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MIGRATION TIMING AND HARVEST RATES OF THE STEELHEAD TROUT POPULATIONS OF THE SKEENA RIVER SYSTEM

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Summary

Migration timing and harvest rates of steelhead trout were examined in relation to the harvest of sockeye salmon in the mixed-stock fishery of the Skeena River. Summer-run steelhead overlap in their migration timing with sockeye salmon to a significant degree (Sprout and Kadowaki 1987). An assessment of the migration timing of specific steelhead stocks was needed to estimate stock-specific harvest rates. A previous PSARC Working Paper (S92-6,8) estimated the habitat carrying capacity and productivity for the main summer-run steelhead populations of the Skeena River. Allowable harvest rates and numbers of spawners and recruits at Maximum Sustained Yield (MSY) were estimated for individual populations (Tautz et al. 1992). This study compares estimates of steelhead harvest with the rates associated with MSY for each stock. Steelhead harvest in Area 4 was considered in relation to other fisheries of Alaska and the Canadian approach waters.

Steelhead and sockeye run timing was reconstructed by adding catches to escapement at Tyee for 1980 to 1991. Sockeye runs peaked on July 24 (day 205, week 29.3) ±5 days. Since catch for steelhead is unreliable, a method was developed using Tyee test-fishery catches for sockeye and steelhead from 1956 to 1991. A curve-fitting procedure was used to estimate the steelhead peaks relative to the sockeye. On average, sockeye peaked on July 22 (day 203, week 29) and steelhead on August 7 (day 219, week 31.3), a difference of 16.5 days.

Stock-specific run timing for several of the major populations of steelhead trout was based on tag recoveries from several studies and racial analysis of catch (Cox-Rogers 1986). Coded-Wire Tags (CWT) and Floy tags were recovered in commercial fisheries of Alaska, Areas 3 and 4, at the Tyee test fishery, or in the sports fishery on the lower river. CWT data was used for estimating the variance as well as relative differences in timing of some individual stocks. Results of scale studies agreed with the conclusion of a timing peak between week 31 to 33 (i.e., near the second week of August) and differences of up to two weeks between peaks for specific stocks. Floy tag recoveries, CWT recoveries, and scale pattern analysis indicated similar run timing patterns, but small sample sizes and problems with sampling effort limited the accuracy of the results. However, the results were sufficient to indicate potential effects of various timing scenarios in the harvest model.

Area 4 harvest rates were calculated for each statistical week by DFO. These weekly rates for the years 1986 to 1991 were applied to steelhead for the same years. The pattern of fishing varied from year to year, with the highest rate of harvest in week 30 (week ending July 26), on average. The fishing pattern was non-symmetrical, with higher rates occurring more frequently during the latter half of the sockeye migration. Harvest rates on steelhead overall were similar to sockeye (93% to 120% of the sockeye rate). Mean harvest rate among individual steelhead stocks was ca. 41% in the general model for area 4 alone.

Sensitivity analysis, using the mean harvest rate from 1986 to 1990, average steelhead timing, and a 17-day difference to sockeye timing, indicated that variations from that estimated in the steelhead timing peaks or normal-curve shapes had small impacts at normal levels of variability. The worse case was for individual stocks with narrow timing curves.

Overall steelhead exploitation included the exploitation in Alaska and Canadian approach waters, which was assumed to be the same as for sockeye salmon (25%), the harvest in Area 4, and the subsequent losses in the river (6%). Thus, exploitation up to Tyee was approx. 56%. Adding the harvest beyond Tyee, including 4% for the native fishery and 1% each for catch-and-release and other losses resulted in total exploitation on steelhead populations in the order of 62%. Uncertainty about these estimates was associated with the vulnerability of steelhead, and the variability of harvest rates, survival rates, run timing, and productivities.

Based on these analyses, several steelhead populations of the Skeena appear to be over-exploited. Low productivity stocks such as the Sustut and Morice would be well below their target escapement at MSY, given equilibrium conditions. Other smaller, less productive populations not included in this analysis would be likewise affected, i.e., harvested at very high rates. Only the most productive stocks (e.g., Babine) were able to sustain spawning population levels that were above MSY.

INTRODUCTION

Mixed-stock fisheries represent a major challenge to fisheries managers given the renewed emphasis in fisheries on maintaining genetic diversity and protecting weak stocks (e.g., Cairns and Lackey 1992; Nehlsen et al. 1991). Not only must catch and escapement be optimized for the target species, but consideration must also be given to the requirements of the less productive stocks. Often, this must be done without the benefit of effective methodologies for assessing small populations, or adequate historical data.

Fish returning to the Skeena River are subjected to a number of sequential mixed-stock fisheries. These include driftnet fisheries in the high seas (until the fall of 1992), seine and gillnet fisheries in Alaska, commercial salmon fisheries in the approach waters to the Skeena (Areas 1, 3, and 5) and the fishery for sockeye in Area 4 (off the mouth of the Skeena River; Fig. 1). These are followed by native food fisheries and sport fisheries in the river, as well as losses from poaching and natural causes (e.g., predators, disease, environmental effects). Recently, native commercial fisheries for sockeye have been added to the list of fisheries exploiting Skeena River stocks, although the selective nature of the latter fisheries should minimize impacts on species other than sockeye.

The mixed-stock fishery of the Skeena River is directed at sockeye (*Oncorhynchus nerka*) and pink (*O. gorbuscha*) salmon, but several other salmonids are harvested as by-catch, and there is growing concern for the less productive stocks. Sprout and Kadowaki (1987) reviewed the management of sockeye salmon and over-harvest of the less productive populations, including steelhead trout (*O. mykiss*), and coho (*O. kisutch*) salmon. Management of these populations has involved Provincial and Federal agencies and several user groups (Hilborn and Walters 1977).

The migration period of summer-run steelhead into the Skeena River coincides with pink and coho salmon and overlaps the migration period of sockeye salmon to a large extent, thus steelhead are harvested as incidental catch. Steelhead and coho experience high harvest rates in commercial fisheries for sockeye and pink salmon in Area 4, but detailed information on a stock-specific basis is lacking. Sprout and Kadowaki (1987) used simplified run-timing curves for steelhead and noted that a number of distinct populations would likely comprise the overall steelhead run; harvest rates on individual populations were unknown. Better assessment of the steelhead migration was needed to determine their harvest rates.

Several studies have examined the stock-specific aspects of steelhead trout populations within the Skeena watershed. Cox-Rogers (1986) analyzed scale patterns to identify steelhead populations sampled from the commercial catch of 1984 and 1985. Radio-tagging has been used to determine migration rates through the commercial salmon fishery and within the river (Beere 1991a; Spence 1989; Lough 1981, 1983). Tautz et al. (1992) developed a habitat-based model to estimate the carrying capacity and productivity of Skeena steelhead trout populations. Minimum escapements, harvest rates at maximum sustainable yield (MSY), as well as estimates of spawners and recruits at MSY for each of the major steelhead populations were obtained.

