A Review of Salmon Escapement Estimation Techniques

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Les Rapports techniques peuvent être considérés comme des publications complètes. Le titre exact paraîtra au haut du résumé de chaque rapport, qui sera publié dans la revue *Aquatic Sciences and Fisheries Abstracts* et qui figurera dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1-456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457-714, à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715-924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, Ministère des Pêches et de l'Environnement. Le nom de la série a été modifié à partir du numéro 925.

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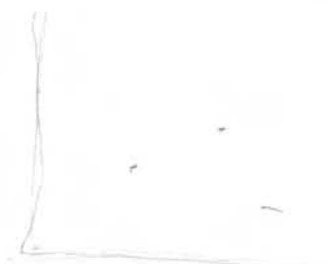

A REVIEW OF SALMON ESCAPEMENT ESTIMATION TECHNIQUES

by

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ABSTRACT

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: vi + 122 p.

This report was prepared to provide a review and assessment of salmon escapement estimation techniques used in the Pacific Northwest by Canadian and U.S. government agencies to enumerate spawning salmon populations. Pertinent information was collected from a literature survey and during interviews with fisheries scientists and biologists in the Pacific Northwest. The review portion of this report is subdivided by techniques. Topics covered for each technique include a short discussion of methodology, locations where these techniques have been used, an outline of effective use and related problems, and a summary of available accuracy and precision data, as well as any information providing comparison of techniques. An annotated bibliography and list of persons interviewed are also included.

Key words: escapement estimation, spawning, salmon, review, bibliography.

RÉSUMÉ

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: vi + 122 p.

Le présent rapport vise à passer en revue et à évaluer les techniques pour l'estimation du nombre de saumons de remonte que les organismes canadiens et américains emploient dans le nord-ouest du Pacifique pour dénombrer les populations reproductrices de saumon. L'information pertinente a été recueillie dans une série d'ouvrages et au cours d'entrevues avec des scientifiques et des biologistes des pêches dans le nord-ouest du Pacifique. Pour chaque tecnhique passée en revue, les détails suivants sont donnés: brève discussion de la méthode, endroits où cette technique a été utilisée, exposé des aspects pratiques et des problèmes s'y rattachant, et résumé des données disponibles sur la précision et l'exactitude. On inclut aussi toute information permettant de comparer les techniques, ainsi qu'une bibliographie annotée et une liste des personnes interrogées.

Mots-clés: estimation des saumons de remonte, fraie, saumon, passage en revue, bibliographie.

INTRODUCTION

This review of salmon escapement estimation techniques was conducted to provide a comprehensive report which compiles and reviews information on the principal techniques currently used in the Pacific Northwest by Canadian and/or U.S. government agencies.

Information was compiled by literature search and interviews, and was reviewed over a three month period. Literature dating from approximately 1930 to the present was searched while interviews were held with persons currently involved with salmon escapement estimation. Consequently, both historical and current state of the art information has been included. While the literature search is considered to be complete, it may not be exhaustive, and it is possible that some papers may have been inadvertently omitted. This is most probable for references not in the primary literature, several of which were identified but could not be located.

Telephone interviews were conducted with a number of prominent workers in the field of salmon escapement estimation from Alaska to California. Much pertinent information was obtained from these conversations and has been incorporated in technique discussions.

Discussion of each technique is subdivided into several sections, as follows: a brief summary of methodology, a listing of areas where this technique is used, a discussion of effective use of each technique with consideration of related problems and limitations (as well as the applicability of different techniques to different stream conditions), and a summary of available information dealing with the accuracy and precision of the technique (including technique comparisons where available). General comments on the suitability of a technique for use in B.C. have been included when appropriate.

This review was designed to summarize available escapement estimation information, rather than provide a comprehensive treatise; therefore references to pertinent papers are made throughout the discussion of each technique to allow the user to obtain additional information on the above aspects, as required. However, this study is not intended specifically as a manual for selection and application of enumeration techniques, and hence detailed field procedures and extensive recommendations are not given.

It has become apparent during the course of this study that the accuracy (and occasionally precision) of many of the escapement estimation techniques used have frequently been tested in practice, or the results compared with those obtained using one or more other techniques. However, much of this information is not available in the literature and is contained in the data files, unpublished results and internal agency memoranda of experienced workers. As a result, much of the comparative information presented herein was obtained directly through telephone and personal interviews with fisheries scientists and biologists involved with salmon escapement estimation.

The nature of escapement estimation also leads to introduction of numerous modifications to a procedure by different workers, often to overcome specific local problems or variations in conditions. As a result, independent estimates of accuracy of a particular technique as given in the literature or during interviews may not always be directly comparable, due to the effects of these modifications.

The body of this report is divided into three main sections - the technique by technique review, an annotated bibliography and a summary of the interviews conducted. Appendix A has been included as a guide to abbreviations used to identify government agencies throughout this report.

REVIEW OF TECHNIQUES

Each technique has been reviewed individually, and discussion has been subdivided under a number of subheadings to assist users in locating discussions of various aspects of each technique. These subdivisions are:

Methodology

Areas of Use

Effective Use and Problems

Accuracy, Precision and Technique Comparison.

Sources from the bibliography portion of this paper are referred to by reference number, while information obtained from interviews has been referenced as personal communication.

ANNOTATED BIBLIOGRAPHY

Within this section, references have been grouped by technique and then arranged alphabetically within each technique. A unique number has been assigned to each reference and is used throughout the text to refer to that specific reference.

A cross-referencing system was developed to assist users of this bibliography because many papers dealt with more than one technique. Each paper has been fully referenced only once, under the primary technique discussed in the paper. To provide access to all information on a specific technique, a "see also reference numbers..." statement has been included at the end of each section in the bibliography.

Each reference was annotated by including a prepared abstract or summary, where obtainable. If these were not available, pertinent sections from an introduction were included or a brief statement regarding the techniques discussed in the paper was prepared.

In addition, a 'notes' section was included to assist users in determining whether a paper is appropriate to their needs. Four categories of information are listed in this section - methodology, problems, evaluations and technique comparisons.

References included in this bibliography contain varying amounts of pertinent information, ranging from references dealing exclusively with a specific aspect of estimation techniques (e.g. evaluation), to papers containing only a brief statement on some aspect of escapement estimation (e.g. problems, accuracy, etc.).

The literature search associated with development of this bibliography was conducted primarily at the Pacific Biological Station during one month of intensive effort, although some references were obtained from biologists interviewed, as well as from the library of J.C. Lee and Associates Ltd.

The search was continued using a variety of media until the same references consistently reappeared. This was taken as an indication that the literature had been thoroughly searched.

Criteria for inclusion in this bibliography were fairly broad, and required only that a paper deal at least partially with a specific aspect of salmon escapement estimation technique (e.g. methodology, problems, precision and accuracy, etc.). Papers using a technique to produce an estimate of a specific escapement were generally excluded, unless they also dealt with one or more evaluative aspects, as outlined above. The literature was searched back to approximately 1930; therefore date of publication was not a determining factor for inclusion in the bibliography.

A wide variety of sources were searched for pertinent references, including fisheries-related journals, various unindexed government agency report series, computerized data bases and published literature compilations. In addition, reference sections of pertinent papers were searched. A more detailed list of most sources is given below.

Indexed Publications

Prominent fisheries-related publications, including:

- Journal of the Fisheries Research Board of Canada
- Canadian Journal of Fisheries and Aquatic Sciences
- Canadian Fish Culturist
- Transactions of the American Fisheries Society
- Progressive Fish Culturist
- International Pacific Salmon Fisheries Commission Bulletin
- California Fish and Game
- U.S. state fisheries bulletins, e.g. WDF

Unindexed Publications

- technical reports, bulletins, leaflets, etc. put out by Alaska, Washington and Oregon state agencies, available at the Pacific Biological Station library.
- technical, data and manuscript reports of the Canadian Department of Fisheries and Oceans.

Computerized Data Bases

- ASFA. Aquatic Sciences and Fisheries Abstracts. 1978-1982. Information Retrieval Ltd. Arlington, Va.
- BIOSIS Data Base. 1969-1982. Biosciences Information Service. Philadelphia, P.A.

Computerized Data Bases, cont'd.

- NTIS. National Technical Information Services. 1964-1982. U.S. Department of Commerce. Springfield, Va.

Literature Compilations

Holmberg, E.K. and R.M. Bush. 1969. A guide to the salmonid literature compilation, 1960-1964. Fisheries Institute, College of Fisheries, University of Washington. Seattle. 190 p.

Holmberg, E.K. and R.M. Bush. 1969. A guide to the salmonid literature compilation, 1960-1964. Fisheries Institute, College of Fisheries, University of Washington. Seattle. Microform collection.

Maxfield, G.H. 1967. Pacific salmon literature compilation - 1900-1959. Instructions and index. U.S. Dept. Interior, Bur. Comm. Fish., Biol. Lab., Seattle. 20 p.

Maxfield, G.H. 1967. Pacific salmon literature compilation - 1900-1959. Microform collection. U.S. Dept. Interior, Bur. Comm. Fish., Biol. Lab., Seattle. 20 p.

INTERVIEW SUMMARIES

To gather information on new techniques not well documented in the literature, as well as unpublished information, a series of interviews were conducted. Prominent workers in the field of salmon escapement estimation in Alaska, B.C., Washington, Oregon, California and Idaho were contacted by telephone. A series of pertinent questions were prepared in order to standardize the information obtained during each interview.

Every biologist involved with salmonid escapement estimation was not contacted, but it is felt that the interviews provided a representative sample of the work being conducted in the Pacific Northwest. In some instances it was not possible to interview prominent researchers, due to their unavailability. In these cases, required information was obtained from colleagues and/or co-workers, whenever possible.

The interview summaries section lists the researcher's name, agency, address and phone number, organized by state or province, along with a brief summary of techniques discussed. Details of each interview have not been included in this section, as pertinent information from interviews has been included in reviews of the appropriate techniques.

REVIEW OF TECHNIQUES

FOOT SURVEYS

Methodology

Estimation of salmon escapement from surveys on foot of spawning grounds and counting of live and/or dead spawners is one of the oldest methods used for obtaining population estimates, and also one of the least standardized techniques currently in use. The earliest estimates simply involve the use of the peak live count (before die-off of spawners) or the peak live plus dead count (at or shortly after the peak of spawning activity) as an estimate of the spawning population, without further adjustment.

It has long been recognized that such counts usually produce serious underestimates of total escapement (2, 17 and 20) and represent an index of abundance at best. To obtain a more accurate estimate it is necessary to correct for turnover within the spawning population with time. The simplest procedure involves several surveys of the spawning ground spaced apart by an interval equal to the stream residence time of spawners, the live counts from each survey being added together to produce an estimate of total escapement (Anderson, pers. comm.; Hyatt, pers. comm.). However, numerous problems arise from variations in run timing, survey timing and interval, and stream residence time from year to year, which seriously reduce accuracy and consistency of the resulting estimates. This is particularly a problem when some fish present are either holding in pools or migrating through spawning areas, rather than actually spawning at the time of counting.

Other procedures involve some method of adjusting a count made at or near the spawning peak to compensate for underestimation due to the turnover of spawners. One procedure used by IPSFC involves frequent (sometimes daily) surveys of spawning grounds to obtain separate live and dead counts through the peak of spawning activity. The sum of the peak live count and accumulated dead count is then multiplied by a counting index (1.8 for sockeye) which has been developed from comparison of similar counts with weir counts or Petersen mark/recapture estimates for the system in previous years (Woody, pers. comm.).

A second method frequently quoted (but not evaluated) in the literature involves the average of several live counts taken through the spawning period and including the peak, on the assumption that the total number of spawners utilizing a given stream section (R) is equal to the average number of live fish (M) multiplied by the ratio of length of time live fish are present (D) to average stream life of individual fish after reaching the section (T) (21). The value 'D' is obtained either from historical information or from repeated surveys, and 'T' could best be obtained from a small scale tagging study if not already available. The formula for calculation of the total population estimate is $R = MD/T$; this procedure is sometimes referred to as the 'factor 5' method because in the original description the ratio D/T was given as 35/7, or 5. The escapement estimate was therefore five times the average live count, though this relationship may not be appropriate for all systems.

This procedure may be further refined by counting only spawners in shallow riffle spawning areas, where counting errors are minimal, and omitting fish holding in pools where counting variability is great (25). A sufficient number of surveys is required to produce an index of abundance throughout the spawning period. If only a proportion of the available spawning grounds are surveyed, this becomes a stream indexing system, and baseline data for the entire stream is required for comparison to obtain an escapement estimate in addition to an index of relative abundance (25).

Another variation which is occasionally useful involves strip counts, where only spawners occurring in narrow strips across the stream are counted (130; Hyatt, pers. comm.). Narrow counting strips (e.g. 1 m wide) are marked off at a fixed interval throughout the spawning areas, and the total escapement estimate is obtained by multiplying the total length of spawning ground occupied by the average number of spawners per meter of counting strip width. A single peak count might provide a reasonable escapement estimate if spawning occurs over a brief period, but the results of several surveys spaced apart by the average stream life of the spawners would be added together to produce a population estimate when spawning occurs over a prolonged period (Hyatt, pers. comm.).

In order to avoid the errors introduced by turnover of spawners, it is possible to estimate escapement entirely from dead recoveries during foot surveys of all or a portion of the spawning grounds (2). Surveys must be frequent (preferably every day, but at least every three days), all dead within reach along shore must be recovered and removed from the stream (or marked to prevent recounting) in a consistent and uniform manner, and the survey area(s) must be a defined and constant portion of the spawning area available. If the dead recovered then represent a reasonable and constant portion of the total dead, the accumulated dead recovery total may either be used as an index of relative abundance of spawners, or if the ratio of recovered dead to total dead is known, the total escapement may be estimated. Care must be taken to recover only recently dead fish to avoid a bias due to long-dead carcasses being refloated and deposited in the recovery area, and additional effort is required to obtain an accurate sex ratio due to differential drift of male and female carcasses (2).

More recently there has been a trend away from estimation of escapements from the accumulated results of extensive ground surveys of spawning areas throughout large watersheds or coastal stream management areas. This is largely due to the greatly increased cost and limited efficiency and accuracy of this type of survey. Instead, effort is being directed towards intensive survey and assessment of escapement to specific streams or spawning ground areas within streams, where spawners can be enumerated accurately and consistently from year to year. Such areas as appear representative of salmon escapement to the surrounding watershed as a whole are considered index systems, and the careful enumeration of spawners in these areas alone can provide estimates of escapement to an entire watershed or area of similar coastal streams, once the data base for such calculation has been established. This approach permits standardization of method and concentration of survey effort where the greatest accuracy and reliability can consistently and economically be obtained. In theory, the results may then be extrapolated to produce reliable escapement estimates for the area represented by one or more index systems. A further discussion of stream indexing techniques is included as a separate topic in this report.

Areas of Use

Historically the technique of obtaining counts by surveying spawning grounds on foot has been used for estimation of escapements of all species of Pacific salmon within a range from California to Alaska, and predates most other methods. This technique in its various forms is still widely used throughout this range, either for producing direct escapement estimates or for producing a partial index from which an overall escapement estimate can be inferred from baseline data.

In B.C. the majority of estimates of escapement are made by DFO fishery officers or guardians from foot surveys. Occasionally, on inaccessible streams (e.g. above canyon areas) observations of fish at the mouth during migration are used as rough indices of abundance for escapement estimation. Usually the count of live plus dead at the spawning peak is either used directly or may be adjusted by a correction factor to produce an estimate of total escapement. In addition, some tributary systems are intensively surveyed as index streams, from which escapement information may be extrapolated to an entire drainage area (Anderson, pers. comm.). Adjusted peak live plus accumulated dead counts are used by the IPSFC for enumeration of pinks and sockeye in tributary systems of the Fraser River, where conditions are appropriate, minimal manpower is available and great accuracy is not required (Woody, pers. comm.). This technique is often combined with more reliable methods, particularly mark/recapture, to provide additional information on distribution of spawners and spawning success.

In Alaska, foot counts are used to determine spawning distribution among tributaries of some large systems, to survey small systems where aerial survey is not appropriate, and to provide additional information for calibration and adjustment of aerial counts, particularly in connection with intensive aerial survey of index areas (Jones, pers. comm.; Rogers, pers. comm.). In the Wood River Lakes system, peak live plus dead counts during carefully timed surveys are used as indicators of escapement to various tributary spawning areas. These counts are then used to apportion spawning distribution from estimates of total escapement obtained from other methods, such as tower or sonar counts (Rogers, pers. comm.).

A similar situation exists in Washington, where most spawning ground surveys for chinook, coho, chum and lake-spawning sockeye salmon are completed from the air. Foot surveys are used in place of aerial surveys in some small headwater tributaries and are carried out once per year in small non-index areas during peak spawning, to determine spawning distribution. Escapements are calculated relative to index values from one or more base years, from intensive survey of a limited number of index areas and analyses of the resulting spawner abundance curves (Ames, pers. comm.; Flint, pers. comm.; Orrell, pers. comm.; Wood, pers. comm.). Pink salmon in mainstem spawning areas of major river systems cannot be enumerated visually while alive due to depth and turbidity. Carcass counts obtained during foot surveys are used to provide estimates of relative abundance from index areas of rivers, and escapement is calculated from baseline data produced from mark/recapture studies (Orrell, pers. comm.).

In Oregon foot surveys once per week are used for development of spawner abundance curves for index stream areas, primarily for wild coho stocks. Escapements are calculated from comparison of estimates of relative abundance from spawner abundance curves with similar data for one or more base years. Supplemental (non-index) areas are surveyed once per season during the spawning peak to determine relative distribution of spawners (88; Nickelson, pers. comm.).

Effective Use and Problems

Foot surveys in general may provide estimates of escapements which range from being reasonably accurate to highly inaccurate and unreliable, depending on where and how they are implemented. Estimates based on peak live plus dead counts alone without further correction, are only reliable in small shallow systems where fish and carcasses are highly visible, and where migration into spawning areas and spawning occur over a relatively short period of 7 - 10 days. This situation may occur with pink salmon, but it is rare with other salmon species (Rogers, pers. comm.). Where spawning occurs in waves or continuously over a period longer than the stream-life (or redd-life) of individual spawners, a correction factor for turn-over of spawners between counts is necessary, and variability is increased (2, 21 and 25; Gjernes, pers. comm.; Woody, pers. comm.). Escapement estimates based on counts which include estimates of fish holding in deep pools are particularly unreliable and better estimates can be obtained by restricting enumeration efforts to shallow riffle areas, then applying a correction factor (21 and 25). Where spawners are evenly distributed and readily observed throughout lengthy shallow riffle areas, the strip count method may be used to quickly and efficiently obtain estimates of the spawning population at a particular time (Hyatt, pers. comm.). However, uneven distribution of spawners will bias estimates, and care must be taken to account for turnover of spawners in the final escapement estimates whenever spawning activity occurs over a period considerably longer than the average life of fish on the spawning gravel. Escapement estimates from visual counts in a stream or stream index area are probably most realiably obtained with repeated surveys and calculation of escapement from a spawner abundance curve (Ames, pers. comm.).

Estimation of escapement from dead recovery alone is a feasible alternative in systems where carcasses are available from streambanks in a manner consistently proportional to die-off, particualarly where a major proportion of spawning is not readily observed (as in turbid or deep water river spawning situtations) and live counts are thus impractical. The previously described conditions for this method should be met, and base-line data which include reliable escapement estimates from another method (such as mark/recapture) will be required for comparison if escapement estimates rather than indices of relative abundance are desired (2). As intensive dead recovery effort is required for reliable estimates, this method may be effectively combined in terminal spawning situations with a Petersen mark/recapture study for comparison, though additional costs are involved for tagging operations.

Foot counts are subject to a variety of factors which may introduce bias or limit reliability of resulting escapement estimates, in addition to those already discussed. These mainly concern personnel experience and ability, stream characteristics, fish migration timing and weather conditions.

There is considerable experience involved in accurately counting fish in a stream and estimating numbers of fish in groups, and evidence has shown that inexperienced personnel tend to greatly underestimate fish in schools and show great variability in counts (7, 10, 16 and 92; Anderson pers. comm.; Withler, pers. comm.; Woody, pers. comm.). Individual observers tend to show a consistent bias in estimating fish numbers; where frequent changes of personnel are involved, accuracy becomes largely a matter of chance and consistency between estimates is lost. In addition, experience in determination of salmon escapements by other more reliable methods (such as mark/recapture or weir counts) is particularly helpful in improving accuracy of counts from foot surveys, and without such comparative experience an observer's accuracy need not increase (7 and 10).

Any factor which reduces visibility of some or all members of a spawning population will adversely affect visual counts and cause underestimation (10, 21, 24 and 26). Turbidity from silt, glacial runoff or humic conditions, spawning in deep water of main river channels, and migration and spawning during freshet conditions all seriously affect reliability of live and dead counts. Deep pools can obscure both live fish and carcasses from observers, and high discharge conditions can obscure spawners and wash carcasses and spawned fish into deep water areas of pools, river channels or lakes where they cannot be counted (5, 21 and 26).

Foot survey techniques (and most other visual techniques) are best suited to shallow, clear headwater tributaries of large systems with stable flow patterns (10; Withler, pers. comm.). In inland areas, where rainfall is less than in coastal areas, weather conditions are less likely to interrupt or prevent survey schedules. Unstable flows are characteristic of most small coastal drainages in the Pacific Northwest due to runoff during periods of high rainfall, and present major problems for enumeration of most species. This is particularly true of pink salmon, which frequently enter a stream during freshet conditions and spawn over a short period (7 - 10 days) (10; Rogers, pers. comm.). Under such conditions spawners cannot be counted, and many small streams are often either unsafe or impossible to walk, so that a survey during the spawning peak may not be possible each year.

Chinook, chum and coho often present similar problems when runs occur late in the year, the latter being particularly difficult to observe on the spawning grounds. Coho are noted for penetrating to the headwaters of river systems and spawning during high flow conditions when access on foot is most difficult, and have even been found to spawn under ice in frozen northern systems (Gunstrom, pers. comm.). Sockeye often present the least problems because of their early migration and spawning habits. In addition, live counts and especially redd counts become difficult and unreliable when multi-species spawning occurs, and redds are rapidly obscured by algal growth in nutrient-rich stream waters (Orrell, pers. comm.).

Acccuracy, Precision and Technique Comparison

The reliability of salmon escapement estimates produced from visual counts obtained during spawning ground surveys on foot has often been criticized, but has only rarely been critically examined in the literature, either directly in controlled experiments or in comparison with other techniques. Numerous comparisons with other methods have been made, but the results of these comparisons are largely unpublished and exist in the files of many experienced fishery biologists and scientists, where they are available only by direct communication. Most of the following information has been obtained in this manner.

It is generally agreed that estimates of escapement based on uncorrected peak counts during spawning periods will underestimate the true value to some degree, barring an unusually excessive positive bias in counts. The degree to which escapement may be underestimated varies greatly with experience of the observers, stream character and conditions when surveyed, timing of the survey in relation to the true spawning peak, and duration of the spawning peak in relation to the length of time spent on the spawning gravel by spawners (2, 24, 25, 26 and 27).

Direct evaluation of the effect of experience on accuracy and precision is not available, but it is known that inexperienced observers usually produce low, sometimes extremely low, estimates, with great variability (10, 92; Anderson, pers. comm.; Withler, pers. comm.; Woody, pers. comm.). In Alaska, Washington, and studies by the IPSFC in B.C., use of inexperienced personnel for visual spawning ground surveys (on foot or aerial) is avoided, and new personnel are trained by experienced personnel before being required to make counts independently.

Under ideal conditions in small, shallow clear-water streams, and when the spawning peak is short (7 - 10 days) so that nearly all spawners are on the grounds at once, an accurately timed peak live plus dead count may include 80 - 90% of the weir count or mark/recapture estimate (Rogers, pers. comm.; Tarbox, pers. comm.). These conditions are often met with pink salmon spawning in small coastal streams in Southeast Alaska (and presumably also in B.C.), but are uncommon with other species. A similar level of accuracy was obtained in an unpublished study at Big Qualicum River in B.C., where intensive repeated surveys of chum spawning grounds were carried out with experienced personnel in a hatchery-controlled system; this procedure would be costly to attempt on a large scale (Anderson, pers. comm.).

Agreement to within 15% of a mark/recapture estimate was obtained with visual estimates from foot surveys under near ideal conditions, while enumerating sockeye escapement to Clemens Creek (Henderson Lake, B.C.) in 1981 (5). Counts were made prior to the spawning peak and included estimates from large schools in pools. The level of accuracy achieved was due mainly to the unusual circumstance that virtually the entire spawning population entered the stream over a period of a few days. A peak live plus dead count was prevented by exceptionally high discharge conditions, and is not available for comparison.

Under less than ideal or "normal" conditions for the majority of foot surveys, where spawning occurs in waves over a period of several weeks, peak counts usually underestimate true escapement values from weir counts or mark/recapture studies by 30% to 50%, due mainly to turnover of spawners. Environmental conditions limiting visibility will further reduce accuracy (3; Rogers, pers. comm.; Tarbox, pers. comm.; Withler, pers. comm.; Woody, pers. comm.). In some situations far more serious underestimates are obtained, as is well illustrated by a 1980 study in Yakoun River, Queen Charlotte Islands, B.C. A mark/recapture study involving tagging of over 2,400 fish and examination of nearly 20,000 carcasses was carried out to estimate the pink salmon spawning population. An initial escapement estimate of 545,967 fish was obtained, which was reduced by 30% to compensate for probable overestimation by the Petersen method due to tag loss. This resulted in a final escapement estimate of 382,177 pink salmon, with 95% confidence limits of 306,955 and 471,488 fish. A routine foot survey of the spawning grounds resulted in escapement estimates of only 60,000 to 80,000 fish (Kadowaki, pers. comm.).

Estimates based on adjusted counts, such as those used in IPSFC studies (peak live plus accumulated dead count, multiplied by a correction factor for the appropriate species) are considered to have an accuracy of ± 30% when made by experienced personnel under ideal conditions in small clear streams with stable flows (Gjernes, pers. comm.). Under average conditions, accuracy may be no better than ± 50%, though tests of accuracy have not been carried out (Woody, pers. comm.). However, the estimate approximates the true population total, rather than consistently being an underestimate. This method is more costly than a peak plus live plus dead count survey, but less costly than an extensive mark/recapture study (Gjernes, pers. comm.).

The probable accuracy of estimates based on the 'factor 5' averaging method and related methods involving calculation from spawner abundance curves depends largely on how well the variables in the calculation formula apply to the area surveyed. Accuracy of ± 10% to ± 15% of weir counts has been obtained from spawning abundance curves under ideal conditions (Flint, pers. comm.). These methods are widely used in connection with escapement estimation from index stream techniques. (A more extensive discussion of these techniques is included under Index Streams in this report.)

Very few attempts have been made to determine precision of estimates of escapement based on visual counts made during foot surveys. Willis (27) has shown that in shallow riffle areas of small systems with ideal conditions of visibility, differences between mean counts of coho spawners made independently by three surveyors were not significant at the 95% level of probability. It was also shown that means of counts made at different times of day (morning, noon, afternoon) were not significantly different at this level.

Sheridan (25) demonstrated that for counts made only on shallow riffles under ideal conditions, variability between counts by different observers was greater than between counts by the same observer, but the difference between observers was only significant at the 95% level once in eight trials. Under more normal conditions simulating a typical foot survey (2,400 m) and involving counts of salmon in both pools and riffles, variation was considerably higher between counts by different observers and between repeated counts by the same observer. This increase was attributed to problems of estimating fish holding in pools, and at times variation in pool estimates appeared approximately random. Some mean counts between observers were significantly different at the 95% level, while others were not. It was recommended that counts during foot surveys should be restricted to riffle areas where the greatest precision may be attained, and that surveys be made at intervals through the spawning period to obtain sufficient information for a spawner abundance curve, from which an escapement estimate can then be calculated.

SNORKLE AND RIVER FLOATS

River floats, either in a small boat or using a wetsuit, face mask and snorkle, are techniques used sporadically where conditions permit and are not well documented in the literature (4, 13, 21 and 130). A downstream float by boat or inflatable raft may be used as an alternative to foot surveys in small clear water systems without major rapids. Access to a point upstream of the survey area is usually required, either by road or by airplane, for launching the boat, though in some larger streams it is possible to motor to the headwaters then drift back downstream.

Snorkle floats are used primarily to obtain visual counts of cryptically coloured species (mainly chinook, coho and particularly steelhead) which tend to hold in deep pools or be sparsely distributed under cover along stream banks. This technique may be combined with foot surveys in some situations where shallow riffle areas alternate with deep pools, and may be the only practical method of enumerating spawners visually in canyon situations.

Both techniques are essentially visual surveys at a point in time, and as such suffer all the limitations outlined previously regarding escapement estimation from counts during foot surveys. Hence any individual survey count represents an index of escapement at best, and will usually underestimate total escapement. Float surveys are additionally limited to narrow streams due to the low angle of visibility and problems of surface reflection, and accuracy decreases as stream width increases (Anderson, pers. comm.). Both techniques are limited by stream flow conditions and turbidity, and have the further disadvantage of providing only one-way coverage of the survey area, thus restricting the amount of information that can be collected.

Accuracy of these techniques has not been reported in the literature, though errors similar to and possibly greater than those noted for foot counts might be expected under similar conditions. In Washington, float counts at 7-10 day intervals are used to construct a spawner abundance curve for sockeye in the Cedar River, from which total escapement is estimated. These estimates are usually within 5% of estimates generated from indexed tower counts (Ames, pers. comm.).

DIVE SURVEYS

Diving surveys using SCUBA gear have seen very limited use as a means of obtaining rough estimates of lake-spawning sockeye populations, though this problem is more commonly overcome by enumerating escapement during or prior to lake entry. The technique may be useful where spawning occurs at depths beyond the range of visibility from the surface, and involves underwater survey of established or probable spawning areas by SCUBA divers and visual enumeration of spawners or redds.

Dive surveys of lake spawning sockeye populations have been carried out from time to time in several lakes on Vancouver Island, B.C., but very little information is available in the literature and standardized spawner enumeration or escapement estimation techniques have not been developed. Early surveys were carried out in Great Central Lake to determine sockeye spawning distribution along the lakeshore and with depth. These indicated that from 50% - 75% of spawning occurred at depths below the range of visibility (3 m) in the three areas surveyed (5), but no attempt was made to estimate escapement on the strength of these surveys.

A more extensive study of deep water lake spawning was carried out using diving surveys in Kennedy Lake in 1980 (4), during efforts to evaluate sockeye escapement to the lake as part of the Lake Enrichment Program undertaken by DFO. Spawners and carcasses were counted in known spawning areas by two divers swimming along depth contours at 3 m depth intervals. The study supported the results of earlier dive surveys which suggested that the total number of spawners present at a given time within spawning areas in Clayoquot Arm of Kennedy Lake was approximately twice the number observed from the surface or from aerial surveys. The surface count might thus serve as an index of spawners present, though this relationship did not hold in other portions of the lake, and would not be adequate for estimatimation of total escapement due to turnover of spawners. A logical approach to escapement estimation in this and similar situations (if a less costly alternative such as mark/recapture was not feasible) might thus involve the completion of several aerial surveys during the spawning period to allow construction of a spawning abundance curve from shoreline counts. Partial escapement estimates from the curve might then be adjusted to represent total escapement on the basis of index values established from underwater surveys (or a reliable independent estimate of total escapement).

Underwater counts individually represent only an index of abundance, as is true of any other fixed time visual count. A series of surveys and an estimate of residence time at the redd site would be necessary for a reliable estimate of escapement from a spawner abundance curve (as discussed with regard to foot surveys). In addition, diving surveys are limited by weather conditions and underwater visibility, time available for the comparatively slow survey procedure and the resulting relatively high cost. A diver propulsion system of some sort to which fish showed minimal avoidance would be an aid to efficiency (4), but survey time will still be considerable when spawning areas are large due to a diver's limited working time at depth and in cold water.

