Quantitative Electrofishing In Newfoundland and Labrador: Result of Workshops to Review Current Methods and Recommend Standardization of Techniques

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The Department of Fisheries and Oceans (DFO) has used electrofishing to conduct research on fluvial production of salmonids for many years and a variety of equipment and techniques peculiar to specific projects have been employed. In 1993 and 1994, workshops were convened to review the objectives, purpose, and techniques used by various researchers in studies employing electrofishing. The primary focus of these workshops was to, by consensus, develop a standardized set of techniques for electrofishing. This workshop report includes a short review of papers presented at the workshops as well as a synopsis of discussions. A comprehensive set of recommendations is provided towards standardizing electrofishing techniques. A set of research recommendations to address several of the issues raised at the workshop is also included. Appendices include: a selection of papers presented at the workshops; a list of habitat variables that should be collected in association with electrofishing studies, including recommended methods of measurement; a set of standardized forms, with instructions, for collection of field data on electrofishing sites, habitat attribute data, fish collection, as well as specifications and coding sheets for computer entry of information.

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Depuis de nombreuses années, le ministère des Pêches et des Oceans (MPO) a recours a la pêche à l'électricité pour ses recherches sur la productivité des salmonidés dans les habitats fluviaux; ils s'est servi à cette fin, selon les projets, de toutes sortes d'équipements et des techniques. En 1993 et 1994, des ateliers ont été organisés pour passer en revue les objectifs et les raisons d'être de ces études, ainsi que les techniques de pêche à l'électricité utilisées par les différents chercheurs. Ces ateliers avaient pour objet principal d'arriver à un concensus sur un ensemble standardisé de techneques de pêche à l'électricité. Le présent rapport d'atelier comprend un bref survol des documents présentés dans le cadre des ateliers, ainsi que les grandes lignes des échanges qui s'y sont désroulés. Il contient aussi un ensemble de recommandations sur la standardisation des techniques de pêche à l'électricité, ainsi que les résponses à plusieurs des problèms soulevés durant les ateliers. En appendice, on trouvera divers documents présentés aux ateliers; un liste des variables reliées à l'habitat dont il faudrait rendre compte dans les futures études de pêche à l'électricité ainsi que des methodes de mesure recommandées; et un série de formules standardisées, accompagnées d'instructions pour la collection de données sur les sites de pêche à l'électricité, sur les attributs de habitat, sur la cueillette du poisson, ainsi que des spécifications et des feuilles de codage pour l'introduction de données sur ordinateur.

Preface

The Department of Fisheries and Oceans (DFO) has employed electrofishing as a technique to collect data and conduct research on fluvial production of salmonids for many years. Over the years, researchers have used a variety of types of equipment, have evolved specific techniques tailored to the particular research project being undertaken, and have employed a variety of approaches to analyses of data, specifically in estimation of populations. As a result, data collected from various studies may not be readily comparable and electrofishing may not be the most appropriate technique for the collection of data. Habitat data are also often collected by various researchers conducting electrofishing studies, to describe the site being studied to assist in the interpretation of data, while others collect detailed habitat data to assist in the development of habitat based models for habitat evaluation, fish production, stock assessment, etc. Similarly, there has been no attempt to standardize habitat attribute data collected in association with electrofishing.

On April 20 to 22, 1993 the Salmonid and Habitat Sciences Division (SHSD), Science Branch, DFO, held an in-house workshop to review the objectives, purpose, and techniques used by various researchers within the Division who employ electrofishing technology in the process of collecting data and conducting research. This workshop resulted in the development of a draft set of recommendations for standardization of methods and collection and use of habitat attribute data. A second follow-up workshop was held one year later (April 21-22, 1994) to review and finalize these recommendations. This second workshop was also intended to discuss issues related to estimation of bias and precision in electrofishing estimates and to identify any research recommendations related to the use of the technology and refinement of methods. These two workshops were attended by a cross section of agencies, companies, and groups who utilize electrofishing to collect or evaluate juvenile salmonids in fluvial environments. Participants included staff of the SHSD, the Salmonid Research Group (Memorial University of Newfoundland), biological consulting companies, Newfoundland and Labrador Hydro, the Newfoundland Department of Fisheries, Food and Agriculture, and DFO's CODE group (Centre of Disciplinary Expertise).

The primary purpose of these workshops was to review the situations, objectives and purpose for using electrofishing techniques for the collection of data and to determine whether electrofishing is the most appropriate and reliable technique for the specific purposes and applications. The workshops were to review, in detail, the various techniques employed by researchers and other practitioners in Newfoundland, with a view towards developing a consensus on standardization of techniques. This would ensure that data collected from various projects and activities would be comparable and information collected could possibly contribute to a larger database for more general applicability. An additional purpose of the workshops was to review the various habitat attributes being measured, and methods of data collection in conjunction with electrofishing, so that a set of variables (with methodologies) could be recommended for inclusion in standard electrofishing studies. A recommended set of habitat attributes, with methods of measurement, is contained in this report. Another major theme of discussions at the workshops was related to quality assurance of electrofishing techniques and the possibility of developing an approach to include the measurement of bias and accuracy associated with quantitative electrofishing.

Other agencies and groups who consult this report should consider that while these workshops were intended as a review of quantitative electrofishing applications and methodologies and consequently all potential applications were not considered. Additionally, this workshop has evaluated the considerations and requirements for rigorous collection and analysis of data. The scientific rigour and attention to detail required for peer review and publication of data may not always be applicable to the full range of situations to which electrofishing may be employed.

Introduction

The Salmonid and Habitat Sciences Division held an Electrofishing Workshop on April 20 to 22, 1993. This workshop resulted, in part, from the Division Program Review and Evaluation process (PRE) which identified concerns regarding the application of population estimates from electrofishing surveys and variations in methodologies used. The workshop was attended by individuals from the Division, the CODE group, and by researchers from the Salmonid Research Group, Memorial University of Newfoundland. The workshop opened with a review of the objectives by the workshop chairpersons (Scruton, Gibson). These objectives were as follows:

(1) Review the objectives and purpose for conducting juvenile population estimates using electrofishing studies, the methodologies/equipment currently in use within the Division, and to determine if the technology is being properly applied.

(2) Examine related aspects such as sampling design, site selection, applications of data obtained from electrofishing, methods of population census, habitat attributes measured, fisheries data collected, etc.

(3) Develop a consensus as to the appropriate electrofishing techniques and methods to be employed, the population estimator(s) that could be used, the potential applications of data (and associated assumptions and limitations), and the appropriate habitat variables that could be collected (including methods of measuring these variables).

This was followed by presentation of prepared papers from individuals from each of the three Sections within SHSD who have used electrofishing techniques extensively in research and assessment. The authors were directed to focus on the following:

- objectives and rationale;
- study design and site selection;
- techniques and equipment;
- habitat data collected;
- fisheries data collected;
- data analyses and population estimation;
- application of data;
- assumptions, constraints, cautions;
- etc.

Papers were presented by R. J. Gibson (Electrofishing and Habitat Measurement Techniques Employed by the Salmon and Char Section), C.E. Bourgeois (Electrofishing Techniques Employed by the Enhancement and Aquaculture Section in Determining Effectiveness of Fry Stocking), and D.A. Scruton (Electrofishing Techniques Employed by the Habitat Research and Assessment Section in Habitat Research and Environmental Effects Monitoring). These papers provided a good cross section of how electrofishing has been used in the Division, for distinctly different purposes. These presentations were followed by short discussion.

Three additional papers were presented on various ancillary issues related to fixed effort electrofishing techniques (C.C. Mullins, DFO, Salmon and Char Section; Length Frequency Sampling Using Fixed Electrofishing Effort), considerations of population size in experimental design (S.C. Riley, Salmonid Research Group, MUN; Under-estimation of Population Size by Removal Estimators), and new approaches to estimation of population size (R.A. Myers, DFO, CODE; Recent Advances in Analyses of Electrofishing Data). These papers were also followed with discussion.

The presentation of papers was followed by general, wide ranging discussion of the various issues raised by the various papers and the specific objectives of the workshop. The major themes of the discussion included:

- habitat variables to be collected and measurement techniques;
- habitat classification and stratification;
- population estimators and related considerations;
- station size as related to population size and statistical considerations;
- quality control/assurance considerations;
- research issues related to improving electrofishing techniques.

A second follow-up workshop was held on April 21-22, 1994 to review and finalize recommendations on standardization of electrofishing techniques and collection of habitat attribute data as developed from the initial workshop. This second workshop was also intended to review and discuss issues related to estimation of bias and precision in electrofishing estimates and to identify any research recommendations related to technology and improvement of methods. This workshop also included participation from outside of DFO (including the consulting community, Newfoundland and Labrador Hydro, Newfoundland Department of Fisheries, Food and Agriculture) in order that recommendations could consider all possible applications of electrofishing techniques and to examine how scientifically rigorous electrofishing methods could be implemented in a variety of situations (e.g., the environmental assessment process). The only formal presentation at this second workshop was by Dr. W. Warren, of DFO's CODE Group, who gave a presentation on the assumptions of constant capture probability associated with maximum likelihood population estimates and proposed a new approach (model) for estimation of populations. This presentation is included and an ICES paper developed from this presentation is contained in Appendix D.

Objectives identified for the second workshop included:

(1) Review and finalize recommendations on standardization of electrofishing techniques.

(2) Review and finalize recommendations on standardization of collection of habitat attribute data.

(3) Discuss recommendations in (1) and (2) above as they relate to all potential regional applications of electrofishing.

(4) Discuss issues relating to estimation of bias and precision in electrofishing population estimates.

(5) Identify and priorize research recommendations related to electrofishing methodology.

This workshop report includes a short review of papers and presentations from the 1993 workshop and also contains a synopsis of discussions from both workshops addressing the workshop themes. A comprehensive set of recommendations for standardizing electrofishing techniques is provided, including quality assurance procedures (bias estimation) that could be included in electrofishing studies. A set of research recommendations is also provided to address several of the issues raised at the workshop. Appendices include: agendas of both workshops (A); a list of habitat variables that could be collected in conjunction with electrofishing, including methods of measurement (B); a set of data forms, with instructions and specifications, for field collection of electrofishing and habitat attribute data (C); a selection of full papers presented at the 1993 workshop (D).

The Canada - Newfoundland Cooperative Agreement for Salmonid Enhancement and Conservation (CNCASEC) has also provided some impetus for these workshops. Under this agreement, funding will be provided to Development Associations, Fish and Wildlife Groups, Conservation Associations, Outfitters, and other third party groups for projects related to Stock Assessment, Salmonid Enhancement, and Habitat Restoration and Improvement. A number of these projects may involve electrofishing and, as many groups may have limited experience in the use of this technology, it was considered that a standardized set of electrofishing techniques would assist groups undertaking these projects and would also ensure these sponsors are collecting reliable data of use to DFO. There are a number of other considerations and concerns related to inexperienced groups/individuals conducting electrofishing and these are provided in the Section on 'Recommendations for Standardization of Electrofishing Techniques'.

Electrofishing Practices Currently Used by the Salmonid and Habitat Sciences Division

This Section provides an overview of electrofishing techniques currently employed by the sections within SHSD, based largely on the papers presented at the 1993 workshop by R.J. Gibson (Salmon and Char Section), C.E. Bourgeois (Enhancement and Aquaculture Section), and D.A. Scruton (Habitat Research and Assessment Section). This Section also includes a presentation by C.C. Mullins on fixed effort electrofishing as a possible tool for stock assessment. These papers were to address: the purposes, objectives and rationale for using electrofishing; issues related to study design and site selection; specific field techniques and equipment used; the habitat data collected and methods of measurement; the fisheries data collected including sub-sampling strategies; analyses of data and estimations of population size (numbers and biomass); how data are used and applied; any assumptions, constraints, cautions, related to the electrofishing methodologies and data analyses. The major purpose of this section is to review the variety of approaches currently in use for areas of commonality and general applicability, examine differences in technique including how these differences have evolved, consider the advantages/disadvantages of the various approaches, and consider liabilities associated with generalization of techniques. A summary of these comparisons is provided in Table 1.

Salmon and Char Section (R.J. Gibson)

Objectives and Purpose

The paper presented by R.J. Gibson largely relates to research being conducted under the Experimental Rivers Program, ongoing since 1984, on three small watersheds on the southeast Avalon Peninsula. This project is concentrating on juvenile Atlantic salmon and brook trout, with a view to understanding the productive potential of river systems ('productive capacity') through assessing salmonid densities related to carrying capacity. The objective of this research is to use information collected to develop habitat based models for stock assessment (advice on optimum spawning escapement and egg deposition) and habitat evaluation (determine habitat 'quality' for environmental assessment, determination of 'no net loss', habitat compensation, etc.). This paper focused largely on the design of the study in relation to selection of sites and stratification of sampling by habitat type, the measurement of habitat attributes, and a general review of techniques. More detail on the techniques employed in this research program are provided in Gibson *et al.* 1993 while the application of these data to development of habitat evaluation methods is provided in Scruton and Gibson 1993.

Another possible application of electrofishing by the Salmon and Char Section, not addressed in the paper but brought out in discussion, is using electrofishing as a means to evaluate the effects of the moratorium on commercial Atlantic salmon fishing introduced in 1992 on juvenile fish production. Electrofishing could be used to provide an index of juvenile abundance in selected reaches of tributaries of major salmon rivers as a means of evaluating effects of (expected) increased spawning escapement related to the moratorium. This would compliment counting fence data on selected rivers or alternatively would provide a means of collecting data on a wider variety of rivers where counting fence operations would be technically difficult or prohibitively expensive.

Site Selection

Sites for population estimates are selected within a river system in representative reaches and within each reach, stations are stratified by types of habitat (Frissell *et al.* 1986), and where possible within each 'stream order' (*sensu*, Horton 1945, modified by Strahler 1957). For the purpose of using habitat attributes to assess the potential production of a watershed, the range of habitat types must be sampled. Replication of stations by habitat type within each reach is preferable; however resource limitations have resulted in compromises with respect to replication. Stations are sampled during the summer from mid-June and mid-August, after the main growing period, but sampling through the growing season is preferable to estimate production, if resources are available.

General types of habitat are taken from Allen (1951) and can be classified into the following major groups: cascade; riffle; run; flat; pool; lake. The general characteristics (velocities and depths) delineating these classifications are given in Table 2. 'Cascade' type habitat has never been sampled in the Experimental Rivers research. The basic strata therefore are the various tributaries within a watershed, and within each (where possible), the following types of habitat: riffle; flat; pool; run. Each station is confined to one habitat type wherever possible.

Electrofishing Techniques

A station is barricaded off with upstream and downstream nets of 0.6 cm square mesh, with the downstream net being installed first. Rubble and boulders for securing the bottom of the barrier nets are taken from outside the station, which is disturbed as little as possible, since the same stations are sampled (replicated) in subsequent years. Population estimates in shallow fast water areas (riffles) are made using an electrofisher by the depletion or removal method (Zippin 1958), with at least four sweeps, moving in an upstream direction. In deeper, slower waters, the electrofisher is not always effective, in which case fish are caught also by beach seine, and by fyke nets in lakes, and population estimates made by the Petersen mark and recapture Petersen method or, in larger lakes, by the multiple mark and recapture, or Schnabel, method (Ricker 1975).

Fish Sampling/Measurements

All fish are anaesthetized with CO_2, by dissolving an Alka Seltzer tablet in a few litres of water, and measured by fork length (total length for sticklebacks and eels), and placed in a recovery cage before release. Marked fish have two fins clipped. About 10 salmonids from each year-class are sacrificed for age, weight, and sex analyses, which includes staging of maturity (Kesteven 1960). These samples are measured fresh the same day. Condition factors (K) are calculated from the expression, $K = W.10^2.FL^{-3}$, where W = weight (g) and FL = fork length (cm). The individual weights of all fish collected are calculated from the mean condition factor for each particular length group. Ages are assigned to length frequency histograms after scale reading and verification of size groups. In autumn sampling, (precocious) mature male parr can be identified by their girth and frequently by release of milt with pressure, and these are identified separately for condition factor and weight, since they are relatively heavier than immature male and female parr.

Habitat Attributes and Measurement

Habitat variables that are measured at each station are shown in Table 3. Length and width to the nearest 0.1 m are measured with a tape measure. Two lengths (left and right banks) are taken if there is some curvature, and usually three width measurements are made (both wetted widths and bank full [bank to bank]). At lease five depths are taken at equidistant points across three transects, divided by n+1 to account for 0 depth at the edges. Mean water column velocity (at 0.6 depth) is measured at ¼, ½, and ¾ the distance across each transect. Until 1989, water velocities were measured with a Hiroi acoustic current meter and since this time, with a model 201D Marsh McBirney current meter. The maximum depth is recorded with a meter-stick (or a plumb line in lakes).

A proxy variable (ice scour height, or height of flood debris, since some rivers lack an ice scour mark) is used as an indicator for range of discharge. The proportion of each type of substrate category is visually measured by estimating substrate type (Bain *et al.*, 1985) in 30 cm sections marked off on a lead line, measured at three transects within the station. Extent of the three types of cover (instream, overhanging, and canopy) are also estimated visually. Riparian vegetation type is also recorded, identified to common names, and later coded as to percentage of coniferous, deciduous, and open with grasses and shrubs.

Enhancement and Aquaculture Section

Objectives and Purpose

The paper presented by C.E. Bourgeois largely relates to the use of electrofishing to determine the effectiveness of fry stocking, more specifically the survival of stocked fish to various juvenile age groups. The Department has been stocking unfed Atlantic salmon fry in areas where anadromous Atlantic salmon had not previously been present as a means of expanding the use of available habitat and increasing production on watersheds undergoing salmon enhancement. A major salmon enhancement project has been ongoing on the Exploits River since the mid 1960's and this paper presents the results from the survey of Lloyd's River, a tributary of the Exploits River, from 1987 through to 1992, to evaluate the success of fry stocking in certain sections since the early 1980's (see paper, Appendix D, for details). The Lloyd's River was chosen for evaluation because it represents the longest distance of helicopter transfers from the Noel Paul's Brook incubation facility, and stress due to transfer could be a factor in the survival of fry in this system. The electrofishing methodology presented in this paper is also the same used by Development Associations and other sponsors on public involvement salmon enhancement projects.

Site Selection

The locations selected for study were Lloyd's River Section III, upstream from King George IV Lake, stocked from 1983 to 1990. Stations were also located in Lloyd's Section II, the area between Lloyd's Lake and King George IV Lake, which had been stocked from 1981 to 1982 and 1984 to 1991. In Section III, only 50,000 fry were stocked in 1992, about 1 km above the electrofishing stations, and this was done to determine the extent of downstream fry movement after stocking.

Sites were selected in the initial year (1987) to cover the full range of available habitat types (e.g., pool, riffle, flat or steady, etc.). In subsequent years, some of the sites with poor juvenile salmon abundance were discontinued while other sites were dropped due to resource constraints. Major factors in site selection included the ability to encompass the site with barrier nets and available resources (time and money). In some instances sites were discrete stations while in other instances, stations were contiguous (leapfrogged). Station sizes were for the most part from 1.0 to 2.5 units (100 m^2).

Electrofishing Techniques

Station are enclosed to emigration/immigration using barrier nets at the top and bottom of each station. For three sided stations, a barrier net is also run longitudinally to meet the upstream and downstream nets. Stations are electrofished, using the removal method to obtain depletion estimates, from the upstream end working in a downstream direction. Generally, three sweeps are conducted. If fish are caught on the third pass, additional sweeps are conducted until no fish are captured (extinction). A Coffelt Electronics VVP shore based electrofishing unit, with a single probe and copper mesh screen cathode, is used in all studies. Salt licks, equally distributed in the station for each run, are generally used to improve the conductivity of the water and improve electrofishing efficiency. Population estimates are developed by regression techniques, from the removal data, for the entire population and separately for each age class. Recently, the use of the Microfish 3.0 program (Van Deventer and Platts 1989), which employs a maximum likelihood (ML) estimator, has been used to calculate population and biomass estimates.

Fish Sampling and Measurement

Each juvenile Atlantic salmon caught from each station are weighed (0.1 g) and measured for fork length (mm). Five fish from each cm length group, for each stream section, have a scale sample collected for subsequent aging. From these ages, all fish are assigned an age based on a length/age key. Sex and maturity are determined from all mortalities. For brook trout, only length and weight are determined.

Habitat Attributes and Measurement

Habitat attributes are measured to generally describe the station conditions and include

Habitat attributes are measured to generally describe the station conditions and include section length (m), width (from three measurements at the upper, middle, and lower end of the station), depth (m) (from three readings [1/4, 1/2, 3/4 of width] at transects at each of the upper, middle, and lower end of the station, streamside vegetation (visual estimate as percent), and substrate composition (visual estimate of % boulder, bedrock, rubble, gravel, etc.).

Application of Results

The author has cautioned that the data collected from this study are limited by the quality and quantity of baseline data at the electrofishing locations on existing populations of landlocked Atlantic salmon juveniles. There were no stations studied before the introduction of fry and therefore it is impossible to conclusively determine if the juvenile salmon found in the electrofishing surveys are all the result of fry stocking. No fry were stocked in 1992 so densities in that year provide some insight in the natural production of landlocked salmon fry.

The author suggests than an additional 2 years of study is required to complete this study in order to follow the 1991 stocking through to the 3+ parr cohort.

Habitat Research and Assessment Section

Objectives and Purpose

The Habitat Research and Assessment Section (HRAS) have used electrofishing as a sampling technique in applied research and environmental effects monitoring studies. The technique has been used to document or assess change in juvenile fish production (numbers, biomass, age class composition, etc.) in response to some change in habitat quality, be it perturbation or beneficial change. Electrofishing has also been employed as part of environmental effects monitoring studies to assess impact predictions from projects undergoing formal environmental assessment, including evaluation of mitigation undertaken to minimize/eliminate impacts and compensation to offset habitat losses. HRAS also evaluates electrofishing surveys and studies undertaken by proponents and/or their consultants, for the most part involving projects undergoing environmental assessment, and are often involved in the selection of sites/habitats and the electrofishing methodologies employed.

Site and Habitat Selection

Site selection has varied from study to study and has generally followed two approaches: i) representative stations for specific habitat types or classes and ii) contiguous (consecutive) stations at a site undergoing perturbation and has generally included stations above the site (control), stations at the site of potential impact, and stations below the activity (to address possible downstream impacts).

The types of habitat studied has depended on site selection (above) and the objectives of each study. Studies arising from the environmental assessment process have sites (stations) are classified using the Beak Consultants Limited (1979) 4 tiered approach (see Table 4) which has served as the *defacto* standard for environmental assessment for the last 14 years. In these studies, electrofishing is normally conducted in Type I and Type II habitats only, which are predominantly riffles and small pools. Several of the applied research studies involve sampling contiguous (consecutive) stations in relation to a reach of habitat to be affected by development. In these situations, the stations are established in relation to size criteria and in relation to boundaries established by the natural distribution of habitats (e.g., location of pools, riffles, undercuts, etc.), similar to habitat stratification by Gibson *et al.* (1987). Examples of habitat and site selection are provided in the full paper, Appendix D.

Generally, sites are located such that the station will encompass the entire stream width. On larger rivers, this has often necessitated that stations be established in reaches where the stream width is divided into 2 or more channels by islands, and the station is established in one of the channels. On occasion (rarely), situations arise on larger rivers whereby a station cannot encompass the entire width of the river (or side channel) and the station is defined by the addition of a third barrier net the length of the station and parallel to the flow (i.e., 'three-sided' sites). We have attempted to avoid 3-sided sites as Bohlin *et al.* (1989) have suggested that on large rivers where the area fished is small relative to the total stream area, quantitative electrofishing for population estimation is probably not reliable.

Equipment

HRAS uses portable, battery operated, backpack electrofishing units as the most appropriate to the types of studies undertaken by the Section, primarily owing to reliability and portability. The two primary models in use are the Smith-Root, Type VIIIA (12 volt lead-acid or gel cell; DC pulsed unit with a voltage ranging from 250 to 850 volts; used from 1984 to 1989) and the Smith-Root, Type 12 (24 volt gel cell; DC pulsed unit for use in the conductivity range 10 to 600 $uScm^{-1}$ and output voltage ranging from 100 to 1000 volts; with audio signal to indicate the appropriate operating range; ni-cad batteries have recently replaced the gel cells; in use since 1989).

Electrofishing Techniques

The station dimensions are usually established in relation to natural boundaries of the habitat, and experience has indicated that a station size of from 2 to 4 units (1 unit=100 m^2) is preferable and produces reliable results. In all cases, each station is completely closed with barrier nets (0.5 cm mesh) to prevent immigration and emigration from the site. On studies where the intention is to replicate sites between years, the upper and lower barrier net locations are permanently marked with paint, flagging tape, and rebar pegs.

Electrofishing is normally conducted in summer months (late June, July, August, early September) in periods of low stable flow, and after salmonid fry have emerged from the gravel and have distributed to preferred habitats. The electrofishing team has consisted of 4 individuals (occasionally 3 to 5), one on the electrofisher, 2 with dip nets, and one looking after the captured fish. HRAS has adopted an approach whereby the same individual works the electrofisher for all runs completed within one station (to minimize variation in approach and effort) and effort is recorded, as number of seconds.

The fisher starts at the downstream end of the station and works across the stream, in standardized widths, in an upstream direction to the upper barrier net. This approach has been adopted to minimize/eliminate the influence of turbidity stirred up by the crew from affecting visibility and hence effectiveness of capture. The area is fished discontinuously (the power is turned off, the anode is moved to another location, and power is resumed) to improve effectiveness by using the 'element of surprise' and by not continually driving fish from the effective field. The dip netters are strategically placed downstream of the fisher in an area previously fished. The netters are equipped with standard dip nets as well as smaller aquarium nets to assist in retrieving small fish (young-of-the-year, YOY, or 0+) from the substrate. Polarized sunglasses are standard equipment to minimize glare from the water surface and to enhance ability to see and capture fish.

All quantitative electrofishing involves use of fixed effort (successive) removal method. The total number of fishings (sweeps or runs) normally varies from 3 (minimum) to 5 sweeps, occasionally up to 6, depending upon the catch rate for each run and the rate of depletion. A minimum of three sweeps is completed and the requirement for additional runs is determined by the catch on the last run (i.e., if the catch on the last run is < 20% of the catch on the first run and < 50% the catch of the previous run, then additional runs are not necessarily required).

Fish sampling/Measurements

All fish captured in each sweep are analyzed between each run. All fish are anaesthetized (a variety of anaesthetics have been used), identified as to species, measured for length (nearest mm), weighed using a portable electronic balance (to the nearest 0.1 g), and all fish greater than 1+ in age have a scale sample collected. For all fish of age 1+ or greater, the information is recorded directly on the scale envelope containing the scale sample. For all 0+ (YOY) fish, the lengths are recorded in a field note book and pooled weights are obtained, for each species. Once the data have been collected, fish are placed in fresh water in another holding container to recover, and once fully recovered they are returned to the river, well removed from the station or any future stations to be sampled.

Scale samples collected are analyzed for total age and measured for total scale radius and the length of each annulus.

Habitat Attributes and Measurement

A number of station attributes and habitat variables are measured and collected at the time of electrofishing. The variables collected and the method of measurement include the general measurements i) station length (0.1 m), one or two (or more measurements if station is irregular in shape); ii) station width (0.1 m), an average of 3 or more widths; and iii) mean depth (cm), as determined from 3 (or more) equally spaced measurements across each width transect and averaged. Habitat is typed (as %) of estimates of the proportion of each of pool, riffle, run, flat (steady), and other (rapids, falls, etc.). Undercut banks are estimated as % of the site (each bank being up to 50%). Gradient is estimated, or measured using surveying equipment, as m(cm)/m. Pool/riffle ratio is determined from the % of pool and rifle habitats. The number of pools is totalled while each pool is measured (length, width and depth of each pool).

Substrate is estimated as proportion (%) of each of large boulders, small boulders, rubble, cobble, pebble, gravel, sand, silt, and bedrock. Similarly, cover is estimated as proportion (%) of each of overhanging, instream (subdivided by debris, algae, and channel vegetation), and canopy cover. Bank erosion is estimated as % of site, each bank being 50%, including a rating of bank stability. Riparian vegetation is estimated as the proportion (%) of each of grasses/shrubs, alders/willow, coniferous, deciduous, and bog in the 5 m riparian area along each bank.

Detailed transects of width, depth, and velocity are occasionally taken at some sites where discharge calculation is warranted or where velocity distribution is a variable that is to be considered. The station is usually sketched to show the location of key features, in order to facilitate replication of the site in future surveys.

Data Analyses and Application of Results

Initially, weights are generated for all fish for which individual weights in the field were not measured (primarily for the YOY), using length-weight regressions (for fish for which both measurements were obtained) for each station, reach, section, etc. All data are sorted and summarized on a Digital VAX mainframe computer for subsequent population estimate/biomass calculation using PC-based programs. All data are summarized and totalled by station, run (sweep), species, and age class.

