4 migration blocks would be removed. The weekly harvest rate is simply the number of daily migration blocks removed divided by the number of migration of daily migration blocks in a week, or 4/7=57.1%.

We repeated these calculations for other migration times (Table 2). For our example, increases in the travel time (decreases in the migration rate) of a single day results in an additional 0.75 migration blocks being removed by the fishery or an incremental increase of 10.7% (0.75/7) in the weekly harvest rate (Table 2). To illustrate how these differences in weekly harvest rates can affect run size estimates and resulting estimates of escapement to the Strait of Georgia, consider a weekly catch of 1 million fish. Run size is essentially estimated as Catch/Harvest Rate. If we assume 5 days travel time through Areas 12 and 13, the weekly harvest rate is 0.571 (Table 1) and the resulting run size would be 1,000,000/0.571, or about 1.751 million. A 4 day travel time would decrease the harvest rate and increase the run size by about 23% to 2.155 million. In contrast a 6 day travel time would increase the harvest rate and decrease the run size by about 16% to 1.472 million. These may seem like relatively small changes to the run size estimates. However, all of the changes to run size estimates are transferred directly into estimates of escapement to the Strait of Georgia because escapement is simply the run size - catch. Thus, for a 5 day travel time the estimate of escapement is 751,000. For a 4 day travel time the estimate would increase by 54% to 1.155 million and for a 6 day travel time the estimate would decrease by 37% to 472,000.

Note that for our simple example we have assumed that the abundance of fish in each migration block is the same and that u does not change with travel time. While relaxing these assumptions would affect the quantities in the tables, the main point is to illustrate that relatively small differences in travel times can have significant impacts on weekly harvest rates and resulting estimates of escapement to the Strait of Georgia. Such differences could exist between years for the same stock or between stocks within a year.

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Table 1. Example of use of elemental harvest rates to calculate weekly harvest rates for a hypothetical 1 day fishery in areas 12 and 13, assuming a migration time of 5 days and u=0.5.

Migration Block	Proportion removed by fishery	Calculation
Entering	0.5	u
Resident	0.75	$2u-u^2$
Resident	0.75	"
Resident	0.75	"
Resident	0.75	"
Leaving	0.5	u
Total number of blocks removed 4.0		
Number of daily migration blocks per week = 7.0		
Weekly Harvest rate = 4.0/7.0 = 57.1%		

Table 2. Effect of migration rate on weekly harvest rate assuming u=0.5.

Days to migrate through areas 12 & 13	Total no. of Migration blocks removed	Weekly Harvest Rate (%)
3	2.5	35.7
4	3.25	46.4
5	4.0	57.1
6	4.75	67.9
7	5.5	78.6

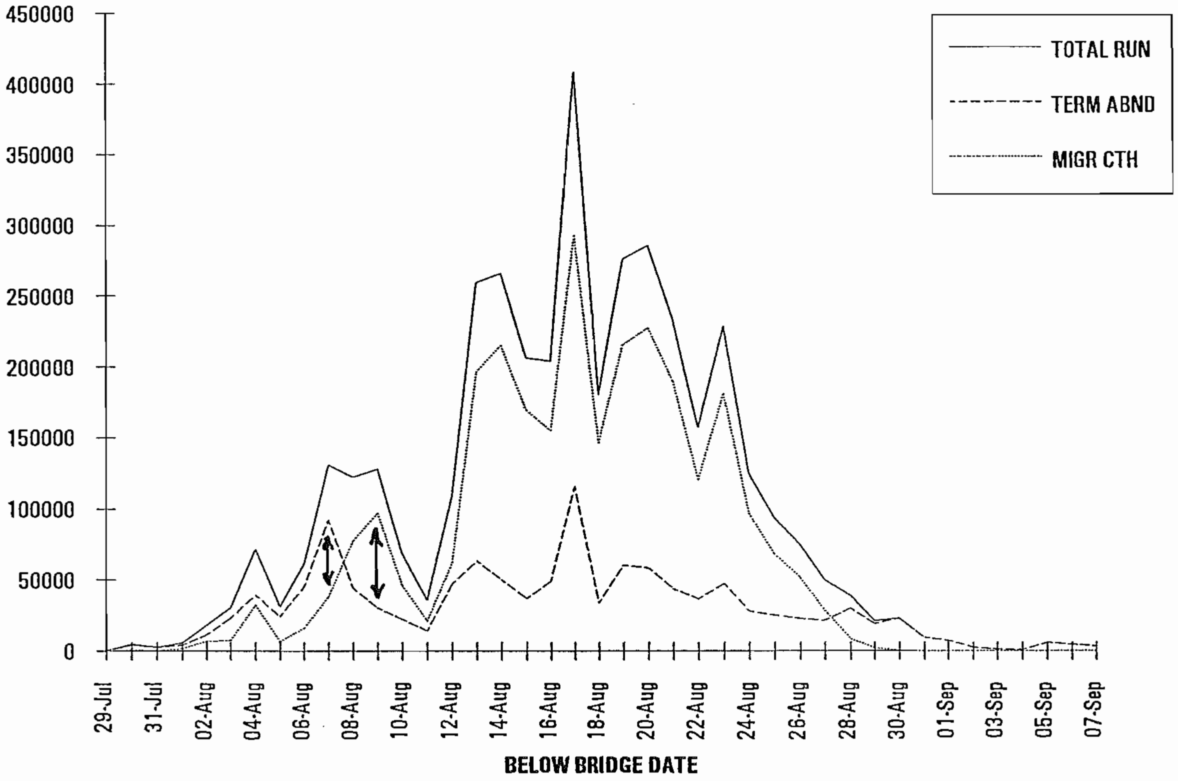

Figure 1. Reconstructed run (smoothed) for the 1992 summer-run migration.