OBSERVATION TOWERS

Methodology

Counts of migrating salmon are made at a point in a river at which the majority of the fish passing can be observed. Observations are made from elevated shore positions or from land-based or floating towers.

Various aids are employed to enhance visibility and counting efficiency. Polaroid glasses reduce glare reflected from the water and hand tallies and audible timers increase enumeration efficiency. Background panels attached to the river bottom silhouette passing fish. The FRI used wire mesh panels coloured light grey in rivers of Bristol Bay area, since sockeye had been observed to avoid white panelled areas of river bottom (29). [Morley (105) observed no such avoidance reaction in sockeye passing over white background panels in the Sproat River in British Columbia.]

V-shaped turbulence reducers anchored upstream of the observation point reduce surface current surge and waves (29), and vertical pickets attached to turbulence reducers shape subsurface currents to minimize surface disturbance. It is recommended that these structures be anchored in at least four feet of water so that fish migration is not disturbed.

High intensity flood lamps, used to illuminate night migration, have produced avoidance reactions in migrating Bristol Bay sockeye, and floodlights are aimed slightly offshore from the main path of fish travel so that any avoidance reaction will be directed toward the river bank. Fish are counted as they pass through the dimly lit area inshore of the light beam focus (29). Red floodlights were used to illuminate sockeye migration at night in the Sproat River because previous studies have shown dark adapted fish to be insensitive to these wavelengths of light (105).

Counting schedules are devised so that counting time is reduced without introducing undesireable error (30). The IPSFC, testing the tower counting technique in the Fraser River system, made periodic 24-hour diel counts from one bank of the river and infrequent counts from the opposite bank to account for diel variations in migration and bypass (Woody, pers. comm.). Atnarko River (Bella Coola system) pink salmon are enumerated by DFO personnel during two thirds of the preferred daily migration time (morning and evening) and one third of the intervening low intensity periods (Anderson, pers. comm.). The 1981 Sproat River sockeye migration was enumerated continuously during daylight hours and night migration was interpolated from 24-hour counts made every four to ten days during the migration period.

In Alaska (particularly Bristol Bay), counts made for ten minutes every hour on both banks of the rivers are extrapolated to estimate hourly escapements (Meacham and Rogers, pers. comm.). Estimated hourly escapements are summed to produce daily and seasonal total escapement estimates. In Washington, the WDF calculates the total Cedar River sockeye escapement by applying counts made during approximately six hours of each day to base year data.

Areas of Use

The tower counting technique has had limited use in British Columbia and Washington but is widely used in Alaska. Sockeye, spawning over approximately twenty miles of the Cedar River, Washington, are enumerated from a tower (Ames, pers. comm.). The IPSFC tested the technique in the Thompson Canyon and Chilko River of British Columbia (Woody, pers. comm.). DFO personnel have employed the technique in a number of river systems, including the Atnarko River (Anderson, pers. comm.) and the Sproat River (105). The tower counting technique has been used by the FRI in the Wood River Lakes system in Bristol Bay, Alaska, since the early 1950's (Rogers, pers. comm.), and the ADFG make extensive use of tower counts in the rivers of the central region, especially Bristol Bay.

Effective Use and Problems

Tower counting is effectively used to estimate total escapement at single-channel points of clear rivers supporting bank oriented salmon migrations. The technique is mainly used to enumerate sockeye and pink salmon migrations since these species seek the low current velocity areas adjacent to river banks. Sockeye and pinks in Alaskan rivers typically form migratory 'bands' which continuously move upriver and contain a minimal proportion of incidental species (29). Species of salmon that do not exhibit this migratory habit (coho, chinook, chum) have been enumerated from towers on narrow, shallow rivers (30).

In Alaska, very large sockeye runs have been enumerated from towers. Escapements as high as 3,000,000 fish have been counted in the Wood River Lake system (Rogers, pers. comm.) and daily passage has reached approximately 1,000,000 fish in rivers of Bristol Bay (Meacham, pers. comm.).

To obtain accurate estimates of escapements from tower counts, an observed migration must have an even temporal and spatial distribution (Woody, pers. comm.). Error is introduced into escapement estimates when migratory patterns deviate from the optimum, and this error is compounded by counter (observer) variation and poor visibility.

In wide rivers, salmon migrations that are not bank oriented cannot be accurately enumerated from towers. Chinook and coho salmon will migrate in high velocity, mid-channel areas (Meacham, pers. comm.), and at low densities, sockeye form schools which exhibit erratic behavior (29).

At high migration densities, sockeye salmon stack vertically in the river, and counts must be made in blocks of as many as 1,000 fish (Rogers, pers. comm.). Enumerating fish in groups is a less accurate method than enumerating individuals.

Poor visibility due to overcast skies, turbid water, river surface disturbances, and glare results in counting errors. Floodlamps used to increase visibility at night have produced avoidance reactions in fish. High intensity lamps with red and amber lenses produced avoidance reactions in Kvichak River sockeye and the lights poorly penetrated turbid water.

Low water levels in the Cedar River, Washington, promoted an increase in the proportion of the daily sockeye total passing the counting tower at night. Since counts were made only during the day, the tower count underestimated the escapement. A similar increase in night migration at low water levels was noted during Sproat River and Stamp River sockeye migrations in 1979 (105).

Visual discrimination of salmon species during mixed species migration may be difficult and may thus introduce additional error. Morley (105) estimated ± 10% error in escapement estimates due to possible incorrect differentiation between sockeye and coho in the Sproat River.

Tower counting requires less manpower than mark/recapture techniques and produces results of equivalent accuracy. The IPSFC discontinued tower counting in the Fraser River because mark/recapture techniques supplied more incidental biological information, such as, arrival times, relative distribution of a population, and spawning success (Woody, pers. comm.). It was also noted that there are very few locations on the Fraser River drainage area suitable for tower counting.

Accuracy, Precision and Technique Comparison

Tower counts made under suitable conditions are considered to provide relatively accurate estimates of total escapement, and thus provide the basis of comparison for studies of the accuracy of other salmon escapement estimation techniques in Alaska. Escapement estimates from test fishing (126), aerial counts (94, 95), and side scan sonar counts in Bristol Bay (104), and side scan sonar counts in Cook Inlet (107) have been tested for accuracy using tower counts as the standard for comparison.

Fishery biologists have provided estimates of the accuracy of the technique under various conditions, though it has only occasionally been evaluated directly in the literature. Tower counts made by the IPSFC on the Thompson and Chilko Rivers were considered within ± 15 - 30% of the actual escapement (Woody, pers. comm.). The accuracy of tower counts made on clear rivers in Alaska by FRI and ADFG personnel is thought to be ± 5 - 10% (Rogers and Meacham, pers. comm.).

Accuracy of daily sockeye escapements estimated by tower counts in Alaska depends upon the frequency and magnitude of fluctuations in migration intensity and the frequency and duration of counts (29). A daily counting schedule is adopted which reduces counting time with a minimal sacrifice in accuracy (30). Tests by the FRI in the Kvichak River showed that reliable escapement estimates (relative error = ± 6%) could be obtained from short duration counts made every hour (29). It was recommended that counts be made for 20 minutes during the peak of migration. Following this strategy, the 1959 sockeye escapement in the Kvichak River was estimated to be 689,613 ± 3.99% (95% level of confidence).

ADFG reevaluated a 10 minute/hour daily counting schedule (30). It was found that the relative error in the estimated hourly counts cancelled over an entire season, and relative error of less than 10% was estimated for season counts. It was suggested that 20 minute counts be made every hour if the migration was erratic, concentrated, or short term.

Variations between single point counts made by different observers can be large; however, this variation is generally unbiased and the relative error cancels out over the migration period. Variation between observers was tested for the Kvichak River sockeye run and, though the range of variation between individual five minute point counts was - 22.1% to + 17.9%, the difference between total counts made during 32 counting periods was only 1.0% (29).

Several technique comparisons have been made in the Pacific Northwest. Estimates of escapement made by tower counting and mark/recapture on the Chilko River were within approximately 5% of each other (Woody, pers. comm.). Sockeye escapement in the Cedar River, Washington, estimated from a series of float counts was within 5% of a WDF tower count (Ames, pers. comm.). The USFWS counted sockeye by a tower and at a weir on the Egegik River, Alaska, in 1956 and 1957. The respective escapements were 984,908 and 1,063,877 (- 7.4% relative error) in 1956 and 712,124 and 631,001 (+ 12.9% relative error) in 1957 (30).

AERIAL COUNTS

Methodology

Aerial counts of salmon on the spawning grounds are commonly made from slow flying airplanes which provide good stream visibility while flying at low altitudes. Both helicopters and fixed wing airplanes are used; the latter are used more commonly because they are much cheaper to operate, though the hovering and slow flight capabilities of helicopters can be extremely useful. Surveys are most commonly flown at a constant altitude of 100 - 200 m, at speeds of 120 - 160 km/hr , though lower altitudes and flying speeds may be used on narrow streams in flat terrain, particularly when surveying by helicopter (31, 32 and 35). Recommendations concerning altitude in relation to flying speed are given by Eicher (32). The survey is flown in such a manner that the observer is between the sun and the objective to avoid glare; polaroid glasses are worn to minimize reflection. The pilot attempts to keep the observer in continuous visual contact with all fish in the survey area, which may require circling while large schools of fish are enumerated (35). Use of a plane with bubble windows for improved downward vision is extremely helpful (89).

Usually an experienced observer will count a group of ten fish, mentally envision ten such groups as a block of 100 fish, then divide each school into similar blocks of 100 fish, accumulating the total of blocks counted on a hand counter. Where large schools or dense concentrations of spawning occur, blocks of 1,000 fish may be used (31, 32 and 35). Counts and other information are recorded on pre-printed forms in standard format. Usually three surveys are flown, when possible, to ensure obtaining a count near the spawning peak despite variations in timing.

A refinement of the technique was used to enumerate chinook spawners in the Morice River, B.C. (34). Eight helicopter surveys of the spawning grounds were made at short intervals throughout the spawning period, with independent counts of spawners (not including fish holding in pools) being made by two observers on each survey. In addition, aerial photographs were taken on some flights and counts made from the photographs were used to develop a correction factor (0.96) for adjustment of aerial counts. Mean corrected counts were plotted against time to produce a spawner abundance curve , the area under the curve thus providing a measure of total spawner days. As spawning ground observations indicated residence time at the redd-site was significantly shorter for late-arriving than early-arriving females, the area under the curve was subdivided into portions representing fish on the spawning grounds before and after the spawning peak. Escapement estimates were calculated separately for each portion of the spawning period using the appropriate mean residence time, and the two estimates were combined to indicate total escapement. This procedure resulted in a reliable escapement estimate with a narrow 90% confidence interval, and is suggested for application when reliable estimates of spawning escapement are required and cannot be obtained directly from a counting facility or from a mark/recapture program (34). The procedure may be used for other species than chinook salmon with little or no modification where conditions are appropriate for aerial counting, and a similar technique is extensively used in Washington in conjunction with the overall index stream system for escapement estimation (Ames, pers. comm.).

Areas of Use

Aerial surveys from fixed wing airplanes are used extensively in Alaska for enumerating sockeye, pink and chum salmon, and less frequently for enumeration of chinook and coho. These surveys generally involve a single trained observer and experienced pilot, and spawning grounds are often surveyed three times to ensure counting during the spawning peak. The peak counts serve either as indices of relative abundance for estimation of total escapement from base year data or established expansion factors (as in S.E. Alaska), or they may be used to apportion tributary spawning distribution to a mainstem total escapement estimate, obtained from sonar or tower counts (as in the Wood River Lakes district) (Gunstrom, pers. comm.; Meacham, pers. comm., Rogers, pers. comm.).

In British Columbia, fixed wing aerial surveys are frequently used by DFO personnel for enumeration of pink salmon in otherwise inaccessible non-glacial rivers of the central coast region. Independent counts from two observers are averaged and the survey is repeated if the counts differ greatly. Surveys may occur more than once during the spawning period in a given system in order to obtain a peak count, which is used directly (or in some cases adjusted upwards) as an estimate of escapement (Anderson, pers. comm.). Some chinook escapements are enumerated by helicopter survey to obtain a peak count, as in the Harrison River in the Fraser River system.

Aerial surveys using both fixed wing airplanes and helicopters are employed extensively in Washington state for enumeration of chinook, coho and occasionally chum salmon. Fish or redd counts are obtained at approximately weekly intervals during spawning from intensively surveyed index areas. Escapements to index areas are then calculated from spawner abundance curves (which have replaced the use of peak counts in recent years) and overall escapement is obtained by comparison of index area escapements with base year data (Ames, pers. comm.; Orrell, pers. comm.).

Effective Use and Problems

Aerial surveys are particularly useful for obtaining counts of spawners quickly and efficiently in areas where access to the spawning grounds is difficult or impossible by other means, and when the streams to be surveyed are too numerous or widespread to obtain sufficient counts by conventional ground-based methods. They also provide immediate rough estimates of escapement which are valuable for in-season stock management purposes (Anderson, pers. comm.; Meacham, pers. comm.). Aerial surveys have proven useful in Washington for obtaining chinook redd-counts from spawning grounds in rivers too large and/or too wide and deep to permit counting with a foot survey or float survey (Orrell, pers. comm.)

The aerial survey technique is best suited to broad shallow clear-water streams and rivers with little or no overhanging vegetation, particularly in relatively flat terrain, and is well suited to survey of shallow lake-spawning areas (32). The technique is of course not effective in glacial or otherwise turbid waters where excessive humic staining occurs, or where spawning occurs in deep water beyond the range of visibility. Best results are obtained with sockeye, pink and chum salmon, which are coloured in contrast to usual background colours and spawn in large aggregations, thus being readily visible and easily counted. Coho may also be counted successfully by aerial survey in some situations (Flint, pers. comm.). Chinook, being cryptically coloured and also often widely dispersed during spawning, are less easily detected and counts may be less reliable (Rogers, pers. comm.). This difficulty and the aforementioned problem of decreasing residence time during the spawning period (34) have been avoided in Washington state by counting chinook (and sometimes coho) redds rather than fish, as redds are highly visible for a known period of time before becoming obscured by growth of bottom flora in the stream. This method requires careful determination of conversion factors for redd-life, false redd ratio and sex ratio, to achieve accuracy in each system surveyed (Ames, pers. comm.; Orrell, pers. comm.). However, redd counts are unreliable when two species spawn concurrently or have overlapping spawning periods on the same grounds, as may occur with chum and coho (Flint, pers. comm.). Live counts are also of limited reliability under these conditions due to the difficulty of accurately distinguishing species from the air (Gjernes, pers. comm.; Wood, pers. comm.).

As with all spawning ground surveys, a peak count does not represe total escapement or even a consistent portion of total escapement, due to variability in spawning timing and duration. This count is at best an index of escapement based on a usually unknown proportion of the total spawning population and should be treated as such (31 and 34). Consequently, peak counts may not produce reliable escapement estimates even when treated as indices, and a more reliable estimate can be obtained by developing a spawner abundance curve from a series of counts made throughout the spawning period, then calculating escapement from the curve on the basis of residence time on the spawning grounds (34; Ames, pers. comm.; Orrell, pers. comm.). If all spawning grounds in a system are repeatedly surveyed, an escapement estimate could be calculated directly from the curve, while, if only representative and easily surveyed index stream areas are included, escapement estimates for these areas would serve as indices for calculation of total escapement from base year data or previously established expansion factors.

Accuracy of estimates derived in this manner will depend on accuracy of both aerial counts and the determination of residence time, but will be consistent from year to year, barring significant alteration of the method or of the spawning area itself, or an undetected change in residence time. As a result, escapement estimates could be justifiably compared between years, while estimates based on presumed peak counts during a single census often cannot, due to variability in spawning duration and timing (34).

A number of personnel factors have been found to affect the reliability of aerial counts, the most significant of these being experience of the observer (32). Inexperienced aerial observers tend invariably to overestimate numbers of fish, and usually choose too low an altitude, thereby reducing the period of time available for enumeration of each group of fish. Observers in Alaska undergo extensive training involving both still photographs and colour motion pictures of fish aggregations, as well as test flights over groups of known numbers of fish, before being required to produce independent aerial counts of fish on the spawning grounds for escapement estimation. Pilot experience is also considered important, as the pilot and observer must work efficiently as a team to produce reliable estimates. Fatigue has been found to reduce efficiency of both the pilot and observer, and Eicher (32) suggests a maximum of six hours of survey effort per day, with landings for short breaks as required to minimize fatigue. Bevan (31) recommends the use of only one observer for all surveys (at least where comparison of estimates between streams or between years are likely) because observers vary individually in their estimates of the same population, and any factor to correct for observer differences will itself vary from stream to stream and from year to year.

Quality of illumination is an important consideration; surveys made late in the day at low sun angles require continual transition between sunshine and deep shade, and result in poor estimates (32). In rugged terrain with steep hills and narrow V-shaped river valleys, as are common along much of the B.C. coast, aerial surveys may thus be limited to a few hours in mid-day when the sun reaches the valley floor. In some such systems the low sun angle during the fall and winter months prevents penetration of sunlight to some or all portions of the streambed, even at mid-day. Where this situation occurs, aerial surveys might be more successful on bright cloudy days than during clear sunny weather (4). Rugged or highly uneven terrain may also require all or part of the survey to be flown at altitudes considerably above the usual 150 - 200 m optimum (unless a helicopter is used). Accuracy of estimates decreases as altitude increases above 200 m, though rough subjective estimates are possible at higher altitudes (32).

Aerial surveys are also subject to the usual limitiations of all spawning ground surveys due to poor weather and temporary high discharge and high turbidity conditions, these being most serious in coastal systems. In addition, and again particularly in coastal situations, aerial surveys are often hampered by fog and low cloud either in the survey area or at the airplane base, when ground surveys would still be feasible. These conditions can easily delay a survey up to a week or more and cause the spawning peak to be missed, resulting in a very poor escapement estimate or no direct estimate, when these are based on peak counts. The method of calculating escapement from a spawner abundance curve produced from counts made at intervals through the spawning period is less vulnerable to complete disruption, because the survey schedule is more flexible and more data is obtained. A data point for a missed or delayed survey may be interpolated from adjacent points, or subjectively estimated from similar curves for previous years or for other similar streams in the same year.

Accuracy, Precision and Technique Comparison

Fish can be enumerated most reliably from the air when dispersed on the spawning grounds at the spawning peak, both in streams and on lake beaches. Less reliable estimates of numbers and an indication of run timing can be obtained from observation of schools at river mouths and in lakes prior to spawning. Studies by the USFWS in Alaska indicate that while observers on the ground can often enumerate spawners in small narrow streams accurately, they cannot consistently provide the accuracy of experienced aerial observers in estimating numbers of fish concentrated in river mouths, in broad streams or densely crowded spawning grounds and in lakes, mainly because of the poor viewing angle available to ground-based observers (32). However, accuracy of aerial live counts is greatest when fish are evenly distributed on spawning grounds in shallow, clear water rivers, and decreases when fish are clumped or densely schooled (Gjernes, pers. comm.).

The most reliable counts from fixed wing aerial surveys are obtained with sockeye and pink salmon, which spawn in relatively dense aggregations. Accurate counts of chum salmon may also be obtained where they spawn in shallow water, though mainstem spawners in large rivers may be difficult or impossible to enumerate accurately. Coho and particularly chinook are often difficult to count in this manner, because their widely dispersed spawning distribution necessitates detection of individual fish rather than groups, and some fish are easily overlocked (Gunstrom, pers. comm.; Rogers, pers. comm.). Accurate aerial counts of these species are often best obtained from a helicopter at low altitude and require good weather and counting conditions.

In a study for the FRI in the late 1950's (31), Bevan investigated the sources and extent of variability in aerial counts of pink salmon spawning grounds in two streams on Kodiak Island, Alaska. The study did not examine the question of accuracy of aerial counts and resulting escapement estimates, other than to advise the use of peak counts only as indices representing a proportion of total escapement. It was found that the variance about the mean of independent counts by two observers increased as the mean count increased, and that one standard deviation of an observer's count will be less than ± 50%, and usually less than ± 25%, of his mean count. In addition, differences between means of replicate counts by different observers, and between means of replicate counts by the same observer when made in different counting units (i.e. blocks of 100 and 1,000 fish) were highly significant. The relationships between closely timed pairs of counts by different observers also varied in a highly significant manner between different streams and between years within the same stream, greatly complicating any attempt to equate counts by different observers or adjust them to a common basis.

It was concluded that an aerial observer could be expected to reliably detect spawning ground population differences of ± 50%

(i.e. approximately two standard deviations of his expected mean count), but that acceptance of smaller differences would require an evaluation of variance in the observer's estimates. The use of only one observer and one counting unit was recommended to minimize variability, and it was pointed out that if more than one observer is necessary, a factor to correct for observer differences may vary between streams and between years(31).

In central and S.E. Alaska, aerial surveys are considered the least accurate of the various enumeration methods used, providing good estimates of relative abundance only. Peak counts from spawning ground surveys are used primarily as indices, either for apportioning spawning distribution to escapement totals determined by reliable mainstem enumeration methods, or for estimation of escapement to tributary systems through the application of established expansion factors which correct for underestimation from various sources in each system (89). Consequently, consistency of method to maximize precision of index counts from year to year is considered as important as accuracy of counts in obtaining escapement estimates that may be reliably compared between years.

Peak counts obtained from aerial spawning ground surveys in Alaskan rivers usually range from 40% to 60% of tower counts considered to be reliable, though variability of accuracy between systems is great (Meacham, pers. comm.; Rogers, pers. comm.). Under good conditions in some Bristol Bay area rivers, aerial peak counts by experienced observers are often within 30% of tower counts; accuracy to within 20% of the tower count was obtained in a trial under ideal conditions, allowing full visibility of the entire spawning ground population (Meacham, pers. comm.). There is also considerable variability between species, with peak counts of pink and sockeye salmon usually being the most accurate estimators of escapement.

Fixed wing aerial counts of pink salmon in the B.C. central coast region at the peak of spawning are considered to be accurate to within ± 20% of the fish present in most instances, though the peak count would be expected to underestimate total escapement to some degree (Anderson, pers. comm.). Peak counts may produce more reliable escapement estimates of pink salmon than of the other species because of their short spawning period. However, no direct evaluation of the accuracy of these escapement estimates was encountered in the literature.

A study of the sockeye spawning population of the Chilko River in 1969 by the IPSFC compared the results of a mark/recapture study with an estimate obtained by visual count from a helicopter at an altitude of 50 m (Gjernes, pers. comm.). Using experienced observers under ideal conditions, a peak count of 80,000 sockeye was obtained, which was within 5% of the mark/recaptrue estimate of 76,000 fish. Two independent counts of beach-spawning sockeye in Kennedy Lake (Vancouver Island, B.C.) in 1980, involving both aerial counts from a helicopter at an altitude of about 50 m and surface counts from the foredeck of a boat on successive days, produced almost identical estimates of visible spawners. The two values differed by approximately 3% in a total lake-spawning population of about 5,000 sockeye, though this count was only a partial escapement estimate due to additional deep water and river spawning (4).

Peak counts of chinook are made annually from helicopter surveys in the Harrison River and Bear River by DFO personnel, with 85% to 90% of the spawning population thought to be present at the peak and about 95% of these expected to be enumerated (Anderson, pers. comm.). Repeated survey of the upper Morice River chinook spawning population by helicopter in 1979 indicated that the peak aerial count included only 52% of the total escapement estimate determined from a spawner abundance curve, using visual counts corrected by aerial photography and accurate determinations of residence time (34). The overall correction factor for aerial counts was 0.96, indicating a slight overcounting in comparison with counts from photographs. An estimate of 2,826 spawning chinook salmon was obtained, with 90% confidence limits (based on residence time variability) of 2,611 and 3,084 (differences of 8% and 9%, respectively, from the escapement estimate). The final estimate was considered to be slightly conservative, primarily because of a shorter residence time in males (unmeasured) than in females (measured), failure to detect 'jacks' from the air, and a small proportion of undetected deep water spawning.

A similar technique used in Washington involves frequent aerial surveys of redds or fish within index areas to produce spawning curves, and calculated escapements to index areas are then extrapolated to give total escapement estimates for chinook, coho and sometimes chum salmon. Very little accuracy information is available at present, at least partly because the major emphasis so far has been on consistency of method to ensure that comparable indices of relative abundance are obtained from year to year, rather than on accuracy of final estimates. However, results of a mark/recapture study in the Duwamish-Green River system by the USFWS in 1976 to determine chinook escapement were compared with those from an aerial redd survey by WDF, using both initial and revised base year data. The initial estimate from the spawning curve and index system procedure was about 10% lower than the mark/recapture estimate, while the updated estimate from the index system using more accurate base year data was only 2% lower than the estimate from the tagging study (51 and 87; Ames, pers. comm.).

PHOTOGRAPHIC ENUMERATION

Methodology

Photographic enumeration has been experimented with as a means of providing a more precise method for year-to-year comparison of escapement estimates with fewer personnel and at lower costs than many other estimation techniques. Two photographic enumeration techniques were developed - aerial photography and photography from counting towers.

In the late 1940's studies using aerial photography were conducted in the Bristol Bay area by the USFWS (32 and 35). These studies employed an aircraft on floats that could safely and easily maneuver at speeds under 145 km/hr and allowed good visibility ahead and down. An aerial camera was mounted on the underside of the aircraft. A combination of film, filters and developer were used that would give the highest contrast between fish and background and make the best use of light rays transmitted by water.

Representative areas were chosen to provide indices to adjacent spawning grounds because photographing all, or a large portion, of the spawning grounds would require prohibitive quantities of film and time, and extensive facilities to process and interpret photographs. The mouths of rivers, beach spawning areas and portions of easily identifiable spawning grounds were covered.

Timing of photographic trips, important if pictures are to be valid indices, was coordinated with peak spawning periods which in turn were substantiated through foot surveys.

Photographs were interpreted by counting fish in squares on a plastic grid superimposed on the print. Depending on the density of fish, individual fish counts or estimates based on water surface area covered and visible shadings of fish density were used. Lines were drawn on the photographs, connecting prominent objects which served as reference points; fish bounded by these lines were those counted in successive years.

The use of time-lapse photography as an automatic counting method from counting towers was developed in the Bristol Bay area, Alaska, in the early 1950's (36). This method of enumeration required a 6 m observation tower, a camera, a lighting system for night photography, a power supply and a timer control. Off-white flashboards were used to increase the contrast between the fish and the background and proved to be a necessary element of photographic enumeration with a camera placed in a tower. V-shaped log booms in front of the camera field were necessary to create a consistently smooth water surface so that sharp, well-defined negatives could be obtained.

Photographs were taken of migrating salmon at intermittent, evenly spaced intervals. A frequency of one frame per minute with an exposure duration of 4 - 6 seconds was attempted. The number of fish in a photograph corresponded to a counting period equal in length to the time required by the average fish to pass the camera field.

To make a total escapement estimate, the number of fish photographed were multiplied by a conversion factor. This was most conveniently determined as the ratio between the actual number of fish passing (determined by direct visual counts) and the number of fish photographed in a given time interval. The conversion factor changed with migration density and time of the season; these changes occurred in a regular manner so that a set of conversion factors were standardized for a given situation.

Areas of Use

Aerial photographic techniques were initially applied to enumeration of spawning sockeye populations in the Bristol Bay area of Alaska in the late 1940's and early 1950's (32 and 35), though these techniques are not discussed in recent Alaskan literature. Aerial photography is useful for training of aerial observers, verification of aerial counts and development of correction factors for these counts in broad shallow spawning areas of clear-water streams and stream index areas. The techniques may be especially useful for verification of aerial counts in areas of heavy fish concentrations, where visual counts are least reliable. Aerial photographs (35 mm) were recently used successfully for determination of a correction factor for aerial (helicopter) counts of spawning chinook salmon in the Morice River, a tributary of the Skeena River in B.C. (34).

Photography from counting towers was utilized to enumerate sockeye escapement from Nushagak Bay to the Wood River lakes (Bristol Bay area, Alaska) (36). Salmon in this system moved along the river banks in 1 - 2 m deep water and swam close to the bottom. The water at the tower sites was relatively clear. This technique is also not discussed in recent literature, and may have been replaced by visual tower counts and sonar counts.

Effective Use and Problems

The use of aerial and tower-based photographic enumeration provides a permanent record of indices to spawning escapement, removes much of the human error introduced by different observers, provides greatest accuracy when large schools are encountered, and reduces the necessary manpower (32, 35 and 36).

Aerial photography is an effective method for estimating abundance of salmon on beach spawning aeras, on broad spawning grounds and in areas of heavy fish concentrations, where visual counts from the bank of the stream are most difficult to obtain (32 and 35). This method also provides a permanent index for rating visual counts, free of the problems of human memory and error (32).

However, chinook 'jacks' were not readily identifiable in aerial photographs of the Morice River, B.C., spawning grounds due to their relatively small size and light colouration, and chinook spawning in depths greater than 5 m were not detected in the photographs (34). In addition to these limitations, the technique is not effective in streams with overhanging vegetation or in systems subject to high turbidity or humic staining, and might not be applicable in steep-sided coastal valleys where all or part of the riverbed often does not receive sunlight during the fall and winter months.

The greatest technical problems associated with aerial photographic enumeration result from the high light demand of the necessary filters and from camera movement, both of wich resulted in some blurring of the picture. As no one filter is effective in all situations, several different filters (yellow, green and polaroid) are required, depending on the stream substrate and water depth, so that fish are revealed in maximum contrast. Fast film speeds (ASA 1000, or greater) and high shutter speeds are necessary to accommodate this high light demand and minimize blurring from vibration and forward motion of the plane.

Problems in scheduling photographic trips to collect representative data at peak spawning times are reduced by conducting visual (aerial or foot) surveys at intervals during the spawning period and by determining the variation in run timing over several years.

The technique is particularly applicable to verification of aerial counts in index areas, which are selected, in part, for their suitability to aerial survey techniques. The method has been used for this purpose in Alaska, and has been used successfully for development of correction factors for aerial counts in B.C. (34).

The tower-based photography system requires a minimum of attention, permits large-scale studies that were formerly not possible, and can be operated by inexperienced personnel (36).

The practicality of this method rests upon the premise that the conversion factor for a river system will remain constant. If this is not the case, a set of conversion factors must be established for every season. Depending upon the cause of the variation, these factors could be determined during brief service visits to the unit in the field. The conversion factor is a direct function of the migration speed of the salmon, which in turn is primarily affected by escapement level and time of the season (36).

The efficiency of this technique varies from stream to stream and depends upon the existence of a well-defined salmon migration path near the river bank. If this path should shift with changes in water level, conversion factors may have to be recalculated for each seasonal change.

Photographic enumeration increases in sampling accuracy with increasing escapements, since migration speed approaches constancy for escapements of 100,000 fish or more per day (36), whereas visual counts in this same situation would decrease in accuracy because observers would tally by groups of 10 or larger to keep pace with the flow of fish.

The frequency of one frame per minute was found to be impractical due to the amount of labour involved in processing and analyzing such quantities of film. The effect of reduced picture frequencies of from one frame per 2 minutes to one frame per 80 minutes was examined. For this particular study, the error was less than 5% in most cases, even at a frequency of one picture per 80 minutes. At an interval of ten minutes between pictures, power requirements were reduced to a point where the unit could be operated 3 - 5 days from a single high-grade storage battery with a capacity of 150 ampere-hours.

The use of artificial lighting during night operations gives the clearest and best defined picture because the silvery sides of the salmon act as reflectors of the directional light source. Care must be taken to ensure that the light source is not sufficiently strong to cause some fish to avoid the counting area in the camera field.