Three different estimators, using data obtained from the removal method, have been employed including i) the regression method described by DeLury (1947) and Ricker (1975), ii) the Maximum Weighted Likelihood (MWL) estimator as described by Carle and Strub (1978), and iii) the Microfish 3.0 program (developed by the U.S. Fish and Wildlife Service, Van Deventer and Platts 1989) which uses a maximum likelihood (ML) estimator and has the advantage that the program can be run interactively or data entry can be automated, and the population estimates can be batched and calculated separately for data subsets (e.g. species, age/size classes). This program also calculates biomass estimates in addition to population estimates. Population estimates (when the data permit it) are derived for subsets of the data as follows:

Tier 1	Tier 2	Tier 3
Total Population (all fish)	Total for Species (1)	Total for Age/Size Class (1)
		Total for Age/Size Class (2)
		Total for Age/Size Class (3)
	Total for Species (2)	Total for Age/Size Class (1)
		Total for Age/Size Class (2)
		Total for Age/Size Class (3)
	Total for Species (3)	Total for Age/Size Class (1)
		Total for Age/Size Class (2)
		Total for Age/Size Class (3)

Related Presentations

Length-Frequency Sampling Using Fixed Electrofishing Effort (C.C. Mullins)

C.C. Mullins (DFO Science, Corner Brook) made a presentation on the use of fixed effort electrofishing as a tool to support stock assessment. This semi-quantitative approach was considered to have considerable potential for application owing to its ease of use; specifically it is not necessary to set up a station (install barrier nets), detailed habitat attributes are not measured, and it is not necessary to conduct repeated sweeps to obtain a precise population estimate. This approach would allow more effort to be deployed to sampling a greater and more diverse habitat area. A number of standard effort sites could be completed with the same effort required for one closed site used for population estimation.

For the purposes of the study described in this paper, sites were closed by barrier nets and were surveyed as required for a successive removal population estimate. The first five minutes (300 seconds) of the initial sweep was taken as the standardized (fixed) effort estimate. The fork length frequency estimate obtained by the fixed effort technique was then compared with that of the successive removal method. Analyses indicated that the duration of electrofishing had no effect on fork length and mean fork lengths were not significantly different between the fixed effort and total estimates.

This approach generated considerable discussion, particularly in light of the potential savings in time and personnel which could be devoted to increase habitat coverage or for other tasks. Concern was expressed over the different catchability of different age/size classes and how that could potentially bias the estimate. Concern was also expressed over the inclusion of habitat attributes in the analysis, as it may be difficult to describe the habitat covered in a 300 second sweep. There was also concern over behaviourial responses to electrofishing and how larger fish may be able to detect the electrical current and escape (i.e., in a closed station they would not be able to leave the site). It was recommended that this technique be tested over the next few years to further evaluate the suitability of the data collected. Specifically, it was suggested that, for all sites where detailed population estimates were being collected, the data from the first 300 seconds of effort should be collected and reported separately. This would permit data from a variety of studies to be used to evaluate the fixed effort estimator.

Under-estimation of Population Size by Removal Estimators (S.C. Riley)

S.C Riley (Salmonid Research Group, Memorial University of Newfoundland) provided a presentation on under-estimation (negative bias) of population size of salmon parr using the removal method, based on research carried out on Newfoundland streams and subsequently published in Riley *et al.* (1993). Standard closed electrofishing stations for population estimation were established and Atlantic salmon parr (1+) were captured from sites near these stations, marked (fin clipped), and a known number were introduced into each station. Four sweep maximum likelihood removal estimates were calculated for each station using the CAPTURE program (White *et al.* 1978). Bias, as a percentage of true population size, was determined from the proportions of marked and unmarked fish for all sites.

The population estimates demonstrated a consistent negative bias (under estimation) in all cases. This bias increased with decreasing parr density and increasing cross sectional area suggesting that removal estimates are more biased at low population densities and in larger streams. The removal method assumes constant capture probability and it was suggested that the negative bias indicated a violation of this assumption (as reported by other authors; e.g. Heggberget and Hesthagen 1979; Mahon 1980) and this was confirmed by the capture probabilities calculated for each sweep by the CAPTURE program.

It was suggested that researchers attempt to estimate bias of population estimates using populations of known size; however, it was recognized that time and resource constraints would prevent this from being achieved on a consistent basis and that this 'quality control' was not always warranted or necessary. Bias estimation may be particularly important when comparing estimates from streams of different sizes.

A New Model for Removal Estimation of Population Abundance (W.G. Warren)

A presentation at the second workshop was made by Dr. W.G. Warren on a possible new model for the calculation of population size by the depletion method. This model was developed in response to concern generated at the first workshop in relation to bias associated with population estimates (largely in relation to S.C. Riley's presentation). The major concern expressed was the violation of constant capture probabilities between removals (sweeps), a key assumption of maximum likelihood population estimators. For example, Riley *et al.* (1993) found capture probabilities to decrease with successive sweeps which can lead to underestimation of population size Zippin (1958).

Dr. Warren's approach is based on the assumption that capture probability will decline with successive sweeps related to the volume of water available to each fish (with volume increasing with each sweep and correspondingly catchability declining) and this assumption can be described by a simple mathematical model. The method involves estimation of a parameter '*k*' and fitting a curve to the relationship between capture probability and volume (as determined from station length, mean width, and mean depth). The parameter *k* is related to catchability and, if assumed to be a random variable, enables a Bayesian approach to population estimation. Maximum likelihood estimates of *k* and *n* (population size) can then be determined. Using this approach with the data presented in Riley *et al.* (1993), the overall error associated with estimates was reduced to 6% from 25%, under the assumption of constant capture probability. If the parameter *k* could be related to stream habitat conditions, then a prior distribution of the parameter could be used to improve the maximum likelihood estimate, and the method could have more wide scale application.

There may however be a wide variety of stream characteristics that influence capture probability, and hence the parameter *k*, including the dimensions (depth and width), velocity, substrate, bank and cover variables, temperature, conductivity, etc. (Jensen and Johnsen 1988). The parameter may need to be adjusted for increasing water depth owing to changing electrofisher efficiency or in relation to other habitat features (e.g., substrate coarseness, water velocity, etc.). It may also be necessary to develop separate parameters for different species. The potential use of the method would be improved by better understanding how the parameter *k* varies with physical and chemical stream characteristics.

Discussion

A major theme of workshop discussions was the need to develop a systematic sampling strategy which would permit extrapolation of the information collected when applied to the entire drainage basin or watershed. Probably the first systematic effort to partition river reaches by stratified sampling, in order to estimate juvenile salmon production and yield of smolt for the entire river, was in the Highlands River ten years ago (Gibson *et al.*, 1987), and the same techniques have been used since (Gibson *et al.*, 1993). Specifically, electrofishing stations should be stratified by types of habitat and stations representing each habitat type should be selected within each stream order. The major habitat types as defined by Gibson *et al.* (1987), which is essentially a derivation or terms employed by other authors, includes: cascades; riffles; runs; flats; pools; lakes. For the most part electrofishing is conducted in riffle, pool, run, and flat habitat, as the technique is not well suited for evaluating cascade (rapids) and lake habitats. The basic characteristics defining these broad habitat classifications are identified in Table 2. Each station should encompass only one habitat type entirely, although practically small pools are often associated with riffle habitats and sampled with that habitat type. Where possible, replications of stations by habitat type/stream order should be conducted; however, limited resources usually dictate a compromise in sampling strategy. For certain studies, sampling throughout the growing season would be appropriate (where resources permit); however, typically sampling is conducted after the main growing period at the low flow, warm period of the summer, from mid-July to mid-August.

Different sampling techniques may need to be employed for sampling different habitat types. Population sampling in riffle areas involves electrofishing using the removal or depletion method, with a minimum of 4 passes or sweeps. In this method the entire area within a station is electrofished and fish captured are removed from the station. This is repeated a minimum of 4 times and estimates are based on the data obtained. In deeper and slower water (e.g., pools and flats), electrofisher efficiency is not as good and beach seines and fyke nets can also be used to obtain mark-recapture estimates (Petersen) or in larger lakes, by the multiple mark-recapture (Schnabel) methods (Ricker 1975). It was argued that the most effective method of sampling various habitats should be employed in order to obtain the most reliable population estimate possible. Others countered that the use of different sampling techniques and population estimates created difficulties in comparison of data and it would be preferable to use the electrofisher and the depletion method at all stations and look to improve electrofishing efficiency in these slower, deeper waters (e.g., use 'salt licks' to increase conductivity and electrofisher output). It follows that steps taken to improve electrofisher performance could also cause problems in data comparability. Generally, it was agreed that the use of electrofishing and the removal method should be employed wherever possible, although the use of alternative methods to sample specific habitat types (e.g., pools and lakes) may be necessary. *Electrofishing is the preferred technique in shallow water, but is generally inefficient in deep water, especially where conductivity is low, so that other methods must be employed to catch fish in these latter conditions. Electrofishing may also be less efficient in certain habitat types (e.g., flats) owing to ability of fish to detect the presence of the field crew or feel the electrical field without being immobilized.*

For studies with continuous data (time) series and where data are compared within a site from year to year, any changes in electrofishing technique, based on the recommendations of this workshop, should be carefully considered in light of affecting comparability with previous data. In many instances, employing recommendations of this workshop could compromise use of previous data and altering techniques and sampling strategies would not be warranted. Implementation of the recommendations of this workshop and standardizing techniques may be most appropriate when designing and undertaking new studies. In some instances for existing studies, it may be possible to 'blend' existing techniques with recommended approaches.

It was suggested, owing to sample sizes required for reliable removal population estimates, that it is probably advisable to stratify estimates by species and then into 2 age/size groups (0+ or fry; greater than 0+), and not attempt to calculate separate estimates for all older age classes. For surveys intended to describe an entire drainage system, sampling stations should be stratified by stream order. It was also suggested that DFO may be 'wasting their time' in sampling large rivers and streams using electrofishing techniques owing to sampling only a portion (and not necessarily a representative portion) of stream width, the likely differential distribution of fish across the stream (related to depth, velocity, substrate, etc.), and generally the difficulty in setting up and sampling in these large systems. Efforts should be restricted to 3rd order and smaller streams. It was noted that many electrofishing surveys are directed at preferred habitats (riffles) and these are the habitats that will be filled first. Consequently, it may be inappropriate to extrapolate estimates from these habitats to other habitat types and the entire river system. This concern supports the rationale for sampling all habitat types, even if certain habitats are not amenable to conventional sampling using electrofishing.

There was considerable discussion regarding measurement of habitat attributes in association with electrofishing studies, specifically the collection of visually estimated subjective data. It was recommended that a study be conducted to determine the bias associated with visual estimation (see Research Recommendations). A recommended set of habitat attributes to be measured as a component of electrofishing studies, including the identification of objective methods for measurement where possible and practical, were developed subsequent to the first workshop and discussed in detail at the second. The recommended habitat attributes, and method of measurement, as agreed to by consensus at the second workshop are detailed in Appendix B.

At the second workshop, there was considerable debate as to the value of the fixed effort, index approach to electrofishing and various approaches to standardizing this technique. Concern was expressed as to the selection of sites (e.g., in proximity to spawning areas), possible error introduced by different operators (e.g., different operators could cover a vastly different area in the 300 seconds), the area of the stream fished (e.g., along the bank versus mid-stream), etc. There was consensus that it was important to standardize the method as much as possible, and to collect some minimum set of habitat attributes to describe the 'station'. Generally, some estimate of area covered should be determined as well as an estimate of depth, substrate, and water velocity. It was recommended that the index approach be evaluated opportunistically, in association with removal population estimates, as well as a discrete study be undertaken to address some of the issues of standardization and comparability with rigorous methods.

It was suggested that there is a need to address the problem of potential bias in population estimation from electrofishing and, if necessary, develop a means of estimating bias for each station and adjusting estimates accordingly. Probability of capture can change with temperature and this could affect electrofishing effectiveness as the day progresses (i.e., the first run could be in the morning under cool water conditions, with subsequent runs being conducted at increasingly warm temperatures). In addition, probability of capture may be related to field visibility (i.e. the presence of intense sunlight or the angle of the sun's rays). The fact that capture probability is strongly related to bias is a strong argument for employing a 4 sweep minimum. Others were concerned that the effort to estimate bias was unwarranted and would be difficult owing to constraints of time and manpower. It was also suggested that efforts to measure bias could introduce additional error into the population estimates.

The discussion at both workshops considered two approaches to estimating bias, both involving having a known number of marked fish introduced into the electrofishing station and then calculating the bias from the number of marked fish captured during a subsequent electrofishing effort. One approach considered using marked fish from outside of the station and introducing them into a closed site (see also Riley *et al.* 1993). The second approach involved marking fish captured during the first sweep and reintroducing the fish for the subsequent population estimate.

In general, most participants felt the second approach would be preferable, for the following reasons: i) introducing marked fish from outside the station would increase the density possibly making fish more vulnerable to capture, or conversely making it difficult to net stunned fish (i.e., there may be too many fish stunned on a pass reducing the netting efficiency); ii) the introduced fish would not have any established territories possibly making them more vulnerable to capture, therefore introducing error into the bias estimate; iii) it would be difficult to determine the appropriate number and size distribution of marked fish to be introduced into a station without some *a priori* knowledge or appreciation of what would be expected in the site (i.e., it would not be appropriate to introduce marked large parr into a site containing mostly fry; similarly it would not be appropriate to introduce 50 marked fish into a station containing only 20 fish); iv) from a practical perspective, capturing and introducing fish from outside of a station would involve additional effort. One possible advantage related to introducing marked fish from outside of the station that was discussed was that it would increase the total fish numbers in the site thereby, in theory, improving the estimate.

Although no decision was reached at the workshops on the appropriate approach to estimate bias, there was consensus on the need to develop an approach. Subsequent to both workshops, a proposed approach to the estimation of bias was developed by the workshop chairmen and circulated to participants for comment. Based on this process, a recommended approach to bias estimation, using marked fish from the first pass (sweep) of a depletion estimate, was developed and is contained in the Recommended Standard Electrofishing Procedures (see recommendation # 23, p. 24).

Concern was also expressed over the potential detrimental effects of electrofishing on salmonids including spine injury, internal and external haemorrhaging, effects on growth and survival, etc. Researchers are referred to recent reviews on electrofishing injury in Fisheries magazine (Snyder 1992 and 1995). Injuries are, for the most part, related to muscle convulsions from reaction to the electric current and resulting damage to the spinal column and the severity of the problem varies with equipment and settings, technique, environmental factors (e.g., conductivity), and species of fish (including size and condition). It has been generally considered that electrofishing operations in Newfoundland will have minimal impacts on resident populations owing to the low conductivities of most waters (excepting carbonate areas in western Newfoundland), the use of DC pulsed current, and use of the technique in cold waters. Researchers suggested that the effect of injury or mortality from electrofishing would have negligible impact on resident fish populations owing to the relatively small area included in an electrofishing site relative to all available habitat. It may be more of a concern for rivers where a considerable proportion of the available area is electrofished or where stations are repeated during the same season or from year to year. It was also suggested that DFO undertake a research study to determine the effect, if any, of electrofishing on injury and mortality to fish. Recently, Smith-Root Inc. have developed a programmable output waveform (POW) control board for their electrofishing units. This permits the units to simulate low frequency waveforms which are reputed to be more effective in capture, less damaging to fish, and will increase the life of electrofishing batteries. It is recommended that any users of Smith-Root consider upgrading their units with this new POW controller board. Concern was also expressed on the potential effect of the use of anaesthetics on fish. Researchers discussed the various anaesthetics used and observed effects. It was pointed out there could be delayed mortalities that would not be observed at the time of sampling.

The issue of safety for electrofishing crews was also raised. It was decided that the manual prepared by the Ontario Ministry of Natural Resources (Goodchild 1988) was a good review of safety issues and should be provided to all crews/individuals conducting electrofishing. It was also decided that a synopsis of safety issues should be developed from this manual for use by public groups.

The issue of using mark-recapture techniques in electrofishing estimates generated considerable discussion at the second workshop. Concern was raised as to the possible effect of fin clipping as a method of marking, on the catchability of fish in subsequent electrofishing collections, and the possible bias this could introduce. It was stressed that, for juvenile salmonids, it was preferable **not** to clip the pectoral or ventral fins. Researchers are advised to consult the American Fisheries Society Symposium No. 7 on Fish Marking Techniques (Parker *et al.* 1990) for guidance in conducting mark recapture studies.

At the second workshop, representatives from the consulting community outlined the applications they have for electrofishing. It was apparent that consultants use electrofishing for a variety of purposes in addition to quantitative population estimation including reconnaissance level sampling, fish collections (e.g. for disease surveys), etc. Consultants expressed a concern as to any standard set of electrofishing procedures that may be developed from the workshops as, in competitive bid situations, costs and manpower associated with electrofishing are important considerations. Many consultant studies are also undertaken in remote situations. Consequently equipment and methods would need to be considered as well as time and cost constraints associated with aircraft access. They would prefer that any standard procedures be considered 'guidelines' rather than a rigorously applied protocol. Representatives from Newfoundland and Labrador Hydro expressed a desire to see a standard set of techniques that would give them a bench mark to include in Request for Proposals, and by which to evaluate consultant proposals. Additionally, as DFO staff are often required to review work by consultants and their proponents, it is in everyone's best interest to establish a standard protocol.

A number of unrelated comments and suggestions were raised during the workshop and these are identified below:

- C. Mullins also described the possible use of an apron seine (a length of seine between two poles used by one or two individuals) as an efficient netting method in fast water and for YOY.

- the use of night lights to collect fish can be effective but is not very quantitative.

- R.J. Gibson described his experience in electrofishing in shallow lakes using an electrofishing boat. Generally electrofishing in ponds is not very effective in sampling salmonids (relative to conventional seining), while it is effective in catching eels and stickleback. This may, in part, be due to the association of juvenile salmonids with the substrate in lakes and being relatively distant from the effective field of the electrofisher.

Recommended Standard Electrofishing Procedures

1. The selection of sites, stratification and replication of habitat types, sub-sampling procedures, and other general aspects of study design should be left to the discretion of individual researchers based on the objectives of their respective projects.

2. No one particular manufacturer or type of electrofisher is recommended. Much equipment has been acquired and is still in use and it would be prohibitively expensive to standardize equipment. Many types of equipment have given advantages and disadvantages and each researcher should make the selection of equipment based on available inventory and their particular needs. For example, backpack units are extremely portable and require one less crew member; however, they are less powerful and batteries require recharging, which can be difficult in remote situations. Shore based units are more cumbersome to transport and set up at the station, often require one crew member to ensure the power cord does not become entangled, but are more powerful and power is readily supplied by generators.

   Generally, any equipment selected for use must be able to effectively capture fish in low conductivity waters common to Newfoundland and Labrador.

3. The preferred timing for electrofishing studies would be determined by the objectives of the study. Generally, the preferred conditions for electrofishing would be sampling during low flow conditions after a period of stable water flow, after fry have emerged and distributed to preferred habitats, and during the summer growth period of salmonids. This is generally the period when habitat is limiting and electrofishing is most efficient. In insular Newfoundland, this period would be from mid to late July through to early September and could vary by location. Fishing earlier in the year (e.g., June) could result in harm to, or mortality of, newly emerged salmonid fry. Later in the fall, water temperatures decline, and juvenile salmonids become less territorial and often burrow into the substrate to overwinter, making electrofishing less effective and meaningful. Additionally, it would also be preferable to not electrofish until after smolt emigration (end of June for most areas) and not after early September as precocious maturation of male salmon parr could alter fish distribution.

4. Sites (stations) should be established within one discrete habitat type (i.e., riffle, run, pool, flat, etc.) as discussed previously. Small pools are often associated with riffle habitats and should be completed as part of a 'riffle' station and the presence of pools would be described by the habitat attribute data used to define this station.

5. The size or dimensions of an electrofishing station should be in consideration of obtaining as large a sample of fish as is practical since the validity of the estimate increases with sample size (i.e., population estimation based on sample sizes of less than 30 are considered poor; if estimates are subset by age groups this 30 fish minimum would apply to each age group). Practical considerations relating to the size of contiguous reaches of

one habitat type, time spent to complete each station, effective deployment of human and monetary resources, efficiency of capture at a given site, etc., will also play a role in determining the appropriate size of the station. Generally, the objective is to improve the precision of the population estimate by whatever means possible and **practical.**

6. Due to low conductivity waters prevalent in insular Newfoundland and Labrador, it is recommended that all quantitative electrofishing stations should be completely closed by barrier nets wherever possible. This includes stations that completely encompass the width of the river, with the standard upstream and downstream barrier nets. 'Three sided' stations (see previous description) would require a net to be run the length of the station, to meet the upstream and downstream barrier nets, to fully enclose the site. The mesh size of the barrier net must be fine enough so as **not** to permit the passage of salmonid YOY (as small as 40 mm in length). Closure of the station also ensures adhering to one of the major assumptions of population estimation, that there is no immigration into or emigration from the site during the period of sampling.

7. The preferred crew size for completing a **quantitative** electrofishing station will be determined by the size and physical attributes of the site, and ultimately the project budget. For most applications, a crew size of 3 to 4 people would be suitable. This would include one individual on the electrofisher (or handling the probe), 1 holding the captured fish (with buckets, etc.) and being responsible for survival of captured fish (i.e., may need to replenish or re-oxygenate water to prevent mortalities) and 1 or 2 persons using dip nets. Another individual may be required for teams using shore based electrofishing units in order to feed the electric cord through the station and to ensure the cord does not get caught up on the substrate, etc. In many instances available human and monetary resources will dictate crew size; however, a crew of 3 would be considered minimum for most situations. For extremely small streams (e.g., less than 2 m width) it may be possible to effectively electrofish with a crew of only 2. Additional crew members may be desirable in larger streams (greater than 3rd order) to assist in setting up the station (e.g., placement of barrier nets), provide additional assistance in netting fish, or assist in the processing of captured fish and data collection.

   In some instances, depending on water velocity, depth and clarity, it may be desirable to employ a lip seine (or pole seine) as a replacement for, or in addition to, a standard dip net(s).

   It is recommended that all crew members use polarized sun glasses to improve ability to see into the water column and thereby improve the ability to capture stunned fish.

8. Holding containers, placed in the stream but outside of the effective electric field, can be used to hold fish for extended periods during the process of completing an electrofishing station. Oxygenation of water and temperature stability to reduce potential mortalities must be ensured. These containers should have holes or be constructed of mesh to permit percolation of water. The use of vegetation or some other water surface cover also

reduces stress on fish.

9. At least one dip netter should have a small, flexible aquarium net of very fine mesh size to assist in retrieving YOY from the substrate. The electrofisher probe can also be outfitted with netting to act as an additional net. The mesh size of the dip nets must be fine enough so as **not** to permit the passage of salmonid YOY.

10 As consistency of sampling effort is very important to a reliable population estimate, it is recommended that the same individual conduct all sweeps at a given sampling station. If a timer is available on the electrofisher (only the type that actually records time when the power is on), then it should be employed to monitor sampling effort and the number of seconds for each sweep should be recorded.

11. At present, the use of means such as the addition of 'salt licks' to improve the conductivity of water is not recommended. While this may improve the effectiveness of the equipment, other considerations such as effect on fish behaviour and discontinuous conductivity are poorly understood and may bias the data collected.

12. Electrofishing should be conducted in a discontinuous fashion, turning the power on and off between passes with the probe, in order to use the 'element of surprise' to improve capture efficiency and in order **not** to drive or herd the fish.

13. A total of 4 sweeps should be considered minimum with respect to population estimates based on the removal method. Requirements for additional sweeps should be based on the rate of decline in catch and researchers should be familiar with the population estimators in order to make field decisions on the need for, and benefit of, additional electrofishing sweeps. At present, the effect of previous sweeps on salmonid behaviour is not well documented, and research is necessary to determine the length of time required for fish to recover from the effects of electrofishing. It is recommended that crews allow as much time as is practical between electrofishing collections (sweeps), with one half hour being considered minimum.

14. It is not a concern whether electrofishing sweeps are conducted in an upstream or downstream direction and there are advantages for sweeping in either direction. Sweeping in an upstream direction ensures that all debris and silt stirred up by the crew is removed by the water flow thereby ensuring good visibility. Electrofishing in a downstream direction may be effective in 'driving' fish into the lower barrier net where they will be efficiently captured. If numbers are high at the lower net, this may result in poor dip net efficiency or possibly in the over shocking of fish. It is most important that sweeps be carefully completed to ensure all habitat is covered in an even and effective manner. The crew should also ensure that they do not enter any habitat area until after it has been electrofished (e.g., install the lower barrier net with as little disturbance as possible, then walk along the bank away from the station to install the upper net).

15. The removal method is recommended for estimation of population size in order to provide for maximum comparability of results. Calculation of the estimate using weighted maximum likelihood estimators is the preferred method. At present, use of the CAPTURE program from the U.S. Fish and Wildlife Service is highly recommended, owing to its ability to generate probability of capture estimates for each sweep, while the MICROFISH 3.0 program, also developed by the U.S.Fish and Wildlife Service, would be acceptable. Both these programs can run on personal computers under DOS, and therefore should be available to a wide number of users. Other estimators are under development at DFO and when these approaches/programs become user friendly the adoption of these techniques as a standard approach will be considered (see presentation by W.G. Warren). It is recognized there is an inherent bias (underestimate) in the Microfish estimate associated with the assumption of constant probability of capture.

    Where catch rates permit, separate estimates should be calculated by species, and age or length class. Previous studies have suggested estimates can be derived for all fish (salmonids), for each species (if sufficiently abundant), and separately for fry and older age/size groups for each species.

    Mark-recapture techniques for population estimation are also recommended in habitats where electrofishing equipment may be inefficient, such as in deep water (i.e., pools, flats, lakes). For these estimates, fish captured from the first sweep (either by electrofisher, beach seine, etc.) are marked (fin clipped or some other technique) and returned to the station. After sufficient time for redistribution and recovery (overnight if possible), the station is again re-sampled. A population estimate based on the number of marked and unmarked fish in the second sample is derived by the Petersen method (Ricker 1975). This process can be repeated for more sampling and a multiple-mark recapture (e.g., Schnabel) estimate obtained (Ricker 1975).

16. All fish collected at a station should be identified to species and have a fork length measured (mm) and, where possible, a weight (0.1 g) taken. A sub-sample of fish, sufficient to establish a length-age key, should have scale samples collected for subsequent ageing (e.g., a minimum of 5 per 1.0 cm length group). Collection of scales from all fish and then subsequent sub-sampling for aging, if required, based on length frequencies is also recommended. For mark-recapture estimates, it is preferable to collect scales on the final sweep. The decision as to sub-sampling protocol based on each station, tributary, habitat type, stream order, etc. is at the discretion of the individual researchers according to the project objectives.

17. The use of an anaesthetic to measure and collect data/samples from fish captured by electrofishing is recommended. A variety of products have been used and no particular one anaesthetic is endorsed; however, the use of Alka-Seltzer tablets (dissolved CO_2) and benzocaine have been employed by DFO and are considered effective and relatively safe for the fish. Should other products be considered for use, it will be necessary for the researcher to seek permission/approval for use from the necessary authorities and use of

the particular anaesthetic should be included in the collection permit.

18. Habitat attribute data should also be collected in association with electrofishing data. A recommended list of parameters and methods of measurement is contained in Appendix B. This listing identifies parameters that should be collected at all stations in order to measure and describe the site as well as a set of optional parameters that could be collected to assist in research studies related to understanding productive capacity, selection of habitats by juvenile salmonids, development of habitat-based stock assessment and habitat evaluation methods, etc.

19. Wherever possible, data should be collected to assist in the evaluation of the potential application of fixed effort INDEX estimates. The catch in the first 300 seconds of the first sweep for any station being sampled for removal estimates should be recorded to assist in determining the relationship between INDEX (fixed effort) catches as compared to removal population estimates. Some general habitat attribute data (e.g., water temperature, flow, substrate, area covered) should also be collected.

20. Electrofishing should not be conducted when water temperatures are high (18^0 C or greater for salmonids) as mortalities are likely to occur. If mortality rates become high electrofishing should be discontinued for a period of time until temperatures diminish. In addition, electrofishing should not be conducted at lower temperatures (less than 7^0 C) owing to the behavioral changes of juvenile salmonids at low temperatures (i.e., the tendency to burrow into coarse substrate) which could make fish more susceptible to effects of repeated electroshocking and/or invalidate quantitative estimates.

21. In order to facilitate a standardized approach to electrofishing technique, the wider use and availability of data collected by electrofishing, and the subsequent archiving of these data, a standard set of field collection data sheets and forms and specifications for computer entry of data have been developed and are recommended for use by all researchers, wherever practical (see Appendix C).

22. Electrofishing is a technique that can be very harmful to juvenile fish if used improperly (for example by over shocking using an excessively high voltage) and can be potentially dangerous to crews not familiar with the technology and equipment. It is highly recommended that each field crew contain at least one individual with considerable electrofishing experience and knowledge of safety considerations. This individual should be the one to use the electrofishing probe, make all settings and adjustments on the equipment, and assign tasks to less experienced crew members until others have demonstrated a capability to participate in the functions.

23. It is recommended that researchers and other practitioners of electrofishing for population estimation include an estimate of bias as a component of the standard protocol. This would be considered a mandatory requirement for major studies and for research where publication of results is anticipated. An approach to bias estimation is detailed below.

The proposed approach to estimation of bias associated with electrofishing population estimates would apply to estimates developed by the fixed effort depletion method only. An electrofishing station would be set up as appropriate for population estimation (i.e., closed off with barrier nets). An initial pass (sweep 1) would be made through the station. All fish captured would be marked with an adipose fin clip and returned to the station. A sufficient amount of time would be allowed for fish to recover and redistribute (preferably overnight). The station would then be electrofished as per usual for a depletion estimate (sweeps 2 through 5 or more as required). The population estimate of **unmarked** fish would be determined from the fish captured from sweeps 2 through 5 (or more). An estimate of bias, as %, would be determined from a depletion estimate of the number of **recaptured marked** fish in the station as obtained in sweeps 2 through 5 (or more), in relation to the total number of marked fish introduced into the station (known), as follows:

$$\text{Bias estimate (\%)} \quad = \quad \frac{\text{'Estimated' no. marked fish} - \text{Total no. marked fish}}{\text{Total no. of marked fish}}$$

As the estimated number of marked fish may be higher or lower than the actual number, the bias could be negative reflecting an underestimate or positive, reflecting an overestimate. The resulting population estimate of unmarked fish could then be adjusted based on the % bias, at the discretion of researchers, or simply the bias reported as a quality control check.