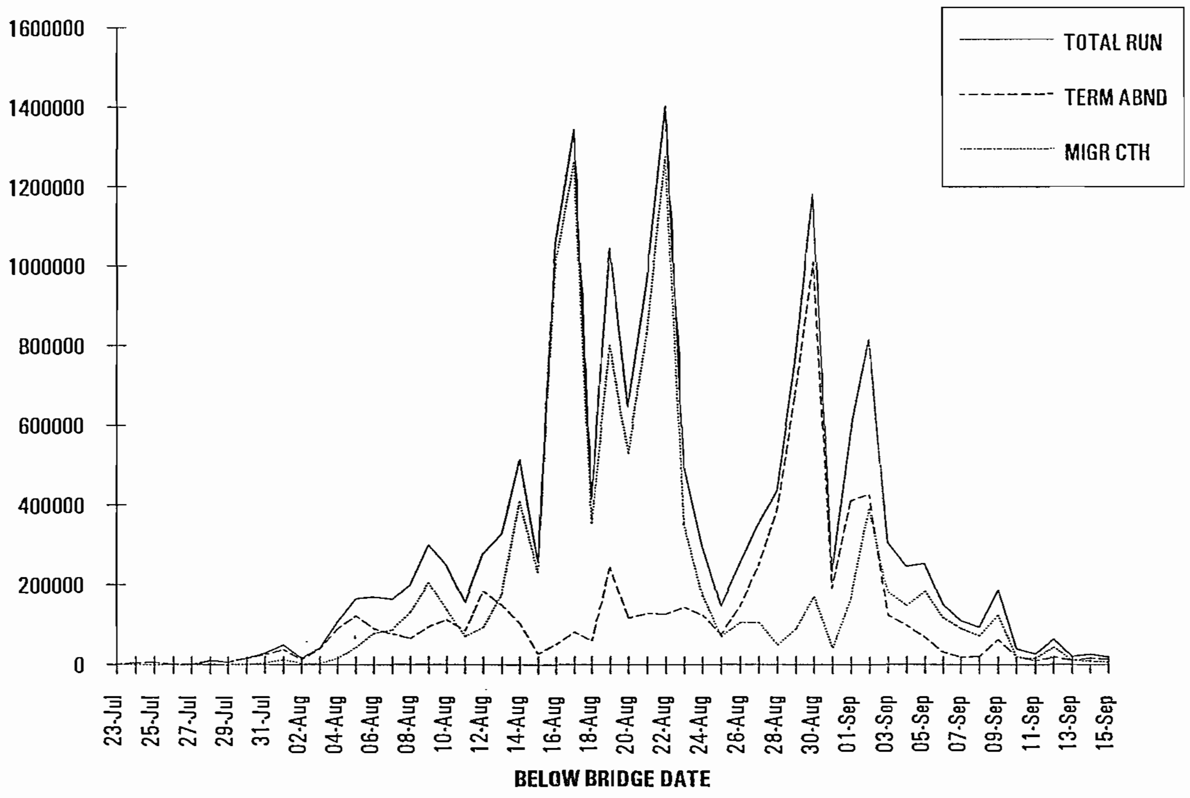

Figure 2. Reconstructed run (smoothed) for the 1993 summer-run migration.

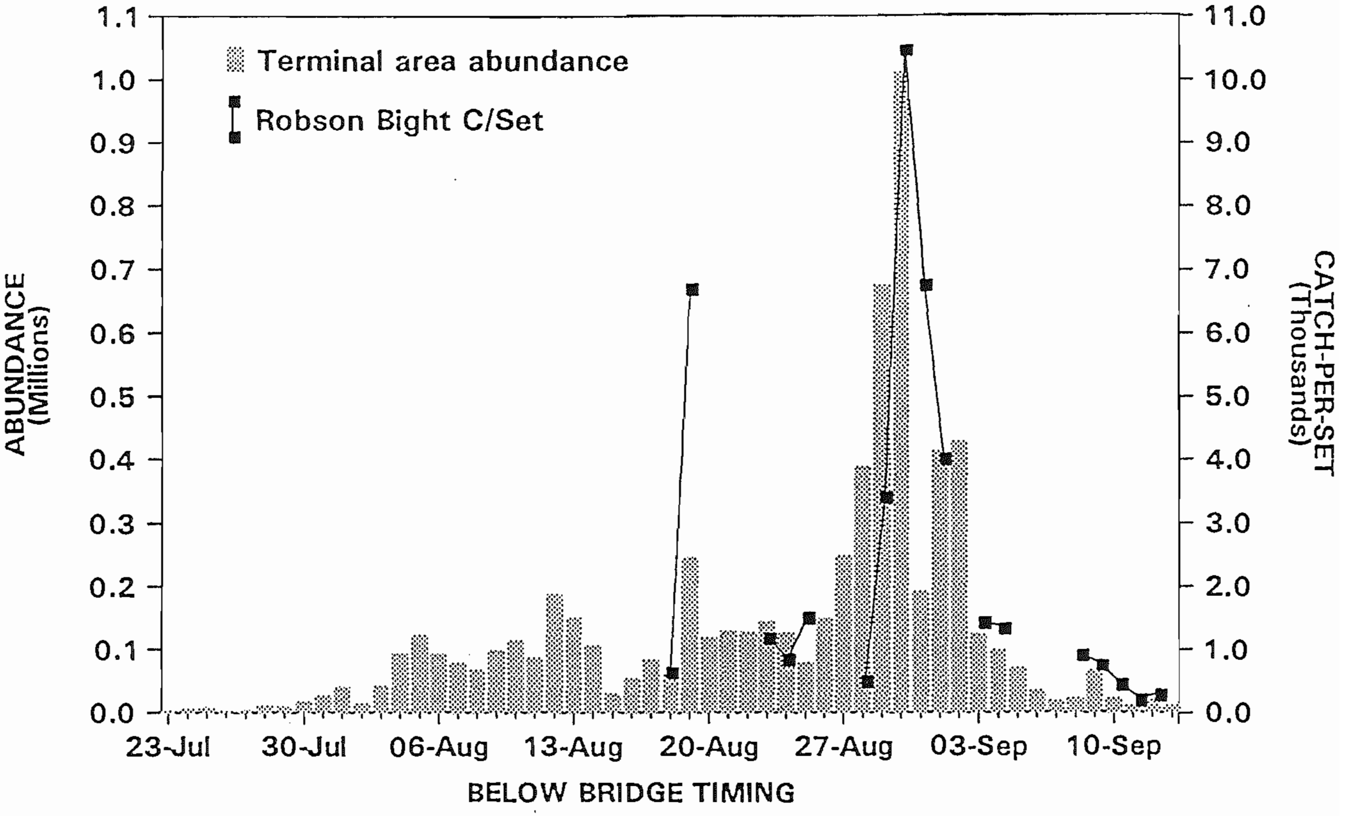

Figure 3. Purse seine test fishery catch-per-set at Robson Bight and terminal area abundance (Area 29) for 1993.

