duplicate ?

RESULTS OF AN ATLANTIC SALMON HABITAT MODEL BUILDING WORKSHOP MARCH 17-20, 1992 ST. JOHN'S, NEWFOUNDLAND

Library's
ONLY
COPY ?

J. W. TERRELL, A. W. ALLEN, D. A. SCRUTON, AND J. CARPENTER

Science Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

March 1995

Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2301

Fisheries and Oceans
Pêches et Océans

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 901-1425 were issued as Manuscript Reports of the Fisheries Research Board of Canada. Numbers 1426-1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Can. Manusc. Rep.
Fish. Aquat. Sci. 2301

March 1995

RESULTS OF AN ATLANTIC SALMON HABITAT MODEL BUILDING WORKSHOP MARCH 17-20, 1992 ST. JOHN'S, NEWFOUNDLAND

by

James W. Terrell[1]

Arthur W. Allen[1]

David A. Scruton

Jeanette Carpenter[1]

Department of Fisheries and Oceans
Science Branch
P.O. Box 5667
St. John's, NF A1C 5X1

[1] U.S. Department of the Interior
National Biological Survey
4512 McMurray Avenue
Fort Collins, Colorado
USA 80525

Cat. No. Fs 97-6/2301 ISSN 0706-6457

Correct citation for this publication:

Terrell, J. W., A.W. Allen, D.A. Scruton, and J. Carpenter. 1995. Results of an Atlantic Salmon Habitat Model Building Workshop, March 17-20, 1992, St. John's, Newfoundland. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2301: vii + 78 p.

TABLE OF CONTENTS

APPENDICES

ABSTRACT/RÉSUMÉ

Terrell, J. W., A.W. Allen, D.A. Scruton, and J. Carpenter. 1995. Results of an Atlantic Salmon Habitat Model Building Workshop, March 17-20, 1992, St. John's, Newfoundland. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2301: vii + 78 p.

The Canadian Department of Fisheries and Oceans (DFO), Newfoundland Region, convened a workshop to develop a Habitat Suitability Index (HSI) model for Atlantic salmon for potential application to habitat evaluation and environmental assessment, habitat planning and inventory, and other aspects related to productive capacity measurement. Regional and international experts on Atlantic salmon habitat requirements and use were invited to a three day model building workshop in St. John's, Newfoundland from March 17 to 19, 1992. This report documents the deliberations and discussions from the workshop including scoping and objective setting, identification of model variables and development of individual (component) suitability indices. Information generated on ideas for the development of additional component suitability indices, alternative variables and methods of criteria development, and other material provided by participants in response to post-workshop requests for additional contributions are also contained in this report. A 'prototype' HSI model for Atlantic salmon, developed after the workshop by the facilitators, is also included and is intended as a catalyst for further discussion, testing, refinement and model developement.

Terrell, J. W., A.W. Allen, D.A. Scruton, and J. Carpenter. 1995. Results of an Atlantic Salmon Habitat Model Building Workshop, March 17-20, 1992, St. John's, Newfoundland. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2301: vii+ 78 p.

PREFACE

In October of 1986, the Canadian Department of Fisheries and Oceans (DFO) released a new national Policy for the Management of Fish Habitat. This policy provides a framework and a series of implementation strategies whereby the conservation, restoration, and development of habitat can contribute to an overall objective of achieving a net gain in fish habitat. The guiding principle behind this policy is that management decisions should be taken to ensure no net loss in the productive capacity of fish habitats. With the implementation of this policy, DFO recognized there was a need to quantitatively evaluate success in attaining policy objectives. Further, it was realized that to achieve these objectives, it was necessary to develop methods to quantitatively evaluate changes in the attributes associated with fish habitats, evaluate the consequences of anthropogenic impacts in causing changes, and translate these changes to gains and losses in the productive capacity of fish habitats.

In response to the implementation of this policy, a special meeting of the Anadromous, Catadromous and Freshwater Fishes Sub-Committee of the Canadian Atlantic Fisheries Advisory Committee (CAFSAC) was convened from April 30 to May 5, 1990 in Moncton, New Brunswick. This meeting was held to address the question of the measurement of habitat attributes to evaluate changes in the productive capacity of habitat and Atlantic salmon production. Specifically, the Sub-Committee was asked to address the usefulness of a variety of attributes for measuring changes in the productive capacity of Atlantic salmon habitat and for evaluating the effectiveness of the Policy for the Management of Fish Habitat. The result of this workshop was a CAFSAC Research Document (90/77) entitled "Collected Papers on Fish Habitat with Emphasis on Salmonids".

The conclusions and advice developed from this meeting indicated that DFO was at an early stage with respect to the development and implementation of Atlantic salmon habitat models. It was recommended that efforts be made to develop, test, and modify methods for the measurement of habitat productive capacity which are appropriate for the intended use (i.e. stock and habitat management) and to determine limits of applicability of these methods. Participants reviewed the development and use of habitat suitability curves (HSCs), and habitat suitability index (HSI) models and determined that there is acceptance in the development and potential use of individual HSCs. There was considerable concern expressed in the combination of several univariate habitat suitability curves into a single HSI to express a "net effect" on habitat productivity. Participants at the meeting indicated there was a particular need for research on interactions among habitat variables, linear constraints in current modelling approaches, and methods of aggregating individual HSCs. Workshop participants felt it was important to assemble as much knowledge and expertise as possible in providing scientific advice on habitat issues. It was recognized that, while HSC's and habitat models are hampered by many constrains and limitations, it is an approach that has been successful in assembling a vast amount of habitat information and representing this information in a usable format.

Building on this 1990 meeting of CAFSAC, DFO (Newfoundland Region) decided to convene a workshop to investigate the development of an HSI model for Atlantic salmon for potential use in habitat evaluation and environmental assessment, habitat planning and inventory, and other applications relative to productive capacity measurement. Regional and international experts on Atlantic salmon habitat requirements and use were invited to a three day model building workshop in St. John's, Newfoundland from March 17 to 19, 1992. This report documents the deliberations and discussions from the workshop. This report also describes ideas for the development of component suitability indices and other material generated by the participants in response to post-workshop requests for additional contributions.

INTRODUCTION

An Atlantic salmon (*Salmo salar*) habitat model building workshop was conducted from 17 to 19 March 1992 in St. John's, Newfoundland, Canada. This workshop was organized and chaired by David A. Scruton of the Department of Fisheries and Oceans (DFO) in St. John's, Newfoundland, and was facilitated by James W. Terrell and Arthur W. Allen, biologists with the U.S. Department of Interior National Biological Survey. This document provides a thorough description of the ideas, discussions, and habitat models developed at the workshop and summarizes comments and results of follow up activities after the workshop.

This document was developed through a multi-step process. Flip charts and notes from the workshop were used to develop a draft document that contained text sections, figures, and appendices that summarized what occurred during the workshop. Workshop participants reviewed this first draft for accuracy and completeness, new information was provided, and results of two exercises assigned at the end of the workshop were summarized and reported. The first exercise was to develop matrices of habitat variables that could be used in the future to develop habitat models, and the second was to rate the overall productive capacity of three example habitats. As part of the second exercise, participants described how they would aggregate data for several habitat variables into a single estimate of productive capacity.

Ideas and material developed at the workshop and in post-workshop activities is presented in three sections to document the evolution of ideas and to provide a report that follows the chronological order of the workshop and follow up activities. The first section of the document, from "WORKSHOP PROCESS" through "OTHER VARIABLES OF SPECIAL CONCERN", describes how the workshop was conducted and summarizes the results of various deliberations that occurred between 17 and 19 March 1992. This section identifies potential model variables identified during the workshop and describes progress towards the development of habitat models.

The second section, "POST-WORKSHOP PARTICPANT COMMENTS", summarizes new material and ideas supplied by participants who reviewed the first draft of the document. It includes their caveats, cautions, criticisms, and other reactions to the workshop approach of habitat model building. This section also includes matrices of potential variables for salmon habitat assessment (Tables A-1 through A-16, Appendix A) and comments from the participants who developed a productive capacity model for rating habitat quality and applied their model(s) to the example matrices of habitat values (provided in Appendix B). Participant's comments and editorial changes related to clarifying the account of what took place at the workshop were incorporated in the first section of the document. A final draft was also reviewed by participants to insure their responses to the initial request for post-workshop material had been accurately incorporated. To prevent an endless review cycle, the workshop chairman kept new material that participants provided during the final review for future use and reference.

The third section, "POST-WORKSHOP FACILITATOR COMMENTS", contains two HSI models described by J.W. Terrell, in response to a post-workshop request by the meeting chairman. The listing of workshop participants does not imply their agreement with the accuracy or usefulness of the models, suitability index curves, and habitat modeling approaches contained in this document. The document has not been subject to editorial review by the Office of Information Transfer of the U.S. Department of Interior, National Biological Survey. Any errors or omissions are the responsibility of the authors.

WORKSHOP PROCESS

The workshop was organized and chaired by David A. Scruton. The facilitators (Arthur W. Allen and James W. Terrell) recorded ideas, graphs, and other information generated by the attendees on flip charts for use throughout the meeting and sometimes became active participants in the meeting process. Jeanette Carpenter organized, summarized, and transformed notes, comments, and sketches into final text and graphics. Collaborative problem solving through group ownership and group evaluation of ideas relative to the objectives of the workshop chairman were emphasized. Individuals summarizing or explaining technical items at the workshop did not have to defend concepts or ideas as "theirs". Techniques emphasizing belonging to and working in a group (having a group check-in when the group reassembled, using group input to build an agenda, consensus building when possible) were followed.

The workshop followed three steps: setting the stage, generating material, and synthesis of material. Stage setting was accomplished during the first half-day of the meeting. Participants gave a brief description of their background and experience with Atlantic salmon and habitat quantification. The chairman outlined the objectives for convening the workshop; these were recorded on flip charts and displayed throughout the meeting. Marvin A. Barnes (DFO, Habitat Management) presented an overview of the environmental assessment process used by regulators to review the impact of proposed projects. Habitat models used by DFO to evaluate compliance with the "no net loss" of productive capacity principle will have to operate within this review/assessment process. The system of habitat quantification currently used in environmental assessment (a 4-class descriptive model developed by the consulting industry, Beak 1980), and other relevant information such as the CAFSAC Research Document (90/77), "Collected Papers on Fish Habitat with Emphasis on Salmonids" (Department of Fisheries and Oceans 1990), were provided to group members who did not already have the material. A U.S. Fish and Wildlife Service (FWS) method (Habitat Evaluation Procedures or HEP) of displaying expected changes in habitat quality and quantity over a long-term (25 to 100 year) planning horizon was described as a way to compare (but not predict) those changes in a standard format. A FWS slide tape on building habitat models was presented. The five-step model building process described in the slide tape (set model objectives, identify potential model variables, structure the model, document the model, verify and test the model) was followed in the later stages of the meeting. As the final part of stage setting, Art Allen described how a moose habitat model initially developed at a similar workshop has been tested, modified, and used for various scales of habitat evaluations and resource planning in the northern U.S. and Canada.

A published summary and critique (DFO 1990) of Atlantic salmon habitat requirements and habitat modeling approaches provided a foundation for the workshop. The material generation stage lasted about 1-1/2 days. Participants worked their way though the initial phases of model building and the facilitators recorded their progress on flip charts. A paper describing model "validation" (Caswell 1976) was provided at the end of the first day to help people think of model building and testing as a single, continuous process instead of thinking of testing as something done only after a model is "completed". Caswell's paper describes how different types of tests are appropriate for different types of models and helps the reader think of a model as something other than a null hypothesis that is tested and rejected. A trip to the Newfoundland Freshwater Resources Centre (fluvarium) helped remind the group what habitat looked like from the fish's perspective.

Information synthesis occupied most of the last day of the workshop and included presentations on salmonid habitat evaluation in France and Norway. The work in Norway involved intensive use of a modified IFIM approach and Jan Heggenes was able to relate some of his experiences in quantifying habitat at different scales of evaluation. After the presentations, the group finished development of suitability indices (SIs) and summarized proposed relationships of model variables to measures of salmon performance (e.g. production, survival), used as indicators of the habitat productive capacity. The group was provided the opportunity both as individuals and as a group to describe how SIs for all of the variables could be considered together to develop a single estimate of productive capacity. No single method was agreed upon and the group decided to revisit the question when reviewing the draft meeting summary (post-workshop activities).

Several participants expressed an interest in applying the process employed at the workshop to other meetings with problem-solving objectives. In addition, an understanding of the process used at the workshop can help potential model users judge the degree to which material in this document fulfills their particular needs. Ideally, this section on WORKSHOP PROCESS should help both of these objectives. Doyle and Straus (1976) provide a detailed description of meeting processes similar to those used at the workshop.

WORKSHOP OBJECTIVES

Workshop objectives were to: (1) develop a model, or suite of models, using variables indicative of productive capacity of Atlantic salmon habitat for use as an environmental assessment tool sensitive to habitat perturbations resulting from medium to large-scale (e.g., hydroelectric) projects; and (2) develop a modelling approach, or classification criteria, applicable for broad scale inventory of habitat that could be integrated with Geographic Information Systems (GIS) and function largely on existing data.

Desired uses of the model include habitat evaluation, habitat management planning, assessment of effectiveness between mitigation alternatives, and documentation of changes in the quality and area of salmon habitat within Newfoundland. A model is needed for use as an operational management tool to help standardize the assessment of habitat impacts and benefits resulting from medium- to large-scale projects. Intended model users are habitat managers, project proponents, and consultants involved in assessing project impacts. Major constraints in the use and testing of a workshop-developed model include: less than 1 year would normally be available for collection of habitat assessment data; the model should be user-friendly; and the model should be testable with existing data bases. Extensive amounts of data collected over several years should not be required to use the model. Ideally, data needed to apply the model are in existing data bases. The ultimate goal of DFO is to integrate habitat model(s) with GIS to assess site specific, broad scale, and cumulative impacts of various sizes of projects throughout the province. The effects of interspecific competition, intraspecific competition, disease, predation, and chemical contamination on productive capacity of Atlantic salmon habitat were not addressed at the workshop, although these factors may significantly influence habitat availability, selection, and use.

WORKSHOP PARTICIPANTS

Arthur Allen, Department of the Interior, National Biological Survey, Fort Collins, Colorado

Jean Louis Baglinière, Laboratoire d'Ecologie Hydrobiologique, Rennes, France

Marvin Barnes, Department of Fisheries and Oceans (DFO), Habitat Management Division, St. John's, Newfoundland

Rick Cunjak, DFO, Science Branch, Monton, New Brunswick

John Gibson, DFO, Science Branch, St. John's, Newfoundland

Richard Haedrich, Director, Ocean Sciences Centre, Memorial University, St. John's, Newfoundland

Jan Heggenes, Department of Biology and Nature Conservation, Agricultural University of Norway, Oslo, Norway

John Horne, Ocean Sciences Centre, Memorial University, St. John's, Newfoundland

Kim Houston, DFO, Science Branch, St. John's, Newfoundland

Mike O'Connell, DFO, Science Branch, St. John's, Newfoundland

Vern Pepper, DFO, Science Branch, St. John's, Newfoundland

Geoff Power, University of Waterloo, Waterloo, Ontario

David Scruton, DFO, Science Branch, St. John's, Newfoundland

James Terrell, Department of the Interior, National Biological Survey, Fort Collins, Colorado

Joan Trial, Maine Department of Inland Fisheries and Wildlife, Bangor, Maine

DESCRIPTION OF WORKSHOP MODEL

The workshop yielded suitability indices (SIs) for 17 habitat variables likely to have a direct influence on the productive capacity of riverine habitat for Atlantic salmon fry and under-yearlings in Newfoundland (Table 1, Figures 1 to 15). The SIs are for comparing (at the appropriate scale of station, habitat type, or watershed) the productive capacity of pre- and post-project construction habitat conditions in order to estimate project impacts and to guide mitigation and habitat compensation activities. The group discussed methods for using SIs for individual variables in a model that would provide a single estimate of productive capacity. However, no consensus was reached at the workshop or during the review process on how (or if) SIs for the variables should be aggregated into a single number for rating habitat. The workshop model consisted of individual SIs (Figures 1 to 15) and instructions for data collection (Table 1). A matrix of potential variables (Table 2) for determining productive capacity of various life stages was developed to aid future DFO modeling efforts.