Similarly, the biomass estimate could also be adjusted by the same factor as most estimation programs (e.g., Microfish) use average weight to calculate biomass. If the estimates are stratified by species and/or age/size group, then separate bias estimates (and adjustment factors) would need to be determined for each level of stratification. If population and biomass estimates are adjusted they should be reported as adjusted. It should also be noted that this approach would also allow for the determination of a Peterson mark recapture estimate (Ricker 1975), using fish marked in sweep 1 and the ratio of marked to unmarked fish in sweeps 2 through 5, as an additional check of the depletion population estimate.

Research Recommendations

The following research recommendations were developed from the two electrofishing workshops. These recommendations arose either during discussion at both workshops or were developed at the second workshop during the session dedicated to addressing research needs. Recommendations are not priorized and may be implemented as researchers see fit and as opportunities arise.

(1) A study should be conducted to determine the possible detrimental effects of electrofishing on fish. This could include holding fish that have been electroshocked in a controlled setting for an extended period of time to observe any delayed mortality. Additionally, a sample of fish could be sacrificed for examination by X-ray and/or necropsy to determine any physical effects that are not externally apparent.

(2) A study should be conducted to determine the appropriate time to be left between consecutive sweeps in a depletion population estimate. Currently, 30 minutes is the 'rule of thumb' for the minimum time to be left between sweeps.

(3) A study should be conducted to determine the relative efficiency and accuracy of electrofishing in developing an estimate of population size in various habitat types as defined in Gibson *et al.* (1987), including a comparison of depletion and mark/recapture methods.

(4) Research should be conducted to determine the validity of the 300 second index (fixed effort) approach as an alternative to the standard standing stock estimation. This could be conducted opportunistically, in association with other electrofishing efforts. In addition, there should be a dedicated, scientifically designed, study conducted to address this issue.

(5) An assessment of the error and variability associated with subjective approaches (i.e., 'wind shield') to estimation of habitat variables should be conducted. This would help determine the error level associated with wind shield habitat assessments and would assist in identifying whether the additional effort associated with quantitative measurement of habitat variables is warranted. Specifically, it was recommended that several diverse electrofishing stations be established and that habitat attributes be estimated using rigorous techniques. The same attributes will be estimated using subjective (visual) means, independently by a number of scientists, biologists, technicians, and student help. The results should be evaluated to determine i) if the rigorous methods are improving the reliability of data, ii) the bias in measurement among observers, and iii) which attributes can be reasonably estimated using visual 'wind shield' methods.

(6) A study should be conducted, using a number of population estimators and the same data set, to comparatively evaluate the estimates derived from the various methods.

(7) A study should be conducted to determine if there is any variability in electrofishing efficiency associated with different operators. This could be expanded to address electrofishing in an upstream or downstream direction, use of different equipment, amount of effort (time) expended in each sweep, use of salt licks to enhance conductivity, etc.

(8) Research should be undertaken to address the validity of the Bayesian approach to population estimation as presented by Dr. W.G. Warren. Specifically, research should address how the parameter k varies under various stream habitat conditions, habitat types, and for different species and size/age classes. Means of making the approach more widely applicable and 'user friendly' should be pursued.

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Table 1. A comparison of electrofishing activities of the Salmon and Charr Section, the Enhancement and Aquaculture Section, and the Habitat Research and Assessment Section.

Group	Purpose	Equipment	Stratification (Habitat)	Station Size	Habitat Attributes Measured	Population Estimation Method	Notes
Salmon and Charr (R.J. Gibson)	habitat research, assessment, and modelling	Coffelt VVP shore based unit; Smith Root backpack (Type VIIIA)	by habitat type and stream order (where possible)	1.0 to 6.0 units	length, width, depth, velocity, cover types, riparian vegetation, substrate, bank scour, pools, etc.	removal (Zippin) and mark-recapture (Petersen)	-barrier nets used
Enhancement and Aquaculture (C.E. Bourgeois)	assessment of fry stocking	Coffelt VVP shore based unit	fry and parr rearing habitat	1.0 to 2.5 units	length, width, depth, riparian vegetation, substrate	removal (Microfish 3.0)	-barrier nets used -salt licks used to increase conductivity
Habitat Research and Assessment (D.A. Scruton)	applied habitat research and impact assessment	Smith Root backpacks (Type VIIIA and 12)	by habitat type, 'before and after' project implementation	2.0 to 4.0 units	length, width, depth, cover types, riparian vegetation, gradient, bank erosion and scour, substrate, pool characteristics, etc.	removal (Microfish 3.0)	-barrier nets used

Table 2. Definition of major salmonid habitat types as used in Newfoundland (Gibson *et al.* 1987), adapted after Allen (1951).

Habitat Type	Description
Pools:	Of two groups: *pools*, with current of less than 38 $cm{\cdot}s^{-1}$ and depth of from 46 to 68 cm; *deep pools*, with current less than 38 $cm{\cdot}s^{-1}$, and depth over 68 cm. The flow is smooth apart from a small turbulent area at the head (top) of some pools.
Flats:	Current under 38 $cm{\cdot}s^{-1}$, mean water depth under 46 cm. Flats are sections of relatively shallow, slow water, but with a smooth surface.
Runs:	Current over 38 $cm{\cdot}s^{-1}$, mean depth over 23 cm. The flow is usually turbulent. In such places, the stream is usually less than the average width.
Riffles:	Current over 38 $cm{\cdot}s^{-1}$, mean depth under 23 cm. These are shallow water with a rapid current and usually a broken flow.
Cascades:	These are rapids in which a steep gradient, combined with a bed of stones or rocks, large in proportion to the stream, produces a very irregular rapid flow, often with some white water.

Table 3. Habitat variables measured at electrofishing stations and used in stepwise multiple regression habitat models (after Gibson *et al.* 1993).

Variable		Description/Method of Measurement	
Mean (wet) stream width	MWIDTH	in m, usually taken at three locations in the station x n^{-1}.	
Mean depth	MDEPTH	in cm, usually at 5 equidistant locations at the same transects as the width measurements $x(n=1)^{-1}$.	
Mean water velocity	VEL	in $m.s^{-1}$, measured at 0.6 of the depth at 1/4, 1/2, and 3/4 of the width, at the same location as the width and depth measurements.	
Maximum flood height	MAXFLDH	in cm, as an indicator of range of discharge (can also be ice scour). height).	
Maximum depth	MAXDEPTH	in cm, at the deepest point in the station.	
Substrate rating	SUB	each proportion of the following substrate types is multiplied by the rating (below), and the results summed for a general substrate rating for the station.	
		Substrate Type	Rating
		irregular or convoluted bedrock.	7
		very large boulders, 2.05 - 4 m.	6
		large boulders, 1.05 - 2 m.	6
		medium boulders, 0.55 - 1 m.	6
		small boulders, 25.2 - 50 cm.	6
		rubble, 15.5 - 25 cm.	5
		cobble, 6.5 - 15 cm.	4
		pebble, 1.65 - 6 cm.	3
		gravel, 2.5 - 16 mm.	2
		sand, 0.1 - 2 mm.	1
		silt, 0.004 - 0.06 mm.	1
		clay, < 0.004 mm.	1
		organic detritus.	1
		flat bedrock.	1

Variable		Description/Method of Measurement
Instream cover	INSTRCOV	as %, undercut banks, tree debris, aquatic plants, etc.
Overhanging cover	OVCOV	as %, structures up to 1 m above the water surface and providing shade, such as alder bushes, etc.
Canopy cover	CANCOV	as %, shade over the stream provided by trees.
Specific conductivity	SPCOND	
Chemical		Nitrate nitrogen; total alkalinity; total phosphorus; total dissolved solids; hydrogen ion; total hardness; calcium; chloride; sulphate; colour.

Table 4. Beak Consultants Limited (1980) system for aerial classification of salmonid habitat in Newfoundland, used in environmental impact assessment from 1979 to date.

Habitat Type	Description
I	Good salmonid habitat, good spawning areas, often with pools for larger age classes, preferred by fry and smaller juveniles. *Flows* - moderate riffle, current 0.1 to 0.3 $m \cdot s^{-1}$. *Depth* - shallow, less than 1 m. *Substrate* - gravel to small cobble sized rock, may be interspersed with boulder.
II	Good salmonid rearing habitat, limited spawning in isolated gravel pockets. Good feeding and holding areas for larger fish in deeper pools, pockets, or backwater eddies. Generally preferred by larger juveniles. *Flows* - riffle to light rapid, current 0.3 to 1.0 $m \cdot s^{-1}$. *Depth* - variable, less than 1.5 m. *Substrate* - large cobble to boulder and bedrock, some gravel pockets interspersed.
III	Poor rearing habitat with no spawning capabilities, used for migratory purposes. Generally considered migratory and non-productive habitat. *Flows* - fast turbulent, heavy rapids, chutes, waterfalls, current greater than 1 $m \cdot s^{-1}$. *Depth* - variable *Substrate* - boulder, bedrock.
IV	Poor juvenile salmonid rearing habitat, no spawning capability. Provides shelter and feeding habitat for larger, older salmonids. Generally used by older age classes, adults, not considered critical to recruitment. *Flows* - sluggish, current less than 0.15 $m \cdot s^{-1}$. *Depth* - variable, often 1 m and greater. *Substrate* - soft sediment or and, large boulders or bedrock covered by sand or silt, aquatic macrophytes often present, especially along shore.

Appendix A

Workshop Agenda(s)

Salmonid and Habitat Sciences Division Electrofishing Workshop

April 20 - 23, 1993

April 20, 09:00 to 17:00

Location: Bally Hally Golf Club

Objectives:

1) Review the objectives and purpose for electrofishing studies and the methodologies/equipment currently in use within the Division.

2) Review considerations for electrofishing studies related to sampling design, site selection, applications of data obtained from electrofishing, methods of population census, habitat attributes measured, fisheries data collected, etc.

3) Develop a consensus as to the appropriate electrofishing techniques and methods to be employed, the population estimator(s) that could be used, the potential applications of data obtained from electrofishing (and associated assumptions and limitations), and the appropriate habitat variables that must and could be collected (including the method of measuring these variables).

4) Publish a report/paper from the workshop (venue to be determined) based on the consensus and recommendations above (3).

Note: All presenters should bring 15 copies of their paper and, where possible, a digital copy (WP 5.1 format, 3.5" diskette preferred).

Agenda

<u>April 20, 09:00 - 12:00</u>
Presentation of prepared papers with discussion of each paper.

R. J. Gibson, Electrofishing and Habitat Measurement Techniques Employed by the Salmon and Char Section.

D.A. Scruton, Electrofishing Techniques Employed by the Habitat Research and Assessment Section in Habitat Research and Environmental Effects Monitoring.

C.E. Bourgeois, Electrofishing Techniques Employed by the Enhancement and Aquaculture Section in Determining Effectiveness of Fry Stocking.

<u>April 20, 13:00 - 17:00</u>
Presentation of prepared papers with discussion of each paper (continued).

C.C. Mullins, Length Frequency Sampling Using Fixed Electrofishing Effort.

S.C. Riley, Under-estimation of Population Size by Removal Estimators.

R.A. Myers, Recent Advances in Analyses of Electrofishing Data.

<u>April 21, 09:00 - 12:00</u>
General discussion of presentations of April 20 towards developing recommendations for standardization of methods and rationale for electrofishing. Decision as to venue for publication and preparation of a skeletal draft of proposed publication. Major areas for consideration will include:

1) Objectives and rationale;
2) Study design and site selection;
3) Techniques and equipment;
4) Habitat data collected;
5) Fisheries data collected;
6) Data analyses and population estimation;
7) Application of data;
8) Assumptions, constraints, cautions, etc.

<u>April 21 and 22, 13:00 - 17:00</u>
Continued discussion and preparation of draft report manuscript.

ELECTROFISHING WORKSHOP

April 21-22, 1994

Bally Hally Golf/Curling Club

This workshop is a follow-up to a 1993 workshop held to review electrofishing techniques used within Fisheries and Oceans, specifically the Salmonid and Habitat Sciences Division. The oucome of that workshop, including recommendations for standardization of techniques and collection of habitat attribute data, are contained in the draft report that has been circulated in advance of this follow-up session. This draft report will be the primary focus of discussions at the current workshop.

The primary objectives of this follow-up workshop are as follows:

(1) review and finalize recommendations on standardization of techniques;

(2) review and finalize recommendations on collection of habitat attribute data;

(3) discuss recommendations (1) and (2) above, as they relate to regional applications of electrofishing;

(4) discuss issues relating to estimation of bias and precision in electrofishing estimates; and

(5) identify any research recommendations related to electrofishing methodology.

This workshop will be extremely informal in nature and there are no formal presentations planned. While, two days have been set aside it is hoped all issues can be resolved in one to one-and-a-half days. A very general agenda for the workshop is attached.

ELECTROFISHING WORKSHOP
AGENDA

April 21, 1994

09:00 to 10:30

Brief Review of 1993 Workshop.
Discussion of Recommendations Re: Standrdization of Techniques

10:30 to 10:45 - Coffee

10:45 to 12:00

Discussion of Recommendations Re: Standrdization of Techniques
Discussion of Recommendations Re: Collection of Habitat Attribute Data

12:00 to 13:00 - Lunch (on your own)

13:00 to 14:30

Discussion of Recommendations Re: Collection of Habitat Attribute Data
Application of Recommendations to Regional Uses of Electrofishing

14:30 to 14:45 - Coffee

14:45 to 16:30

Measurement of Bias and Precision in Relation to Electrofishing Estimates
Recommendations for Future Research

April 22, 1994

09:00 to 10:30

Continuation of Discussions (as/if required)

10:30 to 10:45 - Coffee

10:45 to 12:00

Continuation of Discussions (as/if required)

CONCLUSION OF WORKSHOP

Appendix B

Recommended Techniques for Estimation of Habitat Variables

Habitat Attributes and Measurement

A major purpose of this workshop was to determine the types of habitat attributes required in conjunction with electrofishing studies and methods of quantification. During the workshop discussions, considerable concern was raised as to the widespread use of subjective measurements using visual estimates of certain key habitat attributes. It was suggested that this approach would lead to unreliable data and considerable observer bias, particularly if several individuals within a study team were involved in visual estimation. Some researchers, while recognizing this concern had adopted a process whereby the same individual conducts all the subjective measurements while other researchers had 2 or more individuals conduct subjective measurement and then average the results. It was decided at the workshop to review existing studies in the literature and recommend a set of objective, scientifically rigorous techniques for collecting habitat variables. It was recognized that it was important to keep the number of variables to be measured and the methods of data collection practical and sensible, recognizing that there will be resource constraints (money and personnel) limiting the data collection. It was also identified that by specifying an approach for routine data collection, a comparable data set will be incrementally built that would lend itself to broader applications than the specific study for which the data were collected.

The following section describes a set of habitat attributes, including preferred methods of measurement/data collection, that are recommended to be collected during electrofishing studies. Several parameters that could be considered discretionary are listed at the end. In some instances, several methods of measurement are described with one technique being advanced as preferred. Where specific equipment is required for measurements, this is also identified. Typically, the collection of habitat attribute data is a compromise between statistical considerations (precision, accuracy, bias) and resource considerations (personnel, time, available equipment, funds, etc.). The procedures outlined in the following section attempt to balance these requirements to identify a set of variables that can be reasonably collected in the course of electrofishing studies. Researchers are also referred to Hamilton and Bergerson (1984) for an overview of methods to estimate aquatic habitat variables.

It is also important that the collection of habitat attribute data not interfere or bias electrofishing results. As many of the habitat measurements involve personnel moving through the station, it is recommended that collection of these attributes be conducted at the completion of electrofishing (after the final run). It is also advisable to take one or more photographs of each electrofishing station to assist in documentation, if sites are to be repeated, or possibly to help reconcile inconsistencies or omissions once out of the field.

General Considerations

Typically, in aquatic studies, habitat is stratified by one or more attributes (most commonly stream order, habitat type, etc.) and sampling strategies are based on this stratification. In electrofishing stations, and for many investigations of fluvial habitat, measurements are taken along a line (transect) that either crosses the stream (e.g., depth, width, velocity, etc.) or runs parallel to the stream bank (e.g., overhanging cover or stream bank vegetation, undercut banks, etc.). Depending upon the attribute, one (e.g., discharge) or more (e.g., width, depth) transects may be required. For attributes requiring multiple transects, these are usually selected in either a uniform (standard spacing to divide the station) or random manner. Terrell *et al.* (1982) have recommended at least 10 transects per representative reach (site or station) and more depending upon the variability within that reach. Measurements taken along a transect either represent a point (e.g., depth) or a cell (e.g., substrate).

Habitat Type

Gibson *et al.* (1987) after Allen (1951) has defined general aquatic fish habitats in insular Newfoundland to include cascade, riffle, run, pool, flat and lake (see Table 2). More recently Jowett (1993) has classified stream habitat using river hydraulic measurements. Biologists should be familiar with the distinctions between habitat types and be able to recognize in the field. For the most part, and in consideration of the recommendations of this workshop, all habitat within an electrofishing station will be of one type. In some instances, due to the station area required for accurate population estimates, an electrofishing station may encompass two (2) or more habitat types. In this case, it will be necessary to measure the area of each type and then determine the proportion (percentage, %) of each type within the station.

Station Dimensions (length, width, area)

It is important to accurately measure the dimensions of the wetted area of each electrofishing station as most population data are defined by area (i.e., numbers or biomass (weight) of fish per unit (100 m^2) of habitat). As a minimum, a single measure of length of the section (to 0.1 m) should be taken in the middle of the section. If the station is irregular in shape, then additional length measurements should be taken (a measurement along the left and rights banks in addition to the mid-channel measurement, then averaging the values). The station width should be an average of at least three measurements (to 0.1 m) taken at the top, middle, and bottom of the station. Again, if the station is irregular in shape, then additional width measurements should be taken, at the discretion of the research team. The station area would be the product of mean length times mean width. If the station has a small island or sand/gravel bar within the channel, then these areas will need to be subtracted in order to estimate only the wetted surface area. Measurement of channel, or bank to bank, width may also be of interest and this would be the distance (0.1 m) from the top of the stream bank on either side of the river.

Substrate

Substrate is an important aspect of habitat selection in juvenile fish, is a good indicator of the hydrological dynamics associated with a site, is important in determining benthic productivity, spawning potential, etc., and is also important in determining available cover for fish. An integral part of substrate determination at a given site is a classification system used to describe the various types of substrate. The following system from a modified Wentworth scale (adapted from Cummins 1962 and Platts *et al.* 1983) is a widely used classification based on particle size of substrate, has been in use in the Region for many years, and is recommended to be adopted as the Regional standard.

Category	Diameter
Large Boulders	>1 m
Small Boulders	25.5 cm - 1 m
Rubble	14 - 25 cm
Cobble	6 - 13 cm
Pebble	3.5 - 5 cm
Gravel	20.5 mm - 3 cm
Sand	0.06 - 20 mm
Silt	0.004 - 0.05 mm
Bedrock	N/A

It is important that researchers become familiar with the appearance of each substrate size category so that field distinctions can be accurately made. This can involve practice in estimating substrate sizes with collections that have been categorized (by sieving or with a ruler) or may simply be a function of the experience of the investigator.

To date, most substrate determination at electrofishing sites has involved visual analysis of the surface substrate. Typically a 'wind shield survey' is conducted whereby the study area is observed from a vantage point, or while walking through it, and the proportions (%) of each substrate class is estimated. In some instances this is completed by several members of the electrofishing team and the results are averaged. This method is extremely subjective and prone to observer bias and error.

An alternative approach used by many researchers incorporates subjective visual analysis into intensive transect profiles. Transects should be established at appropriate intervals (either systematic or randomized) and at points equidistant along the transect (0.5 m for narrow streams, 1.0 meter for wide streams) and the dominant substrate (by area) should be determined. The dominant substrate would be determined for a 'cell' (either 0.5 by 0.5 m, or 1.0 by 1.0 m) that is split by the transect (tape or rope). The entire area represented by that cell is inspected visually, and estimates of dominant size class (as well as embeddedness, percent fines, etc., if desired) are made. The substrate classes would then be totalled for each transect, the entire station, and the proportion (%) of each substrate class determined. The number of transects would depend upon the required accuracy and the size of the station. The use of a systematic sampling approach (with permanent marking of transects) would be particularly appropriate for sites that are repeated annually. The transects established for substrate determination could also be used for measurement of width, depth, velocity, instream cover, etc.; consequently, a large amount of the habitat attribute information could be collected along the same transect.

An alternative to the above approach employs random measurements of dominant substrate classes within a station. This could involve randomized selection of transects or the use of some predetermined randomization approach to collect substrate classification at a number of points/cells in the station. At each point, a 'cell' (of predetermined area) is visualized and the dominant substrate class identified. A variation on this approach involves the use of a hoop or square (of known area) which is randomly 'tossed' in the station area and the dominant substrate class in this hoop/square is then determined. The measurements are then totalled and expressed as a proportion (%) of the total station area. A combination of approaches could also be employed which uses random quadrat placement in conjunction with systematic transects, or alternatively, randomly sub-sample the data collected from systematic transects.

For electrofishing studies, categorization by visual analysis would be the most appropriate technique. Studies that require high accuracy and detailed vertical and horizontal analyses call for the relatively labour and equipment intensive sieving of samples obtained by the manual or freeze-core sampling methods. Photographic techniques have also been employed; however, these are also labour intensive, costly, and difficult to use in highly coloured, turbid, or turbulent water.

The degree of embeddedness (the degree to which the larger substrate material is surrounded or covered by sediment and fines) is an important indicator of the substrate quality. Platts *et al.* (1983) has developed a rating system (see below) based on the percentages of fines associated with the coarser material. The embeddedness rating could be collected at the same time as substrate class evaluation using any of the above sampling schemes.

Depth

Depth is an important habitat variable as it has been demonstrated to be an important factor in habitat selection by various species and their age classes. Depth is also an important variable in determining the type and quality of habitat and is also a contributing factor to the definition of other habitat features (e.g., instream cover, pool quality, etc.). Some authors also express population estimates (numbers, biomass) as a function of volume of water (as opposed to area). Water depth is normally measured with a wading rod or meter stick in wadable streams or with a plumb line (weighted and measured line) in deeper waters, to the nearest 0.1 m.

Normally, for the purposes of general description of a station (and determination of mean station depth), measurements (in cm) will be taken along each transect where each width measurement is taken. For each transect a minimum of three (3) measurements are taken at the 1/4, 1/2, and 3/4 points along the transect. For more detailed measurements, or at wider stations, measurements can be taken at 0.5 or 1.0 meter intervals, or subjectively at the break points where there are appreciable changes in depth. For each transect, all measurements are summed and divided by n+1 (to account for the 0 depth at the stream margins) to get an average depth per transect. The averages from all transects are then averaged to get a mean station depth.

For some purposes, it will be of interest to determine the amount of the station at each depth class. In this application, a rigorous sampling strategy is to be employed with subsequent mapping of the station, contouring of depths, and calculation of area in each depth class. In this instance, transects are established at pre-determined intervals and measurements collected at set points along each transect. In some cases, it is desirable to measure the maximum depth found within the station.

It may also be of interest to measure the variability in depths as an alternative, or in addition, to determining the station mean. Here it would appropriate to establish some stratified (as above), random stratified, or random sampling strategy to collect a sufficient number of measurements. The strategy used for substrate determination could also be utilized for depth measurements.

Velocity/Discharge

The choice of method for measurement of velocity and the rigour with which it is measured will be determined by the applications of the data. Velocity is also a measurement that will vary according to discharge, any alteration in stream channel configuration, debris accumulation, etc., and therefore is very time dependent, but should be measured at the same time as the population estimates are made.

For generalized measurements, most commonly three measures of surface velocity (the fastest velocity measurement in the water column) are taken and then averaged. This involves timing the travel of a floating object over a predetermined distance (usually 10 m). This can be converted (for very general use) to water column velocity by multiplying by 0.8 for a rough bottom stream and 0.9 for a smooth bottom stream. This measurement is also somewhat subjective (and crude) in that a straight stretch of stream must be selected, the floating object may not move in a straight line, the object will be affected by wind and eddy effects, etc. Generally, a neutrally buoyant object (e.g. an orange or a 'street hockey' ball) is preferred. This measurement is applicable for general description of the station where the equipment and time required for more accurate measurements are not available and/or not required.

Most rigorous measurements of velocity involve the use of current meters and the measurement of mean column velocity (a velocity representing the average at a vertical point in the stream) at a number of locations along a transect. The mean velocity of the water column, at the point of measurement, is approximated by taking a reading at 0.6 the depth below the water surface (where maximum depth is less than 2.6 m) or at 0.2 and 0.8 of the depth below the water surface (with averaging of the 2 measures, where maximum depth exceeds 2.6 m). A strategy of measurement similar to collection of substrate and depths could then be adopted (i.e., measurements can be taken at 0.5 or 1.0 meter intervals or could be determined subjectively at the break points where there are appreciable changes in depth/velocity). Additionally, if it is of interest to determine the variability in column velocity, then an alternative sampling strategy could be adopted (see above as for depth).

Frequently, it is of interest to determine the velocity, depth, substrate, or cover at the point where fish are maintaining position (holding) in a stream. This is usually defined as nose (focal) or holding velocity and will not be discussed in this report as this measurement is most often associated with micro-habitat research and not standard electrofishing techniques.

Discharge is a measure of the volume of water moving past a specific point in a stream and is normally expressed in cubic meters per second (m^3s^{-1}) or cubic feet per second (ft^3s^{-1}). This would usually be calculated in the office once the required field measurements have been collected. Normally, only one (1) discharge measurement will be taken per station or section/reach. Determination of discharge involves placing a detailed depth and velocity transect at a point in the stream where the flow is unobstructed (not turbulent and flow is parallel to the bank) and as uniform as possible. The mean velocity of the transect is multiplied by the cross sectional area (width times mean depth) to calculate discharge.

A more precise measure of discharge (as described by the U.S. Geological Survey) involves calculation of Total discharge (Q) in partial sections and summation of the partial discharges (q). Discharge (q) in each partial section (i) is calculated from depth (d), velocity (v) and distance from a reference point or stream edge (b) as follows (see also Figure C-1 below):

$$q_i = v_i \text{ x } d_i \text{ x } \frac{(b_{i+1} - b_{i-1})}{2}$$

Figure C-1. An example of measurement locations for determination of velocity and discharge calculations along a station transect. Note that this transect can also be used to collect depth and substrate measurements.

Undercut Banks

Undercut banks are excellent holding areas for fish, constitute valuable fish habitat, and should be recorded in the collection of habitat attributes to describe the electrofishing station. Undercut banks are areas in the stream banks where erosion has caused wetted areas to form under the stream banks. The length of the undercut can be measured and expressed as a proportion (%) of the total stream bank length, considering the total to include both stream banks.

Some authors also measure the distance into the stream bank (the 'depth' of the undercut) and calculate an area (m^2 of undercut banks). In this case, the area is added to the wetted surface area of the station and the undercut is expressed as a proportion of the total area of the station (e.g., wetted area = 200 m^2, undercut = 20 m^2, total is 220 m^2, % undercut is 20/220 or 9.1 %). In this case, the population estimates are expressed as a function of the total station area, including the undercut. The proportion of undercut banks in the station could also be included in the amount of 'submerged cover'.

Ice Scour Height/Flood Debris Height

These measures are proxy variables to indicate the range of discharge, or 'flashiness' of a system, to provide some measure of extreme hydrological events. This proxy variable will provide a measure of maximum flow over an undefined time period, as the high water mark could be the result of erosion during any given year. For stations that are sampled repeatedly, it may be possible to distinguish the high water mark of the preceding year or spring flood of the current year. The indicator of maximum discharge could be an ice scour or erosion mark, debris apparent in vegetation or on the stream banks, or could be interpreted by presence/absence of algae and moss on exposed substrates. This is normally measured as the vertical distance from the water surface level (at low flow) to the indicator mark. This can be estimated, measured using a tape measure, or, if available, a survey level and rod could be used. Debris left at the high water mark has been closely correlated with ice scour (scar) (Gibson *et al.* 1993) and the two can be used interchangeably.

Water/Air Temperature

Water temperature (to 0.1 ^{0}C) at the time of electrofishing and can be important in the interpretation of data collected (i.e., fish may be selecting habitat based on temperature preference or stress). Temperature also influences the effectiveness of electrofishing (i.e., influences electrical conductivity of water and activity/metabolism of fish) and can also effect the lethality of the technique. Water temperature may also vary over the three to four hour period required to complete an electrofishing station. The researcher could take a temperature at the start and completion of the electrofishing and average the two (2) measures. Alternatively, by convention, the temperature would be recorded at the same time as collecting the other habitat variables (at the completion of electrofishing).

Air temperature (to 0.1 ^{0}C) is also frequently recorded during habitat assessments, although it would have limited application to interpretation of the data. The same considerations as for water temperature would apply. If a time series of temperature data is of interest or a high degree of accuracy required, recording thermographs may be deployed for that purpose.

Cover (canopy, overhanging, and instream)

Cover is a very subjective measurement; however, it is critically important in the determination of the amount and quality of habitat. Cover is also very species and life stage dependent, and as such it is important to have common criteria for defining cover. In insular Newfoundland, Gibson *et al.* (1987) has classified three (3) types of cover for juvenile salmonids (Atlantic salmon, brook trout, and brown trout primarily) to include *canopy* cover, *overhanging* (riparian) cover, and *instream* cover (see definitions below).

The definitions of the above cover types (after Gibson *et al.* 1987) are as follows:

Overhanging riparian (structures up to approx. 1 m above the surface of the water and providing shade; e.g., alder bushes)

Instream tree debris, undercut banks, aquatic plants (identified if so desired to algae, mosses, higher plants, etc.), etc.