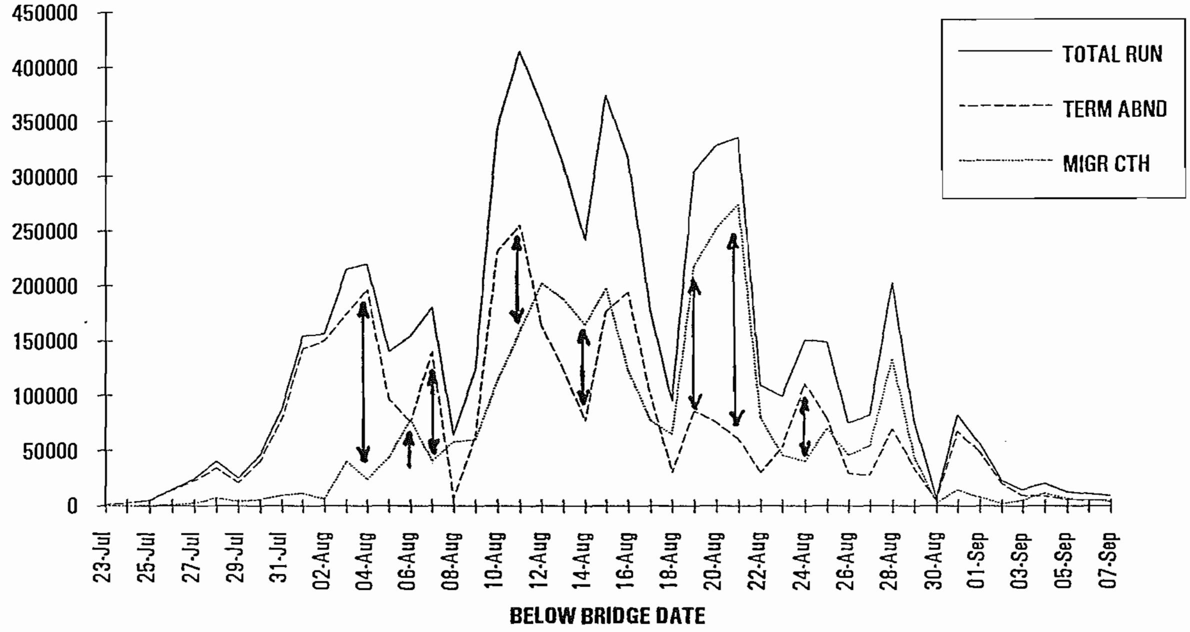

Figure 4. Reconstructed run (smoothed) for the 1994 summer-run migration.

Appendix Q: En-route Mortality: Potential Effects of *Heterosigma carterae* on Migrating and Delaying Late-Run Fraser Sockeye in Georgia Strait

Tim J. Tynan [2]

In the February 2-3, 1995 Pacific Salmon Commission "Workshop on Fraser Sockeye Run Size and Late-Run Escapement Estimation", participants identified potential causes of estimation error that may have led to the significant shortfall in escapement from anticipated levels of late-run sockeye to the Fraser River in 1994. Among other possible causes of the apparent shortfall, en-route mortality in marine waters was identified as requiring further investigation. Due to the magnitude of the escapement shortfall from expected levels, the timing of the late-run migration through inside waters, and the known occurrence of algal blooms harmful to fish in some years coincident with the timing of late-run sockeye migration, this examination of En-route mortality will focus on sockeye losses that may have occurred due to harmful algal blooms.

Introduction

Algal blooms harmful to fish and shellfish have become of growing concern worldwide. This increased concern has stemmed from the growth of fish and shellfish mariculture in areas where blooms have proven detrimental and increased public health concerns regarding the safety of seafood. Researchers in Washington and British Columbia have identified and studied several algal species that have been involved in mortality of aquaculture fish and, likely, wild fish in Puget Sound and Georgia Strait over the last decade (Gaines and Taylor 1986; Rensel et al 1988; Rensel et al 1989; Horner et al 1990; Black et al 1991; Taylor and Haigh 1993; Rensel 1995). The most severe fish kills in these areas have been attributed to *Heterosigma carterae*, a raphidophyte flagellate known worldwide as a fish killer (Rensel 1995).

Blooms of *Heterosigma* caused catastrophic mortality of net-pen fish in northern Puget Sound, near Cypress Island in 1989 and 1990, with fish losses estimated in the hundreds of thousands of pounds. There were reports of wild fish kills and wild fish acting in a distressed manner in several Puget Sound areas, mainly embayments, during the 1989 and 1990 blooms (Rensel 1995). In the fall of 1994, chinook, coho and summer chum as well as several marine fish species were killed by a *Heterosigma* bloom in northern Case Inlet in south Puget Sound (Rensel 1995). It is a shallow area where adult salmon normally hold prior to entering home streams feeding into the terminus of the inlet. Although dead adult chinook salmon were observed by boaters in Bellingham Channel during the 1989 bloom (Rensel 1995), nearly all of the fish mortality observed thus far associated with *Heterosigma* has occurred under conditions where fish are confined in shallow areas or in the upper 10 meters of the water column (e.g. in salmon net-pens) (R.J.T Taylor, pers. comm. 1995).

Heterosigma blooms have also been identified as the cause of net-pen salmon losses in British Columbia (Rensel et al 1989; Black et al 1991; Taylor and Haigh 1993). Taylor and Haigh (1993) report that *Heterosigma* blooms occur on an annual basis in B.C. waters, particularly within Georgia Strait and in Barkley Sound. Heavy losses of net-pen salmon in B.C. were apparently experienced during particularly severe *Heterosigma* blooms in 1986 and 1989. In October, 1994, a *Heterosigma* bloom

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on the mainland side of Queen Charlotte Strait caused a fish kill at a commercial net-pen operation (E. Black, pers. comm. 1995).

The physiological cause of fish mortality from *Heterosigma* is unknown, although severe gill epithelium damage resulting from contact with high concentrations of the cells, or an unknown icthyotoxin contained within the algae, have been implicated (Rensel et al 1989; Rensel 1995). Black et al (1991) reported no pathological abnormality to gills or other internal organs of fish exposed to *Heterosigma*, determining that a labile ichthyotoxic agent was the likely cause of death. Taylor and Haigh (1993) report that deaths of caged salmon in B.C. have resulted from exposure to blooms of *Heterosigma* when cell concentrations exceed several million per liter. The lethal cell concentration for fish is still unknown, however. The cells can be present in high concentrations in a non-toxic state and the mechanism by which *Heterosigma* becomes toxic is also unknown (J. Rensel, pers. comm. 1995).