VALIDATION LEVEL OF WORKSHOP MODEL

Proposed methods for measuring habitat variables for fry and under-yearlings (Table 1) and the individual SI curves (Figures 1 to 15) were considered reasonable (in the context of meeting model objectives) to participants at the close of the workshop. Ideally, performance of model(s) derived from the variables can be evaluated with existing data; however, this was not attempted. DFO is likely to modify SIs based on the "best fit" with existing data. The continued development and refinement of SIs is expected, based on their usefulness in the DFO planning process.

APPLICABILITY OF THE MODEL

The SIs are for use in insular Newfoundland and are based on the knowledge and experience of workshop participants. Applying the indices to other geographic regions of the Atlantic salmon's range or for uses other than DFO policy implementation were not considered.

SEASONAL APPLICABILITY

The SIs are designed to assess productive capacity during the winter and the growing-season. Seasonal constraints in data collection are reflected in variable definitions. Separate winter and growing-season curves are provided for habitat variables where applicable.

ENVIRONMENTAL (COVER) TYPES FOR MODEL USE

Atlantic salmon occupy riverine, lacustrine, estuarine and marine environments in Newfoundland. Development of SIs for riverine environments was emphasized at the workshop. Matrices of potential variables for use in riverine, estuarine and lacustrine habitats were developed by reviewers after the workshop (Tables A-1 through A-16, Appendix A).

LIFE STAGES

The SIs and instructions developed at the workshop (Figures 1 to 15, Table 1) are applicable only for evaluation of habitat for reproduction and fry, or under-yearling (fish hatched less than 1 year ago) life stages in riverine environments, as defined by the workshop participants. In most cases the standard of comparison for an SI is numbers or weight of either fry (or under-yearlings) per unit area, (e.g., number or g/100 m^2). Other standards of comparison (e.g., fry survival) are identified when applicable. In most cases, the numerical scale of the standard of comparison was defined qualitatively (e.g. high, low) relative to the SI.

SPATIAL SCALE OF MODEL APPLICATION

Only available salmon habitat, as defined using existing DFO criteria, is evaluated with the SIs. The minimum area for application of variables, unless otherwise specified, is a DFO sample station (typically 200-500 m^2) for quantification of population densities (numbers and/or biomass). Appropriate spatial scales (sample station, habitat type, watershed) are identified for application of each variable. Usually, DFO habitat inventory and sampling require that a sample station consists entirely of one habitat type.

EMPIRICAL DERIVATION OF SUITABILITY INDEX CURVES

Data to empirically derive SI curves would be collected at the appropriate spatial scale (station, habitat type, watershed) by relating habitat data to fry (or under-yearling) production. Only adequately seeded streams would be used to empirically derive these relationships. SI curve derivation should address the recommendations of Rice (1990) to prevent information loss due to the variability of the original data. A publication released after the workshop (Scruton and Gibson 1993) provides a detailed example of curve derivation.

DESCRIPTION OF INDIVIDUAL SUITABILITY INDICES

WATERSHED SCALE

Percent of Drainage Basin in Recent or Active Timber Harvest

Initially, the workshop looked at approaches that could be applied at the watershed level. Percentage of a drainage basin in active or recent timber harvest (Figure 1) was the only land use for which an SI curve was developed in the workshop. The effects of timber harvest and silvicultural treatments (site preparation, planting, chemical application) on salmon habitat are complex and interrelated. Timber harvest could have negative impacts on salmon habitat, although short term benefits such as increased primary production and salmon growth can sometimes occur in riverine environments where low water temperatures are limiting. The effect of timber harvest will vary in response to density of skid trails, yards, slopes, soil types and soil moisture content. Principal consequences of timber harvest within riverine environments include decreased slope stability, altered runoff patterns and intensity, increased water yield, changes in snow accumulation and depth of soil freezing in harvested areas, altered rates of sediment and nutrient delivery, increased strength and frequency of flood events, increased light, and altered temperature and dissolved oxygen (DO) levels (Chamberlain et al. 1991). Mass movements of soil and accelerated rates of runoff are likely, particularly where buffer strips are not maintained adjacent to streams. Extreme levels of sedimentation decrease diversity of aquatic habitat and can cause long-term impacts to salmon habitat. DO concentrations within riverine substrates may decrease if logging activities increase sediment and organic debris within the stream channel.

The SI for percentage of drainage basin in active or recent timber harvest (Figure 1) assumes adequate buffer strips (following Provincial guidelines) adjacent to riverine environments and the majority of impacts occurring during the 10-15 years subsequent to tree harvest. The relationships between percentage of basin harvested and salmon fry and under-yearling production are assumed to reflect impacts of all activities associated with timber harvest (e.g., road construction, site preparation). In general, the effects of timber harvest are assumed to be proportional to the amount of vegetation removed and the areal extent of the basin that is disturbed. However, no detrimental effects on salmon habitat are assumed to occur when ≤25% of a drainage basin has been harvested within 15 years.

Other land uses with high potential impact on productive capacity include: urbanization, agriculture, mining, hydroelectric development, roads, and recreational access. Productive capacity should decrease as the proportion of a drainage basin subjected to these land uses increases.

Urbanization

Increased use of herbicides, and fertilizers, higher nutrient input from wastewater and septic tanks, and increased sediment loads are all potential impacts affiliated with increased urbanization. Habitat can be lost from channelization and construction of culverts. Removing riparian vegetation and increasing road density due to greater amounts of urbanization can cause changes in stream temperature, hydrology, channel morphology, and substrate characteristics. In urban areas such as St. John's, some cultural enrichment of nutrient-poor waters has resulted in an increase in brown trout production (Gibson and Haedrich 1988).

Agriculture

Agricultural development within a drainage can potentially increase sediment and nutrient (phosphorous, nitrogen) loads and decrease instream flows.

Mining

Potential impacts affiliated with mineral extraction include increased sediment loads, destabilization of stream channels, loss of habitat from use of lakes as settling ponds, alteration of stream chemistry (pH, conductivity), and potential releases of acid wastes and toxic metals.

Hydroelectric Development

Impacts include changes in water chemistry, conversion of riverine to lacustrine environments, and alterations in the frequency and duration of daily and seasonal downstream flow regimes. Potential effects include fish passage problems due to dams, dewatering of spawning beds and rearing habitats, both low-flow and high-flow interference with spawning, changes in daily and seasonal water temperature regimes, changes in ice formation and accumulation, detrimental alteration of downstream channel morphology, and decreased productivity or diversity of invertebrates. Altered hydrological regimes which change flood timing may potentially interfere with fry emergence at swim-up stage, when the fry are vulnerable to washout due to floods and alter cues for migration. On the other hand, the increased waterflows in summer and winter from minimum flow regimes may increase survival at these times.

Roads

Construction or maintenance of roads increases erosion and sedimentation of riverine substrates. Landslides, slump earthflows, and other mass erosion events are frequently the result of road construction, but the extent is largely dependent on the nature of the underlying geology, the grade of cut slopes, and the type of road. Higher conductivities from salting of roads and introduction of herbicide or fertilizer residues from revegetation of cut and fill slopes may occur. Fish passage problems at culverts can be reduced by setting culverts below the grade, but problems caused by culverts and stream crossings differ for juveniles and adults. Even short delays could affect successful reproduction of adults.

Recreational Access

The primary concern regarding recreational access was use of streambeds during low flows by all-terrain vehicles, which (may) compact substrates and degrade riparian vegetation and bank condition.

Vegetation Type and Geomorphology

Although not a land use per se, vegetation associations and geomorphology may provide a broad-scale method to categorize productive capacity of various geographic regions within Newfoundland. For example, regions dominated by steep terrain have more dynamic, high-energy, streams than regions of lower topographic diversity. Soil type, depth and porosity, and chemical composition of bedrock affect erosional processes, availability of nutrients, and dissolved solids within different geologic regions. These physical variables influence stream channel morphology, nutrient concentrations and biological productivity.

HABITAT STATION SCALES

SUBSTRATE RATING

Substrate composition affects intra-substrate water velocity and oxygen transport, media suitable for primary production and trapping of allochthonous detritus, which affect invertebrate production, emergence of embryos, and egg and fry survival. Substrate suitability curves are depicted in Figure 2. Substrate classes are from Bain et al. (1985). The growing season curve is similar to the fry habitat quality SI presented by Scruton (1990). The winter substrate composition habitat rating is based on studies of YOY and older parr by Rimmer et al. (1984) and Cunjak (1988). The SI for a station is the area weighted arithmetic mean of the substrate SIs for point samples along transects (see also Bain et al. 1985). Individual areas represented by point samples are used to calculate the area weighted mean SI of the station. Interstitial spaces are important, especially for parr in the winter (see section on Percent Embeddedness).

MEAN STREAM WIDTH AT MINIMUM SUMMER FLOW

Small Newfoundland streams (1 to 2.5 m wide) produce more fry per unit area (Figure 3) than larger streams, because they have fewer predatory large fish, more stable discharges, slower water velocities, and greater proportions of preferred habitat conditions (substrate, depth, flow, etc.). A station is the smallest reach of stream that should be rated with this curve. The solid line portion of the curve is similar to that presented in Scruton (1990). The proposed dotted line does not go to 0 at high stream width because some fry should be able to inhabit the margins of large streams. Competitive interactions are also influenced by stream size.

PERCENT OVERHANGING COVER AT MINIMUM SUMMER FLOW

Overhanging cover includes material such as living and dead vegetation, boulder/bedrock, downfall, large woody debris, and undercut banks that are ≤1 m above the water surface at minimum summer flow. Optimum conditions for Atlantic salmon fry are assumed to exist when ≤30% of the station is dominated by overhanging cover at minimum summer flow (Figure 4). Of course, optimum conditions for cover are not static but depend on temperature and degree of shading. Habitat suitability is believed to decrease as a greater proportion of a station is dominated by overhanging cover. Negative relationships between overhanging cover and habitat quality may be related to decreased primary production as shading reduces sunlight and water temperatures, resulting in habitat that is more suitable for trout than salmon. The winter suitability curve was suggested after the workshop by a reviewer and is based on readings taken at a similar discharge as the summer curve. High percentages of overhanging cover may provide optimum winter habitat by reducing radiant heat loss and ice formation. Conversely, more cover causing less ice formation may not result in optimum winter habitat; depending on temperature regime and stream gradient, too much cover may produce unstable ice conditions.

Multiple techniques to determine percent overhanging cover have not been evaluated in Newfoundland. The current method (Gibson 1990) relies on a visual estimate and is user-friendly, but subjective. The SI for a station could be determined directly from the graph based on a single visual estimate of mean percent cover for the station at a water surface elevation similar to minimum summer flow. It could also be determined as the area weighted mean of the SIs for point estimates of percent overhanging cover in a station. For any value of percent overhanging cover, adding SIs from the two graphs in Figure 4 will always result in approximately the same sum (1.1 to 1.15). Since only the summer rating was developed at the workshop, there was no discussion on how to use the winter and summer ratings in combination.

PERCENT EMBEDDEDNESS

Interstitial spaces in substrates provide cover for salmon fry in the growing season and in the winter, and can be the primary source of cover in smaller streams. Carrying capacity is reduced both in the growing season and winter as increased embeddedness reduces interstitial spaces. Greater embeddedness can lower production of invertebrate forage for yearlings and reduce intra-gravel flow, oxygen transfer, survival of embryos, and percent of emergence from incubation substrates. Successful emergence of fry decreases at higher levels of embeddedness. Workshop participants emphasized that the relationship between percent embeddedness and fry emergence presented in Figure 5 is very qualitative due to the lack of data and problems with measuring embeddedness in the field. Visual estimates are subjective and other methods (such as cryogenic coring) are costly and labor-intensive and are not likely to be used.

MAXIMUM FLOOD HEIGHT ABOVE BASE FLOW

Maximum flood height above base flow within the last year (Figure 6) is the vertical height above base flow water surface elevation of debris or ice scars on features adjacent to the channel. Extensive alteration in distribution and quality of spawning and incubation habitat occurs in response to scour and flooding associated with high flood heights. Large rivers with high flood heights are more prone to mechanical erosion of channel banks and substrate than smaller, more stable, lower-order streams. The resulting higher rates of siltation and bed load movement, decreased bedform roughness, and lower diversity of in-channel habitats would decrease production and survival of fry and lead to lower fry densities. In addition, invertebrate production is less in 'flashy' rivers than in more stable rivers. Small streams exhibiting maximum flood heights of <100 cm are rated as suboptimum because habitat diversity is lower without the seasonal flushing associated with flood heights exceeding 100 cm.

The effects of ice scour and extremes in discharge are probably more severe within high-gradient, V-shaped channels than within low-gradient, higher order streams with wide flood plains. The relationships presented in Figure 6 may have to be modified to reflect stream order, basin shape, gradient, runoff, or other geomorphological stream characteristics. As defined at the workshop, the maximum flood height value from the previous year determines the SI. It may be appropriate to modify the definition to include data from more than one year; in practice, it may be difficult to distinguish the previous year's ice scar from "older" marks.

MEAN VELOCITY

Optimum mean water velocity (in the summer) for Atlantic salmon fry is between 0.2 to 0.6 m/s (Figure 7). Density of fry is believed minimal where mean velocity at a station is ≤0.1 m/s or ≥0.85 m/s. Cunjak (1988) measured mean water velocities between 0.53 and 1.1 m/sec at winter-time fry locations in Nova Scotia while Rimmer et al. (1984) found maximum water velocities within 1 m of fry in autumn and early winter to be < 0.6 m/s. We recognize that selection of water velocity is dynamic and can be very different depending on season or time of day. Using DFO sampling methods, a single mean velocity for a sample station would be calculated as the arithmetic mean of evenly-spaced mean column velocity measurements collected along three or more transects evenly-spaced within a station. Measurements should be taken at a discharge equal to average summer flow. The SI of the mean velocity for the station would be the SI for the station.

MEAN DEPTH

Mean depth (Figure 8) for a station is calculated as the arithmetic mean of depth measurements collected at the same locations as the velocity measurements described above. It may also be calculated as the water volume of the station divided by the water surface area of the station. Measurements are taken at a discharge equal to the average summer flow.

MEAN DEPTH VERSUS MEAN VELOCITY

Mean depth and mean velocity are highly interrelated in defining habitat quality for Atlantic salmon. An alternative to assessing habitat quality as a function of individual mean depth and mean velocity SIs is to plot suitability "isopleths", as presented in Figure 9. The correct spatial scale for applying the curve was not defined at the workshop. The POST-WORKSHOP sections provided additional ideas.

MINIMUM PH DURING POST-EMERGENCE

Riverine pH can be affected by agricultural runoff of fertilizers and pesticides, chemical spills, salt inputs at road crossings, acid rain, and sewer overflow, and is highly correlated to seasonal variability in discharge (e.g. Scruton 1986). Figure 10 is based on unpublished fry survival data for 72-hour laboratory experiments. Mortality of all fry in highly acidic waters (pH ≤4) is assumed. Maximum survival of fry occurs where minimum pH is never lower than 6 for 72 consecutive hours. Exactly how this variable was to be estimated within the constraints of the model objectives was not determined at the workshop. Short duration events are not considered in SI calculations due to difficulties in obtaining critical data. The POST-WORKSHOP sections contain additional comments and discussion.

NITRATE RATING

Nitrate concentration was considered a surrogate measure of potential invertebrate production for assessing productivity of riverine systems. Nutrient availability may limit invertebrate production in Newfoundland rivers and is as an important component of regional habitat models (Talbot and Gibson 1990). Both nitrate concentration and total hardness were believed to be potential indicators of productivity, but no direct relationships (e.g., X ppm total hardness yields Y productivity of invertebrates) were proposed.

Low invertebrate production may limit productive capacity of Atlantic salmon habitat in Newfoundland. Invertebrate availability is difficult to assess since potential prey items must be within a specific size-class to be eaten by fry. Direct measurement of invertebrate production is too complex and costly to meet model objectives. However, indicators of invertebrate biomass are more easy to collect and may be more useful in future model development (Orr et al. 1990)

Binns and Eiserman's (1979) ratings for nitrate concentrations in Wyoming streams are the starting point for relating nitrate levels to productive capacity (Figure 11). Most workshop participants believed that to an optimum level, productivity of invertebrates (and salmon) could be expected to increase with higher nitrate concentrations. Although the Wyoming streams (and fish species) evaluated by Binns and Eiserman are obviously different than the situation in Newfoundland, there is enough similarity in water quality to make the Wyoming rating system feasible. Figure 11 does not describe a true upper limit for nitrate levels in relation to the potential effects of excessive nitrogen loading on Atlantic salmon habitat quality. The potential accumulation of excessive amounts of nitrate and its effects on productivity and salmon may be greater within lacustrine than within riverine environments. Eutrophication and deoxygenation in the summer and beneath ice in winter may be a consideration with increasing levels of nitrates.

