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A Review of Survey Life Estimates as They Apply to the Area-Under-the-Curve Method for Estimating the Spawning Escapement of Pacific Salmon

C. J. Perrin and J. R. Irvine

Department of Fisheries and Oceans
Biological Sciences Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

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A REVIEW OF SURVEY LIFE ESTIMATES AS THEY APPLY TO THE AREA-UNDER-THE-CURVE METHOD FOR ESTIMATING THE SPAWNING ESCAPEMENT OF PACIFIC SALMON

by

C. J. Perrin[1] and J. R. Irvine[2]

Department of Fisheries and Oceans

Biological Sciences Branch

Pacific Biological Station

Nanaimo, British Columbia

V9R 5K6

[1]Limnotek Research and Development Inc.
4035 West 14 Avenue
Vancouver, British Columbia, V6R 2X3

[2]Author to whom requests for reports should be addressed

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Estimates of "survey life" (the number of days that mature salmon are alive in a survey area (SL)) for Pacific salmon were assembled and reviewed to determine if variation in these data could be explained. Survey life is an important parameter in the area-under-the-curve (AUC) method often used to estimate the spawning escapement of Pacific salmon. Unexplained variation in a survey life estimate may introduce serious error to escapement estimates. For all five species of Pacific salmon (Oncorhynchus sp.), estimates of SL were collected by questionnaire, personal and telephone interviews, computer assisted searches of relevant data bases, and manual library searches. Total sample sizes of SL estimates were generally small, ranging from 30 for coho (Oncorhynchus kisutch) to 83 for chum (Oncorhynchus keta) in a total of 238 estimates for all five species. The average SL estimate was 11.4, 11.9, 17.3, 12.1, and 13.2 days for coho, chum, pink (Oncorhynchus gorbuscha), chinook (Oncorhynchus tshawytscha), and sockeye (Oncorhynchus nerka) salmon respectively. Data for each species were blocked by the method of measurement and location but analyses of variance (ANOVA) failed to show differences in estimates between these strata. Accompanying power tests showed, however, that the ANOVA's were probably inconclusive because of high variability and small sample sizes. Site-specific comparisons of SL estimates suggested that early-run fish had a longer SL than fish spawning late in the run. In consecutive years where methods of measurement, location, and the observers were constant, variation in SL remained high, suggesting that site-specific factors were important in explaining the variation in SL. The sample sizes of several predictor variables including sex ratio, body size, and density were too small from which structured linear models could be developed. Our findings suggest that estimates of survey life cannot be extrapolated from one stock or stream to another, or among years, without potentially introducing serious error in the escapement estimate. Survey life should be determined on a site specific basis each time the AUC method is used to estimate escapement.

RÉSUMÉ

Perrin, C. J. and J. R. Irvine. 1990. A review of survey life estimates as they apply to the area-under-the-curve method for estimating the spawning escapement of Pacific salmon. Can. Tech. Rep. Fish. Aquat. Sci. 1733: 49 p.

Nous avons colligé et examiné des estimations de la période durant laquelle les saumons matures vivent dans une aire d'étude dans le cas de saumons du Pacifique pour voir s'il était possible d'expliquer la variabilité que montrent ces données. Il s'agit d'un paramètre important dans la méthode de la surface sous la courbe souvent utilisée pour estimer l'échappée des géniteurs de saumons du Pacifique. Quand les estimations de ces périodes montrent des variations inexpliquées, les estimations de l'échappée peuvent être gravement faussées. Nous avons recueilli des estimations pour toutes les espèces de saumons du Pacifique (Oncorhynchus sp) au moyen de questionnaires, d'entrevues personnelles et téléphoniques de même qu'en effectuant des recherches assistées par ordinateur dans les bases de données pertinentes et des recherches en bibliothèque. Les tailles des échantillons pour les différentes estimations étaient généralement petites, allant de 30 dans le cas du saumon coho (Oncorhynchus kisutch) à 83 dans le cas du saumon kéta (Oncorhynchus keta). Au total, nous avons examiné 238 estimations pour les cinq espèces. Les estimations moyennes étaient de 11,4, 11,9, 17,3, 12,1 et 13,2 jours pour les saumons coho, kéta, rose (Oncorhynchus gorbuscha), quinnat (Oncorhynchus tshawytscha) et rouge (Oncorhynchus nerka), respectivement. Les données pour chacune des espèces ont été réunies en blocs suivant la méthode de mesure et l'emplacement, mais les analyses de variance que nous avons effectuées ne nous ont pas permis de détecter de différences dans les estimations entre ces strates. Nos tests de puissance connexes ont toutefois montré que l'importante variabilité et la petite taille des échantillons faisaient en sorte que les analyses de variance ne pouvaient être concluantes. En comparant les estimations faites à un même site, nous avons trouvé que les poissons qui remontent au début de la montaison vivent plus longtemps dans l'aire d'étude que les poissons qui viennent frayer vers la fin de la montaison. Les données recueillies d'année en année au même endroit, par les mêmes observateurs et suivant les mêmes méthodes de mesure montrent également des variations importantes des estimations, ce qui laisse penser que des facteurs particuliers au site seraient responsables de ces variations. Les tailles d'échantillonnage pour plusieurs variables servant aux prévisions, dont le rapport des sexes, la taille et la densité étaient trop petites pour élaborer des modèles linéaires. Nos résultats laissent penser

qu'il n'est pas possible d'utiliser ces estimations pour faire des extrapolations relativement à d'autres stocks, cours d'eau ou année, sans risquer de fausser gravement les estimations de l'échappée. Les estimations de la période durant laquelle les saumons matures vivent dans une aire d'étude devraient être déterminées pour chaque site quand le méthode de la surface sous la courbure est utilisée pour estimer l'échappée.

INTRODUCTION

Uncertainty in the status of many stocks of Pacific salmon has increased awareness among fishery managers that accurate estimates of spawning escapement are necessary to manage salmon fisheries over the long term. Escapement estimates provide a basis for setting exploitation rates and for assessing the effect of exploitation or habitat manipulation on stocks. Escapement estimates can also be used to compare and contrast management policies using stock-recruitment relationships (Walters 1975, Walters and Hilborn 1976). They are important in documenting the timing of spawning runs and in helping to achieve optimum egg deposition (Symons and Waldichuk 1984). In long term monitoring or experimental manipulation of stocks, escapement estimates are necessary to quantify trends which may impact on important fisheries.

Several methods are available to estimate escapement (Cousens et al. 1982), but for any one spawning run, they can yield widely different results (cf. Beidler and Nickelson 1980, Flint 1984, Solazzi 1984, Johnston et al. 1986, 1987, Lewis 1987, Bocking et al. 1988). Largely because of cost, fish enumeration fences are not placed on many streams and field surveys conducted by trained observers have become a reasonable alternative. Such surveys include carcass counts, counts from towers or helicopters, swim counts, electronic monitoring, and mark-and-recapture programs. Foot surveys in which observers make visual counts along predetermined reaches have received most use because of their relatively low cost and the short time usually required to complete each survey (Waldichuk 1984). Using a foot survey approach, several calculations or indices are available from which to estimate escapement or make relative comparisons of escapement between streams: peak live counts, peak live plus accumulated dead counts, and area-under-the-curve (AUC) methods are some examples (Mundie 1984). Unfortunately, each method is sensitive to variation in data collection procedures. Environmental factors may also introduce error in escapement estimates. Inconsistent stream conditions among years, for example, may affect measurements of component variables for a specific method and introduce different bias in consecutive estimates of escapement. If environmental variables are not monitored, inherent bias may go undetected.

The AUC method of estimating escapement is particularly sensitive to error in measurements of component variables. Population size (N) is determined as:

$$N = AUC/SL \qquad (1)$$

where AUC is the area-under-the-curve or integral of spawner counts during a survey period and SL is survey life, the number of days that the average spawner can be counted as a live fish in a survey area. The field methods and calculation of the AUC curve are described in detail by Ames (1984). The accuracy and precision of AUC is dependent on the ability of observers to see fish, and usually introduces a linear negative bias to N (Lewis 1987). Bias in SL, however, is much less predictable, widely variable, and most important, may introduce asymmetrical, nonlinear error in N (e.g. Bocking et al. 1988).

If the AUC method is to be accepted as a reliable technique for estimating escapement, we must not only establish bias in observations of fish counts in survey areas, but we must also be aware of bias in measurements of SL, and factors that contribute to that bias. If there are significant relationships between variables that affect measurements of SL and the SL estimate, a measurement from one stream may be extrapolated to another only when the predictor variables are measured in addition to SL, thus allowing possible bias to be corrected.

It has been suggested that relationships between biological variables and survey life are important. van den Berghe and Gross (1986) suggested that body size may influence survey life and Ames (1984) reported that sex ratios and run timing may also be important. Extreme environmental events, selective fishing pressure, and the run timing of specific stocks at different latitudes may also be important.

In this study we have assembled data from wide ranging sources to determine if variation in survey life measurements collected for the five species of Pacific salmon found in British Columbia can be explained by biological and environmental variables. Our objective was to determine if extrapolation of survey life estimates among streams and years is valid when the AUC method is used to estimate escapement. Extrapolation is commonly employed in routine AUC measurements when time or resources do not permit site and time-specific measurements of survey life.

SURVEY LIFE DEFINITION

We have defined survey life as "the number of days that the average spawner is alive in a survey area". This definition has broad spatial limits since it can apply to survey areas as small as a redd, and often called the residence time at a redd (Crone and Bond 1976, Neilson and Geen 1981, Neilson and Banford

1983), or as large as the entire stream and be termed stream life (Ames 1984, Johnston et al. 1986, Bocking et al. 1988). Various other labels have included residence time (Lewis 1987), breeding life (van den Berghe and Gross 1986), turnover time (Cousens et al. 1982, Hickey and Lister 1981), average lifespan (Killick 1955), and others. Most of these terms refer to variations in survey design and field methods, or they are simply different names for the same approach. Some apply to observations of tagged fish (cf. Johnston et al. 1986, Fraser et al. 1983, Schaefer 1951). In most cases, however, trapping and tagging facilities were not available and survey life was approximated by the difference between peak live and dead counts (cf. Scott et al. 1982, Hickey and Lister 1981) or the difference between equivalence points on cumulative live and dead count curves (cf. McGivney et al. 1985a and b, Abbott et al. 1986).

In practice, true survey life cannot be measured with accuracy because fish are usually not observed for some time either before or after spawning. Particularly during high stream flows, fish will hide in refuges or hold in deep pools before spawning, and after fish die, their carcasses may become lodged amongst debris. Since carcass recovery methods are usually employed, survey life can be overestimated if fish are recovered at some time after they die. Conversely, differences between the time fish are first observed and when they actually arrive in a survey area can produce negative bias. The magnitude of error is directly related to the time interval between observations; the greater the time interval, the greater the potential error will be.