The purpose of this paper is to summarize information available on steelhead run timing (i.e., the frequency of occurrence of fish with time) and to estimate current harvest rates on several major stocks. A generalized mixed-stock fishery model based on weekly harvest rates for sockeye estimated stock-specific harvest rates for steelhead stocks. Weekly harvest rates calculated for the sockeye fishery were applied to the estimated proportion of steelhead migrating in that week, and weekly catches were summed over the fishing period. Overall timing of sockeye and steelhead are compared, and timing curves are developed for the populations of steelhead for which information was available from tagging studies. Also, steelhead harvest rates in area 4 are considered in relation to other fisheries in Alaska, the Canadian approach waters, and those conducted by natives in the river, to determine overall exploitation rates.

The sensitivity of the harvest model to variations in steelhead run timing was evaluated by altering the peak and shape of their run-timing curves. We compared the escapement requirements and allowable exploitation rates estimated previously (Tautz et al. 1992) to the exploitation rates resulting from this modelling exercise on harvest rates and steelhead run timing.

METHODS

General Approach to a Skeena Fisheries Model

A model was developed to estimate the weekly harvests of steelhead based on the harvest rates of sockeye salmon in Area 4. We focused on the Area 4 fishery because it accounts for the largest share of the catch, and had the most reliable sources of information to compare timing and catch rates. The impacts from other fisheries were estimated and incorporated into the model to estimate the total exploitation rate on each steelhead stock. Steelhead harvest rates could not be measured directly, due to problems in reporting of catch in the commercial fishery, and difficulties of obtaining accurate escapement estimates.

The most recent information on Skeena sockeye, from the period 1986 to 1991, was used to represent the current situation. The harvest rate for steelhead stocks was obtained by multiplying weekly harvest rates calculated for sockeye by the proportion of the steelhead run moving through the fishery in that week. The proportion was calculated from a normal curve with a specified variance and peak date. The model was constructed so that the sensitivity of specific stocks to wider or narrower run timing could also be examined.

Aggregate Sockeye and Steelhead Run Timing

In the general model, differences in harvest rate result from relative differences in peak timing between sockeye and steelhead, and from differences in the shape of the timing curves (i.e., narrow or wide). Estimates of run timing for sockeye populations were available from run reconstruction based on hail data (catch) from 1980 to 1990 and from the Tyee test fishery (escapement) since 1956. Historical sockeye run timing has been previously documented (e.g., Groot et al. 1975; Lapoint and Staley 1987; Madison et al. 1972), but estimation of peak timing for sockeye and steelhead in a given year (from 1956 and on) was complicated by a number of factors. If just the escapement estimate data were used, the impact of the fishery itself was not taken into account. However, only the sockeye catch was known reliably. Thus, to determine differences in timing of steelhead and sockeye from 1956, the test fishery data for both was used, with a constant adjustment for catch, and by estimating the peaks for each by fitting a normal curve.

Two methods were used to estimate sockeye run timing characteristics, one for the variance and one to estimate differences in peaks from year to year and relative to steelhead. In the first, the data on sockeye escapement and catch from 1980-1991 were used to perform a run reconstruction. Daily catches were moved later in time to match up with the weekly escapement totals (i.e., to compensate for the approx 3 day travel-time difference to Tyee, where escapement was calibrated). The mean dates and variances for the reconstructed curves were then calculated. Calculated means were compared to graphical peaks.

A second method compared sockeye and steelhead escapement peaks, using data derived from the Tyee test fishery. An optimization procedure (Excel solver) was used to minimize the residuals from a normal curve with a standard deviation of 13 days, and which represented the total run fitted to the escapement values. We chose the normal curve since the results of method I were normally distributed. The second method used the test fishery data from 1956-1991. A normal curve was estimated from a histogram of a given year's test fishery catch, expanded to account for commercial catch (60%). (This constant multiplier did not affect the results on estimation of the peak event). The area under the curve was considered to be composed of 40% escapement and 60% catch. The daily escapements were expressed as a proportion of the total escapement and the area under the curve adjusted accordingly. The procedure calculated a peak in the data where the residuals, based on the difference between the normal curve and the histogram, were lowest.

The advantage of this data set was its long history and coverage within each fishing season, as well as the fact that it included both steelhead and sockeye in an identical method. Test fishery data was collected each day at Tyee and started earlier and ended later in the season than the hail information. Since this method was concerned with relative differences between sockeye and steelhead migration timing, problems with the accuracy of the test fishery data in estimating escapement did not apply (assuming no temporal bias within a season). The peak date was estimated as the date for which the residuals were minimized. While biases still could exist, they would likely affect steelhead and sockeye equally. The differences between the sockeye and steelhead timings are of considerable value, even if the absolute estimates of the peak dates may be biased.

A correlation analysis was done between peak sockeye dates estimated by hail and escapement data (1980 to 1990 data) and the test fishery results.

Area 4 Weekly Harvest Rates

Harvest rates are calculated on a statistical week basis by DFO, where a statistical week is defined as the day of the year divided by 7 (e.g., day 210 = week 30,= July 29). Catch, effort and escapement are typically summarized in this manner.

Weekly harvest rates for sockeye were available for several years on the Skeena. Weekly catch was calculated from hails, and weekly escapements estimated from the test fishery at Tyee (Fig. 1). Both estimates were corrected at the season end by using data from sales slips and spawner counts. Daily stock size was determined from the daily escapement and by distributing the catch from one day over a seven-day period, the latter based on the estimated migration time of a block of fish from the fishing grounds to Tyee, and designed to take account of fast and slow migrating fish. Thus, the catch was redistributed (adjusted to Tyee) in the following pattern, where, for example, 10% of the fish caught on day 1 would have been expected at Tyee had they not been harvested, etc.:

DAY 1	10%
DAY 2	20%
DAY 3	20%
DAY 4	20%
DAY 5	15%
DAY 6	10%
DAY 7	5%

Estimates of effort were obtained from areal (usually upon opening) and on-the-water (during the opening) counts of gillnet and seine vessels, by sub-area, for each day.

Steelhead Stock-Specific Run Timing

The aggregate run-timing curve for steelhead is composed of a number of distinct populations which spawn at different times and in different tributaries. Different stocks may migrate at different times relative to one another, and the variance of each population's timing curve is likely less than the variance of the aggregate distribution. We examined the variance of timing of the overall stock and individual populations, as well as the relative timing of different stocks.

Over the years, a number of marks have been applied to Skeena steelhead populations in various studies (e.g., population estimation). The tag data provided marginally useful information on stock-specific run timing, travel time, catch rates, etc. For most years, the effort directed at recovery (commercial and sport catch) of these tags spanned the migration period, since the commercial fishery in area 4 (and in area 3 and Alaska) started prior to the steelhead migration, and the sport fishery at the Skeena bar continued throughout the summer and fall. Nevertheless, some very late runs may have migrated beyond the sampling period. We used the CWT information to determine the variance in timing for the overall steelhead run and for individual stocks, and further adjusted the recoveries by fishing effort to examine individual peaks, and used the Floy tag information to determine relative differences between stocks.