Nitrate ratings from a single sample of water collected at a station could be used to calculate an SI for a station. If nitrate levels vary by flow and season, the discharge weighted mean nitrate concentration for the year would be used to calculate a single SI for the area of stream that is upstream of the sample point (and downstream of the next upstream sampling point). This approach in calculating an SI could be used for any scale of measurement (e.g., station, habitat type, watershed) or sampling intensity, at the discretion of the investigator.

TOTAL HARDNESS

Although little specific data are available for Newfoundland streams, total hardness is believed to provide an indication of potential productivity based on studies of lacustrine environments (Scruton 1983). Summer measures of ≥200 ppm are assumed to reflect maximum production of Atlantic salmon fry (Figure 12). Calculation of an SI for total hardness should follow the same steps as those recommended for determination of an SI for nitrate.

MINIMUM DAILY FLOW

Minimum stream flows can occur during the growing season or winter. Although minimum flows in summer (July-August or September) are typically evaluated, minimum flows in winter (November-April) may be more limiting in relation to production of Atlantic salmon in Newfoundland. Excessively low winter flows may result in limited availability of, and accessibility to, suitable winter habitats, increased frequency of anchor ice, scouring of substrates by ice, and freezing of redds. These conditions all potentially result in higher winter mortality and lower production. Inadequate growing-season flows can limit fish movements, increase water temperatures, and reduce availability of spawning and rearing habitat.

A proposed relationship between minimum daily flow and maximum fry survival is presented in Figure 13. Minimum daily flow is expressed as a percentage of the daily mean annual discharge (mean annual discharge/365). A single value for this variable for a station would be calculated from flow data for the station. In both seasons, flows below optimum levels are assumed to decrease fry survival. Flow data may be readily available (Environment Canada hydrometric stations), may be extrapolated from hydrometric data, or a sampling scheme may need to be implemented.

TEMPERATURE

Water temperature during incubation affects the rate of embryo and alevin development, dissolved oxygen capacity, and growth and survival of under-yearlings. Upper temperature for fry and parr growth is approximately 25 °C (Figures 14a and 14b). Water temperature varies spatially, daily, seasonally, and annually. Higher temperatures, within the critical threshold, provide conditions suitable for faster rates of development and a shorter incubation period. Growth rates are expected to decrease at the extremes of the suitable range because most nutritional resources are used for maintenance at high (and low) temperatures. Suitability indices for a habitat type would be calculated from temperatures measured near the middle of the water column at the downstream end of the habitat type. Temperature measurements should be collected over a minimum of three contiguous days. Methods for using the curve with multiple temperature measurements (i.e., for continuous recorded data) were not described at the workshop.

Figures 14c and 14d illustrate assumed relationships between maximum water temperature (sustained for ≥ 3 days) and cumulative degree days to percent of maximum survival and percent of maximum growth rate of fry, respectively. Several references suggested at the workshop (Elliott 1991; Wright et al. 1991) for providing data to assist in SI construction did not provide specific documentation for Figures 14c and 14d as hoped. Percent survival might fall to zero when maximum temperatures are less than 27.5 °C (Figure 14c).

HABITAT TYPE

In an attempt to incorporate interrelationships between physical variables that influence productive capacity in riverine environments, and to help develop models that were applicable at large spatial scales, workshop participants assigned SIs to stream habitat types (Figure 15). The habitat types use classification criteria defined by Allen (1951) and presented in Gibson (1990). Habitat types are delineated prior to placement of sampling stations, and a sampling station should be located entirely within a habitat type. Habitat type esentially integrates a number of microhabitat variables (eg. depth, velocity, substrate, etc.) into one classification.

OTHER VARIABLES OF SPECIAL CONCERN

Several additional variables were identified during the workshop that could limit the productive capacity of Atlantic salmon habitat in Newfoundland. Insufficient data on the effects of these variables on growth, survival, or standing stock prevented workshop participants from developing specific curves or evaluation criteria. Participants recommended identifying the variables as topics of "Special Concern" to consider in habitat assessment and future research projects.

ICE

The effects of ice are one of the least understood aspects of riverine environments. However, increased amounts and duration of frazil and anchor ice are expected to increase winter mortality of salmon and decrease potential habitat productivity. Projects that increase water turbulence (tailwaters) and reduce riparian canopy may exacerbate the effects of ice formation on habitat quality for Atlantic salmon.

Extensive amounts of ice may restrict winter stream flow and intensify severity of instream scour and bank erosion. Supercooling of substrates contributes to formation of frazil and anchor ice particularly in riffles and runs. Because wide, open-canopied, shallow, rocky streams supercool more quickly, they have greater susceptibility to formation of anchor ice than do deep, canopied, narrow rivers. Movement of anchor ice scours riverine channels, causing extensive redistribution of substrate materials and destruction of redds. Within small streams, extensive conversion of water to ice may influence the amount and distribution of available habitat by reducing in-channel flow and accessibility to suitable habitats. Detrimental effects can include lowering of intra-gravel water temperatures, freezing or mechanical destruction of eggs and alevins, and dewatering of redds. Ice jams can divert flow into side channels, scour substrates, erode banks, and degrade wintering areas.

BIOCHEMICAL OXYGEN DEMAND (BOD)

The primary effect of excessive BOD is low dissolved oxygen concentration. Within riverine environments, BOD may be of concern in slow, low-gradient streams where aeration is low or in sites where excessive amounts of organic debris increase oxygen demand. During winter, deoxygenation is a possibility where surface aeration is precluded under ice cover. BOD is assumed not to be a limiting characteristic of riverine environments within Newfoundland. However, BOD may be a limiting factor within lacustrine environments, especially within urban areas, around processing mills, and where historical waterborne transportation of logs has deposited woody debris. BOD should be included as a variable for evaluation of salmon habitat within lacustrine environments and only as a special consideration in riverine environments. Evaluation of BOD in lacustrine environments would require curves for maximum and mean BOD over a specified time period.

DISTANCE TO POTENTIAL SPAWNING SITES

Workshop participants considered using distance to upstream spawning sites to help determine the value of an evaluation site as fry habitat. Areas with high potential as fry habitat may not be used due to the absence of suitable spawning sites within reasonable emigration distances for fry. The distance between suitable rearing areas and spawning locations would be short for fry, and primarily in a downstream direction, and longer for older parr. However, the group decided to rate fry habitat quality without considering the distance to spawning sites since all upstream spawning sites may not be known, and adequately determining their location would require more effort at off-site reconnaissance than the model users were willing to expend. Known obstructions to adult passage (e.g., impassable waterfalls, beaver dams) should be considered during the evaluation process.

POST-WORKSHOP PARTICIPANT COMMENTS

This section summarizes predominately new and cautionary information provided by participants after completion of the workshop. Comments involving corrections or clarifications to draft text describing the material generated at the workshop have been incorporated into the preceding sections of this document.

DEVELOPMENT OF MATRICES OF POTENTIAL HABITAT VARIABLES

At the end of the workshop, participants developed a matrix of habitat variables likely to be useful for rating habitat quality for various life stages and habitats (Table 2). As a post-workshop exercise, participants were asked to determine (1) which variables are applicable for assessment of habitat for other life stages; (2) how to modify fry curves to assess parr, smolt, or adult habitat; (3) if additional variables are necessary for evaluating habitat for other life stages; and (4) which variables (those listed or additional) are necessary for assessing productive capacity of Atlantic salmon habitat in lacustrine and estuarine environments. Responses to this request are presented in Tables A-1 through A-16, Appendix A.

DEVELOPMENT OF A PRODUCTIVE CAPACITY MODEL

Each SI developed at the workshop (Figures 1 to 15) is a variable model of a measure of productive capacity such as survival, density, or standing stock. The "tightness" of the SIs is likely to vary by variable and across the range of values for an individual habitat variable. For the workshop-developed SIs, the frequency of occurrence of individual data points should be greater inside the curves than outside the curves; however no specific frequencies were proposed. Participants recognized that SIs could be developed from data as suggested by Rice (1990). Some participants recommended that individual SIs derived from the curves should be aggregated into a predictive model by using them as independent variables in a regression analysis as in Binns and Eiserman (1979). Others cautioned that a regression based on SIs was unrealistic and would likely violate the assumption that model variables are independent. The facilitators emphasized that aggregation techniques should consider the units of measure and the spatial scale (e.g., biomass/unit area; survival rates) incorporated in the SIs.

After the workshop, participants were asked to estimate productive capacity for the three different combinations of habitat variable ratings displayed in Appendix B and provide a set of rules (or equations) for aggregating individual SIs. Only a few participants completed this activity. No consensus was reached on how to combine individual variable SIs into a single estimate of productive capacity. Participants emphasized the desirability of using an extensive set of real data in the process and were generally uncomfortable with trying to develop rules without independent data. Comments from participants who developed an HSI from individual SIs, using the provided matrices, are included in Appendix B. Subsequently, at the request of the meeting chairman, the facilitators developed an HSI model after the workshop adjourned (see POST-WORKSHOP FACILITATOR COMMENTS).

COMMENTS ON THE WORKSHOP-GENERATED SUITABILITY INDEX GRAPHS

Overhanging Cover at Minimum Summer Flow (Figure 4)

At minimum summer flow, light intensity could be a more objective method to quantify the effect of overhanging cover. Light intensity can be easily measured with a three-inch white disk described in Platts et al. 1987. Although this method has not been used in Newfoundland, it has been used in other parts of Canada, particularly British Columbia.

Embeddedness (Figure 5)

Chalk-streams with 100% embeddedness in the northern part of France produce sterile habitats that are not used by either adults or emergent fry (Fournel et al. 1987) and would have an SI of 0.0. Low embeddedness, which is found in many Newfoundland streams, would have an SI approaching 1.0.

Maximum Flood Height (Figure 6)

The absolute scale on the x-axis may not be relevant to all streams and another measure (e.g., percent maximum flow as a function of mean base flow) may be more generally appropriate. The necessity and benefit of flushing will depend on algal growth and sediment load. In situations where algal growth or sedimentation is not a problem, flashiness may be a negative influence. In Norway, regulated rivers often include a peak flow "pulse" which, along with temperature, is used as the stimulus to cause adult salmon to migrate upstream and smolts to migrate downstream.

Mean Velocity (Figure 7)

It is important to consider the dynamic element of habitat selection with respect to mean velocity. Velocity selection may vary by season and from day to night. Recent observations on Newfoundland rivers suggest very different habitat selection at night.

Mean Depth (Figure 8)

The curve presented may be biased on the basis of the types of stream from which they were developed (i.e., based on small or wide, shallow streams). In Norway, parr are tolerant of the greater depths, and deeper water has a higher suitability than is shown in Figure 8.

Mean Depth vs. Mean Velocity (Figure 9)

Combining depth and velocity into an "isopleth" plot avoids the complications caused by the correlation between the two variables. Zones of SI ratings are provided in Figure 16. The current DFO sampling method uses evenly-spaced velocity measurements along transects. To use Figure 9, depth would be measured at the same points that velocity is measured and the combined suitability of a sampled point is determined from Figure 9. The suitability of an evaluation site would be the area weighted mean SI of the areas represented by the points.

Minimum pH During Emergence (Figure 10)

Expected frequency of specific events should be included in an SI for pH. This would require data on rainfall pH, snow meltwater pH, stream alkalinity at base flow, and rainfall frequency - volume probabilities. An alternative would be to use pH data for a nearby stream with similar water quality to assess the probability that a low pH event would occur. Qualitative levels (e.g., never, seldom, often) of occurrence were used to determine the SI in Figure 17 (adapted from Trial and Stanley 1984). Smolts exposed to pH below 6.0 suffer high mortality when they enter saltwater.

Nitrate Rating (Figure 11) and Total Hardness (Figure 12)

Using these variables as a surrogate for food availability should be a useful indicator of productive capacity (carrying capacity). Alkalinity could also be used in a similar manner. Alkalinity and hardness are highly correlated in many regions of Newfoundland. Huntsman (1948) noted differences in productivity related to farming in the watershed.

Using a surrogate for food does not address if the limiting factor for salmon production is food or territory. Juvenile salmon are territorial; this is especially well documented for parr.

Ranking streams with identical physical habitat and temperature regimes could be based on the selected productivity surrogate and other water quality factors. Likewise, rating streams of equal productivity could be based on physical habitat, other water quality factors, and temperature regime. However, when productivity, physical habitat, and temperature regime all differ, how do you rate the streams? It might be possible that several areas could produce the same number of smolts annually, but some would produce the smolts in a short period (1 year) and others in a longer period (2-4 years). Habitat quality is related to temperature regime as well as food availability. Generally, streams with younger smolts are more productive and produce more smolts than rivers with older smolts (Egglishaw 1967).

Nitrate concentration and total hardness are not the only parameters related to invertebrate productivity; water temperature is also an important factor; this is especially true in Norway. It would be interesting to get a single value of the biotic index for a station or reach.

Minimum Daily Flow (Figure 13)

The relationship between minimum daily flow as a function of mean annual flow will be entirely dependent on stream size. It is likely to be irrelevant in larger stream, or may even be a positive relationship, as was found in a large Norwegian stream (> 100 $m^{-3}s^{-1}$).

Temperature Variables (Figures 14a - 14c)

The review by Bley (1987) may be useful in refining the temperature curve related to growth (Figures 14a and 14b). He reviews several papers that relate growth to temperature. Hatchery records or data from the St Andrew's Biological Lab could also be used.

Users may want to revise Figure 14c as Elliott (1991) did not find any differences in upper lethal temperature for fry (YOY) and parr. Temperature curves V1 and V2 in Trial and Stanley (1984) may also be useful in evaluating habitat quality. An example of how the probability that temperature will exceed a given maxima for extended periods can be incorporated in an SI is provided (Figure 18).

An alternative to the thermal sum growth model in Figure 14d is to calculate increase in lengths or weights using Figures 19 and 20. The growth curve in Figure 19 relates cumulative degree-days from the mean date of emergence with fork length of 0+ salmon. The data were collected during the growing season in a Brittany brook, and should be published soon. Simulated temperature-growth relationships in Figure 20 were developed from the work of Brett et al. (1969) and other sources.

Habitat Types (Figure 15)

The habitat types defined by Gibson et al. (1987) use water depth, current velocity, and substrate size; these habitat types can be used in model-building approaches.

COMMENTS ON VARIABLES OF SPECIAL CONCERN

Ice

This variable also relates to an event. It may be possible to rate suitability based on the most likely condition for the section (station)--frazil ice, anchor ice, or ice cover--under "normal" winter conditions or the probability that a given ice condition will exist. Again, qualitative evaluations of the chance that an event will occur would be input into the SI curve.

BOD

A suitability curve for biochemical oxygen demand (BOD) (Figure 21) was based on percent BOD versus fry density. Although there are no data for the curve beyond 60% BOD, the SI value for 70% BOD is undoubtedly zero.

Others

The SI curves do not take into account intra- and interspecific competition for space and food. These parameters could influence juvenile production in concert with climatic conditions (e.g., overwinter survival), stream order (e.g., presence of brook trout in Newfoundland tributaries), and density-dependent use of sub-optimal habitats (e.g., pools and lakes).

OTHER COMMENTS AND INFORMATION

Adult

Moreau and Moring (1993) report the results of testing a model of adult habitat. They found temperature, maximum depth, percent of instream cover, and proximity of spawning habitat to be important in discriminating pools that hold fish.

Parr

Trial (1989) found that depth, velocity, and substrate were not adequate to predict average parr densities (10 years of data). A parr model may need to include some aspect of cover. Parr territory size may be related to their ability to see competitors. On rough substrate fish may be more closely "packed" then in open substrate, because the larger rocks block a fish's lateral field of view. Vegetation may also serve the same purpose. The parr model needs to include additional variable(s) that characterize the effect of instream cover on density. Figure 22 attempts to characterize this effect, based on personal observations.