Accuracy, Precision and Technique Comparison

Accuracy of the results of aerial photographic enumeration was considered comparable to or superior to that of aerial or ground visual surveys. Eicher (32) stated that the photographic method provided the greatest accuracy when large schools of salmon were encountered. Neilsen and Geen (34). used photographic enumeration to determine a correction factor (0.96) for aerial visual counts, based on the assumption that the accuracy of aerial photographic enumeration methods was higher than that of aerial visual counts. However, no quantitative information on accuracy or precision was given and no further information was available in the literature or interviews.

However , counts from aerial photographs of spawning grounds during the spawning peak will suffer the same limitations as any other peak count in estimating total escapement, and will generally underestimate escapement to some degree. Hence accuracy of escapement estimation will ultimately depend either on the reliability of factors used to convert the peak count (an index of relative abundance) to an estimate of total escapement, or on the reliability of determination of stream residence times, if a spawner abundance curve based on results of several surveys is used.

Escapement estimates derived from the tower-based photographic enumeration method were compared to estimates from a series of intermittent visual counts. The product of the number of fish photographed each day and the observed conversion factor yielded daily escapement estimates. These estimates showed little deviation from those based on the visual counts. The total escapement estimates from these two methods differed by 5,239 fish or 0.6%, with the photographic estimate being the lower (36).

An approximation to universal conversion factors valid in the Wood River lakes system for certain intervals of migration density was obtained by fitting a curve to the daily conversion factors determined in this study. The efficiency of the calculated conversion factors was tested in terms of the deviation of the seasonal estimate from the estimate based on observed conversion factors and that based on visual counts. The maximum deviation between any two of these three estimates was 21,762 fish or less than 3% of a total escapement of close to 900,000 fish.

A picture frequency of one frame per minute gave a seasonal estimate differing by approximately 2% (16,000 fish) from that obtained through visual counts. When the picture frequency of the photographic technique was reduced, the deviation, or error, was less than 5% in most cases for a total escapement close to 900,000 fish, even at a picture frequency of one exposure every 80 minutes (36).

The maximim error involved by the indicated reduction in picture frequency was calculated as the standard deviation of the different estimates within each picture frequency group. This standard deviation was expressed in percentage deviation from the expected mean. A high probability level (P = 0.01) was selected to include any extreme variability in migration patterns. At 2 minutes between exposures, the percentage deviation was less thai 1%; at 10 minutes, the percentage deviation was approximately 6%; a percentage deviation of 12% was reached at the 80 minute maximum interval between frames (36.)

FENCE COUNTS

Methodology

Permanent and temporary fences constructed on streams and rivers have been used extensively by fisheries personnel to obtain accurate counts of adult fish migrating upstream to spawn. These fences are generally low, pervious dams, which obstruct fish passage; however, a more recent development has been the construction of dams to serve a similar purpose as fences (129).

Adult salmon migrating upstream are either counted through a fence or are directed to traps attached to the fence where they are removed by dip net for examination purposes and are released unharmed to continue upstream. In situations where fish are counted through a fence, flashboards are situated in front of gates in the fence. The flashboards increase the contrast between the fish and the background where fish and substrate colouration are similar or where turbidity of the water may restrict visibility.

Observers generally use hand counters to keep a tally of fish as they pass through the fence. When several species are migrating at the same time, a multi-bank hand counter can be used to keep the tallies of each species separate.

A thorough discussion of various types of permanent and temporary fences with their uses and problems are found in the literature (37, 41, 42, 43, 44, 45, 46, 129 and 130). These may be either sturdy structures that remain in the stream or river the year round, usually with removable panels that may be inserted to obstruct fish passage during migration and removed to permit minimally restricted water and debris passage, or they may be comparatively frail structures which are constructed as required each year and subsequently removed. Numerous other artificial restrictions to fish passage, such as fishways and locks, also provide an opportunity to enumerate salmon as they migrate past a point where they can readily be observed.

Areas of Use

Almost every country with rivers supporting migrating fish has records of fences being used to trap fish (129). Counting fences are presently used in all provinces and states of the Pacific Northwest from Alaska to California to enumerate escapement of all Pacific salmon species.

Fences are generally constructed on rivers where variations in water flow and water depth are minimal, such as at lake outlets (129; Withler, pers. comm.), so that the possibility of a fence wash-out during freshets is reduced as much as possible.

Effective Use and Problems

Fish counting fences are constructed on rivers when an accurate count of adult salmon escapement is required. Because initial construction costs are high, permanent counting fences are only used on rivers with important salmon runs and/or hatcheries, such as the Babine River (Withler, pers. comm.). As lake spawning sockeye are difficult to enumerate, the use of fence counts to estimate escapements before the salmon enter the lake have proven to be effective (42 and 130).

The effectiveness of fences as counting sites is influenced by many factors. The choice of the building site is extremely important. The streambed and banks should not be made up of material that is readily eroded and they may require reinforcement; banks should be of a height that the surrounding area is not inundated during freshets; and the site should be as wide as possible to reduce the water pressure on the fence. These factors affect whether the fish are counted through the fence or bypass it during freshets.

The design details of the fence are also important to prevent wash-out during freshets, prevent small fish squeezing through the pickets or dowels and minimize debris collection.

The variation in water levels and particular height of flood levels over several seasons should be examined to ensure that the height and stability of the fence is adequate and that fish will not bypass the fence during high water levels. The occurrence and amount of ice accumulation during winter months and spring break-up in northern or interior areas should also be examined as these factors may determine the type of fence constructed.

The removal of fences during freshets to avoid wash-outs, broken dowels or pickets, wash-outs and delayed installation of fences due to high water levels may allow fish to pass upstream without being counted and thus result in an underestimate of escapement.

Accuracy, Precision and Technique Comparison

Fence counts are generally regarded by researchers as the most accurate technique available for escapement enumeration (when all fish pass via the counting gates or traps) as the result is supposedly an absolute count of escapement. Consequently, this method is used as a standard to which results of other enumeration techniques are compared for determination of accuracy, and no information on accuracy and precision of fence counts appears in the literature. Counts of fish passing a fixed point of restricted but not obstructed passage, such as a fishway, appear to have little in common with regard to accuracy, which is largely a function of local conditions at the counting site and the amount of variation in these conditions that may occur.

MARK/RECAPTURE

Methodology

The Petersen mark/recapture method of population estimation is based on the general principal that the number of individuals in a population of unknown size may be estimated by marking or tagging a representative sample of individuals, releasing these to become distributed throughout the population, then obtaining a second sample at random for examination. Knowing the original number of individuals marked (M), the number of individuals examined for marks (C) during the recovery phase, and the number of marked individuals recovered (R), it is then possible to calculate an estimate of the total population size (N) from the ratio of marked to unmarked individuals examined, employing the basic Petersen formula $N = MC/R$.

Numerous variations of the basic mark/recapture method have been developed to meet a wide range of population assessment requirements in both fisheries-related and other disciplines (131). The method as applied to estimation of salmon escapement generally involves capture, tagging and/or marking and release of fish during their migration toward the spawning grounds. Tags are recovered during periodic surveys on foot of the spawning grounds throughout the spawning period (as well as from any fisheries intercepting tagged salmon), and the numbers of tagged and untagged carcasses encountered during each survey are recorded. Usually carcasses are either marked or removed from the stream when first counted to prevent recounting on subsequent surveys. After spawning and die-off are complete, an estimate of the escapement may be calculated from the combined results of all surveys, using either the above formula or one of several modifications.

It has been shown that in many situations the original Petersen formula ($N = MC/R$) is biased in that it tends to overestimate the true population, particularly when tagging and/or recovery sample sizes are small (131). A number of minor modifications of the original formula are possible to reduce or eliminate bias under specific conditions. The adjusted Petersen estimate most commonly used has the formula $N^* = (M+1)(C+1)/(R+1)$, and provides an unbiased estimate of $\underline{N}$ whenever $(M+C)$ is greater than N. Whenever MC is greater than four times N, the probability of negative statistical bias will be less than 2%, and in practise the probability of statistical bias can be ignored if recaptures number at least 3 (for 95% confidence) or 4 (for 99% confidence). The adjusted Petersen formula is preferred in most situations, though the discrepancy between estimates by both formulas decreases as the number of recaptures (R) increases, and becomes slight at large values of R (131).

Technically, 'marking' refers to some form of superficial mutilation for purposes of later recognition, such as fin clipping or branding, while 'tagging' implies the affixing of coloured identifying tags to fish for the same purpose. The latter technique is most commonly employed, often involving the use of brightly coloured (and sometimes individually numbered) plastic 'Petersen' disk tags, attached by a nickel pin inserted through the flesh beneath the dorsal fin. These tags are particularly conspicuous and are readily observed on both live fish and carcasses. When tag loss occurs (either naturally or due to unauthorized collection by memebers of the public) paired circular scars from the disks usually remain to indicate the fish had been tagged, though information from tag colour or number is lost. Other types of tags, such as tubular plastic 'anchor' or 'spaghetti' tags, or clamp-on metal jaw or opercular tags may be used in some situations, though close inspection of carcasses may be necessary to avoid overlooking tags and tag loss may be less readily apparent. Fin clips and other types of marks are particularly inconspicuous and are easily overlooked on the spawning grounds, and may be obscured by or confused with fin erosion and other forms of damage occurring naturally during spawning. However, some marking techniques (particularly the adipose fin clip) may be useful in addition to tagging in detailed studies when tag loss is of concern, and a second mark which cannot be lost is desired to allow estimation of the magnitude of this factor (58). The term 'mark/recapture' is subsequently used herein to refer generally to procedures involving tagging and/or marking methods unless specifically stated otherwise.

Capture and tagging is normally carried out at some point on the migration route before the spawning ground is reached, though tagging on the spawning grounds is a feasible alternative in some situations. Ideally, tagging should occur sufficiently near the spawning grounds to minimize effects of straying and tag loss, while still allowing adequate mixing of tagged and untagged fish throughout all spawning areas utilized (82). In practise, tagging is usually carried out in the estuary or mouth and lower reaches of small coastal stream and lake systems, but may occur some distance upstream in large rivers, wherever fish are readily obtained. Beach seines (or boat-operated seines in deep water) are generally used to capture samples for tagging, as this gear involves minimal selectivity for sex and size range. However, gill nets are sometimes used when other gear is not appropriate or available, and both fishwheels and large cylindrical Fyke traps have been used effectively, primarily in glacially turbid rivers in Alaska where gear avoidance is minimized.

Ideally, a fixed proportion of daily migration would be tagged, so that a constant tag ratio is maintained throughout the run; a single survey of carcasses on the spawning ground would then provide the necessary information for calculation of a reliable escapement estimate (55). However, in practise this is nearly impossible to accomplish unless a weir is used, in which case fish can simply be counted and a Petersen estimate is unnecessary.

In nearly all instances tagging is disproportionate, with either a constant number being tagged each day, or more commonly with fish being tagged in numbers determined by the availability of fish or the capacity of the tagging operations. Consequently, the ratio of tagged to untagged fish fluctuates from day to day and is not known precisely. The often bell-shaped, and sometimes bimodal or more complex curve of daily salmon migration, in combination with varying (and often decreasing) mean stream life during migration and spawning, further complicate the matter of obtaining a reliable escapement estimate on the basis of the ratio of tagged to untagged carcasses (55, 65 and 82). As a result, the most accurate estimate of escapement is usually obtained by surveying the spawning grounds frequently (usually at intervals of one to ten days) throughout the period of die-off to minimize carcass loss due to freshets, examining and marking or removing all carcasses and recording the numbers of tagged and untagged carcasses on each survey, then calculating the population estimate using the cumulative numbers of carcasses examined and tags recovered after die-off is complete. When tagging is disproportionate, the cumulative tagged proportion of carcasses examined may vary widely from the actual ratio of tagged to untagged fish in the population until die-off is largely complete, and population estimates based on tag recoveries prior to this time are of limited value for estimation of escapement (55).

Estimation of salmon escapement by the mark/recapture method is based on the assumption of a random mixing of tagged individuals throughout the entire spawning population. In addition, either the tagged salmon or the recovered carcasses (and ideally both) should form a representative random sample of the escapement for a reliable estimate to be obtained (131). These assumptions are often particularly difficult to satisfy in practise, and departure from their limitations may introduce considerable bias into the Petersen estimate. The difficulties arise from incomplete mixing of tagged and untagged salmon between the tagging site and the spawning grounds, and from changing age and sex composition and spawning ground destination of migrants passing the tagging site as the run progresses, resulting in an uneven distribution of tagged salmon on the spawning grounds (82).

In some situations these difficulties can be at least partially overcome by Schaefer's modification of the Petersen method, for use with stratified populations (131). While this procedure, like the basic Petersen method, is also most reliable when either tagging or subsequent sampling for tag recovery is random and without bias, Schaefer's method is more reliable than the latter is the more common situation where mixing of tagged individuals in incomplete and some stratification exists. This method remains applicable in the limiting situation where the spawning population is completely stratified with respect to tag distribution. The spawning population is generally stratified by time of tagging and either time or location of recovery, for calculation purposes; the resulting components of the population are estimated separately and summed to produce an escapement estimate. This procedure requires the use of either numbered or colour coded tags for identification of tagging date.

Unlike most other methods of escapement estimation, the mark/recapture method permits design of the field study to achieve the desired levels of statistical accuracy and precision in the estimate, whenever a reasonable guess at the magnitude of the spawning population can be made in advance. This is accomplished by selecting appropriate levels of tagging and recovery effort in relation to expected population size, using graphs constructed for this purpose and described in detail by Robson and Regier (80). The procedure is briefly summarized for the ±25% level of accuracy by Ricker (131). Should the escapement greatly exceed expectations, so that the selected levels of tagging and recovery effort would no longer provide the desired accuracy and precision (and if this fact is apparent before the field program is completed), it may still be possible to achieve these goals by appropriately increasing the number of tags applied or carcasses examined for tags, or both. However, it is important to realize that while theoretical accuracy and precision, as related to total escapement and sample sizes, may be easily predetermined in this manner, the procedure will not overcome bias arising from failure to meet one or more of the assumptions on which reliable mark/recapture estimation is based, and a statistically reliable but highly inaccurate estimate may be produced under these circumstances. [Ricker (131) reviews and discusses these assumptions in detail, and they are considered briefly here in the section concerning 'Effective Use and Problems'.]

Areas of Use

Historically, estimation of population size on the basis of the ratio of marked and unmarked members dates to 1783, when Laplace estimated the human population of France on the basis of the total number of births and the ratio of births to population totals in a sample of parishes (53 and 58). The method of tagging and recapture was first applied to estimation of the magnitude of fish populations by Petersen in 1896, who used the ratio of tagged to untagged individuals in samples to calculate a population estimate for plaice (and for whom the technique has been named in the literature). Estimation of Pacific salmon populations by this technique (as well as studies of migration of tagged individuals) was first attempted in the northern North Pacific by Japanese workers in 1938 and by the IPSFC in the Fraser River, B.C. in 1939.

The technique was applied more extensively to salmon populations in the Pacific Northwest in the 1940's and particularly after 1950, when numerous variations of the procedure were developed, both for estimation of spawning escapement and the more complex estimation of total return of a stock prior to commercial harvest and subsequent escapement to spawn (53). The technique has since been widely used throughout the Pacific Northwest for obtaining reliable escapement estimates of salmon populations and for calibrating or checking other often less accurate escapement estimation techniques.

Petersen mark/recapture techniques are used in B.C. primarily on large rivers supporting major salmon runs, where suitably reliable escapement estimates cannot be obtained by other methods. The IPSFC tags sockeye (every four years, when large escapements cannot be counted visually) and pink salmon in the Fraser River to obtain escapement estimates (Woody, pers. comm.). Carcasses are examined for tags and are pitched on at least two or three days each week throughout the spawning period (up to six weeks) on selected sockeye spawning grounds, and throughout the entire system for pinks. The latter utilize both the mainstem and tributary systems for spawning, and separate tag/recovery studies are carried out on tributary streams to estimate spawning escapement to these systems. The combined total of estimates from tributary streams is then subtracted from the overall escapement estimate and the difference is considered an estimate of Fraser River mainstem spawning.

The DFO also uses mark/recapture methods to some extent in B.C., either directly or through contract studies by biological consultants, on large systems and some smaller coastal systems where an accurate estimate is desired and weir counts are impractical. As the technique is labour-intensive and therefore costly, it is utilized in systems supporting escapements of a sufficient magnitude to justify the large expenditures involved (Anderson, pers. comm.). A number of such studies have been carried out in recent years, involving all five Pacific salmon species, as part of the preliminary studies, monitoring and evaluation of specific projects within the Salmonid Enhancement Program (5, 60, 61 and 69).

In Alaska, mark/recapture techniques have been used extensively for both in-season estimation of total return prior to commercial harvesting and for estimation of escapement (53, 54, 64 and 71). The method has been used to evaluate and calibrate the results of other escapement estimation procedures such as tower counts and aerial surveys, and has played an important role in collection of base year data for development of stream indexing techniques, for estimation of escapement from indices of relative abundance. The technique has been used most extensively with sockeye and pink salmon, but has been applied for estimation of escapements of all five Pacific salmon species. Mark/recapture methods are not widely used on a routine basis for enumeration because of the large amount of effort required and the resulting high cost (Rogers, pers. comm.). Estimations of a similar level of accuracy and reliability are often available using less labour-intensive procedures, such as tower counts, and consequently mark/recapture studies are generally carried out on large systems supporting major runs which cannot be enumerated effectively by other techniques.

In Washington, mark/recapture studies are now used by USFWS primarily for collection of reliable base year escapement data, for incorporation in the stream indexing system used by WDF. Escapement estimates in subsequent years are calculated from comparison of index area counts with those obtained during the base year, for which total escapement was estimated independently (Cole, pers. comm.). Recent studies have been centered mainly in the Puget Sound area of Washington State, which has been surveyed extensively by the USFWS during the period 1974-1980. Spawning populations of chinook, chum and coho have been studied, often through projects conducted jointly with local Native Indian bands. The mark/recapture technique is thus used primarily as a specialized tool for obtaining detailed baseline information on a particular stock, rather than as a routine method of escapement estimation.

A similar situation occurs in Oregon, with escapements of most wild stocks (primarily coho) being estimated using a comprehensive index stream system. Base year data may be obtained or updated using mark/recapture methods where appropriate, but the procedure does not appear to be used for routine estimation of escapements to any great extent.

In California, a modified version of the Petersen mark/recapture technique using a Schaefer multiple-census procedure is employed by the CDFG to estimate spawning chinook populations in two major river systems - the Sacramento River/San Joaquin River system and the Klamath River/Trinity River system (78; Rawstron, pers. comm.). The method involves tagging of fresh carcasses and counts of tagged and untagged carcasses during frequent surveys on foot of the spawning grounds throughout the spawning period. Fresh carcasses are tagged on each survey and old carcasses are pitched and tags recovered. The resulting calculated estimate of carcasses is then used as an index of relative abundance rather than a total escapement estimate.

Effective Use and Problems

The mark/recapture method has been used to estimate salmon spawning escapements in a wide range of situations, including both large and small rivers, tributary systems and lakes, with varying degrees of success. The method may be applied to salmon stocks whenever migrating adults are accessible for capture and tagging at some point prior to reaching (but preferably near) the spawning grounds, and when spawned-out carcasses are available for periodic inspection during and immediately following the die-off period. However, there are a number of assumptions which must be satisfied if a reliable population estimate is to be obtained, and violation of one or more of these assumptions can introduce considerable bias (131). These conditions are often difficult to satisfy in a practical manner, and the degree to which they may be met is often at least partially beyond the control of the investigator.

A well-designed mark/recapture study is both time-consuming and labour intensive (and therefore costly), and is made more so by the need to incorporate adequate safeguards to ensure that all the necessary assumptions are met as nearly as possible and that violations are quantified. As a result, this technique is not normally used for routine escapement estimation when other less costly techniques of adequate reliability are applicable. Mark/recapture may be used routinely in situations where reliable estimates are required and other techniques are not suitable (usually in major river systems supporting large escapements, such as the Fraser River), or where statistically supportable base year data is required for one or several years for evaluation of a project or establishment of an index system of escapement estimation. The procedure has the added advantage of providing considerable incidental information regarding migration timing and variation, migration routes, stock separation, and spawning distribution and success (Anderson, pers. comm.; Rogers, pers. comm.; Woody, pers. comm.).

The majority of technical problems associated with estimation of salmon escapements by mark/recapture techniques concern violation of one or more of the basic assumptions underlying the reliability of population estimation by this method. These have been considered in detail by various authors, including Cameron (55), Howard (65) and Schaefer (82), and are summarized and discussed for a broad range of applications by Ricker (131). A more recent discussion specifically concerning migrating salmon populations in Puget Sound, Washington is given by Eames et al (59). These assumptions and the major effects of their violation will be discussed here briefly in the context of estimation of spawning escapements subsequent to any commercial harvest which may occur. It should be clearly apparent that any fishery occurring between the point of tagging and point of recovery (such as a native food fishery) must be monitored closely to ascertain both total catch and capture of tagged fish, so that appropriate adjustments can be made prior to estimation of escapement. The more complex problem of estimation of total stocks prior to commercial harvest, from tagging offshore and return of tags recaptured in a commercial fishery as stocks migrate through the fishing area, is beyond the scope of this study, but is discussed by Bevan (53), Eames et al (59), Reisenbichler and Hartmann (79), and Vernon et al (84).

The underlying assumptions of the mark/recapture method as discussed by Ricker fall generally into two categories; those relating to biasing of the tagged:untagged ratio in the recovery sample through loss of tags from the sampled population, and those concerning the distortion of this ratio away from the true value due to irregularities in the distribution of tagged fish with respect to the total population, or a consistent bias in both tagged and recovered samples. Assumptions belonging to the first category are as follows:

1) Marked fish suffer the same natural mortality as unmarked fish.

2) Marked fish are no more (or less) vulnerable to any subsequent fishing effort than are unmarked fish.

3) Marked fish do not lose their identifying mark during migration and spawning.

4) All marks are recognized and recorded during recovery operations.

Violation of one or more of these assumptions will result in a selective reduction of the proportion of tagged fish in the population, often without the knowledge of the investigator, producing what has been referred to as a Type (1) loss (or Type A error, by Ricker), equivalent to a reduction in the number of fish tagged (72). The result of this type of bias, if not detected and accomodated in the estimation procedure, will be a reduction in the number of tags available for recovery from that expected, and hence an overestimation of the escapement (131).

In practice Type (1) losses do commonly occur during salmon migration and spawning, with frequently at least one and often several of the above assumptions being violated during the course of a mark/recapture study (53, 58, 59, 68, 72, 76 and 82). As Type (1) losses can occur throughout migration and spawning their effect is cumulative, and the magnitude of the resulting overestimation of the true population (without compensating adjustments) thus increases with the distance between the tagging site and the spawning ground recovery location (59, 82 and 84). The strategy for dealing with Type (1) losses, since they cannot be totally eliminated, involves the use of techniques which minimize these types of losses, and incorporation of precautionary measures which permit evaluation of the various sources of error and adjustment of the resulting escapement estimates.

Loss of tags due to tagging mortality is reduced by use of fish handling procedures which minimize stress and trauma during tagging operations, and an indication of probable mortality may be obtained by noting the condition of each fish when released (53, 58 and 131). The latter procedure is most useful when numbered tags are used and each fish can be identified, as a fish in poor condition on release can be discounted from those tagged, and can be recognized and ignored if it should survive and be subsequently recovered. Tag shedding, another common source of bias, can be minimized by care to ensure secure tag application, and can be substantially reduced by use of small (6 mm) clear buffer disks on the outside of each coloured Petersen disk to minimize disk failure (68). Tag loss can be estimated by double-tagging (with numbered tags) a proportion of those fish released, or by using a readily recognizable secondary mark (e.g. a fin clip or opercular punch) in addition to the primary tag (53, 58, 62 and 81). Tag scars may also be used as indicators of tag loss in some instances, though these are far harder to find than tags, and may heal rapidly (53 and 131; Woody, pers. comm.).

Failure to recognize tags during recovery operations is also a common problem, particularly when recovery crews are inexperienced and pitch carcasses too rapidly, without thorough examination. The problem may be largely eliminated by use of experienced personnel where possible and by careful examination of carcasses, while removal of tags during pitching and subsequent re-pitching of a proportion of the carcasses to recover missed tags permits estimation of the magnitude of this source of error (131; Woody, pers. comm.). IPSFC studies have indicated up to 10% of available tags may be overlooked during the first examination (85) and inexperienced crews working in areas of heavy carcass accumulations may miss up to 25% (Woody, pers. comm.).

Selective removal of tagged fish, as might occur if tagged fish were more likely to become entangled in gill nets than were untagged fish, is a more difficult problem to detect and evaluate, and losses of this type often pass undetected or are included in mortality (131). Careful monitoring of the fishery is required to ensure reporting of all tags. Sampling of the migration using a relatively non-selective gear type such as a seine may be the most likely method of detecting any selective bias in the fishery, by comparing the proportion of tagged fish taken by the two methods. (It should be noted that reduced vulnerability of tagged salmon to capture by a fishery, perhaps due to temporary behaviour modification following tagging, as noted by Bevan during a 48-hour period following tag application with pink salmon (53), will produce a population overestimate on the basis of the tagged proportion of the fishery catch, while population estimates based on spawning ground recoveries will underestimate the original unfished population.)

Emmigration of tagged fish from the population under study represents another source of tag loss often included in overall mortality. Significance of this factor decreases as distance from the tagging site to spawning grounds decreases (59), but even fish tagged on the spawning grounds have been recovered in a different stream or river system on occasion. The magnitude of 'straying' cannot be determined unless an effort is made to recover tags from at least the spawning areas of adjacent systems, though this effort may not be justified when tagging occurs well above the mouth of the system under study and adjacent systems would not otherwise be surveyed.

The second category of assumptions, concerning the distribution of tagged salmon within the total population and the recovery sample, generally requires random mixing of tagged fish throughout the entire population (or precautions such as stratification of tagging and recovery samples when mixing is incomplete). It is commonly stated that either the tagged sample or the recovery sample must be random if an unbiased population estimate is to be obtained, and it is recommended as a precautionary measure that attempts be made to collect both samples randomly to increase reliability (131). However, it is frequently difficult or impossible to obtain simple random samples of wild populations (59) and it is generally recognized that salmon tagged during migration are rarely completely mixed throughout the population, even after completion of spawning and die-off, but are usually stratified to some degree with respect to time and sometimes other factors as well (53 and 131). This situation may often be accomodated by appropriate stratification of samples as recommended by Schaefer (53), but estimates thus obtained are often not significantly different from those obtained from the simple method without stratification (59).

Junge (66) has shown that both samples may be non-random (i.e. selectivity may exist) without introducing bias in the population estimate provided that the sources of selectivity in the two samples are independent and are also independent of the mark status in the second (recovery) sample (59). If the sources of selectivity are not independent, then a valid estimate is obtained only if sufficient mixing occurs to provide a uniform distribution of tagged individuals with respect to the source of selectivity prior to collection of the recovery sample. Where mixing of tagged individuals is insufficient, it becomes necessary to distribute recovery effort over the entire spawning area throughout the period of die-off and a method of stratifying the population may be required to produce a reliable estimate.

Selectivity in the tagging sample is minimized by use of fishing gear with minimal selectivity, such as a seine, and by continuation of tagging throughout the major portion of the migration. However, some selectivity is often present, as for example with seines in which males of some salmon species (e.g. sockeye, coho, chum) become readily entangled by their prominent teeth, and are thus caught in greater abundance than females (Geen, pers. comm.). Also, because of major fluctuations in migration intensity, proportional tagging is nearly impossible to achieve and some selectivity in relation to age and/or size is frequently present.

Selectivity in the recovery sample may be minimized by frequent and thorough coverage of all or the major portion of the spawning area by recovery crews throughout the die-off period. However, selectivity may persist with regard to sex, as females tend to die in the shallows near their redds and be more easily recovered than males, which are more mobile and often die in deeper water after spawning (58). Additional selectivity of recoveries with respect to fish size is often apparent, and may occur in relation to time or location of recovery, or may be imposed by freshet conditions which wash out carcasses from a specific component of the population and limit recovery to other components (55). It is particularly important to avoid selectivity with regard to time of death in the recovery sample, as this factor will not usually be independent of time of migration past the tagging location.

Accuracy, Precision and Technique Comparison

As mentioned previously, the Petersen mark/recapture method includes a simple procedure for selecting the appropriate sizes of the tagged and recovery samples to achieve desired levels of theoretical accuracy and precision in the population estimate, when the order of magnitude of the escapement can be estimated approximately in advance (80). Having obtained an escapement estimate, it is generally a simple procedure to calculate 95% or 99% confidence limits for this estimate (131). However, these procedures imply that all assumptions necessary for an unbiased estimate of the population have been fully satisfied, a condition which rarely applies in the estimation of salmon escapements. More commonly a variety of Type (1) losses of tags from the population prior to tag recovery will introduce a degree of bias which, if not detected and corrected before calculation of an estimate, will result in overestimation of the true population. In addition other sources of bias involving selectivity in tagging and recovery samples and non-uniform distribution of tagged fish, if not eliminated, may introduce further tendencies to overestimate or underestimate the true value. As a result, the theoretical accuracy and precision of a Petersen mark/recapture study may be considered reliable only when adequate precautions have been made to eliminate or correct for violations of the basic assumptions.

An independent measure of the accuracy of a mark/recapture estimate of salmon escapement is of course rarely available to the investigator except in the unusual situation where the mark/recapture study is carried out in conjunction with a fence or weir count, and such studies are understandably scarce in the literature. Howard (65), in initial studies of the method by the IPSFC at Cultus Lake, B.C., obtained estimates which exceeded actual counts through the fence by only 3% for both 1938 and 1939 escapements (13,342 and 73,189 sockeye, respectively), when proportionate tagging was carried out at the fence immediately below the spawning grounds. By contrast, Brett (17) obtained mark/recapture estimates for Babine Lake sockeye which were approximately twice the actual count, when proportionate tagging was carried out at the fence a considerable distance below the spawning grounds. Schaefer (82) noted that agreement between estimates from tagging at the mouth of spawning streams and tagging downstream in the main river decreased as the distance of the downstream site from the spawning grounds increased, the disagreement resulting from overestimation by the downstream estimate (due mainly to Type (1) losses). A similar effect was noted by Vernon et al (84) in a study on the Glendale River in 1961. Estimates from tagging pink salmon at the weir and at two locations below the weir overestimated the weir count by 17%, 34% and 41%, respectively, again presumably due to Type (1) losses that were not taken into account. However, estimates based on spawning ground recoveries of tags passed through the weir from the two downstream tagging locations were within 6% of the weir count.

A study on the Yukon River (1976-1978) and Tanana River (1979-1980) indicated that Petersen population estimates for chum salmon in each year were consistently higher than the sum of catch and observed escapement (as indicated by aerial peak counts) (54). Discrepancies between documented and estimated escapements ranged from 36% to 253%; the aerial peak counts were considered to be minimum values which underestimated the true escapement considerably, while the Petersen estimates were thought to be inflated by failure of fishermen to report all tags taken. As the primary objective of the study was identification of stocks and migration routes rather than estimation of populations, other factors which may have resulted in losses of tags or tagged fish were not taken into account, and these factors may also have contributed to inflation of population estimates.

A detailed mark/recapture study was carried out by Eames and Hino (58) on Big Beef Creek, Washington, in 1980-81 in conjunction with an adult weir and trap. Coho were enumerated as they were dipped from the trap and every fourth coho received a numbered jaw tag for identification, as well as a secondary fin clip for subsequent assessment of tag loss, before being released upstream. Tagging was proportional to migration and sources of Type (1) losses were evaluated and taken into account before escapement was estimated. Selectivity by sex and size in the recovery sample was also determined. A population estimate of 1,482 coho was produced, which under-estimated the weir count of 1,613 coho by approximately 8%. While the weir count and Petersen estimate agreed fairly closely, the confidence interval for the latter (1,048 - 1,808) was much wider than anticipated due to a low tag recovery rate during spawning ground surveys, resulting in part from carcass losses during freshets.