The onset of mortality can be quite rapid when fish are exposed to high concentrations of the algae, when the algae are toxic. The 1989 bloom at Cypress Island in Puget Sound killed nearly all of the rearing salmon at two large net-pen sites in just a few hours, over a single ebb tide. In bloom mitigation studies with juvenile chinook in net-pens, Black et al (1991) reported 100 % mortality of fish exposed to *Heterosigma* blooms within 45 minutes at one site and within 200 minutes at another site. Dead and moribund adult fish were observed to sink directly to the bottom of the 10 meter deep holding pens during the 1989 Cypress Island event. Similarly, Black et al (1991) reported that juvenile chinook succumbing to contact with *Heterosigma* in their study also sank.

Bloom Development, Timing and Duration

Despite the large amount of oceanographic research done in Puget Sound waters, little is known about the temporal and spatial distributions, abundances and ecology of noxious phytoplankton species present there (Rensel et al 1989). The paucity of consistent, area-wide harmful algal bloom monitoring prevents prediction of bloom development and limits the ability to determine when, where and under what conditions deleterious blooms occur on a reliable basis. However, researchers and mariculturists in B.C. and Washington have expanded the extent of knowledge in recent years regarding harmful bloom development, including identification of conditions that lead to *Heterosigma* bloom proliferation (Rensel 1989; Horner et al 1990; Taylor and Haigh 1993).

As mentioned above, *Heterosigma* blooms have been documented to occur on an annual basis in Georgia Strait, appearing there with great regularity in the late spring since 1967 (Taylor and Haigh 1993). Blooms of this algae have been shown to be seeded from shallow areas in the vicinity of the Fraser River plume (e.g. English Bay area) with spread of the bloom accomplished by Fraser-influenced currents in Georgia Strait (Taylor and Haigh 1993). Blooms are generally advected northward by Fraser currents up the mainland side of Georgia Strait and the entire Strait can eventually become affected (Taylor and Haigh 1993). *Heterosigma* concentrations during some years have been observed to exceed 500 million cells per liter (Taylor and Haigh 1993).

The detrimental *Heterosigma* bloom in Puget Sound in 1989 was apparently associated with the Fraser River plume in northern Puget Sound (Rensel 1995). Although their paper focuses on bloom development in Georgia Strait, 1991 data presented in Taylor and Haigh (1993) indicate that *Heterosigma* blooms originating in the Fraser River vicinity are also advected southward, leading to high cell concentrations in the northern San Juan Islands in some years.

The appearance and development of *Heterosigma* blooms in Georgia Strait coincides with a rise in water temperature above 15°C and a decline in surface salinity to less than 15 ppt (Taylor and Haigh

1993; R.J.T. Taylor, pers. comm. 1995). Run off from the Fraser River contributes to proliferation of the bloom, by stratifying the water (increasing surface residence time for the algae) and possibly by contributing iron and other required micronutrients (Taylor and Haigh 1993). Blooms intensify as they are advected northward (R.J.T. Taylor, pers. comm. 1995). *Heterosigma* blooms that occurred in Puget Sound in 1989 and 1990 apparently required quiescent water conditions prior to bloom proliferation, with strong vertical stratification of the water column due to freshwater run-off and perhaps solar heating seeming to be prerequisites (Rensel 1995).

Heterosigma blooms are believed to be generally confined to surface waters, to a maximum depth of 5 to 10 meters (Rensel 1995; R.J.T. Taylor, pers. comm. 1995; J. Rensel, pers. comm. 1995), and observed fish mortalities have been associated with fish holding or entrained in those areas. This species, however exhibits strong diel vertical migration, and is capable of moving up to 1 meter/hour to obtain nutrients from subsurface depths (Taylor and Haigh 1993; Rensel 1995). Blooms can also be mixed into deeper waters in highly turbulent channels (R.J.T. Taylor, pers. comm. 1995) and by winds (J. Rensel, pers. comm. 1995) and high cell concentrations have on occasion been found at depths greater than 10 meters.

The duration of *Heterosigma* blooms each season is dependent on the persistence of stratification in the Strait of Georgia (Taylor and Haigh 1993). Blooms usually develop in May or early June near the mouth of the Fraser River, in the vicinity of English Bay, coinciding with progressive warming of waters from 10oC to 15oC and the time of maximum run-off and greatest development of the Fraser plume (Taylor and Haigh 1993; R.J.T. Taylor, pers. comm. 1995). Blooms have been reported to last as long as four months, with the bloom in 1989 continuing from June through October and into November in some locations (Taylor and Haigh 1993).

Heterosigma Bloom Occurrence in Georgia Strait in 1994

Dr. F.J.R. Taylor from the Department of Oceanography, University of British Columbia was consulted regarding *Heterosigma* bloom formation in Georgia Strait in 1994. Dr. Taylor reported that his sampling work in lower Georgia Strait did not detect a major *Heterosigma* bloom in that area during the spring or summer last season. Run-off from the Fraser River in 1994 during the normal peak in May was lower than in previous years, and surface salinities remained high as a result. Although water temperatures were high, high surface salinities present did not create a stable, stratified water column in the lower Strait. The surface water residence conditions necessary for a large bloom to develop in the vicinity of the Fraser River were therefore lacking in 1994. Dr. Taylor noted that because *Heterosigma* bloom monitoring last year was confined to the lower Georgia Strait area, blooms forming in inlets tributary to the Strait, and in northern portions of the Strait, may have gone undetected.

According to Dr. Taylor, this was the second consecutive year that conditions in lower Georgia Strait were not conducive to development of a large bloom. Until 1993, large, June blooms of *Heterosigma* had been considered the norm, as they had occurred on an annual basis for prior years (since 1967). It is thought that warm-water episode or "El Niño" years do not present the conditions necessary for significant *Heterosigma* blooms to develop in lower Georgia Strait. Dr. Taylor is interested in what will occur in 1995, as it appears that warm-water conditions in Georgia Strait may again predominate, but, in contrast to the last two years, salinities may drop this spring to optimal levels for *Heterosigma* bloom development due to a healthy snow-pack in the Fraser drainage.

Migration Timing and Holding Area of the Late Adams Sockeye in Georgia Strait During 1994

The timing of sockeye migration and holding in the Strait of Georgia and the depths where the fish hold prior to the onset of migration into the river are important factors in the assessment of their susceptibility to a deleterious *Heterosigma* bloom.