Coded-wire tags were inserted in the nasal cartilage of steelhead fry during headwater stocking programs from 1985 to 1988 brood years (e.g., Schultze and Lough 1987). The fry were derived from native wild broodstock and released to headwaters of their natal streams (Bulkley, Suskwa, Zymoetz, and Morice Rivers). The coded-wire tags provided sufficient numbers of recoveries to compare relative timing of stocks within a given year. CWT recoveries were adjusted to a common recovery site, as explained below for Floy tags, and for effort (boat days) in the commercial fishery of Area 4.

Spaghetti tags (also called Floy tags or anchor tags - Floy Tagging and Manufacturing tag FDS-88 or similar) were placed on steelhead migrants in various fisheries. Most of these tags were applied by Ministry staff (e.g., O'Neill and Whately 1984; Pinsent 1973) on adults prior to spawning. These fish were used to estimate population size, but many were also recovered in the commercial fishery, returning as repeat spawners.

Fish released by commercial purse seiners in 1988 (n = 80 tags) and by the Tyee test fishery from 1987 to 1991 (Spence 1989, Beere 1991a) were also tagged. An intensive steelhead tagging program took place in 1992 which was associated with studies of the release of steelhead caught in gill nets of the Area 4 fishery. Marked steelhead were recaptured in fisheries in Alaska (Area 101-104), Statistical Areas 3 and 4, the Tyee test fishery, the Skeena bar sports fishery, and the sports fishery further up river.

Adjustments were necessary in order to analyze the date-of-capture information. A correction for catch location was based on travel times estimated from radio-tracking studies (Spence 1989, Beere 1991a), i.e., fish caught further away would have passed Tyee on the same date as fish caught later, but closer. Recovered tags were pooled into 7 major stock groups: the Babine, Sustut, Bulkley, Kispiox, Zymoetz, Suskwa, and Morice River stocks. It was not possible to adjust for tagging and recovery effort, since effort and relative population sizes were unknown (e.g., in the bar fishery). The Floy tag recovery data served only to indicate relative timing differences between the major stocks when all capture methods were lumped, thus more or less covering the complete migration period.

The second objective of this analysis was to estimate the variance of timing curve for each stock. This was done using the range of CWT recoveries for each stock in each year. The range statistic (i.e., the date of the earliest and latest recapture), as used in control systems analysis, was applied here as a method to estimate variance from a relatively small sample. The theory is that difference between the earliest and latest recovery will be a function of the population variance and the number of recoveries. Specifically, the number of recoveries and the range in dates was used to estimate the standard deviation:

2. $$\delta = R/d_2$$

where R = maximum minus minimum date of recovery
d_2 = factor for estimating δ based on sample size

The value d_2 is a tabled function of the number of tags recovered (i.e., number of observations; Samson et al. 1970, Table A). Given the problem of varying effort (in particular, low effort in the latter portion of the run), the range estimate should be considered a minimum.

Timing was also indicated from other studies. The capture of steelhead in purse seining operations associated with radio-tracking studies indicated the overall run timing for part of 1988, and Cox-Rogers (1986) sampled steelhead from the commercial catch in 1984 and 1985 to conduct a racial analysis from scale pattern features, and to examine the timing of the various groups.

Steelhead Trout Harvest in Area 4

As noted above, the process for calculating the stock-specific steelhead harvest rates involved estimating the proportion of the steelhead stock passing through the fishing area on any given week and applying the weekly harvest rate to that component of the run. The overall harvest rate for the stock is simply the weighted average of the weekly harvest rates:

3. $$\mu = \sum_{i=23}^{i=36} r_i p_i$$

where μ = overall harvest rate for a stock
r = harvest rate in week i
p = proportion of the stock in week i
and i = statistical week (week of the year)

The proportion of the run migrating in a given week was estimated by determining the peak week of migration and the variance of the stock. By assuming normality, the proportion in a week was calculated as:

4. $$p_i = (1/(\delta\sqrt{2\pi}))e\string^-((Yi-\hat{y})^2/2\delta^2)$$

where δ = standard deviation of timing
Y = week
$\hat{y}$ = mean week (peak of timing event)

Harvest rates on steelhead were assumed to be the same as those for sockeye salmon within each statistical week. Merestic measurements of steelhead suggest they are longer than sockeye salmon but have similar girth. We assume there is little difference in their catchability in gillnets, unless their behaviour is radically different (Facchin et al. 1991). Also, it appears that a significant proportion of steelhead are caught in the river/gap/slough area, where nets are hung in a way which facilitates tangling rather than gilling. Also, evidence suggests that steelhead migrate closer to the surface (Ruggerone et al. 1990), which may in fact make them more susceptible to capture. We did not incorporate this behavioral difference into the analysis.

Overall Steelhead Exploitation Rates

After the determination of the stock-specific harvest rates in area 4, the additional impacts of Alaska, Canadian approach waters (Areas 1, 3, and 5), and the native fishery were considered. Without detailed information, the average rates from the various fisheries were applied either before or after the area 4 calculations as appropriate (e.g., Alaskan impacts were calculated prior to area 4, native fisheries after).

Native harvest rate has been estimated at ca. 10% (e.g., Beere 1991b), and mortality associated with angling (catch-and-release regulations) has been estimated at 2% of annual catch (Hooton 1987). An additional 2% rate from natural mortality and poaching was considered conservative given the fact that the fish may be in freshwater for up to 10 months. When these values were combined with the results from the Area 4 model, estimates of the stock-specific exploitation rates were obtained.

Effects on Recruitment

After determination of the overall exploitation rate on each stock, it was possible to undertake several other calculations incorporating the carrying capacity and Beverton-Holt estimates of Tautz et al. (1992). For example, the exploitation rate that a number of spawners can sustain is given by:

6. $$u_E = A(1\text{-}P/P_r)$$

where
u_E = equilibrium rate of exploitation
A = Beverton-Holt A value
P = spawners
P_r = replacement level of stock.

and the spawners required to sustain an equilibrium rate of exploitation (P_E) may be calculated as:

7. $$P_E = 1 - u_E/A$$

Equation 7 also demonstrates a characteristic of the Beverton-Holt formulation, namely that if the exploitation rate exceeds the A value of the equation, P will become negative, and the population will eventually go to zero.

Stock-specific exploitation rates were also compared to the MSY exploitation rates (Ricker 1975, Appendix 3). The number of populations currently below their MSY escapement requirements based on these estimated exploitation rates was identified. From these calculations, it was also possible to examine the amount of change required to the current exploitation rate scenario in order to achieve target escapement levels (100% of MSY spawners for all stocks).