Canopy shade cover directly over the stream provided by tree branches and foliage

In the past, cover has often been estimated subjectively by researchers and is subject to the same criticisms as 'wind shield surveys' of substrate. In some studies, a more rigorous measure of cover may be required. For these studies, a preferred approach to measurement would involve identification of the particular cover type using approved criteria (below), measurement of the total area (which is usually a sum of several pockets of cover), and then the total is expressed as a percentage of the station area (Binns and Eiserman 1979). It may also be necessary to more clearly define the criteria describing the cover types (e.g., surface water turbulence can be considered an instream cover attribute).

In Norway, cover types are assigned a code from 1 to 7, as follows: submerged logs, roots, etc. -1; other submerged attributes - 2; stones, boulders, etc. - 3; overhanging vegetation (0-50 cm in height) - 4; broken water surface - 5; organic debris, fine material -6; submerged vegetation -7. Similarly, cover type percentages are determined, from visual estimation, and assigned a code based on percentage (J. Heggenes, pers. comm.).

Bank Stability

An estimate of the percentage of the site containing eroding banks should be obtained. Again, this can be done when measuring station length and would be a measure of the various lengths of eroding banks, expressed as a percentage of the total bank length (including both banks).

Riparian Vegetation

An estimate of the percentage of each of the following categories should be obtained: Grass/Shrubs, Alders/Willows, Coniferous trees, Deciduous trees, Bog, other. It is difficult to prescribe a rigorous sampling methodology that will not be too onerous. For those studies where a detailed estimation of streamside vegetation is required, researchers are advised to consult Hays *et al.* (1981) to determine a suitable methodology. For the purposes of general station description, a visual estimate of the above vegetation classes in the 5 meter riparian zone of the study stream should be conducted.

Pools

The number of pools within the station should be noted (totalled) and the riffle/pool ratio should be estimated. Each pool should be measured for length, width (at the middle of the pool) and mean depth should be estimated (by taking a number of depths at random locations and then averaging). The pool to riffle ratio would be determined as a ratio of the total pool area (total of areas for individual pools, determined by the appropriate geometric equation) to the total riffle area (total station area minus pool area).

If more rigorous classification of pool habitat is required, a modification of a rating system developed for Idaho streams (after Platts *et al.* 1983) could be developed.

Appendix C

Standard Forms for Field Collection of Electrofishing and Habitat Data

Standardized Forms for the Collection and Entry of Electrofishing Data

This appendix contains a number of forms, including instructions and coding specifications, that have been developed to assist in the standardization of data collected from electrofishing studies. Forms developed for the collection of field electrofishing data (site information, survey details, etc., and fish data) are intended to be used by all/most practitioners employing quantitative electrofishing in an effort to develop a consistent approach to data collection that would permit comparability of information collected. Also included are computer data coding (entry) forms and coding specifications. This format is primarily intended for storage and archiving of data on a mainframe computer but could be adapted for use with software for personal computers (e.g., database and spreadsheet programs). Owing to the wide variety of possible methods of collection and use of rigorously collected detailed habitat data, including the measure and classification of variables, no specific form has been provided for this purpose. The Field Data Collection Form contains a number of habitat variables that are to used to generally describe the habitat features of each station.

Included in this appendix are the following:

(1) **Field Data Collection Form** - a recommended standardized form for site description, collection of station and habitat data, information on electrofishing equipment, settings, and a summary of fishing results;

(2) **Field Fish Data Collection Form** - a recommended standardized form for the collection of data from fish captured;

(3) Instructions for (1) and (2) above;

(4) **Data Entry (Coding) Sheet** - a form for computer entry and archiving of data collected in a mainframe ASCII format; and

(5) Coding Specifications for (4) above.

Quantitative Electrofishing - Field Data Collection (revised 22-01-1995)

SITE DESCRIPTION:

River Name:		River Code:	
Latitude:		Longitude:	
Station Identifier:		Map Reference:	
Date:	Start:	Time:	Start:
	End:		End:
Field Crew:			
Description:			

STATION/HABITAT INFORMATION:

Length (m):	(1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ Mean _____	Width (m):	(1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ Mean _____
Station Area (m^2): ________		No. of Units (100 m^2): ________	
Depth (cm):	(1)____ (2)____ (3)____ (4)____ (5)____ (6)____ (7)____ (8)____ (9)____ Mean _____	Velocity (ms^{-1}): Type_____	(1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ Mean _____
Photographs (y/n):______ Roll#______ Exposures:________			Water sample (y/n): __________
Water Temp. (° C):	Start:	Air Temp. (° C):	Start:
	End:		End:
Weather:			
Detailed Habitat Collected (y/n):__________		(if no complete below)	
Habitat Type (%): Riffle_____ Run_____ Pool_____ Flat_____ Rapid_____ Other_____			
Substrate (%): Bedrock______ Lg.Boulder______ Sm.Boulder______ Rubble______ Cobble______ Pebble______ Gravel______ Sand/silt/clay______ Detritus______			
Cover (%): Instream ________ Overhanging ________ Canopy ________			
Riparian Vegetation (%): Grass/shrub ______ Alder/willow ______ Conif. tree ______ Decid. tree ______ Bog ______ Other ______			
Ice Scour Height (m):	(1)_____ (2)_____ (3)_____ (4)_____ (5)_____ (6)_____ Mean _____	Undercut Banks (y/n):______ % Station ______	
		Bank Stability (g/f/p): __________	
Number of Small Pools: __________		Pool/riffle Ratio: __________	

ELECTROFISHING INFORMATION:

Estimate Type:	Removal: _______	Barrier Nets (y/n): ______	Timer (y/n): _____
	Mark/recapture: _______	Equipment: ________________	
	Multiple Mark/recapture: _______	Pulse Width: ___________	Frequency: _________
	Index (300 s.): _______	Voltage: ________	Output: __________

Sweep No.	1	2	3	4	5	6	7	8
Timer (start):								
Timer (end):								

ELECTROFISHING RESULTS (Summary):

Species	Age Class	1	2	3	4	5	6	7	8	Total
	0+									
	1+									
	2+									
	> 2+									
	Total									
	0+									
	1+									
	2+									
	> 2+									
	Total									
	0+									
	1+									
	2+									
	> 2+									
	Total									
	0+									
	1+									
	2+									
	> 2+									
	Total									
Eels:										
Sticklebacks:										
Others:										

Comments: ____

____

Number of Fish Data Field Forms appended: ______________

Page _____ of _____

Field Fish Data Collection Sheets

River Name: ______________________	Station: ______________________
Date(s): ______________________	Responsibility: ______________________

No.	Sweep	Species	Age	Length	Weight	Marked (y/n)	Recap. (y/n)	Index Sample (y/n)	Aging Sample (y/n)	Remarks

Instructions for Completion of the Field Data Collection Form

SITE DESCRIPTION

River Name: The common name of the system being studied from the Canada Gazetteer or 1:50,000 topographic map. If the river is a tributary of a larger system, include the name of the main drainage as well.

River Code: This is the 7-digit river code assigned to all rivers. Codes are found in Waldron (1974) or in map booklets housed at Fisheries and Oceans. This can be added later when out of the field.

Latitude/Longitude: The geographic coordinates associated with the site location. This can be taken off of a topographic map or may be determined by Geographical Positioning Systems (GPS). The accuracy, to degrees/minutes/seconds (or decimal minutes), is at the discretion of the researcher. This can be added later when out of the field.

Station Identifier: An alpha-numeric code assigned to uniquely identify the site. It is recommended that this be a 2-digit code.

Map Reference: Indicate the 1:50,000 map that the site is located on. This can be added later.

Date: Indicate the date of the start and completion of the electrofishing survey.

Time: Indicate the time at the start and completion of the electrofishing survey.

Field crew: Indicate the names of the individuals involved in the electrofishing survey.

Description: Generally describe the site characteristics, site access, hydrological conditions, location of barrier nets, and other distinguishing features of the site.

STATION/HABITAT INFORMATION:

Length: Take one or more measures of the station length to the nearest 0.1 m. If multiple measures are taken, compute the mean (can be completed later).

Width: Take one or more measures of the station width to the nearest 0.1 m. If multiple measures are taken, compute the mean (can be completed later).

Station Area: Calculate the station area in m^2 from the mean length and width (can be completed later).

Number of units: Determine the number of habitat units (100 m^2) from the station area (can be completed later).

Depth: Take several measures of station depth (cm) and calculate the mean (can be completed later).

Velocity: Take one or more measures of the water velocity and calculate the mean (can be completed later). Indicate where the measurement was taken (i.e., surface or mid-water column) and how it was collected (i.e., meter and type, floating ball, etc.).

Photographs: Indicate whether photographs were taken and indicate the roll and exposure number.

Water Sample: Indicate whether a water sample was collected.

Water Temperature: Determine the water temperature (0.1 ^{0}C) at the start and completion of the electrofishing survey.

Air Temperature: Determine the air temperature (0.1 ^{0}C) at the start and completion of the electrofishing survey.

Weather: Generally describe the weather conditions at the time of the survey.

Detailed Habitat Survey: Indicate whether a detailed habitat survey/study was completed at this site. If not, collect the remaining habitat data identified on the form.

Habitat Type: Estimate the proportions of each habitat type in the station. See Table 2, pg. 33, for a description of each habitat type.

Substrate: Estimate the proportion of each substrate size class in the station. See Table 3, pg. 34, for a description of each substrate size class.

Cover: Estimate the proportion of each of three cover types (see page B-8, Appendix B for a definition) in the station.

Riparian Vegetation: Estimate the proportion of each vegetation type in the riparian habitat (within 5 m on either side of the station).

Ice Scour Height: Measure or estimate the height of any ice scour (scar) mark or debris in riparian vegetation which could indicate the height of the peak flows in the preceding spring. If necessary take more than one measure and calculate the mean (can be completed later).

Undercut Banks: Indicate whether there are undercut banks within the station and estimate the portion of the bank that is undercut.

Bank Stability: Indicate the relative (good, fair, poor) stability of the stream banks.

Number of Pools: Indicate the number of small pools in the station. If the entire site is a pool this is not relevant.

Pool to Riffle Ratio: From the proportions of habitat types calculate the ratio of pool to riffle habitats.

ELECTROFISHING INFORMATION:

Estimate Type: Indicate the type of quantitative estimate being determined in the survey. Note that it is possible to be completing two types of estimate at the station at the same time (e.g., a removal estimate may be conducted while data are also collected for the 300 s index).

Barrier Nets: Indicate whether barrier nets were used at the station.

Timer: Indicate whether the various collections (sweeps) were timed.

Equipment: Indicate the make and model of the equipment used.

Pulse Width: If variable settings on the electrofisher are possible, indicate the pulse width selected.

Frequency: If variable settings on the electrofisher are possible, indicate the frequency selected.

Voltage: If variable settings on the electrofisher are possible, indicate the voltage selected.

Output: If the electrofisher is metered indicate the output, in mili-amps, that the electrofisher is producing.

Timer: If the electrofisher is equipped with a timer, record the settings at the start and completion of each collection (sweep).

ELECTROFISHING RESULTS:

This section is primarily intended to provide a sweep by sweep summary of the electrofishing catch so that the field crew can monitor the progress of the survey and to permit the researcher to evaluate the need for, and benefit of, additional survey effort (e.g., additional sweeps to improve the population estimate). The researcher may, if so desired, subset the catch by species and size/age class. While it is not the intention to use this information directly in population estimates, some programs (e.g., MICROFISH 3.0) can be run interactively, using catch totals from each sweep, to calculate a population estimate.

Comments: This allows the field crew to provide any comments, cautions, and caveats related to the survey that could be used at a later time to explain some of the results.

The last space for field data entry is to indicate the number of Fish Data Field Forms appended. Detailed data on all fish collected will be entered on the Fish Data Field Forms and this entry will identify how many of these additional forms are associated with the completion of the station.

Instructions for Completion of the Fish Data Field Form

This form is used to collect detailed data and measurements of fish collected during the electrofishing survey. The number of forms that need be completed will be determined by the number of fish captured with each sheet capable of recording data for 28 fish. The field crew, should indicate at the top of each sheet which page has been completed out of the total number of Fish Data Field Forms for that station, to ensure no sheets and data are misplaced.

River Name: Use the same name as provided on the Field Data Collection Form.

Station: Use the same 2-digit alpha-numeric code assigned to the station on the Field Data Collection Form.

Date(s): Indicate the dates on which the fish were collected. If, in certain circumstances, fish are captured on a given date and retained for measurement and analysis at a later time, the date the fish were captured should be entered. This is to ensure that the Fish Data Field Forms are clearly associated with the Filed Data Collection Form.

Responsibility: Indicate the member of the field crew that has been designated responsible to ensure these forms are completed properly and attached to the Field Data Collection Form.

The following information should be obtained for each fish:

Specimen Number: A consecutive specimen number should be assigned to each fish. This can be completed at a later time.

Sweep: Indicate the sweep on which the fish was captured.

Species: Indicate the species of fish. It is preferable to use the 3 digit species code (Aitkenhead and Legrow 1984) developed by DFO; however, the common or Latin name could also be used.

Age Class: It is not absolutely necessary to include this information as it is often difficult to reliably determine age in the field. For some species (e.g., Atlantic salmon), it is relatively simple to assign an age class in the field. In other situations, age class will be determined during data analysis by interpretation of scales and other hard body parts or analysis of length-frequency distributions.

Length: The length of the fish from the snout to the fork of the tail (fork length) should be determined to the nearest mm.

Weight: The weight of the fish should be determined to the nearest 0.1 g. For some fish (e.g., salmonid fry) it may not be practical to weigh individual fish and weights could be estimated later using length-weight regressions.

Sex: For fish that are sacrificed, indicate the sex as male (M), female (F), uncertain (U) from examination of the gonads.

Maturity: For fish that have been sacrificed, indicate maturity as mature (M) or immature (I), from gonadal examination.

Marked: In the case of mark-recapture studies, indicate if the fish was marked to be released back into the station.

Recapture: For mark-recapture studies, indicate if the fish had been previously marked and was recaptured on a subsequent sweep.

Index Sample: Indicate if this fish was captured in the first 300 s of electrofishing (i.e., to be used in an Index estimate).

Aging Sample: Indicate if a scale or hard body part sample was collected for subsequent aging.

Remarks: This space is provided to allow the field crew to make any comments regarding an individual fish (e.g., incidence of external parasites, any external abnormalities, etc.)

Data Entry Coding Sheet

This form is intended to be used for the entry and analysis of data collected from electrofishing studies into a mainframe ASCII archive. While this form is primarily intended for DFO users, the approach could be adapted for database and spreadsheet applications on personal computers. A set of coding specifications defining the fields and identifying codes to be used is also included. **Any modifications or additions to the fields and codes should be discussed with the Environmental Monitoring Section, Environmental Sciences Division, Science Branch at DFO, prior to implementation.**

The data entry coding sheet is structured into 4 sub-sections. The first section contains the 'tombstone' information for the station and needs to entered only once for each station. The second section identifies the sweep number. The third section identifies the species and descriptor. The fourth section allows for detailed data entry for each fish. This allows for entry of field measurements as well as data generated from aging analysis. Only fish that were captured in a given sweep (identified in section 2) are coded on a given sheet (i.e., a new sheet must be started for each sweep). Similarly, a new sheet must be started for each species within a sweep.

Data Entry Form - Electrofishing Data

Study Type(1)	River Code (2-8)	Station (9-10)	YR-Start (11-12)	MO-Start (13-14)	Day-Start (15-16)

YR-End (17-18)	MO-End (19-20)	Day-End (21-22)	Latitude (23-28)	Longitude (29-34)	Area(35-37)

Space Reserved (38-50)

Sweep (51-52)	Space Reserved (53-56)

Species (57-59)	Descriptor (60)

Specification	Column	Data								
Specimen No.	61-63 (3)									
Mark	64 (1)									
Recapture	65 (2)									
Index Sample	66 (1)									
Length	67-69 (3)									
Weight	70-74 (5)									

Sex	75 (1)									
Maturity	76 (1)									
Scale Age	77-78 (2)									
Total Radius	79-81 (3)									
1st Radius	82-84 (3)									
2nd Radius	85-87 (3)									
3rd Radius	88-90 (3)									
4th Radius	91-93 (3)									
5th Radius	92-94 (3)									
6th Radius	95-97 (3)									
7th Radius	98-100 (3)									
8th Radius	101-103 (3)									
9th Radius	104-106 (3)									
10th Radius	107-109 (3)									
Reserved Space	110-120									

Coding Specifications - Data Entry Coding Sheet - Electrofishing Data

Position	Variable	Specification
1 (1)	Study Type	1 = habitat research 2 = habitat assessment 3 = stock assessment 4 = habitat modelling 5 = enhancement 6 - 9 to be assigned at the discretion of the researcher
2-8 (7)	River Code	Waldron's (1974) 7-digit numeric river code
9-10 (2)	Station	2-digit alpha-numeric code to be assigned at the discretion of the researcher
11-12 (2)	Year - Start	1995 = 95; start of station
13-14 (2)	Month - Start	1 - 12; start of station
15-16 (2)	Day - Start	1 - 31; start of station
17-18 (2)	Year - End	1995 = 95; end of station, blank if completed on the same day
19-20 (2)	Month - End	1 - 12; end of station, blank if completed on the same day
21-22 (2)	Day - End	1 - 31; end of station, blank if completed on the same day
23-28 (6)	Latitude	In degrees, minutes, seconds. If resolution does not include seconds, then leave spaces 27 - 28 blank.
29-34 (6)	Longitude	In degrees, minutes, seconds. If resolution does not include seconds, then leave spaces 33 - 34 blank.
35-37 (3)	Area	Station area in m^2.
38-50	Reserved Space	Reserved for additional fields to be added at the discretion of researcher.
51-52 (2)	Sweep	1 - n; consecutive number of electrofishing sweeps

53-56	Reserved Space	Reserved for additional fields to be added at the discretion of researcher.
57-59 (3)	Species	3-digit species code as per Aitkenhead and Legrow (1984) 172 = Atlantic salmon (landlocked) 173 = Atlantic salmon (anadromous) 174 = Brown trout 175 = Rainbow trout 177 = Arctic char 178 = Brook trout 179 = Lake trout 180 = Lake whitefish 182 = Round whitefish 191 = Northern pike 261 = Lake chub 267 = Longnose sucker 268 = White sucker 342 = American eel 426 = Threespine stickleback 428 = Ninespine stickleback 464 = Burbot 824 = Mottled sculpin 825 = Slimy sculpin
60 (1)	Descriptor	1 = landlocked 2 = anadromous
61-63 (3)	Specimen Number	numbered consecutively for each fish captured
64 (1)	Mark	1 = yes blank = no
65 (1)	Recapture	1 = yes blank = no
66 (1)	Index Sample	1 = yes blank = no
67-69 (3)	Length	fork length in millimetres
70-74 (5)	Weight	weight in grams to 1 decimal (0000.0)

75 (1)	Sex	1 = male 2 = female blank = uncertain
76 (1)	Maturity	1 = immature 2 = mature
77-78 (2)	Scale Age	total years from scale interpretation (Note: 0 is valid)

Note: Total scale radius and measurements of individual annuli are made using a standard magnification of 46 X

79-81 (3)	Total Radius	annulus measurement in millimetres
82-84 (3)	1st Radius	annulus measurement in millimetres
85-87 (3)	2nd Radius	annulus measurement in millimetres
88-90 (3)	3rd Radius	annulus measurement in millimetres
91-93 (3)	4th Radius	annulus measurement in millimetres
94-96 (3)	5th Radius	annulus measurement in millimetres
97-99 (3)	6th Radius	annulus measurement in millimetres
100-102 (3)	7th Radius	annulus measurement in millimetres
103-105 (3)	8th Radius	annulus measurement in millimetres
105-107 (3)	9th Radius	annulus measurement in millimetres
108-110 (3)	10th Radius	annulus measurement in millimetres
110-end	Reserved Space	Reserved for additional fields to be added at the discretion of researcher.

Appendix D

Workshop Presentations

Electrofishing and habitat measurement techniques employed by the Salmon and Char Section

by

R. J. Gibson

Electrofishing and habitat measurement techniques employed by the Salmon and Char Section

by

R. J. Gibson

Introduction

Research has been undertaken in Newfoundland on juvenile Atlantic salmon to better understand the productive potential of river systems, with a view to providing advice on adequate seeding of eggs, and assessing juvenile salmon densities related to the possible carrying capacity. Advances in stream ecology have only been applied in methodology for estimating salmonid production in river systems in the last fifteen years (e.g., Binns and Eiserman 1979). Previously, the wide range of production within a system had not been realized, so that simply average population estimates for young salmon were made from random samples for the whole system, by using convenient sites, usually riffle areas, but with inadequate measurements of habitats (e.g., Elson and Tuomi 1975). Probably the first systematic effort to partition river reaches by stratified sampling in order to estimate juvenile salmon production and yield of smolt was in the Highlands River ten years ago (Gibson *et al.* 1987) and the same techniques have been used since (Gibson *et al.* 1993). Electrofishing is the preferred technique in shallow water, but is generally inefficient in deep water, especially where conductivity is low, so that other methods must be employed to catch fish in these latter conditions.

Materials, Methods and Discussion

Sites for population estimates are selected within a river system in representative reaches. Within each reach, stations are stratified by types of habitat (Frissell *et al.* 1986). Stations representing each type of habitat are therefore selected within each 'stream order' (*sensu*, Horton 1945, modified by Strahler 1957). If a habitat change occurs in a segment, such as a pond or lake, stations are selected both above and below such standing water. We attempt to make replicate stations of habitat types within each reach under study, but resources dictate that usually we select single habitat types within some reaches and not all tributaries are sampled. Stations are sampled during the summer between the second week of July and mid-August, after the main growing period, but sampling through the year is preferable if resources are available.

General types of habitat are taken from Allen (1951). Terminology varies with different authors, eg., riffle and stickle, flat and glide, run and rapids; however, habitats can be classified into the following major groups, which all overlap, and of course merge into one another: cascade; riffle; run; flat; pool; lake. Velocities and depths delineating these are given in Table 1. 'Cascade' has not been sampled in our studies. Our basic strata therefore are the various tributaries, and within each, where possible, the following types of habitat: riffle; flat; pool; run. This classification is not used in derivation of multiple linear regression models, for which values of the measured habitat variables are used, since variables may differ amongst habitat types.

All of a habitat type is included within a station, if possible. A station is barricaded off with upstream and downstream nets of 0.6 cm square mesh, with the downstream net being installed first. Workers keep well away from the sides of the river bounding the station until both nets are in place, only entering the water to place the nets. Rubble and boulders for securing the bottom of the barrier nets are taken from outside the station, which is disturbed as little as possible, since the same stations are sampled in following years. Population estimates in shallow fast water areas (riffles) are made using an electrofisher by the depletion method (Zippin 1958), with at least four sweeps, moving in an upstream direction. In deeper slower waters, the electrofisher is not always effective, in which case fish are caught also by beach seine, and by fyke nets in lakes, and estimates made by the Petersen mark and recapture method or, in larger lakes, by the multiple mark and recapture, or the Schnabel method (Ricker 1975). All fish are anesthetized with CO_2 by dissolving an Alka Seltzer tablet in a few litres of water, and measured by fork length (total length for sticklebacks and eels), and placed in a recovery cage before release. Marked fish have two fins clipped. About 10 salmonids from each year-class are killed for age, weight, and sex analyses, which includes staging of maturity (Kesteven 1960). These samples are measured fresh the same evening. Condition factors (K) are calculated from the expression, $K=W.10^2.FL^{-3}$, where W = weight (g) and FL = fork length (cm). The individual weights of all fish collected are calculated from the mean condition factor for each particular length. Ages are assigned to length frequency histograms after scale reading and verification of size groups. In autumn sampling, mature male parr can be identified by their girth and frequently by release of sperm with pressure, and these are identified separately for condition factor and weight, since they are relatively heavier than immature male and female parr.

Habitat variables that are measured are shown in Table 2. Length and width to the nearest 0.1 m are measured with a tape measure. Two lengths (left and right banks) are taken if there is some curvature, and usually three width measurements are made (both wet widths and bank to bank). At lease five depths are taken at equidistant points across three transects, divided by n+1 to account for 0 depth at the edges. Mean water velocity (0.6 depth) is measured at ¼, ½, and ¾ the distance across. Until 1989, water velocities were measured with a Hiroi acoustic current meter, and, from this time also and at most sites, are measured with a model 201D Marsh McBirney current meter. The maximum depth is recorded with a meter-stick (or a plumb line in lakes). A proxy variable is used as an indicator for range of discharge. For this we use either ice scour height, or height of flood debris, since some rivers lack an ice scour mark. Where both variables can be measured, they have been found to be highly correlated (r^2=0.9). We visually estimate the proportion of each type of substrate category (Bain *et al.* 1985). The extent of the three types of cover (instream, overhanging and canopy) are estimated visually. Riparian vegetation type is also recorded, identified to common names in a field note book, but coded as to % of coniferous, deciduous, and open with grasses and shrubs. Conductivity and temperature are also recorded.

Biomass and densities have been correlated with various attributes by a stepwise regression technique. Variables were entered in the regression model only if the variable was significant at P< 0.05. Variables were selected by a forward stepwise procedure with deletion (Neter and Wasserman 1974). Results have been reported elsewhere (e.g., Gibson *et al.* 1987, 1992). Salmon densities and biomass were found to be positively related with substrate rating, and negatively with mean river width and % overhanging cover. Relationships differed somewhat between rivers (Freshwater River, N.E. Trepassey River), probably because wider ranges of habitat variables were available in the larger (Highlands) river and habitat use varies with different densities. However, they all indicate that juvenile salmon were most abundant over a coarse substrate. Total densities of salmon was positively related with mean water velocity, but 2+ parr were negatively related, probably due to their more frequent occurrence in medium water depths. Such models are therefore useful in describing productive capacity of habitat for different size classes and for estimating whether habitat in a system might be limiting for a certain year class.

The differences in coefficients for habitat use found among rivers suggests that general models of habitat use will be possible only with long-term, large-scale experimental studies of salmon populations throughout the range of the species. For assessment purposes the range of habitat types must be sampled.

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Table 1. The major types of habitat recorded. Habitat types were taken from Allen (1951).

Pools:	Of two groups: pools, with current of less than 38 $cm \cdot s^{-1}$, and depth 46 cm to 68 cm; and, deep pools, with current less than 38 $cm \cdot s^{-1}$, and depth over 68 cm. The flow is smooth apart from a small turbulent area at the head of some pools.
Flats:	Current under 38 $cm \cdot s^{-1}$, mean depth under 46 cm. Flats are sections of relatively shallow water, but with a smooth surface.
Runs:	Current over 38 $cm \cdot s^{-1}$, mean depth over 23 cm. The flow is usually turbulent. In such places the stream is usually of less than average width.
Riffles:	Current over 38 $cm \cdot s^{-1}$, mean depth under 23 cm. These are shallow water with a rapid current and usually a broken flow.
Cascades:	These are rapids in which a steep gradient, combined with a bed of stones or rocks large in proportion to the size of the stream, produces a very irregular rapid flow, often with some white water.

Table 2. Habitat variables measured for derivation of stepwise multiple regression equations (adapted after Platts *et al.* 1983 and Bain *et al.* 1985).

Mean stream width (m) - usually at three locations in the station x n^{-1}. (Both wet, and bank to bank)

Mean depth (cm) - usually five equidistant locations at the same transects as the width measurements x $(n+1)^{-1}$.

Mean water velocity ($m \cdot s^{-1}$) - measured at 0.6 of the depth at a quarter and half distance locations at the same transects as the depth measurements.

Maximum flood height (cm) - experimental rivers, or ice scour height (m), Highlands River - an indicator of range of discharge.

Maximum depth (cm).

Substrate rating -	irregular or convoluted bedrock	7
	very large boulders, 2.5-4 m	} 6
	large boulders, 1.5-2 m	} 6
	medium boulders, 0.55-1 m	} 6
	small boulders, 25.5-50 cm	} 6
	rubble, 15.5-25 cm	5
	cobble, 6.5-15 cm	4
	pebble, 1.65-6 cm	3
	gravel, 2.5-16 mm	2
	sand, 0.1-2 mm	} 1
	silt, 0.004-0.06 mm	} 1
	clay, $\leq$0.0039 mm	} 1
	organic detritus	} 1
	flat bedrock	} 1

Each proportion of substrate type is multiplied by the rating, and the results summed for a general substrate rating.

Instream cover (%) - undercut banks, tree debris, aquatic plants, etc.

Overhanging cover (%) - structures up to about 1 m above the surface and providing shade, such as alder bushes, etc.

Canopy cover (%) - shade over the stream provided by trees.

Specific conductivity (µsi/cm)

Electrofishing techniques employed by the Enhancement and Aquaculture Section in determining the effectiveness of fry stocking

by

C.E. Bourgeois

Electrofishing techniques employed by the Enhancement and Aquaculture Section in determining the effectiveness of fry stocking

by

C.E. Bourgeois

Introduction

This paper addresses the electrofishing techniques utilized by the Enhancement and Aquaculture Section (EAS). The data set that will be used as an example of work conducted will be that of Lloyd's River. The methodology used is also the approach used within public involvement projects.

The major objective of electrofishing conducted by the EAS is to determine the survival of stocked fish. Sub-objectives of this work is to determine survival of stocked fish to various age groups, i.e. 1+, 2+, 3+ and adult. To fully understand the survival of stocked fry, individual researchers require very good baseline data on the landlocked population that existed previous to stocking. The data collected beyond the 1+ stage should be useful in any study determining freshwater survival.

The Lloyd's River site (Section III) was primarily chosen as it represents the longest duration of any helicopter transfers made from the Noel Paul's Brook incubation facility and the author believes that the survival of fry in this area is the lowest of any areas stocked if stress due to transfer is a factor in fry survival. Additionally this area of the watershed is fed by runoff from the Long Range Mountains and should water temperature and length of growing season be factors in fry survival it again should be the lowest in this area. Therefore the author notes caution in broadly applying these survival figures to enhancement in general as they are likely low. Coincidentally, a new fry transfer system was utilized at Noel Paul's Brook in 1987.