In IPSFC studies using mark/recapture techniques in the Fraser River for estimation of sockeye and pink salmon, a 95% confidence interval of 20% of the estimated value is considered to indicate a 'good' (i.e. quite reliable) result, while 95% confidence intervals of 40% and 60% are considered to indicate 'average' and 'poor' results, respectively (using Ricker's formulae for confidence intervals). The accuracy of the technique is considered to be quite variable between areas, but has rarely been measured independently. Comparison of a Petersen population estimate with a tower count on the Chilko River produced agreement within 10% between estimates (Woody, pers. comm.). In general, accuracy of mark/recapture estimates in DFO and IPSFC studies is considered to average ±25% to ±30% (Anderson, pers. comm.; Gjernes, pers. comm.).

INDEX STREAMS

Methodology

An escapement index is a measure of the relative magnitude of a salmon population from counts made on selected spawning grounds. The index is used to compare escapements from year to year, but is not a measure of absolute escapement. Counting surveys are made on index areas (or survey units) within river systems. Index areas are chosen because they are accessible, stable, have good visibility and are representative of the spawning grounds of a drainage area. Aerial and float surveys are made on larger rivers and foot surveys are made on small tributaries. Index area counts are expanded to estimates of total escapement using either spawning ground area expansion factors, or calibration factors developed through comparison with escapement estimated by an independent method for one or more 'baseline' years.

In Washington state, the WDF make aerial redd-count surveys of index areas to enumerate chinook salmon. Historically, peak index area counts were applied to a base year factor to estimate total escapement (87). The base year factor was calculated during a year for which the total escapement had been estimated by an independent (often subjective) method.

The technique has been refined in the Skagit River to more accurately accommodate in-season fluctuations in the magnitude of chinook migration (Ames and Orrell, pers. comm.). Redd counts from a number of surveys made during the spawning period are plotted against time to form a spawning curve. The area under the curve (AUC), an estimate of a total redd-days, is divided by a value representing redd-life (21 days) to calculate the number of redds. (Redds are normally visible from the air for about 21 days before becoming obscured by algal growth.) Correction factors for the number of false redds (0.95) and the number of fish/redd (2.5) are applied to the redd number to calculate index area escapement.

To estimate coho escapement, spawning curves are plotted from counts of live and dead coho salmon in terminal index areas, and the area under the spawning curve (total fish-days) is related to base year data to produce an estimate of total escapement within a drainage area (Flint, pers. comm.). Base year data is being updated by more accurate estimates of total escapement from mark/recapture surveys made by the USFWS. Chum salmon escapement is similarly calculated by relating counts of live and dead, and live and dead/mile, to 1968 base year data.

Pink salmon are difficult to count while on their mainstem spawning grounds due to water depth and turbidity; therefore estimates are made from carcass counts (Orrell, pers. comm.). A range of escapement values are obtained by directly relating total carcasses to base year data and by regressing total carcasses and carcasses/mile against base year data.

In Oregon, coho wild stocks are enumerated by the ODFW on 40 standard survey units, each approximately one mile long (Nickelson, pers. comm.). Counts of live and dead coho are used to construct spawning curves and the area beneath the curve (total fish-days) is divided by coho stream life

(11 days) to estimate index area escapement, from which total escapement estimates are calculated. Spawning curves have recently replaced the use of peak counts because the former are considered to provide more reliable estimates of abundance (88).

In Alaska, the ADFG use aerial survey techniques as a primary method of enumerating salmon in spawning ground index areas. Aerial counts of pink salmon in index streams of the S.E. Alaska region are expanded to estimate total escapement to a district on the basis of the proportion of spawning streams surveyed (93). Index area counts of all species are related to total escapement estimates made by sonar counters to apportion escapement to tributary areas in the Cook Inlet area (Tarbox, pers. comm.). In the Wood River system of the Bristol Bay area, index area counts of sockeye on spawning grounds are related to estimates of total escapement made by tower counts on the mainstem, and are used to estimate mainstem and tributary spawning escapements by apportionment of the mainstem total (89).

Areas of Use

Index stream techniques have been in use in Washington and Oregon for estimation of Pacific salmon escapements since about 1950, and were adopted in Alaska in the mid 1950's. Initially used as a means of determining relative abundance of spawners from year to year, various modifications of the technique are now widely used in all three states to obtain salmon escapement estimates. In Washington, recent refinements of the method of estimating chinook escapement from redd counts have been made, primarily on the Skagit River. The technique is not widely used in B.C. at present, though some limited application is being attempted (Anderson, pers. comm.).

Effective Use and Problems

Indices of salmon escapement are used to generate estimates of escapement to the spawning grounds of large drainages containing many tributary spawning areas, and to some coastal areas containing numerous spawning streams of similar type. In Oregon, with 4,700 coho spawning tributaries and coastal streams (Nickelson, pers. comm.) and in S.E. Alaska, with 2,500 salmon spawning streams (93), stream indexing techniques are particularly effective and cost efficient. Because only a small portion of the total available spawning area is surveyed, the survey effort requires a minimum of man hours, equipment and expense, and can be done with very few personnel when aerial survey is possible. Reasonably accurate estimates of relative abundance of spawners from year to year in large river systems or coastal areas can usually be obtained quickly and efficiently. If index areas are representative and adequately surveyed, accuracy of the total escapement estimate depends largely on reliability of the base year data on which estimates are based. However, emphasis is placed on estimating overall escapement to a major watershed or coastal district rather than accurately estimating escapement to any one stream or tributary. When the two above conditions are met, yearly changes and trends in relative abundance of spawners will usually be evident directly from comparison of mean index values for an area, prior to estimating escapement. In many instances these indications may be of greater interest than the actual escapement values, which become secondary.

Selection of index areas can present considerable difficulties, since abundance of spawning salmon in these areas should be representative of abundance throughout the spawning grounds to which escapement is to be estimated. Ideally these areas should also remain representative from year to year, despite changes between years in abundance and relative distribution of spawners. The latter condition is often the most difficult to satisfy, and evaluation may not be possible until several years of survey data and one or more years of baseline data have been collected. The distributions of spawning pink and chum salmon in rivers in Washington state vary from year to year (Orrell, pers. comm.), and in some years low water conditions prevent coho from reaching the terminally-located index areas (Flint, pers. comm.). In Oregon, many index areas have near ideal spawning conditions, and density of coho salmon in these areas is thought to be higher than the mean density for the entire region (Nickelson, pers. comm.). In addition, some index areas are close to hatcheries and receive hatchery strays, which would bias the index for estimation of wild stocks (88).

In general, surveys of stream index areas are subject to all the limitations of the spawning ground enumeration technique(s) used to carry out the survey. However, when surveys of all index areas are made in a consistent manner by the same method, the effects of many of these limitations may be reduced or eliminated, as estimates are produced by comparison rather than direct evaluation of survey results. Where more than one survey method is required (or changes occur between years), standardization of results between methods is desirable to minimize the introduction of additional variability. Also, in order that escapement estimates may be compared from year to year, it is necessary that a constant proportion of the total population be counted each year (92). However, enumeration of a constant proportion of a population is made difficult by year to year changes in the character of the spawning migration, environmental and stream flow conditions, survey techniques and personnel involved.

Since surveys of index areas typically involve one visual technique or another, limitations of visibility in all or a part of a drainage may restrict application or reliability of the indexing method. Areas of glacial turbidity or deep water (mainstem or lake) spawning cannot be visually surveyed, and it is extremely difficult if not impossible to determine if escapement to adjacent shallow clear water spawning grounds is representative of these areas (Ames, pers. comm.).

Migrant or 'transport' fish, counted as they move through index areas on the way to other spawning grounds (and possibly recounted in upstream index areas during subsequent surveys), are thought to increase the variability of index area counts (91). Spawning of two or more species concurrently within index areas also introduces considerable error, as species discrimination by most visual survey techniques is poor (Wood, pers. comm.).

Spawning peak live plus dead counts obtained by aerial surveys provide a rapid method of acquiring an index of escapement and similar results may be obtained from peak redd counts, where spawners (especially chinook) are dispersed and difficult to count and redds are highly visible (Meacham, pers. comm.). However, Orrell (87) found that chinook escapements to the Skagit River basin as estimated from peak redd counts were poorly correlated with returns four years later. Consequently, the WDF now produces seasonal spawning curves from periodic aerial surveys and redd counts during the spawning period, for both chinook and coho, to permit more reliable estimation of escapement from index area surveys. Inclement weather or high stream flows may interrupt a survey schedule, so that one or more data points on the spawning curve may require subjective interpolation (Flint, pers. comm.), but the escapement estimation procedure is less vulnerable to disruption than when a single peak count survey is employed.

Conversion factors for calculation of escapement estimates from spawning curves of fish or redd counts may be specific to a particular drainage. The conversion factors for calculating chinook escapements in Washington state have been researched in the Skagit River basin only, and may not be applicable to other systems (Ames, pers. comm.). Chinook redd life has been found to vary considerably with the nutrient content of a river system, since the growth rate of algae which obscure the redds is dependent upon the concentration of available nutrients (Orrell, pers. comm.). The proportion of false chinook redds counted during surveys has also been found to vary greatly (87), and should be determined for each system independently. Stream life of coho salmon in Little Bear Creek, Washington, was also found to be highly variable, and stream life values for males and females were significantly different (91).

Ultimately, the reliability of escapement estimates produced by index stream techniques depends on the accuracy of the base year data on which the estimates are based. Base year data are frequently obtained either from mark/recapture studies or (less often but more accurately) from weir counts, though less reliable techniques are occasionally used when better alternatives are not feasible. Early base year escapements for pinks, coho and chum in Washington are thought to be inaccurate and are being updated, primarily by extensive mark/recapture studies (Flint, pers. comm.; Orrell, pers. comm.). As a result, escapement estimates derived from the early base year data are now considered unreliable. When major variations in escapement and spawning distribution occur in cycles from year to year, as is common with pink and chum salmon, it is often necessary to obtain base year data for two or more years, and calculate escapement estimates from data for the appropriate base year (Ames, pers. comm.). It has also been noted on several occasions that years of average escapement are more reliable than years of high or low extremes as base years, and that base years should be selected accordingly whenever possible.

Accuracy, Precision and Technique Comparison

Salmon escapement indexing techniques were initially developed to provide a method of estimating relative abundance of spawners in a large area from year to year on the basis of yearly variations in abundance within a limited number of representative index areas. The technique was developed empirically, with emphasis placed on consistency of method from year to year to reliably indicate fluctuations in abundance, rather than yield accurate escapement numbers. Accuracy was desirable at the overall escapement level, but could not usually be tested and was implied from sampling theory; accuracy at the individual stream level was not expected due to variability in spawning timing and duration. In most instances there is no basis for comparison with a second escapement estimate in large drainages or coastal regions, and accuracy can usually be practically tested by independent study only in small systems. In situations where changes in index values (relative abundance) rather than actual escapement estimates are of particular concern, a measure of accuracy may not be appropriate.

In the Wood River lakes system of Alaska, extensive spawning ground surveys involving both peak aerial and ground counts have been used to apportion known total sockeye escapements (obtained from mainstem tower counts) to the various tributary subsystems or 'spawning units', using the 'chain-link' method (94). The survey peak counts can also be used as a comprehensive set of indices for estimation of the total known escapement, and the accuracy and reliability of this method was tested in this manner for escapements between 1959 and 1963. Chain-link index estimates differed by 1.5% to 7.3% of tower counts over this period, with a mean variation of 4.3% (94). In addition, reliability of the chain-link method in estimating escapement to two tributary systems (Little Togiak Lake and Lake Kulik) was tested in 1961, using a tower count tag recovery method to obtain independent population estimates. The two methods produced estimates differing by 5% and 15% (94), indicating considerable reliability of escapement estimation by this technique, when extensive spawning ground surveys are involved.

More recently, index area sockeye escapement estimates for the Kenai River system in Alaska were compared with sonar count estimates, by correlation analysis of estimates by both methods for the period 1969 - 1975 (107). There was a highly significant linear correlation ($r = + 0.99$) between estimates produced by the two methods.

A test of the accuracy of Puget Sound, Washington, coho escapement estimates based on peak coho counts in index areas was carried out in 1974 and 1975, using independent estimates of wild coho escapement calculated from the ratio of catch of wild and hatchery-origin coho in Puget Sound, and hatchery returns. The catch ratio was determined from recovery of tags used for hatchery evaluation studies, and assumed equal harvest rates of wild and hatchery stocks (98). Results of the comparison indicated the estimates based on the stream index surveys were 8% and 19% lower than tag recovery estimates in 1974 and 1975, respectively, and survey estimates were subsequently increased by the mean of 14%.

Independent chinook escapement estimates made by WDF (escapement index) and USFWS (mark/recapture) on the Duwamish - Green system in 1975 and 1976 are given in the following table (51).

	1975	1976
WDF (escapement index)	4060	2800
USFWS (mark/recapture)	3394	3135

The two estimates agreed closely for both years of the study (within 9% and 6% of the mean values, respectively). Another study in a small Washington river system with a weir compared coho escapement estimates from index areas surveys in 1980 and 1981 with weir counts. Spawning curves were constructed and used to produce the index area estimates, which were within 10% of the weir counts for both years (Flint, pers. comm.).

An indication of the precision of escapement estimation from survey of index areas is given by two independent estimates of escapement to the Quinalt River in Washington, by the WDF and the Quinalt Indian Band. Both groups used similar methods for survey of index areas and the resulting estimates differed by less than 15%, though no evaluation of accuracy of the estimates was made (Wood, pers. comm.). The WDF also found a significant correlation ($r = +0.69$) between counts of coho made in an index area of Big Beef Creek in 1980 - 1981 and a series of counts made over the entire drainage (58), suggesting that the index area counts were representative of the system.

As a result of these and similar studies the WDF has considerable confidence in their estimates of chinook and coho escapement based on index area surveys, particularly since the introduction of spawning curves rather than peak counts as a basis for calculation, and since mark/recapture methods were applied to update original base year data. This is primarily because the index areas are representative for these species and spawning distribution is fairly consistent from year to year, though occasional extremely high or low water levels may create difficulties in completing surveys and obtaining reliable estimates (Flint, pers. comm.). However, they have considerably less confidence in index area-based estimates of pink and chum escapements, mainly because of major shifts in spawning distribution from year to year. A recent estimate of pink salmon escapement ranged from 50,000 to 150,000 fish, exemplifying this uncertainty (Orrell, pers. comm.).

Beidler and Nickelson (88) have extensively analysed the procedure for generating escapement indices for coho in Oregon streams by the ODFW. The level of sensitivity desired initially was detection of yearly changes of ± 25% in the coast wide mean peak fish per mile index with a 90% level of confidence, though absolute estimates of abundance were ultimately desired. Their study showed that sensitivity at this level of confidence could be increased from ± 72% to ± 32% of the mean escapement index by increasing the number of survey units (index areas) from 10 to 40, but that further increases in number of survey units would have little effect. The desired ± 25% sensitivity level could not be attained with 90% probability, due primarily to the variation associated with the use of peak counts rather than a spawning curve as a basis for the index. The 90% confidence limits for estimates of coho escapements to three river drainages, based on mean index area counts/mile, ranged from ± 43% to ± 53% (Nickelson, pers. comm.).

Recent expansion of surveys to include 40 index areas and replacement of the peak count method with spawning curves constructed from weekly surveys of these areas have been carried out with the expectation of achieving the desired goals of accuracy and precision stated previously. Eventually, with stratification of river drainages according to distribution of fish (number of fish per mile) in individual tributaries, and classification of spawning grounds by intensity of use, it is hoped to reduce the variance associated with mean escapement estimates to ± 10% (Nickelson, pers. comm.).

ELECTRONIC COUNTERS

Introduction

Methods to enumerate salmonids electronically during their upstream spawning migrations have been either available or under development since the 1950's (103), though attempts to enumerate Pacific salmon electronically do not appear to have begun in the Pacific Northwest until after 1960. These methods fall generally into three categories based on the nature of the technology involved: photoelectric techniques, conductivity (resistivity) techniques and sonar techniques.

Photoelectric techniques appear to have been experimented with briefly but were initially limited by problems of temperature instability, turbidity changes, fouling from algae growing on transparent source and detector windows in the light beam, and the potentially more serious problems such as size discrimination and false target (debris) rejection. Some of the problems have been largely overcome (99), but methods employing this technology do not appear to be currently in use for enumeration of adult salmon escapements on the Pacific coast and the techniques are not further considered in this study.

Conductivity sensing methods incorporate the basic principle of balancing resistivity of the water, in the absence of fish, against adjustable balancing resistors or a second water resistivity-sensing unit from which fish are excluded; comparison may be direct or via a conventional Wheatstone Bridge circuit. Presence of a fish in the detection zone of these counters causes an increase in conductivity because its body fluids are more conductive than the surrounding medium, which must be fresh (not brackish or salt) water of fairly low conductivity. The temporarily increased conductivity is detected by the control unit and is registered as a count in a cumulative display or printout from memory.

Conductivity sensing counters are of two basic types, either utilizing a long 'mat' of sensor cables placed on the streambed and over which fish must pass to be counted (103), or employing one or more sensor tunnels located at a point of restricted fish passage so that all upstream migrants must pass through the tunnel(s) and be counted (105). Both types of counter have reached an advanced level of development and appear to work well within their ranges of limitations, though in quite different counting situations. However, the mat-type counter does not appear to be available or in use in the Pacific Northwest at present and it is not considered here in further detail.

Tunnel-type counters are used to some degree in British Columbia and Washington, where criteria for their use can be met, and at least two designs by different manufacturers are available. The unit manufactured by Pulsar Electronics Limited of Vancouver, B.C., is discussed here because it is the more sophisticated (though less portable) of the two, and because more information on its operation is available (4, 5 and 105). (Some of this information is drawn from previous work involving one of the authors (4 and 5) and unreferenced comments concerning operation of this counter are drawn from his personal experiences with two such machines in 1980 and 1981.) A second tunnel-type counter manufactured by Smith-Root Inc. of Vancouver, Washington, is basically similar in installation and operation, though without programmed constant-interval counts and printed output. The principle of operation of this unit differs from that of the Pulsar unit somewhat, and involves a conventional Wheatstone Bridge circuit. Results of practical applications of this unit were not found in the literature, but general comments concerning operations and limitations of the Pulsar unit are probably also applicable to this model. Additional information may be available from the manufacturer on request.

A number of salmon counters using sonar have been tested since development began in 1961. Most have been developed by the Bendix Corporation (Electrodynamics Division, Sylman, California) with support and funding provided mainly through contracts with the ADFG. The earlier model, utilizing a bottom-mounted array of 30 upward-looking transducers, was developed in the mid 1960's and has been in use in Alaska since 1968. More recently, the Bendix side scan sonar system has been developed and has been widely used in Alaska since 1976. Both units count bank-oriented migration of salmon in clear or glacially turbid river channels, the fish being detected from their echoes as they swim through a pulsed sonar beam. The side scan model may be more accurately calibrated, distinguishes between debris and fish, and is considered a major improvement over earlier models. The side scan sonar system is the current method of choice for salmon escapement enumeration using sonar, and as such is considered in greater detail in the following discussion.

In addition, two new sonar systems are currently being developed and tested for salmon enumeration; fan scan sonar (also from Bendix) and a Doppler sonar system from Biosonics Inc. in Seattle, Washington. These two systems are briefly described, with comments on the early tests, though development of prototypes is not complete and their applications in salmon escapement enumeration are not yet tested.

1. Pulsar Conductivity (Resistivity) Multiple Tunnel Fish Counter

Methodology

The Pulsar electronic fish counter is installed at a point of restricted fish passage, usually in weirs or fishways, so that all fish travelling upstream must pass through an array of counting tunnels. One tunnel module or 'bank' consists of four counting tunnels and one reference tunnel, the latter being blocked to fish passage. The reference tunnel provides a continuous reading of water conductivity (which may fluctuate), against which the four counting tunnels are continually compared in rapid sequence. The machine is capable of monitoring a series of up to eight tunnel modules, or 32 counting tunnels (though existing units monitor from one to four modules).

Passage of a fish through a counting tunnel temporarily increases conductivity between electrodes on the tunnel walls; this brief unbalance with respect to the reference tunnel is detected and is registered as a count in memory. The counter is able to distinguish between and separately count upstream and downstream passage of adult salmon, though downstream passage is unlikely when tunnels are correctly located, and does not usually occur (105). In practice, downstream counts often result from a fish hesitating or drifting back partway in a tunnel, and are usually ignored for counting purposes unless downstream movement is observed. (A sudden increase in downstream counts usually indicates either interference during periods of intense migration or spurious counts due to tunnel fouling.)

The counter is a microprocessor-based system with variable-count-interval printed output on paper tape. It is programmed by the operator for date, time, print rate (counting interval) and other information, and is normally set to print hourly totals of fish passage. Once operating properly, the machine should continually monitor fish passage with little further attention, other than operation and maintenance checks and periodic visual counts to check accuracy.

Areas of Use

Only a small number of Pulsar multiple-tunnel-module fish counters are currently in use. Two are used by DFO to enumerate sockeye escapements to Sproat Lake and Great Central Lake on Vancouver Island, B.C. Both are installed in fishways through which sockeye pass to enter the lakes (4, 5 and 105). Two additional units have been installed by the IPSFC, at the fishway bypassing the dam on Seton Creek and at the entrance weir of the Nadina River spawning channels, both in the Fraser River system of British Columbia (Fretwell, pers. comm.; Woody, pers. comm.). These machines are used to count sockeye and pink salmon escapements. A fifth unit is currently being tested for effective enumeration of sockeye escapement into Hobiton Lake, also on Vancouver Island, by J.C. Lee and Associates Ltd., under contract through the Lake Enrichment Studies program at the Pacific Biological Station (DFO) in Nanaimo, B.C. Counting tunnels for this unit will be installed in a temporary broomstick fence placed across the Hobiton River, a tributary of Nitinat Lake.

The Pulsar counter has thus seen only limited application in the Pacific Northwest primarily within B.C. Pulsar reports production of several other units for use in areas outside the Pacific Northwest, though performance data is not yet available.

Effective Use and Problems

The Pulsar electronic counter and similar tunnel-based systems are best suited to enumeration of single species salmon migration past a point where fish passage is restricted (e.g. fishways, weirs and counting fences). The tunnels must be installed in a barrier screen which blocks all fish passage except via the counting tunnels, so that fish cannot bypass the counter. Otherwise some method of correction for the proportion of migration bypassing the counter is necessary (5). Some degree of flow and debris control at or above the installation site is often desirable to minimize the dangers of washout and debris damage and to stabilize water flow through the counting tunnels, though this is not always necessary and depends on site location and normal flow stability.

Sockeye and pink salmon have shown no indication of tunnel avoidance (Fretwell, pers. comm.) so that fish passage, while restricted, is not obstructed providing that tunnel modules are installed correctly and in sufficient number to accomodate peak rates of fish passage during migration. Consequently, diel patterns of fish migration are not greatly disturbed, and the hourly or other fixed-interval print-out rate permits monitoring of diel migration patterns, and seasonal changes in this pattern, without the cost or inconvenience of extended or continuous human observation (5). When installed, programmed and functioning properly, the machine should require very little attention other than periodic monitoring of counting accuracy, checks to record counts and to ensure that a malfunction has not occurred, basic maintenance such as battery checks (if AC power is not available), and occasional tunnel cleaning and clearing of accumulated debris.

A problem arises when two or more species of salmon migrate together, as occurs with sockeye and coho entering Great Central and Sproat Lakes in August and September. Under these circumstances individual species totals are obtained by subdividing machine counts on the basis of proportion of each species observed from visual counts during the daily migration peak (4 and 5). Trapped or netted samples may also be used for this purpose if a species-related bias is not present (105).

Periodic visual counts made in conjunction with machine counts are also necessary for determination of machine accuracy and counting error. Counter sensitivity is initially adjusted so that machine error is minimal (near zero) at low fish passage rates. As the rate of fish passage increases, counting error increases, and at high fish passage rates (5,000 - 7,000 fish/hr) the machine may undercount by 15 - 25% (4, 5 and 105). When the counter is adjusted and functioning correctly, counting error is a curvilinear function (usually parabolic) of fish passage rate, and corrections can thus be accomplished from a correction curve fitted to % error data obtained from comparison of visual and machine counts (4, 5 and 105). This procedure is now performed for Great Central Lake and Sproat Lake sockeye escapements using a microcomputer and appropriate software (5). As a consequence of this correction procedure, counter sensitivity should not be adjusted, once properly set, unless a major change in machine accuracy occurs, as each setting will require a separate correction curve.

For optimum accuracy, dimensions of the counting tunnels should be carefully matched to the size of fish being counted, as tunnels designed to permit passage of large fish will frequently fail to count small fish. For example, tunnels sized for counting large coho will overlook some small jacks, and tunnels designed for counting chinook salmon would yield poor counts of pinks or sockeye. It is also desirable that counting tunnels be installed so that fish will use all available tunnels approximately evenly (5).

The tunnels are subject to gradual fouling and buildup of a layer of organisms (particularly algal films and accumulations of blackfly larvae), which can alter conductivity between the electrodes and ultimately give rise to spurious upstream and downstream counts and erratic performance. Algal growth can be greatly limited by appropriate shading of the tunnels, and both problems are overcome by periodically cleaning all tunnels (including reference tunnels) with a soft brush. The tunnels should therefore be installed in a manner that permits either their easy removal or cleaning in situ.

Accuracy, Precision and Technique Comparison

Accuracy of the Pulsar electronic counter (and similar units) is determined on a day to day basis from simultaneous visual counts, as already described. The unit at Seton Creek is reported to routinely provide accuracy within ± 1 - 2% of observed fish passage, with daily totals at peak migration of 10,000 - 15,000 fish (Fretwell, pers. comm.; Woody, pers. comm.). Almost this level of accuracy has been attained at the Great Central Lake installation under ideal operating conditions and at migration intensities below 1,000 sockeye/hr (accuracy of ± 5%). At higher fish passage rates (up to almost 7,000 sockeye/hr) accuracy has occasionally been observed as low as -25% for a few hours during peak migration periods (5 and 105). It should be noted that the Seton Creek unit operates with only one tunnel module near the water surface, while that at Great Central Lake has four tunnel modules near the fishway floor to accommodate potentially greater peak migration intensities. It may be that the greatest accuracy at peak migration rates is attainable with the minimum number of counting tunnels (one module or four tunnels) because each tunnel is then scanned for fish passage at the maximum frequency, though minor delays in fish passage might result at peak migration intensities above 3,000 - 5,000 fish/hr. There are also behavioural differences between pink (Seton Creek) and sockeye (Great Central Lake) salmon; the latter are more prone to group passage and overlap in the tunnels, this being the major source of passage-rate dependant counting error. The counter at Sproat Lake has been unstable and less accurate to date due to installation, maintenance and operational problems which have not yet been eliminated completely; accuracy here has been variable and is being improved (5).

Precision of the Pulsar counter is considered to be high at both Seton Creek and Great Central Lake on an hourly total basis, particularly at fish migration rates below about 1,000 fish/hr. However, precision has not yet been critically examined and a procedure for setting confidence limits to final escapement estimates has not yet been established. Efforts to develop this information are underway and it is expected to be forthcoming for the Great Central Lake installation shortly.

Relatively few escapement estimates have been produced to date using this system, and none have been estimated by other techniques for comparison. This is largely because application of this equipment has been limited to fishway and weir installations, and because day-to-day determination of accuracy from visual counts indicates greater accuracy than most other techniques available for comparison. The method is usually applied as a cost-effective measure to reduce manpower requirements and eliminate the expense of more extensive enumeration attempts, as well as to improve accuracy of escapement estimates, so that comparison studies are unlikely to occur.

2. Bendix Side Scan Sonar Fish Counter

Methodology

The Bendix side scan sonar system and its predecessor, the transducer array sonar system, were developed by Bendix Corp. in association with the ADFG to provide a means of eletronically enumerating bank-oriented upstream spawning migrations of salmon in both clear water and glacially occluded Alaskan rivers. The side scanning unit represents a considerable improvement over the earlier array system in terms of adaptability to varying stream conditions and fish species, ease of calibration, sensitivity, accuracy, and false count (debris) rejection (106 and 109).

The side scan system consists of a single transducer mounted on the inshore end of a 20 m long by 20 cm diameter submersible aluminum-pipe boom or 'substrate', a computer/counter/printer unit for signal analysis and output of fish counts, and a solar panel for charging the internal 28 amp. hour battery. The artificial substrate is assembled on shore and placed in the river, initially parallel to the bank, with the end bearing the transducer downstream. After this end is anchored in position, the upstream end is swung out from the bank and downstream until the substrate floats perpendicular to the current, where it is held in place by a cable from the offshore and submerged into operating position by flooding the boom (107 and 109). A small mesh net is hung from the downstream side of the boom and weighted to block any gaps between the boom and the uneven streambed, which might otherwise permit fish to pass beneath the substrate without being counted.

Fish are counted acoustically as they swim upstream over the artificial substrate within 20 m of the river bank, thus passing through the narrow (2° - 4°) conical ensonified beam immediately above the substrate. Discrimination between fish and debris is accomplished on the basis of the number of echoes returned from each target. The pulse repetition rate is adjusted in relation to fish swimming speed so that a fish passing upstream over the substrate intercepts and returns a sufficient number of pulses to be counted, while most water-borne debris carried downstream does not. The unit may be adjusted for accuracy from visual observation as fish pass over the substrate, where this is possible, but optimum accuracy and calibration are obtained using an oscilloscope to compare target echoes with machine counts. Frequent determination of the calibration factor provides a check on accuracy throughout operation and produces an error correction curve of calibration factor vs. time which can later be used to adjust machine counts throughout the migration period (109 and Bendix information pamphlet, unpublished).

Fish counts are accumulated individually for 12 - 16 adjacent sectors along the substrate, and sector totals are printed on a paper strip at preset intervals (usually hourly) along with other information, including presence of debris. Oscilloscope calibration data can also be recorded automatically on magnetic tape for a short period each hour and later displayed on an oscilloscope for checking of calibration factors before data adjustment (109). In addition, full testing of all circuits, including transducer operation and alignment, occurs automatically twice each day and on command, with results printed out to permit rapid problem isolation (106).

Some species composition information may be obtained directly from a separate counter total printed for large fish (e.g. chinook), as determined on the basis of relative target signal strength, but this information is more reliably obtained for all species from escapement sampling procedures. This is accomplished either with fishwheels (particularly in glacial rivers where gear avoidance is minimal), or with set or drift gillnets, beach seines or trip seines (the latter being the least species and size selective) (104). The catches are also generally sampled to provide information on biological characteristics of the escapement (e.g. age, length, weight and sex).

Areas of Use

The Bendix side scan sonar system and its predecessors were initially developed for use in clear and particularly glacially turbid Alaskan rivers. Upward-looking transducer array sonar counters have been in use since 1968 on some systems discharging into Cook Inlet and Bristol Bay, and are still being used where river conditions are suitable. Side scanning sonar counters have become widely used in these areas since becoming available in 1976, and have replaced array-type counters on some systems. In 1978, there were 17 side scan units either in operation in Alaska or on order by ADFG for the 1979 season, and expansion to the Copper River in Prince William Sound and a number of other systems was planned (106).

The side scan counter does not appear to have been used to any extent outside Alaska to date. However, one such system has recently been ordered by DFO (Pacific Biological Station, Nanaimo, B.C.) and is scheduled for testing in B.C. in 1982.