RESULTS AND DISCUSSION

Sockeye and Steelhead Aggregate Run Timing

It was determined from run reconstruction that sockeye runs at Tyee on average peaked on July 24 (day 205). During 1980-1991, timing varied from July 19 in 1980, to July

28 in 1990 (Table 1). Differences may be related to the relative strength of different components of the overall population, or actual differences in arrival times from year to year. The standard deviation of the sockeye timing curves, averaged over all years, was 12.9 days. The catch plus escapement data was, in general, normally distributed and the calculated mean dates corresponded with the peak days in all but 1988 and 1989. Those years were apparently normal in shape of the timing curve, but displayed an early one-day peak event (1989) and a later one-day peak event (1988), each of which was associated with an opening of the fishery. We concluded that the calculated mean dates, rather than the peak day, best described the run timing.

In using the test fishery data alone, an optimization routine was used to detect peaks in both the steelhead and sockeye data. For a few years, where the escapements were small and "flat", no peak was detected, and no date was recorded (e.g., sockeye in 1976; Table 2). This result provided some confidence that the method actually detected a peak rather than simply finding the mean of the values (Fig. 2, Fig. 3). (The minimized residuals were the differences between the escapement values and the values on the normal curve). In Fig. 2, the bar values represent escapement, and the remaining area under the curve represents catch.

Over the 35-year period, the mean date of sockeye timing past Tyee was July 22, (day 203) while the mean date of steelhead passage was August 7 (day 219; Table 2). Steelhead ranged from as early as July 27 in 1959 and 1966 to as late as August 21 in 1989. The earliest arrival for sockeye was July 11, in both 1977 and again in 1978, and the latest was July 29 in 1985 (Table 2). The standard error of the peak date for steelhead was 7.34 days; sockeye, 4.97.

The results of the second method of estimating sockeye timing were compared to the first. For the same years, the mean peak was one day earlier from the fitted method compared to the run reconstruction. A weak but significant correlation was observed between the values derived from each method ($r^2 = 0.47$, $p < 0.05$).

There was no correlation between the two species in peak date of arrival, i.e., years of early sockeye timing were not necessarily years of early steelhead timing. Nor were there any significant trends towards earlier or later timing detected. However, it is noteworthy that in 1987, 1988, and 1989 steelhead appeared later than usual. The absence of correlation may not be surprising. With several populations involved, variation in stock-specific abundance could appear to move the peak, independent of environmental factors such as annual variation in migration speed, departure date, etc. However, it is possible to conclude from this data that the environmentally-induced timing variations are small relative to stock-specific differences. A more rigorous approach would require more detailed examination of the timing of specific stocks of steelhead and sockeye over a number of years.

Area 4 weekly sockeye harvest rates

From 1986 to 1991 weekly harvest rates varied between 9% and 72% during the Area 4 fishery (Table 3). Specific weekly averages, measured over six years, varied between 3%

and 50%, with the maximum harvest rate occurring in week 30 (week ending ca. July 26). Equally significant, the pattern is not symmetrical; high harvest rates occur during the peak and continue through the latter half of the sockeye fishery (Fig. 4). Harvest rates on steelhead, which peak in time after sockeye, were thus equal to the annual sockeye rate. It was thought that the difference in timing between the sockeye and steelhead would benefit steelhead, but such would not appear to be the case (Table 3).

Stock-Specific Run Timing

The evidence for different run timings among steelhead stocks and estimates of stock-specific variance was derived from tag data and studies of stock separation by scale characteristics. Only a small amount of tag recovery data exists, which limited the accuracy of the conclusions. Excluding coded-wire tags (CWT) recovered in the Alaska fisheries, 307 marked fish (CWT and Floy tags) were recaptured in Areas 3 and 4, at Tyee, or at the Skeena bar fishery. The majority of the tag recoveries were from fish of the Bulkley (85 recaptures) and the Morice (69 recaptures) River systems. The raw data is summarized in Appendix 1 (CWT) and Appendix 2 (Floy tags). Kelts were evident in the catch from the early portion of the run (week 27 or earlier) but were excluded from the analysis.

CWT recoveries were adjusted for differences in recovery effort in Area 4 (boat days), and the mean date of recovery for each stock estimated, where there were > 7 CWT recoveries for each year (Appendix 1). Morice fish (total n = 35) were earlier than Bulkley (n = 17) by 4.2 days, later than Zymoetz (n = 9) by 2 days, and earlier than Suskwa (n = 28) by 7.1 days (Appendix 1). While the Morice recoveries were generally earliest, Bulkley fish appeared earliest in one year (1992). These results must be interpreted with caution - returns of fish with CWTs likely mirror the migration of the broodstock used, which we assumed to be randomly selected and thus representative of that stock. Furthermore, the effort-adjusted data appears to be skewed in some cases (e.g., Morice 1992) and sample sizes are small, which limits conclusions on comparisons between years (Appendix 1). Modes were generally in weeks 32 and 33 (modes are indicated by "*" in Appendix 1), in agreement with the estimation of average timing in week 32 for the overall stock (Table 2).

The standard deviations of steelhead run timing, based on CWTs, varied between 6.1 and 14.8 days, with a mean S.D. of 9.5 days (Table 4). These results are neither surprising, nor conclusive, since it is possible that the variance could increase if the span of fishing effort expanded over the migration period. We concluded that standard deviations of the individual steelhead populations were narrower than the standard deviation of the aggregate sockeye (13 days). Thus, 9.5 days (1.3 weeks) was the S.D. value used in the study of impacts of harvest rates and run timing on steelhead stock status.

The analysis of the remaining data (non CWT - Appendix 2) was directed at obtaining relative differences between stocks from a pooled analysis (i.e., all years), adjusted to the common point of the Tyee test fishery. As with the CWT data, average recoveries of Morice fish (n = 29) were early, Bulkley fish (n = 65) displayed middle timing (6 days later than Morice) and Suskwa fish (n = 7) were late (20 days later than Morice). Additional stocks for which tag data were available included Zymoetz (n = 14; 1 day later than Morice), Babine (n

= 45; 2 days earlier), Kispiox (n = 20; +9 days) and Sustut (n = 14; +9 days). Since the largest sample size was from Floy-tagged fish and several stocks were comparable, this data was used in the general harvest model to examine stock-specific effects. (Note that we later examined the effect of moving the peak timing one and two weeks earlier and later). Exact dates of stock-specific timing are thus not well defined, but this analysis served as a starting point to examine relative effects of various timing scenarios.

While the mean date of recovery may not necessarily represent the peak date for these stocks, since they are not corrected for effort, they do indicate that stocks could differ in the peak timing by up to 20 days. Further, the fact that these tags are somewhat later than the test fishery estimate (cf Table 2 and Appendix 2) may be because the tags were placed on fish which had already passed the commercial fishery at least once, or that if the effort correction was applied, the peak would move earlier. Modes for Floy-tag recoveries differed from the means. For example, the mode of tag recovery of Babine fish was 6 days later than the mean, at Aug. 12, whereas the mode of recovery for Sustut fish with Floy tags was 9 days earlier, on Aug. 2, and the data suggested a secondary later peak for that stock. Both modes and means would differ if adjusted for effort, but this was not possible with the Floy tag results. The important point is that differences in peaks likely exist, and that there are groups of stocks with early, middle and late timing.