Smolt migration

A smolt model should relate habitat characteristics to survival for the riverine portion of the migration. A potential variable is the proportion of impoundments and deep deadwaters in the main stem of a river (Figure 23). The graph assumes that increased amounts of impounded, or slow deeper water, reduces smolt migration speed and increases predation rates. In areas outside of Newfoundland, impounded areas may have higher densities of predators than fast water. For example, Barr (1962) discussed pickerel predation on outmigrating smolts. This topic is also reviewed by Bley (1987).

Passage through or around hydroelectric turbines is a site-specific factor in downstream survival that could be assessed using height of dam, turbine type, or other characteristics of the hydro facility.

GENERAL CONCERNS ABOUT HSI MODELS

During and after the workshop, various participants expressed a variety of concerns with developing habitat models. A frequently-discussed problem was the request to aggregate individual SI curves into an HSI model. Many participants felt that it was difficult or impossible to aggregate the curves in a method that made biological or logical sense, and that avoided potential mathematical or ecological problems. Aggregation should be approached with caution, especially if a good empirical or theoretical reason is absent. It is easy to manipulate aggregation procedures to get the result you want, and this should be avoided.

Participants also expressed concerns with the overall modeling approach used at the workshop. Problems included: the model's static nature whereas streams are dynamic; the high probability of a lack of transferability (as detailed by other studies); the assumed independence among habitat variables; the temporal nature of interaction among individual SIs; the inability to step from habitat simulations and habitat quality assessments to model-based fish production estimates; the lack of consideration of biotic factors.

POST-WORKSHOP FACILITATOR COMMENTS

Development of adequate models using suitability indices (SIs) as independent variables in regression equations will require a range of values for the independent variables that is similar to the ranges over which the equations will be applied. Until realistic statistical models can be derived from independent data sets, any aggregation of SIs into HSI model may be, at best, only marginally acceptable to many participants. Efficient use of new information, including unpublished data and opinions, will be necessary if there is to be any acceptance of recommendations based on habitat model use. Acceptance of any HSI formulae will require some successful applications to environmental planning and assessment activities. The main purpose of a planning model is timely, effective use of the body of knowledge on Atlantic salmon. It is important not to lose sight of that purpose by overemphasizing the need for a single model or unanimous opinions.

Rather than a standard formula, we suggest a standard approach to using SIs. The biologists responsible for an assessment should determine SIs (present and future values) for as many individual variables listed in these proceedings as is practical and necessary. SI curves could be modified as new data or model testing becomes available. Additional variables, regression models, and other habitat modelling approaches would be applied as available. As a minimum, each biologist would then describe their preference on how to use SI values to determine a single HSI. The more familiar a biologist is with the system, the more accurate their assessment should be. Predictions based on assessment approaches that do not use the material in this document could be compared to assessments based on the approach outlined in this document. Taking advantage of available knowledge and experience and having a defensible impact assessment is more important than agreeing on a single model. After doing some real assessments, it may be possible to concentrate on the models or methods that have proven to be most useful. An academic version of asking biologists to develop their own approach was part of the post-workshop effort. Participants (reviewers) were asked to develop HSIs for the data in Appendix B and document their approach. The modeling approaches were highly variable; the dominant feeling seemed to be that the exercise was futile, given the limits of knowledge on the species. The diversity of approaches is likely to increase when carrying capacity is modeled in a real system.

At the request of the meeting chairman, after the workshop one of the facilitators (JWT) developed two HSI models describing how to use the SIs developed at the workshop (Figures 1-15) to rate habitat. The two models are one biologist's opinion on how to use the different response measures, SIs, and scales of application described at the workshop in a logical manner. There is no attempt to model underlying mechanisms or use a cause and effect approach and no implication that other participants agree with the approach. It is offered as a catalyst for future discussion. The pimary purpose of developing these "prototype" models was to begin the process of testing, evaluation, modification, and validation of this type of modelling approach to determine its' potential value as a tool for habitat/environmental assessment.

The variable-labeling convention used in the following models corresponds to Figure numbers (eg., V5 = suitability index derived from Figure 5).

HSI MODEL FOR RATING A WATERSHED

The HSI model for rating large drainage basins is limited to one variable: V1, based on percent timber harvest, defined on a watershed scale. It would not be used in conjunction with the other model variables to rate smaller (station, habitat type) areas of habitat because it is assumed that the more intensive, smaller spatial scale data would provide a better characterization of a station or habitat type (i.e., the station model would replace, not modify the simple one-variable watershed model). An alternative approach to rate a watershed would be to apply a sampling design whereby ratings from the model for rating a station could be extrapolated to a watershed rating.

HSI MODEL FOR RATING A STATION

According to the workshop documentation, a station (electrofishing or habitat mapping station) is normally 200-500 m^2 and must consist of one habitat type. The model is described based on this assumption of one habitat type per station. The habitat types listed in Figure 15 will occur in patches that are smaller than 200 m^2, so following the size boundaries for a station may result in sampling heterogeneous areas that contain more than one habitat type. If this occurs, a separate HSI is calculated for each habitat type using the same approach described for a station. The station HSI would then be the area weighted mean of the HSIs calculated for each habitat type in the station.

Variables listed in Table 1 for measurement at the scale of a habitat type are related to water quality and station variables to physical habitat. Anyone sampling a station would have the option of either using the appropriate "habitat type" water quality data for the station or collecting separate water quality data for each habitat type within a station. There may be little variability in water quality parameters in contiguous stations and a single sample for a reach of stream may be sufficient. The model is meaningless unless all measurements are taken in available habitat. The basic model structure for a station HSI has four components:

Station HSI = **Density Component** (maximum number of fry/unit (100 m^2) supported by physical habitat) x **Survival Component** (proportion of fry that survive) x **Growth Component** (maximum weight of an individual fry) x **Productivity Component** (adjustment for basic productivity)

= weight of fry/unit that could be supported by the station.

The units of measure for the model components are as follows:
(Fry/unit) x (unitless proportion) x (g/fry) x (unitless proportion) = (g/unit)

Most workshop curves describe the units of measure (such as survival), but not the magnitude of the y-axis scale. The model will not estimate a specific g/ha value unless y-axis scales for all of the curves are specified. Using available curves, the model yields an estimated proportion of an undefined maximum g/ha of fry that could be found at a station at the end of the growing season. This is not a production estimate as weight gains of fry that do not survive the time period are not included. The actual maximum weight of an individual fry is undefined, and would be constrained by the daily growth rates listed for Figures 14a and 14b. Fry habitat is rated for growing season by estimating fry present at the end of the growing season. A winter season estimate could be developed with a similar approach. Variables contained in each model component and the reasons for the inclusion are described below.

Density Component

$$\text{number of fry/ha} = \{[V15 \text{ or } V9 \text{ or } (V7+V8)/2] + V2 + V3\}/3 \times V4 \times V6$$

The variables V15 and V9 both estimate fry density based on velocity and depth combined; the mean of V7 and V8 is another estimate of density based on velocity and depth combined. Each of the three estimates describe habitat selection, using essentially the same data. The best of the three approaches should be selected. The reviewer-developed relationship (V16) could replace all of these variables.

Fish use substrate (V2) in a variety of ways. Substrate can be cover, shelter from velocity, and a production site for food organisms. Substrate influences fry density in a different manner than velocity and depth. Stream width (V3) also represents a variety of processes. The above equation averages three estimates of fry density (one related to depth and velocity, one to substrate, one to width) based on the effects of instream habitat; this approach gives each estimate of fry density "equal" weight in developing a combined estimate of fry density.

Suboptimum values of variable V4 are an "out of stream" reducer of densities supported by instream habitat. Variable V6 represents an event that can also result in density reductions. The density component is sensitive to suboptimum values of these variables, but optimum values cannot increase fry/ha above the estimate based on instream habitat.

Survival Component

$$\text{Proportion of maximum number surviving} = (V5 \times V10 \times \mathrm{V13} \times \mathrm{V14c})$$

Suitability indices for variables in this component show survival rates as the response variable, starting with survival to emergence in relation to substrate embeddedness (V5). Survival rates are assumed to be independent and cumulative. This component could easily be changed if more detailed interactions are known.

Growth Component

$$\%\ \text{maximum weight of individual fry} = V14d$$

Variables 14a and 14b are not used in this model, even though there are curves available. Since "cumulative degree days" are usually estimated with a few temperature readings, and not with a continuous temperature record, V14d is assumed to incorporate the relationships depicted in V14a and V14b. Variables 14a and 14b depict relationships that have been determined experimentally. If detailed, continuous temperature data were available, V14a and V14b could be used to estimate growth (and ultimately individual weight of fry) instead of V14d. The growth component is based on the assumption that percent maximum growth rate is directly proportional to percent maximum weight.

Productivity Component

Productivity adjustment factor = (V12 if available, else V11)

Both variables are related to the basic productivity of the stream. The nitrate variable is used as a standing crop estimator because the original authors estimated standing crop. However, both variables are viewed as independent estimates of upper limits to production and standing crop imposed by the chemical composition of the water. Since V11 is based on salmonids in Wyoming, V11 should not be used unless total hardness data (V12) are unavailable. Variables V11 and V12 may be more synergystic than independent and the two could be used in combination.

LITERATURE CITED

Allen, K.R. 1951. The Horokiwi stream. A study of a trout population. Wellington, New Zealand. Fisheries Bulletin 10:1-231.

Bain, M.B., J.T. Finn, and H.E. Booke. 1985. Quantifying stream substrate for habitat analysis studies. North American Journal of Fisheries Management 5:499-506.

Beak Consultants Limited. 1979. Fisheries Investigations for the Upper Salmon Hydroelectric Development. Newfoundland and Labrador Hydro, St. John's, NF. x + XX p.

Barr, L.M. 1962. A life history of the chain pickerel, *Esox niger* Le Sueur, in Beddington Lake, Maine. University of Maine, Orono. M.S. thesis. 88 pp.

Binns, N.A., and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108(3):215-228.

Bley, P.W. 1987. Age, growth, and mortality of juvenile Atlantic salmon in streams: a review. U.S. Fish and Wildlife Service Biological Report 87(4). 25 pp.

Brett, J.R., J.E. Shelbourn and C.T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration site. Journal of the Fisheries Research Board of Canada 26:2363-2384.

Caswell, H. 1976. The validation problem. Pages 313-325 *in* B.C. Patton, editor. Systems analysis and simulation in ecology. Academic Press, New York, N.Y. 593 pp.

Chamberlin, T.W., R.D. Harr, and F.H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. Pages 181-206 *in* W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, Md. 751 pp.

Cunjak, R.A. 1988. Behaviour and microhabitat of young Atlantic Salmon (*Salmo salar*) during winter. Canadian Journal of Fisheries and Aquatic Sciences 45:2156-2160.

Department of Fisheries and Oceans. 1990. Collected papers on fish habitat with emphasis on salmonids. Anadromous, Catadromous, and Freshwater Fishes Subcommittee of CAFSAC. Department of Fisheries and Oceans. Dartmouth, Nova Scotia, Canada. 423 pp.

Doyle, M., and D. Straus. 1976. How to make meetings work. Jove Books, Berkeley Publishing Group. 200 Madison Avenue, New York, N.Y. 301 pp.

Egglishaw, H.J. 1967. The food, growth, and population structure of salmon and trout in two streams in the Scottish Highlands. Freshw. Salm. Fish. Res. 38: 1-32.

Elliott, J.M. 1991. Tolerance and resistance to thermal stress in juvenile Atlantic salmon, *Salmo salar*. Freshwater Biology 25:61-70.

Fournel, F., G. Euzenat, and J.L. Fagard. 1987. Rivières à truite de mer et à saumons de Haute-Normandie. Réalités et perspectives. Le cas de la Bresle. In "Restauration des rivières à saumons". M. Thibault et R. Billard, editors, INRA, Paris, 315-325.

Gibson, R.J. 1990. Quantification of productive capacity of stream habitat for Atlantic salmon. Pages 115-140 *in* Collected papers on fish habitat with emphasis on Salmonids. Anadromous, Catadromous and Freshwater Fishes Subcommittee of CAFSAC. Department of Fisheries and Oceans. Dartmouth, Nova Scotia, Canada. 423 pp.

Gibson, R.J., and R.L. Haedrich. 1988. The exceptional growth of juvenile Atlantic salmon (*Salmo salar*) in the city waters of St. John's, Newfoundland, Canada. Polish Archives of Hydrobiology 35:385-407.

Gibson, R.J., T.R. Porter, and K.G. Hillier. 1987. Juvenile salmonid production in the Highlands River, St. George's Bay, Newfoundland. Canadian Technical Report of Fisheries and Aquatic Sciences 1538, v + 109 pp.

Huntsman, A.G. 1948. Fertility and fertilization of streams. Journal of the Fisheries Research Board of Canada 7(5):248-253.

Moreau, D.H. and J.R. Moring. 1993. Refinement and testing of the habitat suitability index model for Atlantic salmon. Final report to the U. S. Fish and Wildlife Service Silvio O. Conte Anadromous Fish Research Center. Cooperative Agreement 14-16-0009-1557, Work Order 22 with the Maine Cooperative Fish and Wildlife Research Unit, 5451 Murray Hall, Orono, Maine, 04469-5751.

Platts, W.S, and 12 coauthors. 1987. Methods for evaluating riparian habitats with applications to management. General Technical Report INT-221. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Ogden, Utah. 177 pp.

Rice, J.C. 1990. Contribution to the problem of quantifying productive capacity of fish habitat. Pages 255-280 *in* Collected papers on fish habitat with emphasis on salmonids. Anadromous, Catadromous, and Freshwater Fishes Subcommittee of CAFSAC. Department of Fisheries and Oceans. Dartmouth, Nova Scotia, Canada. 423 pp.

Rimmer, D.M., U. Pain, and R.L. Sanders. 1984. Changes in the selection of microhabitat by juvenile Atlantic salmon (*Salmo salar*) at the summer-autumn transition in a small river. Canadian Journal of Fisheries and Aquatic Sciences 41:469-475.

Scruton, D.A. 1983. A survey of headwater lakes in insular Newfoundland, with special reference to acidification. Can. Tech. Rep. Fish. Aquat. Sci. 1195: v + 110 pp.

Scruton, D.A. 1986. Spatial and temporal variability in the water cheemistry of Atlantic salmon (*Salmo salar*) rivers in insular Newfoundland: Can. Tech. Rep. Fish. Aquat. Sci. No. : x + XX p.

Scruton, D.A. 1990. Habitat suitability curves for Atlantic salmon (*Salmo salar L.*) in insular Newfoundland and the potential applicability of suitability indices to habitat management. Pages 185-209 *in* Collected papers on fish habitat with emphasis on salmonids. Anadromous, Catadromous, and Freshwater Fishes Subcommittee of CAFSAC. Department of Fisheries and Oceans. Dartmouth, Nova Scotia, Canada. 423 pp.

Scruton, DA and R.J. Gibson. 1993. The development of habitat suitability curves for juvenile Atlantic salmon (*Salmo salar*) in riverine habitat in insular Newfoundland, Canada. Pages 149-161 *in* Production of juvenile Atlantic salmon, *Salmo salar* in natural waters. Canadian Special Publication of Fisheries and Aquatic Sciences 118: 262 pp.

Talbot, A.J. and R.J. Gibson. 1990. Habitat utilization by juvenile Atlantic salmon in Newfoundland Rivers. Pages 163-182 *in* Collected papers on fish habitat with emphasis on salmonids. Anadromous, Catadromous, and Freshwater Fishes Subcommittee of CAFSAC. Department of Fisheries and Oceans. Dartmouth, Nova Scotia, Canada. 423 pp.

Trial, J.G. 1989. Testing habitat models for blacknose dace and Atlantic salmon. Doctoral Dissertation. University of Maine, Orono. 129 pp.

Trial, J.G. and J.G. Stanley. 1984. Calibrating effects of acidity on Atlantic salmon for use in habitat suitability models. Completion Report project A-054-ME 14-34-0001-0121. Land and Water Resource Center, University of Maine, Orono. 37 pp.

White, W.J. 1990. Limitations of Habitat Evaluation Procedure (H.E.P.) models for fish habitat management. Pages 237-251 *in* Collected papers on fish habitat with emphasis on salmonids. Anadromous, Catadromous, and Freshwater Fishes Subcommittee of CAFSAC. Department of Fisheries and Oceans. Dartmouth, Nova Scotia, Canada. 423 pp.