Effective Use and Problems

The Bendix sonar salmon counters, and particularly the side scan unit, are effectively used to produce total estimates of salmon escapement when salmon upstream migration is bank oriented (as is often the case in large river systems). On systems wider than 20 m, where migration follows both banks, two systems are employed on opposite banks at a point where the entire river flow is contained in one channel (104 and 107). This method is particularly effective for enumerating sockeye and pink salmon, which characteristically migrate in slower water along streambanks and avoid faster moving currents in centre stream, and is equally effective in clear or glacially turbid waters. The sonar counters are usually less effective when enumerating coho, chinook or chum salmon, because migration of these species is not strongly bank oriented and many fish pass offshore beyond the range of the sonar beam. In these instances counts of fish passing over the artificial substrate are considered an index of escapement, and accurate escapement estimation requires knowledge of the proportion of fish moving offshore beyong the sonar counter (104; Tarbox, pers. comm.).

The side scan unit has been effectively used to enumerate sockeye runs ranging from 50,000 to 500,000 fish, at peak migration intensities up to 120,000 sockeye/day. Saturation of the counter may occur at fish passage rates above 20,000/hr, as the fish mass absorbs sonar pulses, though migration at this intensity is uncommon. At fish passage rates below 3,000/day accuracy decreases due to difficulty of calibration at low fish densities, and constant monitoring is required (Tarbox, pers. comm.).

The major problems encountered during operation of the side scan counter involve site selection, avoidance of the artificial substrate and/or offshore distribution of upstream migrants, detection and removal of debris fouling on the substrate, false counts due to air entrainment, current strength and milling of spawning fish which pass back and forth over the substrate. Most of these relate in some degree to site selection and can be largely avoided by careful choice of the installation site, though this choice may be limited by channel braiding, rapids, boat use, and nearshore streambed topography.

Site selection is most limited in heavily braided systems, as counting should take place where the river flows through a single channel, so that all fish may be intercepted (104). Rapids immediately upstream are undesirable as they cause air bubbles to be entrained in the water, which may produce false counts as they pass through the sonar beam. Power boat operation also causes air entrainment with similar results, and areas frequently used by boats should be avoided (101).

Substrate avoidance may occur on occasion, particularly in clear water systems, but apparently is uncommon except at the beginning of migration and thus is not of great concern (104). If this problem persisted, or if fish migration was distributed beyond the 20 m range of the counter (as may occur in shallow gently sloping shoreline areas), the site would be unsuitable and the counter should be relocated in deeper water, preferably to a point where the streambed drops off sharply for several feet and fish pass close to the bank (104). Temporary offshore migration may occur at otherwise optimal locations as a result of extreme low water levels (Tarbox, pers. comm.).

Debris is an ongoing problem that cannot be completely avoided, and any in-stream structure will tend to accumulate some debris. It is the general practice to raise the artificial substrate for inspection and removal of accumulated debris every 1 - 2 days, or whenever the counter print-out indicates debris is present in the sonar beam (104, 107 and 109). Free-floating debris is not usually a problem, as echoes from small debris passing through the sonar beam with the current are rejected if current speed is above 1.1 m per second (Bendix information pamphlet, unpublished).

Limitations of use in conditions of high river flows due to current strenth are uncertain, though the counter has been successfully used at discharge levels ranging from 7,000 cfs to 40,000 cfs (Tarbox, pers. comm.).

Repeated passage of the same fish back and forth through the sonar beam due to milling of spawning fish in the vicinity of the counter will obviously cause overcounting with regard to upstream migration, and is a potential problem to be considered during site selection. The problem can best be avoided by locating the counting site some distance from known spawning areas or suitable spawning gravel, whenever possible.

Accuracy, Precision and Technique Comparison

Accuracy of the side scan counter is determined by the precise adjustment of the machine for fish swimming speed, which determines the appropriate pulse repetition rate for most effective enumeration (107). Under optimum conditions of moderate fish abundance, stable current and fish swimming speed and good visibility, accuracy of the machine has been found to be better than 95%. On the Anvik River the counter was tested in conjunction with a counting tower during the sockeye run, and the machine total was 98.6% of the tower count. A similar test on the Russian River at an opening in a weir resulted in a machine count of 97.5% of the visual count through the weir (106). A third clear water test in the Wood River yielded a machine count of 95.3% of the tower count. It was found during this test that development of a calibration factor by hand counting echoes from an oscilloscope screen could improve accuracy, by allowing adjustment of machine counts to compensate for slight over- or under-counting resulting from variations in fish swimming speed. After calibration and adjustment of machine counts, the final estimate was within one percent of the tower count (106). Under conditions where all fish travel through the sonar beam (sockeye and pink salmon), the adjusted machine counts are therefore considered accurate estimates of escapement, probably differing from the actual value by less than 5 - 10% (Tarbox, pers. comm.).

In the glacially occluded Kenai River a test involving pink salmon indicated an accuracy of only 90% of the associated weir count, due to lower fish migration density and some offshore movement resulting from low water levels (Tarbox, pers. comm.). However, the ability to accurately count pink salmon was demonstrated, though they represent a considerably poorer acoustic target than sockeye or the other salmon species.

In 1980, extremely large escapments of all salmon, and particularly sockeye and pinks, occurred in the Nushagak River system, causing side scan sonar counts to be only about one third of tower counts for all species. This was the result of extremely intense migration causing both saturation of the counter and considerable offshore migration beyond the sonar beam (104). However, machine counts were considered an accurate index of total escapement, and percentage composition values for chinook, coho and chum salmon from machine counts and net samples were all within 1% of estimates from aerial and tower counts (104).

Side scan sonar estimates for sockeye migration have been found to correlate well with estimates obtained from test fishing operations for the Nushagak River, with r = 0.8986 in 1979 and r = 0.8465 in 1980 (104). In addition, sonar estimates have shown high correlation with escapement estimates from escapement index methods, with r values ranging as high as 0.99 (107).

3. Bendix Fan Scan Sonar Fish Counter

The fan scan sonar unit is being developed by Bendix Corp. in conjunction with the ADFG to meet the need for a method of enumerating escapements of all species of salmon to large river systems, where existing methods of acoustically enumerating bank-oriented migration are inappropriate. The system consists of one or more transducer pods, a shore-based computer/counter unit and an interconnecting impulse cable. A series of transducers on each pod, located on the river bottom in deep water, emits sonar beams over a vertical 184° arc or 'fan' with a radius of 15 m. One pod can thus effectively monitor acoustically a 30 m wide by 15 m deep semicircular cross section of a river. Larger cross sectional areas can be monitored by using two or more transducer pods spaced at 30 m intervals across the width of the river (Nickerson, pers. comm.).

This system has been undergoing tests during 1980 and 1981 on the Kuskokwim River in Alaska by the ADFG, for enumeration of chinook, chum, coho and sockeye. Results of these tests will be summarized in a report currently being prepared for publication. To date, results on the Kuskokwim River have been poor, and indicate that this river may not be a suitable location for effective use of the fan scan system. The major problems have been fouling of the impulse cable on bottom debris while moving the sonar pods, and calibration of the unit. These problems are related, since bottom fouling has resulted in parting of the cable on several occasions, and recalibration is required each time the cable is replaced. As a result it has been difficult so far to obtain agreement between oscilloscope fish counts and printed machine counts. In 1982 the fan scan counter is to be further tested in the Yukon River (in conjunction with tests of the Biosonic Doppler sonar counter), where it is hoped these problems can be overcome (Nickerson, pers. comm.).

As with all electronic fish counting methods, fan scan sonar counts must be apportioned by species before escapement estimates can be produced or compared. Species composition is obtained by appropriate methods of test fishing during counting periods, and the total sonar count is apportioned on the basis of relative abundance of each species for the appropriate period (Nickerson, pers. comm.).

4. Biosonics Doppler Sonar Fish Counter

The Doppler sonar counter is being developed by Biosonics Inc. to meet requirements similar to those outlined previously for the fan scan system. The system employs the Doppler effect to distinguish between upstream movement of fish and downstream movement of debris. A pulsed acoustic beam is aimed downstream and changes in frequency of the reflected echoes indicate the direction of movement of a target, either towards or away from the transducer.

The system is still under development, and has undergone initial tests by the manufacturer in the Quinalt River in Washington. Details of the system components were not available at this writing, and application of this system in estimating salmon escapements has not yet been fully tested. Field tests are planned for 1982 in the Yukon River (Nickerson, pers. comm.).

HYDROACOUSTIC (SOUNDER) SURVEYS

Methodology

Hydroacoustic surveys are made from vessels following established transects over migrating or holding salmon populations (Woody, pers. comm.). The number of target echoes is expanded to estimate salmon abundance in the area represented by the transects (111 and 112). Surveys are generally made at night at which time the salmon are dispersed at mid depths rather than tightly schooled, and therefore most effectively enumerated (113).

Sockeye escapement past the Fraser River commercial fishery is estimated from daily hydroacoustic surveys made at Mission, B.C. (Woody, pers. comm.). The daily escapement estimate is produced by integrating target density and rate of travel, and these in-season estimates provide an interactive management tool for regulation of the commercial fishery.

The FRI has tested the use of sounder surveys in the estimation of potential escapement of adult sockeye in Lake Washington (111 and 112). Transects were established which were thought to represent the distribution of adult sockeye in the lake. Counts were made of echoes exceeding a threshold amplitude - a strategy designed to exclude the smaller resident fish from enumeration. Counts of large resident fish, enumerated before sockeye immigration occurred, were subtracted from the total abundance estimate.

Sounder surveys were made in Rivers Inlet to test the feasibility of estimating sockeye escapement in the inlet (113). Separate surveys were made in holding and immigration areas since at no time was the entire sockeye population present in the holding area.

The DFO tested a method of back-calculating the adult sockeye escapement to Nimpkish Lake in 1980 from a hydroacoustic estimate of the juvenile brood population in the lake in 1981. An egg to fry survival rate, the potential egg deposition/female, and the sex ratio of the adult population were applied to the estimate of juvenile abundance to back-calculate adult escapement (Hyatt, pers. comm.).

Areas of Use

Hydroacoustic surveys are generally used to estimate salmon escapement past a commercial fishery, and are usually carried out near the mouth of major rivers supporting large salmon populations. Information available during the present literature survey and discussed herein concerns sounder surveys on the Fraser River (Woody, pers. comm.), Lake Washington (111 and 112) and Rivers Inlet (113).

Effective Use and Problems

Hydroacoustic surveys are rapid, relatively inexpensive, and require few manhours to complete (112; Hyatt, pers. comm.). These surveys provide in-season estimates of escapement for use in the management of a fishery (Woody, pers. comm.). The FRI made a series of hydroacoustic surveys to estimate potential sockeye escapements which were necessary for the regulation of commercial and sport fisheries on Lake Washington (111 and 112). The technique was judged to be effective for sockeye in Lake Washington because the entire population resides in the lake before completing their migration to the spawning grounds. Tests in Rivers Inlet indicated that hydroacoustic surveys can provide reliable escapement estimates for use in managing the commercial sockeye fishery (113).

Thorne (112) outlined three sources of error associated with hydroacoustic surveys in Lake Washington: 1) calibration of the acoustic system introduced a minimal counting error; 2) error in the estimation of the sonic detection volume was minimal and can be reduced by increasing the sonic pulse repetition rate; 3) resolution of resident fish from adult sockeye on the basis of target strength was difficult and was probably the greatest source of counting error.

A major problem associated with the estimation of Rivers Inlet sockeye abundance was the constant immigration of sockeye to the holding areas and gradual emmigration to the spawning grounds (113). Since the entire population was not available at any one time for enumeration, surveys of the holding area were supplemented by surveys of an assumed immigration area, though holding areas and immigration areas were not well delimited.

Comparative analysis of tide levels and sockeye abundance estimates indicated that more fish are counted during rising tides than during falling tides.

Sampling error also resulted from imprecise estimation of the sonic detection volume and the masking of surface area target echoes by tracings of density lines between water layers of differing salinity.

Accuracy, Precision and Technique Comparison

Woody (pers. comm.) noted that the level of accuracy of daily hydroacoustic estimates of Fraser River sockeye was dependent upon the magnitude of the daily passage. At passage rates of less than 10,000 fish/day hydroacoustic surveys generally overestimate escapement and estimation error may be as high as 50%. For passage rates up to 100,000 fish/day, hydroacoustic surveys underestimate escapement with an estimation error of approximately 10%. Daily errors tend to cancel during a season such that the error associated with a total escapement estimate is approximately ± 10%.

Thorne (112) found that hydroacoustic estimates of potential sockeye escapement in Lake Washington from 1972 to 1975 compared well with lock counts and with tower counts combined with spawning ground surveys. Mean escapements estimated by the three techniques over the four years equalled 206,000, 210,000 and 206,000, respectively.

Hydroacoustic estimates of migrating sockeye in Rivers Inlet for each year in the period from 1968 to 1970 were reported as a wide range of values corresponding to minimum and maximum estimates of sounder detection volume (113). Hydroacoustic surveys in the inlet underestimated escapement relative to spawning ground surveys (deviations ranged from

11% to 270%). The relative vertical distribution of sockeye in the inlet varied with the density of the escapement such that a greater proportion of the stock was enumerated at high densities than at low densities.

The techniques used to produce escapement estimates to which hydroacoustic estimates of sockeye in Lake Washington and Rivers Inlet were compared were subject to inaccuracies (112 and 113). Thus differences between escapement estimates of the same population cannot be assumed to be entirely due to error in the hydroacoustic estimate.

The DFO back-calculated sockeye escapement from a hydroacoustic estimate of juvenile brood population in Nimpkish Lake while testing the effects of their lake enrichment program on sockeye returns (Hyatt, pers. comm.). The hydroacoustic estimate of fry abundance in the lake is probably accurate to within ± 25%. Variation associated with the conversion factors used in the calculations introduced further error into the escapement estimate. Egg to fry survival rate is dependent upon environmental conditions on the spawning grounds and therefore varies between systems. A range of survival rates (1.5 to 4.5%) has been found in various systems; the value applied for Nimpkish Lake (4%) was that obtained for a lake with similar spawning conditions. Accuracy of the final escapement estimate produced (142,000 sockeye) is unknown, for lack of a more reliable estimate for comparison, but would be ± 25% at best, and could be considerably lower due to error in the conversion factors, particularly when these are not determined directly.

CATCH PER UNIT EFFORT AND TEST FISHING

Methodology

Catch per unit of effort (CPUE) has been widely used as an index of the relative abundance of a fish population (12 and 14). Indices of total salmon abundance and of escapement past a fishery have been calculated from catches by test fisheries and by commercial and subsistence fisheries. This information is necessary to permit forecasting of preliminary abundance estimates on which to base commercial fishery management decisions, before salmon enter the rivers and escapement counts become available. Test fishing is carried out with standard gear according to a standard sampling schedule such that a salmon run is sampled consistently from year to year.

Fraser River chum gillnet test fishing was initiated in 1961 (119). A daily CPUE index of escapement, expressed as catch/1000 fathom-minutes, was produced from two 30-minute drifts at low tide. A similar CPUE index was produced for the Nass River sockeye run (125). Fraser River sockeye test fishing indices are accumulated throughout the duration of a run (Woody, pers. comm.). The cumulative CPUE to a given point in a test year is related to a regression of total CPUE and total escapement (from historic data) to estimate in-season escapement. A similar method was used to estimate in-season chinook escapement in the Columbia River (122).

In Bristol Bay, the ADFG carry out test fisheries for sockeye, chum and pink salmon (126). Daily indices of total abundance, expressed as fish caught/100 fathom-hours (or "index points"), are produced from catches made by a drift gillnet set along an offshore transect near or beyond the outer fishing boundary. Inshore test fishing, carried out with set gillnets in the lower sections of Bristol Bay rivers inshore of commercial fishing areas, produces daily indices of escapement similarly expressed in index points. Several methods may then be used to convert accumulated index points from each test fishery to estimates of salmon abundance (before commercial harvest) and escapement from the fishery. Long term prediction models of catchability have been developed for each offshore and inshore test fishery to permit adjustment of index values for variation from year to year in age structure and length frequency. These models account for a large proportion of the variation between index values and salmon abundance resulting from yearly variations in catchability, due to variable mean fish size (as length or weight) and the size selectivity of test fishing gillnets(126).

Initial escapement forecasts at the beginning of a run are determined from the catchability model, in which historic values of cumulative mean length have been regressed against seasonal values of tower count per index point. The cumulative mean length of fish caught in the current season is applied to this regression to obtain an expected value of tower count per index point, which is multiplied by the current cumulative test fishing index to produce an escapement estimate. When lag time from the test fishery area to the counting tower has been determined later in the run, by tagging and/or escapement curve matching, a second independent escapement estimate is made by relating the actual cumulative escapement from tower counts to the associated cumulative test fishing indices (126).

The CPUE of commercial or subsistence fisheries may be used as a comparative index of abundance if it is assumed that the fishermen's ability to sample the population remains constant from year to year (117). In analyses of historic Columbia River chinook catch records, Silliman (121) and Gangmark (117) used CPUE values for fishermen active in the fishery for a number of years to indicate broad changes in the size of the return. Mathiesen calculated past sockeye escapements to the Nushagak River, Alaska, by applying coefficients of catchability and fishing effort to catches of each size range of sockeye (118). The FRI is presently examining the possibility of using the catch of chinooks by the Nushagak River (Alaska) subsistence fishery as an in-season index of escapement. A scaling factor, taken from a regression of CPUE (subsistence fishery) and total escapement (aerial spawning ground survey), was used to calculate in-season escapement.

Areas of Use

Test fishing is carried out on or adjacent to major river systems requiring in-season escapement estimates for the management of an associated commercial fishery. The technique is used to some degree for preliminary escapement prediction and fishery management with most large salmon runs in Alaska, B.C. and Washington. Major systems discussed in this summary are the Columbia River, Fraser River, Nass River and rivers of the Bristol Bay area.

Effective Use and Problems

Test fishing provides a 'real-time' index of abundance for use in the management of commercial salmon fisheries (Woody, pers. comm.). Fisheries are managed such that seasonal escapement goals are achieved. To be effectivel used, test fishing techniques must consistently sample a salmon population from year to year in proportion to the otherwise unobstructed passage of fish through the test fishing area. Error in escapement estimates derived from test fishing indices are generally a result of the disproportionate sampling of runs from year to year (Woody, pers. comm.).

An increase in the efficiency of the Nass River sockeye test fishery was attributed to the physical presence of log dumping grounds concentrating the sockeye migration at the test site (125). High water levels interfered with test fishing in the Nass River, while Stockley (122) noted that low, clear water decreased the efficiency of gillnets in the Columbia River.

ADFG attributed a large proportion of the variability in the ratio of tower counts/test fishing index in past years to variations in the catchability of the salmon populations from year to year. The catchability model described in the methods section was designed to compensate for this variation.

CPUE of the subsistence fishery in the Nushagak River has provided a reasonable indication of changes in the magnitude of chinook escapement; however, there were large differences in the total escapements calculated from the subsistence fishery and those observed during aerial spawning ground surveys (115). It was speculated that this error was due to variations in the catchability of the run. Such variations can result from changes in the age and size composition of the salmon run or changes in the mesh size and dimensions of gillnets used in the fishery. Small subsistence fisheries may also be limited by variable water level and their ability to handle catch, and are therefore unsuitable as escapement indices (2).

Escapements estimated from historic commercial fishery catch data are subject to many sources of error (118). Changes such as increases in gear efficiency and reduction in fishing time due to closures decrease the precision of year to year comparisons (117 and 121).

Accuracy, Precision and Technique Comparison

Test fishing indices for the Fraser River are more precise indicators of seasonal escapement than of daily fish passage (Woody, pers. comm.). Unbiased errors associated with the daily indices cancel each other over the duration of a season.

Palmer (119) noted a high correlation (r= + 0.9) between seasonal test fishing indices and total escapement of chum salmon in the Fraser River (1963-1969). Differences between calculated escapements and actual escapements produced by mark/recapture techniques ranged from -27% to +37%.

WDF reports (116, 122, 123 and 124) on the Columbia River chinook test fishery for the years 1967, 1969, 1971 and 1973 indicate there was a low correlation between the test catch and actual upriver escapement (range in r: +0.339 to +0.691). The confidence intervals about regressions of test catch and escapement ranged from 9% to 39% for the years discussed.

In 1980, the Bristol Bay area in-season cumulative test fishing indices paralleled the tower counts, indicating the indices provided a reasonable in-season estimate of run magnitude(126). Seasonal calculated escapements based on catchability models for the Kvichak, Egegik and Ugashik Rivers underestimated escapement by 75%, 4% and 14%, respectively (though the Kvichak River estimate was terminated prematurely).

CPUE from the Nushagak River subsistence fishery provides a reasonable index of relative chinook abundance, but calculated seasonal escapements differ greatly from actual escapements (115). In 1980, the observed spawning ground escapement was 145,000 while the calculated escapement was 88,096. Further error results from the inaccuracy of spawning ground escapements, used to calibrate the subsistence fishery CPUE. An intensive baseline survey of spawning ground escapement is required to increase the overall accuracy of the technique.

ANNOTATED BIBLIOGRAPHY

The annotated bibliography lists references dealing with salmon escapement estimation which were obtained either from the literature search or from scientists interviewed during the information gathering process.

References are arranged alphabetically by author within sections corresponding to techniques discussed in the main body of the text. These sections are as follows:

A. General - includes references dealing with general statistical analysis of techniques; papers where several techniques are described and/or evaluated, with approximately equal emphasis placed on each technique; and references not fitting into other divisions.

B. Foot Surveys

C. Snorkle and River Floats

D. Dive Surveys

E. Observation Towers

F. Aerial Counts

G. Photographic Enumeration

H. Fence Counts

I. Mark/Recapture

J. Index Streams

K. Electronic Counters

L. Hydroacoustic (Sounder) Surveys

M. Catch Per Unit Effort and Test Fishing

N. Addendum

Each reference is numbered, and includes the paper's source, an annotation and, for most papers, a short note.

The annotation consists of the author's abstract or summary, where available. If no published abstract was available, pertinent sections from an introduction were included or a brief statement regarding the techniques discussed in the paper was prepared.

The 'notes' section has been included in the annotation to indicate what information the paper contains pertinent to escapement estimation but not mentioned directly in the annotation. This section was included to assist users in determining whether a paper is appropriate to their needs. Information has been categorized into four types for purposes of these notes:

1) methodology - technique descriptions.

2) problems - limitations to use of a technique, and/or suggested improvements.

3) evaluation - use of technique to determine population size; mathematical evaluation; description of precision and/or accuracy; comments on effectiveness of technique.

4) comparisons with other techniques - comparison of population estimates made using two or more techniques.

Many papers deal with more than one technique, therefore a -referencing system was developed. Each paper has been fully refer- only once, under the primary technique discussed in the paper.

To assist reference users in obtaining all information on cific technique, a "see also reference numbers..." statement has included at the end of each section in the bibliography.

A. GENERAL

1. Anon. 1962. Supplementary information on salmon stocks of the United States: Return-escapement relationships: salmon. Int. North Pac. Fish Comm. Bull. 10: 67-72.

This report contains return-escapement data and analyses for two United States salmon populations: Prince William Sound pink salmon and Karluk River red salmon. As return-escapement data for other salmon populations are compiled, checked for validity and completeness and analyzed, they will be presented in accordance with the Ad Hoc Committee's request.

Notes - contains information on evaluation.

2. Atkinson, C.E. 1944. The problem of enumerating spawning populations of sockeye salmon. Int. Pac. Salmon Fish. Comm. Annu. Rep. 1943: 37-44.

The problem of enumeration of spawning sockeye salmon is much less complex than that of measuring the usual fishery stock. The total run of spawning salmon may be divided into the three components: (1) fish still to come, (2) live fish present and (3) dead fish. The best measurement of a total run of salmon is based upon either the counts of incoming fish or the total dead. The live counts, on the other hand, are dependent upon the lengths of time between arrival and death. A brief discussion of several methods for the enumeration of spawning salmon has been given and the inherent sources of error in each have been pointed out.

Notes - contains information on methodology, problems and evaluation.

3. Brett, J.R. and D. MacKinnon. 1952. Some observations on olfactory perception in migrating adult coho and spring salmon. Fish. Res. Board Can. Prog. Rep. Pac. Coast Sta. 90: 21-22.

Observations and experiments testing the migratory behavior of coho and chinook salmon adults and the effects of olfactory stimulation were carried out at Stamp River fishway in 1952.

Notes - contains information on problems.

4. Cooke, K.D. and N.B.F. Cousens. 1981. Results of adult sockeye enumeration and sampling program 1980. J.C. Lee and Associates Ltd. Report Series 2-2: 167 p.

Adult sockeye salmon (*Oncorhynchus nerka)* returning to ten British Columbia lakes to spawn were enumerated and sampled for biological information as part of the ongoing monitoring and evaluation phase of the Lake Enrichment Program.

Sockeye spawning in five lakes located in northern coastal B.C. (Kitlope, Lowe, Bonilla, Curtis and Devon Lakes) were enumerated using streambank visual counts. Aerial surveys and float techniques were also employed on most of these systems.

Sockeye spawning in five lakes located on Vancouver Island were enumerated using a variety of estimation techniques.

Sockeye migrating to Hobiton Lake were enumerated by counting them as they passed through a chainlink fence constructed on the Hobiton River.

Escapements to Sproat and Great Central Lakes were monitored continuously throughout the run using two conductivity-type electronic fish counters. Calibration of the counters and adjustment of machine counts for error correction were accomplished from periodic visual counts to monitor counter accuracy throughout the migration period.

Sockeye spawning in Clemens Creek at the head of Henderson Lake were enumerated by streambank visual counts.

Sockeye escapement to Kennedy Lake was enumerated using aerial surveys (float plane and helicopter), as well as by visual counts. SCUBA surveys were conducted at the main spawning areas to assess the extent of spawning activity below the limit of visibility from the surface.

Notes - contains information on problems, evaluation and technique comparison.

Cousens, N.B.F. 1982. Results of adult sockeye enumeration and sampling program 1981. Section two. J.C. Lee & Associates Ltd. Report Series 2-5: 187 p.

Adult sockeye salmon (*Oncorhynchus nerka)* returning to three Vancouver Island lakes to spawn were enumerated and sampled for biological information as part of the ongoing monitoring and evaluation phase of the Lake Enrichment Program.

Escapement to Great Central and Sproat Lakes was monitored contiuously throughout the run using two conductivity-type electronic fish counters. Calibration of the counters and adjustment of machine counts for error correction were accomplished from periodic visual counts to monitor counter accuracy throughout the migration period. Sockeye escapements and partial escapements were estimated from machine counts for the period June 1 to October 1, 1981.

Sockeye spawning in Clemens Creek, at the head of Henderson Lake were enumerated by two methods - streambank visual counts and the Petersen mark-recapture technique. Results of the two methods are compared.

Notes - contains information on problems, evaluation and technique comparison.

Fredd, L.C. 1966. Review and analysis of fish counts, counting techniques and related data at Corps of Engineers dams on the Columbia and Snake Rivers. U.S. Army Corps of Engineers, Fish. Eng. Res. Program Prog. Rep. 3: 91-95.

Discrepancies in fish counts between two dams on the Columbia River were observed. The relative influences of counting error and fish loss on these discrepancies are analyzed.

Notes - Contains information on problems.

7. Fry, D.H., Jr. 1961. King salmon spawning stocks of the California Central Valley, 1940-1959. Calif. Fish Game 47(1): 55-71.

The fish counts of Central Valley salmon were started in 1937 as a result of the plans to build Shasta Dam. Enumeration has been by the California Department of Fish and Game, the U.S. Fish and Wildlife Service and (less extensively) by the U. S. Bureau of Reclamation. Methods used have included fish ladder counts, fish weir counts, estimates of spawners, tag and recovery calculations, and (more recently) redd counts from the air. Many counts have been incomplete because counting weirs could not be kept fish-tight or were washed out by floods. In the early years most help was relatively inexperienced and gave estimates which were too low. Tag and recovery calculations gave satisfactory results on the American and Stanislaus Rivers, but results on the upper Sacramento River have been much less satisfactory. Aerial redd counts seem to have possibilities but have not yet been standardized against fish ladder counts.

Notes - contains information on problems and evaluation.

8. Hallock, H.J. and D.H. Fry, Jr. 1967. Five species of salmon, *(Oncorhynchus)* in the Sacramento River. Calif. Fish Game 53(1): 5-22.

King salmon *(O. tshawytscha)* are abundant in the Sacramento-San Joaquin river system of California, but other species of salmon are uncommon or rare. To determine the occurrence and abundance of the less common species, all such fish encountered during routine king salmon studies and hatchery operations were examined and recorded. From 1949 through 1958, a total of 130 chum, pink, sockeye and silver salmon *(O. keta, O. gorbuscha, O. nerka, and O. kisutch)* was identified. All were from the Sacramento, its tributaries, or the Sacramento-San Joaquin Delta. No salmon other than kings were found in the southern tributaries of the Delta. These 130 fish do not include planted silver salmon, which began entering the rivers in 1956. After this planting was discontinued, silver salmon rapidly declined and have almost vanished from the Sacramento. Highly tentative estimates were made of the numbers of chum, pink and sockeye salmon occurring in the Sacramento River system. It was concluded that these three species are present as very small spawning runs, but that silver salmon were so scarce that they should be regarded as strays.

Notes - contains information on evaluation.

9. Johnson, D.R. 1948. Size of the Willamette River spring chinook salmon run, 1947. Oreg. Fish Comm. Res. Briefs 1(1): 18-21.

Until 1946 the escapement of migrating salmon into the upper Willamette River was unknown. All of the spring chinook salmon escaping into the Willamette's tributaries pass through Oregon City Falls, except a small number that enter the Clackamas River. Enumeration is possible at the falls because of a fishway constructed prior to 1946.

Evaluations of escapement and catches are included.

Notes - contains information on problems and evaluation.

10. Lagler, K.F. 1968. Capture, sampling and examination of fishes. p. 7-45 In: Ricker, W.E. (ed). 1968. Methods for assessment of fish production in fresh waters. Int. Biol. Prog. Handbook 3: 313 p.

Methods of capture and sampling are described and discussed with emphasis on randomness of sampling.

Notes - contains information on problems and evaluation.

11. Rich, W.H. 1942. The salmon runs of the Columbia River in 1938. U.S. Fish Wildl. Serv. Fish. Bull. 50(37): 103-147.

Studies were carried out to assess salmon runs in the Columbia River prior to construction of the Grand Coulee Dam. Data from 1938 are presented in this paper.

Migrating adults were enumerated at fish ladders at the Bonneville and Rock Island dams. Catch data from commercial fisheries were added to escapement numbers to obtain estimates of total stock.

Possible means to preserve the runs are discussed briefly.

Notes - contains information on problems.

12. Ricker, W.E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can. Bull. 119: 300 p.

This bulletin has been prepared to meet a need for a summary of the computations used in estimating statistics of population size and exploitation - particularly those most applicable to fishes. Contributions to this field have appeared rapidly in recent years, and a review should help to relate the ideas and procedures of the various workers. I have included most of the basic procedures and important variants which have come to my attention through 1956. Worked examples are given of those which have been most used, or which seem to offer promise of wide usefulness.

13. Ricker, W.E. (ed). 1968. Methods for assessment of fish production in fresh waters. Int. Biol. Prog. Handbook 3: 313 p.

A collection of papers providing instruction in and discussion of methods of assessing fish production.

14. Robson, D.S. and H.A. Regier. 1968. Estimation of population number and mortality rates. p. 124-158 In: Ricker, W.E. (ed). 1968. Methods for assessment of fish production in fresh waters. Int. Biol. Prog. Handbook 3: 313 p.

Methods of estimating population numbers are described and discussed. These include mark and recapture, monitoring catch and fishing effort of an exploited population, correlated population enumeration and direct enumeration.