MATERIALS AND METHODS

SELECTION OF SURVEY LIFE DATA

The criteria we used to select data from the various sources centred on our general definition of survey life. Most information was expected to come from observations that had positive or negative bias. To obtain a reasonable sample size for our analyses, we included these biased data, recognizing that stratification by method could be important in analyses which examine relationships between survey life and variables which may affect field measurements. We did not include data pertaining to "redd life" (Ames and Phinney 1977) since it was limited only to the time a redd was visible to an observer and did not include actual observations of fish.

Variables that could potentially affect survey life included: data collection methods; geographic location; time of arrival to spawning grounds (Killick 1955, Neilson and Geen 1981, Ames 1984); sex ratios (Ames 1984, van den Berghe and Gross 1986); density (van den Berghe and Gross 1986); and body size (van den Berghe and Gross 1986). Data collection methods had theoretical importance because of potential contribution to bias in survey life estimates. We included geographic location on the basis that regional differences in temperature or other habitat criteria may influence survey life.

DATA COLLECTION

Survey life data and information pertaining to environmental variables were collected by questionnaire, personal and telephone contacts, computer assisted literature searches, and by manual literature and data search methods. A questionnaire was sent to key personnel of state government agencies in Oregon, Washington, and Alaska in the United States, and to Provincial and Federal agencies, the International Pacific Salmon Commission and selected environmental consultants in British Columbia. The telephone survey enabled us to clarify data submitted on questionnaires and to prompt those to return information who had not done so within a two month period. The computer literature search was used as a guide for manual searches of relevant articles and data compilations in the primary literature, technical and management report literature and consultant's reports. Information from citations was examined during direct visits to libraries at Department of Fisheries and Oceans (DFO) headquarters in Vancouver, B.C., at the Pacific Biological Station (PBS) in Nanaimo, B.C., the International Pacific Salmon Commission (IPSC) in Vancouver, B.C., University of British Columbia (UBC), Simon Fraser University (SFU), University of Victoria (UVic) and the University of Washington (UW). Interlibrary loans were used to access articles from Oregon State University (OSU) that could not be obtained elsewhere. Personal interviews were conducted with those who either could not return important data via the questionnaire, or when detailed clarification of raw data was required.

Questionnaire and telephone survey

The questionnaire (Appendix A) was specific in requesting a clear definition of survey life based on field methods. For any one method, the recipient was asked to submit appropriate measurements or relevant publications and other reports. Data forms were included with the questionnaire to expedite translation of raw field data where necessary. Forms included space for data on descriptive variables including year, species, location, size of survey area, sex ratios, body size, spawner density and run timing. In addition, the questionnaire asked for comments on successes or failures in the application of the AUC method in streams managed or being used as research sites by the respondent.

Names and addresses of recipients were selected from current literature, agency address and telephone lists, government directories in libraries, and references from telephone contacts. Workshop proceedings, particularly those reported by Symons and Waldichuk (1984), provided a valuable source for contacts. Numerous referrals also resulted from telephone contacts made initially using listings of US agencies in the Vancouver Public Library, and in the American Fisheries Society (AFS) directory (McAleer 1987). DFO recipients were selected from the department telephone listings. Addresses for recipients in the B.C. Fisheries Branch (Provincial Ministry of Environment) were accessed from BC List (1987) and from listings at the Provincial Fisheries Research Section office, UBC. Agencies or organizations that received the questionnaire were: Washington Tribal Fisheries, Washington government agencies, Oregon government agencies, Alaska government agencies, IPSC, DFO Management, DFO Hatchery Managers and Fishery Officers, DFO Research personnel, environmental consultants, Provincial Fisheries Branch, and faculty and students of UBC, SFU, UVic, UW, and OSU.

Of the 84 questionnaires that were mailed, 46 were returned with information, a 55% successful response rate.

Computer assisted literature search

Five data bases were searched for relevant literature. Canadian Water Resources References (Aquaref) from 1970 to 1987 were examined. Biosciences Information Service (Biosis), was scanned for titles between 1969 and October 15, 1987. For each relevant title, abstracts were accessed and for those which possibly contained survey life or related information, the article was examined. Aquatic Sciences and Fisheries Abstracts (ASFA) and National Technical Information Service (NTIS) databases were searched primarily for US government reports or reports sponsored by US government agencies. Dialogue Dissertation Abstracts (DDA) was searched for theses mainly from US universities.

Of the more than 500 references accessed in the computer search, only 27 were found to have relevant information.

Manual data search

Most information was retrieved from manual literature searches. Citations in recent journal articles and miscellaneous management reports revealed most important published work. Telephone contacts were invaluable to establish key references that various centres were using, and to access raw data that otherwise were not available.

DATA ORGANIZATION

Measurements of survey life and several descriptive variables found in the information sources were organized by species (Appendix B).

Survey life estimates were entered in units of days for males, females, and both sexes combined, with careful attention to the specific method that was used. In the compilation, methods were classified and assigned codes which in turn were assigned to each survey life measurement.

Where data were available, the descriptive variables were quantified for each entry of survey life either by direct measurements reported in the data source or by an arbitrary classification. Body size was entered as the post orbital-hypural length for both males and females. Density was defined as the number of females per m^2. Time of arrival to spawning areas was often not clearly defined and thus was given a very general classification as; early, middle, and late in the run.

Location was defined by region: Oregon (OR), Washington (WA), Alaska (AK), Georgia Strait (GS), Johnstone Strait (JS), west coast of Vancouver Island (WI), Lower Fraser (LF), Upper Fraser (UF), Thompson system (TS), Central Coast (CC), and Prince Rupert (PR). LF included the Fraser River and its tributaries from the estuary to the municipality of Hope. UF included all reaches and tributaries of the Fraser system upstream of Hope excluding the Thompson River and its tributaries (TS). GS included all coastal drainages on the mainland and Vancouver Island from Campbell River south to Victoria and into Juan de Fuca Strait to Port Renfrew. WI included all drainages from Port Renfrew north to Cape Scott. JS included drainages on the mainland and Vancouver Island from Campbell River north to Cape Scott on Vancouver Island and Cape Caution on the mainland. CC extended north from Cape Caution to the southern tip of Banks Island and midchannel of Douglas Channel but not including the Queen Charlotte Islands. PR included all mainland drainages north of the southern tip of Banks Island and midchannel of Douglas Channel, including the Skeena and Bulkley River systems.

These geographic boundaries approximated those of the DFO commercial catch areas.

DATA ANALYSIS

When compiling the data we recognized that variability in SL estimates may be explained by various combinations of associated variables that could be used to stratify the data or develop models to explain the variation. There were essentially two types of variables. The first was categorical (ie. method of measurement and location) which could be used for stratification and the other was a predictor variable (i.e. body size, sex ratio, density, etc.) which could be included in a structured linear model to explain variation within strata (or within the whole data set if strata were insignificant).

Independent one-way analyses of variance (ANOVA) were first conducted using SYSTAT (Evanston, Ill.) to determine if there were significant differences in SL by strata of categorical variables. Separate analyses were run for each variable. Where appropriate, the data were transformed to improve homogeneity of variances, and power tests (Peterman 1990) were performed.

The next step was to have been the development of structured linear models for each species using predictor variables in a path analysis (Sokal and Rohlf 1981). The advantage of this approach is it allows hypothesis testing. One can propose relationships directly and indirectly between predictor variables and the criterion variable (SL) and quantitatively compare them. This approach allows one to identify the path that best explains variation in SL and to minimize residual error associated with unknown factors. If unexplained error remains large after exploring various paths, it suggests that there were important factors not measured in the field and new hypotheses should be developed. Unfortunately, data on predictor variables were usually incomplete and this quantitative analysis was not possible. We were able to examine data qualitatively on a site-specific basis.

RESULTS

DATA SOURCES

A total of 238 individual estimates of survey life were found for all five Pacific salmon species in 52 references (including personal communications). These estimates included separate measurements of male and female survey life where they occurred in some references. There were 30, 36, 83, 39, and 50 estimates for each of coho, sockeye (O. nerka), chum, chinook (O. tshawytscha), and pink (O. gorbuscha) salmon respectively. Each estimate was either that reported in a reference with or without a specific combination of environmental variables or was an average value calculated from a listing of raw data. Reports by consultants working in British Columbia for the Department of Fisheries and Oceans (DFO) were the most important single source in contributing 32% of all data. IPSC reports, Alaska government technical reports, and university theses followed in importance, each contributing about 11% of all entries. Personal communications provided 9% of the data and primary literature, DFO technical reports, technical reports of the Washington Department of Fisheries, Oregon State agencies, and U.S. Fish and Wildlife comprised the remaining 26%. Data for any one species was not restricted to any one source. Pink, coho, and chum entries came from more than seven of these 10 categories. Chinook data came from four categories, but of these, consultant's reports were most important. Sockeye data came from four categories.

Because of the international importance for pink and sockeye enumeration, the IPSC stores voluminous files of stream surveys documenting escapement estimates for Fraser River streams (Woodey; IPSC, Vancouver, British Columbia; pers comm). Much of these survey data include population estimates based on the Peterson mark-recapture method (Ricker 1975) and counts of fish-days from frequent walks of survey areas; similar variables to those described in equation 1. Equation 1 can be reorganized to solve for SL using IPSC data assuming AUC and N are measured from the same population of a specified reach and AUC is measured from observations throughout the entire run.

Unfortunately, these assumptions were not valid for the IPSC data. Live counts that could be used to determine AUC were only used to obtain a rough estimate of the number of fish to tag for the Peterson estimate and did not continue throughout the run. Also, consecutive observations were often not conducted within the same survey area. Thus, AUC and N did not have identical spatial and temporal criteria thereby invalidating the calculation of SL. For this reason, raw data from IPSC files were not included in our compilation.

SURVEY LIFE ESTIMATES BY SPECIES

Summary statistics (Table 1) of the complete listing of survey life estimates (Appendix B) by species shows that estimates of SL were similar among species but the range and variation in the data was large. An overview of the data for each species is as follows.