A second point is that several stocks may have an early and late timing segment, which could occupy different sections of a major tributary. For example, the Morice stock is clearly distinct from both the Suskwa and Bulkley. A similar situation likely exists for the upper and lower Sustut, where tagging information combined with fish counts in 1992 suggested that over half of the Upper Sustut run was in the river prior to the date that tagged fish arrived in the system. The tags were applied during the last week of July and first week of August, indicating that a number of fish likely past Tyee before tagging in the commercial fishery commenced.

Biological markers such as scales (Cox-Rogers 1986) also provided evidence of differences in steelhead run timing. When adjusted for effort in the commercial fishery, the run timing estimates of 1984 and 1985 indicated peaks around week 33. There also appeared to be differences in the shapes of curves for each year (Table 5). In 1984, a peak in abundance also occurred at or before week 29, whereas in 1985, a secondary peak was evident in week 31. Cox-Rogers (1985) also provided evidence for stock-specific run timing of the Kispiox, Zymoetz, Sustut, Babine, and Morice River steelhead. The peak week for the Morice River steelhead was also found to be in week 30 by Cox-Rogers, but a non-normal distribution was suggested from the data (Table 5).

Comparing mean timing of several stocks where possible from 3 data sources provided the following:

source	Babine	Kispiox	Morice	Sustut	Zymoetz
racial analysis	Aug 9	Aug 8	Aug 3	Aug 4	Aug 7
Floy tags	Aug 6	Aug 13	Aug 4	Aug 13	Aug 5
coded-wire tags			Aug 5		Aug 3

Despite all the possible sources of variability in tag recovery data, there appears to be close agreement for at least the Morice and Zymoetz results, and general agreement (less than a week difference) for the results from Babine and Kispiox fish. A difference of 9 days in results from Sustut fish may reflect the two components (early and late, upper and lower river stocks) of the run timing to that area of the river, or error in the data.

Timing of specific steelhead stocks was based on the data from Floy tags; timing of individual stocks was determined relative to Morice. The coded-wire tag data for Morice was used to estimate the difference of Morice timing with the overall steelhead peak on an annual basis. In 1992, CWT Morice fish were 3.6 days earlier than the peak; in 1991, 7.3 days earlier; in 1990, 6.9 days earlier (Appendix 1), for a mean difference of 5.7 days earlier. The overall peak that was generated from all tagging information was compared with a normal curve with the mean estimated at Tyee (day 219 - Table 2) and a standard deviation of 13 days. The reconstructed curve with the combined stocks under non-harvested conditions (i.e., at capacity), which comprised > 60% of the Skeena steelhead population (Tautz et al. 1992), suggested a peak at day 218 (Aug. 6), and the curve shape closely resembled the timing curve at Tyee. We concluded that our stock-specific run timing more-or-less approximated the overall steelhead timing and was thus reasonable for modelling purposes.

Steelhead Harvest in Area 4

Weekly harvest rates in Area 4 for sockeye salmon (Table 3) were applied to several steelhead stocks for the years 1986 to 1991. Steelhead timing was determined relative to the sockeye timing (Table 1), with steelhead 17 days later. Proportions of the run for each stock were assigned to each week and the harvest rate for that week applied. In years of high effort, such as 1988, Area 4 harvest rates on steelhead stocks apparently exceeded 50% (Table 6). In years of low effort, impacts were reduced correspondingly (Table 6). No one stock seemed to be consistently hardest hit, indicating the effect of variation in the pattern of harvest relative to steelhead run timing.

Harvest tends to be concentrated during the latter half of the sockeye run, with the effect that weeks of high harvest rate are more closely associated with the steelhead peak than with the sockeye peak. Harvest rates on individual steelhead stocks were greater than the rate experienced by sockeye by about 9%, on average (Table 6). Maximum differences between sockeye and steelhead harvest rates were estimated from 1987 data (steelhead harvest 120% of sockeye harvest rate) and 1989 (steelhead harvest estimated to be 93% of the sockeye rate). Actual rates that occurred are unknown, but this modelling exercise suggested more-or-less equal stock vulnerability based on the pattern of harvest and run timing. This was related to the lower standard deviation of the timing of specific steelhead stocks compared to the overall sockeye population, and due to the pattern of harvest. The main reasons for the concentration of fishing effort into the latter part of the sockeye run are conservation of the early sockeye stocks and targetting on the later pink salmon run.

Sensitivity Analysis

To test sensitivity of the model to changes or error in the run-timing curves for steelhead, we used the weekly mean harvest rate for 1986 to 1991 (Fig. 2, Table 3), average steelhead timing (Table 2, Table 4), and a 17-day difference between steelhead and sockeye timing (Table 2) to develop an average-case model (Table 7).

The effect of altering the peak weeks of steelhead abundance in Area 4 was tested by moving peak weeks one and two weeks earlier and later in the model (Table 8). Moving the peak one week early had little effect on the harvest rates in general, and moving all stocks one week later relative to the sockeye peak likewise had little effect, other than to redistribute the impact among stocks. A two-week difference reduced harvest by an average 17% (max 28%) if two weeks earlier, an average 15% (max 27%) if two weeks later. In general, the effects were not large. These results indicate that the mean harvest model is relatively insensitive to steelhead timing, i.e., an error in the peak timing event by up to two weeks has little effect on the exploitation rates estimated.

The effect of the shape of the run-timing curve was also examined. Narrower curves (i.e., reduction of S.D.) resulted in larger impacts (2 to 3 percentage points higher) on a stock specific basis (Table 8). Increasing the S.D. (by 100%) resulted in reduced catch, but harvest rates were still about 32% vs 41%. In other words, if the duration of steelhead run timing in individual stocks is narrower, the harvest situation is worsened, whereas broader run-timing curves imply harvests are lower, and escapements higher. Whereas the overall steelhead migration may occur over a broad time period, given that it is composed of a number of individual stocks, the timing for most individual stocks appears to be relatively narrow, which increased the probability of high harvest rates.

We did not test the sensitivity of the harvest model to variations in abundance of steelhead nor variations in harvest rate. The year-to-year harvest patterns from 1986 to 1990 that were examined (Table 6) provided sufficient evidence that altering the harvest pattern simply redistributed the impacts, and increases or decreases in sockeye harvest rate had the obvious result to steelhead. The general harvest model was examined by considering equilibrium rates of exploitation from all fisheries (see below). While large variations in returns are common in steelhead stocks (Ward and Slaney 1988), and Skeena stocks appear to respond in the same manner as other British Columbia steelhead (Ward and Wightman 1989), the long-term average effect of return rate and exploitation are more easily analyzed by use of the equilibrium rate (Ricker 1975). Ward (1993 in prep.) argues for more conservative allowable exploitation rates than estimated by the Beverton-Holt stock-recruitment parameters when stocks display highly variable return rates, but for purposes of this modelling analysis, the MSY allowable exploitation rates were sufficient.