Methods of estimating mortality rates include catch per unit effort and monitoring age composition of the catch.

Notes - contains information on problems and evaluation.

15. Straty, R.R. 1960. Methods of enumerating salmon in Alaska. Trans. 25th N. Am. Wildl. Nat. Resour. Conf.: 286-297.

The purpose of this paper is to discuss the various methods currently used or being developed by the Bureau of Commercial Fisheries in Alaska for enumerating adult and juvenile salmon.

Successful management of Alaska's salmon resources is dependent upon accurate prediction and subsequent assessment of the size of salmon runs returning to spawn. Predicting the magnitude of returning runs and manipulating the catch and escapement require a continuous inventory of salmon during various stages of their life history.

Five species of Pacific salmon are fished commercially in Alaska: king, *Oncorhynchus tshawytscha;* red, *O. nerka;* pink, *O. gorbuscha;* coho, *O. kisutch*; and chum, *O. keta*. Most of the research effort directed toward perfecting methods of enumeration, however, has centered on the two most commercially important species, red and pink salmon.

Notes - contains information on problems and evaluation.

16. Thompson, W.F. 1962. The research program of the Fisheries Research Institute in Bristol Bay, 1945-58. p.1-36 In: Koo, T.S.Y. 1962. Studies of Alaska red salmon. Univ. Wash. Publ. in Fish. New Ser. 1: 449 p.

A broad overview is presented on the history and direction of fisheries research on the streams draining into Bristol Bay, Alaska during the years 1945-58 and includes plans for future research.

Notes - contains information on problems and evaluation.

B. FOOT SURVEYS

17. Brett, J.R. 1952. Skeena River Sockeye escapement and distribution. J. Fish. Res. Board Can. 8(7): 453-468.

Population estimates made from observations on the number of sockeye salmon in the various spawning streams of the Skeena River, B.C., during the period 1944-48 are presented. The methods used include a fence count at Babine Lake, the most important spawning area, supplemented by stream counting in the other areas and sample tagging at Lakelse. Estimates made at Babine by the latter methods were compared with the fence counts; the stream count estimates were about one-third of th actual number present, whereas estimates from tagging were about twice the actual.

A brief description of the spawning streams of the Skeena is accompanied by a map showing their location. Best estimates of 1946-47 escapements to major spawning areas are: Babine, 480,000; Morice, 70,000; Bear, 42,000; Lakelse, 29,000. These comprise 92 percent of the total for the river system. The area of the spawning beds used by sockeye in the system is about 100 acres, or of the order of 1.5 square yards per spawning pair. The division of the whole run is approximately 45 percent to the commercial fishery, 6 percent to the Indian Fishery, and 49 percent escapement.

Notes - contains information on problems and technique comparisons.

18. Craddock, D.R. 1958. Spawning escapement of Okanogan River blueback salmon (*Oncorhynchus nerka)*, 1957. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 275: 8 p.

The blueback salmon spawning area of the Okanogan River has been surveyed extensively each year since the start of a Canadian flood-control project in 1951. The spawning populations have been estimated and their distribution above Rock Island Dam determined. The large number of fish unaccounted for may be partially attributed to mortalities caused by the high water temperatures existing in the Okanogan River prior to spawning.

The age, length and sex compositions of the 1957 Okanogan River spawning escapement were determined from samples collected on the spawning grounds. Although some delay in passage occurred at the thirteen newly completed drop structures, completeness of spawning was not abnormally low.

The occurrence of large numbers of 3_2's in the spawning population seems to be peculiar to the Okanogan River.

The distribution of fish on the spawning grounds has not changed appreciably since 1952.

Notes - contains information on methodology.

19. 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.

The freshwater life of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeastern Alaska, was studied from the fall of 1963 through the summer of 1968. Additional information on age composition and fecundity of adults returning to Sashin Creek and a nearby stream was collected through the fall of 1972. Some pre-1963 data on coho salmon entering and leaving Sashin Creek were used. Weir counts and estimates of numbers of adult salmon determined from spawning ground counts and mean redd life were poor measures of the total escapement of coho salmon in Sashin Creek; an estimate made from tagging a portion of the escapement and subsequently determining tagged-to-untagged ratios of spawners on the riffles proved to be a more reliable measure. The number of spawning coho salmon varied for the years 1963 through 1967 from 162 to 916; the dominant age group was 4_3. The salinity of the surface water of the estuary of Sashin Creek usually is less than 10-15^{o}/oo; bio-assays of salinity tolerance indicated that coho salmon fry can survive in these salinities. In 1964, 44,000 coho salmon fry migrated to the estuary soon after emergence, although none of the scales collected from returning spawners in subsequent years showed less than 1 year of freshwater residence. Survival curves constructed from periodic estimates of the stream population of juvenile coho salmon for the years 1964-67 showed that mortality was highest in midsummer of the first year of life, when 62 percent to 78 percent of the juveniles were lost in a 1-mo. period. Most coho salmon smolts migrated from Sashin Creek in late May or early June. In the spring of 1968, 1,440 smolts left Sashin Creek - 37 percent were yearlings, 59 percent were 2-year-olds, and 4 percent were 3-year-olds. The average fork lengths were 83 mm for yearlings, 105 mm for 2-year-olds and 104 for 3-year-olds.

Notes - contains information on methodology, problems and technique comparisons.

20. French, R.R. and R.J. Wahle. 1960. Salmon runs - upper Columbia River, 1956-57. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 364: 15 p.

Important runs of salmon pass Rocky Reach Dam site on the Columbia River. The escapement of chinook salmon past Rocky Reach in 1957 was estimated to be approximately 11,000 spring chinook which spawn in the small remote tributaries and 6,000 summer chinook which spawn in the large tributaries of the Columbia River.

Blueback salmon passing Rocky Reach Dam site in 1956 and 1957 accounted for approximately 72 and 60 percent of the escapement passing Rock Island Dam, or about 67,000 fish in 1956 and 43,000 fish in 1957. They spawn in the Okanogan River in Canada. The rate of travel of blueback salmon was 13.5 miles per day.

Notes - contains information on evaluation.

21. Gangmark, H.A. and L.A. Fulton. 1952. Status of Columbia River blueback salmon runs, 1951. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 74: 29 p.

In 1947, 948, 1949, and 1951, blueback salmon *(O. nerka)* spawning ground surveys were made on several tributaries of the Columbia River. A system based on averages was applied to the counts to provide estimates for total spawning populations. Relating these estimates to the square yards of spawning gravel available (as determined by stream surveys), followed by application of a given square-yard gravel requirement for spawning bluebacks provided data to support the conclusions that overcrowding was not a significant problem on streams surveyed.

Notes - contains information on methodology and problems.

22. Mattson, C.R. 1948. Spawning ground studies of Willamette River Spring chinook salmon. Oreg. Fish Comm. Res. Briefs 1(2): 21-32.

Spawning ground surveys were begun during the summer of 1946 and expanded in 1947. They were started during the first week of July and completed by the end of the spawning season (early October). The stream and river surveys were made either by foot or boat.

The purpose of the spawning ground surveys were to determine: (1) the proportion of fish injured prior to spawning in the upper reaches of the various rivers; (2) the cause of these injuries; (3) the cause of mortality prior to spawning; (4) salmon spawning areas in relation to the proposed damsites; (5) the size of the spawning populations in the various river systems; (6) the effects of water temperatures on the salmon; and (7) the effects of hatchery holding areas on the salmon.

Notes - contains information on technique comparisons.

23. Pirtle, R. 1956. Enumeration study Upper Columbia and Snake Rivers. U.S. Army Corps of Engineers, Fish. Eng. Res. Program, Prog. Rep. Nov. 1956: 112-116.

After considerable analysis of possible methods of enumerating runs, methods ranging downward in cost and accuracy from total counts in all tributaries presently supporting runs to a review of present knowledge, the method to be used was evolved. This consisted of two parts:

1. A tagging and recovery study in Snake River by the Oregon Fish Commission to enumerate the runs ascending the Snake, and
2. A spawning ground survey combined with counts at existing structures to determine the final distribution of these runs.

This report is concerned with the second portion of the enumeration study.

Notes - contains information on evaluation.

24. Pritchard, A.L. 1937. The findings of the British Columbia pink salmon investigation. Part I - Introduction and general observations. Biol. Board Can. Prog. Rep. Pac. Biol. Sta. and Pac. Fish. Exper. Sta. 33: 3-6.

A close examination of pink salmon runs at Masset Inlet, B.C. was carried out in 1928 and 1929 to gain insight into the life history of the species.

Notes - contains information on problems.

25. Sheridan, W.L. 1962. Variability in pink salmon escapements estimated from surveys on foot. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 408: 7 p.

Spawning pink salmon were enumerated in five study streams in the Hollis area of Southeastern Alaska. One stream was logged, two were being logged and two were unlogged. Because enumeration required the ground survey as well as other methods, tests were made to assess variability in estimates of pink salmon abundance from surveys on foot between different observers and between successive counts by the same observer. Variability was lower when observers counted spawning salmon in well-defined riffle areas than when they counted in both pools and riffles. A method is proposed for obtaining more reliable indices of abundance from routine foot surveys.

Notes - contains information on problems and evaluation.

26. Van Hyning, J.M. 1973. Factors affecting the abundance of fall chinook salmon in the Columbia River. Oreg. Fish. Comm. Res. Briefs 4(1): 87 p.

The population of Columbia River fall chinook salmon (*Oncorhynchus tshawytscha*, Walbaum) was studied to determine the cause of a severe decline in the numbers of fish returning to the river in the late 1940's and early 1950's. Fluctuations in abundance of other major salmon runs in North Pacific were examined to detect any coastwide pattern but none was apparent. Life history stages during marine life, upstream migration, reproduction and incubation, and downstream migration were examined for the pre-(1938-46) and post-decline (1947-59) year classes.

Notes - information on evaluation and technique comparisons.

27. Willis, R.A. 1964. Experiments with repeated spawing ground counts of coho salmon in three Oregon streams. Oreg. Fish Comm. Res. Briefs 10(1): 41-45.

Surveys of spawning coho salmon (*Oncorhynchus kisutch*) have been conducted for many years to obtain indices of the abundance of mature fish returning from the ocean. Unit (standard) areas, established 10 years ago in certain Oregon tributaries of the lower Columbia River, have been surveyed each year, some several times a year. Prior to 1959, the total lineal distance of the unit surveys was 42 miles. Since 1959, the surveys have been reduced to 6.1 miles. Coho salmon usually mature at 3 years of age when they are approximately 21-36 inches in length and are often accompanied by 2-year-old jacks (16-20 inches in length).

To secure information on the validity of spawning ground counts under ideal conditions, the Milton, Sierkes and Trestle Creek units (Figure 1) were independently surveyed by three biologists.

Notes - contains information on problems and evaluation.

See also reference numbers 1, 2, 4, 5, 7, 8, 16, 28, 59, 60, 69, 94, 95 and 98.

C. SNORKLE AND RIVER FLOATS

28. Anthony, V., G. Finger and R. Armstrong. 1965. King salmon *(Oncorhynchus tshawytscha)* spawning ground surveys in the Behm Canal area of Southeastern Alaska. Alaska Dep. Fish Game Inf. Leaflet 63: 39 p.

In contrast to the larger king salmon (*Oncorhynchus tshawytscha)* producing areas in the northern district of Southeastern Alaska (Taku, Alsek and Stikine Rivers) where some information was available on catch, escapement and spawning ground locations, the size of the runs and locations of the spawning grounds were largely unknown in the southern or Ketchikan District. To obtain information of the king salmon stocks in this area a field survey crew covered the larger reported king rivers in this district throughout the summer of 1961. The area surveyed comprised all of the larger mainland streams in the Behm Canal area. The surveyed rivers are reported as separate spawning units.

The river surveys were made by means of a 24-foot river boat with outboard and lift, float plane, helicopter (shared program with the Branch of River Basin Studies, Fish and Wildlife Service) and by foot parties. One or more of these methods were used in any one survey, depending on the terrain, but the greatest effort was provided by a river boat and foot party combination.

Notes - contains information on problems.

See also reference numbers 4, 13, 21.

D. DIVE SURVEYS

See reference number 4.

E. OBSERVATION TOWERS

29. Becker, C.D. 1962. Estimating red salmon escapements by sample counts from observation towers. U.S. Fish Wildl. Serv. Fish. Bull. 61(192): 355-369.

Three counting towers were used on the Kvichak River system (Bristol Bay, Alaska). Tower locations were chosen according to migration habits of salmon and physical characteristics of the river.

A sampling procedure was established to obtain a reasonably accurate estimate of the total run from properly distributed visual counts throughout the migration.

Several sources of error are identified and discussed. A method of determining confidence limits is illustrated and accuracy is found to be $\pm$ 3.99 percent (95 percent level of significance) for the 1959 data.

Notes - contains information on methodology, problems and evaluation.

30. Seibel, M.C. 1967. The use of expanded ten-minute counts as estimates of hourly salmon migration past counting towers on Alaskan rivers. Alaska Dep. Fish Game Inf. Leaflet 101: 35 p.

Data collected during the 1965-66 seasons at the counting towers on eight Alaskan rivers was anlyzed to evaluate the use of 10-minute counts per hour as the basis for estimating the magnitude of the hourly migration, and hence, the daily and seasonal migration of salmon returning to spawn. In general, relatively large errors between the hourly estimates (based on 10-minute counts) and the hourly counts (assumed to be hourly migration) could be tolerated if these errors were unbiased and tended to cancel out over the duration of the season.

The relative errors between the sample total hourly estimates and total hourly counts ranged from -34.9% to +21.8%. These errors were equally divided between over-estimates and under-estimates. The arithmetic mean relative error of +0.9% was not statistically different from zero at the 95% level. The 95% confidence interval for the mean relative error was (-7.1%, +8.9%).

Notes - contains information on problems, evaluation and technique comparisons.

See also reference numbers 36, 90, 92, 94, 95, 104, 105, 107 and 126.

F. AERIAL COUNTS

31. Bevan, D.E. 1961. Variability in aerial counts of spawning salmon. J. Fish. Res. Board Can. 18(3): 337-348.

A study of spawning ground surveys for pink salmon (*Oncorhynchus gorbuscha* was made in two streams on Kodiak Island. An experimental design is described which permits replication of observers' counts of spawning salmon. The variance in an observer's estimate was found to be proportionate to the size of the estimate. The experiments indicated that an observer will detect differences in population size of plus or minus 50%.The relationship between counts of one observer and another changes within different streams, but within each river the observations of one observer were correlated with those of another. The results of the experiments are summarized in recommendations for aerial surveys of spawning salmon.

Notes - contains information on problems and evaluation.

32. Eicher, G.J. 1953. Aerial methods of assessing red salmon populations in western Alaska. J. Wildl. Manage. 17(4): 521-527.

A method of visual aerial survey of spawning red salmon on Bristol Bay grounds has been developed for assessing populations quantitatively. Aerial photography has been found effective for providing permanent records of indices to spawning numbers.

Notes - contains information on methodology, problems and evaluation.

33. Erickson, R.C. and D.E. Bevan. 1964. Stream surveys in the Kodiak Island area - 1962. Univ. Wash. Fish. Res. Inst. Circ. (unpubl. manuscr.) 214: 45 p.

Results of the 1962 surveys in the Kodiak Island region are summarized. Discussion includes pink salmon escapements, trends in catch and escapement, magnitude and timing, and success or failure of runs.

Notes - contains information on problems.

34. 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.

A method for estimating populations of spawning chinook salmon *Oncorhynchus tshawytscha* using aerial counts and residence time of spawning females is presented. Studies of spawning female chinook salmon in the Morice River, British Columbia showed that as the spawning season progressed, the residence time at the redd site decreased. The population estimate method described here is based on several aerial counts and incorporates a correction for the observed difference in residence time.

Notes - contains information on methodology, problems and evaluation.

See also reference numbers 1, 4, 7, 15, 16, 23, 28, 35, 47, 55, 89, 92, 93, 94, 95, 97 and 104.

G. PHOTOGRAPHIC ENUMERATION

35. Kelez, G.B. 1947. Measurement of salmon spawning by means of aerial photography. Pac. Fisherman 45: 46-51.

Annual population censuses of spawning salmon in all the streams of Western Alaska by means of field parties is beyond the limits of practicability. The Fish and Wildlife Service has, therefore, utilized aerial observations, particularly in the Bristol Bay area, to estimate relative annual abundance of spawners. Because the personal equation in this method is large, experiments have been carried on for some time to develop a more precise method for year-to-year comparisons. Aerial photography now promises such a means of enumeration.

Notes - contains information on methodology, problems and evaluation.

36. Mathisen, O.A. 1962. Photographic enumeration of red salmon escapement. p. 349-372 In: Koo, T.S.Y. 1962. Studies of Alaska red salmon. Univ. of Wash. Publ. in Fish. New Ser. 1: 449 p.

There exists today a growing demand for automatic and inexpensive methods for enumeration of salmon escapements. Research by the Fisheries Research Institute, University of Washington, has resulted in the development of a photographic enumeration unit. The equipment is described, and results obtained in Nushagak, Bristol Bay, Alaska, in 1955 are discussed.

The work has been financed in its entirety by the Alaska salmon industry

Notes - contains information on methodology, problems, evaluation and comparisons.

See also reference numbers 16, 32 and 34.

H. FENCE COUNTS

37. Aro, K.V. 1961. Summary of salmon enumeration and sampling data, Babine River counting weir, 1946 to 1960. Fish. Res. Board Can. MS Rep. 708: 63 p.

A weir installed on the Babine River in 1945-46 was used to enumerate and sample migrating salmon and steelhead spawners. A summary of data including numbers, lengths, fecundities and potential egg deposition is included, as well as a description of installation and function of the weir.

Notes - contains information on evaluation.

38. Brown, M.W. 1938. The salmon migration in the Shasta River (1930-34). Calif. Fish Game 24(1): 61-65.

This report is a preliminary account of the general salmon investigation conducted on the Shasta River by the California Division of Fish and Game under the direct supervision of the Bureau of Fish and Conservation.

As part of the general investigation the Division has conducted an annual census of the spawning migration of king salmon in the Shasta River. This paper is a summary of the data collected during the fall months of 1930 to 1934 inclusive.

A counting rack was installed for enumerating migrating salmon.

Notes - contains information on evaluation.

39. Cramer, F.K. and D.F. Hammack. 1952. Salmon research at Deer Creek, California. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 67: 16 p.

A portion of the early spring run of salmon in the Sacramento River was transferred by truck to Deer Creek.

Studies were carried out from 1940-1948 to determine the success of the transfers.

Notes - contains information on problems.

40. Hanson, H.A., O.R. Smith and P.R. Needham. 1940. An investigation of fish salvage problems in relation to Shasta Dam. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 10: 200 p.

Abundance of chinook salmon in the Sacramento River is estimated at Redding, California. Other counts were carried out on smaller streams in the system.

Experimental hauling and holding were also carried out, prior to the actual transfer.

Notes - contains information on problems and evaluation.

41. Hunter, J.G. 1954. A weir for adult and fry salmon effective under conditions of extremely variable run-off. Can. Fish Cult. 16: 27-33.

A fence designed to trap and enumerate both fry and adult salmon was built at Hooknose Creek, B.C. The fence was designed to handle fluctuating flows. The fence worked well and exhibited some self-cleaning properties.

Notes - contains information on problems and evaluation.

42. Jordan, F. P. and H.D. Smith. 1972. Summary of salmon counts and observations from the Babine River counting fence 1967-1971. Fish. Res. Board Can. Tech. Rep. 331: 63p.

The report gives fish counts and sampling data 1967-1971, as well as general physical and biological data pertinent to the operation of the Babine River counting fence.

Notes - contains information on problems.

43. Lill, A.F. and P. Sookachoff. 1974. The Carnation Creek fish counting fence. Env. Can. Fish. Mar. Serv. Tech. Rep. Pac./T 74-2: 23 p.

The upstream-downstream fish counting fence structure is a major evaluation tool to determine the effects of environmental change on fish populations in the Carnation Creek Experimental Watershed Study.

The counting fence is designed to operate continuously in flows as great as 1,000 cubic feet per second when trapping all upstream migrating

salmon and trout. When converted to trap downstream migrants, the structure screens all water up to flows of 200-250 cubic feet per second, depending on the quantity of debris. During greater flows, only one of the five traps is fished to sub-sample fish that might be moving with the freshet.

Specific site requirements and construction features of the counting fence are described in this report.

Notes - contains information on methodology, problems and evaluation.

44. Merrell, T.R., Jr. 1964. Ecological studies of sockeye salmon and related limnological and climatological investigations, Brooks Lake, Alaska, 1957. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 456: 66 p.

Ecological studies on the fresh-water phases of the life history of sockeye salmon and studies on related limnology and climatology were made at Brooks Lake, Alaska, in 1957.

Data are presented and interpreted on adult sockeye salmon spawning distribution and behavior, age, sex, length, fecundity and bear predation; on juvenile sockeye salmon ages, food, growth, migration from the lake, relative abundance and distribution in the lake; and on climatological and limnological factors that may influence sockeye salmon behavior and abundance.

Notes - contains information on problems and comparison between techniques.

45. Mottram, W. 1977. Design and construction of the Keogh River fish enumeration fence. (manuscr.) Fish. Tech. Circ., B.C. Fish Wildl. 25: 18 p.

The design, construction and operation of a fish counting fence on the Keogh River are described. A description of the river system is also included. The fence was used for enumeration and trapping of upstream migrating steelhead, cutthroat and Dolly Varden trout, and coho salmon and downstream migrating smolts.

The trap functioned at flows up to $34m^3$/sec. and the fence withstood flows up to $184m^3$/sec.

Notes - contains information on evaluation.

46. Needham, P.R., H.A. Hanson and L.P. Parker. 1943. Supplementary report on investigations of fish salvage problems in relation to Shasta Dam. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 26: 50 p.

Abundance of chinook salmon and steelhead are estimated in the Sacramento River using a fish ladder (Deer Creek) and a counting weir (Redding).

Notes - contains information on problems.

47. Nelson, P.R. 1960. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon (*O. nerka)*. U.S. Fish Wildl. Serv. Fish. Bull. 60(159): 59-86.

Bare Lake, a 120-acre, unstratified lake on Kodiak Island, Alaska, was fertilized each year from 1950 to 1956 with inorganic fertilizers to determine whether fertilization will increase production of red salmon (*Oncorhynchus nerka*). Various phases of the life history of the species were studied.

From 1950 through 1956 the annual spawning population of red salmon in Bare Lake ranged from 52 to 551 fish. Red salmon vary in age at maturity. The majority of Bare Lake red salmon remain in the lake slightly longer than a year, then migrate to the sea to spend 3 years before returning to the lake to spawn. Females predominated over males in the spawning escapement each year. Data are presented on fecundity, egg retention and the annual egg deposition.

A relation was found between the growth of young red salmon and the gross rate of photosynthesis. Fertilization has brought about an increase in size of the seaward-migrating red salmon smolts. There is good evidence to show that the larger smolts survive in greater numbers at sea. For the years 1950-53, fresh-water survival has ranged from 1.0 to 5.1 percent and marine survival increased from 3.3 to 7.9 percent. Limited information is available on the effect of fertilization on other fish populations in Bare Lake.

Notes - contains information on evaluation.

48. Ricker, W.E. and A. Robertson. 1935. Observations on the behavior of adult sockeye salmon during the spawning migration. Can. Field Nat. 49(8): 132-134.

The presence of an adult counting fence at the point where Sweltzer Creek flows into the Vedder River was believed to be deterring migrating adult sockeye salmon from entering the creek. Observations and a marking experiment revealed that passage of the fish was delayed, but not prevented.

Notes - contains information on problems.

49. Seiler, D., S. Neuhauser and M. Ackley. 1981. Upstream/downstream salmonid trapping project, 1977-1980. Wash. Dep. Fish. Prog. Rep. 144: 197 p.

Upstream and downstream migrant trapping and enumeration was carried out on four Washington salmon streams to acquire a data base prior to enhancing salmon populations. Adults were trapped in existing facilities for enumeration and juveniles in floating downstream traps.

Notes - contains information on problems.

50. Sumner, F.H. 1953. Migrations of salmonids in Sand Creek, Oregon. Trans. Am. Fish. Soc. 82: 139-150.

A picket barrier with upstream and downstream fish traps was maintained on Sand Creek, a small Oregon Coast stream, during 4 upstream and 3 downstream fish runs (1946-1949), and a smaller trap was operated on a tributary during part of 1947. Two species of trout, coast cutthroat, *Salmo clarki clarki* Richardson, and steelhead, *Salmo gairdneri gairdneri* Richardson, and two species of Pacific salmon, the coho salmon, *Oncorhynchus kisutch* (Walbaum), and the chum salmon, *Oncorhynchus keta* (Walbaum), made spawning runs during the fall and winter. Downstream migrations of fry and fingerlings, and of spent adult trout, occurred in the spring.

Physical data on Sand Creek included water temperatures and information on occurrence and magnitude of freshets. Records on fish trapped included the numbers of salmonids in each migration, lengths, weights, sex ratios in upstream runs, loss in weight after spawning and survival rates.

The results of this experiment indicate the need for a careful study of environmental and ecological conditions in order that a trapping structure may be adapted to extremes of water levels and to the habits of all species of migratory fishes found in the stream.

Notes - contains information on problems and evaluation.

See also reference numbers 2, 4, 7, 16, 17, 19, 22, 30, 53, 64, 65, 85 and 92.

I. MARK/RECAPTURE

51. Adair, R.A. and D.L. Cole. 1977. Population estimation of the 1976 fall chinook runs in the Duwamish - Green River and the Lake Washington watershed. Muckleshoot Indian Tribe and U.S. Fish and Wildlife Service Fisheries Assistance Office, Olympia, Washington. Preliminary Report: 12 p.

Population studies were conducted to estimate the size of the 1976 fall chinook runs to the Duwamish - Green River system and the Lake Washington watershed. The chinook were tagged in the lower Duwamish River and at the Ballard Locks. Run size estimates were calculated from tagging and tag recovery information.

Notes - contains information on methodology, problems and evaluation.

52. Anon. 1956. Investigations and field studies relating to numbers and seasonal occurrence of migratory fish entering the Columbia River above

Bonneville and the Snake River and their final distribution among principal tributaries thereto. U.S. Army Corps of Engineers, Fish. Eng. Res. Program Prog. Rep.: 104-111.

The primary objectives of the project are to estimate the numbers and seasonal occurrence of adult salmon and steelhead entering the Snake River and their final distribution among the principal tributaries. The fish counts which are made at Bonneville and Rock Island Dams on the Columbia River and at Washington Water Power Company Dam on the Clearwater River, have been utilized to obtain rough estimates of the annual Snake River runs.

In addition, fish have been captured and tagged in the Snake River near Lewiston, Idaho by means of a number of large metal cylindrical fyke nets (Table 1). Subsequently some of the tagged fish have been recaptured by sportsmen, by other fyke nets, at traps on upstream dams and on the spawning grounds. By the use of certain mathematical formulae these recaptures have been used to estimate the numbers of fish which pass the Lewiston area.

Notes - contains information on problems and evaluations.

53. Bevan, E.B. 1962. Estimation by tagging of the size of migrating salmon populations in coastal waters. p. 377-449 In: Koo T.S.Y. 1962. Studies of Alaska red salmon. Univ. Wash. Publ. in Fish. New Ser. 1: 449 p.

As a part of research on the life history of the red salmon (*Oncorhynchus nerka*) of Kodiak Island, tagging experiments were conducted to determine the migration pattern and to obtain estimates of the size of populations. Over 11,000 red salmon were tagged during two years of field study. About 45 percent of the tagged fish were recovered.

The experiments demonstrated that the majority of the fish were bound for spawning grounds at Karluk Lake. There was little interchange of fish between the northwest coast of the Kodiak Islands and nearby areas.

An experiment with double tags indicated that the rate of shedding of tags was about 10 percent.

Tags were recovered from a wide range of locations indicating that tagged fish were mixed within the untagged population. Evidence from opposed migrations between two tagging locations and from tagged fish recaptured more than once indicated that the fish wander through the fishery rather than migrate directly to the spawning streams.

An experiment which subjected the fish to severe maltreatment did not show an increase in mortality but the results were qualified.

Evidence is presented that the behavior of the tagged fish may be modified for a period of at least 48 hours.

A high mortality rate was indicated for fish tagged early in the season prior to the start of the fishing season. After fishing began the tagging indicated relatively uniform mortality rates during the period of study.

The assumptions necessary for successful estimation of population size by means of tag and recovery methods are reviewed and it is pointed out that the estimates should be used as indexes until they have been empirically tested.

Methods of calculating mortality rates that consider either returns from one tagging experiment during several recapture periods, or returns from several tagging experiments during one recapture period, are applied. It is recommended that neither method be used to the exclusion of the other. The application of the two methods gave similar results. The estimates of the rate of exploitation indicate that between 42 and 67 percent of the available tags were taken each fishing period. A measure of the survival of tagged fish indicates that after a period of between three and five days only half of the tags remain in the fishing area.

The problems of combining weir or tower counts and catch statistics to obtain total run estimates are discussed. It is pointed out that a total run calculated by this method may be in error under conditions resulting from increases and decreases in the size of the run.

The tagging estimates are compared to the total run calculated from combining catch and escapement. There is a close agreement between the estimates and the total run.

Notes - contains information on evaluation and comparison between techniques.

54. Buklis, L.S. 1981. Yukon and Tanana River fall chum salmon tagging study 1976-1980. Alaska Dep. Fish Game Inf. Leaflet 194: 40 p.

A fall chum salmon tagging study was conducted on the Yukon River in 1976, 1977 and 1978, and on the Tanana River in 1979 and 1980.

The estimates of populations based on tag recoveries are all higher than the sums of harvest and observed escapement. Reasons for disparity are discussed.

Notes - contains information on problems, evaluation and comparison between techniques.

55. Cameron, W.M. 1968. The tagging ratio and its use in the estimation of a spawning salmon population. Fish. Res. Board Can. MS Rep. 991: 38 p.

The method described involves tagging a known number of immigrant salmon spawners with brightly coloured disc tags. Afterwards the stream is searched and the ratio of tagged to untagged fish is noted. This ratio is applied to the number of tagged fish released to estimate the total stream population.

Variables affecting the applicability of this theory are discussed, including: 1) proportion of fish tagged, 2) duration of tagging, 3) frequency and spatial distribution of stream inspection and 4) length of fish life in the stream. Possible solutions to these problems are discussed.

Notes - contains information on methodology, problems and evaluation.

56. Chapman, D.G. 1948. A mathematical study of confidence limits of salmon populations calculated from sample tag ratios. Int. Pac. Salmon Fish. Comm. Bull. 2: 69-85.

An important problem in all fisheries work is the estimation of populations. Tagging programs have been used increasingly in recent years in an attempt to obtain a scientific solution of this problem. Such a program involves tagging some members of the population and subsequently obtaining a sample of the population which is random with respect to tagged and untagged fish. The evidence available from experiments designed to test this assumption of randomness is considered elsewhere.

In this paper procedures for finding point and interval estimates of the population are considered; in particular confidence limits are found for the estimate of the population which form an interval estimate that is optimum in a certain sense.

Notes - contains information on problems and evaluation.

57. Davis, W.S. 1964. Graphic representation of confidence intervals for Petersen population estimates. Trans. Am. Fish. Soc. 93(3): 227-232.

Probable confidence intervals for Petersen population estimates play an important part in decisions concerning the number of animals that must be marked and the size of the catch from which recaptures must be obtained. Requirements for an acceptable confidence interval may be so difficult to satisfy as to make a study impractical, even though the confidence interval itself is based only upon magnitude of numbers and not upon their accuracy. Graphs of the changes in confidence intervals from large to small as the magnitudes of marks applied, marks recovered, and catch change from small to large are presented to give perspective for the planning and development of Petersen population estimates. Confidence intervals were estimated by use of published formulas, tables and graphs.