Wright, P.J., D. Rowe, and J.E. Thorpe. 1991. Daily growth increments in the otoliths of Atlantic salmon parr, *Salmo salar* L., and the influence of environmental factors on their periodicity. Journal of Fish Biology 39:103-113.

Table 1. Summary of habitat variables, suggested spatial scale for collection of data, seasonal constraints for data collection, and method for calculation of suitability index (SI) values.

Variable	Location of Measurement			Calculation of Variable SI for a:			
	Multiple transects per station	Single location per station	Single location per habitat type	Season	Station	Habitat Type	Watershed
Land Use in Drainage basin				A			C
Substrate rating	X			S,W	A		
Mean Stream Width	X			S	B		
% Overhanging Cover	X			S	B		
% Embeddedness	X			A	A		
Maximum Flood Height		X		S	C		
Mean Velocity	X			S	B		
Mean Depth	X			S	B		
Depth X Velocity	X			S	B		
pH			X	S		C	
Nitrate Rating			X	S		C	
Total Hardness			X	S		C	
Minimum Daily Flow				S,W	C		
Temperature (instantaneous growth)		X	X	S		C	
Maximum Water Temperature			X	S		C	
Cumulative Degree days (% max.			X	S		C	
Habitat Type			X	A		C	

Season: S = summer, W = winter, A = all seasons (no constraints).
Calculation of SI: A = measure variable at multiple points, calculate an SI for each point, use the area weighed (i.e., area represented by each point) mean of the SIs as the SI for the station; B = measure variable at multiple points (or times), calculate the area weighted mean of the variable, convert this mean to an SI; C = a single value for the variable is converted to an SI (the single value, such as degree days, could be derived from a series of measurements).

Table 2. Matrix of potential variables for habitat assessment and life stages of Atlantic Salmon.

Newfoundland Salmon HSIs

March 1992 Workshop

Environment: ____________________

Season: ____________________

	VARIABLE	REPRO	FRY	PARR	SMOLT	ADULT
1.	Substrate Rating					
2.	Stream Width					
3.	% Overhanging Cover					
4.	Total Hardness					
5.	% Embeddedness					
6.	Max Flood Height					
7a.	Mean Velocity					
7b.	Depth versus Velocity					
7c.	Mean Depth					
8.	Proximity to Spawning Site					
9.	pH					
10.	Nitrate Rating					
11.	Minimum Flow					
12a.	Degree Days Growth					
12b.	Lethal Temperature					
12c.	Degree Days Incubation					
13.	Air Temperature					
14.	Land Use					
15.	BOD					
16.	Habitat Type					

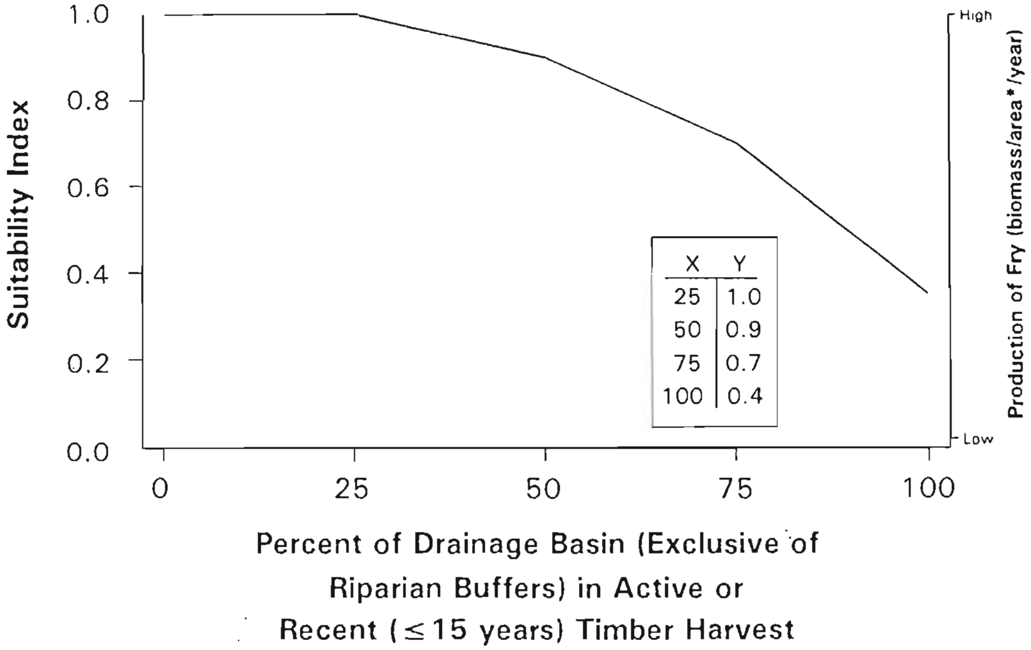


Figure 1. Hypothetical relationship between percent of drainage basin in active or recent (<15 years) timber harvest and productive capacity for under-yearling Atlantic salmon.

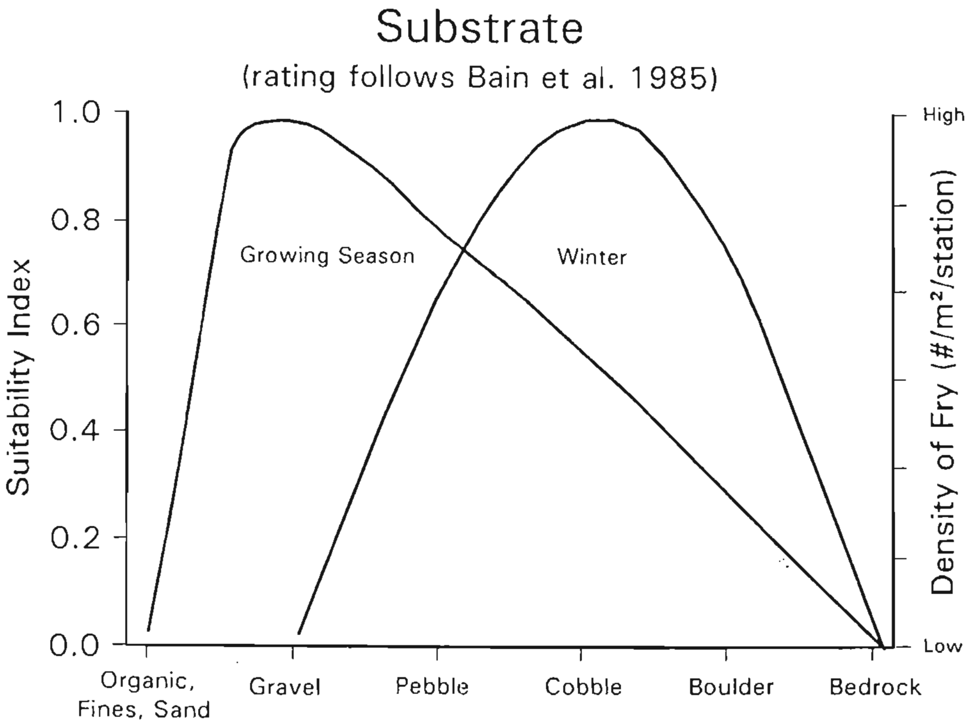
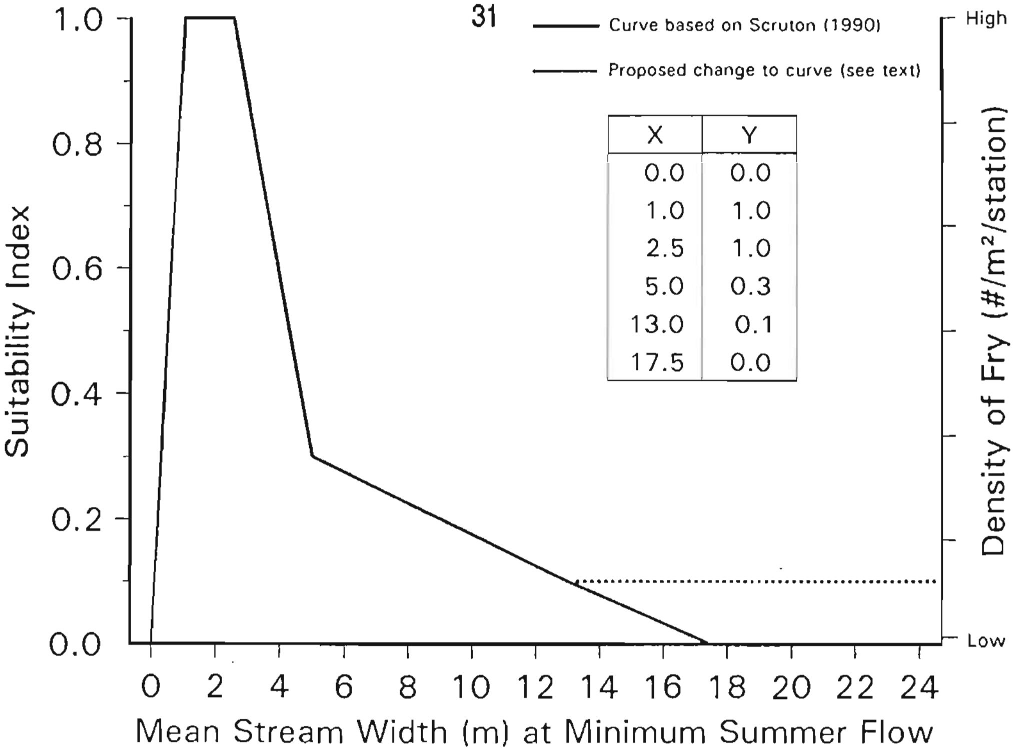
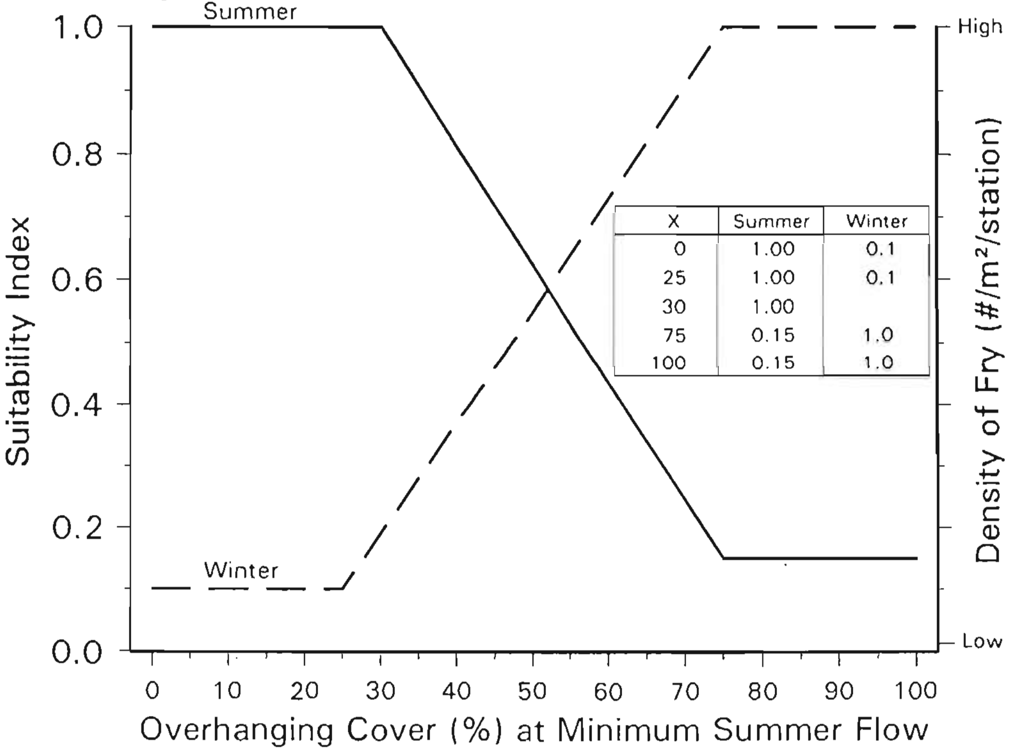


Figure 2. Relationships between substrate rating for a station and Atlantic salmon fry density at a station in the growing season (curve 1) and winter (curve 2).



X	Y
0.0	0.0
1.0	1.0
2.5	1.0
5.0	0.3
13.0	0.1
17.5	0.0

Figure 3. Proposed relationship between mean stream width, measured at minimum summer flow, and production of Atlantic salmon fry.



X	Summer	Winter
0	1.00	0.1
25	1.00	0.1
30	1.00	
75	0.15	1.0
100	0.15	1.0

Figure 4. Proposed relationship between percent overhanging cover at a station and density of Atlantic salmon fry. Habitat data should be obtained during minimum summer flow.

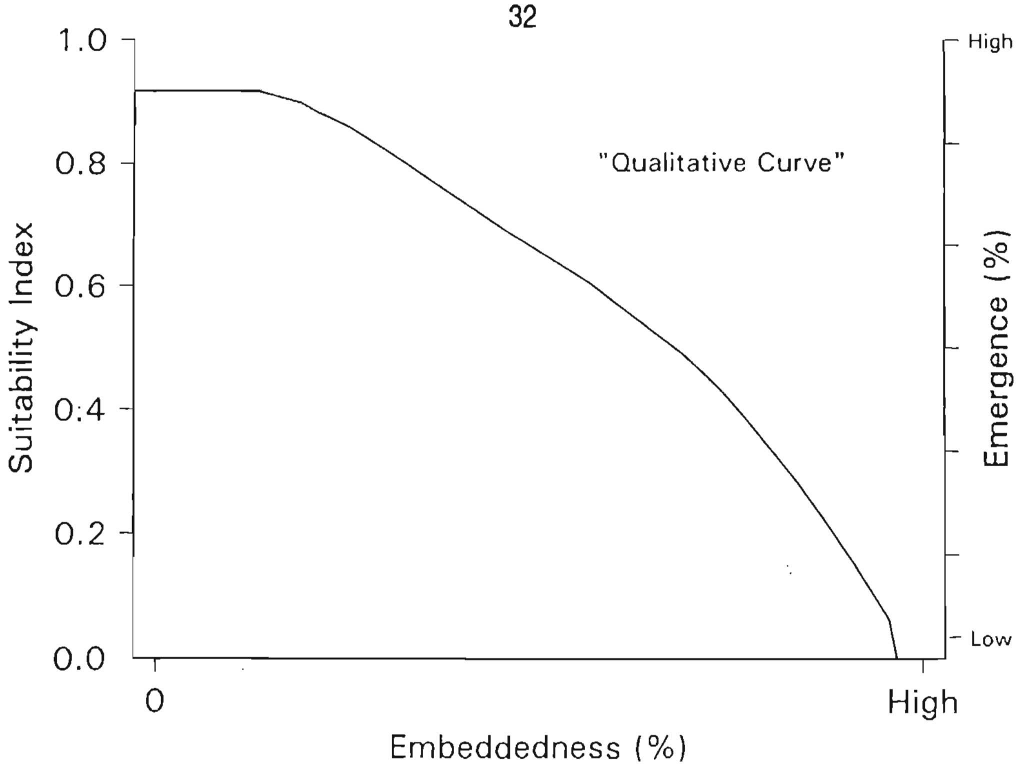


Figure 5. Estimated relationships between percent embeddedness and percent emergence of Atlantic salmon fry.