Materials and Methods

The areas electrofished were Lloyd's Section III (1987-1992) and Lloyd's Section II (1988-1992). Section III (the area upstream of King George IV Lake) was stocked from 1983-1990 and Section II (the area between Lloyd's Lake and King George IV Lake) was stocked from 1981-1982 and 1984-1991. Section III, while stocked in 1990, received only 50,000 fry within the study area approximately 1 km upstream of the electrofishing sites. This was done to determine how far downstream fry would move and indicated considerable downstream movement as fry were found in good habitat several miles below the stocking area.

The areas to be electrofished are completely enclosed with 0.48 cm barrier nets starting with the installation of the lower barrier net. The net is placed by a crew of 6 with the net strung the appropriate length and the lowered into the water. The net is not dragged through the water if at all possible. The net then has the apron or bottom of the net completely covered with rocks. If the station lends itself, the upper net is then placed in the same manner. The lower net is rocked on the upstream side and the upper net is rocked on the downstream side to aide in fish removal and prevent emigration or immigration. Should the station only cover a small section of the width of the river an outer barrier net is placed after the lower net is placed. This net would have rocks placed on the station side of the apron or bottom of the net. As the nets are placed and rocked the tops of the nets are elevated with 5 foot conduit pipes which are extremely strong and have little surface area to resist water flow and cause drag.

A variable voltage pulsator electrofisher (Coffelt Model) set on 750-900 volts of pulsed output with a single probe and copper ground screen are used to stun the fish. Two salt licks are used per station. All population estimates are based on the successive removal method. Three sweeps are made of the station using as much as possible constant effort. It should be noted that a pass is made through the station approximately every two feet. Fish are collected on the probe (covered with mesh) and by an individual with a dip net. As much as possible these two individuals are not altered within a study. A fourth sweep is conducted if more than ten fish are captured on the third sweep. The station is swept until no fish are captured if the catch at any pass exceeds the previous catch. In 1987 and 1988, the stations were swept starting downstream and working upstream and since that time the approach has been reversed.

Sites for the Lloyd's River survey in year one (i.e., 1987) were selected to cover all possible types of habitat. After year one some of the poorer habitat sites (where only sticklebacks were collected) were dropped as well as some of the fry stations. In addition, the two best large parr habitat stations were dropped as well due to timing constraints. Sites ranged from all 0+ habitat to all steady and pool habitat (i.e., primarily trout habitat) and all combinations in between. Major elements in site selection were the ability to completely enclose the area with barrier nets and resourcing constraints. Sites for the most part, ranged from 1 to 2.5 units. In many instances, the lower barrier net would be leapfrogged above the upper net to provide coverage of a larger area within the same location. Each station would be mapped and habitat attribute data collected including substrate, length and width, depth, velocity, riparian vegetation and cover, bank characteristics, habitat type, etc.

The fish recovered from each station would all be weighed and a length taken. Only 5 fish per length cm group would be scale sampled with sex and maturity collected on any mortalities. With respect to brook trout, only length and weight data are usually collected. In some years samples of parr below 5 cm were preserved to ensure proper ageing.

The electrofishing results for the 1987 - 1991 period saw population estimates calculated by conducting a linear regression on the sweep data. The 1992 data used the Microfish 3.0 (M-Fish) population estimator, which is thought to underestimate population size. Once the population size is estimated for each station the age/length relationship for that area is applied to the length data for that station. This results in the fish of various lengths being assigned an age giving the data in the previous tables.

Results

Tables 1-3 detail the dates and results of electrofishing activities conducted in Lloyd's River Sections II and III 1987-1992. In comparing the habitat as a whole, Section 1 would be classified as under yearling habitat and Section II as large parr habitat. As can be seen from Table 1, the highest density of fry per unit was achieved in 1987 when predominantly fry habitat was electrofished. It is further evident from Tables 1 and 2 that the 1989 and 1990 fry per unit figures were lower than the previous two years and the author feels the reason for this was conditions in both years that displaced the fry. Of particular note is the number of 1+ parr recaptured in 1991 from the 1990 fry in that it appears that large numbers of these parr moved into the area. Another possibility is that the high water conditions were not conducive to fry collection utilizing electrofishing, especially in light of water colour.

The low number of 1+ parr captured in 1992 suggests that the lower stocking level in 1991 within Section III had a dramatic impact. Generally speaking, since this section is predominantly under yearling habitat, the author feels that parr production is good with an average of 2-3 smolt sized fish being produced per unit. The very low abundance of 4+ and older parr suggest that mortality on 3+ and older parr is very high or that they are emigrating from the area. Even in 1989, when the survey was conducted in September, little evidence of older fish was encountered; however, 1 maturing female was encountered in that year.

Table 2 reveals somewhat lower densities of fry than Table 1; however, it reveals excellent larger parr densities. Of particular interest is the low fry density encountered in 1992 when no fry stocking was conducted. The low fry density in 1991 can only possibly be explained by poor fry survival or the fact that some fry drops were missed on this section of the river. This section of the river reveals 1+ parr densities higher than fry densities found in the previous year. This suggests that the dynamics of parr freshwater movement is high if habitat is available. The author does not believe that the fry are there and are not being captured; however, this is a possibility. In this section the parr seem to disappear after their third year as well.

Figures 1-5 display the total salmon captured per unit as well as the yearly cohorts.

Discussion

Consistent with the objectives of this workshop, the author would like to list a few points that, as researchers, it is incumbent to have answers to to make the workshop a success. I regret that there are possibly as many views to these questions as there are individuals around the table and, consequently, unless some decision is made no consensus may be possible. Several issues to consider include:

(1) Do fish remain in a relatively discrete area or is constant emigration and immigration ongoing?

(2) As fish grow very rapidly in a short growing season how do their habitat requirements change and how do they adapt to these changing habitat requirements.

(3) With respect to river size and discharge how does habitat change? I suggest that small streams (e.g. Rennies Mill River) have limited habitat and are thus more constant than Lloyd's River (800-1000 feet wide) and thus not comparable.

(4) Is enough known about fish behaviour to know when to conduct population estimates (guesses)?

(5) What role does density play and at what density level do the above criteria become critical?

(6) Finally can researchers map habitat well enough to known the density of fish that could be there with all other inherent problems?

The results presented in the previous section of this paper have to be interpreted cautiously as no baseline data exists; however, the 1992 data can be considered to be of a baseline nature as no fry stocking occurred in 1992. A meaningful and complete analysis of the success of fry stocking would require an additional 2 data points (2 years of study) to be of any consequence.

Table 1. Numbers of fish at age per unit Lloyd's River section III, 1987-1992.

	Year Class						
YEAR	0+	1+	2+	3+	4+	5+	6+
1987*	34.60	3.22	5.13	0.0	0.0	0.0	0.0
1988	26.90	6.78	1.95	1.42	0.0	0.0	0.0
1989	8.79	4.92	3.45	1.13	0.19	0.0	0.0
1990	8.71	4.91	4.17	2.71	0.30	0.0	0.0
1991	0.52	6.39	5.16	3.91	0.71	0.0	0.01
1992	1.87	0.96	2.99	1.83	0.60	0.14	0.0

* the total for 2+ in 1987 includes all parr > 1+

Table 2. Numbers of fish at age per unit Lloyd's River section II, 1988-1992.

	Year Class						
YEAR	0+	1+	2+	3+	4+	5+	6+
1988	5.73	9.04	3.65	1.58	0.0	0.0	0.0
1989	15.93	14.76	14.76	3.81	0.0	0.0	0.0
1990	10.96	14.72	5.80	3.09	0.41	0.0	0.0
1991	1.23	29.55	12.66	7.16	2.41	0.23	0.16
1992	0.20	4.44	17.97	5.56	1.27	0.0	0.0

Table 3. Dates and water conditions by year that electrofishing work was completed.

Year	Dates Work Conducted	Water Conditions
1978	Aug. 3 - 6	normal (not low)
1988	Jul. 28 - Aug. 2	normal
1989	Sept. 3 - 8	high
1990	Jul. 30 - Aug. 30 Aug. 10 - Aug. 12	high
1991	Aug. 1 - Aug. 7	low
1992	Jul. 28 - Aug. 4	normal

Note: A water gauging station is located on Lloyd's River section II and data on water levels is available however it is not available for presentation here at this time.

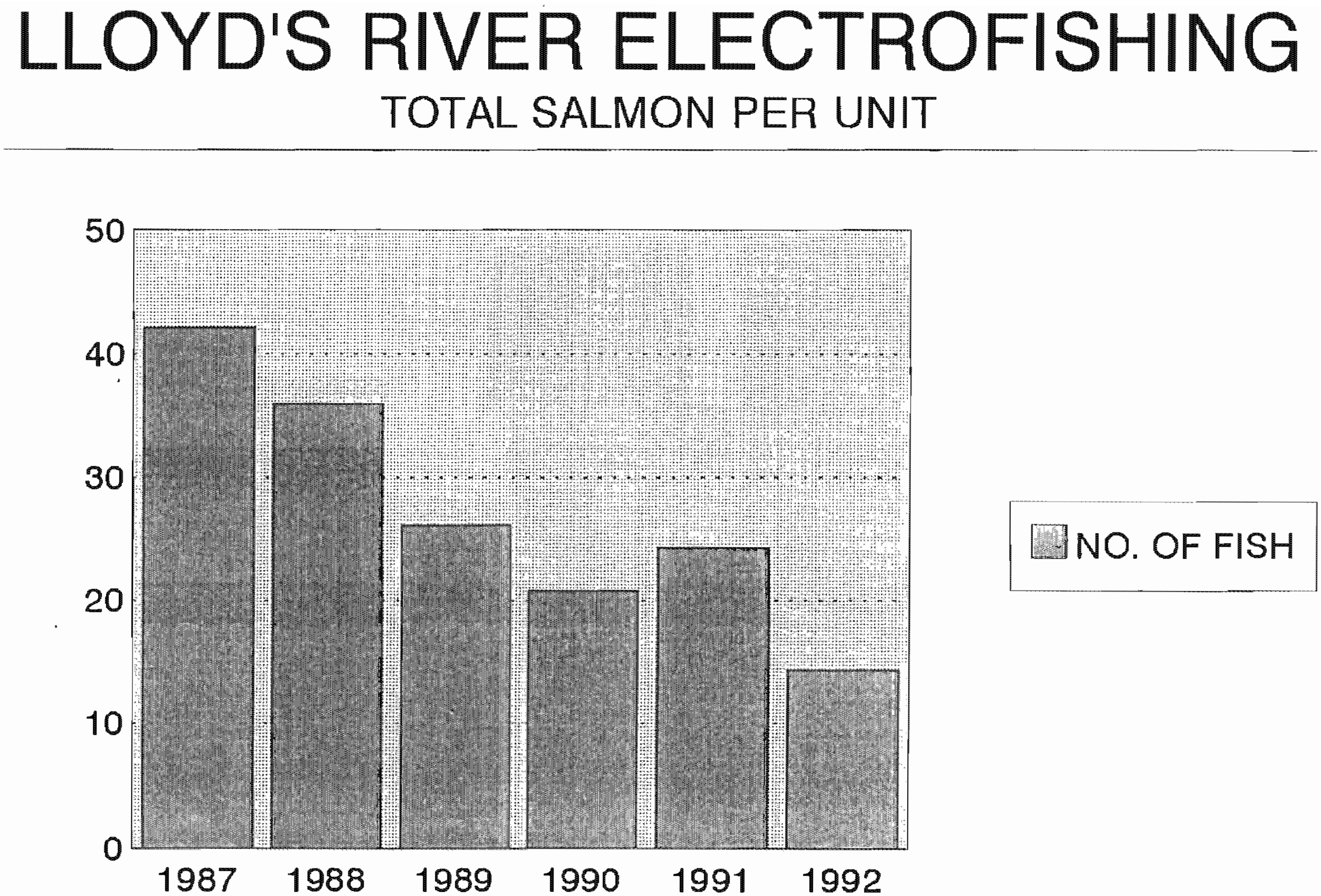
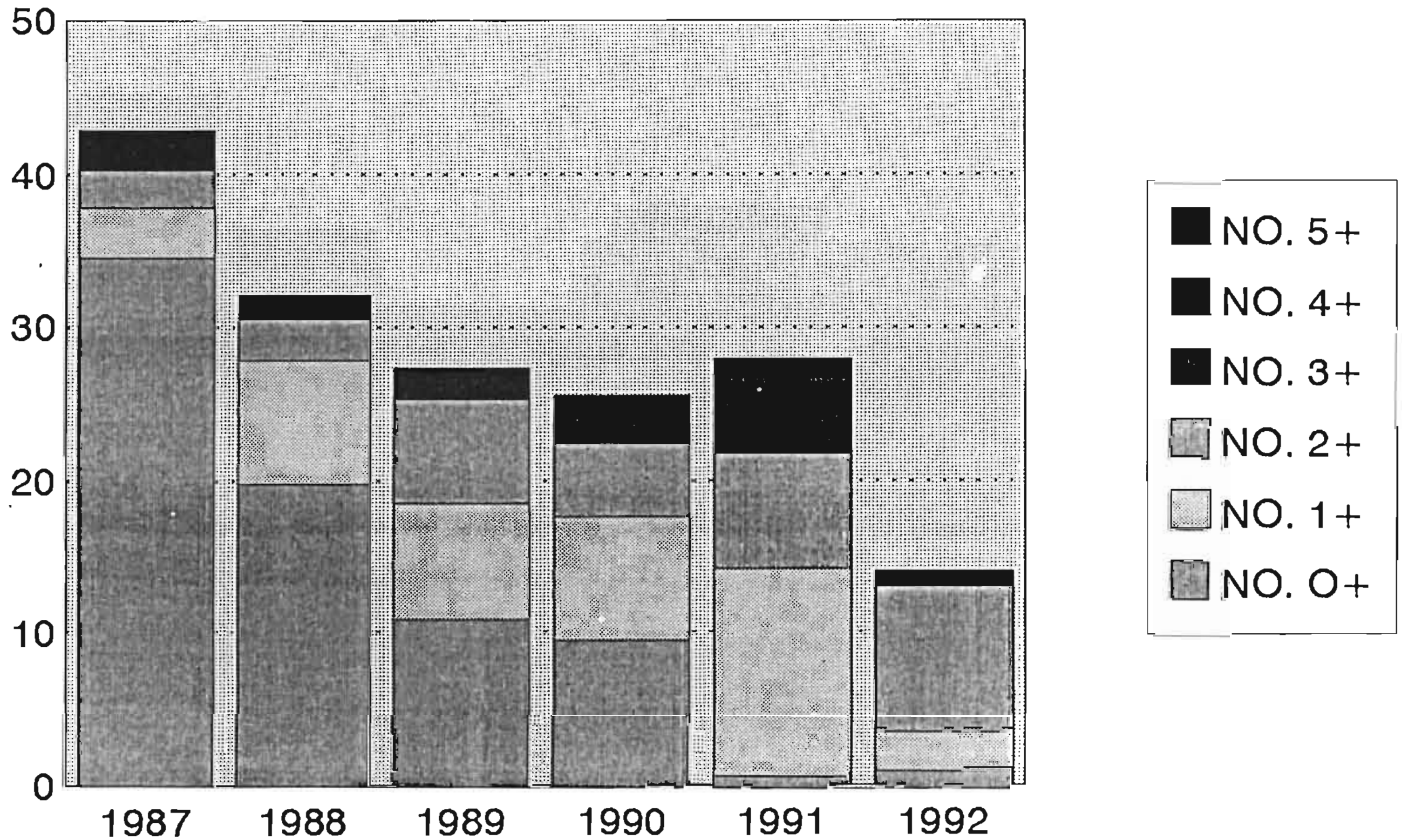


Figure 1. Average densities of all juvenile salmon from electrofishing studies, Lloyd's River, 1987 to 1992.

NO.'S AT AGE PER UNIT FOR LLOYDS ELECTROFISHING BY YEAR

POPULATION ESTIMATE



1991 NO FRY STOCKING

Figure 2. Average densities of all juvenile salmon, by age class, from electrofishing studies, Lloyd's River, 1987 to 1992.

LLOYD'S ELECTROFISHING

YEARLY COHORTS

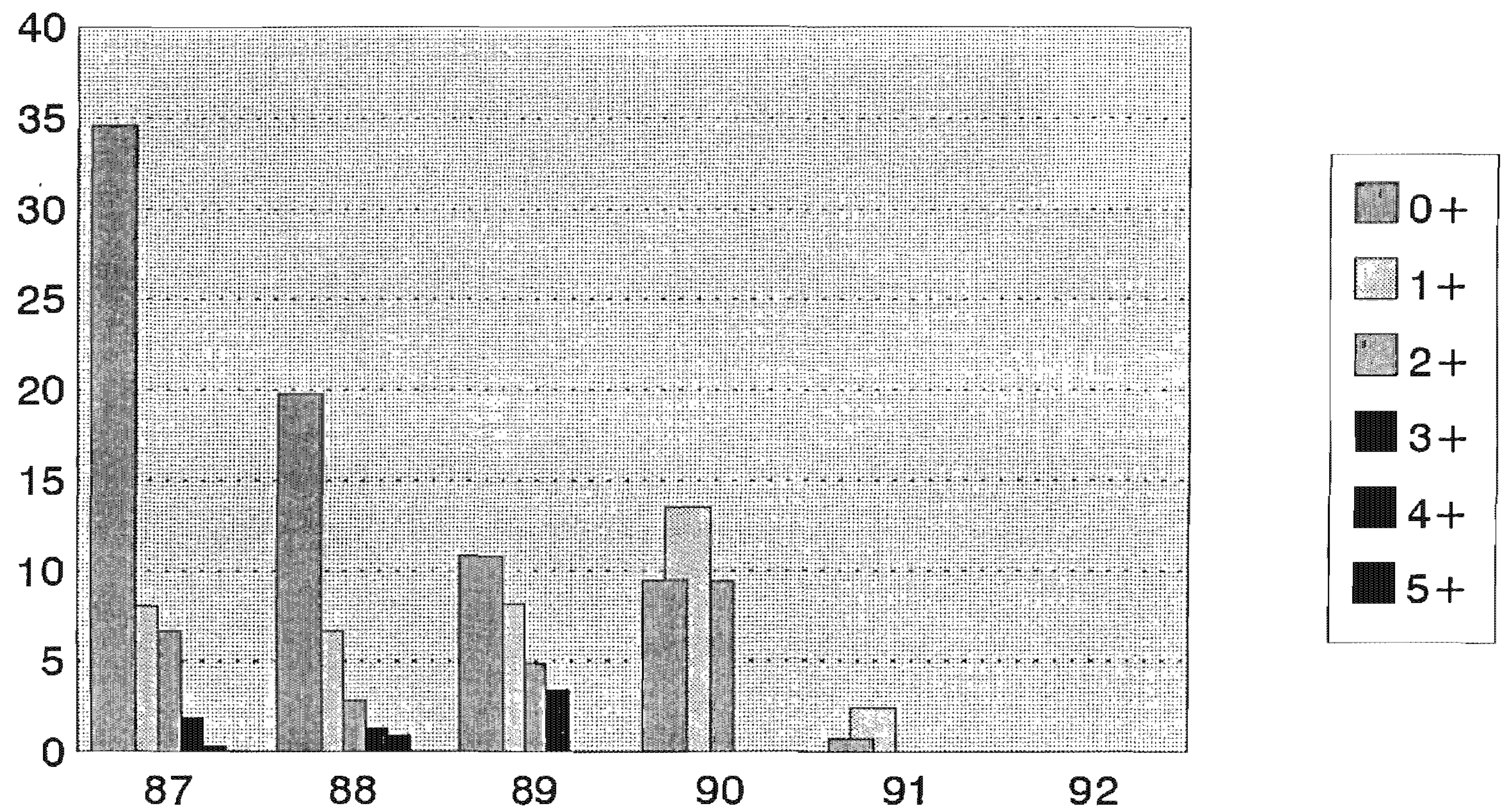


Figure 3. Yearly cohorts of juvenile salmon from electrofishing studies, Lloyd's River, 1987 to 1992.

LLOYD'S SECTION 2

YEARLY COHORTS

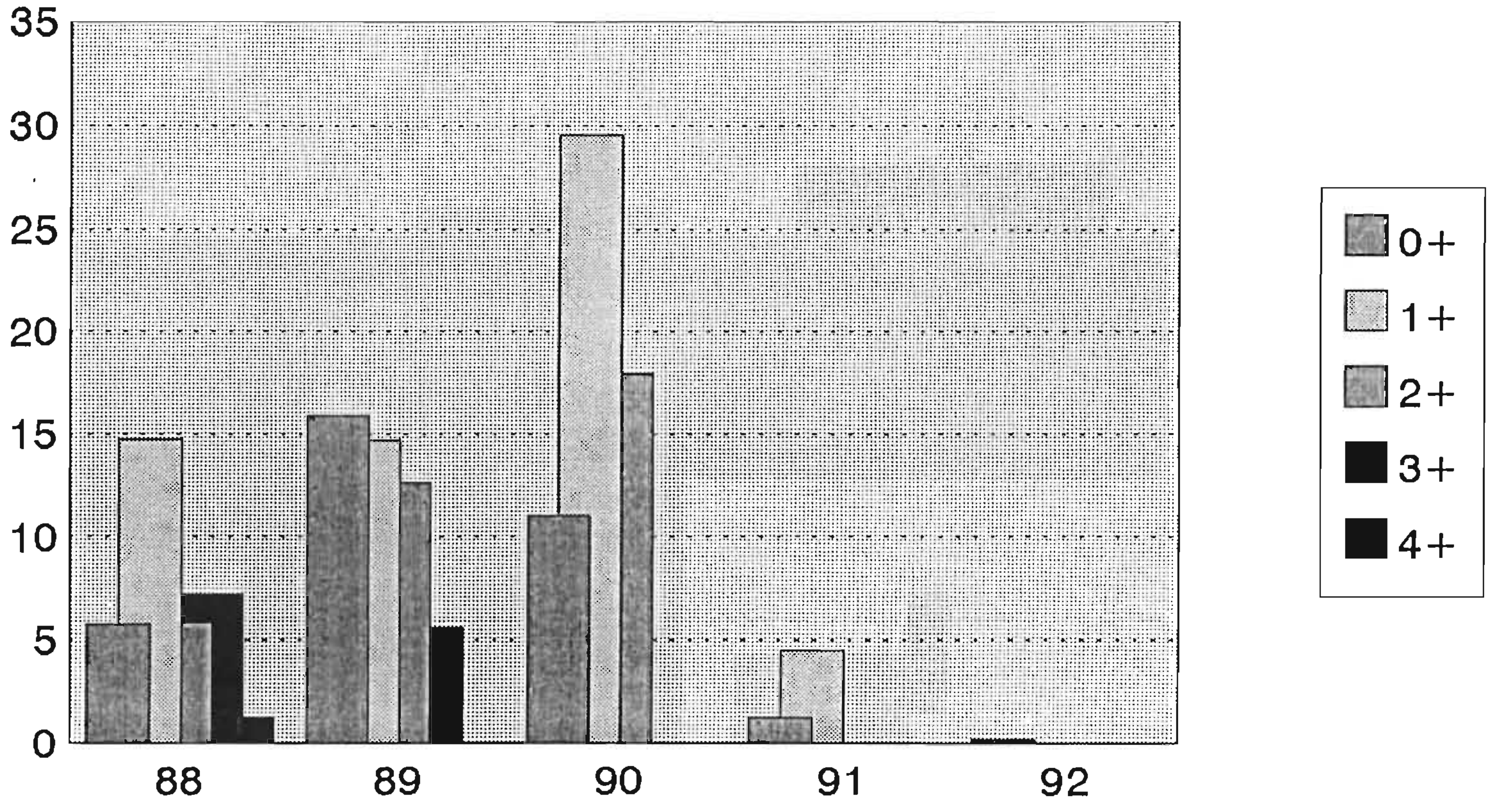


Figure 4. Yearly cohorts of juvenile salmon from electrofishing studies, Lloyd's River, Section 2, 1987 to 1992.

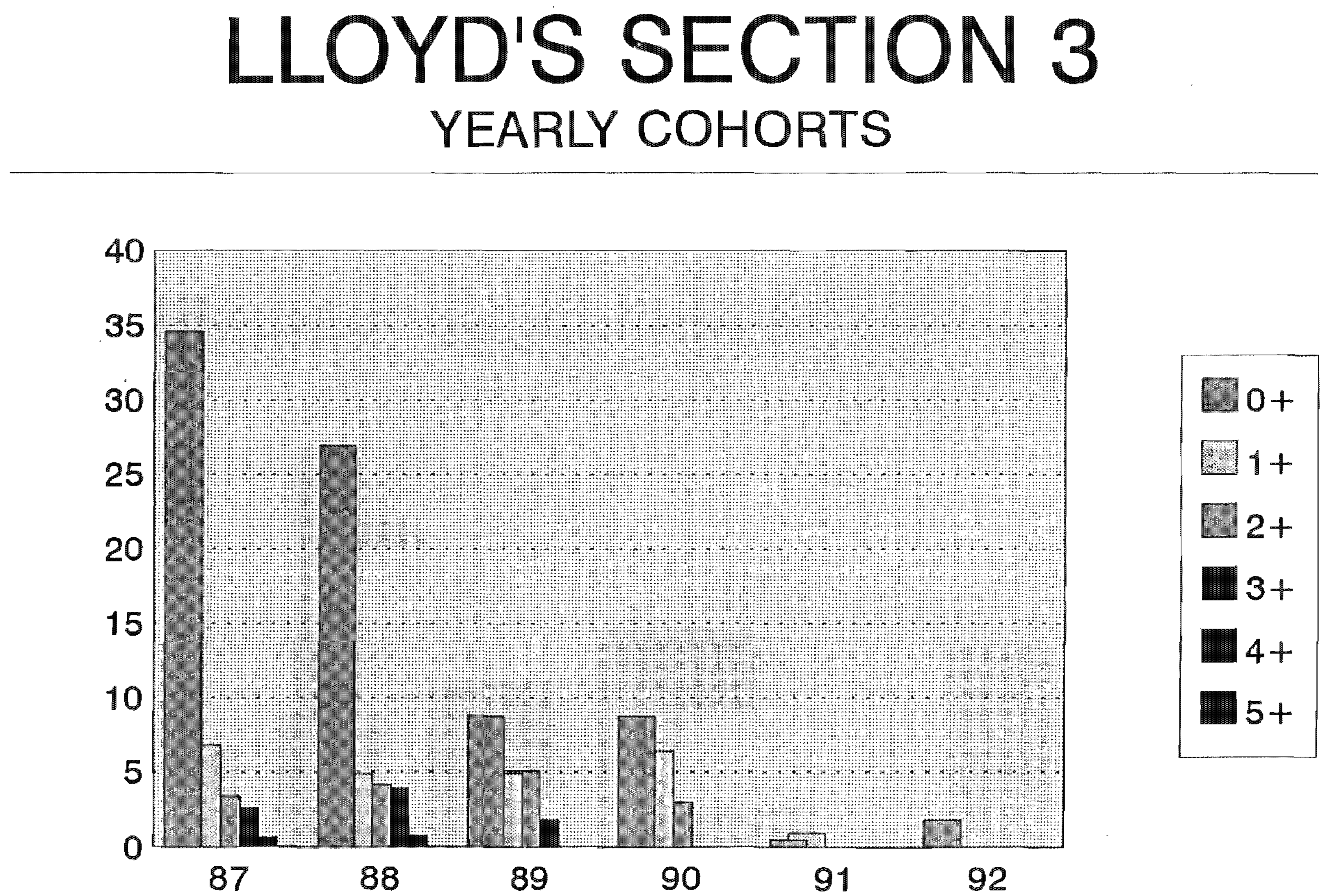


Figure 5. Yearly cohorts of juvenile salmon from electrofishing studies, Lloyd's River, Section 3, 1987 to 1992.

Electrofishing techniques employed by the Habitat Research and Assessment Section in habitat research and environmental effects monitoring

by

D.A. Scruton

Electrofishing Techniques Employed by the Habitat Research and Assessment Section in Habitat Research and Environmental Effects Monitoring

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Abstract/Summary

This paper reviews the rationale and approach to electrofishing that has been employed by the Habitat Research and Assessment Section in applied habitat research studies and environmental effects monitoring programs. The paper discusses the objectives of these studies, selection of habitats and sites, site set up, equipment employed, basic field sampling techniques, fisheries and habitat data collected, and method of analyses of data including population estimation. Representative data sets are used to demonstrate results from studies using different estimators. Techniques are discussed with respect to satisfying assumptions of fixed effort removal population estimates. Comments and recommendations are made with respect to the methodology currently in use.

Introduction

The Habitat Research and Assessment Section (HRAS) has employed electrofishing as a major component of applied research and environmental effects monitoring studies over the last 7 years. These projects have been undertaken in relation to developments and referrals for which the Department has a mandate to conserve and restore fish habitat as identified in the Policy for the Management of Fish Habitat. Projects have been undertaken in relation to most of the development sectors in the province that have potential to significantly impact fish habitat, specifically the transportation sector (South Brook, Commonwealth Avenue Interchange; Seal Cove River, TCH); the forestry sector (Beaver Brook, Northwest Gander River; Pamehac Brook, Exploits River); hydroelectric development (West Salmon River, Upper Salmon Hydroelectric Project); the mining sector (Cinq Cerf River, Hope Brook Gold Mine); and others.