Notes - contains information on evaluation.

58. Eames, M. and M. Hino. 1981. A mark-recapture study of an enumerated coho spawning escapement. Wash. Dep. Fish. Prog. Rep. 148: 22 p.

A mark-recapture program was carried out at Big Beef Creek (Puget Sound) in 1980-81, in conjunction with an adult weir trap.

A proportion of immigrant coho were marked with numbered aluminum or monel butt end tags, as well as a secondary fin clip. Dead fish recovery was carried out over the migration period to retrieve tags. Tag loss was found to be 22.2 percent (S.D. 7.9 percent) and tag mortality was low.

The population estimate based on mark-recovery was 1428 ± 26 percent (95 percent confidence limit), compared to a weir count of 1613.

Notes - contains information on problems, evaluation and comparison of techniques.

59. Eames, M., T. Quinn, K. Reidinger and D. Haring. 1981. Northern Puget Sound 1976 adult coho and chum tagging studies. Wash. Dep. Fish. Tech. Rep. 64: 217 p.

Coho and chum salmon were captured in Puget Sound by means of purse seine, tagged with aluminum or monel butt end jaw tags and then released. The purpose of the study was to obtain escapement estimates for the Snohomish, Skagit and Nooksack River systems, as well as information on run timing, exploitation rates and gear selectivity in terminal areas.

Recoveries were made by intensive spawning ground surveys, as well as recoveries from commercial and sport fisheries, hatcheries and fish plants.

Assessments of tag loss, tagging mortality and sex selectivity in recovery were made.

Notes - contains information on problems and evaluation.

60. Glova, G.J. and P.J. McCart. 1979. Salmon enumeration studies in five streams draining into Tlupana Inlet, B.C., 1978. P. McCart Biological Consultants Ltd.: 197 p.

Baseline biological and physio-chemical studies were made in five salmon producing streams on the west coast of Vancouver Island. Spawning chum salmon, as well as other salmon species spawning coincidentally with the chums, were enumerated visually and with the mark/recapture method.

Notes - contains information on methodology, problems and evaluation.

61. Glova, G.J., W.A. Grant, P.J. McCart and M.L. Jones. 1979. Chum salmon spawning enumeration, Mathers Creek, Princess Louise Island, British Columbia 1978. P. McCart Biological Consultants Ltd.: 59 p.

Baseline biological information was gathered on the spawning population of chum salmon in Mathers Creek and its major tributary. Mark/recapture techniques were used to measure chum salmon escapement.

Notes - contains information on problems and evalutation.

62. Gulland, J.A. 1963. On the analysis of double-tagging experiments. p. 228-229 In: Anon. 1963. North Atlantic Fish Marking Symposium. Int. Comm. Northwest Atl. Fish. Spec. Sci. Publ.: 370 p.

The rate of tag loss from adult fish was examined by double-tagging and observing the number of single-tagged fish recovered.

Notes- contains information on evaluation.

64. 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 Wildl. Serv. Spec. Sci. Rep. Fish. 483: 26 p.

Intertidal spawning of pink salmon is of major importance in Prince William Sound. Studies were initiated at Olsen Bay in 1960 to ascertain how much these intertidal spawners contributed to the total production of pink salmon.

Olsen Creek is inundated with tidewater about 80 percent of the time at the 3-foot tide level and about 7 percent of the time at the 11-foot level. Saline water was shown to penetrate the gravel at redd depth during high tides. The highest concentration at the 11-foot tide level was $9.3^{\circ}/oo$ during a 14.5-foot tide. Temperature changes of up to 10° F. would occur within 1 hour at elevations up to the 8-foot level on floodtide.

The occurrence of spawners in 1960 and 1961 was bimodal; however, in 1960 the late run utilized only the intertidal spawning area, while in 1961 the late run utilized both the intertidal and fresh-water areas. During the 2 years the early run spawned in both environments. In 1960, 98,574 pink salmon spawned in Olsen Creek and in 1961, 135,905 spawned. During both years 74 percent of the total run spawned in the intertidal portion of the stream.

Temporal and spatial distribution of spawners, size differences and seasonal changes in sex ratios provide evidence for the existence of discrete spawning groups or races.

Live egg densities and survival over winter to the preemergent fry stage were progressively greater from the lower to the higher levels in the intertidal area. Overwinter survival between egg and fry stages below the 4-foot level was 0. Survival at the 7- to 9-foot level and the 10- to 11-foot level was 20 and 54 percent respectively.

Notes - contains information on problems and evaluation.

65. Howard, G.V. 1948. A study of the tagging method in the enumeration of sockeye salmon populations. Int. Pac. Salmon Fish. Comm. Bull. 11: 9-66.

Experiments were conducted at Cultus Lake by the International Pacific Salmon Fisheries Commission in the years 1938 and 1939 for the purpose of determining the feasibility of estimating the size of a population of spawning sockeye by tagging a portion of the migrants as they moved into the spawning area. The tag ratio in the population was established from the examination of samples of dead fish. Complete control was exercised at Cultus Lake by making an accurate count through a weir of all sockeye entering the area. Tagging was conducted throughout two years' migrations. In 1938, 4,416 fish, or one-third, were tagged of the 13,342 sockeye counted through the weir between September 27 and December 27; and 3,660 sockeye, or one-twentieth of the 73,189 fish entering the lake between October 10, 1939 and January 20, 1940 were tagged.

The populations, when all tags and all recoveries were considered, were calculated to be 13,765 in 1938 and 75,441 in 1939. The limits of confidence were between 14,475 and 13,090 in the first year and between 85,523 and 68,966 in the second.

Recommendations are given for obtaining optimum accuracy in similar systems.

Notes - contains information on problems and evaluation.

66. Junge, C.O. 1963. A quantitative evaluation of the bias in population estimates based on selective samples. p. 26-28 In: Anon. 1963. North Atlantic Fish Marking Symposium. Int. Comm. Northwest Atl. Fish. Spec. Sci. Publ.: 370 p.

A quantitative measure of the degree by which a sample deviates from being random or representative is developed. In some cases, such a measure permits an evaluation of the magnitude and direction of bias in estimates based on selective samples.

The usual requirement that either tagging or recovery by nonselective (x or y, constant) is not a necessary condition for an unbiased estimate. Further, it can be shown that bias is somewhat insensitive to variations in tagging and recovery rates even if x and y are perfectly correlated. Severe distribution functions are considered to illustrate this effect. In making use of this principle, however, situations which can introduce extreme bias must be recognized. These situations are discussed.

Notes - contains information on evaluation.

67. Kruse, T.E. 1964. A comparison of spaghetti and Petersen tags used on steelhead trout at Gnat Creek, Oregon. Oreg. Fish Comm. Res. Briefs 10(1): 57-66.

The purpose of this study was to compare suitability of spaghetti and Petersen tags for use on large salmonids. The study was conducted in Gnat Creek, a tributary to the Columbia River. Steelhead trout (*Salmo gairdneri*) were trapped at a weir and tagged during three seasons (1955-58) with Petersen disc and plastic spaghetti tags.

Notes - contains information on problems and evaluation.

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

Petersen disk tag loss from spawning chum salmon was studied over a three-year period in an artificial spawning channel. The time from tagging to recovery averaged approximately 11 days. Accurate enumeration of fish entering the channel and virtually complete recovery of dead on completion of spawning enabled estimation of tag loss on the basis of changes in the tagged:untagged ratio over the spawning period.

The average rate of tag loss from males (30%) was significantly higher than the loss from females (9%). Loss among males was also related to date of entry into the channel, with tags applied early in the run having a greater chance of loss than those applied late in the run. The addition of accessory buffer disks to the tag reduced loss by 50 percent, thus indicating that disk failure was the primary factor responsible.

Notes - contains information on problems and evaluation.

69. McCart, P.J., O. Fleming, W.A. Grant, and M. Walsh. 1980. Adult salmon enumeration in the Nitnat River, British Columbia. P. McCart Biological Consultants Ltd.: 69 p.

Baseline biological and physio-chemical studies were made on the Nitnat - Little Nitnat River System on the west coast of Vancouver Island. Escapement estimates for chum and chinook salmon were derived from mark/re-capture surveys in 1979. Visual surveys were made to enumerate coho and sockeye.

Notes - contains information on methodology, problems, evaluation and comparison of techniques.

70. Morgan, A.R. and K.A. Henry. 1959. The 1955-1956 silver salmon run into the Tenmile Lakes system. Oreg. Fish Comm. Res. Briefs 7(1): 57-77.

In order to estimate the magnitude of silver salmon escapement to the Tenmile Lakes system in 1955-56, a mark-recapture study was carried out. Assuming a 1:1 sex ratio, the spawning potential of the run was also estimated.

Notes- contains information on problems and evaluation.

71. Parker, R.R. and W. Kirkness. 1954. Estimates of spawning king salmon in the Taku River, Alaska, for the year 1951. p. 179-191 In. Anon. 1954. Proceedings of the Third Alaskan Science Conference, 1952. Alaska Div. Am. Assoc. Adv. Sci.: 221 p.

An investigation of the king salmon (*O. tshawytscha*) stocks r to the Taku River of Southeastern Alaska was initiated by the Alas Department of Fisheries in 1951. The program was designed primarily t discover the effects, both numerical and biological, of existing fish upon the population. This report deals with the problem of assessing numerical level of the mature portion of the population as it enters the river on the spawning migration.

Notes - contains information on problems and evaluation.

72. Paulik, G.J. 1963. Exponental rates of decline and type (1) losses fc populations of tagged pink salmon. p. 230-237 In: Anon. 1963. North At Fish Marking Symposium. Int. Comm. Northwest Atl. Fish. Spec. Sci. Publ.: 370 p.

Interpretation of salmon tagging experiments is complicated b the possibility of what Beverton and Holt (1957) call type (1) losse use this term to include all losses which have the same effect as rec the initial numbers of fish tagged. If type (1) losses are present, t apparent rate of exploitation calculated from the tag returns will be too low. Ricker (1958) has called this sort of bias Type A error. The primary sources of type (1) losses in salmon tagging are immediate ta mortality and incomplete tag reporting.

This paper re-examines the results of a major salt-water tagg experiment involving pink salmon that was conducted in Southeastern Alaska during 1950.

Notes - contains information on problems and evaluation.

73. Paulik, G.J. 1963. Detection of incomplete reporting of tags. p. 238- Anon. 1963. North Atlantic Fish Marking Symposium. Int. Comm. Northwes Atl. Fish. Spec. Sci. Publ.: 370 p.

When the primary objective of a tagging or marking experimen is to estimate the rate of exploitation of a population supporting a fishery, it almost invariably follows that the actual recovery of th of the tagged or marked fish is out of the hands of the investigator conducting the experiment. A major part of the responsibility of det and reporting recaptures of tagged fish must be entrusted to the commercial, sport or native fishermen who harvest the population.

The purpose of this paper is to provide the biologist planni a tagging experiment with a preliminary guide to help him decide how tags should be put out and how much of the catch should be inspected be reasonably sure of discovering non-reporting of a certain magnitu

Notes - contains information on methodology, problems and evaluation

74. Pritchard, A.L. 1945. Sockeye salmon tagging of the Skeena River in 1945. Fish. Res. Board Can. Prog. Rep. Pac. Coast Sta. 65: 77-79.

Sockeye salmon were tagged off the Skeena River in 1945. Results of recoveries and conclusions drawn from these results are presented.

Notes- contains information on problems.

75. Pritchard, A.L. 1947. Attempts to employ tagging in estimation of salmon spawning populations. Fish. Res. Board Can. MS Rep. 533: 17 p.

The report contains a general discussion of the theory and some problems related to the use of mark/recapture methods in estimating spawning population size. Examples of "proportionate" and "disproportionate" tagging experiments are included.

Notes - contains information on problems and evaluation.

76. Pritchard, A.L. 1947. The use of a tagging ratio to estimate escapement, Babine fence 1946. Fish. Res. Board Can. MS Rep. 531: 17 p.

Tagging of salmon at Babine fence was carried out in 1946 to check the method of estimating the numbers in the escapement.

The estimate obtained was more than double the fence count. Suggestions are made for improving the accuracy of the method.

Notes - contains information on problems and evaluation.

77. Pritchard, A.L. and F. Neave. 1942. What did the tagging of coho salmon at Skutz Falls, Cowichan River, reveal? Fish. Res. Board Can. Prog. Rep. Pac. Coast Sta. 51: 8-11.

1156 coho salmon were dipnetted from the shores of pools, tagged and released during the fall of 1941.

Based on recapture of 23 tagged and 1256 untagged coho upstream from the falls, an estimate of 66,000 coho was arrived at for the number of spawners above Skutz Falls.

Information on distribution, behavior and timing was also obtained.

Notes - contains information on problems.

78. Reavis, R.L. Jr. (ed). 1981. Chinook (king) salmon spawning stocks in California's Central Valley, 1980. Calif. Dep. Fish Game, Anadromous Fish Br. Admin. Rep. No. 81-7: 36 p.

This report covers the 28th annual inventory of chinook salmon (*Oncorhynchus tshawytscha*) spawning populations in the Sacramento - San Joaquin River system. It is a compilation of estimates of fall- and spring-

run chinook salmon spawning populations for every stream in the Sacramento-San Joaquin system which supports a significant spawning run, and partial counts of late-fall and winter-run chinook salmon.

Estimates are made from counts of fish entering hatcheries and spawning channels, fish migrating past dams, carcasses and live fish on spawning areas, and aerial redd counts.

The estimated 1980 escapement of fall spawning (fall- plus spring-run) chinook salmon in the Central Valley is 184,605 fish. This figure is 65% of the historic (1953-1979) average of 283,000 and is 80% of the 1979 estimate of 230,709.

The decline in 1980 escapement may be partly attributed to the 1976-77 drought. The continuing decline of recent years is probably caused by the exports of large amounts of water from the Sacramento-San Joaquin Delta. This results in screening problems and reduces the nursery area, and in turn greatly depresses survival of juvenile salmon migrating to the ocean.

Salmon counts at Red Bluff Diversion Dam and sport catches above the dam are shown in Appendix Tables 1 and 2, respectively. Spawning populations for all Central Valley streams are summarized in Appendix Tables 3-5. Fin mark and coded-wire-tag recoveries are presented in Appendix Tables 6 and 7.

Notes - contains information on carcass tag methodology.

79. Reisenbichler, R.R. and N.A. Hartmann, Jr. 1980. Effect of number of marked fish and years of repetition on precision in studies of contribution to a fishery. Can. J. Fish. Aquat. Sci. 37(4): 576-582.

Methods are developed for predicting the expected precision for studies of the contribution of fish to a fishery, based upon the number of fish marked and the number of years an experiment is repeated. Studies concerned with estimating catch-release ratios, comparing catch-release ratios, and comparing distributions of catch are considered. It is suggested that releases of marked fish should be repeated for at least three or four broods, and often there is little advantage in releasing more than 50,000 marked fish per release group. Although we explicitly address studies of contribution to ocean fisheries, the methods apply directly to a broad range of studies involving marked fish, from evaluations of harvest rates on catchable-trout plants to estimates of catch-escapement ratios for Pacific salmon.

Notes - contains information on evaluation.

80. Robson, D.S. and H.A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Trans. Am. Fish. Soc. 93(3): 215-226.

The efficient planning of a Petersen-type mark and recapture experiment requires some knowledge of the order of magnitude of the population size N. Sample sizes M and C of the mark and recapture samples, respectively, may then be ascertained on the basis of a guessed value of N to achieve any desired degree of accuracy with any specified degree of confidence. Restrictions on the sample sizes M and C are that MC must exceed 4 times the guessed value of N and the total costs of M and C must be equal. Graphs and formulas are given defining sample size to attain preassigned levels of accuracy and precision of population estimation. A method of choosing sample sizes such that experimental costs are minimized is described.

Notes - contains information on methodology and evaluation.

81. Robson, D.S. and H.A. Regier. 1966. Estimates of tag loss from recoveries of fish tagged and permanently marked. Trans. Am. Fish. Soc. 95: 56-59.

The annual rate 'r' of tag loss may be estimated from observations on the proportion of tag retentions among recoveries of fish which were both tagged and permanently marked at the time of release. In samples recovered 't' years after release, the proportion of marked fish still bearing tags is assumed to be an estimate of r^t. Homogeneity of these 't'-year loss rates for different year classes may be tested by Chi-square, and the information from all samples may then be combined in the form of a maximum-likelihood estimator of 'r'. Finally, a goodness-of-fit Chi-square may be calculated to test the assumption of a constant annual rate of tag loss. When applied to recapture data on lake whitefish in Georgian Bay, these tests failed to detect any errors in this simple model.

Notes - contains information on evaluation.

82. 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 by means of marked members. Int. Pac. Salmon Fish. Comm. Bull. 4: 207 p.

Experiments were conducted in 1939, 1940 and 1941 in the Harrison River system to gain information on the structure and behavior of populations of migrating adult salmon to examine the validity of marking methods for making population estimates, and to lay a foundation for employing these methods in a variety of stream systems.

Notes - contains information on problems, evaluation and comparison of techniques.

83. Stott, B. 1968. Marking and tagging. p. 78-92. In: Ricker, W.E. (ed.) 1968. Methods for assessment of fish production in fresh waters. Int. Biol. Prog. Handbook 3: 313 p.

The paper discusses various fish marking techniques and their application for purposes such as population estimates, movements and migrations, growth and age determinations and behavior studies.

Notes - contains information on methodology, problems and evaluation.

84. Vernon, E.H., A.S. Hourston and G.A. Holland. 1964. The migration and exploitation of pink salmon runs in and adjacent to the Fraser River convention area in 1959. Int. Pac. Salmon Fish. Comm. Bull. 15: 296 p.

A program was carried out to tag pink salmon entering convention waters from northern and southern approaches and follow their migrations.

The field program encompassed over 1,800 miles of mainland coast and was the most intensive program of its type ever carried out on Pacific salmon. More than 53,000 tags were applied along the migration route, 32,000 of which were recovered from the 5.6 million fish examined for tags in the catches and on the spawning grounds. The fishing area and week of capture were established for practically all of the 7.6 million pink salmon caught by commercial and sport fishermen during the migration. The 2.6 million spawners were enumerated mainly by stream tagging and recovery programs, involving the tagging of a further 52,000 pinks and the examination of over 360,000 carcasses for tags.

Notes - contains information on problems and evaluation.

85. Ward, F.J. 1959. Character of the migration of pink salmon to Fraser River spawning grounds in 1957. Int. Pac. Salmon Fish. Comm. Bull. 10: 70 p.

The characteristics of the migration of pink salmon to the Fraser River system in 1957 are related, in this study, to the requirements of scientific management of the fisheries. Analysis of catch, tagging and escapement data indicated that populations of pink salmon spawning in particular streams, which are defined as races of pink salmon, could be classified into early and late migrating groups. It is suggested that fishing mortality rates affecting the early groups were greatest, particularly in Fraser River fishing areas. Pink salmon delayed off the mouth of the Fraser River for a considerable period but migration through the remaining fishing areas was rapid and direct. Two early migrating races moved directly to respective spawning areas but the two major late races delayed in the lower sections of their spawning streams for considerable periods. Although chronological order of migration was maintained from passage through Fraser River commercial areas until death, races which delayed lost chronology but regained it during residence on the spawning grounds. Total escapement of pink salmon to the Fraser River system was enumerated by the use of tagged individual The abundance of fish spawning in individual streams was estimated by a number of methods. Sources of error affecting each method are discussed.

Notes - contains information on methodology and evaluation.

86. Willis, R.A. 1954. Population limits of the silver salmon run in Tillamook Bay during the 1951 fishing season. Oreg. Fish Comm. Res. Briefs 5(1):3-7.

Coho juveniles from the Wilson River, Oregon were tagged using fin clips in 1949. The number of marked adults recovered in the 1951 catch were used to estimate the total returning population.

Notes - contains information on evaluation.

See also reference numbers 2, 5, 7, 8, 12, 14, 16, 17, 19, 20, 44, 91, 92, 107 and 119.

J. INDEX STREAMS

87. 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 up-dates. Wash. Dep. Fish. Tech. Rep. 29: 71 p.

The report explains methods used by the Washington Department of Fisheries to develop Puget Sound summer-fall chinook escapement goals, escapement estimates, pre-season run forecasts, and in-season run updates.

Escapement estimates are based on counts from a number of index areas in each river basin made by aerial, boat and ground surveys.

Notes - contains information on problems and evaluation.

88. 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. Oreg. Dep. Fish Wildl. Res. Develop. Sect. Info. Rep. Fish. 80-9: 23 p.

The purpose of this study was to use existing data to: (1) evaluate the four principle assumptions underlying the ODFW standard spawning index; (2) to determine the precision of the present standard index and the sample size needed to achieve the desired level; (3) to determine the effect of hatchery fish on the standard index and (4) to recommend inprovements for evaluating coho escapement to Oregon coastal streams. The results of this study indicate that the standard index should be expanded to at least 40 survey units, and the use of the peak count as an index of run size be eliminated and replaced with total fish-days or an estimate of the number of spawners. It was also found that the standard index appears to have been influenced by hatchery production. The use of spawning fish surveys as an absolute measure of abundance is discussed. It is recommended that the standard index be expanded to 40 units which are representative of all the coho habitat on the Oregon coast. It is further recommended that the expanded survey should emphasize streams which have not been heavily stocked with hatchery fish, or that a separate index for wild fish be established.

Notes - contains information on methodology, problems and evaluation.

89. Bucher, W.A. 1982. Spawning ground surveys in the Nushagak and Togiak districts of Bristol Bay, 1981. Alaska Dep. Fish Game Bristol Bay Data Rep. 87: 31 p.

Aerial surveys of salmon spawning grounds were conducted in 1981 continuing a program initiated in 1956 to determine distribution and abundance of salmon escapements. Coverage was limited to those river systems in Nushagak and Togiak districts where escapement estimates were not made or where distribution of the spawning populations was of concern.

King, chum and sockeye salmon were enumerated in the 1981 surveys. In addition, coho surveys were flown for a second year in Togiak district drainages. Weather conditions were generally good this year, and almost all surveys were completed on or near peak of spawning. All key index streams were surveyed, although high, turbid water conditions precluded surveys again this year in the important salmon spawning areas of the upper Nushagak-Mulchatna River drainage.

Notes - contains information on methodology.

90. Crumley, L. and D. Pratt. 1977. The Lake Washington sockeye enumeration study at the Hiram M. Chittenden Ship Canal, 1972 through 1976. Wash. Dep. Fish. Prog. Rep. 23: 23 p.

This report provides results of the sockeye enumeration study carried out at the Hiram M. Chittenden Ship Canal (Ballard Locks) from 1972 through 1976. Included are daily and cumulative estimates, plus average percent complete for sockeye passing through the ship canal area, entering the Lake Washington water system. Details concerning the methods used in calculating sockeye passage through both the locks and the newly rejuvenated fish ladder are provided.

Notes - contains information on comparison of techniques.

91. Flint, T. and G. Zillges. 1980. Little Bear Creek coho salmon stream life study. Wash. Dep. Fish. Prog. Rep. 124: 40 p.

This study was conducted in 1978 to estimate the stream life, redd life and population size of adult coho in one type of stream common to Puget Sound. It was hoped that information gained from this study would help calibrate adult index counts with total escapement in a given creek, determine how frequently coho surveys should be made, and generally increase our knowledge of coho life history.

Notes - contains information on problems and evaluation.

92. Gilbert, J.R. 1968. Surveys of sockeye salmon spawning populations in the Nushagak District, Bristol Bay, Alaska, 1946-1958. p. 199-267 In: Burgner, R.L. 1968. Further studies of Alaska sockeye salmon. Univ. Wash. Publ. Fish. New Ser. 3: 267 p.

Methods of enumeration of salmon spawning populations are reviewed with emphasis on spawning survey techniques. The methods used to survey sockeye salmon spawning grounds in the Nushagak District of Bristol Bay, Alaska, are presented. These surveys sought reliable yearly estimates of the total spawning population in the district and in each of its major spawning areas. Because the data derived and the methods are used extensively in studies of the Nushagak sockeye, they are presented in detail. Results of surveys encompass the years 1946 through 1958.

Estimates were obtained primarily by the application of chain-link indices, derived from spawning ground survey data, to initial total population estimates, obtained from comprehensive spawning survey or tower count data for each lake system in the district. The sources and magnitude of error were examined, and the possibility of large errors was recognized. However, the work done by Nelson and Church in 1959-1961, when results could be checked against known population totals, confirmed the practical worth of the survey estimates, particularly those for the years since 1953.

Notes - contains information on methodology, evaluation and comparison of techniques.

93. Jones, D. and J. Dangel. 1981. Southeastern Alaska 1980 broad year pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) escapement surveys and pre-emergent fry program. Alaska Dep. Fish Game Tech. Data Rep. 66: 214 p.

Pink salmon spawning escapements in Southeastern Alaska were highly variable in 1980 from district to district. Generally the southern Southeastern escapements were good in Districts 101, 102 and 103 and very poor in Districts 105, 106 and 107. The northern districts were good with the exception of District 114. Pre-emergent fry indices in 1981 were generally fair with above average fry indices in most districts.

Notes - contains information on methodology.

94. Nelson, M.L. 1963. Red salmon spawning ground surveys in the Nushagak and Togiak Districts, Bristol Bay, 1963. Alaska Dep. Fish Game Inf. Leaflet 61: 24 p.

In 1963 the Alaska Department of Fish and Game conducted intensive aerial surveys of red salmon spawning grounds in the Nushagak and Togiak districts of Bristol Bay. This was the fourth consecutive year the

Department has been responsible for the spawning ground distribution estimates. The program was initiated in 1946 by the Fisheries Research Institute and continued through 1959 by that agency.

The purpose of this survey program is to provide accurate estimates of abundance and distribution of red salmon in the various spawning areas. Results obtained are essential to both research and management for optimum escapement studies and the attainment of escapement goals. The distribution of fish on the spawning grounds in the past few years has become an important factor in the determination of escapement levels for the Nushagak and Togiak districts.

Survey methods included tower counts, aerial surveys and some supplemental ground surveys to check accuracy of aerial counts. A "chain-link" survey method, using peak aerial counts and tower counts was used to estimate total populations and spawner distributions.

Notes - contains information on methodology, evaluation and comparison between techniques.

95. Nelson, M.L. 1965. Red salmon spawning ground surveys in the Nushagak and Togiak Districts, Bristol Bay, 1965. Alaska Dep. Fish Game Inf. Leaflet 84: 40 p.

The purpose of the survey program is to provide accurate estimates of abundance and distribution of red salmon in the various important spawning areas. In systems where counting towers are not situated, aerial surveys are used to determine spawning escapements as well as distribution. Distribution of fish on the spawning grounds is an important factor in the determination of optimum escapement and utilization of types of spawning areas to evaluate different levels of escapement. Supplemental ground counts in some systems were valuable for comparison.

Systems surveyed included primary red salmon spawning areas in the Nushagak and Togiak districts: Wood River Lakes, Igushik Lakes, Lake Nunavaugaluk, Tikchik Lakes, Nushagak-Mulchatna River system, Togiak Lakes and tributaries and the Kulukak system (Figures 1-8).

The reliability of the "chain-link" method of estimation is tested statistically.

Notes - contains information on problems, evaluation and comparison of techniques.

96. Oakley, A.L. 1966. A summary of information concerning chum salmon in Tillamook Bay. Oreg. Fish Comm. Res. Briefs 12(1): 5-21.

The Oregon Fish Commission has collected information on chum salmon (*Oncorhynchus keta*) in Tillamook Bay from 1947 through 1962 to obtain data necessary for managing the commercial fishery. This report summarizes the pertinent published findings and important unpublished data gathered during this period.

Henry (1953) discussed the Tillamook Bay commercial fishery, life history studies and factors affecting chum salmon production. He developed a relationship between minimum stream flow occurring between January 15 and March 20 and the abundance of returning adults. In 1954 Henry reported on the age and growth of Tillamook Bay chum salmon. Results of a tagging study in 1953 provided an estimate of the chum population as well as the rate of harvest by the commercial fishery (Henry, 1964). Ricker (1958) made certain assumptions and used Henry's data to plot a reproduction curve for Tillamook Bay chum salmon defining the best level of escapement and yield.

Biologists collected information on chum salmon from the commercial fishery in Tillamook Bay in 1947-50 (Henry, 1953 and 1954) and during 1959-61. The Fish Commission closed Tillamook Bay to commercial fishing in 1962 in order to protect the stocks which had dropped to a low level and all data collected that year were from spawning fish sampled throughout the Tillamook Bay watershed. The abundance of spawners has been measured annually since 1947 by counting fish in specific areas of Tillamook Bay tributaries. Daily records of fish buyers have provided information on the average weight of fish from the commercial fishery.

Notes - contains information on evaluation.

97. Pirtle, R.B. 1977. Historical pink and chum salmon estimated spawning escapements from Prince William Sound, Alaska streams, 1960-1975. Alaska Dep. Fish Game Tech. Rep. 35: 332 p.

The report documents the initiation of a data file for the Prince William Sound, Alaska, pink and chum salmon spawning escapement program. The report includes a description of aerial and ground survey procedures as well as escapement estimates for 1960-1975.

Note - contains information on methodology.

98. Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, 1977 pre-season run size prediction and in-season run assessment. Wash. Dep. Fish. Tech. Rep. 28: 65 p.

The methods used by the Washington Department of Fisheries to determine Puget Sound escapement goals, escapement estimates, preseason run predictions and in-season run prediction updates are described.

Hatchery return data and catch data are used to provide supportive estimates of wild escapement.

Notes - contains information on methodology, problems and evaluation.

See also reference numbers 2, 27, 51, 107 and 109.

K. ELECTRONIC COUNTERS

99. Bell, W.H. and M.C. Armstrong. 1970. A photo-electric fish counter. Fish. Res. Board Can. Tech. Rep. 215: 23 p.

The apparatus described replaces older models which were not of uniform sensitivity for all photo-detector circuits and did not function well at all levels of turbidity. Other improvements include ability to distinguish between smolts and other similar objects, easily replaceable circuitboards and minimum disturbance to flow.

The paper describes the new design, which has functioned successfully in the field for three seasons. The design is not restricted to use on smolts but may be applied to fish of any size.

Notes - contains information on methodology (design) and evaluation.

100. Cross, B.A., S.L. Marshall, T.L. Robertson, G.T. Oliver and S. Sharr. 1981. Origins of sockeye salmon in the upper Cook Inlet fishery of 1979 based on scale pattern analysis. Alaska Dep. Fish Game Tech. Rep. 58: 76 p.

Linear discriminant function analysis of scale pattern of age 5_2 and age 4_2 sockeye salmon (*Oncorhynchus nerka)* sampled from the escapements and from the commercial harvest of Upper Cook Inlet, Alaska provided the basis for apportioning the catch into component stocks. The five component stocks are: Susitna River, Kenai River, Kasilof River, Crescent River and Fish Creek. The total return of sockeye salmon to Upper Cook Inlet in 1979 was estimated to be 1,658,640, of which 923,518 (55.7%) were harvested and 735,122 escaped to spawn. The total return and exploitation rates for the principal stocks contributing to the return were: Kenai River 597,884 (0.525); Kasilof River 442,893 (0.675); Susitna River 376,831 (0.583); Crescent River 123,454 (0.339); and Fish Creek 117,578 (0.584). Estimation of escapement to the rivers of Upper Cook Inlet is complicated by turbid waters. In most cases hydroacoustic techniques provide estimates of escapement.

Notes - contains information on methodology.