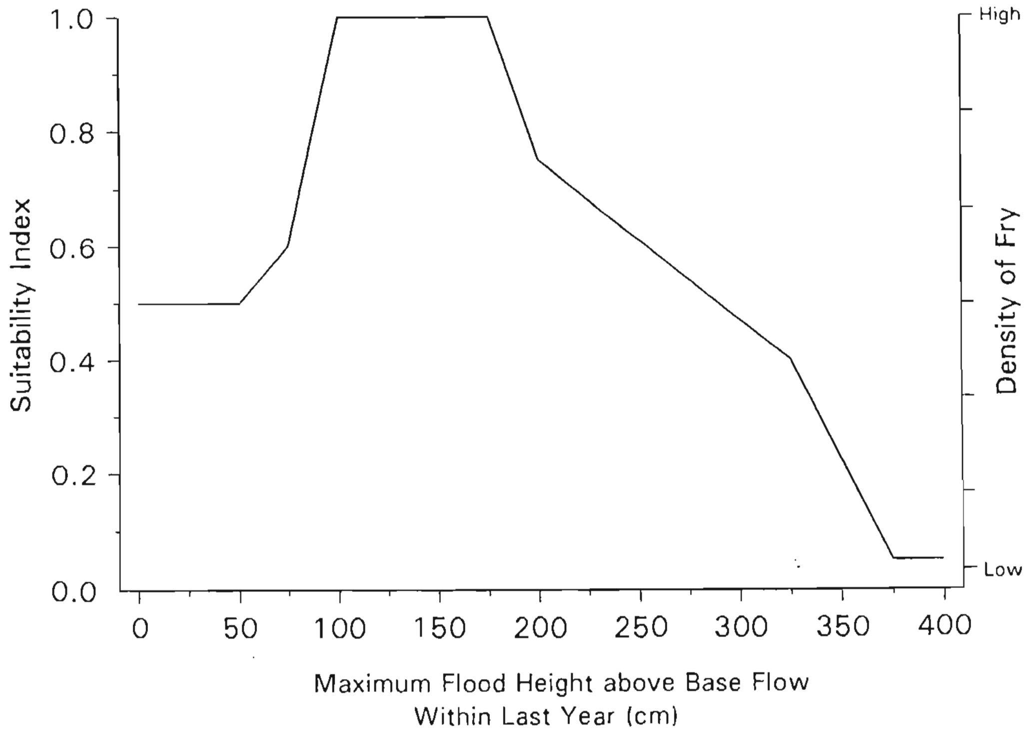


Figure 6. Relationships between maximum flood height, measured within the last year, above base flow stage and density of Atlantic salmon fry.

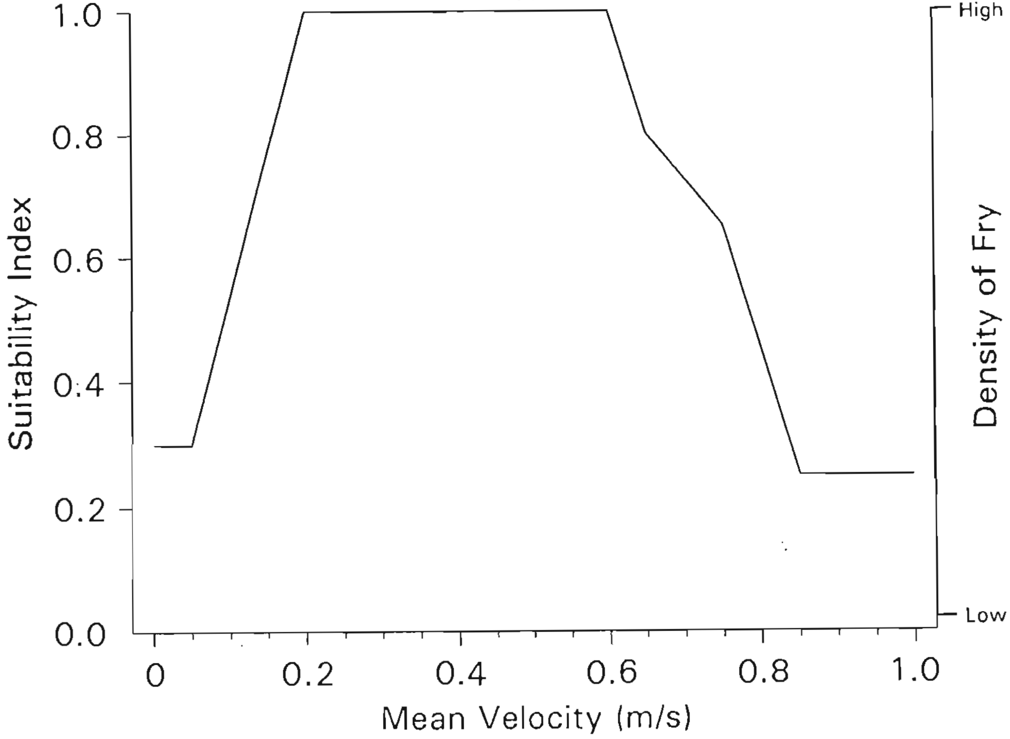


Figure 7. Relationships between mean velocity and density of Atlantic salmon fry.

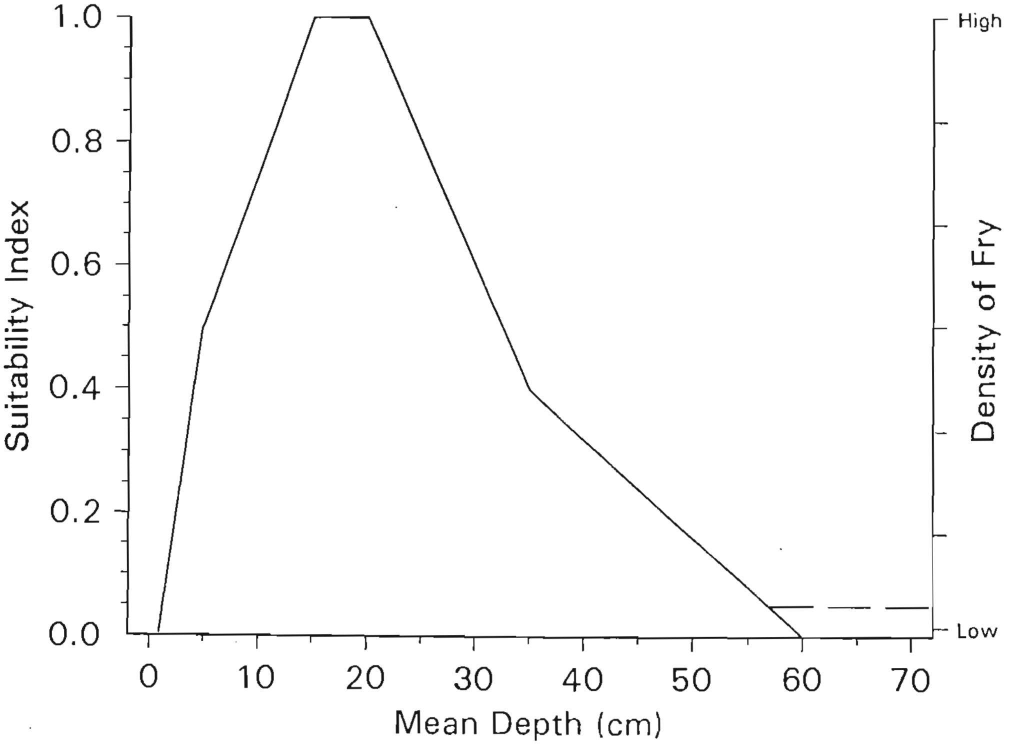


Figure 8. Proposed relationships between mean depth of a station and density of Atlantic salmon fry.

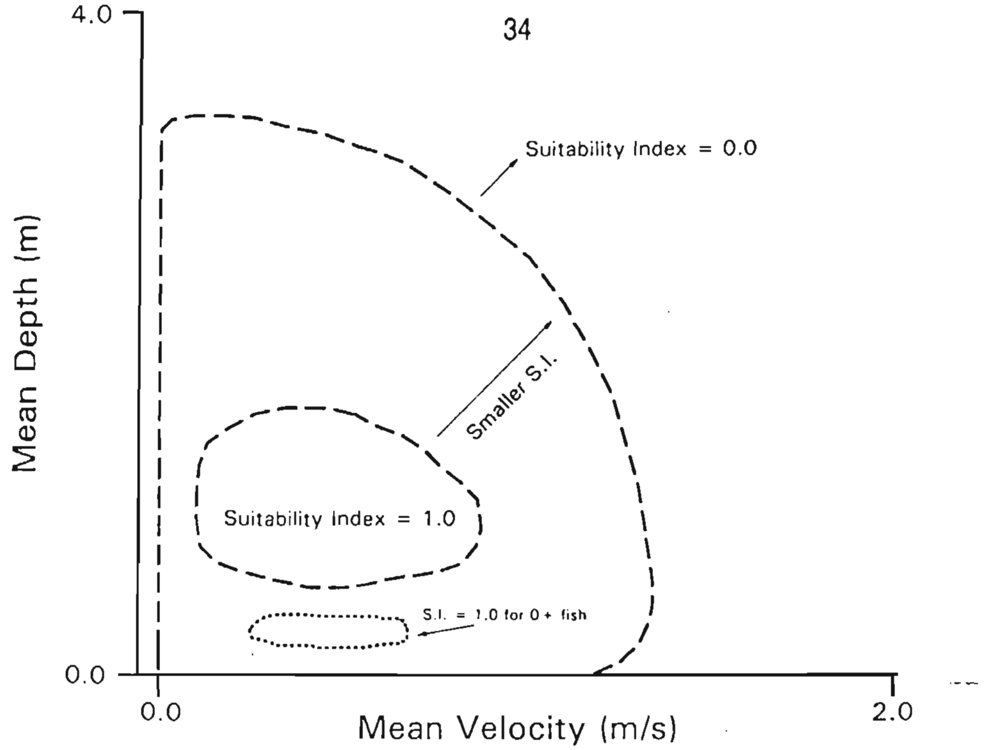
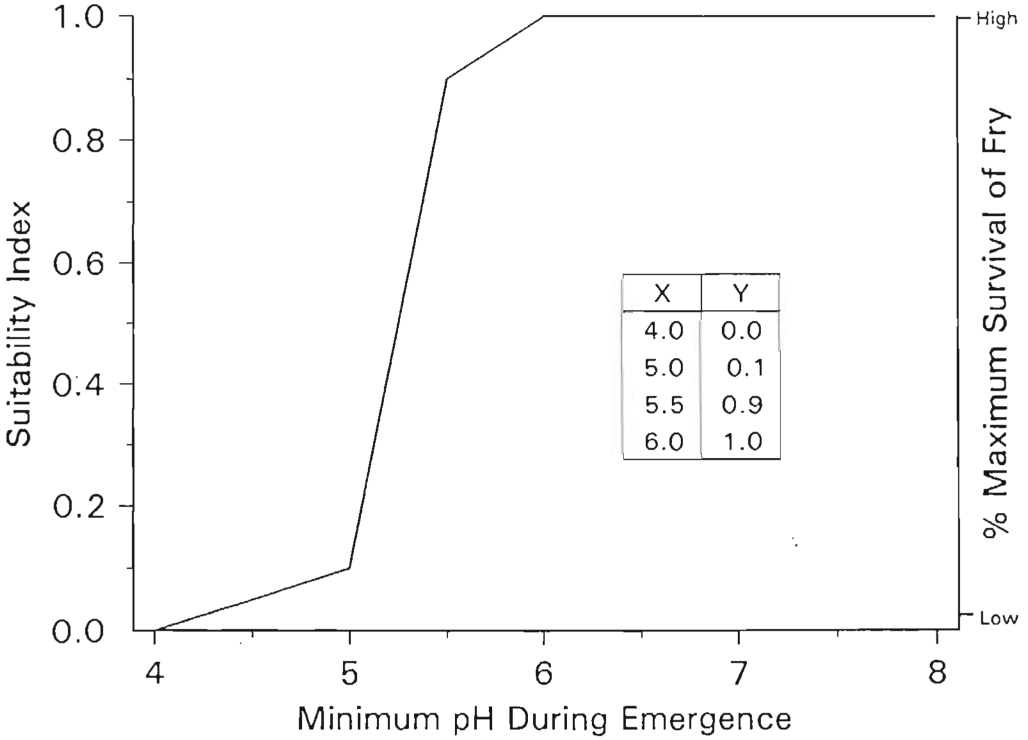
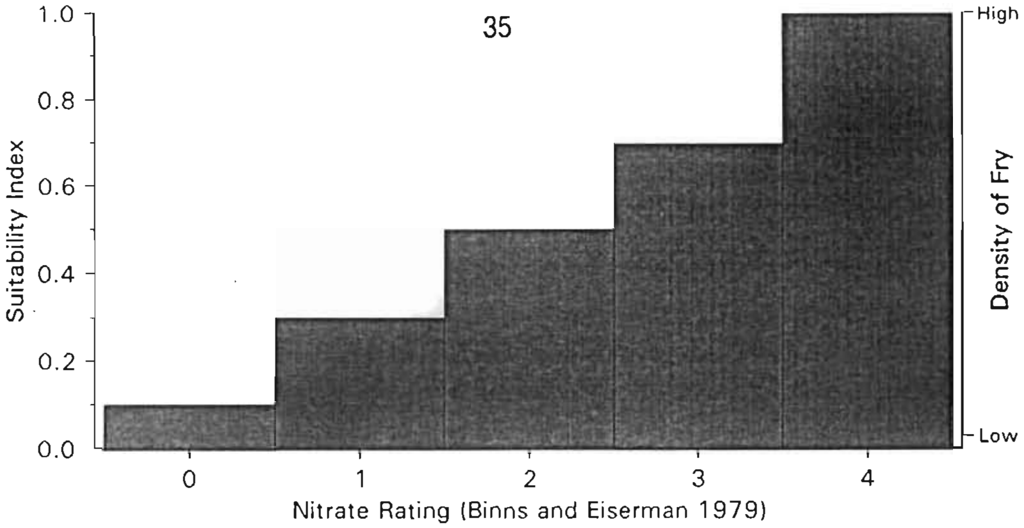


Figure 9. Proposed relationships between mean depth, mean velocity, and habitat quality for Atlantic salmon fry.



X	Y
4.0	0.0
5.0	0.1
5.5	0.9
6.0	1.0

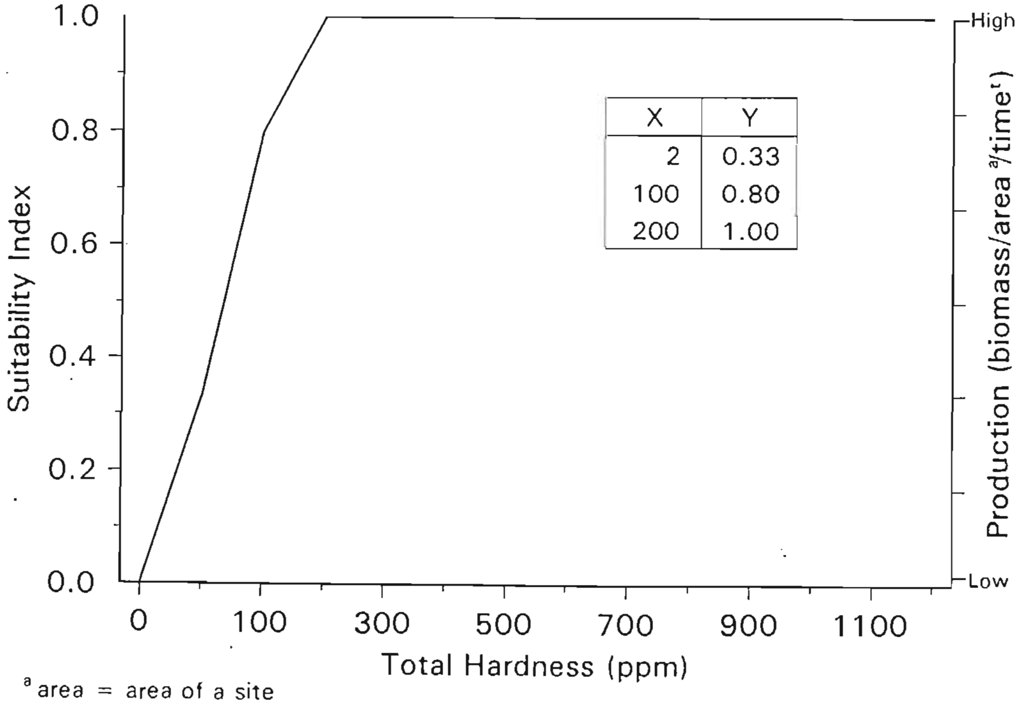
Figure 10. Proposed relationships between minimum pH during post emergence survival of Atlantic salmon fry.



0 (worst)	1	2	3	4 (best)
<0.01 or >2.0	0.01-0.04 or 0.91-2.0	0.05-0.09 or 0.51-0.90	0.10-0.14 or 0.26-0.50	0.15-0.25

(Measurements in mg/l)

Figure 11. Proposed relationship between nitrate concentration and density of Atlantic salmon fry.