Materials and Methods

Objectives:

Generally, the objectives of the above applied research and environmental effects monitoring studies have been:

(i) to document or assess change in juvenile fish production (numbers, biomass, age class composition, etc.) in response to some change in habitat quality, be it perturbation (e.g., road construction, South Brook, Commonwealth Avenue Interchange; forest harvesting without buffer strips, Beaver Brook, Gander River) or beneficial change (e.g., habitat restoration through rewatering of Pamehac Brook, Exploits River); or

(ii) to conduct environmental effects monitoring to assess impact predictions from projects undergoing formal environmental assessment. This would also include evaluation of mitigation undertaken to minimize/eliminate impacts (e.g., controlled flow release, West Salmon River, Upper Salmon Hydro Project) and compensation to offset habitat losses (e.g., habitat compensation, Seal Cove River, twinning of the TCH).

HRAS is also routinely involved in evaluating electrofishing surveys and studies undertaken by others (e.g., proponents and/or their consultants) involving projects undergoing environmental assessment. Proponents are required to quantify habitat associated with a specific project and electrofishing is often conducted at selected stations to collect information with respect to species and age classes present and densities/biomass. This information serves as baseline data for post-construction monitoring as well as to assist in the prediction of impacts and identification of appropriate mitigation and/or compensation requirements. As this information is often used in applied research projects undertaken by the Section, HRAS is often interested (and involved) in the selection of sites/habitats and the electrofishing methodologies employed.

Site Selection:

Site selection has varied from study to study and has generally followed two approaches:

(i) Representative stations for specific habitat types or classes (e.g., West Salmon River-Upper Salmon; Pamehac Brook; Cinq Cerf River, Hope Brook Gold Mine; Beaver Brook); and

(ii) Contiguous (consecutive) stations at a site undergoing perturbation. This has generally included stations above the site (control), stations at the site of potential impact, and stations below the activity (to address possible downstream impacts) (e.g., Seal Cove River, TCH; South Brook, Commonwealth Avenue Interchange).

Sites are located such that the station will encompass the entire stream width. On larger rivers, this has often necessitated that stations be established in reaches where the stream width is divided into 2 or more channels by islands, and the station is established in one of the channels. On occasion (rarely), situations arise on larger rivers whereby a station cannot encompass the entire width of the river (or side channel) and the station would be defined by the addition of a third barrier net the length of the station and parallel to the flow (i.e., 'three-sided' sites). We have attempted to avoid 3-sided sites as Bohlin et al. (1989) have suggested that on large rivers, where the area fished is small relative to the total stream area, quantitative electrofishing for population estimation is probably not reliable.

Habitats Studied:

The types of habitat studied has depended on the site selection (above) and the objectives of each study.

The Upper Salmon and Cinq Cerf projects resulted from the environmental assessment process and sites were initially established by the proponent (consultant) and subsequently followed up by HRAS. Habitats were classified using the Beak (1979) 4 tiered approach (see Appendix 1) which has served as the defacto standard for environmental assessment for the last 14 years. Habitats are generally classified from the air (helicopter), with ground truthing, into 4 habitat types; Type I, riffle/pool habitat with spawning substrates, preferred by fry and smaller juveniles; Type II, riffle/pool habitat with larger substrates, generally preferred by larger juveniles; Type III, rapids, falls, runs, etc., generally considered migratory and non-productive habitat; and Type IV, standing water habitat, flats/steadies, generally used by older age classes, adults, not considered critical to recruitment). In these studies, electrofishing is normally conducted in Type I and Type II habitats only, which is predominantly riffle/pools.

<u>Example:</u>

The West Salmon River, Upper Salmon Hydro Project, was to be dewatered as a result of dam construction and diversion associated with the project. Baseline studies determined that this portion of the river had most of the potential spawning and rearing habitat in the entire drainage and migratory studies documented extensive migrations by ouananiche and brook trout from large lakes and reservoirs in the system to use this spawning habitat. This habitat was considered critical to recruitment for the watershed and controlled flow release below the West Salmon dam was negotiated to protect this habitat. A study was undertaken, jointly by DFO and Newfoundland and Labrador Hydro, to address fish production under these controlled flow releases.

As part of this study, electrofishing stations were established on the West Salmon River at locations influenced by the controlled flow conditions, as well as at locations under natural flow conditions (controls) (Figures 1 and 2). Eight stations were established on the West Salmon River under controlled flow conditions; 4 in Type I habitat and 4 in Type II habitat. Seven control stations were established; 6 on a neighbouring watershed (Newfoundland Dog Pond tributary) including 2 in Type I and 4 in Type II habitats, and one (Type II) on a tributary of the West Salmon River (Southwest Tributary). Three of these stations on the West Salmon River were electrofished prior to the development (baseline) in 1979 while the 15 stations were studied in 1985, 1987 and 1988. Newfoundland and Labrador Hydro has since replicated a number of these stations as part of a follow-on monitoring study in 1992.

Several research studies have involved sampling contiguous (consecutive) stations in relation to a reach of habitat to be affected by development. In these situations, the stations were established in relation to size criteria (to follow) and in relation to boundaries established by the natural distribution of habitat (e.g., location of pools, riffles, undercuts, etc.).

Example:

The Seal Cove River, near Butterpot Provincial Park, was to have 160 m of habitat buried as a result of twinning of the Trans Canada Highway. The Newfoundland Department of Works, Services, and Transportation agreed to compensate for this loss by constructing a stretch of river on the opposite side of the highway. HRAS undertook an applied research study to address i) the productive capacity of the habitat lost, ii) the comparative productive capacity of the compensatory habitat (i.e., ability to achieve 'no net loss'), iii) the effectiveness of habitat improvement structures (lunkers) employed in habitat construction, and iv) any long term effects from highway and/or compensatory habitat construction.

Electrofishing stations were established for both pre- and post-construction as identified in Figure 3. Stations were established above the lost and compensatory habitat to serve as controls for the study. Stations were also established below the compensatory habitat (post-construction) to address downstream impacts of construction and erosion. The compensatory habitat was also sub-divided into small sections of discrete pool and riffle sections so that i) pools with and without improvement devices (lunkers) and ii) low and high gradient riffle habitats could be compared.

The need for systematic design in site selection and choice of habitats will depend upon the objectives of study. When the intention is to use electrofishing as a means of determining the population (and characteristics) of a specific reach, tributary, or watershed, and where representative stations are used infer/calculate values for a larger area of unsampled habitat, more attention to sampling design is required. Bohlin et al. (1989) provide a thorough discussion of the considerations related to this type of study. The major concern is the validity of estimated numbers in an enclosed area and the use of these numbers to estimate population sizes/parameters for the entire stream (Anonymous 1983).

Equipment:

HRAS has adopted the use of portable, battery operated, backpack electrofishing units as appropriate and suitable to studies undertaken by the Section. The primary reasons were reliability and portability (as frequently sites are only accessible by helicopter). In low conductivity waters, batteries are an effective means of delivering the required current as they are not rapidly discharged as they would be at higher conductivities (Bohlin et al. 1989). The two primary models used were:

(i) Smith-Root, Type VIIIA, a 12 volt (lead-acid or gel cell) DC pulsed unit with a voltage ranging from 250 to 850 volts, with 2-piece anode pole (with dead-man switch) with hoop (11 inch dia.), floating (84 square inch) or rat tail (heavy copper cable) cathode, timer (to measure effort), and voltage and frequency adjustment. This was considered the preferred backpack equipment for use in low conductivity waters and was employed over the period 1984 to 1989; and

(ii) Smith-Root, Type 12, a 24 volt (gel cell) DC pulsed unit for use in the conductivity range 10 to 600 $uScm^{-1}$. The unit has an output voltage range from 100 to 1000 volts, amp output from 4 - 40 amps, and has a 2-piece anode pole with 11 inch dia. hoop, dead-man switch, floating or rat tail cathode, timer, and voltage and frequency (15 to 120 pps) adjustment. The unit also uses an audio signal to indicate the appropriate operating range which is very useful to ensure proper settings and prevents 'over shocking' of fish. The 800 to 1000 volt range is recommended for conductivities from 10 to 200 $uScm^{-1}$. The 24 volt gel cells have been replaced with ni-cad batteries (innovation undertaken by HRAS) owing to longer battery life, greater reliability, and lesser weight. This model replaced the type VIIIA as the preferred equipment for use in low conductivity waters and has been in use since 1989.

Techniques:

For the most part, the general approach to electrofishing by HRAS, regardless of the study and habitat selected, has been as detailed as follows.

The dimensions of the station are usually established in relation to natural boundaries of the habitat (i.e., if there is a pool within a station the station would either include all or none of the pool). Experience has indicated that a station size of from 2 to 4 units (100 m^2) is preferable, produces reliable results, is optimum for low conductivity waters, and generally permits from 2 to 3 stations to be completed within one day. The station length varies according to width to achieve the 2 to 4 unit size. In all cases, each station is completely closed with barrier nets (0.5 cm mesh) to prevent immigration and emigration from the site. Barrier net placement is careful so as not frighten fish from the station and nets are secured on the bottom and on the stream edges to ensure complete closure. On 'three-sided' stations, a third barrier net is run the length of the station parallel to the flow. On studies where the intention is to replicate sites between years, the upper and lower barrier net locations are permanently marked with paint, flagging tape, and rebar pegs.

Electrofishing is normally conducted in summer months (late June, July, August, early September) in periods of low stable flow, and after salmonid fry have emerged from the gravel and have distributed to preferred habitats. This is also determined by practical and safety considerations as electrofishing efficiency (and safety) is reduced in faster, deeper water. Additionally, this is the period where wetted stream width and depth, and hence available habitat, is at a minimum and consequently most limiting.

The electrofishing team has consisted of 4 individuals (occasionally 3 to 5), one on the electrofisher, 2 with dip nets, and one looking after the captured fish. The anode hoop is also fixed with netting to permit the fisher to assist in fish capture. HRAS has adopted an approach whereby the same individual works the electrofisher for all runs completed within one station (to control variation in effort as much as possible). Electrofishing effort is recorded, as number of seconds, and kept as constant as possible. Generally, the fisher starts at the downstream end (barrier net) of the station and works across the stream, in standardized widths (as determined by the effective fishing diameter of the electric field), to the upstream barrier net until all of the habitat has been fished (bottom to top, downstream to upstream direction). This approach has been adopted to minimize/eliminate the influence of turbidity stirred up by the crew from affecting visibility and hence effectiveness of capture. Working in a downstream direction has also tended to 'herd' fish into the lower barrier net, resulting in large catches on the first sweep, which can 'front load' the estimates resulting in underestimation of populations size and occasionally in model failure (Anonymous 1983). The area is fished discontinuously, that is the power is turned off and the anode is lifted out of the water, moved to another location and power is resumed. This is to improve the effectiveness by using the 'element of surprise' and by not continually driving fish from the effective field. The dip netters are strategically placed downstream of the fisher in an area previously fished while the person handling fish is positioned so as to readily receive captured fish. The netters are equipped with standard dip nets (wooden handles, metal hoop or rectangle shape, net mesh of 0.5 mm) as well as smaller aquarium nets to assist in retrieving small fish (young-of-the-year or YOY) from the substrate. Polarized sunglasses are standard equipment to minimize glare from the water surface and enhance ability to see and capture fish. Fish are sampled between runs, thereby allowing the fish remaining in the station to recover and redistribute (a 0.5 hour period is considered minimum).

To date, all quantitative electrofishing has involved the use of the fixed effort, (successive) removal method. The full station area is fished for a number of consecutive times and fish captured are removed from the station each time. The total number of sweeps (or runs) has normally varied from 3 (minimum) to 5, occasionally up to 6, depending upon the catch rate each run and the rate of depletion. Generally, a minimum of three sweeps is required and the requirement for additional runs is determined by the catch on the last run. If the catch on the last run is < 20% of the catch on the first run and < 50% the catch of the previous run, then additional runs are not necessarily required. Any dead fish found on the substrate in a given run (i.e., obviously dead and not affected by the electric field of the current effort) are added to the previous run. An electrofishing form was developed by HRAS to summarize catches to determine the requirement for additional runs.

All fish captured in each sweep are analyzed between each run. All fish are anaesthetized (MS-222, tri-amyl alcohol, 'Alka-seltzer', and others), identified as to species, measured for length (nearest mm), weighed using a portable electronic balance (to the nearest 0.1 g), and all fish greater than 1+ in age have a scale sample collected. For all fish of age 1+ or greater, the information is recorded directly on the envelope containing the scale sample. For all 0+ (YOY) fish, the lengths are recorded in a field note book and pooled weights are obtained for all YOY, grouped by species. Once the data have been collected, fish are returned to fresh water in another holding container to recover, and once fully recovered they are returned to the river outside of the site, well removed from the station or any future stations to be sampled.

Data Analyses:

Once back in the laboratory, the first task is to collect, collate, and record all the fish data onto coding sheets for entry onto a Digital VAX mainframe. Data collected in the field on scale envelopes and in field note books are transcribed onto the coding sheets. Scale samples collected are also analyzed for total age and measured. Scale samples are cleaned and projected using a Bausch and Lomb microprojector, at standard magnification (46X), and the total number of annuli, total scale radius, and radius of each annuli recorded. Data is entered and checked for coding errors. Weights are generated for fish for which weights were not measured (primarily YOY) by length-weight regression to facilitate biomass calculations.

Data are sorted and summarized (PROC SORT, PROC SUMMARY) on the VAX mainframe for subsequent population estimate/biomass calculation using PC-based programs. All data are summarized and totalled by station, run (sweep), species, and age class. Three different estimators, using data obtained from the removal method, have been used to calculate population size and biomass. Initially (to 1987), the population estimates were derived using the regression method described by DeLury (1947) and Ricker (1975). In 1987, a Maximum Weighted Likelihood (MWL) estimator, described by Carle and Strub (1978), was used based largely on the recommendations at the Scotia-Fundy electrofishing workshop (Anonymous 1983) and availability of a PC based software program (Gerdeaux 1987).

Recently, the Microfish 3.0 program, developed by the U.S. Fish and Wildlife Service (Van Deventer and Platts 1989), employing a maximum likelihood (ML) estimator, has been used. This program can be run interactively or data entry can be automated (entered from a ASCII data file) and the population estimates can be batched and calculated separately for data subsets (e.g., species, age/size classes). This program also calculates biomass estimates (previously biomass had been determined by applying a mean weight to the population estimate). Owing to the problem of differential catchability between species and size and/or age classes, population estimates are derived for subsets of the data as follows:

Tier 1	Tier 2	Tier 3
Total Population (all fish)	Total for Species (1)	Total for Age/Size Class (1)
		Total for Age/Size Class (2)
		Total for Age/Size Class (3)
	Total for Species (2)	Total for Age/Size Class (1)
		Total for Age/Size Class (2)
		Total for Age/Size Class (3)
	Total for Species (3)	Total for Age/Size Class (1)
		Total for Age/Size Class (2)
		Total for Age/Size Class (3)

Station/Habitat Data Collected:

A number of measurements and habitat variables are collected at the time of electrofishing. The variables measured and the method of measurement are identified below:

station length (0.1 m) - one length measurement, mid-channel, if station is rectangular in shape or average of 2 or more measurements if station is irregular in shape.

station width (0.1m) - an average of 3 or more widths, depending on shape of station, usually at upper and lower station boundaries and 1 or more within the station.

mean depth (cm) - as determined from 3 (or more) equally spaced measurements across each width transect and averaged (divided by n+1 for each transect); then averaged for the station.

habitat type (%) - estimate of proportion of each of pool, riffle, run, flat (steady), and other (cascades, falls, etc.)

undercut banks (%) - estimate as % of site, each bank being 50%.

gradient - estimated, or measured using surveying equipment, as cm/m or m/km.

pool/riffle ratio - as determined from the % of pool and rifle habitat.

no. of pools - total number of pools in station, including a pool quality rating.

pool measurement - measurement of length, width and depth of each pool.

substrate (%) - estimate of proportion of each of large boulders, small boulders, rubble, cobble, pebble, gravel, sand, silt, and bedrock.

cover (%) - estimate of proportion of each of overhanging, instream (subdivided by debris, algae, and channel vegetation), and canopy cover.

bank erosion (%) - estimate as % of site, each bank being 50%, including a rating of bank stability.

riparian vegetation (%) - estimate of proportion of each of grasses/shrubs, alders/willow, coniferous, deciduous, and bog in the 5 m riparian area along each bank.

Detailed transects of width, depth and velocity are occasionally taken at some sites where discharge calculation is warranted or where velocity distribution is a variable to be considered. The station is usually sketched to show the location of key features. Information on the electrofishing equipment used, including voltage, frequency, and output amperage is recorded. The amount of effort for each sweep, in seconds from the timer on the fisher, is recorded as is the total catch per run (divided into species, and for 0+ and older age classes) in order to assist in determining the required number of sweeps.

Results

Representative results from two of HRAS studies are presented as an example of the types of data output from electrofishing. The population estimation results from the Upper Salmon Hydroelectric Project Environmental Effects Monitoring Study, using the Carle and Strub MWL estimator and interactive GWBASIC program, are contained in Tables 1a, 1b, and 1c. Data was taken from the program output and summarized in these tables (note: confidence limits, variance, deviations, capture probabilities, and other output from the program have not been included).

The data output from the Microfish 3.0 program for the Seal Cove River Habitat Compensation Study, for 1988 and 1989 only, is also presented as an example of the output and analytical capabilities of this program (Tables 2a and b).

Discussion and Conclusions

Population studies/estimates based on the removal method have a number of conditions that must be satisfied, if at all possible (Moran 1951, Cowx 1983). These conditions (assumptions) include:

(i) the population should be isolated, with no migration, natural mortality or recruitment during the study period;

(ii) the effort (CPUE) should significantly reduce the population size;

(iii) the probability of capture should remain constant during the study period;

(iv) the probability of capture is the same for all individuals; and

(v) the population should not be so large that capture of one fish affects capture of other fish.

Electrofishing by HRAS has tried to consider and design studies to accommodate these assumptions. Electrofishing has been completed on closed stations (barrier nets) over short time frames (4 hours to 0.5 day) to satisfy the condition of isolation. Bohlin et al. (1989) have suggested that the use of block nets may not be necessary. Sufficient effort to significantly reduce the population has been met by using the appropriate equipment to maximize efficiency in low conductivity waters common in Newfoundland. Electrofishing is also conducted at low flow periods to maximize the effectiveness of the technique. Other researchers have advocated the use of 'salt licks' to increase conductivity, and hence effectiveness of equipment; however, confounding factors (i.e., discontinuity of conductivity within the station, possible effect of salt on fish behaviour, etc.) can cause additional biases.

The requirement of probability of capture remaining constant over the sampling period is one that is difficult, or impossible, to satisfy. Mahon (1980) and others have determined that the vulnerability of fish declines in successive sweeps owing to the reduced activity of previously stunned, uncaptured fish. This can be overcome by allowing sufficient time to recovery between sweeps, possibly up to 6 hours; however, this would be impractical (in terms of resources) for most studies. Operating in the appropriate voltage and frequency range, so as not to excessively shock fish, is an important consideration.

The condition of probability of capture being the same for all individuals within the station is also difficult to meet. It is widely understood that larger fish are more susceptible to electrofishing (i.e., more easily captured) than smaller fish, and electrofishing crews tend to select for the larger fish in capture efforts, largely because they are more visible. This situation can be confounded by the fact that larger, older fish select faster, deeper water, over larger substrate where the efficiency of capture using electrofishing apparatus is reduced (Karlstrom 1976). Fish behaviour, and consequently their selection of habitat (position in the stream), will also effect the relative catchability of species, individuals and life stages. This concern has not been adressed in sampling, but has been addressed in analyses of data (i.e., estimating population size/biomass, separately, by species and size/age class), as recommended by several authors (e.g., Junge and Libosvarsky 1965; Cowx 1983; Bohlin et al. 1989).

A major consideration in selection of equipment and techniques for electrofishing in insular Newfoundland is the low conductivity of waters (frequently below 50 $uScm^{-1}$ and occasionally below 25 $uScm^{-1}$). Electrofishing is normally conducted in summer months, at higher water temperatures and a concern is to prevent mortalities of fish. In these situations, fish recovery is monitored closely and electrofishing is discontinued if mortalities are high. The Smith-Root Type 12 electrofisher (24 volt) has been extremely reliable, powerful, and the audio signal produced by the unit (to indicate it is operating in the effective range) is a major enhancement over the 'trial and effort' method to find the effective operating range.

Another consideration with respect to the effectiveness of electrofishing is the clarity of Newfoundland waters. Many systems on the island are highly coloured, related to high organic (humic) content of freshwaters, and this can affect visibility. The use of polarized sunglasses to minimize glare off the water surface and improve ability to see into the water column in these situations is recommended.

Electrofishing is considered a reliable and useful tool when comparisons are made between similar habitats, same species, using the same techniques and equipment (Bohlin et al. 1989). The technique is also considered reliable when sites are replicated from year to year, under similar conditions (i.e., discharge, season, temperature, etc.).

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Table 1a. Population estimates per habitat unit (100 m^2) for the Upper Salmon Hydroelectric Project Effects Monitoring Study - 1985, as determined by the Carle and Strub (1978) maximum weighted likelihood (MWL) method. Experimental stations are under regulated (controlled) flow release while control stations are on unregulated sites.

	Habitat Type	Station	Total (all salmonids)	Ouananiche			Brook Trout		
				All	YOY	>YOY	All	YOY	>YOY
Experimental	1	11	60.5	43.9	40.7	3.2	18.2	17.8	-
		12	27.9	24.0	17.8	6.3	3.8	3.4	-
		13	21.0	-	-	-	18.2	13.3	5.5
		14	93.4	50.0	40.8	9.2	43.4	27.6	15.1
	2	21	66.8	63.7	42.6	20.5	3.2	-	-
		22	49.7	47.3	12.0	34.7	-	-	-
		23	40.4	23.6	-	22.5	16.9	9.0	7.8
		24	73.3	46.7	8.2	38.5	26.2	15.9	10.8
Control	1	11	30.2	19.4	11.6	8.5	10.1	7.0	-
		12	44.8	39.1	31.8	6.8	5.7	5.2	-
	2	21	49.4	44.5	35.6	8.9	5.3	5.3	-
		22	-	-	-	-	-	-	-
		23	41.7	36.4	6.1	29.9	4.9	-	-
		24	32.7	27.4	-	26.8	4.8	-	-
		21(SWT)	19.9	12.0	-	9.4	7.9	4.7	6.8

Note: Habitat Types after Beak (1979), 1 = Type I, 2= Type II
YOY = young of the year or 0+ in age
>YOY = all fish greater than 0+ in age

Table 1b. Population estimates per habitat unit (100 m^2) for the Upper Salmon Hydroelectric Project Effects Monitoring Study - 1987, as determined by the Carle and Strub (1978) maximum weighted likelihood (MWL) method. Experimental stations are under regulated (controlled) flow release while control stations are on unregulated sites.

	Habitat Type	Station	Total (all salmonids)	Ouananiche			Brook Trout		
				All	YOY	>YOY	All	YOY	>YOY
Experimental	1	11	83.8	77.9	-	10.0	6.3	-	-
		12	30.2	29.2	21.0	7.5	-	-	-
		13	91.9	68.1	36.7	31.9	22.9	-	11.4
		14	119.7	85.9	72.2	13.6	33.3	12.1	20.7
	2	21	62.2	55.0	32.8	22.2	7.2	5.6	-
		22	57.7	26.4	10.9	14.5	31.4	15.0	15.0
		23	24.0	13.9	13.5	-	9.6	6.7	-
		24	-	-	-	-	-	-	-
Control	1	11	84.9	63.1	52.4	10.7	21.3	12.4	8.4
		12	95.8	70.0	56.3	15.8	25.8	12.1	15.2
	2	21	96.5	75.5	67.0	9.0	20.5	11.0	9.5
		22	129.1	117.2	102.1	15.1	11.5	11.5	-
		23	76.8	46.3	31.1	15.3	30.5	18.4	13.2
		24	7.5	-	-	-	4.2	-	-
		21(SWT)	20.5	11.9	3.3	8.6	8.6	3.8	4.8

Note: Habitat Types after Beak (1979), 1 = Type I, 2= Type II
YOY = young of the year or 0+ in age
>YOY = all fish greater than 0+ in age

Table 1c. Population estimates per habitat unit (100 m^2) for the Upper Salmon Hydroelectric Project Effects Monitoring Study - 1988, as determined by the Carle and Strub (1978) maximum weighted likelihood (MWL) method. Experimental stations are under regulated (controlled) flow release while control stations are on unregulated sites.

	Habitat Type	Station	Total (all salmonids)	Ouananiche			Brook Trout		
				All	YOY	>YOY	All	YOY	>YOY
Experimental	1	11	129.6	119.2	116.3	2.9	10.4	9.6	-
		12	68.3	66.5	60.9	5.0	1.8	-	-
		13	171.9	155.2	137.1	17.1	18.6	13.8	4.8
		14	215.6	176.3	156.6	19.2	38.9	22.2	16.2
	2	21	-	-	-	-	-	-	-
		22	169.5	143.2	121.8	21.0	25.5	19.1	6.4
		23	13.9	5.3	-	-	8.6	4.8	3.8
		24	-	-	-	-	-	-	-
Control	1	11	25.9	20.9	18.0	-	4.7	3.2	1.5
		12	-	-	-	-	-	-	-
	2	21	40.8	33.3	31.0	-	6.6	5.6	-
		22	-	-	-	-	-	-	-
		23	43.3	35.4	32.3	-	12.8	11.6	-
		24	31.1	6.7	-	-	24.4	19.3	-
		25	26.5	10.7	-	-	22.7	17.3	-
		21(SWT)	33.3	23.1	16.3	6.8	-	-	-

Note: Habitat Types after Beak (1979), 1 = Type I, 2= Type II
YOY = young of the year or 0+ in age
>YOY = all fish greater than 0+ in age

Table 2a. Population estimates (± S.D.) for the Seal Cove River Habitat Compensation Project in 1988 and 1989, using the maximum likelihood estimator of Microfish 3.0. Data for 1989 only have been adjusted per unit of habitat 100m^2.

1988

Species/ Age Group	Site 1	Site 2	Site 3	Site 4	Site 5
Atlantic salmon (age 0+)	170 (±1.9)	15 (±0.0)	7 (±0.1)	31 (±0.7)	0
Brook trout (age 0+)	44 (±0.8)	16 (±0.0)	24 (±0.6)	6 (±1.0)	0
Atlantic salmon (> 0+)	5 (±0.4)	23 (±0.8)	0	12 (±0.0)	38 (±0.7)
Brook trout (> 0+)	59 (±0.0)	105 (±3.0)	26 (±0.4)	27 (±0.2)	84 (±1.6)

1989

Species/ Age Group	Site 1	Site 2	Site 3	Site 4	Site 5
Atlantic salmon (age 0+)	64.4 (±4.3)	10.3 (±0.5)	1.8 (±0.2)	1.3 (±0.0)	4.1 (±0.2)
Brook trout (age 0+)	25.2 (±1.8)	8.0 (±0.2)	6.7 (±0.2)	0.7 (±0.0)	0.5 (±0.0)
Atlantic salmon (> 0+)	2.2 (±0.1)	0	1.1 (±0.1)	0.4 (±0.0)	1.8 (±0.1)
Brook trout (> 0+)	13.1 (±0.4)	14.8 (±0.2)	10.8 (±0.6)	9.4 (±0.0)	11.5 (±0.2)

Table 2b. Biomass estimates for the Seal Cove River Habitat Compensation Project in 1988 and 1989, using the maximum likelihood estimator of Microfish 3.0. Data for 1989 only have been adjusted per unit of habitat $100m^2$.