The normal timing of the peak of the late Adams sockeye run in the Strait of Juan de Fuca (Area 20) is August 22. Pacific Salmon Commission staff indicated that the 1994 late-run migration through Area 20 peaked on August 18, which is four days earlier than normal. Post-season run reconstruction data for the 1994 late Adams run prepared by PSC staff suggest that the run peaked in Georgia Strait on or about August 20 (Cave, unpublished data 1995). The estimated peak upstream movement of late Adams fish in 1994 was September 24 at Mission and September 29 at Hell's Gate. From these timing estimates, it appears that late Adams sockeye migrated into Georgia Strait and held at the mouth of the Fraser River for about four weeks in 1994.

The area of Georgia Strait where sockeye concentrate prior to entering the Fraser covers approximately 1000 km^2. Average depths in this area are greater than 100 m (Levy et al 1991). Levy et al (1991) report that the intra- and inter-annual variability in the location of sockeye concentrations in the Strait is largely unknown, and hydroacoustic data showed a wide and patchy distribution of delaying fish in the Gulf. Gilhousen (1960) indicated that delaying sockeye slowly wander southern Georgia Strait within the area where Fraser River discharge is present in the form of a distinct brackish layer at the surface. The sockeye do not approach the Fraser mouth when they first arrive in the Fraser Delta, but keep to deeper, clearer waters beyond the edge of the tidal flats, moving onto the flats close to the time of river entry (Gilhousen, 1960).

In most years, a constant body of delaying sockeye can be found off the mouth of the Fraser River from the Lightship north to the flats (I. Todd, pers. comm., 1995). This observation is consistent with sockeye concentration behavior reported in Levy et al (1991), which showed a marked tendency for fish to concentrate along the Fraser Delta side of the Strait of Georgia. Fish concentrations found in this area were thought to reflect a progressive concentration and delay pattern of sockeye off the mouth of the Fraser River (Levy et al 1991). In 1994, sockeye were observed holding to the south of the river mouth and not in the previously mentioned area. This may not have been an artifact of fish behavior changes however, but may instead have been a reflection of the low abundance of late-run sockeye actually present in the Gulf last season.

The vertical distribution of late-run sockeye delaying in the Gulf of Georgia is variable, and appears to be related to degree of maturity of delaying fish, river and estuarine tidal and water quality conditions and perhaps time of day. Night-time hydroacoustic studies conducted in the Gulf in 1986 to assess late-run abundance found maximum sockeye densities at 15-25 meters (Levy et al 1991). Levy et al (1991) theorized that the high sockeye densities at these depths may be a result of holding behavior prior to freshwater migration. Gear used for the 1986 study prevented sampling in inter-tidal and shallow sub-tidal areas, however, and vertical profile data showing highest densities in the 15-25 meter range may be biased (Levy et al 1991). Day-time tracking of ultrasonically tagged sockeye in another study reported within Levy et al (1991) indicates that the fish are in a depth zone below 5 meters approximately 80% of the time. Trollers fishing in the Gulf of Georgia (Area 29) typically have greatest success capturing sockeye at a depth range of 10-30 fathoms, centered at 20 fathoms (I. Todd, pers. comm. 1995).

Discussion

Available data regarding the apparent lack of development of a *Heterosigma* bloom in lower Georgia Strait in 1994 would indicate that significant mortality of delaying sockeye from this algae in the Gulf was not likely last season. The depths in the Gulf at which the majority of sockeye have been reported to hold, and their assumed ability to move to greater depths to avoid high cell concentrations, would also decrease the likelihood of massive mortalities from normally surface water-oriented *Heterosigma* blooms.

The large number of unknowns associated with the geographic and vertical distributions of this algae, combined with the lack of consistent annual monitoring of bloom development across all sockeye migration and holding areas and time periods in Georgia and Johnstone Straits, lends caution to the above assessment. As it now stands, significant late-run sockeye mortalities from a harmful *Heterosigma* bloom would likely go undetected, due to lack of area-wide bloom monitoring and the observation that salmon succumb very rapidly to toxic concentrations of the algae and sink upon dying.

Increased monitoring of bloom distribution and abundance, and of sockeye behavior in migration corridors or holding areas, is needed to draw a definitive conclusion that *Heterosigma*, or other harmful algal blooms, do not adversely affect Fraser River sockeye in a given year. The proven, intense toxicity of *Heterosigma* to salmon in shallow marine waters, and the documented occurrence of large blooms in Fraser sockeye migration and holding areas, should focus the attention of managers on the susceptibility of late-run fish staging in the Gulf, and the potential for catastrophic losses in future years.

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Appendix R: Effect of Summer-run Escapement Estimation on Late-run Escapement

Errors in hydroacoustic estimates of summer-run sockeye escapement at Mission have been suggested as a potential source of error in the estimation of late-run sockeye escapement to the Strait of Georgia. The hypothesis is as follows: If Mission escapements were over-estimated, the calculation of summer-run sockeye harvest rates in migratory area fisheries would have been under-estimated, i.e., large escapement relative to catch. The subsequent application of low harvest rates to large catches of late-run fish in migratory areas would generate over-estimates of the total number of late-run sockeye and, hence, over-estimates of escapement to the Strait of Georgia using methods which depend on summer-run harvest rates. While the subject of Mission escapement estimates has been reviewed by the Fraser River Sockeye Public Review Board and the probability of significant over-estimation is considered to be minimal, there remains uncertainty as to the actual escapement of summer-run sockeye at Mission in 1994. In order to examine the issue of the impacts of errors in the Mission estimates, we divided the problem into several questions: Were the summer-run escapement estimates generated from the Mission hydroacoustic program important in the assessment of harvest rate? What was the impact of terminal area catch on the calculation of migratory area harvest rates? How was the timing of the various runs important to this hypothesis? These issues are treated separately below.

Estimates of daily and weekly harvest rates on Fraser River sockeye salmon in migratory area fisheries have been used since the early 1980's as one method to estimate the escapement of late-run stocks to the Strait of Georgia. In this procedure (see Appendix F), catches of summer-run stocks in migratory area fisheries and escapements to terminal areas are used to estimate harvest rates in the migratory route fisheries. Estimates of daily and weekly harvest rate are then applied to catches of late-run sockeye to generate total daily and weekly abundance of these latter stocks from which catch is subtracted, resulting in estimates of late-run sockeye escapement to the Strait of Georgia.