X	Y
2	0.33
100	0.80
200	1.00

^{a}area = area of a site
^{t}time = time in period t

Figure 12. Proposed relationship between total hardness and production of Atlantic salmon fry.

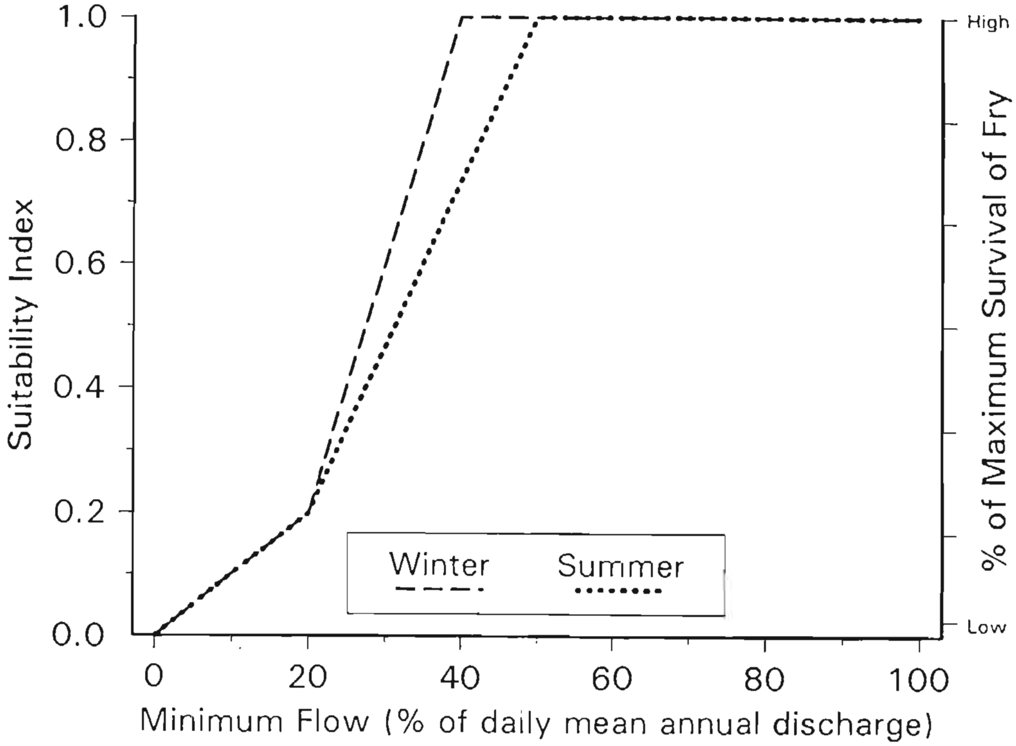


Figure 13. Proposed relationships between minimum flows in winter (November-June) and summer (July-August) and survival of Atlantic salmon.

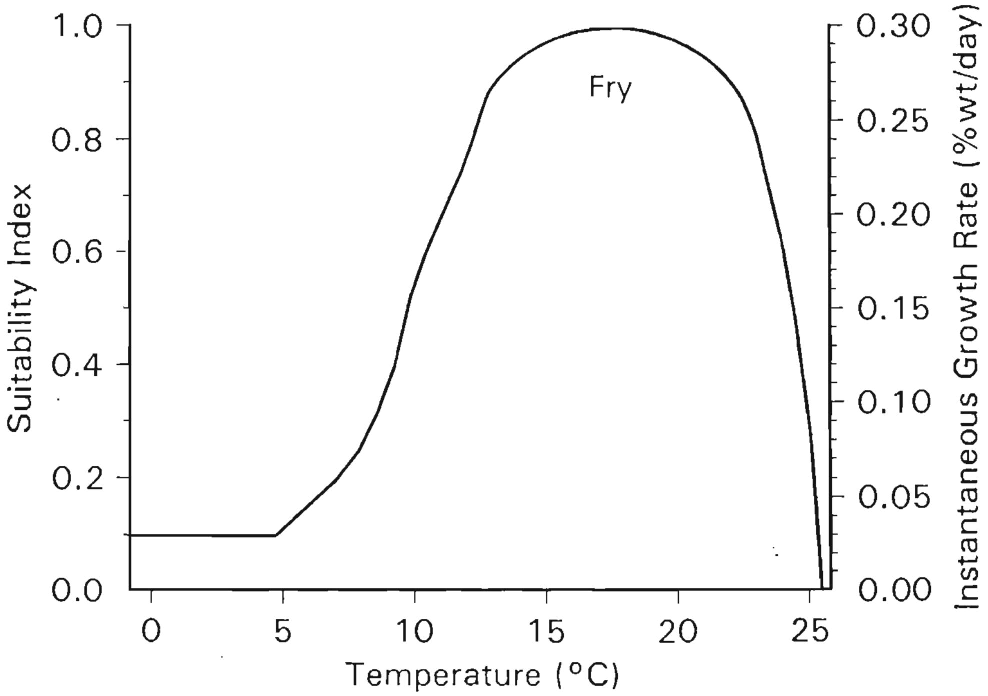


Figure 14a. Proposed relationships between temperature (at a station) and instantaneous growth of Atlantic salmon fry, when food is not limiting.

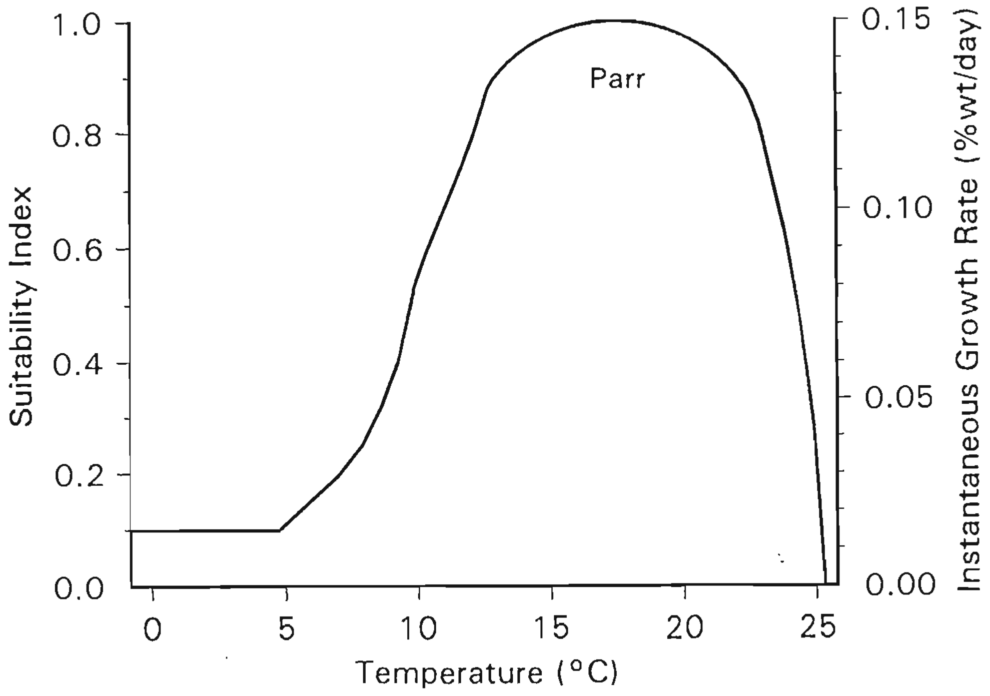


Figure 14b. Proposed relationships between temperature (at a station) and instantaneous growth of Atlantic salmon parr.

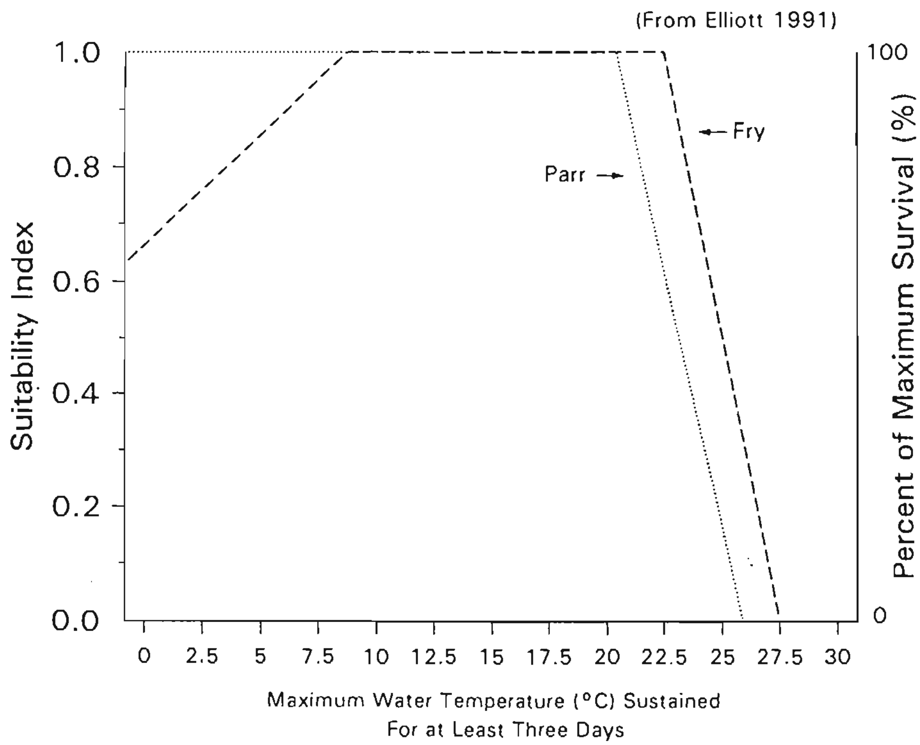


Figure 14c. Proposed relationships between maximum water temperature (sustained for ≥3 days and percent of maximum survival for Atlantic salmon fry.

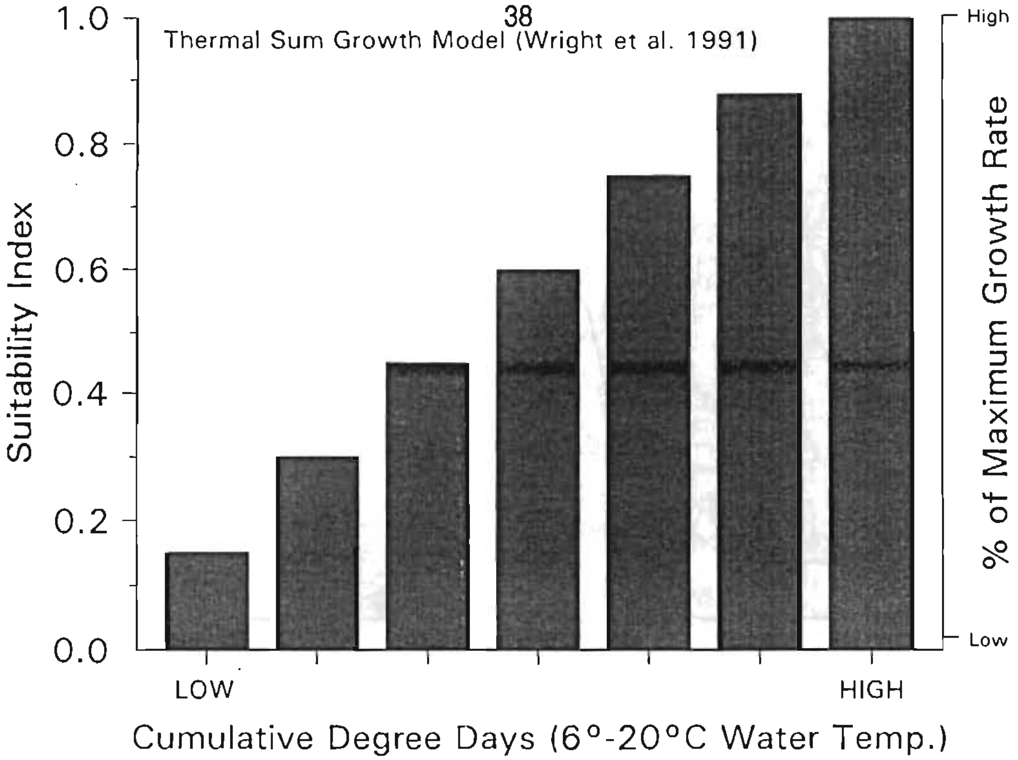
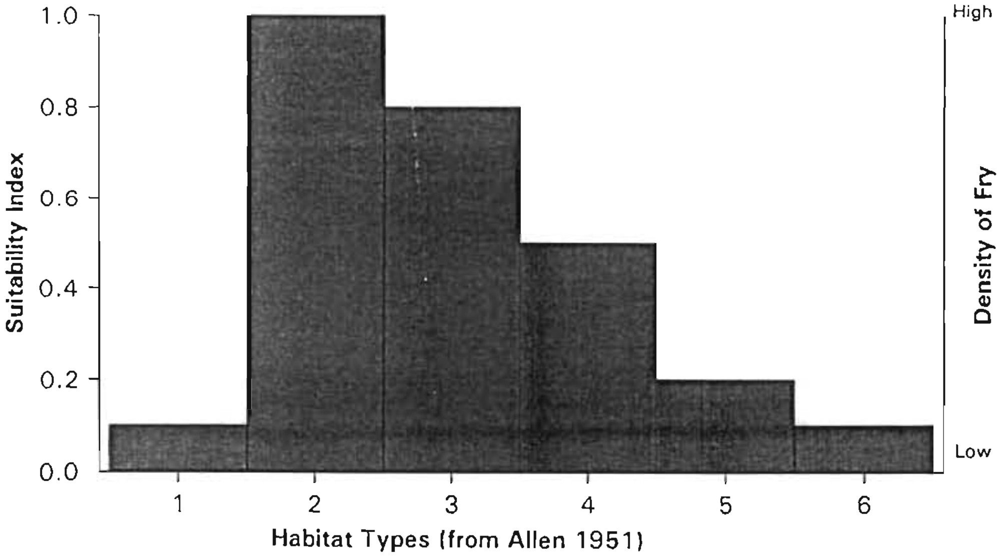


Figure 14d. Proposed relationships between cumulative degree days and percent of maximum growth for Atlantic salmon fry.



1. Very shallow areas: ≤ 5 cm max. depth
2. Shallow riffle: 5-23 cm max. depth, > 38 cm/s current
3. Deep riffle: > 23 cm max. depth, > 38 cm/s current
4. Flat: < 46 cm max. depth, < 38 cm/s current, smooth surface
5. Pool: 46-68 cm max. depth, < 38 cm/s current
6. Deep Pool: > 68 cm max. depth, < 38 cm/s current

Figure 15. Proposed relationships between habitat type and density of Atlantic salmon fry.

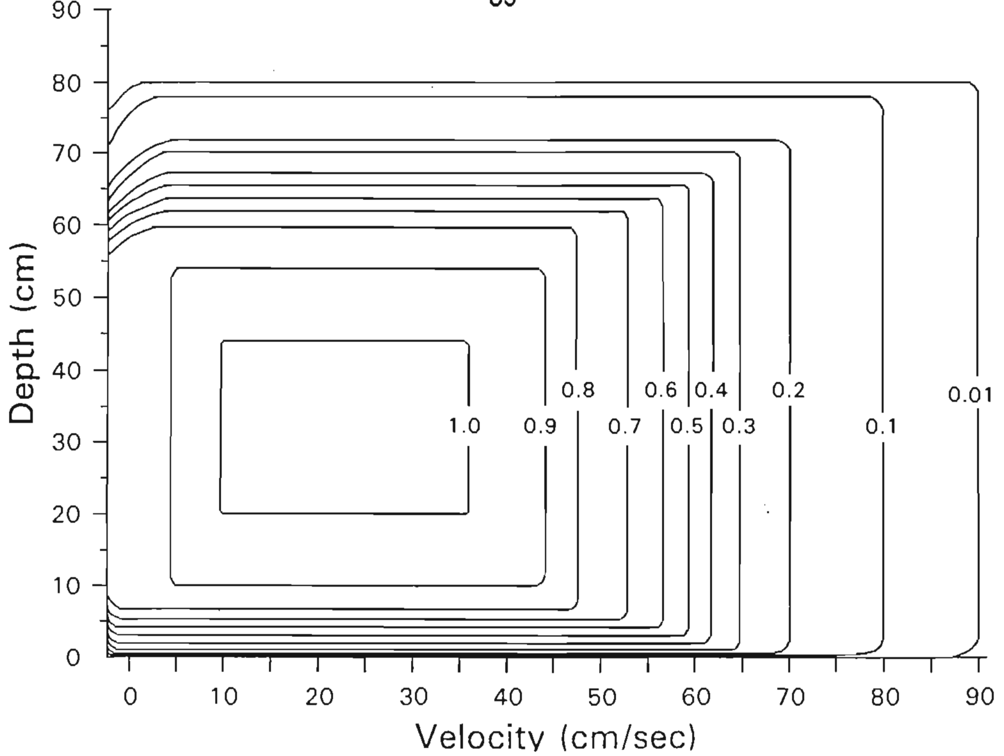


Figure 16. Proposed relationship between mean depth, mean velocity, and habitat quality for Atlantic salmon fry; curve developed by reviewer.