1988

Species/ Age Group	Site 1	Site 2	Site 3	Site 4	Site 5
Atlantic salmon (age 0+)	256 gm	32 gm	16 gm	72 gm	0 gm
Brook trout (age 0+)	81 gm	44 gm	59 gm	20 gm	0 gm
Atlantic salmon (> 0+)	79 gm	100 gm	0 gm	62 gm	156 gm
Brook trout (> 0+)	1022 gm	1668 gm	508 gm	327 gm	1274 gm

1989

Species/ Age Group	Site 1	Site 2	Site 3	Site 4	Site 5
Atlantic salmon (age 0+)	76 gm	16 gm	3 gm	2 gm	11 gm
Brook trout (age 0+)	34 gm	13 gm	13 gm	1 gm	1 gm
Atlantic salmon (> 0+)	37 gm	0 gm	16 gm	7 gm	19 gm
Brook trout (> 0+)	201 gm	244 gm	260 gm	241 gm	240 gm

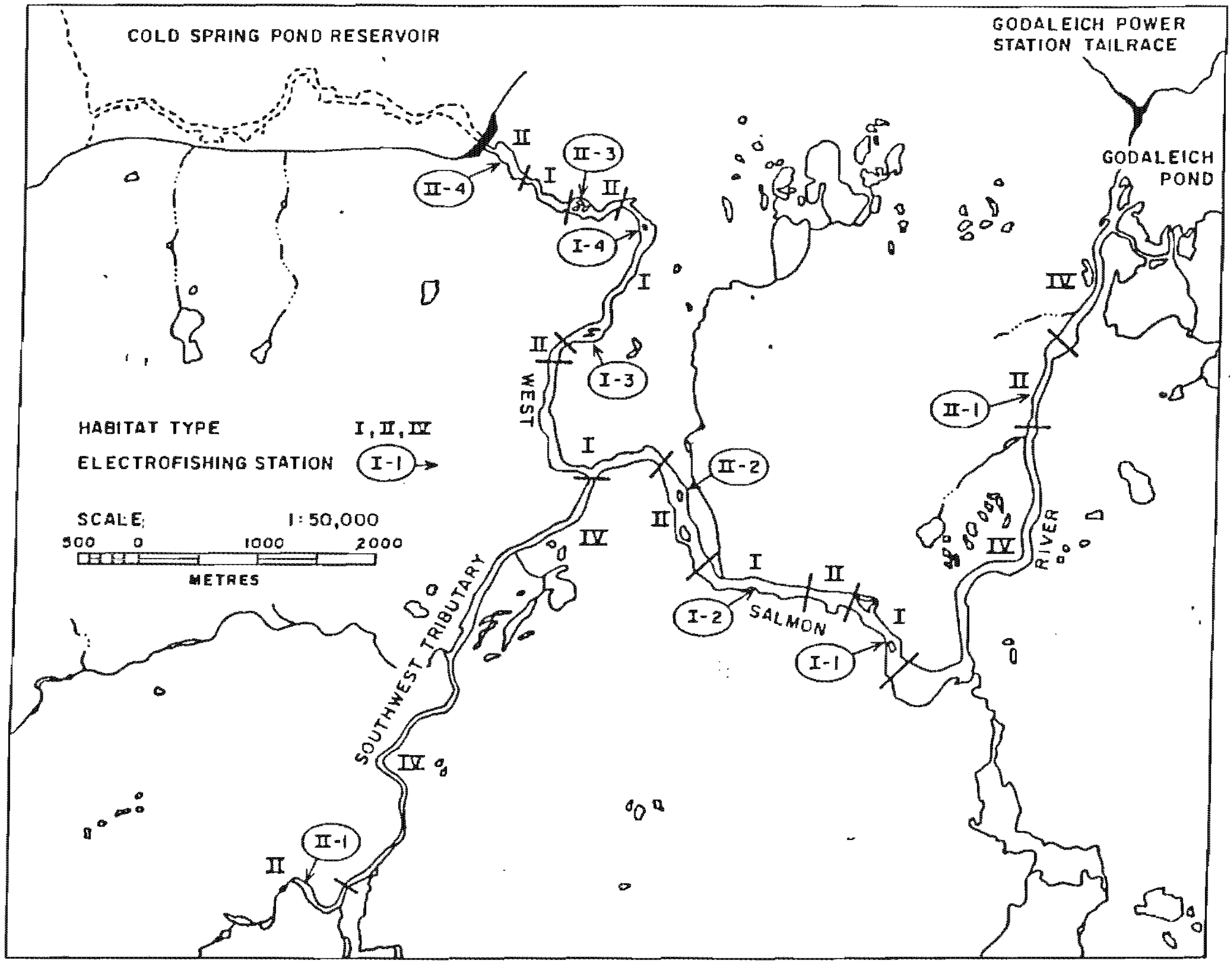

Figure 1. Electrofishing sites (regulated) and habitat distribution on the West Salmon River, Upper Salmon Hydroelectric Development.

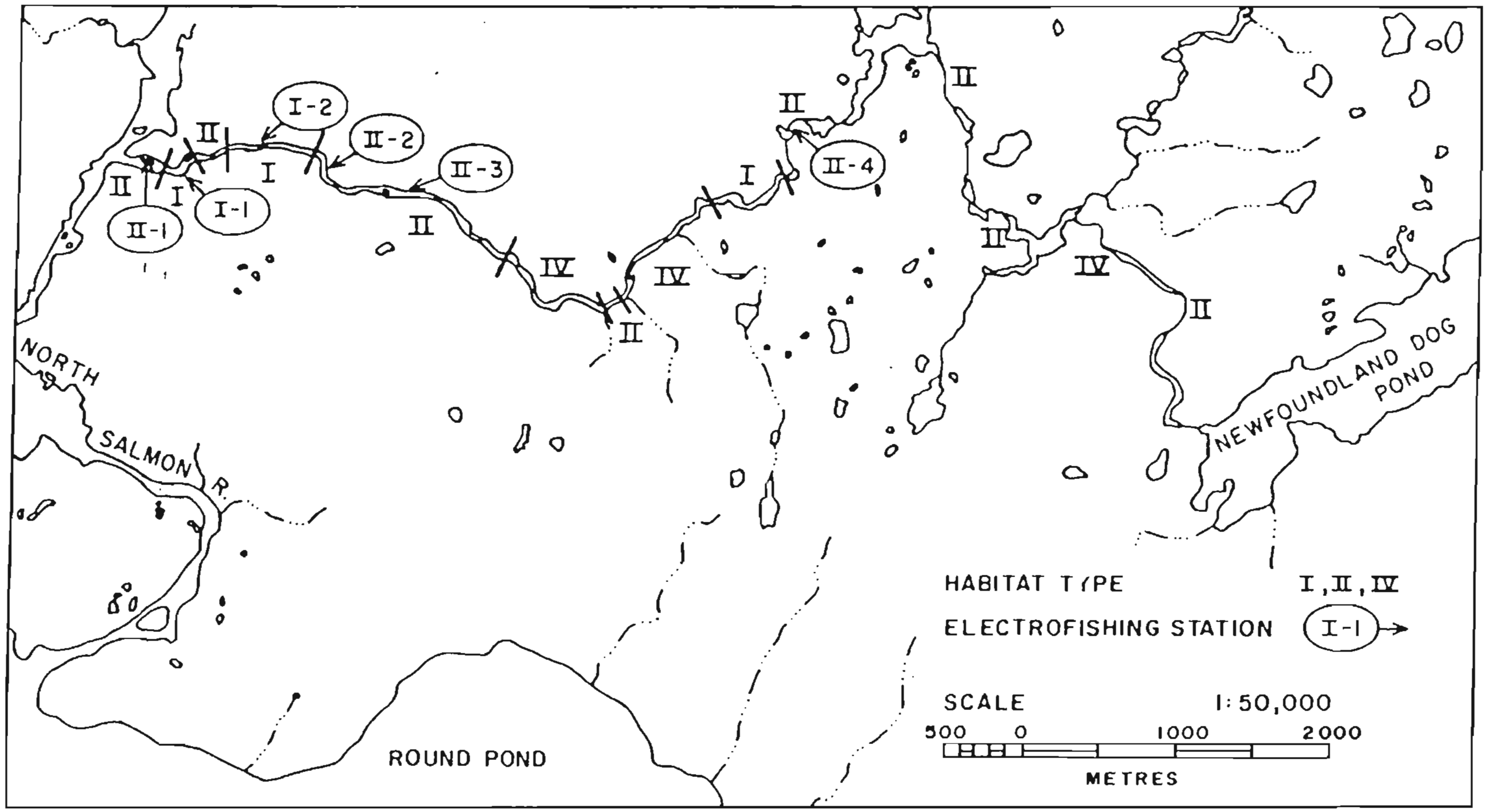

Figure 2. Electrofishing sites (control) and habitat distribution on the Newfoundland Dog Pond Brook, within the Upper Salmon Hydroelectric Development.

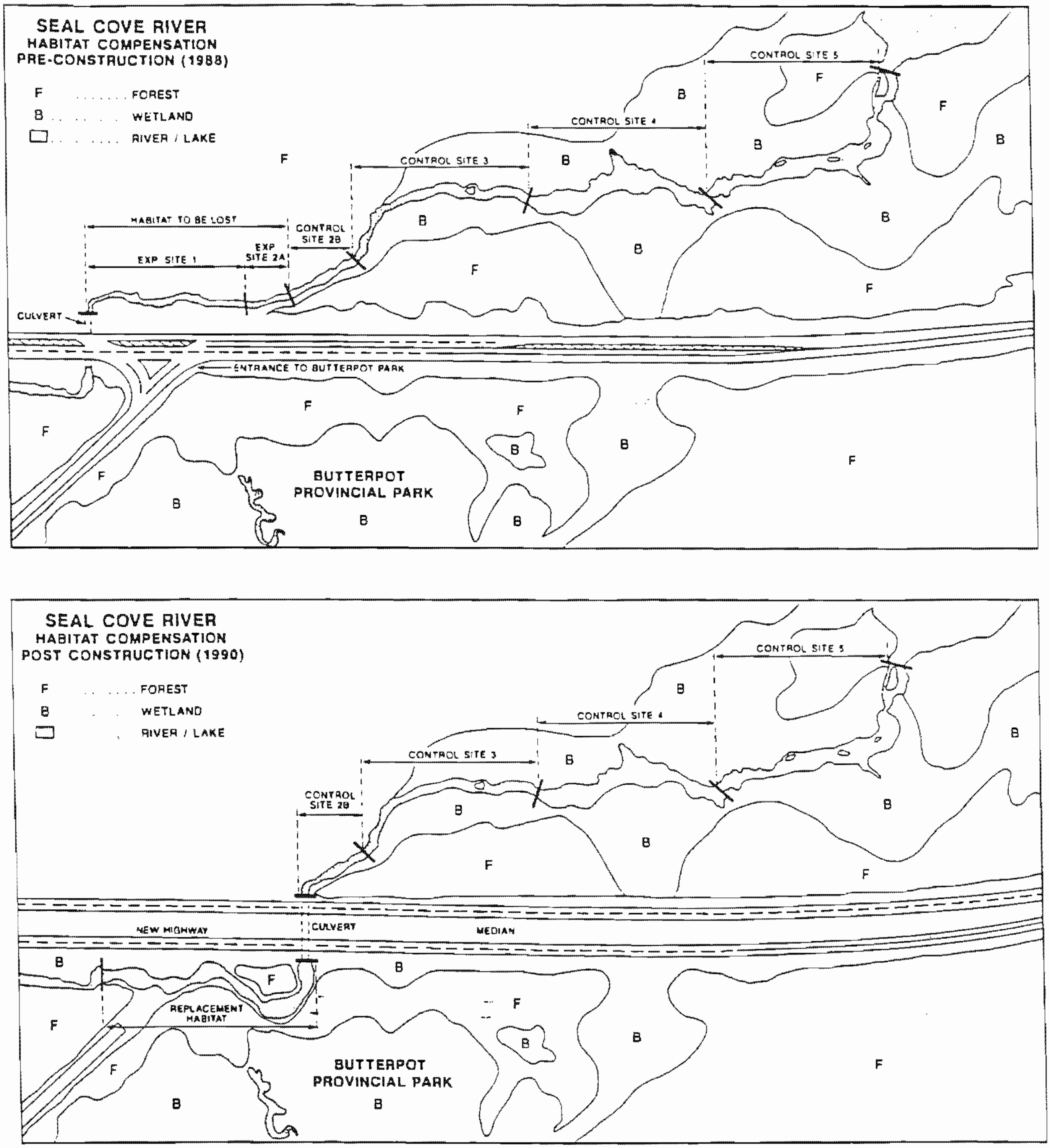

Figure 3. Electrofishing sites (upstream - control; compensatory reach - experimental; and downsteam) on the Seal Cove Brook Habitat Compensation Project.

Appendix 1. The method used for aerial classification of salmonid habitat employed in environmental impact assessment in Newfoundland (Beak 1979).

Habitat Type	Description
I	Good salmonid habitat, good spawning areas, often with pools for larger age classes, preferred by fry and smaller juveniles. *Flows* - moderate riffle, current 0.1 to 0.3 $m \cdot s^{-1}$. *Depth* - shallow, less than 1 m. *Substrate* - gravel to small cobble sized rock, may be interspersed with boulder.
II	Good salmonid rearing habitat, limited spawning in isolated gravel pockets. Good feeding and holding areas for larger fish in deeper pools, pockets, or backwater eddies. Generally preferred by larger juveniles. *Flows* - riffle to light rapid, current 0.3 to 1.0 $m \cdot s^{-1}$. *Depth* - variable, less than 1.5 m. *Substrate* - large cobble to boulder and bedrock, some gravel pockets interspersed.
III	Poor rearing habitat with no spawning capabilities, used for migratory purposes. Generally considered migratory and non-productive habitat. *Flows* - fast turbulent, heavy rapids, chutes, waterfalls, current greater than 1 $m \cdot s^{-1}$. *Depth* - variable *Substrate* - boulder, bedrock.
IV	Poor juvenile salmonid rearing habitat, no spawning capability. Provides shelter and feeding habitat for larger, older salmonids. Generally used by older age classes, adults, not considered critical to recruitment. *Flows* - sluggish, currents less than 0.15 $m \cdot s^{-1}$. *Depth* - variable, often 1 m and greater. *Substrate* - soft sediment or and, large boulders or bedrock covered by sand or silt, aquatic macrophytes often present, especially along shore.

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by

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INTRODUCTION

Evaluation of the impact on the status of Atlantic salmon stocks of fisheries management measures and juvenile stocking programs is often an immediate requirement of fisheries managers and biologists. However, it is one that cannot be fully realized without several years of careful monitoring of subsequent fisheries harvests, spawning escapement of adults, and spawning success. Often is the case, however, that an attempt is made to obtain an early indication of change in spawning success by comparing the relative density of surviving juvenile age-classes in the rivers with those in previous years (Randall et al. 1990; Claytor and Mullins, 1989). Full scale juvenile density survey techniques can be costly and time consuming. Recently, however, attempts have been made to estimate juvenile salmon densities based on a standardization of electrofishing effort (Lobon-Cervia and Utrilla, 1993; Strange et al., 1989). The use of predictive models to estimate age-class density in a large area based on the density or catch from a single sweep or from a smaller area, for example, assumes that population parameters such as age and length are not affected by the smaller sample sizes or the sampling procedure. The application of these predicted densities in formulations such as percent habitat saturation (PHS) index developed by Grant and Kramer (1990) also requires that the mean length of fish in each life stage be accurately determined. The accuracy of length frequency data obtained from standardized electrofishing effort relative to that obtained from larger sample sizes in traditional density estimation surveys was evaluated on the Humber River, Western Arm Brook, and Pinchgut Brook a tributary of Harry's River in 1992 from samples collected using both methods.

MATERIALS AND METHODS

Fork length samples were collected from Atlantic salmon captured during regular juvenile density surveys. Sixteen sites were surveyed on the Humber River, three on Pinchgut Brook and three on Western Arm Brook in July and August 1992 (Table 1). Sites were restricted to a maximum wading depth of <1.0 m and a water flow rate of <1.0 m/sec.

Fish were removed from each site using a single anode Smith-Root, model VIII-A backpack electrofishing unit. Conductivity of the water was usually <150 umhos and a 450 volts output was found to be the most effective. Where the conductivity was >150 umhos, a 250 volt output was used.

Sites were closed by barrier nets and surveyed as for density estimation, using the successive removal method. The electrofishing was carried out by a three man crew (probe, seine, bucket) starting at the upstream barrier and progressing from bank to bank towards the downstream barrier. The first five minutes (300 sec.) of electrofishing was taken to represent the standardized fishing effort. The fish removed by standardized effort were sampled separately from the fish removed in the remainder of the site survey. After the period of standardized effort had expired, additional samples were collected from three or four successive sweeps of the site. For density estimation, the catch in the first five minutes formed part of the total catch for the first sweep.

Fork length (0.1 cm) and weight (0.1 gm) were measured for all fish captured. Comparisons were made between the fork length frequency distribution and means of juvenile Atlantic salmon sampled by the standardized effort method and those sampled in the remainder of the electrofishing effort required to complete the removal of fish from the site.

RESULTS

The fork length frequency distributions of fish captured in the first five minutes (5 Minutes) of effort were similar to the distributions of samples caught in the effort required to complete the survey of the entire site (Total-5 Min.) on each river. However, the combined catch from 11 sites sampled with five minutes of effort on the Humber River appeared to produce the most representative length frequency distribution for 0+ fry. For the two values of effort on the Humber River (Fig. 1), and Western Arm Brook (Fig. 2) the modal distribution of the 0+ fry age-class was <5.0 cm, but this age-class was not clearly represented in the small sample size from Western Arm Brook. On Pinchgut Brook the distribution of 0+ fry was <5.5 cm for the two values of effort (Fig. 3). The fork length frequency distribution of age-classes of parr aged 1+ and up were more identifiable in the smaller sample sizes from the standardized five minute effort interval at Western Arm Brook and Pinchgut Brook than was the 0+ fry age-class.

In sites containing Atlantic salmon, at least one was captured in the first five minutes of electrofishing on Humber River and Pinchgut Brook (Tables 2, 4), the exception being site 3 on Western Arm Brook (Table 3). On Western Arm Brook (Table 3) and Pinchgut Brook (Table 4) catches of 1+up parr tended to be higher than catches of 0+ fry in the first five minutes and in the total minus five minutes of effort. On the Humber River catches of 0+ fry were higher (Table 2).

Thirteen sites on the Humber River contained Atlantic salmon and on 11 sites with more than one fish, 15% of the cumulative catch occurred in the first five minutes of electrofishing effort (Fig. 1). Similarly, 20% of the cumulative catch from three sites on Western Arm Brook, occurred in the first five minutes (Fig. 2) and 19% of the cumulative catch from three sites on Pinchgut Brook occurred in the first five minutes of fishing effort (Fig. 3).

Analyses of the variance (SAS, GLM Procedure) estimates of fork length samples from 0+ fry and 1+up parr, indicated that the duration of electrofishing effort had no effect on fork length ($p>.05$ for 13 out of 15 sites with 0+ fry; $p>.05$ for all sites with 1+up parr) (Table 5). The means of fork lengths obtained by the standardized electrofishing effort at each site were also not significantly different ($p>.05$ for 13 out of 15 sites with 0+ fry; $p>.05$ for all sites with 1+up parr) from means of fork lengths obtained by the traditional, non-standardized effort method.

DISCUSSION

Five minutes of electrofishing represents only 12% of the actual fishing time required to complete three to four sweeps of a closed site measuring approximately 340 sq.m.. Considering the added time required to transport and set up barrier nets at one closed site, equal time allotted to a survey using standardized effort would result in similar information on length frequency distribution and in greater coverage of the available habitat. Standardizing the effort at five minutes produced 15-20% of the total cumulative catch for closed sites sampled using successive removals. Increasing the effort several times could increase the sample size and improve separation of age-classes based on length frequency and still allow for a number of standardized effort sites to be completed in the same time as one closed site.

The presence of a larger proportion of 0+ fry in removals from Humber River sites than from Western Arm Brook or Pinchgut Brook may not be due entirely to higher densities. Kennedy and Strange (1981) and suggest that fishing efficiency is related to river width and Zalewski (1985) suggests that larger fish may not be sampled as efficiently in wider sites.

Length frequency distributions from both the standardized effort and the traditional method resulted in similar conclusions being drawn about the separation of juvenile age-classes, particularly for the 0+ fry and combined 1+ and greater parr.

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Table 1. Site descriptions and electrofishing effort.

RIVER	SITE #	DATE	AREA (sq.m.)	MEAN WIDTH (cm)	MEAN DEPTH (cm)	MAXIMUM DEPTH (cm)	SWEEPS	EFFORT (sec) Total	5 Min.	Total – 5
HUMBER RIVER	1	AUG–10	173.85	6.1	17.0	46.0	4	1652	300	1352
	37	AUG–19	335.03	14.5	21.0	33.0	3	3273	300	2973
	38	AUG–11	250.00	13.3	30.0	39.0	3	1897	300	1597
	39	AUG–11	457.40	12.8	17.0	28.0	3	3688	300	3388
	40	AUG–12	270.00	9.0	16.0	28.0	4	3929	300	3629
	41	AUG–17	218.33	8.3	11.0	25.0	4	2495	300	2195
	42	AUG–05	366.25	15.0	27.0	34.0	4	3551	300	3251
	50	AUG–20	219.99	13.3	24.0	36.0	3	2489	300	2189
	52	AUG–25	143.00	13.0	29.0	39.0	3	2166	300	1866
	53	AUG–18	385.47	9.8	14.0	24.0	4	3547	300	3247
	58	SEPT–24	247.79	10.4	20.0	33.0	3	2121	300	1821
PINCHGUT BROOK	3	AUG–13	343.70	6.9	14.0	22.0	3	2149	300	1849
	7	AUG–14	466.40	20.5	17.0	24.0	3	2057	300	1757
	12	AUG–12	365.70	15.8	18.0	27.0	3	1853	300	1553
WESTERN ARM BROOK	1	JUL–29	377.00	13.8	27.0	61.0	3	2986	300	2686
	3	JUL–28	517.00	20.6	21.0	36.0	3	2766	300	2466
	10	JUL–30	576.00	20.1	20.0	42.0	3	3340	300	3040

Table 2. Mean fork length of 0+ fry and 1+up parr on the Humber River, 1992. Means are calculated for the first five minutes of the first sweep, the total electrofishing effort minus the first five minutes and the total electrofishing effort.

		STAGE							
		0+ Fry				1+up Parr			
SITE #	EFFORT	CATCH	MEAN	RANGE	STD	CATCH	MEAN	RANGE	STD
1	Total	38	3.47	2.0	0.36	47	7.58	7.4	1.55
	5 Minutes	7	3.21	0.5	0.18	16	7.41	5.5	1.41
	Total – 5	31	3.52	2.0	0.37	31	7.66	7.4	1.63
37	Total	52	3.72	2.0	0.43	26	6.40	4.0	0.96
	5 Minutes	5	3.44	1.3	0.60	2	6.35	1.3	0.92
	Total – 5	47	3.75	2.0	0.40	24	6.41	4.0	0.98
38	Total	91	3.47	2.1	0.35	8	7.66	6.3	2.05
	5 Minutes	10	3.57	1.0	0.37	2	6.85	0.5	0.35
	Total – 5	81	3.46	2.0	0.35	6	7.93	6.3	2.34
39	Total	182	3.69	1.2	0.25	150	6.72	10.0	1.73
	5 Minutes	11	3.79	0.8	0.24	12	6.72	1.9	0.64
	Total – 5	171	3.69	1.2	0.25	138	6.72	10.0	1.80
40	Total	249	3.53	2.3	0.30	47	6.91	8.3	1.55
	5 Minutes	29	3.45	1.6	0.32	1	6.60	0.0	.
	Total – 5	220	3.55	2.0	0.30	46	6.92	8.3	1.57
41	Total	235	3.68	2.2	0.38	81	6.76	7.6	1.43
	5 Minutes	57	3.62	1.7	0.35	21	6.96	7.6	1.61
	Total – 5	178	3.70	2.1	0.39	60	6.70	7.2	1.37
42	Total	247	3.40	1.2	0.21	91	7.33	5.6	1.14
	5 Minutes	31	3.43	0.9	0.21	14	6.66	1.3	0.43
	Total – 5	216	3.39	1.2	0.21	77	7.45	5.6	1.19
50	Total	40	3.67	1.4	0.38	53	7.23	6.6	1.56
	5 Minutes	10	3.61	1.2	0.47	9	6.49	3.0	1.08
	Total – 5	30	3.70	1.4	0.35	44	7.38	6.6	1.61
52	Total	4	4.20	1.4	0.63	60	7.78	6.9	1.64
	5 Minutes	2	4.30	0.6	0.42	14	8.21	6.3	2.09
	Total – 5	2	4.10	1.4	0.99	46	7.65	6.9	1.47
53	Total	221	3.66	2.0	0.38	183	7.27	11.3	1.75
	5 Minutes	41	3.70	1.0	0.27	22	7.34	4.9	1.55
	Total – 5	180	3.66	2.0	0.40	161	7.26	11.3	1.78
58	Total	20	4.88	1.4	0.33	41	8.55	7.1	1.65
	5 Minutes	6	5.02	0.4	0.16	.	.	.	.
	Total – 5	14	4.83	1.4	0.38	41	8.55	7.1	1.65

Table 3. Mean fork length of 0+ fry and 1+up parr at Western Arm Brook, 1992. Means are calculated for the first five minutes of the first sweep, the total electrofishing effort minus the first five minutes and the total electrofishing effort.

	STAGE							
	0+ Fry				1+up Parr			
SITE # EFFORT	CATCH	MEAN	RANGE	STD	CATCH	MEAN	RANGE	STD
1 Total	20	3.66	1.5	0.36	100	9.10	9.1	2.06
5 Minutes	3	3.47	1.0	0.58	19	8.69	6.6	2.02
Total – 5	17	3.69	1.3	0.33	81	9.20	9.1	2.07
3 Total	4	3.97	0.8	0.35	72	9.46	12.9	2.77
5 Minutes	.	.	.	.	15	10.38	12.1	3.06
Total – 5	4	3.97	0.8	0.35	57	9.22	10.4	2.66
10 Total	.	.	.	.	47	8.51	9.1	2.14
5 Minutes	.	.	.	.	11	8.83	5.9	2.13
Total – 5	.	.	.	.	36	8.41	9.1	2.16

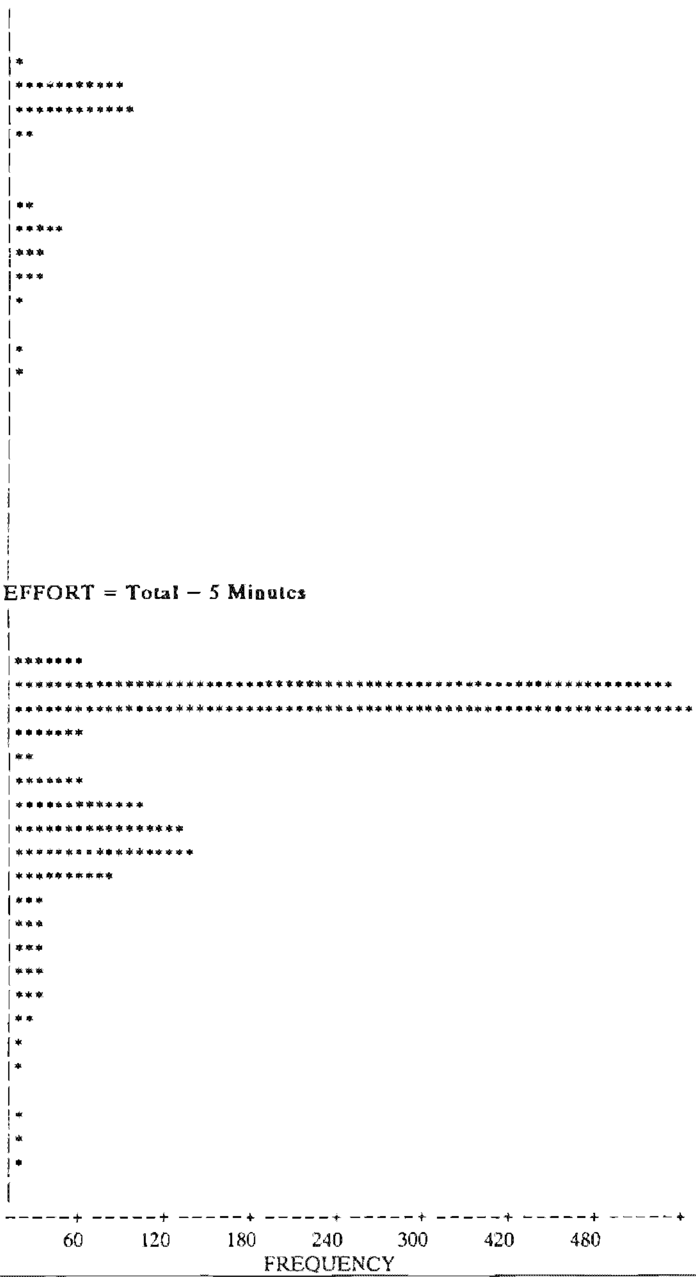
Table 4. Mean fork length of 0+ fry and 1+up at Pinchgut Brook, 1992. Means are calculated for the first five minutes of the first sweep, the total electrofishing effort minus the first five and total electrofishing effort.

	STAGE							
	0+ Fry				1+up Parr			
SITE # EFFORT	CATCH	MEAN	RANGE	STD	CATCH	MEAN	RANGE	STD
3 Total	15	4.54	1.0	0.28	17	9.31	4.6	1.67
5 Minutes	3	4.73	0.6	0.31	4	10.18	2.4	1.01
Total – 5	12	4.49	1.0	0.27	13	9.05	4.6	1.77
7 Total	24	3.86	2.9	0.70	38	8.01	7.4	2.15
5 Minutes	5	4.30	1.4	0.57	8	7.65	6.8	2.47
Total – 5	19	3.74	2.9	0.70	30	8.11	7.4	2.09
12 Total	18	3.81	1.4	0.43	100	9.77	9.0	2.46
5 Minutes	2	3.00	0.0	0.00	19	10.46	8.5	2.43
Total – 5	16	3.91	1.1	0.34	81	9.61	8.8	2.45

Table 5. SAS GLM results. Tests of hypothesis Ho:Mean fork length in 5 Minutes = Mean fork length in Total − 5 minutes. *=ns at p>.05 and **=ns at p>.01.

		p−VALUES	
RIVER	SITE #	0+ Fry	1+up Parr
HUMBER	1	0.0391 **	0.5937 *
RIVER	37	0.1244 *	0.9360 *
	38	0.3586 *	0.5583 *
	39	0.1851 *	0.9879 *
	40	0.1043 *	0.8432 *
	41	0.1452 *	0.4754 *
	42	0.3089 *	0.0167 *
	50	0.5415 *	0.1190 *
	52	0.8174 *	0.2702 *
	53	0.5006 *	0.8516 *
	58	0.2576 *	.
WESTERN	1	0.3307 *	0.3355 *
ARM	3	.	0.1510 *
BROOK	10	.	0.5804 *
PINCHGUT	3	0.1950 *	0.2491 *
BROOK	7	0.1167 *	0.5998 *
	12	0.0021	0.1754 *

HUMBER RIVER, 1992



Fork Lt. Midpoint (cm)	Freq.	Percent	Cumulative Freq.	Cumulative Percent
EFFORT = 5 Minutes				
1.8	0	0.00	0	0.00
2.3	1	0.05	1	0.05
2.8	10	0.48	11	0.52
3.3	85	4.04	96	4.56
3.8	90	4.28	186	8.84
4.3	16	0.76	202	9.60
4.8	1	0.05	203	9.64
5.3	3	0.14	206	9.79
5.8	12	0.57	218	10.36
6.3	34	1.62	252	11.97
6.8	22	1.05	274	13.02
7.3	19	0.90	293	13.92
7.8	4	0.19	297	14.11
8.3	2	0.10	299	14.20
8.8	4	0.19	303	14.39
9.3	4	0.19	307	14.58
9.8	3	0.14	310	14.73
10.3	1	0.05	311	14.77
10.8	1	0.05	312	14.82
11.3	2	0.10	314	14.92
11.8	0	0.00	314	14.92
12.3	1	0.05	315	14.96
12.8	1	0.05	316	15.01
13.3	0	0.00	316	15.01
EFFORT = Total − 5 Minutes				
1.8	1	0.05	317	15.06
2.3	0	0.00	317	15.06
2.8	56	2.66	373	17.72
3.3	497	23.61	870	41.33
3.8	530	25.18	1400	66.51
4.3	55	2.61	1455	69.12
4.8	17	0.81	1472	69.93
5.3	52	2.47	1524	72.40
5.8	101	4.80	1625	77.20
6.3	126	5.99	1751	83.18
6.8	135	6.41	1886	89.60
7.3	74	3.52	1960	93.11
7.8	24	1.14	1984	94.25
8.3	20	0.95	2004	95.20
8.8	20	0.95	2024	96.15
9.3	20	0.95	2044	97.10
9.8	22	1.05	2066	98.15
10.3	12	0.57	2078	98.72
10.8	6	0.29	2084	99.00
11.3	4	0.19	2088	99.19
11.8	3	0.14	2091	99.33
12.3	5	0.24	2096	99.57
12.8	4	0.19	2100	99.76
13.3	5	0.24	2105	100.00

Figure 1. Fork length frequency distribution of juvenile Atlantic salmon captured by electrofishing on the Humber River in August, 1992.