With the exception of three anomalous values, survey life of coho ranged from 3 days in Funny Creek, Alaska (Crone and Bond 1976) to 15.1 days in Black Creek, Vancouver Island (J. R. Irvine, unpub. data). The average survey life was 11.4 days. An anomalous value of 76.7 days was reported by Shaul (Alaska Dept. Fish and Game, pers comm), but it included time that fish stayed in Hugh Smith Lake before moving onto actual spawning grounds. Holding time was also reported for coho in the Lake Washington system resulting in a relatively long survey life of 23 days. Similarly, fish held for extended periods below spawning areas in the Big Qualicum system, resulting in a high survey life value of 33 days despite a relatively short migration distance of less than five km. Peak spawning in the Big Qualicum occurred 11 days after the peak spawning ground count (Fraser et al. 1983).

Wide variation was also found in the survey life of chum. The shortest was 4 days, reported by Murray and Hamilton (1981) during surveys in Horetzky Creek of the upper Fraser region and the longest was 21.2 days, reported by Scott and Rosberg (1987) during observations in the Vedder River of the lower Fraser River system. The overall average was 11.9 days. One anomalous value of 25.8 days was reported by Barrett et al. (1985) from Alaskan studies but fish held outside of the spawning area for an average of 19 days after tagging before entering a spawning slough. Once in the slough, the average survey life was 6.8 days.

Pink survey life was highly variable ranging from 4.6 to 40.5 days with an average of 17.3 days in a sample size of 36 estimates. Lowest (Helle et al. 1964) and highest (Thomason and Jones 1984) estimates came from Alaskan surveys but there was no evidence in either study to suggest that conditions were anomalous. Freshets were mentioned as a factor that may have produced positive bias in estimates of SL, but high water conditions were typical during most of the observations in all studies.

Of the 38 measurements for chinook, survey life ranged from as low as 3 days in the West Torpy River (Rosberg and Aitken 1982) in the upper Fraser system to 20 days in the Bowron River (Murray et al. 1981) and Mussel Creek (Whelen and Morgan 1984). The average was 12.1 days. The value of 30 days given by Shardlow et al. (1987) was excluded from Table 1 because it related only to fish being held in tanks at a hatchery and was not comparable to the other data for fish in natural spawning habitat.

Survey life of sockeye ranged from 7 to 26.5 days with an average of 13.2 days. Because sockeye frequently hold in lakes before moving onto spawning grounds, all data were quoted in relation to time in the spawning area. The time of migration through lake systems was not included in the estimates.

Despite the similarities in mean SL estimates among species, we have considered each species separately in the following analyses.

Table 1. Mean, range, variation (CV), and sample size (n) of survey life estimates for each species of Pacific salmon. Obvious outliers that could be explained were omitted from the data. Where SL estimates for both males and females and for both sexes combined were available from concurrent measurements, estimates only for the combined sexes were included.

	Mean SL	Range	CV	n
Coho	11.4	3-15.1	0.23	22
Chum	11.9	4-21.2	0.42	54
Pink	17.3	4.6-40.5	0.44	36
Chinook	12.1	3-20	0.33	38
Sockeye	13.2	7-26.5	0.37	23

CATEGORICAL VARIABLES

For all species, the method of measurement of SL and the location from which data were collected were two potentially important categorical variables. It was reasonable to expect that bias between methods could affect estimates of SL and although there were no *a priori* data, it was also possible that SL varied by location depending on factors such as water temperature, distance of migration, holding patterns of fish prior to spawning, etc. A location effect may provide an index of effects by variables that were site-specific. Method and location were used to stratify the SL estimates in separate one way ANOVA's for each species. A nested effect of location within method or vice versa was also considered, but there were no data with which to pursue this approach for any of the species.

Another categorical variable was the time of arrival to spawning grounds. These data were considered separately as they were examined on a site-specific basis for where there were observations of single populations arriving at the spawning area at different times during the respective runs. The relative differences between SL estimates for late and early-arriving fish were then compared qualitatively between studies.

Methods of survey life measurement

Nine independent methods for estimating survey life were found. Six variations described a time of residence in a survey area and these were identified as RT1, RT2....RT6. The other three were residence time at a redd (RTR), fish life at a hatchery (FLH), and true survey life (TSL).

To estimate RT1, fish were captured at a fish enumeration fence or by seining (or other capture technique) downstream of a survey area. Usually, Peterson disc or spaghetti tags were attached and during routine foot surveys the tags were recovered from carcasses. RT1 was the average number of days between fish tagging and carcass recovery. RT1 estimates were potentially greater than true survey life because there was a time lag between the death and recovery of fish. Although the distribution of numbers of spawners in a survey area through time is usually skewed, Thomason and Jones (1984) found estimates of RT1 to be similar between modal, weighted average, and 50% mortality methods of calculating RT1. The modal estimate was from data collected on the day of maximum recoveries after tagging. The average estimate was weighted according to numbers of carcasses recovered on each day, relative to the total number recovered. The 50% mortality method was the estimate determined on the day when 50% of the tags were recovered. The similarities between these estimates suggest that despite a non-normal distribution of the data, average values from observations of individual fish may give a reasonable approximation of RT1.

The RT2 and RT3 estimates did not involve tagging or marking fish, but were based on repetitive counts of live and dead fish in a survey area.

RT2 was the number of days between the peak live and peak dead counts and like RT1 was potentially greater than true survey life. RT1 and RT2 estimates could differ depending on effects of streamflow and fish density, which may influence the accuracy of live and dead counts in the survey area.

For RT3, differences in time between equivalence points on cumulative live and dead count curves were used to estimate survey life. The equivalence points were usually the 10th, 50th, and 90th percentiles of the total numbers of spawners. Differences in time between these points were interpreted as a temporal trend in residence time. RT3 was one method where negative bias was potentially important. Where the efficiency of observers to see fish was poor, there could be a delay between when fish entered survey areas and when they were first observed. Since RT3 used carcass recovery surveys to estimate the dead count, positive bias was also involved. Under ideal conditions where visibility was good, Lewis (1987) found these opposing biases could cancel each other and that RT3 may give an estimate very close to true survey life. The extent of opposition in the biases, however, is likely to be variable depending again on relative differences in the ability of an observer to see carcasses and live fish.

RT4 was determined by dividing accumulated live fish-days by known escapement to the survey area. This method was used where the total number of spawners could be determined by a method other than the AUC method but included regular counts in the survey area. The method was particularly useful in a spawning channel (Johnston et al. 1987) where the survey area was small (the length of a channel) and an accurate count of spawners was possible. If the escapement estimate was accurate, little bias would be expected in the RT4 estimate. It may, however, be affected in the negative direction if observer efficiency was low. At spawning channels, however, where visibility is generally unrestricted, error was likely minimal.

The RT5 method involved tagging fish with Peterson discs at the boundary of a survey area followed by counts of live, tagged fish during routine foot surveys. The number of tagged fish were plotted against time to produce a tag depletion curve. This approach was quite different from RT1 in which fish were recovered as mortalities and survey life was the average time between tagging live fish and the recovery of carcasses. RT5 was the area-under-the-tag-depletion curve (live fish-days) divided by the total number of tags applied. We are aware of only one study (Bocking et al. 1988) in which this approach was reported but the potential bias would appear to be small compared to the other approaches. There was no obvious bias associated with time between the death and recovery of fish and the integration of counts through time lessened the affect of variation in observer efficiency.

Bocking et al. (1988) also developed a method (which we will call RT6 for this study) to be used where coho numbers were too small for a tag depletion curve to be drawn. A population mortality model used combined data from fence counts and foot survey counts to simulate the upstream migration of spawners.

Various mortality rate factors were applied to adult numbers at different stages of the simulated run, to determine the total number of adults in the survey area at any point in time. This estimate of fish-days was divided by the estimated escapement (mark-recapture) to determine the RT6 value. Opercular punches were used as marks and the fish were recovered dead.

Bias in RT6 was least predictable of all methods. Any error in the simulation of the number of fish-days may have resulted in bias but the direction of that bias was uncertain. The survey life estimate may also have been affected by error in the mark and recapture population estimate.

Some surveys, particularly those by Neilson and Geen (1981) report residence time at a redd (RTR) which restricts the spatial scale of the survey area. Neilson and Geen (1981) defined their observations as the time a female first defends a redd site to the time that she permanently vacates the redd. For purposes of escapement estimation, RTR is of little use because the survey area is reduced to the size of a redd and except for the one pair, the population of interest is actually outside the survey area. However, if we consider RTR only for an estimate of the life of the spawning pair, we can expect negative bias. The time between when a fish enters a stream and when it is counted at the redd and between the time the fish leaves the redd to when it dies would contribute bias to survey life estimates.

Data reported by Shardlow et al. (1987) were unique in dealing with the life of spawners held in a hatchery facility: FLH. FLH may have contained positive bias in that the facility artificially eliminated territorial defense that is likely important in determining individual longevity. Reduced competition, aggression, and overall activity in a holding box may have resulted in a longer life than might be expected on the spawning grounds.

Some data were considered unbiased, either because field observations were corrected for known bias (Lewis 1987) or observations included actual times of entry to a survey area and actual death (Killick 1955, Schroeder 1973). These data were termed true survey life (TSL).

The number of methods used to determine survey life for each species ranged from two for sockeye to six for coho (Table 2). For all species except chinook, RT1 was the most commonly used. Most estimates for chinook were from projects conducted by DFO contractors at remote sites where fence or tagging facilities were not available. Logistics required that the estimates be determined by the RT2 and RT3 methods.

Table 2. Mean survey life values, results from analyses of variance and power tests performed, and sample sizes by method[1] for each species of Pacific salmon.

	SURVEY LIFE METHODS[2]									
	RT1	RT2	RT3	RT4	RT5	RT6	RTR	TSL	ANOVA[3]	POWER[4]
COHO[5]										
mean	12.1	12.5		13.3	11.7	10.2	9.3		n.s.	<0.2
SE	0.8	1.0			1.3	3.1	2.7			
n	5	4		1	4	2	3			
CHUM										
mean	12.3		11.5	8.9			5.85	13.9	n.s	<0.2
SE	1.0		1.7	0.5			0.15	0.6		
n	26		12	4			2	9		
PINK										
mean	18.4	16.8	14.4						n.s	<0.2
SE	1.7	1.8	1.7							
n	25	2	9							
CHINOOK[6]										
mean	13.3	11.3	12.5				12.3		n.s	<0.2
SE	2.5	0.9	1.2				1.8			
n	4	16	14				4			
SOCKEYE										
mean	13.9			8.7					n.s.	<0.2
SE	1.1			2.0						
n	20			3						

[1]Data were only for both sexes combined. Where there were survey life estimates for both males and females and both sexes combined, only the estimate for both sexes was included.

[2]Methods abbreviations description:

RT1: Number of days between tagging and carcass recovery.

RT2: Number of days between peak live and peak dead counts.

RT3: Number of days between equivalence points on cumulative live and dead count curves.