Summer-run sockeye which escape migratory area fisheries provide for catch in the Strait of Georgia and Fraser River fisheries and for gross escapement which is estimated at Mission. Therefore, the impacts of any over-estimates of escapement at Mission are mediated by the fact that only part of the terminal abundance is estimated as upstream escapement. Also, if any error is present in Mission hydroacoustic estimation of escapement, the error would be partly compensated for by under-reporting of catch in the terminal area fisheries. Cash sales and take-home of fish caught in Fraser River gillnet fisheries has been recognized for many years. However, estimation of these catches ceased in 1990 when Commission staff recommended that this function be transferred from the PSC to Canada. DFO did not take over the sampling and estimation of these catches nor did DFO maintain the database of Area 29 gillnet fishery catches that go unreported. In the average year, this lack of data would result in an under-estimation of terminal abundance and over-estimation of harvest rate in migratory fisheries and would result in an under-estimation of late-run sockeye escapement to the Strait of Georgia.

In 1994, the summer-run exploitation rate models tracked late-run escapement into the Strait of Georgia beginning on August 4 (Below Bridge date). Prior to this period no discernable catch of late-run sockeye was identified in migratory area fisheries. The analysis of late-run escapement was discontinued on September 10 (Below Bridge date), which was the last day of identifiable late-run catch in migratory area fisheries.

The total catch of summer-run sockeye in terminal area fisheries, and the escapement past Mission of summer-run sockeye, from the period spanning August 4 to September 10 were 1,321,000 and 1,866,000, respectively (Table 1). If the Mission summer-run escapement data are replaced with (i) upstream accounted estimates of summer-run net escapement, corresponding to the Below Bridge dates from August 4 to September 10, inclusively, and (ii) with catches reported by DFO in the Native fishery for the same dates, then the gross escapement estimate is reduced from 1,866,000 to 1,449,000 (Table 1). The difference between the two estimates is 417,000 fish.

The discrepancy of 417,000, in the estimation of the terminal area abundance of summer-run sockeye, amounts to 13.1% of the terminal area summer-run abundance estimated by the PSC at the end of the season. The question arises, what would be the impact of these changes in the summer-run terminal area abundance on the estimate of late-run escapement to the Strait of Georgia derived using the Summer-Run Exploitation Rate Model?

Tables 2 and 3 summarize the weekly estimates of summer-run exploitation rates, and the resulting late-run weekly and seasonal Strait of Georgia escapement estimates, derived from the Summer-Run Exploitation Rate Model. Table 2 incorporates Mission summer-run gross escapement data, while Table 3 uses DFO upstream accounting data, plus Native summer-run catches above Mission, in place of the PSC's estimate of gross escapement past Mission. When the upstream accounting data are used in place of the Mission gross escapement data, the apparent migratory exploitation rates of summer-run stocks increase in every week but one. Correspondingly, the estimates of late-run escapements to the Strait of Georgia decrease. The net result for the entire season of the estimated late-run escapement to the Strait of Georgia, is a reduction from 3,679,000 fish to 2,971,000 fish (Tables 2 and 3). This is a drop of 708,000 late-run sockeye which the model projected to have escaped the migratory area fisheries and entered the Strait of Georgia.

Further examination of summer-run sockeye terminal area catches and escapements in 1994 led to two additional analyses which shed light on the question of possible escapement estimation errors. First, there appears to be a reasonably consistent relationship between Cottonwood gillnet test fishing CPUE and Mission escapement during the main summer-run sockeye time period from July 25 to September 5 (Figure 1). Regression of the data from July 25 to August 14 and from August 17 to September 5 indicate that the relationship between Cottonwood test fishing and Mission escapement (all stocks) showed higher efficiency of test fishing in the earlier time period (i.e., higher ratio of CPUE to escapement, Figure 2). If Mission escapement estimates were biased high in either period, these data would suggest that the error would be greatest in the later time period (i.e., more fish migrating per CPUE). However, the actual escapements in the latter time period were substantially smaller (661,000 versus 1,695,000) which makes it unlikely that large numerical errors occurred in this time period. Catches in three fisheries after August 16 totalled 414,000 summer-run sockeye while two fisheries before August 14 netted 452,000 fish of these stocks.

A so-called "hole filling" calculation (Walters MS) compares the size of the depression in the migration at Mission with the reported catch in Fraser River commercial fisheries. This method can be used to evaluate bias in the escapement estimates. If the "holes" left after the fisheries are larger than the indicated catch, either the escapement estimates are high, thus producing a larger "hole" than could be filled by the catch, or the catch is under-estimated, giving the appearance of "too large a hole". In 1994, the "hole filling" method was not used in the first fishing week, August 7-13, because of unusual migratory behaviour and timing of fisheries in the river. Holes in the migration at Mission corresponded well to the size of commercial catches after August 14, suggesting that the Mission echo sounding was not overestimating escapement (Table 4). In turn, any errors in the estimation of terminal abundance of summer-run sockeye would be insignificant and, therefore, the harvest rate-based procedures used for estimating escapement to the Strait of Georgia would not be biased.

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Table 1. Comparisons of projections of summer-run escapement into the Strait of Georgia, with the gross escapement component derived from Mission hydroacoustic and lower river Native catch data versus spawning escapement and in-river Native catch data.

	Projection of Escapement into the Strait of Georgia (Mission Data)			Projection of Escapement into the Strait of Georgia (Upstream Accounting)		
W/E DATE	Mission Gross Escp	Terminal Catch	Total	Native Catch & Spawning Arrival	Terminal Catch	Total
8/7	453,003	164,482	617,485	263,425	164,482	427,907
14	655,105	291,751	946,856	658,342	291,751	950,093
21	331,929	442,836	774,765	305,330	442,836	748,166
28	236,548	246,728	483,276	166,101	246,728	412,829
9/4	159,834	169,627	329,461	42,540	169,627	212,167
10	29,919	5,472	35,391	12,921	5,472	18,393
	1,866,338	1,320,896	3,187,234	1,448,659	1,320,896	2,769,555

Table 2. Summer-run exploitation rate model with gross escapement determined from Mission hydroacoustic and lower river Native catch data.