Impacts of the Alaskan and Canadian Approach Fisheries

In addition to the Area 4 fishery, steelhead are harvested in Alaska and approach waters to Area 4 (e.g., Area 3). We assumed that the harvest rate on steelhead was equal to the sockeye rate for these areas.

The DFO estimate of the share of the total sockeye run taken in Alaska and Canadian approach waters is 25%. The fact that a significant number of steelhead are taken by Alaska is confirmed by CWT recoveries, where as many have been recovered from Alaska as from the Area 4 fishery (data on file, Fish. Br., Smithers). However, relative sampling effort has not been evaluated to calibrate these results.

The share of the total run taken by the area 4 fishery is calculated as the proportion of the run remaining after the approach fisheries (i.e., 75%), multiplied by the harvest rate for the area (40% to 42%). Exploitation rate up to and including area 4 was thus ca. 56% (Table 9). Adding harvest rates beyond Tyee translated to a share of approximately 4% exploitation for the native fishery, and 1% each for catch-and-release and other (poaching, etc.) incidental mortalities. In conclusion, total exploitation rates appeared to be in the order of 62% for most stocks of Skeena steelhead (the major stocks examined here represent about 60% of the total Skeena steelhead at productive capacity; Tautz et al. 1992) (Table 9).

Ability to achieve target escapements

Under the assumptions of the harvest model, several populations of steelhead appear to be over-exploited. At exploitation rates of 60%, MSY target escapements were not achieved for several stocks (Fig. 5), in the equilibrium (i.e., exploitation sustained for long periods) state. Low productivity stocks such as Morice and Sustut (which could comprise >10% of the Skeena steelhead, based on production at capacity) were only at 21% to 8% of their target escapement, respectively, and only the more productive stocks (e.g., the Babine) reached the MSY target. The overall Skeena steelhead population was 78% of the MSY target, and under these conditions, the numbers of steelhead past Tyee would be estimated at ca. 22,000.

To achieve MSY escapement for all Skeena steelhead stocks (i.e., 100% MSY spawners in all streams) would require more fish past Tyee. Our model suggests ca. 44,000 past Tyee would supply all Skeena tributaries with their MSY spawner requirements. That level would require a reduction in harvest rates in Area 4 by approximately 70%, if no change occurred in other fisheries. Use of MSY target levels to define conservation requirements was of considerable use, but is it noteworthy that benefits to steelhead anglers would be maximized by maximizing the number of fish back to the river, i.e., at escapement levels that are well above the number of spawners at MSY. Maximized opportunity in the commercial sockeye fishery entails higher harvest rates, but increases the risk to several steelhead populations.

Many smaller, less productive stocks identified in a previous PSARC document, S92-6(8), were not included in this discussion, but are likely affected nonetheless. Of the 13 steelhead stocks identified in S92-6(8), 10 are likely experiencing exploitation rates in excess of their previously estimated allowable exploitation rates at MSY.

Steelhead stocks may not have performed exactly as the steady state harvest rate model has predicted (i.e., near-extinction of the least productive stocks) for several reasons, including: the variable nature of the harvest rate pattern year-to-year, annual variation in steelhead survivals, errors in estimation of steelhead productivity in the Skeena River, variation in steelhead run timing from that predicted, and differences between vulnerability of steelhead and sockeye. The combined effect of sequential fisheries, possible reduced survivals in the ocean, additional impacts from native fisheries without corresponding reductions in the commercial catch, incremental habitat loss, etc., underline the stated concerns.

Until more information is available to refine estimates of the items listed, a conservative approach to management seems warranted. Improved run-timing information would be of interest, but would add only slightly more detail to the case. Perhaps the techniques of Cox-Rogers (1986) should be examined over more years, since the results were readily corrected for effort in the commercial fishery. The test fishery information may be augmented by other methods of estimating stock abundance. Live capture techniques can be developed as examples of how they might eventually be used for commercial harvest on a stock-specific basis. The magnitude of the harvest effects, vulnerability of different species (and stocks) and information on stock abundance and productivity might be further explored as part of a live capture program in the lower Skeena and approach waters.

CONCLUSIONS

1. In the absence of accurate long-term data on steelhead catch and escapement, the use of harvest rates on sockeye salmon, adjusted for differences in run timing, was an acceptable alternative for estimating steelhead harvest rates.

2. The estimate of the exploitation rate for steelhead of the Skeena River (all fisheries) was approximately 60%, using the approach in (1). The accuracy of this estimate is uncertain.

3. An analysis of run timing information indicated that the aggregate steelhead run was approximately 2 weeks later than the aggregate sockeye salmon run.

4. Steelhead harvest rate was relatively insensitive to shifts in run timing based on simulation techniques that used the current weekly fishing patterns in area 4.

5. Ten of the thirteen steelhead stocks defined in PSARC S92-6(8) are likely experiencing exploitation rates in excess of the previously estimated MSY allowable exploitation. The model suggested a differential impact among stocks, and indicated the potential for severe overharvesting of unproductive stocks.