RT4: Accumulated live fish-days divided by known escapement.

RT5: Area of a tag-depletion curve divided by total number of tags.

Table 2 (cont'd)

RT6: Number of fish-days estimated from a population-mortality model divided by population estimate determined by mark-recapture.

RTR: Number of days at a redd.

FLH: Number of days a fish is alive in a hatchery holding facility.

TSL: Number of days that a spawner can be counted as a live fish in a survey area.

[3]Any method for which there was less than three estimates of survey life was not included in the ANOVA.

[4]Power of the ANOVA was approximated using procedures in Dixon and Massey (1969) and Winer (1971).

[5]Three estimates for coho for which survey life methods could not be determined were omitted from the table. Three others were anomalous and were also not included.

[6]The single FLH estimate for chinook was omitted from the table.

The question of whether different approaches actually did give different estimates of SL in practice was examined in an ANOVA among means of estimates by method (Table 2). For each species, the ANOVA failed to reject H_o ($p<0.05$) that the survey life estimates differed among measurement methods and may suggest that potential bias among methods did not affect estimates of survey life. We also recognize, however, that the power of the analyses (Peterman 1990) was poor. Using procedures described by Dixon and Massey (1969), the approximate power of each ANOVA was found to be less than 0.2. Since a minimum value of 0.8 is recommended before one can accept H_o with confidence (Peterman 1990), the result of this test suggested that there was more than an 80% chance of failing to detect differences in survey life among methods when differences may have existed. Hence, the small sample sizes and large variability in survey life estimates produced an inconclusive ANOVA.

Location

An overview of the distribution of samples from each region is presented in Table 3. Alaskan streams provided the largest single source of estimates, contributing data for all species except chinook. Most information on pink SL originated from Alaskan surveys. Four of the five species were also represented in surveys from Johnstone Strait and the Thompson System but sample sizes were very small. Only data for chinook were found from the Prince Rupert region (Neilson and Geen 1981). Coho was the only species reported in work from Oregon, but the data were in three separate studies (Koski 1966, Willis 1954, Beidler and Nickelson 1980). Twenty estimates covering pink and chum on the central coast were found in consultant's reports. More than half the estimates from Georgia Strait streams were for chum, largely because of data collected for chum hatcheries or spawning channels. On the West Coast of Vancouver Island, only three estimates were found (Hyatt pers comm.), and those were only for sockeye. The combination of surveys from the Fraser and Thompson systems provided most data from a single watershed for all species (54 estimates). Sixteen estimates came from surveys in Washington for coho and chum.

Although it is uncertain whether there were differences in survey life among methods, all data were pooled for each species for a similar analysis to examine variation in SL by location. Results of the ANOVA (Table 3) were similar to the methods analysis by failing to reject H_o. Again the power of the test was very low and indicated that the sample sizes were too low and the variability was too high for the ANOVA to be conclusive.

Despite the analytical uncertainties of the effect of categorical variables on SL, a comparison among years of SL estimates on the same stream where the same methods were used revealed wide variation that was due to factors other than method and location. In Table 4, paired data for sequential observations suggest that even when location and method are constant, there can be large differences in SL between years. The differences were greatest when observers changed between years, but at 11 of the 16 sites in Table 4, the observers were the same in each year, and estimates still differed by up to 48.8%. On the Adams River, a sequence of four years of data were collected by Killick (1955) using similar methods and SL varied from 14.8 to 18.7 days. Clearly, factors unrelated to location, method of measurement, and even the identity of observers contributed to variation in SL estimates.

Table 3. Mean survey life values, results from analyses of variance and power tests performed, and sample sizes by location for each species of Pacific salmon.

	LOCATIONS AK	OR	WA	JS	GS	TS	CC	LF	WI	UF	PR	ANOVA[1]	POWER[2]
COHO													
mean	9.3	12.1	9.6	13.0	11.5	12.5						n.s.	<0.2
SE	2.7	0.5	0.4		1.1	1.02							
n	3	5	2	1	7	4							
CHUM													
mean	12.7		11.7	19.0	13.5		10.0	21.2	9.9			n.s.	<0.2
SE	2.5		0.8		0.7		1.5		0.9				
n	10		14	1	9		13	1	5				
PINK													
mean	17.7			18.2		16.5	12.6	25.2		14.0		n.s	<0.2
SE	2.1			1.6			1.5	2.1					
n	19			5		1	7	3		1			
CHINOOK													
mean				15.0	18.0	10.2				12.9	10.4	n.s.	<0.2
SE				5.0		.8				0.9	2.7		
n				2	1	13				20	2		
SOCKEYE													
mean	14.4					17.8		10.9	8.7	11.2		n.s.	<0.2
SE	2.0					0.7		1.1	2.0	1.1			
n	9					4		4	3	3			

[1]Any location for which there was less than three estimates of survey life was not included in the ANOVA.

[2]Power of the ANOVA was approximated from procedures in Dixon and Massey (1969) and Winer (1971).

Table 4. Comparison of SL estimates at locations where methods were constant. References are listed in Appendix C.

Stream	Reference	Method	Years	SL	Difference (%)
COHO					
Black Creek	Irvine[1]	RT5	1987	15.1	
			1988	9.6	36.4
CHUM					
Tarrant Creek	22,1	RT3	1984	18.0	
			1985	5.6	68.8
Nekite River	23,36	RT3	1984	19.0	
			1985	4.3	77.4
Traitors River	24	RT1	1962	17.9	
			1963	11.5	35.8
Traitors River	24	RTR	1962	5.7	
			1963	6.1	6.6
Walker Creek	19	RT1	1984	17.5	
			1985	15.8	9.7
Walker Creek	19	TSL	1984	12.7	
			1985	13.2	3.9
PINK					
Asseek River	22,1	RT3	1984	18.0	
			1985	13.0	27.8
Nekita River	23,37	RT3	1984	10.0	
			1985	6.4	36.0
Union Bay Creek	Jones[2]	RT1	1986	20.9	
			1987	10.7	48.8
Pleasant Bay Creek	Jones[2]	RT1	1986	10.7	
			1987	14.4	34.6
Sashin Creek	Jones[2]	RT1	1986	10.5	
			1987	10.3	1.9
CHINOOK					
Slim Creek	27,30	RT3	1980	12.5	
			1981	14.9	16.1

Table 4 (cont'd)

Stream	Reference	Method	Years	SL	Difference (%)
SOCKEYE					
Weaver Creek	32	RT1	1940	8.8	
			1941	9.3	5.7
Birkenhead River	32	RT1	1940	12.3	
			1941	13.2	7.3
Adams River	16	RT1	1946	14.8	
			1950	18.7	
			1951	16.2	
			1954	18.1	

[1]Irvine, J. R. (unpubl. data)
[2]Jones D. Alaska Dept. Fish and Game. (pers. comm.)

Time of arrival to spawning reaches

For each species except coho (for which there were no relevant data) the SL of fish observed early in a particular run was greater than that observed later in the same run (Table 5).

Table 5. A comparison of survey life in each species of salmon arriving in a survey area early and late in the run. References are listed in Appendix C.

Species	Reference	Stream (Region)	Survey Life Early	Survey Life Late
COHO		No data		
CHUM	26	Horetzky Cr. (CC)	9.0	4.0
	26	Kemano R. (CC)	9.0	4.0
	9	Big Qualicum (GS)	14.0	11.0
	Ames [1]	Johns Creek	10.7	9.7
	33	Big Beef Cr. (WA)		
		1970 males	16.7	13.9
		1970 females	15.9	14.0
		1971 males	17.2	16.4
		1971 females	15.5	13.5
PINK	12	Olsen Cr. (AK)	21.2	4.6
	39	Salmon Cr. (AK)	14.5	13.4
		Starrigavin Cr. (AK)	33.1	27.0
		White R. (AK)	40.5	24.7
	41	Early run in Fraser System		
		Harrison R.	21.5	
		Vedder R.	28.9	
		Fraser R.	25.3	
		Late run in Fraser System		
		Seton Cr.		14.0
		Thompson R.		16.5
CHINOOK	28	Morice River (PR)	13.1	7.7
	29	Nechako River (UF)	16.5	12.0
SOCKEYE	16	Forfar Creek (UF) (females)	13.6	8.4
		Forfar Creek (UF) (males)	12.4	9.8

[1]Ames, J. Washington Dept. Fisheries. pers. comm.

The paired chum data reported by Fraser et al. (1983) showed a decline in survey life from 14 to 11 days in early and late spawners respectively. Murray and Hamilton (1981) measured a 55% decline in two different streams. Schroeder (1973) and Ames (pers comm.) found smaller but consistently lower estimates of SL for late spawners compared to that for early spawners. Detailed observations by Jones (Alaska Dept. Fish and Game, pers comm.) clearly showed a decline in SL through the runs in Pleasant Bay Creek, Alaska (Table 6).

In three streams surveyed by Thomason and Jones (1984), the survey life of late arriving pinks was 8% to 39% less than that of the early arrivals. The magnitude of change was variable but again the direction was consistent. More extensive raw data from Pleasant Bay Creek and Union Bay Creek, Alaska (Jones, pers comm.) showed significant negative correlations between survey life and time of arrival in two different years (Table 6). Ward (1959) observed that "races" migrating furthest in the Fraser River system had shorter life spans on the spawning grounds compared to those migrating over shorter distances. If we assume that distance was directly proportional to time of arrival on the spawning grounds, these data may indicate differences in SL between early and late arrivals.

Table 6. Variation in survey life between years and correlation of time of arrival and survey life for pink and chum salmon in Alaskan streams[1].

	Pink		Pink		Pink		Chum
	Union Bay Creek		Pleasant Bay Creek		Sashin Creek		Pleasant Bay Creek
	1986	1987	1986	1987	1986	1987	1987
Early	31.6	24.8	15.3	30.8	12.8	12.8	16
Middle	16.6	10.1	11.7	9.3	9.8	10.2	5.3
Late	5.6	7.0	6.7	4.5	5.9	8.4	5
n	43	35	42	59	24	19	24
r	-0.86[2]	-0.71	-0.9	-0.92	-0.87	-0.67	-0.71

[1] Raw data provided by D. Jones. Alaska Dept. Fish and Game.
[2] All correlation coefficients were significant at $p<0.05$.

Chinook and sockeye surveys which reported SL early and late in runs were also consistent with the observations for other species. In two chinook rivers, Neilson and Geen (1981) and Neilson and Banford (1983) found that early-arriving fish lived longer than late arrivals (Table 5). The same was true for observations of sockeye in the upper Fraser and in streams on the West coast of Vancouver Island (Hyatt, pers comm.).