	Summer Runs				
BB Date	Total Migr Catch	Area 29 Catch & DFO Upstream Accounting	Weekly Exploit Rate	Late Runs Total Migr Catch	Cummulative Late Run St of Georgi Delay
04-Aug	36,205			9,871	
05-Aug	44,901			9,103	
06-Aug	48,131			8,898	
07-Aug	63,120	427,907	31.0%	9,759	83,714
08-Aug	59,192			13,417	
09-Aug	144,382			35,066	
10-Aug	92,495			29,190	
11-Aug	63,483			21,397	
12-Aug	76,620			35,420	
13-Aug	219,785			97,184	
14-Aug	175,809	950,093	46.7%	80,916	440,771
15-Aug	226,697			196,646	
16-Aug	252,224			208,418	
17-Aug	34,475			28,177	
18-Aug	20,865			27,130	
19-Aug	17,012			27,782	
20-Aug	128,795			166,972	
21-Aug	120,226	748,166	51.7%	150,592	1,194,009
22-Aug	232,823			525,347	
23-Aug	233,798			526,481	
24-Aug	10,455			12,250	
25-Aug	7,864			14,851	
26-Aug	7,129			16,346	
27-Aug	37,055			132,460	
28-Aug	36,483	412,829	57.8%	131,851	2,186,357
29-Aug	77,025			235,478	
30-Aug	77,025			235,478	
31-Aug	77,025			235,478	
01-Sep	3,752			21,119	
02-Sep	3,608			21,820	
03-Sep	544			3,457	
04-Sep	544	212,167	53.0%	3,457	2,856,263
05-Sep	8,836			53,150	
06-Sep	8,836			53,150	
07-Sep	7,514			47,735	
08-Sep	7,514			47,735	
09-Sep	6,970			44,278	
10-Sep	1,000	18,393	68.9%	7,000	2,970,705

Table 3. Summer-run exploitation rate model with gross escapement determined from spawning escapement and in-river Native catch data.

	Summer Runs				
BB Date	Total Migr Catch	Area 29 Catch & PSC Mission Escapement	Weekly Exploit Rate	Late Runs Total Migr Catch	Cummulative Late Run St of Georgia Delay
04-Aug	36,205			9,871	
05-Aug	44,901			9,103	
06-Aug	48,131			8,898	
07-Aug	63,120	617,485	23.8%	9,759	120,485
08-Aug	59,192			13,417	
09-Aug	144,382			35,066	
10-Aug	92,495			29,190	
11-Aug	63,483			21,397	
12-Aug	76,620			35,420	
13-Aug	219,785			97,184	
14-Aug	175,809	946,856	46.8%	80,916	475,821
15-Aug	226,697			196,646	
16-Aug	252,224			208,418	
17-Aug	34,475			28,177	
18-Aug	20,865			27,130	
19-Aug	17,012			27,782	
20-Aug	128,795			166,972	
21-Aug	120,226	774,765	50.8%	150,592	1,256,160
22-Aug	232,823			525,347	
23-Aug	233,798			526,481	
24-Aug	10,455			12,250	
25-Aug	7,864			14,851	
26-Aug	7,129			16,346	
27-Aug	37,055			132,460	
28-Aug	36,483	483,276	53.9%	131,851	2,418,995
29-Aug	77,025			235,478	
30-Aug	77,025			235,478	
31-Aug	77,025			235,478	
01-Sep	3,752			21,119	
02-Sep	3,608			21,820	
03-Sep	544			3,457	
04-Sep	544	329,461	42.1%	3,457	3,459,112
05-Sep	8,836			53,150	
06-Sep	8,836			53,150	
07-Sep	7,514			47,735	
08-Sep	7,514			47,735	
09-Sep	6,970			44,278	
10-Sep	1,000	35,391	53.5%	7,000	3,679,051

Table 4. An assessment of Mission hydroacoustic estimates of summer-run escapement, by comparison of the size of "holes" in the daily escapements (caused by downstream commerical catches) with actual commercial catches.

AB Date	Original Catch	Walters' Revised Escp	Revised Escp + Native Cth	Area 29 Commercial Catch	Avg Daily Abund Before & After A29 Com Fishery	Avg Daily Catch & Mis'n Esc During A29 Com Fishery	Difference
07-Aug	60,820	124,850					
08-Aug	148,553	(3,751)					
09-Aug	11,760	13,323					
10-Aug	35,009	1,349					
11-Aug	153,597	21,041					
12-Aug	385	35,387	35,387	0			
13-Aug	838	327,485	327,485	0			
14-Aug	24,780	135,974	160,083	0			
15-Aug	38,815	130,434	168,726	0	126,318		
16-Aug	107,644	81,581	96,101	92,726		152,345	(26,028)
17-Aug	115,926	(44)	(44)	115,908		152,345	(26,028)
18-Aug	284	83,909	83,909	0	126,318		
19-Aug	223	121,387	121,387	0	68,651		
20-Aug	51,593	15,250	15,250	51,359		67,594	1,057
21-Aug	63,744	4,859	11,195	57,384		67,594	1,057
22-Aug	9,590	6,428	15,914	0	68,651		
22-Aug			15,914		62,918		
23-Aug	10,433	81,297	84,409	7,030		95,633	(32,714)
24-Aug	78,532	11,993	11,993	78,407		95,633	(32,714)
25-Aug	95,640	9,442	9,442	95,617		95,633	(32,714)
26-Aug	28	(5,795)	(5,795)	0			
27-Aug	175	109,923	109,923	0	62,918		
28-Aug	137	13,655	13,655	0			
29-Aug	140	15,554	15,554	0			
30-Aug	209	93,619	93,619	0	62,453		
31-Aug	46,537	8,911	8,911	47,460		42,022	20,431
01-Sep	32,520	(4,837)	(4,837)	32,509		42,022	20,431
02-Sep	118	31,287	31,287	0	62,453		0
03-Sep	94	10,470	10,470	0			
04-Sep	0	25,165	25,165	0			
05-Sep	0	8,489	8,489	0			