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Area 4 Management Region

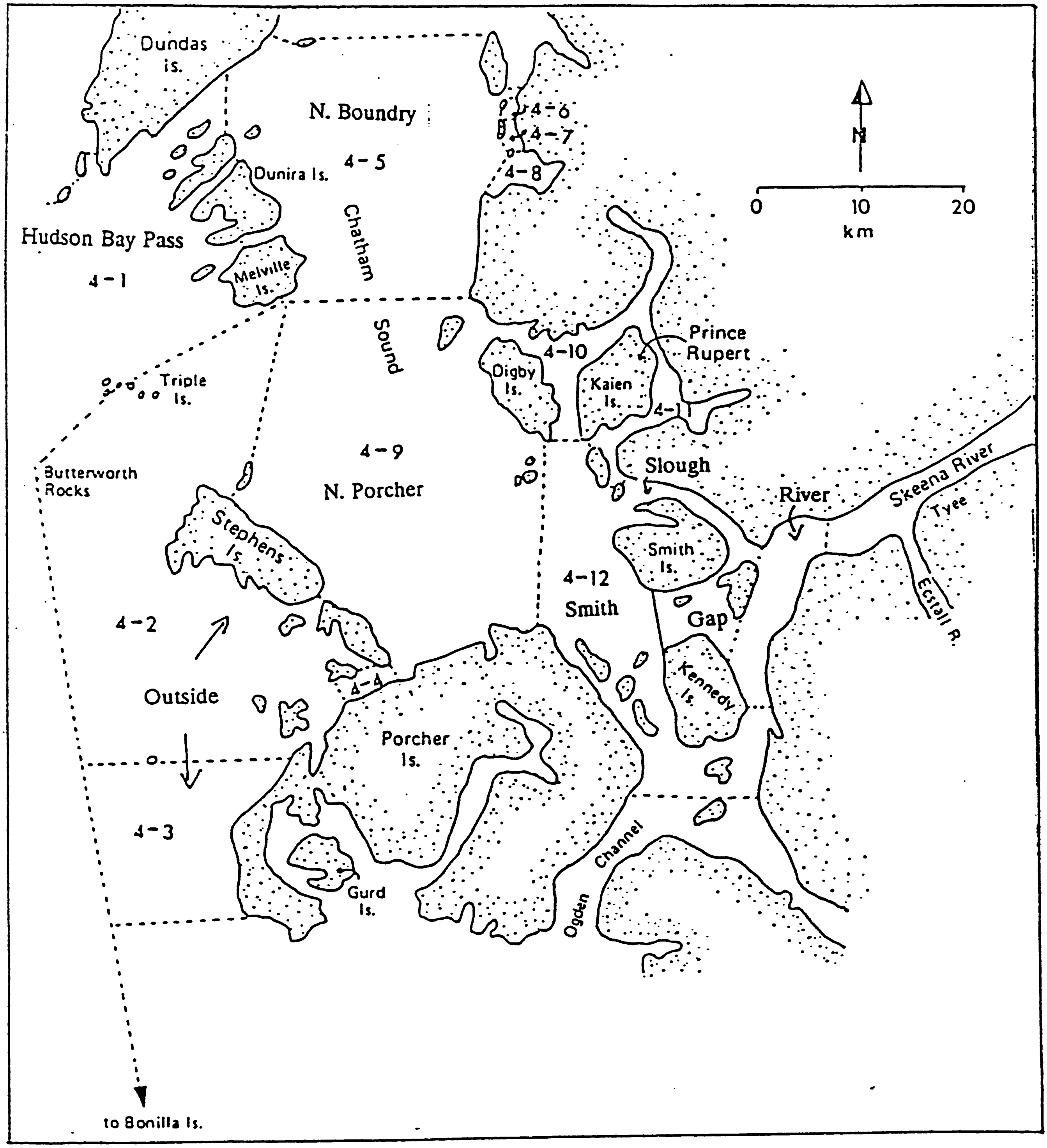

FIG. 1 Area 4 Statistical area and sub areas

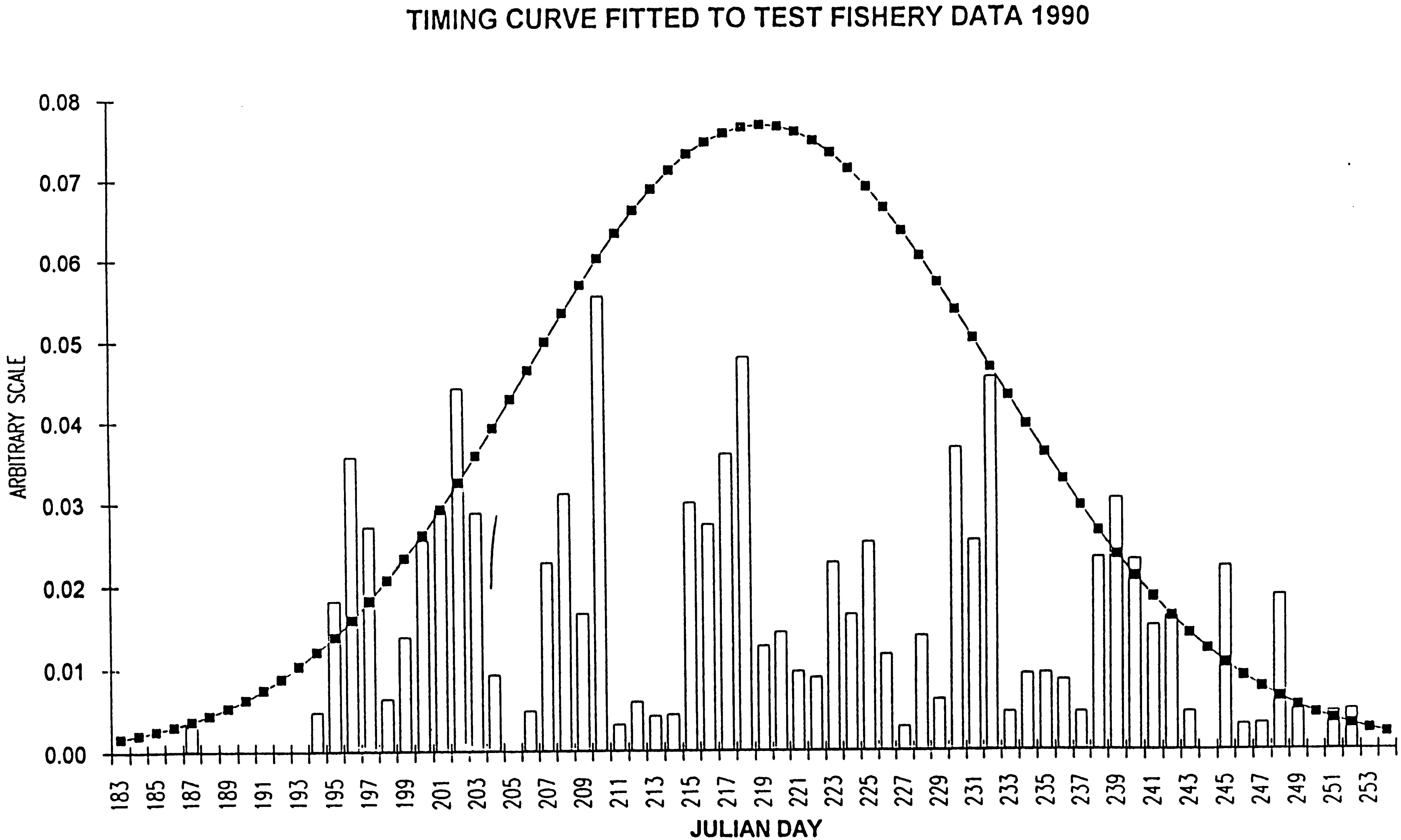

Fig. 2 Fitted curve for Tyee escapements.
Bars represent daily escapements, normalcurve represents catch & escapement.