PREDICTOR VARIABLES

Four predictor variables (sex ratio, density of females, and body size of males and females) in various combinations with SL estimates were found (Appendix B) that could be included in the paths of a multiple regression model for each species to explain variation in SL. Table 7 identifies the variables and corresponding sample sizes that could be included in such an analysis.

Table 7. Combinations of predictor variables that could explain variation in the criterion variable, SL, in paths of a multiple regression analysis for each species. Sample sizes are shown for independent samples of predictor variables and complete data for all variables.

Species	Predictor Variables	Sample size (single variable)	Sample size (all variables)
Coho	sex ratio	9	5
	male body size	6	
	female body size	8	
Chum	sex ratio	28	10
	density	18	
	male body size	25	
	female body size	25	
Pink	sex ratio	13	7
	density	7	
	male body size	17	
	female body size	17	
Chinook	sex ratio	21	20
	male body size	20	
	female body size	22	
Sockeye	no data on predictor variables		

An obvious problem here is that the stratification of low numbers of samples results in even smaller sample sizes. Nevertheless, the regressions were run on both multiple and single predictor variables and in all cases the regression coefficients and F ratios were insignificant ($p<0.05$). Again the analyses failed to reject H_o. The analyses were somewhat irrelevant, however, since it was clear that further reductions in sample sizes from the whole data set, combined with the high variability in SL, made the results more inconclusive than what was found from the analysis of effects of categorical variables.

Data were available to examine differences in survey life between males and females (Appendix B), but again sample sizes were small. For each species, the available data set contained less than 30 cases. When Student's t tests were performed, differences in SL between sexes were never found ($p<0.05$). The results must, however, be regarded as inconclusive because it was not possible to determine if the data were normally distributed.

DISCUSSION

Despite an exhaustive data search, we were unable to explain the variability around the SL estimates we obtained for any of the species of Pacific salmon. After stratification of SL estimates by method of measurement and location, analyses of variance failed to reject the hypothesis that SL varied between these strata. However, low statistical power (Peterman 1990), the result of small sample sizes and large variability, meant that it would have been difficult to detect differences even if they existed. Low power was also a concern in running linear models to explore the importance of predictor variables including sex ratio, density, and body size. Sample sizes were also too small to determine if differences in SL between males and females were significant.

Progress was made in a qualitative review of the data. First, many SL estimates were collected during two consecutive years where the method of measurement, location, and in many cases, the same observers were used (Table 4). Despite the constancy of these variables, variation in SL estimates remained high, suggesting that site-specific factors were important. Although the data were inadequate to examine the significance of sex ratio and body size, which were previously concluded to be important (Ames 1984, van den Berghe and Gross 1986), there was consistent evidence that the time of arrival to the spawning grounds was important (Table 5 and 6). Fish arriving early had a longer SL than fish arriving late.

Schaefer (1951), Barrett et al. (1985), and Hyatt (pers comm.) each commented on stocks holding in lakes, sloughs, and other slow moving areas. In many cases, fish waited for sufficient water levels before they moved into spawning areas. Hence, the survey life of individuals of a particular stock may be determined by the timing of weather patterns which can influence migration timing. If physical conditions are suitable for active migration early in the run, survey life in a spawning area may be considerably longer than if fish must hold at various stages during their upstream migration.

Much of the unexplained variation in survey life may be related to variables for which there were little data. We have suggested that flow conditions that vary among years may influence survey life. Water temperature may also be important. For example, the survey life of coho in the Little Qualicum spawning channel was estimated to be 13.3 days in 1986 (Johnston et al. 1987) but 22 days in 1987 (Hargrove, Little Qualicum Spawning Channel, pers comm.). Conditions were similar in both years except for lower water temperatures in 1987. Other possible explanations for variations in survey life include genetic characteristics, differences in aggressive behaviour related to density effects, and the condition of the spawners upon entering fresh water.

An experimental approach could be used to examine the importance of various factors in determining SL. For instance, in a spawning channel where it was possible to manipulate or at least measure factors including flow, temperature, spawner density, and sex ratios, it would be posssible to determine which were important. The number of predictor variables would be limited and path analysis (Sokal and Rohlf 1981) could be used to evaluate alternative models. Unfortunately it might require more effort to measure the predictor variables than to measure SL. Obviously it would be unrealistic to adopt a quantitative model which was so complex that its use was impractical. It would appear that the model could not have any more than two or three predictor variables to be useful.

Since the AUC method of estimating escapement is based on visual surveys that can be completed quickly and at relatively low cost, it will continue to be used. The method is often perceived to give reasonable estimates of escapement without any requirement for crews to count fish through an expensive trap facility. Unfortunately, it is not uncommon for an estimate of survey life from one site or system to be used in an AUC estimate of escapement for other sites, or for a SL value determined from one period of observation to be used for other years. Since survey life can vary among years within a stream, and among streams within a year, SL estimates should not be transferred among streams or years. This can produce serious errors in the escapement estimate. SL should be determined on a site specific basis each time the AUC estimate is used to estimate escapement.

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REFERENCES CITED

Abbott, J. C., G. O. Stewart and P. R. Murray. 1986. South Bentinck Arm adult salmonid reconnaissance program 1985. Contract report for DFO prepared by Envirocon Ltd. 126 p.

Ames, J. 1984. Puget Sound Chum escapement estimates using spawner curve methodology. In: Proceedings of the workshop on stream indexing for salmon escapement estimates. West Vancouver, B.C. February 1984. Can Tech. Rep. Fish. Aquat. Sci. 1326: 135-148.

Ames, J. and D. E. Phinney. 1977. 1977 Puget Sound summer-fall Chinook methodology: escapement estimates and goals; run size forecasts and in-season run size updates. Wash. State Dept. of Fish. Tech. Rep. No. 29. 71 p.

Barrett, B. M., F. M. Thompson and S. N. Wick. 1985. Adult anadromous fish investigations: May-October 1984. Alaska Dept. of Fish and Game, Susitna Hydro Aquatic Studies, Report No. 6. Prepared for Alaska Power Authority, Anchorage, AK.

Beidler, W. M. and T. E. Nickelson. 1980. An evaluation of the Oregon Department of Fish and Wildlife standard spawning fish survey system for coho salmon. Oregon Dept. of Fish and Wild. Info. Rept. 80-9. 23 p.

Bocking R. C., J. R Irvine, K. K. English and M. Labelle. 1988. Evaluation of random and indexing sampling designs for estimating coho salmon (Oncorhynchus kisutch) escapement to three Vancouver Island streams. Can. Tech. Rep. Fish. Aquat. Sci. No. 1639: 95 p.

B.C. List. 1987. British Columbia list of official personnel in Federal, Provincial, and Municipal governments in the Province of British Columbia. B & C List (1982) Ltd.

Cousens, N. B. F., G. A. Thomas, C. G. Swann and M. C. Healey. 1982. A review of salmon escapement estimation techniques. Can. Tech. Rep. Fish. Aquat. Sci. 1108: 122 p.

Crone, R. A. and C. E. Bond. 1976. Life history of coho salmon, Oncorhynchus kisutch in Sashin Creek, southeastern Alaska. Fishery Bulletin 74(4): 897-923.

Dixon, W. J. and F. J. Massey Jr. 1969. Introduction to statistical analysis. McGraw Hill. New York.

Flint, T. 1984. A comparison of stream indexing methods to estimate coho escapements in Harris Creek, 1980-83. Can. Tech. Rept. Fish. Aquat. Sci. 1326: 149-159.

Fraser, F. J., E. A. Perry and D. T. Lightly. 1983. Big Qualicum River salmon development project, Vol 1: A biological assessment 1959-1972. Can. Tech. Rept. Fish. Aquat. Sci. No. 1189: 198 p.

Helle, J. H., R. S. Williamson and J. E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish. and Wild. Serv. Special Sci. Report - Fisheries. No. 483: 26 p.

Hickey, D. G. and D. B. Lister. 1981. Salmonid enhancement baseline investigations at Stuart River, B.C. in 1980. Part II Adult chinook study. Prepared by D.B. Lister and Assoc. Ltd. for DFO.

Johnston, N. T., J. R. Irvine and C. J. Perrin. 1987. Instream indexing of coho salmon (Oncorhynchus kisutch) escapement in French Creek, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1573: 37 p.

Johnston, N. T., J. R. Irvine and C. J. Perrin. 1986. A comparative evaluation of fence count, mark-recapture, and Bendix sonar estimates of salmon escapements in the Keogh River, a variable-flow coastal stream. Can. Tech. Rep. Fish. Aquat. Sci. No. 1453: 44 p.

Killick, S. R. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning and death. Int. Pac. Sal. Fish. Comm. Bull. VII. 95 p.

Koski, K. V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. MSc. Thesis. Oregon State Univ. Corvallis Oregon. 84 p.

Lewis, A. F. J. 1987. The effects of breeding completion and abiotic factors on the behaviour and reproductive success of female chum salmon (Oncorhynchus keta). MSc. Thesis. Simon Fraser University. Dept. Biological Sciences. 186 p.

McAleer, B. D. 1987. The directory of North American Fisheries and Aquatic Scientists. American Fisheries Society. Maryland.

McGivney, K. K., G. J. Holowatiuk and P. R. Murray. 1985(a). South Bentinck Arm salmonid reconnaissance program. 1984. Prep. by Envirocon Ltd. for DFO. 128 p.

McGivney, K. K., S. L. Bowman and P. R. Murray. 1985(b). Smith Inlet adult salmonid reconnaissance program. Prep. by Envirocon Ltd. for DFO. 106 p.

Mundie, J. H. 1984. Stream indexing: its usefulness and limitations. Can. Tech. Rep. Fish. Aquat. Sci. 1326: 43-48.

Murray, P. R. and S. R. Hamilton. 1981. Baseline biological data on adult chum salmon in the Kemano River system. 1979. Prepared by Envirocon Ltd. for DFO. 68 p.

Murray, P. R., G. O. Stewart and S. R. Hamilton. 1981. Studies on adult chinook salmon (Oncorhynchus tshawytscha) in the Bowron and Willow Rivers and Slim Creek, B.C. during 1980. Prepared by Envirocon Ltd. for DFO.

Neilson J. D. and G. H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Trans. Am. Fish. Soc. 110: 554-556.

Neilson, J. D. and C. E. Banford. 1983. Chinook salmon (Oncorhynchus tshawytscha) spawner characteristics in relation to redd physical features. Can. J. Zool. 61(7): 1524-1531.

Peterman, R. M. 1990. Statistical power analysis can improve fisheries research and management. Can. J. Fish. Aquat. Sci. 47: 2-15.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board. Can. 191: 382 p.