101. Davis, A.S. 1968. Salmon counting by acoustic means. Alaska Dep. Fish Game Inf. Leaflet 113: 28 p.

Commercial salmon fishery management requires a reliable estimate of the numbers of spawning salmon that have escaped from the harvest. Visual escapement estimates are possible in clear streams only. Enumeration of salmon escapements into glacially turbid waters has been a major problem for years and it has been apparant that some new means of salmon counting had to be developed in order to accomplish the task.

The Electrodynamics Division of the Bendix Corporation with the assistance of the Alaska Department of Fish and Game, tested various modified sonar units during the salmon runs of 1961, 1965, 1966 and 1967. The early sonar salmon counters utilized a single transducer. The sonar beam was aimed horizontally through the water in order to intercept the migrating salmon. The difficulties encountered with these systems made it necessary to utilize a series of bottom mounted transducers with the beams pointed towards the water surface. Visual counts versus electronic counts showed the system would enumerate salmon with better than 90 percent accuracy. Installation sites will require certain characteristics due to the limitations of the transducer array.

Notes - contains information on problems, evaluation and comparison between techniques.

102. Hellawell, J.M. 1973. Automatic methods of monitoring salmon populations. Int. Atl. Salmon Found. Spec. Publ. Ser. 4(1): 317-337.
Reference not available for review.

103. Kristinsson, B. and M. Alexanderdóttir. 1978. Design and calibration of a salmon counter. J. Agr. Res. Icel. 10(2): 57-66.

A resistivity counter is described. A novel feature is the counter sensor which is a mat made of five parallel, uninsulated steel ropes placed directly on the river bottom. Calibration tests against a mechanical counter in Ellidaár gave comparable results as long as the salmon were actively migrating across the sensor mat. Data obtained in Ellidaár show a distinct diurnal migration pattern, with migration heaviest in the period from sunset to sunrise.

Notes - contains information on methodology, problems and evaluation.

104. McBride, D. and D. Mesiar. 1981. Nushagak sonar enumeration project, 1980. Alaska Dept. Fish Game Bristol Bay Data Rep. 83: 45 p.

The Nushagak sonar enumeration project was initiated in 1979 and expanded in 1980. In 1980 the sonar estimates for sockeye, king, chum and pink were substantially less than aerial and tower estimates. Extremely high salmon passage rates in 1980 were thought to be the major cause of undercounting.

Notes - contains information on methodology, problems and comparison between techniques.

105. Morley, R.B. 1981. Adult sockeye escapements to Sproat Lake and Great Central Lake (Somass River system, Port Alberni, B.C.) in 1979. Can. MS Rep. Fish Aquat. Sci. 1614: 68 p.

The sockeye escapement to Sproat Lake in 1979, estimated on the basis of partial visual counts, was 76,446. The estimated escapement to Great Central Lake, based mainly on counts obtained from an automatic counter, was 263,995. Entry of sockeye into Sproat Lake began and ended about 2 wk earlier than at Great Central Lake; at both locations peak periods of passage were associated with high water levels in early July and early September. Diurnal migration patterns differred at the two counting sites. Peak passage generally occurred earlier in the morning at Great Central Lake than at Sproat and the proportions of the daily runs passing at night reached much higher levels at Great Central Lake. The considerable variations in diurnal migration patterns at both locations was not completely random and allowances were made for this when making estimates based on partial visual counts. Some observations on the passage of other salmon species were also made.

Notes - contains information on problems and evaluation.

106. Namtvedt, T. 1978. Tests of the new side-scanning salmon counter. Alaska Dep. Fish Game. Div. Comm. Fish. (unpubl. manuscr.): 5 p.

A Bendix side-scanning sonar counter was tested in several Alaskan Rivers in 1977. The side scan sonar counted within 5% of visual counts made at towers or weirs.

Notes - contains information on problems and evaluation.

107. Namtvedt, T.B., N.V. Friese & D.L. Waltemyer. 1979. Cook Inlet sockeye salmon studies. Alaska Dep. Fish Game. Tech. Rep. for period July 1, 1977 to June 30, 1978: 41 p.

Sockeye salmon (*Oncorhynchus nerka*) research investigations were performed in the Upper Cook Inlet Area from July 1, 1977 through June 30, 1978 as part of a continuing effort to develop the technology and obtain the information required for the eventual restoration of depleted stocks and the optimum management of the fishery. In the course of these investigations the commercial fishery was monitored, assistance was provided to evaluate a technique of separating salmon stocks on the basis of scale pattern analyses, the side scanning solar salmon counter was further developed and tested, the sockeye salmon escapement into the Kenai, Kasilof and Susitna Rivers was monitored, and optimum escapement studies were conducted within the Kenai and Kasilof River drainages. A summary and recommendations for future studies are included.

Notes - contains information on methodology, problems and evaluation.

108. Namtvedt, T.B., N.V. Friese, D.L. Waltemyer, M.L. Bethe and D.C. Whitmore. 1977. Investigations of Cook Inlet sockeye salmon. Alaska Dep. Fish Game Tech. Rep. for period July 1, 1975 to June 30, 1976: 75 p.

Commercial catches of sockeye salmon in the Cook Inlet area have declined noticeably in recent decades. Management of the fishery on a maximum sustained yield (MSY) basis has not been possible. Studies were conducted to develop the technology and obtain the information required for the eventual restoration of depleted stocks and management of the fishery on a MSY basis. The magnitude and timing and the age, length and sex characteristics of sockeye salmon harvested were monitored. Various genetic characteristics of 13 breeding populations of sockeye salmon were categorized. Work was initiated on developing a computer model capable of calculating the proportions of stocks commercially harvested in a mixed fishery catch. Sockeye salmon escapement in numerous lakes and streams was enumerated and/or monitored. Optimum escapement investigations in the Kenai and Kasilof River drainages were continued. A summary of the findings derived from these investigations and recommendations for further study are included.

Notes - contains information on comparions between techniques.

109. Tarbox, K.E., B.E. King and D.L. Waltemyer. 1981. Cook Inlet sockeye salmon studies. Alaska Dep. Fish Game. Tech. Rep. for period July 1, 1979 to June 30, 1980: 101 p.

The total return (catch and escapement) of salmon to Cook Inlet area is tabulated. Sockeye salmon escapements to the major rivers were measured by hydroacoustic methods. Sockeye escapement and fry abundance were compared.

Notes - contains information on methodology and comparison between techniques.

110. Whitt, F.R., D.M. Gaudet and R. Johnson. 1981. An improved echo counter for low-target density surveys. Univ. Wash. Fish. Res. Inst. Circ. 81-3: 12 p.

A series of six bottom-mounted transducers, spaced 3 m apart, connected to a receiver and counting system, were employed in the Kvichak River (Alaska) to obtain indexes of daily upriver passage rates of migrating adult sockeye salmon.

Limitations of the system are discussed.

Notes - contains information on problems and evaluation.

See also reference number 5.

L. HYDROACOUSTIC (SOUNDER) SURVEYS

111. Thorne, R.E. and J.J. Dawson. 1974. An acoustic estimate of the escapement of sockeye salmon (*Oncorhynchus nerka*) into Lake Washington in 1971. J. Fish. Res. Board Can. 31: 222-225.

The feasibility of estimating the escapement of sockeye salmon (*Oncorhynchus nerka*) into Lake Washington by hydroacoustics was explored during 1971. Surveys were made of large fish targets within the lake just before and after the spawning migration of sockeye salmon up the Cedar River. A decrease was observed after the spawning migration comparable to the estimated escapement as determined by weir counts and spawning ground surveys.

Notes - contains information on evaluation and problems.

112. Thorne, R.E. 1979. Hydroacoustic estimates of adult sockeye salmon (*Oncorhynchus nerka*) in Lake Washington, 1972-75. J. Fish. Res. Board Can. 36: 1145-1149.

Hydroacoustic techniques were used on Lake Washington from 1972 to 1975 to estimate the potential escapement of sockeye salmon (*Oncorhynchus nerka*). Target strength measurements were used to establish a threshold which would separate the larger adult sockeye salmon from smaller resident fish. The acoustic estimates of escapement were very similar to those obtained from visual observations at the Hiram M. Chittenden ship canal locks, observations on the Cedar River and spawning ground surveys.

Notes - contains information on problems, evaluation and comparison between techniques.

113. Wood, F.E.A. and B. Mason. 1971. Echo sounder enumeration of Rivers Inlet sockeye salmon, 1967-1970. Can. Dep. Fish. For., Fish Serv. Pac. Reg. Tech. Rep. 71-12: 40 p.

A commercial fishing vessel, equipped with a Furuno Model 701 "midget" 50 kHz echo sounder was chartered to conduct sounding surveys in Rivers Inlet, above the commercial fishing boundaries.

Data were used to estimate escapements in the system.

Compared to spawning ground surveys, calculated estimates based on this method were low. Deviations were 58%-270% in 1968, 12%-57% in 1969 and 11%-150% in 1970.

Notes - contains information on problems and evaluation

114. Vroom, P.R. 1971. An attempt to determine abundance and distribution of migrating Skeena River salmon stocks by acoustical means. Can. Dep. Fish. For., Fish. Serv. Pac. Reg. Tech. Rep. 71-5: 33p.

Reference not available for review.

See also reference number 90.

M. CATCH PER UNIT EFFORT AND TEST FISHING

115. Alexandersdóttir, M. and O.A. Mathisen. 1981. Nushagak Bay king salmon escapement model. Univ. Wash. Fish. Res. Inst. FRI-UW-8114: 43 p.

Age composition, exploitation rate, fecundity and management theory for Nushagak king salmon are discussed.

A method of estimating king salmon escapements, employing catch per unit effort data from subsistence fisheries is described and compared to escapement estimates made by aerial surveys. The calculated value for 1980 was 88,000, as compared to an aerial estimate of 145,000.

Suggestions are made to improve the accuracy of the method and to use it to predict egg depostion potential as well as total escapement.

Notes - contains information on methodology, problems, evaluation and technique comparison.

116. Austin, A.D. 1970. The 1969 Columbia River spring test fishing program. Wash. Dep. Fish. (unpubl. manuscr.): 26 p.

The eleventh annual spring chinook test fishing program on the Columbia River was conducted in 1969 during March and April to determine run size, timing and distribution prior to the setting of the 1969 spring commercial Columbia River gill net season. Due to an abnormally early freshet the spring chinook migration was delayed. As a result the linear relationship between test fishing catches and run size underestimated the actual run.

Notes - contains information on problems and evaluation.

117. Gangmark, H.A. 1957. Fluctuations in abundance of Columbia River chinook salmon, 1928-54. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 189: 21 p.

The U.S. Fish and Wildlife Service is legislatively charged by the Coordination Act of 1934 as ammended August 14, 1946, to investigate Federal water-use influence on the fishery and to provide for the protection of these resources. This is an evaluation of the Bonneville Dam influence on chinook salmon pupulations in the Columbia River based on the availability of the fish to the gill net (Catch-per-unit-effort).

Breaking the fishing year into spring, summer and fall components, return estimates based on the periods before and after construction of the dam show mixed trends. The spring returns are better after dam construction, the summer returns are far worse and the fall returns balance.

Ratios of return to escapement for the three seasons of the year show a spring improvement after dam construction, a large drop in summer and a lesser drop in fall. Return-to-escapement ratio levels after Bonneville Dam appear related to the proportion of chinook which pass Bonneville Dam as adults and again as juveniles. For example, all summer chinooks spawn above Bonneville Dam while roughly two thirds of the spring chinooks spawn above the dam. On the other hand, the annual abundance curve reveals no change in trend before and after dam construction and the mixed trends of spring, summer, and fall seasons do not appear influenced by the construction date of Bonneville Dam.

Notes - contains information on problems.

118. Mathisen, O.A. 1971. Escapement levels and productivity of the Nushagak sockeye salmon run from 1908 to 1966. U.S. Fish Wildl. Serv. Fish. Bull. 69(4): 747-763.

Since the inception of a commercial fishery for sockeye salmon in Nushagak District, Bristol Bay, Alaska, the annual yields have followed a definite pattern. Catches increased during a relatively short development phase of the fishery, then stabilized for some years and then declined in two steps separated by periods of relative stability.

For years the cause of the decline had been thought to be overfishing, and various measures of curtailment had been placed upon the fishing industry.

Evidence is presented in this paper that the average escapement or the potential egg deposition remained about the same during each of three periods (1908-1919, 1925-1945 and 1946-1966); hence the diminution in the runs was due not to lack of spawners but to a decline in the rate of return per spawner.

So that the cause or causes of the present low reproductive potential can be ascertained, the effects of fishing on the stocks of salmon must be examined. Besides removing part of the run, the yearly commercial fishing operation may have altered either the age composition or the distribution of the escapement.

Available historical records were examined for evidence of these types of changes but largely with a negative result; therefore, the hypothesis was advanced that the observed declining rate of return per spawner is caused by a declining basic productivity of the nursery areas. The latter is then ascribable to the cumulative effect of relatively little enrichment of bioenergetic elements from salmon carcasses since the instigation of commercial fishing operations in comparison with the prefishing era when the entire virgin run escaped to the spawning grounds.

Suggestions are made for future field testing of this hypothesis.

Notes - contains information on methodology, problems and evaluation.

119. Palmer, R.N. 1972. Fraser River chum salmon. Can. Dep. Env., Fish. Serv. Pac. Reg. Tech. Rep. 72-1: 284 p.

The purpose of the report is to present a summary and analysis of data obtained during the 1960-69 period and to describe the population dynamics and racial characteristics of Fraser River chum salmon.

A review of the commercial fishery for Fraser River chum salmon is included.

The report includes a discussion of the productivity of the stock, escapement estimates and requirements, proposed fishing patterns, exploitation rates and potential for stock enhancement.

Notes - contains information on methodology, evaluation and technique comparisons.

120. Rounsefell, G.A. 1949. Methods of estimating total runs and escapements of salmon. Biometrics 5(2): 115-126.

A method of estimating total salmon population in a system, using gillnet catch data, is described. Data are taken from the Fraser River, 1894-1945.

Notes: contains information on evaluation.

121. Silliman, R.P. 1950. Fluctuations in abundance of Columbia River chinook salmon (*Oncorhynchus tschawytscha*), 1935-1945. U.S. Fish Wildl. Serv. Fish. Bull. 51(51):363-383.

The United States Fish and Wildlife Service is charged by statute with the responsibility of reviewing plans for all water-use projects of the Federal Government, in order to determine their effect on populations of fish and to provide for the protection of these populations. Where runs of anadromous fish in the Columbia River Basin are concerned, the function has three primary aspects: (1) the determination of the species and size of the particular runs affected; (2) the ascertainment of the types of fish protective devices, if any, needed and the economic feasibility of these; and (3) the evaluation of the success of fish protective devices by comparison of the size of the runs before and after construction of dams and other such works. The present study is concerned with the most abundant of the Columbia River anadromous fish, the chinook (spring or king) salmon, *Oncorhynchus tschawytscha*.

In brief, the purposes of this report are to (1) present a detailed description of a method of calculating catch-per-unit-of-effort, for use in extending the present series of data both forward and backward; (2) indicate a method of deriving from the calculated catch-per-unit values a measure of abundance; and (3) make a preliminary appraisal of the importance of the various factors affecting abundance.

Notes - contains information on problems and evaluation.

122. Stockley, C.E.1969. The 1967 Columbia River spring chinook test fishing program. Wash. Dep. Fish. (unpubl. manuscr.): 38 p.

The year 1967 marked the ninth season of test fishing to estimate the size and timing of the spring chinook run to the Columbia River. The Woody Island estimate of 139,000 fish in the run was significant as the total run fell within the statistical range of variance. Relating the Corbett test catches to annual runs resulted in an over estimate. Records were made of the location of the fish in the nets. The data show that, how, and where the fish were caught and net marked, depended on the size of the fish and the size of the nets.

Notes - contains information on problems and evaluation.

123. Stockley, C.E. 1972. The 1971 Columbia River spring chinook test fishing program. Wash. Dep. Fish. (unpubl. manuscr.): 24 p.

The spring of 1971 marked the thirteenth season of test fishing to estimate the size and timing of the spring chinook run to the Columbia River.

Test fishing catch trends at Woody Island and Corbett indicated a normal entry and passage up to the river, however, higher than normal flows in late March and early April delayed ascent at Bonneville Dam. Control of flows to reduce nitrogen in late April resulted in a rapid passage of the run up the river.

Run estimates at both sites indicated an average run, but confidence limits were so broad that estimates were not significant. A new multiple regression of Corbett catches and January-February water temperatures resulted in a significant relationship ($r=.69$) and $y=171,720$. The actual run was 175,000 fish.

Notes - contains information on evaluation.

124. Stockley, C. E. 1974. The 1973 Columbia River spring chinook test fishing program. Wash. Dep. Fish. (unpubl. manuscr.): 30 p.

The spring of 1973 marked the fifteenth season of test fishing to estimate the size and timing of the spring chinook run.

A low, clear river with steadily increasing water temperature, with high early catches at Woody Island and Corbett, indicated early entry and rapid passage of the run up the river.

Run estimates at both sites indicated an above average run. Woody Island - 222,000, Corbett - 200,000, Corbett multiple - 240,000. The actual preliminary estimate was 237,900 fish in the upriver run.

Analysis of the Corbett catch for sex, age, length and weight continued to show predominance of large females preferred for escapement and reproduction, in this early portion of the run.

Notes - contains information on evaluation.

125. Todd, I.S. and F.V. Dickson. 1970. Nass River sockeye salmon. A review of the commercial fishery and a summary of the 1963 to 1969 biological programs. Can. Dep. Fish. For., Fish. Serv. Pac. Reg. Tech. Rep. 70-10: 60 p.

The Nass River is British Columbia's fourth largest producer of sockeye salmon. Commercial exploitation of the sockeye stocks of the Nass was initiated in 1881 with the opening of the Nass River Cannery at Nass Harbour, and a major fishery still prevails although canneries are no longer operated in the area. Catches have ranged as high as 450,000 sockeye and until the early 1940's averaged approximately 250,000 annually. Since that time major changes have occurred in the fishery, and the stock, as reflected by catches in the estuarine region, has declined substantially in abundance.

The Resource Development Branch of the Department of Fisheries and Forestry of Canada in 1963 initiated a biological program designed to provide the information required for precise management of the Nass River sockeye stocks. The purpose of this report is to review the history of the Nass River sockeye fishery and to present the results of the biological programs conducted to date.

Notes - contains information on methodology.

126. Yuen, H.J. (ed). 1981. 1980 Bristol Bay salmon test fishing projects. Alaska Dep. Fish Game Tech. Data Rep. 65: 73 p.

Test fishing was conducted to estimate salmon run timing and size into Bristol and Nushagak Bays, and to estimate escapements in four selected rivers. Tagging to determine lag time between escapement test fishery and escapement counting towers was also conducted. Summary and data tables are presented.

Notes - contains information on methodology, problems, evaluation and technique comparisons.

See also reference numbers 16 and 104.

N. ADDENDUM

127. Hallock, R.J., D.F. Fry, Jr. and D.A. Lafaunce. 1957. The use of wire fyke traps to estimate the runs of adult salmon and steelhead in the Sacramento River. Calif. Fish Game 43(4): 271-298.

This article describes the construction and use of large cylindrical fish traps and their effectiveness in capturing king salmon, steelhead, trout, silver salmon, striped bass, American shad and other species of fishes in the Sacramento River.

Detailed material lists and construction directions are given, together with fishing and transportation methods.

The trap was fished in flows between 5,000 and 10,000 cfs with velocities of 2-3 feet per second near the shore.

Seven of these traps were fished at Fremont weir and captured from 10-20% of the steelhead run, 1% of the king salmon run and, in 1956, approximately 11% of the silver salmon run.

Notes- contains information on methodology and evaluation.

128. Tait, N., J.L. Hout and F.V. Thorsteinson. 1962. An evaluation of fyke trapping as a means of indexing salmon escapements in turbid streams. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 428: 1-18.

Test-fishing experiments conducted on the Kenai River in Alaska in 1957, 1958 and 1959 showed that large metal fyke traps were effective for obtaining indices of the escapement of red salmon into turbid streams. The traps also provided information about the age and size composition and rate of migration of red salmon runs of the Kenai River in those years.

The traps were evaluated as test-fishing gear by comparing the characteristics of the catch in them with the commercial catch and with the results of test gill netting and seining. Traps were fished at various locations to determine the influence on the catch of water depth and velocity and proximity to shore. The studies revealed that red salmon migrated chiefly along the bank in the turbid water of the Kenai River. This same migration pattern has been observed in clear-water streams.

The number of red salmon caught in the traps each year was used as an index of the escapement. The data show a significantly lower escapement occurred in 1959 than in 1957 and 1958.

Notes - contains information on problems and evaluation.

129. Clay, C.H. 1961. Design of fishways and other fish facilities. Department of Fisheries. Ottawa. 301 p.

Information is provided on the design and operation of fish locks, fish elevators, fish fences, fish screens and artificial spawning channels used on the Pacific coast of Canada.

Notes - contains information on methodology and problems.

130. Wright, M.C. 1982. Results of adult sockeye enumeration and sampling program 1981. Section One. J.C. Lee and Associates Ltd. Report Series 2-4. 89 p.

Adult sockeye salmon *(Oncorhynchus nerka)* returning to five British Columbia lakes to spawn were enumerated and sampled for biological information, as part of the ongoing monitoring and evaluation phase of the Lake Enrichment Program.

Sockeye spawning in four lakes in northern coastal B.C. were enumerated using streambank visual counts, Petersen mark/recapture and snorkle float techniques.

Sockeye migrating to Hobiton Lake on Vancouver Island were enumerated as they passed through a broomstick fence constructed on the Hobiton River.

Notes - contains information on problems, evaluation and technique comparisons.

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

This Bulletin is the author's third that deals with the general field of biological statistics of fish populations. The earlier ones date from 1948 and 1958, respectively, and both are long out of print. The present work began as a revision of the 1958 text, but so many changes, additions, and deletions proved desirable that it has become in many respects a new work. Even so, the text does not attempt to include all the developments in this field in recent years. The general plan and arrangement of materials is similar to that of the 1958 Bulletin (see reference 12).

INTERVIEW SUMMARIES

This section lists names and addresses of people interviewed to obtain information on techniques used to estimate escapement of Pacific salmon stocks.

A representative selection of biologists from B.C., Alaska, Washington, Oregon, California and Idaho were interviewed by telephone to obtain information on new estimation techniques and/or unpublished information on existing techniques.

Pertinent information from the interviews has been incorporated into the review of each technique, therefore only a short summary outlining techniques discussed is included in this section.

BRITISH COLUMBIA

A.D. Anderson
Senior Biologist, North Coast Management Biology Unit
Field Services Branch, Department of Fisheries and Oceans
60 Front St.
Nanaimo, B.C. V9R 5H7
(604) 753-4181

Techniques discussed included foot surveys, float survey, aerial (fixed wing and helicopter), and mark/recapture techniques. These were used to enumerate all salmon species in central British Columbia.

Mike Fretwell
Project Biologist, Engineering Section
International Pacific Salmon Fisheries Commission
Box 30
New Westminster, B.C. V3L 1B3
(604) 521-3771

Use of a Pulsar electronic fish counter to enumerate sockeye and pink salmon passing through the Seton Creek fishway in British Columbia was reviewed.

Dr. Glen H. Geen
Professor of Biological Sciences
Simon Fraser University
Burnaby, B.C. V5A 1S6
(604) 291-3536

Dr. Geen discussed the following salmon escapement estimation techniques:

1) the mark/recapture technique used by the International Pacific Salmon Fisheries Commission to enumerate sockeye and pink salmon in the Fraser River.
2) an aerial (helicopter)/photographic method used to enumerate chinook salmon spawning in the Morice River of British Columbia in 1979.

Terry Gjernes
Biologist, Lake Enrichment Program
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
(604) 758-5202

Foot surveys, aerial (helicopter) surveys, fence counts and mark/recapture surveys made by the International Pacific Salmon Fisheries Commission to enumerate sockeye and pink salmon in British Columbia were discussed.

Robin Harrison
Senior Biologist, Fraser River, Northern B.C. and Yukon Division
Field Services Branch, Department of Fisheries and Oceans
Room 309, 549 Columbia St.
New Westminster, B.C. V3L 1B3
(604) 524-7143

Robin Harrison has used foot surveys, aerial and broomstick fence techniques to enumerate all species of salmon in British Columbia.

Dr. Kim D. Hyatt
Head of Lake Enrichment Program
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
(604) 758-5202

Discussion focused on the following salmon escapement estimation techniques used in British Columbia:
1) foot surveys to enumerate spawning kokanee.
2) a method of back-calculating sockeye escapements from hydroacoustic estimates of fry abundance in a lake.

Studies comparing foot surveys to mark/recapture surveys, hydroacoustic surveys, fence counts and electronic counter counts were also outlined.

Ron Kadowaki
Biologist, North Coast Management Biology Unit
Field Services Branch, Department of Fisheries and Oceans
Room 109, 417 - 2nd Ave. West
Prince Rupert, B.C. V6J 1G8
(604) 627-8730

A comparison of mark/recapture and foot survey estimates of pink salmon escapement in the Yakoun River, B.C. was discussed. A method incorporating discriminant analysis of Nass River sockeye salmon scale circuli in the estimation of tributary escapements was also outlined.

Jack MacDonald
Salmon Biology Section
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
(604) 758-5202

This interview examined foot surveys and mark/recapture surveys used to estimate salmon escapement in British Columbia.

James I. Manzer
Research Biologist, Lake Enrichment Program
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
(604) 758-5202

General observations were made on most salmon escapement estimation techniques used in British Columbia.

David C. Schutz
Senior Biologist, South Coast Division
Field Services Branch, Department of Fisheries and Oceans
1090 W. Pender St.
Vancouver, B.C. V6E 2P1
(604) 666-1497

The use of foot surveys, aerial surveys and fence counts to estimate salmon escapement in British Columbia was reviewed.

Fred C. Withler
Coastal Habitat Ecology Unit, Salmon Habitat Section
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
(604) 758-5202

Foot surveys and fence counts made to enumerate sockeye and pink salmon in British Columbia were discussed.

Jim C. Woody
Assistant Chief, Fishery Management Division
International Pacific Salmon Fisheries Commission
Box 30
New Westminster, B.C. V3L 1B3
(604) 521-3771

This interview covered a number of techniques in detail including foot surveys, float surveys, tower counts, fence counts, mark/recapture, hydroacoustic and test fishing methods used by the International Pacific Salmon Fisheries Commission to enumerate sockeye and pink salmon in the Fraser River.

ALASKA

Gary K. Gunstrom
Region One Research Supervisor, Commercial Fisheries Division
Alaska Department of Fish and Game
230 South Franklin St., Suite 301
Juneau, Alaska 99801
(907) 465- 4250

This interview considered aerial surveys and incidental techniques used to produce indices of escapement for all salmon species in the S.E. region of Alaska.

J. Doug Jones
Pink and Chum Salmon Investigation, S.E. Alaska Region
Alaska Department of Fish and Game
230 South Franklin St., Suite 301
Juneau, Alaska 99801
(907) 465-4250

The aerial survey technique used to estimate pink salmon escapement in S.E. Alaska was discussed.

Charles P. Meacham
Regional Research Supervisor, Central Region
Alaska Department of Fish and Game
333 Raspberry Rd.
Anchorage, Alaska 99502
(907) 344-0541

The use of tower and aerial counts to estimate sockeye escapement in central Alaska was reviewed during this interview.

Dick Nickerson
Research Biologist, Division of Commercial Fisheries
Alaska Department of Fish and Game
333 Raspberry Rd.
Anchorage, Alaska 99502
(907) 344-0541

Tests of the Bendix fan scan sonar fish counter in the Kuskokwim River, Alaska were discussed.

Kenneth E. Tarbox
Cook Inlet Research Project Leader, Commercial Fisheries Division
Alaska Department of Fish and Game
Box 3150
Soldotna, Alaska 99669
(907) 262-5338

The following methods used to estimate salmon escapement in the Cook Inlet area of Alaska were outlined:

1) foot surveys, aerial counts and weir counts used as an index of escapement to spawning areas.
2) Bendix side scan sonar fish counters used to estimate the total escapement in river systems.

WASHINGTON

Jim Ames
Fishery Biologist, Puget Sound Harvest Management Division
Washington Department of Fisheries
Room 115, General Administration Building
Olympia, Washington 98504
(206) 753-0198

The various salmon escapement estimation techniques used to produce escapement indices in the Puget Sound area of Washington were discussed, as follows:

1) float, tower and aerial counts used to enumerate sockeye salmon in the Lake Washington system.
2) redd counts made by foot surveys, float surveys and aerial surveys to estimate chinook escapement.
3) stream walking to estimate chum escapement.

Donald L. Cole
Fisheries Management Biologist
U.S. Fish and Wildlife Service
Fisheries Assistance Office
2625 Parkmont Lane, Building A
Olympia, Washington 98502
(206) 753-9460

A mark/recapture method of estimating chum, chinook and coho salmon escapement in the Puget Sound area of Washington was reviewed.

Tim Flint
Fish Biologist, Coho Stock Assessment, Harvest Management Division
Washington Department of Fisheries
Room 115, General Administration Building
Olympia, Washington 98504
(206) 753-0198

This interview considered the use of index stream surveys to estimate the escapement of coho salmon in the Puget Sound area of Washington.

Russ Orrell
Regional Biologist, Skagit Lab
Washinton Department of Fisheries
302 Sharon Ave.
Burlington, Washington 98233
(206) 755-0421

Mary Aguero and Don Hendrick of the Washington Department of Fisheries also participated in the interview.

The following salmon escapement estimation techniques used in the Puget Sound area were discussed:

1) aerial redd surveys within index areas to estimate chinook salmon escapement.
2) carcass counts made in index areas to estimate pink salmon escapement.
3) live and dead counts to estimate chum salmon escapement.

Dr. Don E. Rogers
Fisheries Research Institute
University of Washington, WH 10
Seattle, Washington 98105
(206) 543-7628

The use of foot, aerial, tower and mark/recapture surveys to estimate sockeye escapement in the Wood River Lakes system of Alaska was reviewed.

Bill Wood
Management Biologist, North Coast Region
Washington Department of Fisheries
Route #1, Box 1375
Forks, Washington 98331
(206) 374-9440

This interview covered the use of foot, float and aerial redd surveys of index streams to estimate coho and chinook salmon escapement in Washington's Olympic Peninsula.

OREGON

Thomas E. Nickelson
Research Project Leader
Oregon Department of Fish and Wildlife
Research and Development Section
303 Extension Hall, Oregon State University
Corvallis, Oregon 97331
(503) 754-4431

The use of index stream surveys to estimate coho escapement in Oregon was discussed.

CALIFORNIA

Bob Rawstron
Anadromous Fisheries Branch
California Department of Fish and Game
1701 Nimbus Rd. #B
Rancho Cordova
Sacramento, California 95670
(916) 445-3531

Use of a carcass mark/recapture technique to estimate chinook escapement in California was outlined during this interview.

IDAHO

John Coon
Anadromous Fishery Manager, Bureau of Fisheries
Idaho Department of Fish and Game
P.O. Box 25
Boise, Idaho 83707
(208) 334-3700

The use of redd surveys and hatchery returns to estimate chinook escapement in Idaho was briefly discussed.

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We also wish to express our thanks to the many fisheries scientists and biologists who contributed to this project through interviews. Without their participation and co-operation, most of the unpublished information collected in this report could not have been obtained.

Appendix A. List of abbreviations used to identify U.S. and Canadian government agencies.

DFO - Canada Department of Fisheries and Oceans

WDF - Washington Department of Fisheries

USFWS - U.S. Fish and Wildlife Service

FRI - Fisheries Research Institute

ADFG - Alaska Department of Fish and Game

ODFW - Oregon Department of Fish and Wildlife

CDFG - California Department of Fish and Game

IDFG - Idaho Department of Fish and Game

IPSFC - International Pacific Salmon Fisheries Commission