MIGRATION PEAK AT TYEE FOR SKEENA SOCKEYE AND STEELHEAD

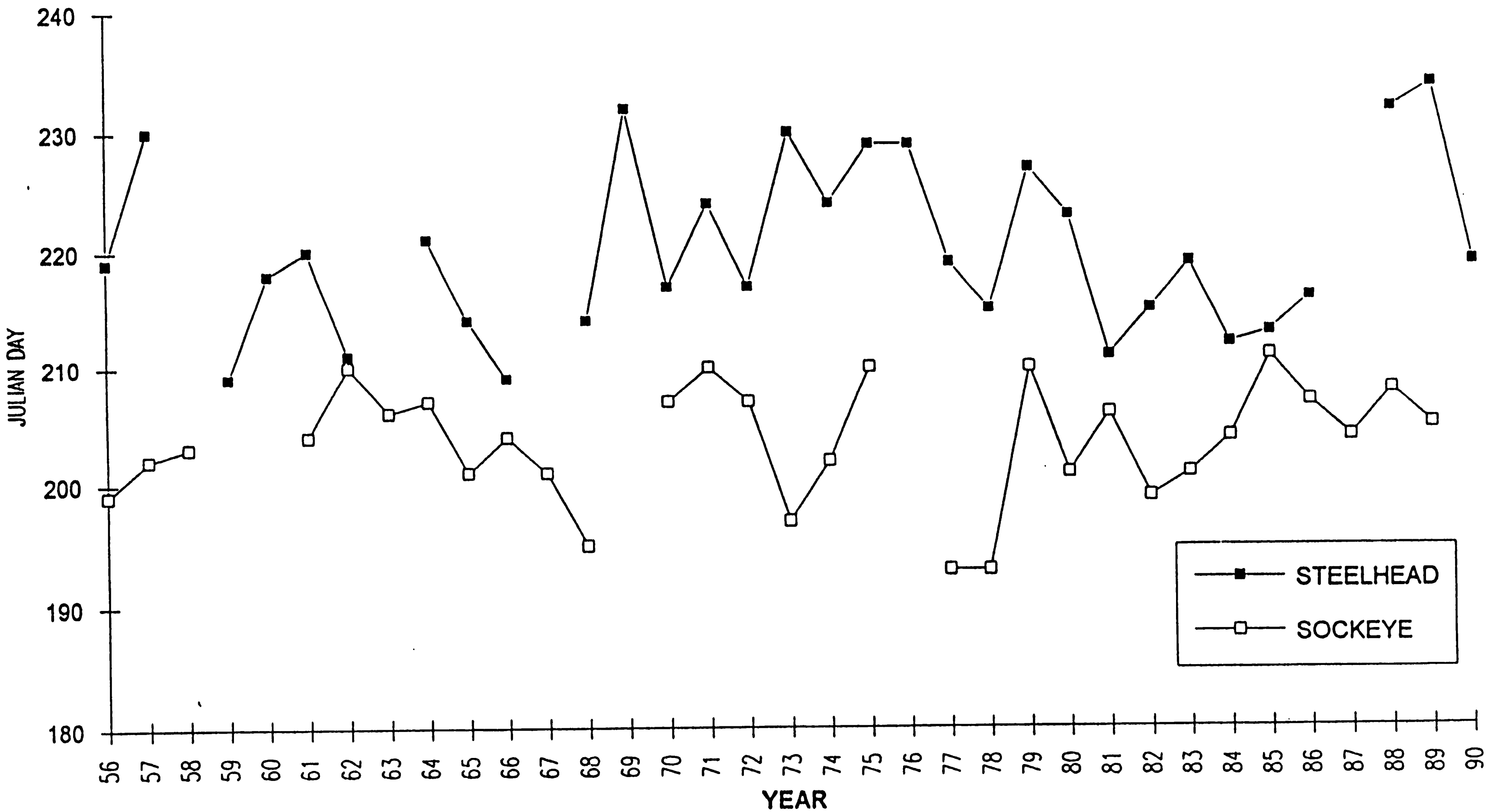

Fig 3. Reconstructed migration peaks based on test fishery data collected at Tyee.

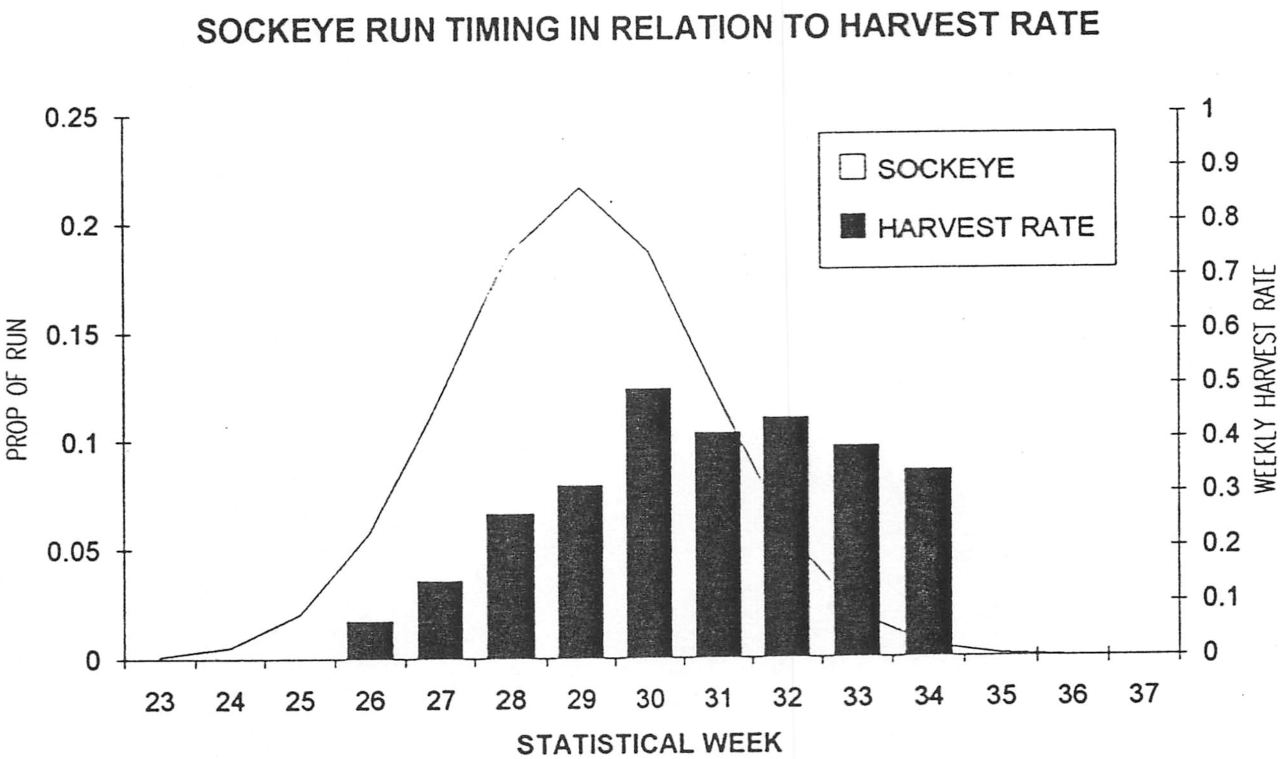

Figure 4. Average weekly harvest rates of Skeena River sockeye salmon in Area 4 for the years 1986 to 1991 and the estimated sockeye run timing. Week 31 is the week ending August 2.