Rosberg, G. E. and D. Aitken. 1982. Adult chinook salmon studies in four tributaries to the upper Fraser River. 1981. Prepared by Beak Consultants Ltd. for DFO. 140 p.

Schaefer, M. B. 1951. A study of the spawning populations of sockeye salmon in the Harrison River system with special reference to the problem of enumeration of means of marked members. Int. Pac. Sal. Comm. Bull. IV. 207 p.

Schroeder, S. L. 1973. Effects of density on the spawning success of chum salmon (Oncorhynchus keta) in an artificial spawning channel. MSc. Thesis. University of Wash. 1973. 78 p.

Scott, K. J. and G. E. Rosberg. 1987. Adult chum salmon studies and escapement estimation in the Vedder/Chilliwack River. 1986. Prepared by G.E. Rosberg and Assoc. for DFO. 51 p.

Scott, K. J., M. A. Whelen and W. R. Olmsted. 1982. 1981 biophysical studies of selected chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon producing tributaries of the North Thompson River drainage. Prepared by EVS Consultants. for DFO.

Shardlow. T., R. Hilborn and D. Lightly. 1987. Component analysis of instream escapement methods for Pacific Salmon (Oncorhynchus sp). Can. J. Fish. Aquat. Sci. 44(5): 1031-1037.

Solazzi, M. F. 1984. Relationships between visual counts of coho salmon (Oncorhynchus kisutch) from spawning fish surveys and the actual number of fish present. Can. Tech. Rep. Fish. Aquat. Sci. 1326: 175-186.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Company. New York.

Symons, P. E. K. and M. Waldichuk. 1984. Proceedings of the workshop on stream indexing for salmon escapement estimation. Can. Tech. Rep. Fish. Aquat. Sci. 1326: 1-22.

Thomason, G. J. and J. D. Jones. 1984. Southeastern Alaska pink salmon (Oncorhynchus gorbuscha) stream life studies, 1983. Alaska Dept. of Fish and Game Information Leaflet No. 236. 15 p.

van den Berghe, E. P. and M. R. Gross. 1986. Length of breeding life of coho salmon (Oncorhynchus kisutch). Can. J. Zool. 64: 1482-1486.

Waldichuk, M. 1984. Chairman's summary. Can. Tech. Rep. Fish. Aquat. Sci. 1326: ix-xv.

Walters, C. J. 1975. Optimum harvest strategies for salmon in relation to environmental variability and uncertain production parameters. J. Fish. Res. Bd. Can. 32: 1777-1784.

Walters, C. J. and R. Hilborn. 1976. Adaptive control of fishing systems. J. Fish. Res. Bd. Can. 33: 145-159.

Ward, F. J. 1959. Character of the migration of pink salmon to Fraser River spawning grounds in 1957. Int. Pac. Sal. Fish. Comm. Bull. X.

Whelen, M. A. and J. D. Morgan. 1984. 1983 spawning salmonid studies in selected watercourses of Knight Inlet, B.C. Prepared by EVS Consultants for DFO. 172 p.

Willis, R. A. 1954. The length of time that silver salmon spent before death on the spawning grounds at Spring Creek, Wilson River in 1951-52. Ore. Fish Comm. Res. Brief. Vol 5: 27-31.

Winer, B. J. 1971. Statistical principles in experimental design. McGraw Hill. New York.

APPENDIX A

SALMONID SURVEY LIFE QUESTIONNAIRE

Date:______________

Name:____
Title:____
Job Activity ____
____

Agency/Organization:________________________________
Address:____
____
____

Phone: (   )____-_____ ext.___

1. What technique do you presently use and have you previously used to estimate escapement of salmonids in streams under your management or in your research?

Present method(s)
Coho ____
Chum ____
Chinook ____
Pink ____
Sockeye ____
Steelhead ____
Other (   ) _______________________________

Previous method(s) ______________________________
(if different from above) ______________________________
____
____
____
____

If your escapement estimation technique <u>includes</u> the area under the curve (AUC) method for one or more species, go to question 3.

If your escapement estimation technique <u>does not include</u> the area under the curve (AUC) method for one or more species or you are not familiar with the AUC method, go to question 2.

Survey Life Questionnaire-----Page 2

2. In the space provided or if necessary on a separate page, briefly describe your method(s) of estimating salmonid escapement from your data obtained in field surveys. If you prefer, enclose copies of articles and reports that discuss the use of your particular method(s). If copies are not readily available please indicate where they can be obtained. Based on your experience, any comments on advantages and disadvantages of the method(s) you use would be appreciated.

Go to question 7.

3. As part of the AUC method, do you use or have you used survey life data for salmonids to obtain an estimate of escapement?

   If Yes, go to statement 5.

   No, AUC is used only as an index of relative abundance. Survey life data are not considered.
   Go to statement 4.

   No, freshwater life data other than what is defined as survey life in the covering letter is used in the AUC estimate.
   Go to statement 5.

4. Briefly describe how you calibrate the AUC index to escapement. Use a separate page if necessary. If you prefer, enclose data or reports which have been used to establish the relation between the AUC index of relative abundance and escapement.

   Go to question 7.

5. Provide a definition of your freshwater life data that is used in your AUC method to estimate salmonid escapement.

____
____
____
____

Go to statement 6.

6. We would appreciate receiving copies of reports, operating manual, field notes, or other information that includes a tabulation of;

   a) the freshwater life parameter defined in statement 5
   or
   b) survey life as defined in the covering letter and noted in question 3.

that you have prepared for Pacific salmonids in streams under your management or in your research. If you prefer, enter the information on the enclosed data sheets.

Data for descriptive variables including; year, species, location, size of survey area, sex ratios, body size, spawner density, timing of the run, or other variable which you may have considered for survey life entries would also be appreciated. An example of formatting is shown on the enclosed data sheets.

If these freshwater life or survey life data are not readily available, please indicate where they can be obtained.

____
____

Go to Question 7.

7. In any of your stream surveys that may or may not be related to escapement estimation, have you conducted repetitive counts or recaptures of adult salmonids? In this regard, mark and recapture surveys, other tagging studies, and general field observations would be important to consider.

Yes No

If Yes, please enclose recapture data or related reports or enter data on the enclosed data sheets; then go to statement 8.
If No, go to statement 8.

8. If you are not familiar with AUC methods for estimating salmonid escapement, go to statement 10.

   If you are familiar with AUC methods for estimating salmonid escapement, go to statement 9.

9. Any comments pertaining to your experience with the use of AUC methodology for estimating salmonid escapement would be appreciated. Direct your comments at comparisons of AUC with other methods and the appropriateness of using AUC methods in your area. If you prefer, enclose appropriate reports or articles that discuss this topic.

   Go to statement 10.

10. Thank you for taking time to complete this questionnaire. Your contribution will be most valuable and will help make the project a success.

Please circle the appropriate response below if you wish to receive a copy of the final report and data base that will result from this project:

Yes, I do wish to receive a copy of the final report.

No, I do not require a copy of the final report.

Please forward your completed questionnaire and data sheets to:

Chris J. Perrin
Limnotek Research and Development Inc.
4035 West 14 Ave.
Vancouver, B.C.
Canada, V6R 2X3

Thank you again for your very important contribution.

Procedure for AUC Estimate of Escapement

The AUC estimate of escapement is determined by dividing the number of fish days in a survey area by the life of the average spawner. Procedures are as follows.

1. Spawner Counts

   A time series of counts of spawners are made on regular surveys within a survey area. Results are then plotted. Counts may be corrected for percent visibility or the escapement estimate may be corrected to observer efficiency.

2. Estimate of Fish Days

   A line is fit to the plotted data and fish days are determined by measuring the area under the curve. Integration methods are used or the area is determined with a polar planimeter. The number of fish days are calculated by multiplying the area by the number of fish days in 1 cm^2. As it stands this measurement can only be used as an index of relative abundance.

3. Estimate of Survey Life (in days)

   Survey life is defined as the number of days that the average spawner can be counted as a live fish in a survey area. The estimate is determined from stock specific tagging studies or from information thought to be representative of the stock for which the escapement estimate is required.

4. Estimate of Escapement.

   Fish days are divided by survey life to yield the escapement estimate in units of numbers of fish.

APPENDIX B[1]

Listing of survey life estimates and values of descriptive variables for all species

COHO

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body Size	SL	SL	S & L
06 (1965)	RTR	AK: Sashin Cr.								13.0
06 (1967)	RTR	AK: Sashin Cr.								11.0
06 (1967)	RTR	AK: Funny Cr.								3-7
18 (1966)	RT1	OR: Deer Cr.		16.2			71.2			13.7
18 (1966)	RT1	OR: Flynn Cr.		28.6			68.9			13.1
40 (1981)	RT1	WA: Deer Cr.		39.2		49.7	55.0	09.4	09.0	
45 (1952)	RT1	OR: Spring Cr.		28.5				12.0	11.0	
15 (1985)	RT1	JS: Keogh R.				42.2	54.1		06.7	13.0
09 (1959-72)	RT1	GS: Big Qualicum		55.7		52.7	52.7			33.0
F[2] (1982)	RT1	AK: Hugh Smith Lake								76.7
08 (1978)	RT1	WA: Little Bear Cr.		69.0		56.5	56.9	27.0	21.0	23.0
14 (1986)	RT4	GS: Little Qualicum								13.3
F[3]		OR: all streams								11.3
07 (1980-3)		WA: Harris Cr.								10.0

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[1]References in Appendix B are listed in Appendix C. Abbreviations for methods are explained under Methods of survey life estimates in the main text. Abbreviations for location are explained under Data Organization in the main text.

[2]Shaul, pers comm. Alaska Dept. Fish and Game, Douglas, Alaska.

[3]Jacobs, pers comm. Oregon Dept. Fish and Wildlife, Corvallis, Oregon.