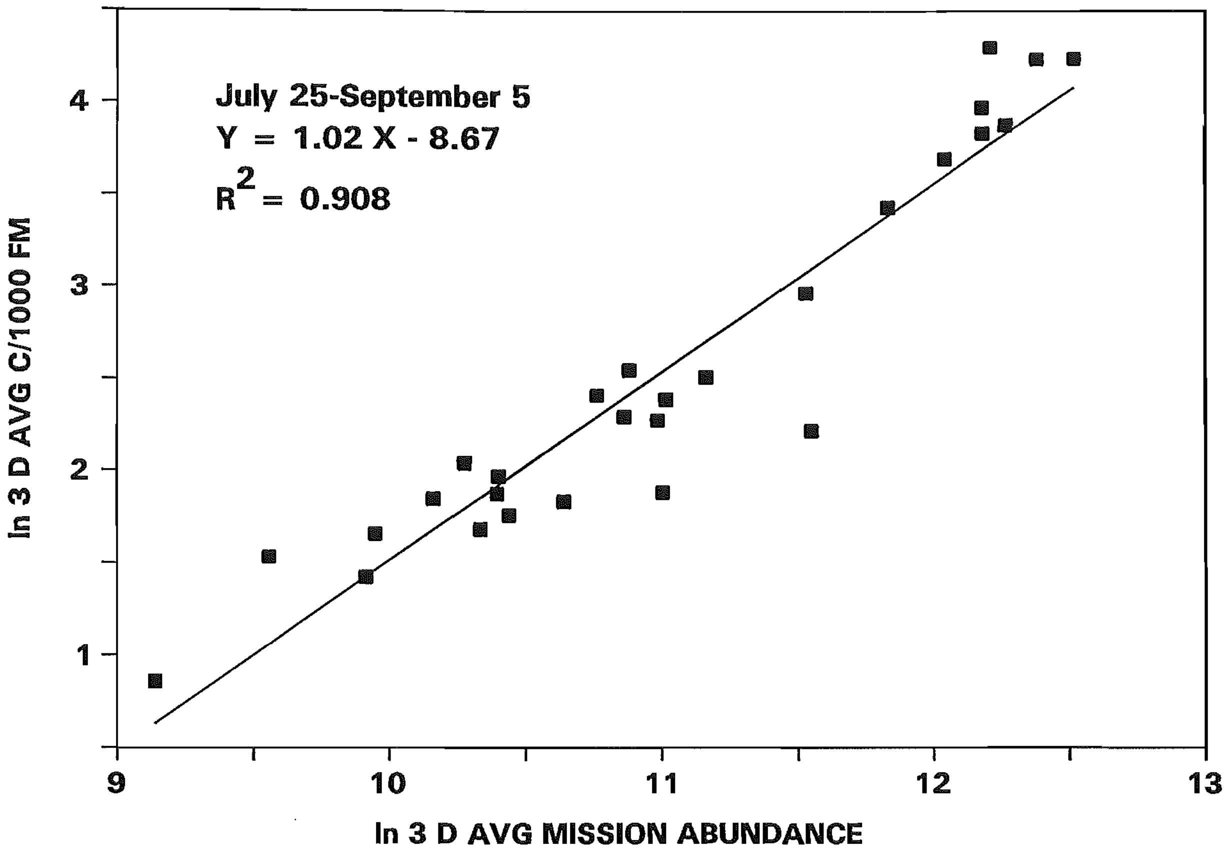

Figure 1. Regressions of ln 3-day average Mission abundance versus ln Cottonwood gillnet test fishing CPUE for July 25-September 5.

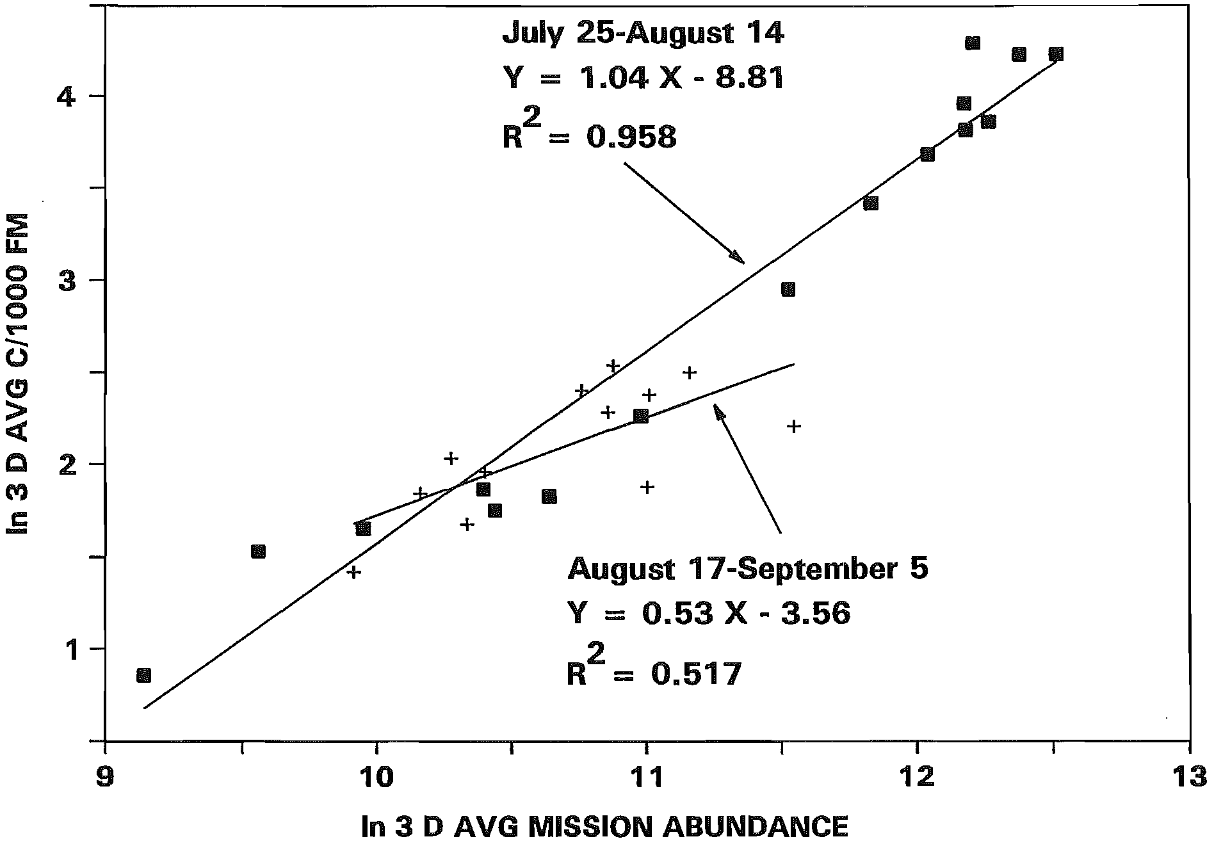

Figure 2. Regressions of ln 3-day average Mission abundance versus ln Cottonwood gillnet test fishing CPUE for July 25-August 14 and for August 17-September 5..