WESTERN ARM BROOK, 1992

Fork Lt. Midpoint (cm)		Freq.	Percent	Cumulative Freq.	Cumulative Percent
	EFFORT= 5 Minutes				
2.8	**	1	0.41	1	0.41
3.3		0	0.00	1	0.41
3.8	****	2	0.82	3	1.23
4.3		0	0.00	3	1.23
4.8		0	0.00	3	1.23
5.3		0	0.00	3	1.23
5.8	**	1	0.41	4	1.65
6.3	**********	5	2.06	9	3.70
6.8	**********	5	2.06	14	5.76
7.3	****	2	0.82	16	6.58
7.8	********	4	1.65	20	8.23
8.3	********	4	1.65	24	9.88
8.8	******	3	1.23	27	11.11
9.3		0	0.00	27	11.11
9.8	******	3	1.23	30	12.35
10.3	**********	5	2.06	35	14.40
10.8	******	3	1.23	38	15.64
11.3	**	1	0.41	39	16.05
11.8	********	4	1.65	43	17.70
12.3	******	3	1.23	46	18.93
12.8	**	1	0.41	47	19.34
13.3		0	0.00	47	19.34
13.8		0	0.00	47	19.34
14.3	**	1	0.41	48	19.75
	EFFORT = Total − 5 Minutes				
2.8	**	1	0.41	49	20.16
3.3	**********	5	2.06	54	22.22
3.8	**********************	11	4.53	65	26.75
4.3	********	4	1.65	69	28.40
4.8		0	0.00	69	28.40
5.3		0	0.00	69	28.40
5.8	********	4	1.65	73	30.04
6.3	************************	12	4.94	85	34.98
6.8	**************************************	19	7.82	104	42.80
7.3	**	26	10.70	130	53.50
7.8	******************************	15	6.17	145	59.67
8.3	******************************	15	6.17	160	65.84
8.8	************************	12	4.94	172	70.78
9.3	********	4	1.65	176	72.43
9.8	************************	12	4.94	188	77.37
10.3	********************************	16	6.58	204	83.95
10.8	********************	10	4.12	214	88.07
11.3	**********	5	2.06	219	90.12
11.8	****	2	0.82	221	90.95
12.3	************	6	2.47	227	93.42
12.8	**********	5	2.06	232	95.47
13.3	****	2	0.82	234	96.30
13.8	******	3	1.23	237	97.53
14.3	************	6	2.47	243	100.00

2 4 6 8 10 11 12 14 16 18 20 22 24 26

FREQUENCY

Figure 2. Fork length frequency distribution of juvenile Atlantic salmon captured by electrofishing on Western Arm Brook, July 28–30, 1992.

PINCHGUT BROOK, 1992

Fork Lt. Midpoint (cm)		Freq.	Percent	Cumulative Freq.	Cumulative Percent
EFFORT = 5 Minutes					
2.3		0	0.00	0	0.00
2.8	********	2	0.94	2	0.94
3.3		0	0.00	2	0.94
3.8	************	3	1.42	5	2.36
4.3	********	2	0.94	7	3.30
4.8	********	2	0.94	9	4.25
5.3	****	1	0.47	10	4.72
5.8	********	2	0.94	12	5.66
6.3	************	3	1.42	15	7.08
6.8	************	3	1.42	18	8.49
7.3	****	1	0.47	19	8.96
7.8	****	1	0.47	20	9.43
8.3	****	1	0.47	21	9.91
8.8	****************	4	1.89	25	11.79
9.3		0	0.00	25	11.79
9.8		0	0.00	25	11.79
10.3	****************	4	1.89	29	13.68
10.8	****	1	0.47	30	14.15
11.3	************	3	1.42	33	15.57
11.8	****	1	0.47	34	16.04
12.3	****************	4	1.89	38	17.92
12.8	****	1	0.47	39	18.40
13.3		0	0.00	39	18.40
13.8	********	2	0.94	41	19.34
EFFORT = Total − 5 Minutes					
2.3	****	1	0.47	42	19.81
2.8	************	3	1.42	45	21.23
3.3	**	10	4.72	55	25.94
3.8	**	14	6.60	69	32.55
4.3	**	13	6.13	82	38.68
4.8	********************	5	2.36	87	41.04
5.3	****	1	0.47	88	41.51
5.8	****************	4	1.89	92	43.40
6.3	**	10	4.72	102	48.11
6.8	**	17	8.02	119	56.13
7.3	**	15	7.08	134	63.21
7.8	**	12	5.66	146	68.87
8.3	************************	6	2.83	152	71.70
8.8	********************	5	2.36	157	74.06
9.3	************	3	1.42	160	75.47
9.8	************************************	9	4.25	169	79.72
10.3	****************************	7	3.30	176	83.02
10.8	************************	6	2.83	182	85.85
11.3	****************	4	1.89	186	87.74
11.8	************************	6	2.83	192	90.57
12.3	************************	6	2.83	198	93.40
12.8	****************************	7	3.30	205	96.70
13.3	****************	4	1.89	209	98.58
13.8	************	3	1.42	212	100.00

```
--+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+--
  1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17
                          FREQUENCY
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Figure 3. Fork length frequency distribution of juvenile Atlantic salmon captured by electrofishing on Pinchgut Brook, August 12–14,1992.

Removal estimates of Atlantic salmon parr: maximum likelihood and Bayesian methods

by

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Removal Estimates of Altantic Salmon Parr: Maximum Likelihood and Bayesian Methods.

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ABSTRACT

A new model for removal estimates of abundance is introduced in which the probability of capture is assumed to decrease with removals in a prescribed manner. While not as accurate as might be desired, the new maximum likelihood estimates are, in general, much closer to the actual abundances than the maximum likelihood estimates obtained under the assumption of constant capture probability. The new method involves a parameter which is related to catchability and, if assumed to be a random variable, enables a Bayesian approach to be employed for the estimation of abundance. In the examples, the Bayes estimates differ little from the maximum likelihood estimates; there is, however, potential for improvement if the variance of the prior distribution of the parameter can be reduced through better knowlege of the effect on catchability of stream characteristics such as velocity, water temperature, electrical conductivity, vegetation and other such physical and chemical properties.

Introduction

In spite of some concerns about the viability of the method expressed by, for example, Mesa and Schreck (1989) and Hardin and Connor (1992), electrofishing remains a popular tool for assessing and comparing the abundance of, in particular, salmonids in various habitats (e.g. Amiro 1993; Gibson et al. 1993). The concerns often relate to the comparability of results among stations (locations), of within stations but at different times. Electrofishing has sometimes been combined with the removal method for estimation of abundance. The three assumptions that underly the removal method are (Seber 1982, p.312)
1. The population is closed,
2. Equal catchability for all individuals,
3. Equal catchability among removals.

In this paper it is assumed that (1) and (2) apply; indeed, the experiments referred to were conducted so that (1) would be reasonably satisfied. An alternative approach is introduced whereby Assumption (3) is replaced by having the probability capture decline with successive removals in accordance with a simple mathematical model which can, however, be given a physical interpretation.

Background

Riley et al. (1991) report the results of a study undertaken to assess the effects of parr density and stream size on the bias of removal estimates of Atlantic salmon parr. In brief, age 1+ Atlantic salmon parr were collected from areas near each of the seven stream sections chosen for the study and released into these study sections, which had been enclosed by fine mesh seines beforehand. Thus the actual number of individuals, n, was known. Four-pass removal estimates of abundance were then obtained by using a bank electrofisher. Experimental details are contained in Riley et al. (1991).

Removal estimates of abundance are generally obtained by the method of maximum likelihood. Let u_i denote the number captured at the i^{th} removal and $s_i = \sum_{j=1}^{i} u_j$, $s_0 = 0$. Let p_i be the probability of capture at the i^{th} removal and n the total (initial) abundance. The u_i and hence the s_i are known (observed) whereas the p_i and n are not. With four removals the likelihood of the data is

$$L = \frac{n!}{u_1!(n-s_4)!} \prod_{j=1}^{4} p_i^{u_i}(1-p_i)^{n-s_i}$$

and the maximum likelihood estimates of n and the p_i are the values that maximize L. (It should be noted, however, that there is no solution solution if all the p_i are assumed to be different (Otis et al. 1978, p.46; White et al. 1982, p.109). Maximizing L is equivalent to maximizing

$$\log(L) = \log(\Gamma(n+1)) - \log(\Gamma(n+1-s_4)) + \sum_{j=1}^{4}[u_j \log(p_j) + (n-s_j)\log(1-p_j)]$$

since, being independent of n and the p_i, the term $-\log\Gamma(u_1+1)$ can be omitted.

Riley et al. (1991) give the maximum likelihood estimates of abundance under the assumption that the probability of capture remains constant ($p_i = p$, all i). These are reproduced in Table 1 along with the known abundances.

Table 1
Actual abundance and abundance estimates by different methods for study 1 (Riley et al. 1991, data).

Site	1	2	2	4	5	6	7
Abundance (n)	118	72	64	88	56	33	79
$\hat{n}$ ($p_i = p$)	56	55	44	85	50	25	68
$\hat{n}$ (mle)	91	70	50	107	50	33	77
$\hat{n}$ (Bayes)	93	70	53	105	52	33	77
k - "true"	42.6	79.9	90.2	155.0	132.6	96.4	69.8
$\hat{k}$ (mle)	84.6	90.8	333.6	38.4	2553.1	110.6	86.2

In all cases the estimates are less than the known abundance, sometimes substantially so. Riley et al. note that Zippin (1958) observed that violation of the assumption that the probability of capture remains constant will lead to underestimation of population size. The maximum likelihood estimates of the p_i, given that n is known, are $\hat{p}_i = u_i/(n - s_{i-1})$. Riley et al. found that, with the exception of one site, these probability estimates decreased with successive removals. It is worthwhile noting that it is site 4, where the estimated probabilites remain relatively constant (i.e. 0.523, 0.571, 0.556 and 0.375, respectively), for which the maximum likelihood estimate is close to the actual abundance.

Riley et al. (1991) also obtained, but did not present, maximum likelihood estimates under the assumption that $p_2 = p_3 = p_4$ but $\neq p_1$, and found that "in general, this estimator produced poor estimates of the actual capture probabilities" and, thus, the abundances, and that "the constant capture-probability model fitted better in all cases". Indeed, if the estimates are calculated (as indicated in Appendix I) the abundances will be found to be the same as, or slightly less than, those obtained under the constant probability assumption.

As pointed out by Otis et al. (1978), maximum likelihood estimates can be obtained as long as it is assumed that the capture probabilities are the same for at least two removals. Accordingly, estimates were calculated under the assumption that $p_1 \neq p_2 \neq p_3$ but $p_3 = p_4$. This resulted in no improvement; indeed the estimates were either the same as under $p_2 = p_3 = p_4$ or even further removed from the actual abundances.

Maximum Likelihood Estimation with a New Model for Capture Probability

It seems reasonable that the probability of capture would be an increasing function of parr density or, equivalently, a decreasing function of the volume of water available per fish. Specifically, it is assumed that catchability would be related to volume of water available to each fish and that, as fish are removed, the remaining individuals relocate throughout the section; the volume of water per fish is thus increased and, hence, the probability of capture reduced. As noted above, a direct estimate of the probability of capture at the i^{th} removal is $u_i/(n - s_{i-1})$ and by plotting this against the number of parr per square meter (of stream surface area), Riley et al. (1991) demonstrated that there was a poorly defined, but clearly positive, relationship. However, a somewhat tighter relationship emerges if the number of parr per cubic meter (or steam volume) is used in place of the number per square meter or, perhaps more conveniently, against the average volume per fish. Now the probability of capture is constrained between 0 and 1. The simplest monotonically decreasing function that satisfies this requirement is, perhaps, $k/(v + k)$, where v is the volume per fish and k a constant, at least for the stream section at the time of the study. (As $v \to 0$, the number of fish, n, $\to \infty$ and $p \to 1$. Likewise, as $v \to \infty$, $n \to 0$ and $p \to 0$). The plots of the direct estimates of the probability of capture do, indeed, appear to be reasonably well tracked by a curve of the form $p = k/(v + k)$.

Under this model, in the expression for the likelihood, p_i is replaced by $\frac{k}{V/(n-s_{i-1})+k}$ where V denotes the volume of the study section of the stream (length (m) × mean width (m) × mean depth (cm)). Maximum likelihood estimates of k and n can then be obtained (Appendix I). These have been included in Table 1.

For the most part these estimates are closer, and usually much closer, to the actual abundances than the estimates under the constant probability assumption. The notable exception is site 4, the only site for which, for some unknown reason, the constant-probability assumption appeared reasonable. The overall error is about 6% compared to 25% under the constant probability assumption.

Some comment needs to be made with respect to the very large estimate of k for site 5. Here the u_i were 48, 2, 0 and 0. These numbers suggest that the entire population had been captured by the second removal, resulting in a high value for k (i.e. a capture probability approaching unity), with the initial population size estimated accordingly.

To explore whether comparable results would be obtained more generally by this new appoach, a similar, more recent data set was was provided the author by J.B. Dempson. Initially the results with these new data were disappointing, however, the data differed from that of Riley et al. (1991) in that both age zero and 1+ parr were used. It may be reasonably supposed that, under electrofishing, the probability of capture of age 0 parr differs from that of 1+ parr and therefore the proportion of age 0 parr in the removals would differ from the proportion released into the study site. It was found possible to determine the numbers of 1+ parr released and in the removals; these numbers confirmed the differential catchability of the age classes. Accordingly the final analysis was based on 1+ parr only. The basic data are presented in Table 2. In sites 3 and 4 there were 5 and 6 removals, respectively, instead of 4; for consistency, the results of only the first four removals were included in the analysis.

Table 2
Removals and stream parameters for study 2.

Site	u_1	u_2 / s_2	u_3 / s_3	u_4 / s_4	Length(m)	Width(m)	Depth(cm)
1	37	6	3	0	22.8	5.4	22
		43	46	46			
2	21	9	5	1	32.9	10.7	33
		30	35	36			
3	13	7	7	4	22.7	9.3	26
		20	27	31			
4	15	5	7	2	23.0	8.7	27
		20	27	29			
5	10	7	2	0	29.7	10.6	16
		17	19	19			
6	32	17	4	1	26.4	7.7	33
		49	53	54			
7	16	14	3	3	34.4	8.9	29
		30	33	36			
8	18	3	5	1	29.1	18.6	19
		21	26	27			

The actual abundances, their estimates under the constant probability assumption and maximum likelihood estimates of n and k under the new model are given in Table 3.

Table 3
Actual abundance and abundance estimates by different methods for study 2.

Site	1	2	3	4	5	6	7	8
Abundance (n)	46	56	75	58	24	67	61	69
$\hat{n}$ ($p_i = p$)	46	37	38	31	19	54	38	27
$\hat{n}$ (mle)	49	45	57	41	23	65	51	32
$\hat{n}$ (Bayes)	50	48	50	41	25	66	52	35
k - "true"	846.7	98.0	13.8	23.8	193.0	105.0	53.2	25.4
$\hat{k}$ (mle)	193.8	253.1	30.1	75.8	240.6	124.8	101.8	396.9

With the exception of site 1, estimates based on the constant probability assumption are again less, and generally substantially less, than the actual abundances. Site 1 is unusual in that all released fish were caught by the third removal. In general, the new method also underestimates the abundance, although in most cases the bias is noticeably less than under the assumption of constant capture probability. The more substantial underestimation occurs at those sites with the smaller proportions of the population captured. Overall the error is about 20% compared to about 36% under the constant-probability assumption.

Thus, while estimates under the new model are by no means perfect, they are, in general, much closer to the actual abundances than the estimates made under the assumption of constant capture probability.

Confidence Limits

In testing a hypothesis it is known that twice the difference between the logarithms of the likelihoods is asymptotically distributed as chi-squared with degrees of freedom equal to the difference in the number of parameters estimated. This enables us to compute a confidence region for (n, k). Let $\log(L(\hat{n}, \hat{k}))$ be the maximized likelihood, i.e. the likelihood evaluated at $n = \hat{n}$,

$k = \hat{k}$. Suppose that arbitrary values of n and k are given. Then, asymptotically, $-2[\log(L(n,k)) - \log(L(\hat{n},\hat{k}))]$ will be distributed as χ^2 on 2 degrees of freedom. Let $\chi^2_{2,0.95}$ be the 95^{th} percentile χ^2 on 2 d.f. Then the set of points (n,k) such that $\log(L(\hat{n},\hat{k})) - \log(L(n,k))$ $< \chi^2_{2,0.95}/2$ forms a 95% confidence region for (n,k). An example is given in Fig. 1. A 95% confidence interval for n is then given by (n_l, n_u) where n_l is the smallest integer ($\geq s_4$) such that $\log(L(\hat{n},\hat{k})) - \log(n_l,k)) \leq \chi^2_{2,0.95}$ and n_u is the largest integer such that $\log(L(\hat{n},\hat{k})) - \log(n_u,k)) \leq \chi^2_{2,0.95}$. Confidence intervals for n so obtained are given in Table 4.

Table 4.
Confidence intervals (95%) for abundance.

Site	Study 1	Study 2
1	54 - ∞	46 - 57
2	58 - 104	38 - 69
3	45 - 65	36 - ∞
4	92 - 140	32 - 110
5	50 - 53	19 - 47
6	26 - 69	57 - 86
7	70 - 90	40 - 106
8		27 - 50

The intervals for site 1-1 and 2-3 appear to be open-ended. For these cases it turns out to be possible for n to tend to ∞ and k to tend to 0 such that $\log(L(\hat{n},\hat{k}) - \log(L(n,k)$ remains less than $chi^2_{2,0.95}$. This should not be viewed as too unusual since, clearly, it is clearly possible for $n \rightarrow \infty$ and $k \rightarrow 0$ such that $k(n - s_{i-1}) \rightarrow p_i V/(1-p_i)$.

In 12 of the 15 cases the intervals contain the known abundance; the exceptions are sites 1-4, 1-5 and 2-8. As noted above, in site 1-4 the actual capture probabilites are relatively constant instead of decreasing, so that the poor result by the new approach is not surprising. Again as noted above, the data are site 1-5 are also exceptional in that they suggest that all the released parr were recaptured by the second removal, although some remained uncaptured after the fourth removal. (It is assumed that neither mortality nor escape have occurred). The upper 95% limit is 53 compared with the acutal 56. Contrast this with site 2-1 in which all the released parr were recaptured. There is, however, nothing obviously unusual in the data from site 2-8.

Confidence intervals for k may be likewise constructed (not presented) and are remarkably wide. It should be noted, however, that, when k is large, relatively large differences in k correspond to relatively small differences in $p_i = k/(V/(n - s_{i-1}) + k)$. For example, at $V/(n - s_{i-1}) = 80$, a change in k from 200 to 300 causes the same change in p_i as a change in k from 50 to 68, or from 400 to 790.

A Bayesian Approach

From the likelihood equation $\partial L/\partial k = 0$, the value of k can be determined that, if assumed known, would lead to the estimate of the abundance being exactly the abundance. We refer to this as the "true" k. These values are also given in Tables 1 and 3. These and the maximum likelihood estimates of k dispel any hope that k is a universal constant, or even relatively constant. This, perhaps, should not be surprising since k is related to catchability which, no doubt, varies with steam conditions (see the Discussion Section below). The estimates of k can, perhaps, be regarded as a random sample from some distribution with probability distribution function $F(.)$. Let k_1, k_2, ... k_{15} be the estimated values ordered so that $k_1 < k_2 < ... < k_{15}$. Then $F(k_i) = P(k < k_i)$ can be estimated as $i/16$. (Other estimates could be used, for example $(i - 0.5)/15$ or $(i - 0.3)/15.4$ Using the "true" k_i and plotting $\log(k_i)$ against $\Phi^{-1}(i/16)$ yields, apart from one outlier (site 2-1 where all released parr were recaptured), a reasonably straight line; this suggests that a lognormal assumption for the distribution of k would be reasonable. With the outlier removed, but with $i/16$

still used for the so-called plotting positions, the least-squares estimate of the line is

$$\log(k_i) = 4.3077 + 0.9601\Phi^{-1}(i/16)$$

i.e. $\log(k)$ is normally distributed with mean 4.3077 and variance $0.9601^2 = 0.9218$. (This corresponds to a mean k of $\exp(4.3077 + 0.9218/2) = 117.8$).

[The results are similar if the maximum likelihood estimates of k are used instead of the "true" k. Again with an outlier omitted, although from a different site (site 1-5, see above), the least-squares regression estimate is $\log(k_i) = 4.8898 + 0.9565\Phi^{-1}(i/16)$].

Let us take the lognormal distribution $\Lambda(\mu, \sigma^2) = \Lambda(4.3077, 0.9218)$ as a prior distribution for k.

By Bayes theorem, the posterior probability density of a (vector valued) parameter, θ, given the data, $\mathbf{x}$, is given by

$$f(\theta|\mathbf{x}) = \frac{f(\theta)L(\theta|\mathbf{x})}{\int f(\theta)L(\theta|\mathbf{x})d\theta}$$

where $f(\theta)$ is the prior density of θ and $L(\theta|\mathbf{x})$ the likelihood. The demoninator merely ensures that the posterior density integrates to unity. Thus the posterior density is proportional to the likelihood multiplied by the prior density.

In our case, θ is (n, k) and to be Bayesian we should, strictly speaking, place a prior distribution on n as well as on k. This could be a noninformative prior. This we have not done but, instead, have simply taken the posterior density of n and k to be proportional to

$$\frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(\log(k)-\mu)^2}{2\sigma^2}\right]\frac{n!}{u_1!(n-s_4)!}\prod_{j=1}^{4} p_i^{u_i}(1-p_i)^{n-s_i}$$

where $p_i = k/(V/(n - s_{i-1}) + k)$, and instead of determining the posterior mean, we find n and k so as to maximize the posterior density or, equivalently, its logarithm. The partial derivative of the logarithm of the posterior density with respect to n is the same as the partial derivative of the log likelihood. The partial derivative with respect to k is also the same as the partial derivative of the log likelihood with the addition of the term $-(\log(k) - \mu)/k\sigma^2$.

The resulting estimates of abundance are included in Tables 1 and 3. In general, these are the same as, or differ only slightly from, the maximum likelihood estimates, although when different are, more often that not, are closer to the actual abundances. The small difference stems from the relative uncertainty expressed in the prior distribution for k. Note that the prior 95% confidence interval for k extends from approximately 11 to 507. How this uncertainty might be reduced is taken up the in Discussion Section below.

The above is open to criticsm in that "Bayesian" estimates have been obtained for the same data sets from which the prior distribution of k was derived. The test of the method is then, in this sense, biased. To some extent this objection is overcome in the following.

Unmarked Parr

In the second study, the number of unmarked parr obtained at each removal was recorded, i.e. those parr that were in the stream section prior to the introduction of known number of marked parr. These data are given in Table 5 with the maximum likelihood and "Bayes" estimates given in Table 6. The maximum likelihood estiamtes under $p_i = p$, all i, are either equal to s_4 or, at most, $s_4 + 4$ (site 2-7).

Table 5.
Removals of unmarked parr in study 2.

Site	u_i	u_2	u_3	u_4
		s_2	s_3	s_4
1	21	12	2	1
		33	35	36
2	24	18	7	2
		42	49	51
3	18	7	6	2
		25	31	33
4	5	1	0	2
		6	6	8
5	21	11	1	1
		32	33	34
6	9	8	0	0
		17	17	17
7	60	20	13	8
		80	93	101
8	5	1	3	1
		6	9	10

Table 6.
Abundance estimates of unmarked parr in study 2.

Site	1	2	3	4	5	6	7	8
$\hat{n}$ (mle)	43	71	44	9	40	19	131	14
$\hat{n}$ (Bayes)	43	72	45	14	41	22	130	21
$\hat{n}$ (ratio)	36	79	80	16	43	21	171	26

The only notable difference between the maximum likelihood and Bayes estimates occur with sites 4 and 8; in both cases very few unmarked parr were caught.

Under the assumption that the ratio of unmarked to marked parr caught is the same as the ratio in the study area, another estimate of the total number of unmarked parr can be obtained by multiplying the known number of marked parr in the stream section by the ratio of the number of unmarked caught to the number of marked caught. These estimates are included in Table 6. Only in site 3 is there a serious discrepacy beween this and the other estimates.

Discussion

The maximum likelihood estimates of abundance under the assumption that the probability of capture is equal to $k/(V/(n - s_{i-1}) + k)$, while being less accurate than one might desire, are, in general, much closer to the actual abundances than the maximum likelihood estimates based on a constant probabililty of capture (or even unequal probabilities provided equality is assumed for at least two removals). The parameter, k, relates to catchability and, thus, is dependent on various stream conditions. The observed range of k is sufficiently large for the Bayesian approach to yield estimates that differ little from the maximum likelihood estimates.

How may abundance estimation be improved? If k could be related to stream conditions then it should be possible to choose a prior distribution for k with mean closer to its actual (but unknown) value and with relatively small variance. The smaller variance would cause greater weight to be given to the prior and thus move the maximum likelihood estimate towards the prior mean, i.e. closer to the actual value. [The extreme case of zero variance means that, *a priori*, k is known exactly and its estimate is independent of the data]. Jensen and Johnsen (1988) list several factors that affect catchability under electrofishing; they include width of reach, depth of water, water velocity, configuration of bottom and banks, water vegetation, water temperature and electrical conductivity, and indicate that there may well be other physical or chemical properties that have an effect. Hardin and Connor (1992) mention moon phase, season and electrode configuration. In the studies analysed above, there is no obvious relationship between k and depth but such relationship could be obscured by one or more other (unrecorded) factors. Research geared to elucidating the effects of stream characteristics on k would appear to be well justified.

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APPENDIX

With $p_i = \frac{k}{V/(n-s_{i-1})+k}$ the likelihood becomes

$$L = \frac{n!}{u_1!(n-s_4)!} \prod \frac{k^{u_i}(V/(n-s_i))^{n-s_i}}{(k+V/(n-s_{i=1}))^{n-s_{i-1}}}$$

Thus, with $\log(\Gamma(u_1+1))$ omitted

$$\log(L) = \log(\Gamma(n+1)) - \log(\Gamma(n-s_4+1)) + s_4\log(k) + \sum_i (n-s_i)\log(V/(n-s_{i-1}))$$

$$-\sum_i (n-s_{i-1})\log(k+V/(n-s_{i-1}))$$

Then

$$\frac{\partial \log(L)}{\partial n} = \psi(n+1) - \psi(n-s_4+1) + 4\log(V) - \sum_i \log(n-s_{i-1})$$

$$-\sum_i (n-s_i)/(n-s_{i-1}) - \sum_i \log(k+V/(n-s_{i=1})) + \sum (V/V+k(n-s_{i-1}))$$

and

$$\frac{\partial \log(L)}{\partial k} = s_4/k - \sum_i \frac{(n-s_{i-1})^2}{V+k(n-s_{i-1})}$$

where $\psi(.)$ denotes the digamma function.

The maximum likelihood estimates are obtained by setting $\partial\log(L)/\partial n$ and $\partial\log(L)/\partial k = 0$ and solving for n and k.

Under the original model with $p_i = p$, all i, the maximum likelihood estimates are given by the solution of

$$p = s_4/(4n - s_1 - s_2 - s_3)$$

and

$$\psi(n+1) - \psi(n-s_4+1) + 4\log(1-p) = 0$$

If it is assumed that $p_2 = p_3 = p_4$ but $p_1 \neq p_2$ then the maximum likelihood estimates are given by the solution of

$$p_1 = s_1/n, \quad p_2 = (s_4 - s_1)/(3n - s_1 - s_2 - s_3)$$

and

$$\psi(n+1) - \psi(n-s_4+1) + \log(1-p_1) + 3\log(1-p_2) = 0$$

Finally if that only $p_3 = p_4$ the maximum likelihood estimates are given by the solution to

$$p_1 = s_1/n, \quad p_2 = (s_2 - s_1)/(n - s_1), \quad p_3 = (s_4 - s_2)/(2n - s_2 - s_3)$$

and

$$\psi(n+1) - \psi(n-s_4+1) + \log(1-p_1) + \log(1-p_2) + 2\log(1-p_3) = 0$$