Appendix B Continued: COHO

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body SL Size	SL	S & L
05 (1980)		OR: Oregon streams							11.0
F[4] (1987)	RT6	GS: French Cr.							13.3
F[5] (1988)	RT5	GS: French Cr.							12.5
F[5] (1987)	RT5	GS: Black Cr.							15.1
F[5] (1988)	RT5	GS: Black Cr.							09.6
F[5] (1987)	RT6	GS: Trent R.							07.1
F[5] (1988)	RT5	GS: Trent R.							09.6
43 (1982)	RT2	TS: Eagle		62.1		50.4	49.9		12.5
43 (1982)	RT2	TS: Salmon		39.7		43.8	45.8		15.0
43 (1982)	RT2	TS: Adams		48.1					10.0
43 (1982)	RT2	TS: Coldwater							12.5

CHUM

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body SL Size	SL	S & L
22 (1984)	RT3	CC: Tarrant			0.08				18.0
23 (1984)	RT3	CC: Nekite R.		47.6	0.02	58.1	55.6		19.0
23 (1984)	RT3	CC: Walker Cr.		35.7	0.03	55.1	55.9		15.0
37 (1985)	RT3	CC: Walkum Cr.		47.6		53.4	62.2		06.2
37 (1985)	RT3	CC: Nekite R.		60.6	0.13	55.2	53.8		04.3
1 (1985)	RT3	CC: Taleomy		55.6	0.18	58.0	53.8		10.3
1 (1985)	RT3	CC: Noeick		66.7	0.01	56.5	51.2		12.7

[4] Irvine, J.R. Unpubl. data. Address on Title page.

Appendix B Continued: CHUM

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body Size	SL	SL	S & L
1 (1985)	RT3	CC: Tarrant		52.6	0.24	58.1	55.0			05.6
1 (1985)	RT3	CC: Asseek		45.5	0.01	57.0	53.0			13.0
26 (1979)	RT3	CC: Horetzky	early	50.0		60.7	57.5			09.0
26 (1979)	RT3	CC: Horetzky	late	50.0		60.7	57.5			04.0
26 (1979)	RT1	CC: Kemano R.	early	58.1		59.9	56.9			09.0
26 (1979)	RT1	CC: Kemano R.	late	58.1		59.9	56.9			04.0
42 (1983)	RT2	JS: Ahnuhati		42.2	0.04	63.8	59.8			14.0
42 (1983)	RT2	JS: Glendale		40.0		61.0	62.7			12.0
34 (1986)	RT3	LF: Vedder		47.0		60.7	58.4			21.2
09 1959-72	RT1	GS: Big Qualicum		51.3		59.0	59.0			13.0[5]
09 1959-72	RT1	GS: Big Qualicum	early	51.3	0.8	59.0	59.0			14.0
09 1959-72	RT1	GS: Big Qualicum	late	51.3	0.8	59.0	59.0			11.0
31 (1952)	RT1	WA: Minter Cr.								10.5
02 (1974)	RT1	WA: Perkins								9.5
02 (1977)	RT1	WA: Johns	early							10.1
02 (1977)	RT1	WA: Yelm	late							09.7
15 (1985)	RT1	JS: Keogh		67.0		56.9	56.9	09.0	22.0	19.0
24 (1962)	RT1	AK: Traitors R.						18.3	17.6	
24 (1963)	RT1	AK: Traitors R.						11.6	11.4	
21 (1962)	RT1	GS: Big Qualicum								13.0
04 (1984)	RT1	AK: Susitna								25.8[6]
19 (1984)	RT1	GS: Walker Cr.						18.0	16.7	17.5

[5]Survey life varied from 12.2 days in spawning channel #1 to 9.5 days in spawning channel #2.

[6]Fish held in the river before entering a slough for spawning.

Appendix B Continued: CHUM

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body Size	SL	SL	S & L
19 (1985)	RT1	GS: Walker Cr.						16.3	15.2	15.8
F[7] (1987)	RT1	AK: Union Bay						05.7	04.3	04.9
F[8] (1987)	RT1	AK: Sashin Cr.						07.5		07.5
F[8] (1987)	RT1	AK: Pleasant Bay						06.7	05.3	05.8
11 (1978)	RT1	WI: Sucwoa		56.5		59.9	58.1			08.2
11 (1978)	RT1	WI: Canton		58.7		59.4	57.1			09.0
11 (1978)	RT1	WI: Conuma		55.4		59.7	57.9			13.4
11 (1978)	RT1	WI: Tlupana		56.3		58.7	57.0			09.4
11 (1978)	RT1	WI: Deserted		55.4		57.8	56.6			09.5
17 (1976)	RT1	AK: Traitors R.	early			63.3	60.9			20.8
17 (1976)	RT1	AK: Katlian Cr.								20.7
F[8] (1983)	RT4	WA: Yelm		56						08.8
F[9] (1982)	RT4	WA: Yelm								09.7
F[9] (1986)	RT4	WA: Yelm		56						07.7
38 1975-83	RT4	WA: Yelm	late	56						09.7
20 (1966)	TSL	GS: Big Qualicum		52.5	0.8			10.5	11.0	11.0
33 (1970)	TSL	WA: Big Beef Cr.	early		0.15			16.7	15.9	
33 (1970)	TSL	WA: Big Beef Cr.	middle		0.91			13.9	11.4	
33 (1970)	TSL	WA: Big Beef Cr.	late		0.24			13.9	14.0	
33 (1971)	TSL	WA: Big Beef Cr.	early		0.04			17.2	15.5	
33 (1971)	TSL	WA: Big Beef Cr.	middle		0.45			15.4	13.8	
33 (1971)	TSL	WA: Big Beef Cr.	late		0.97			16.4	13.5	
19 (1984)	TSL	GS: Walker Cr.						12.3	13.3	12.7
19 (1985)	TSL	GS: Walker Cr.						12.7	13.8	13.2
24 (1962)	RTR	AK: Traitors R.						05.9	06.2	06.0
24 (1963)	RTR	AK: Traitors R.						05.0	06.4	

[7]Jones, pers comm. Alaska Dept. Fish and Game.

[8]Tweit, B. Unpubl. data. Nisqually Tribal Fisheries, Olympia, Washington.

Appendix B Continued: PINK

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body Size	SL	SL	S & L
25 (1960)	RT1	AK: Harris R.								10.8
15 (1985)	RT1	JS: Keogh R.				41.3	41.9	16.7	15.6	16.0
12 (1961)	RT1	AK: Olsen Cr.		51.0		44.0	45.0			11.1
12 (1961)	RT1	AK: Olsen Cr.	early	51.0		44.0	45.0			21.2
12 (1961)	RT1	AK: Olsen Cr.	middle	51.0		44.0	45.0			13.0
12 (1961)	RT1	AK: Olsen Cr.	late	51.0		44.0	45.0			04.6
F[9] (1986)	RT1	AK: Union Bay						22.1	19.3	20.9
F[10] (1987)	RT1	AK: Union Bay						10.6	10.8	10.7
F[10] (1986)	RT1	AK: Pleasant Bay						12.0	09.6	10.7
F[10] (1987)	RT1	AK: Pleasant Bay						17.6	11.8	14.4
F[10] (1986)	RT1	AK: Sashin Cr.						11.4	09.6	10.5
F[10] (1987)	RT1	AK: Sashin Cr.						10.8	09.4	10.3
41 (1957)	RT1	UF: Seton Cr.								14.0[10]
41 (1957)	RT1	LF: Fraser R.								25.3
41 (1957)	RT1	TS: Thompson R.								16.5
41 (1957)	RT1	LF: Harrison R.								21.5
41 (1957)	RT1	LF: Vedder R.								28.9
39 (1983)	RT1	AK: Salmon Cr.	early							14.5
39 (1983)	RT1	AK: Salmon Cr.	late							13.4
39 (1983)	RT1	AK: Starrigavin	early							33.1
39 (1983)	RT1	AK: Starrigavin	late							27.0
39 (1983)	RT1	AK: White R.	early							40.5
39 (1983)	RT1	AK: White R.	late							24.7
17 (1976)	RT1	AK: Traitors R.	early			48.1	48.7			23.4
17 (1976)	RT1	AK: Katlian Cr.								21.8

[9] Jones, unpubl. data. Alaska Dept. Fish and Game.

[10] Ward noted that fish arriving early lived longer than late arriving fish.

Appendix B Continued: CHINOOK

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m^2)	Body Size	Body SL Size	SL	S & L
44 (1981)	RT2	TS: South Thompson							07.0
42 (1983)	RT2	JS: Mussel Cr.		52.6		48.7	48.3		20.0
42 (1983)	RT2	JS: Ahnuhati		52.1		50.5	52.8		10.0
30 (1981)	RT3	UF: Slim Cr.		54.6		64.4	70.0		14.9
30 (1981)	RT3	UF: Holmes R.		66.7		87.3	70.9		10.7
30 (1981)	RT3	UF: Morkill		60.6					15.1
30 (1981)	RT3	UF: Torpy R.		60.5		73.1	73.1		14.7
30 (1981)	RT3	UF: Walker Cr.		50.7		67.9	71.3		06.9
30 (1981)	RT3	UF: West Torpy R.		58.8		73.1	73.1		08.5
30 (1981)	RT2	UF: Slim Cr.							9-16
30 (1981)	RT2	UF: Holmes R.							14.0
30 (1981)	RT2	UF: Morkill							11.0
30 (1981)	RT2	UF: Torpy R.							16.0
30 (1981)	RT2	UF: Walker Cr.							13.0
30 (1981)	RT2	UF: West Torpy R.							3-7
35 (1981)	RT2	TS: Finn Cr.		46.5		63.6	68.8		11.0
35 (1981)	RT2	TS: Raft		37.1		54.6	67.1		15.0
35 (1981)	RT2	TS: North Thompson		49.5		62.5	70.7		09.0
35 (1981)	RT1	TS: Finn Cr.							11.0
35 (1981)	RT1	TS: Raft							17.0
13 (1980)	RT2	UF: Stuart R.		60.2		68.9	70.7		10.5
13 (1980)	RT1	UF: Stuart R.							07.3
28 (1979)	RTR	PR: Morice R.	early					13.1	
28 (1979)	RTR	PR: Morice R.	late					07.7	
29 (1980)	RTR	UF: Nechako R.	early				71.3		16.5
29 (1980)	RTR	UF: Nechako R.	late				71.3		12.0
36 (1987)	FLH	GS: Big Qualicum							30.0
09 1959-72	RT1	GS: Big Qualicum		45.3		70.2	70.2		18.0

Appendix B Contintued: SOCKEYE

Reference (Year of Data)	Method	Location: Stream	Timing	Percent	Density (# /m²)	Body Size	Body Size	SL	SL	S & L
10 (1951)	RT1	AK: Karluk Lk.								07.0
F[11] 1980's	RT4	WI: Henderson Lk.	early							10-15
F[12] 1980's	RT4	WI: Henderson Lk.	late							8-10
F[12] 1980's	RT4	WI: Muriel L. streams								05.0
04 (1985)	RT1	AK: Susitna R.								08.4
03 (1972)	RT1	AK: Glacier Fl. Cr.								14.4
03 (1972)	RT1	AK: Moose Cr.								13.9
03 (1972)	RT1	AK: Bear Cr.								11.8
03 (1972)	RT1	AK: Seepage Cr.								14.7
03 (1972)	RT1	AK: Nikolai Cr.								20.6
03 (1972)	RT1	AK: Crystal Cr.								12.6
03 (1972)	RT1	AK: Clear Cr.								26.5
16 1946-54	RT1	UF: Forfar Cr.	early					13.6	12.4	
16 1946-54	RT1	UF: Forfar Cr.	middle					11.5	11.5	
16 1946-54	RT1	UF: Forfar Cr.	late					08.4	09.8	
16 (1946)	RT1	TS: Adams R.						17.7	14.8	
16 (1950)	RT1	TS: Adams R.						19.5	18.7	
16 (1951)	RT1	TS: Adams R.						17.8	16.2	
16 (1954)	RT1	TS: Adams R.						19.5	18.1	
32 (1940)	RT1	LF: Birkenhead						11.0	13.5	
32 (1941)	RT1	LF: Birkenhead						13.6	13.1	13.2
32 (1940)	RT1	LF: Weaver Cr.						08.7	08.9	
32 (1941)	RT1	LF: Weaver Cr.						10.6	08.9	09.3

[11] Hyatt, K. Unpubl. data. Dept. Fisheries and Oceans. Pacific Biological Station. Nanaimo, B.C.

APPENDIX C

References for Data Sources in Tables 4 and 5 and Appendix B

1. Abbott, J. C., G. O. Stewart and P. R. Murray. 1986. South Bentinck Arm adult salmonid reconnaissance program 1985. Contract report for DFO prepared by Envirocon Ltd. 126 p.

2. Ames, J. 1984. Puget Sound Chum escapement estimates using spawner curve methodology. In: Proceedings of the workshop on stream indexing for salmon escapement estimates. West Vancouver, B.C. February 1984. Can Tech. Rep. Fish. Aquat. Sci. 1326: 135-148.

3. Barrett, B. M. 1972. 1972 Tustumen sockeye salmon research report. Alaska Dept. of Fish and Game, Dept. of Commercial Fisheries, Soldotna, AK.

4. Barrett, B. M., F. M. Thompson, S. N. Wick. 1985. Adult anadromous fish investigations: May-October 1984. Alaska Dept. of Fish and Game, Susitna Hydro Aquatic Studies, Report No. 6. Prepared for Alaska Power Authority, Anchorage, AK.

5. Beidler, W. M. and T. E. Nickelson. 1980. An evaluation of the Oregon Department of Fish and Wildlife standard spawning fish survey system for coho salmon. Oregon Dept. of Fish and Wild. Info. Rept. 80-9. 23 p.

6. Crone, R. A. and C. E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch* in Sashin Creek, southeastern Alaska. Fishery Bulletin 74(4): 897-923.

7. Flint, T. 1984. A comparison of stream indexing methods to estimate coho escapements in Harris Creek, 1980-83. Can. Tech. Rept. Fish. Aquat. Sci. No. 1326: 149-159.

8. Flint, T. and G. Zillges. 1980. Little Bear Creek coho salmon stream life study. Wash. State Dept. of Fish. Prog. Rept. No. 124. 40 p.

9. Fraser, F. J., E. A. Perry and D. T. Lightly. 1983. Big Qualicum River salmon development project, Vol 1: A biological assessment 1959-1972. Can. Tech. Rept. Fish. Aquat. Sci. 1189: 198 p.

10. Gangmark, H. A. and L. A. Fulton. 1952. Status of Columbia River Blueback salmon runs. U.S. Fish and Wildlife Service Special Scientific Report Fisheries No. 74. 22 p.

11. Glova, G. J. and P. McCart. 1979. Salmon enumeration studies in five streams draining into Tlupana Inlet, B.C., 1979. Prepared by P. McCart Biological Consultants Ltd. 207 p.

12. Helle, J. H., R. S. Williamson and J. E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish. and Wild. Serv. Special Sci. Report - Fisheries. No. 483. 26 p.

13. Hickey, D. G. and D. B. Lister. 1981. Salmonid enhancement baseline investigations at Stuart River, B.C. in 1980. Part II Adult chinook study. Prepared by D.B. Lister and Assoc. Ltd. for DFO.

14. Johnston, N. T., J. R. Irvine and C. J. Perrin. 1987. Instream indexing of coho salmon (Oncorhynchus kisutch) escapement in French Creek, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1573: 37 p.

15. Johnston, N. T., J. R. Irvine, and C. J. Perrin. 1986. A comparative evaluation of fence count, mark-recapture, and Bendix sonar estimates of salmon escapements in the Keogh River, a variable-flow coastal stream. Can. Tech. Rep. Fish. Aquat. Sci. No. 1453: 44 p.

16. Killick, S. R. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning and death. Int. Pac. Sal. Fish. Comm. Bull. VII. 95 p.

17. Kingsbury, A. P. 1977. Alaska Dept. of Fish and Game completion report for project No. AFC-50, for period July 1, 1974 to June 30, 1977. Dec. 1977. 90 p.

18. Koski, K. V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. MSc. Thesis. Oregon State Univ. Corvallis Oregon. 84 p.

19. Lewis, A. F. J. 1987. The effects of breeding completion and abiotic factors on the behaviour and reproductive success of female chum salmon (Oncorhynchus keta). MSc. Thesis. Simon Fraser University. Dept. Biological Sciences. 186 p.

20. Lister, D. B. and R. A. L. Harvey. 1969. Loss of Petersen disc tags from spawning chum salmon (Oncorhynchus keta). Can. Fish. Cult. 40: 33-40.

21. Lister D. B. and C. E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho, and chinook salmon in Big Qualicum River. Can. Fish. Cult. 37: 3-25.

22. McGivney, K. K., G. J. Holowatiuk and P. R. Murray. 1985(a) South Bentinck Arm salmonid reconnaissance program. 1984. Prep. by Envirocon Ltd. for DFO. 128 p.

23. McGivney, K. K., S. L. Bowman and P. R. Murray. 1985(b). Smith Inlet adult salmonid reconnaissance program. Prep. by Envirocon Ltd. for DFO. 106 p.

24. Mattson, C. R., R. G. Rowland and R. A. Hobart. 1964. Chum studies in southeastern Alaska, 1963. U.S. Fish. and Wildlife Serv. Management Rep. 64-8. 22 p.

25. McNeil, W. J. 1964. Redd superimposition and egg capacity of pink salmon spawning beds. J. Fish. Res. Bd. Can. 21(6): 1385-1396.

26. Murray, P. R. and S. R. Hamilton. 1981. Baseline biological data on adult chum salmon in the Kemano River system. 1979. Prepared by Envirocon Ltd. for DFO. 68 p.

27. Murray, P. R., G. O. Stewart and S. R. Hamilton. 1981. Studies on adult chinook salmon (Oncorhynchus tshawytscha) in the Bowron and Willow Rivers and Slim Creek, B.C. during 1980. Prepared by Envirocon Ltd. for DFO.

28. Neilson J. D. and G. H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Trans. Am. Fish. Soc. 110: 554-556.

29. Neilson, J. D. and C. E. Banford. 1983. Chinook salmon (Oncorhynchus tshawytscha) spawner characteristics in relation to redd physical features. Can. J. Zool. 61(7): 1524-1531.

30. Rosberg, G. E. and D. Aitken. 1982. Adult chinook salmon studies in four tributaries to the upper Fraser River. 1981. Prepared by Beak Consultants Ltd. for DFO. 140 p.

31. Salo, E. O. and R. E. Noble. 1952. Minter Creek Biological Station - Progress Rep. (Sept-Dec. 1952) Unpubl. Rept. Wash. Dept. Fish. 58 p.

32. Schaefer, M. B. 1951. A study of the spawning populations of sockeye salmon in the Harrison River system with special reference to the problem of enumeration of means of marked members. Int. Pac. Sal. Comm. Bull. IV. 207 p.

33. Schroeder, S. L. 1973. Effects of density on the spawning success of chum salmon (Oncorhynchus keta) in an artificial spawning channel. MSc. Thesis. University of Wash. 1973. 78 p.

34. Scott, K. J. and G. E. Rosberg. 1987. Adult chum salmon studies and escapement estimation in the Vedder/Chilliwack River. 1986. Prepared by G. E. Rosberg and Assoc. for DFO. 51 p.

35. Scott, K. J., M. A. Whelen and W. R. Olmsted. 1982. 1981 biophysical studies of selected chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon producing tributaries of the North Thompson River drainage. Prepared by EVS Consultants. for DFO.

36. Shardlow, T., R. Hilborn and D. Lightly. 1987. Component analysis of instream escapement methods for Pacific Salmon (Oncorhynchus sp). Can. J. Fish. Aquat. Sci. 44(5): 1031-1037.

37. Slaney, T. L. 1986. Adult salmonid reconnaissance of selected Smith Inlet streams in 1985. Prepare by Aquatic Resources Ltd. for DFO. 85 p.

38. Svoboda, P. and B. Harrington-Tweit. 1983. Estimating chum salmon escapements in the Nisqually River system from spawning ground survey data for the years 1975/76-1982/83. Nisqually Indian Tribe Technical Rep. No. 8. 19 p.

39. Thomason, G. J. and J. D. Jones. 1984. Southeastern Alaska pink salmon (Oncorhynchus gorbuscha) stream life studies, 1983. Alaska Dept. of Fish and Game Information Leaflet No. 236. 15 p.

40. van den Berghe, E. P. and M. R. Gross. 1986. Length of breeding life of coho salmon (Oncorhynchus kisutch). Can. J. Zool. 64: 1482-1486.

41. Ward, F. J. 1959. Character of the migration of pink salmon to Fraser River spawning grounds in 1957. Int. Pac. Sal. Fish. Comm. Bull. X.

42. Whelen, M. A. and J. D. Morgan. 1984. 1983 spawning salmonid studies in selected watercourses of Knight Inlet, B.C. Prepared by EVS Consultants for DFO. 172 p.

43. Whelen, M. A., J. R. Arthur, W. R. Olmsted and J. D. Morgan. 1983. 1982 studies of spawning coho salmon (Oncorhynchus kisutch) in tributaries of the south and mainstem Thompson Rivers, B.C. Prepared by EVS Consultants Ltd. 100 p.

44. Whelen, M. A. and W. R. Olmsted. 1982. 1981 biophysical studies of selected chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon - producing tributaries of the south Thompson River drainage. Part II. Prepared by EVS Consultants Ltd. 133 p.

45. Willis, R. A. 1954. The length of time that silver salmon spent before death on the spawning grounds at Spring Creek, Wilson River in 1951-52. Ore. Fish Comm. Res. Brief. Vol 5: 27--31.