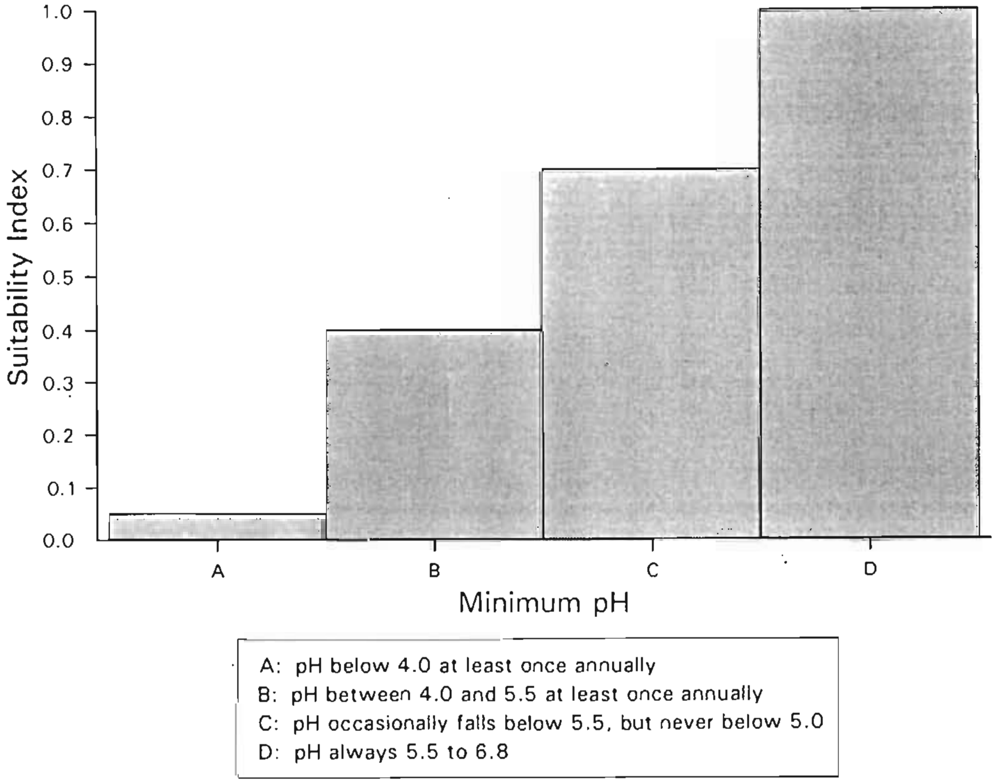


Figure 17. Proposed relationship between minimum pH and habitat quality for Atlantic salmon fry; curve developed by reviewer.

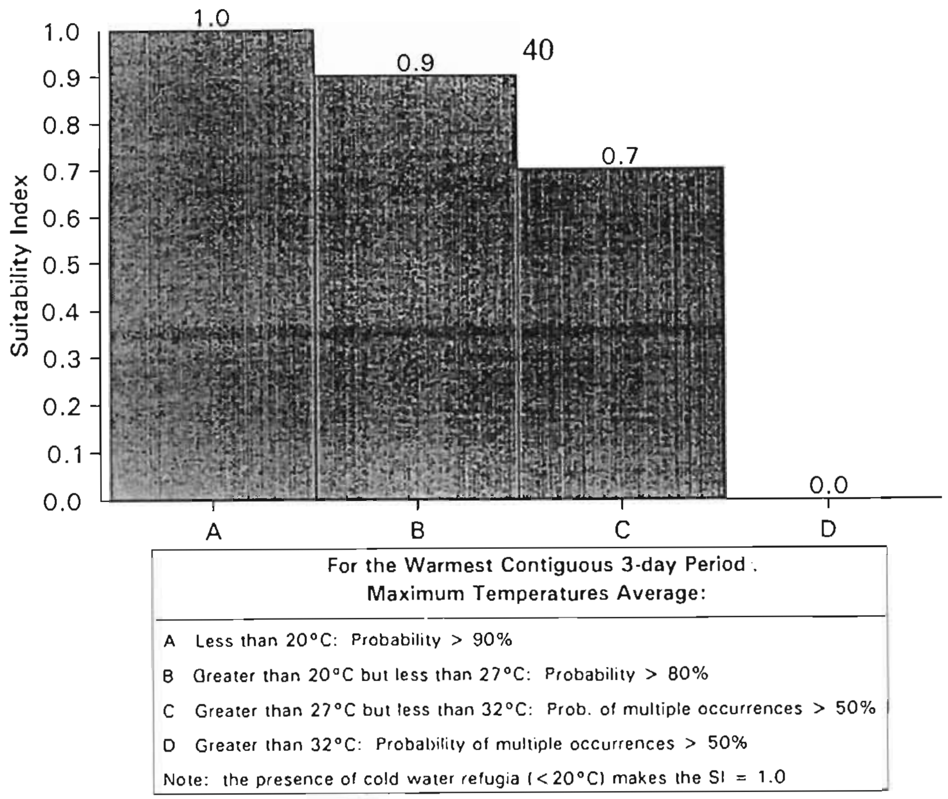
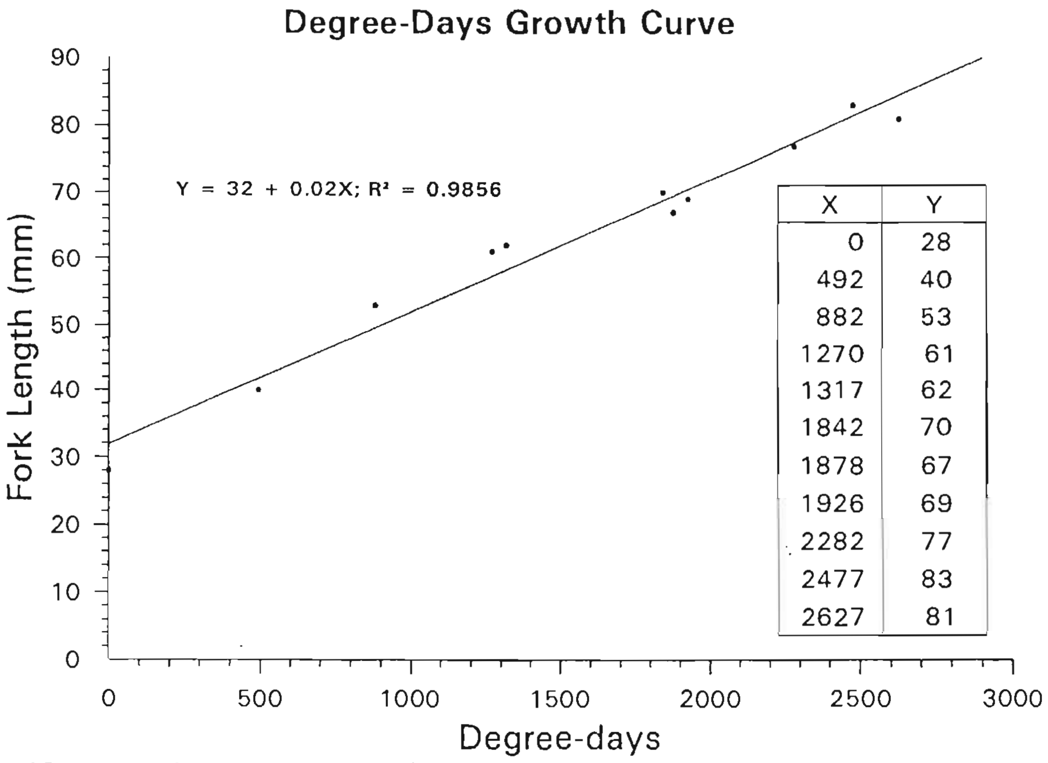
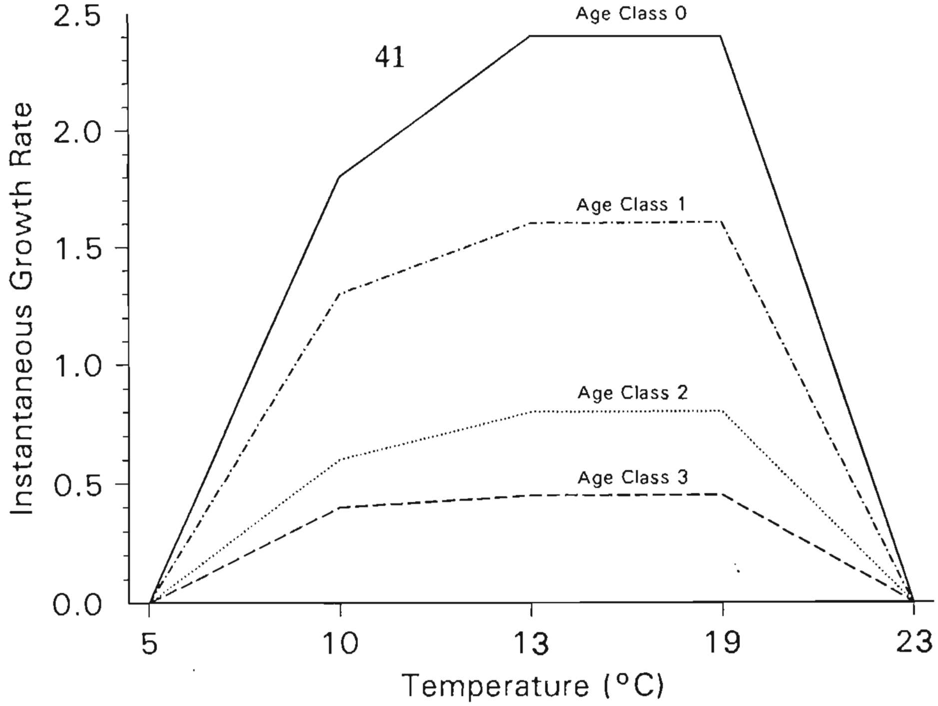


Figure 18. Proposed relationship between maximum temperatures during the warmest contiguous 3-day period and habitat quality for Atlantic salmon fry; histogram developed by reviewer.



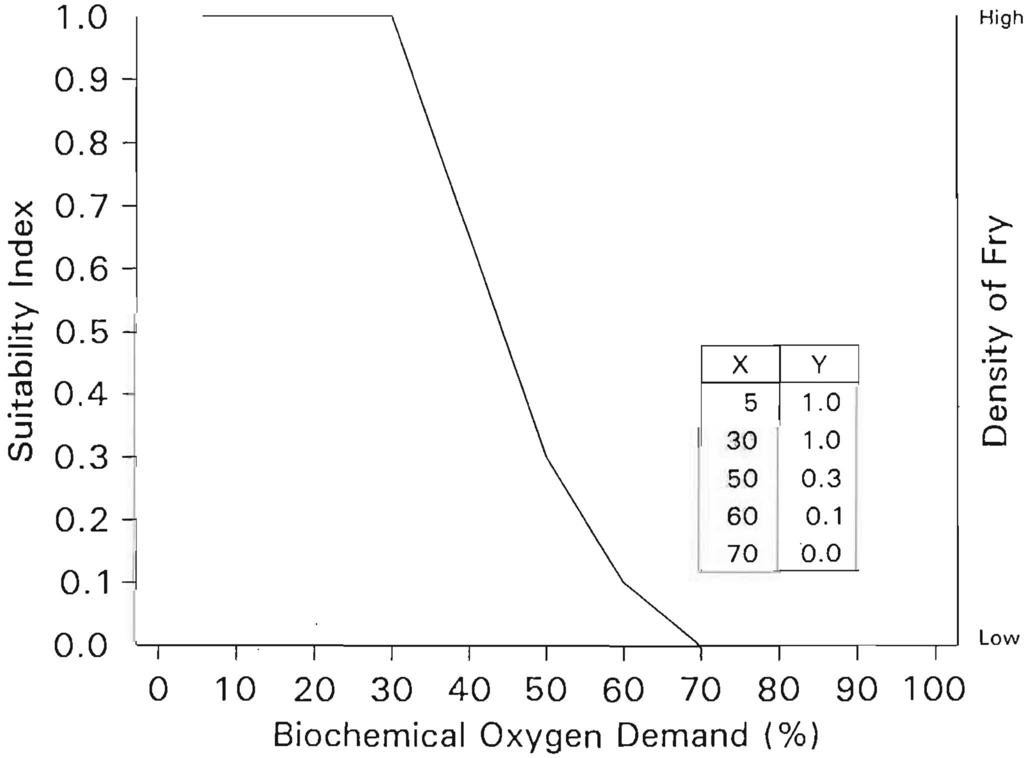
X	Y
0	28
492	40
882	53
1270	61
1317	62
1842	70
1878	67
1926	69
2282	77
2477	83
2627	81

Figure 19. Growth curve for Atlantic salmon fry, developed by reviewer.



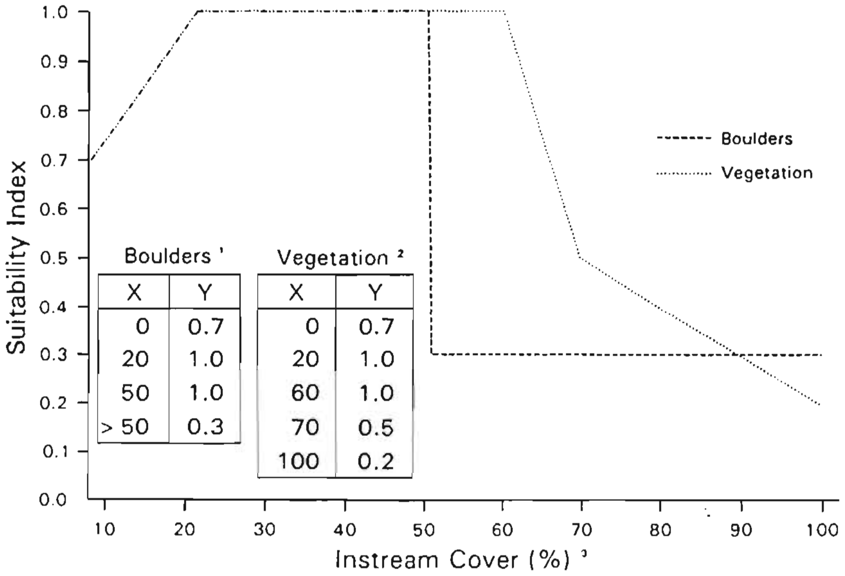
Note: Simulated temperature-growth relationships calculated from the work of Brett, Shelbourn and Shoop (1969), references in the literature to minimum and maximum feeding temperature tolerances, and field data on the growth characteristics of New Brunswick stocks.

Figure 20. Simulated temperature-growth relationships for Atlantic salmon fry, developed by reviewer.



X	Y
5	1.0
30	1.0
50	0.3
60	0.1
70	0.0

Figure 21. Proposed relationship between biochemical oxygen demand and density of Atlantic salmon fry; curve developed by reviewer.



Boulders [1]

X	Y
0	0.7
20	1.0
50	1.0
> 50	0.3

Vegetation [2]

X	Y
0	0.7
20	1.0
60	1.0
70	0.5
100	0.2

[1] Submerged and/or emergent boulders

[2] Vegetation includes large woody debris

[3] Percent of area with cover above the plane of the dominant substrate

Note: if boulders are greater than 50%, then suitability for instream cover is the same as for dominant substrate (Figure 2)

Figure 22. Proposed relationship between percent instream cover and habitat quality for Atlantic salmon Parr curve developed by reviewer.

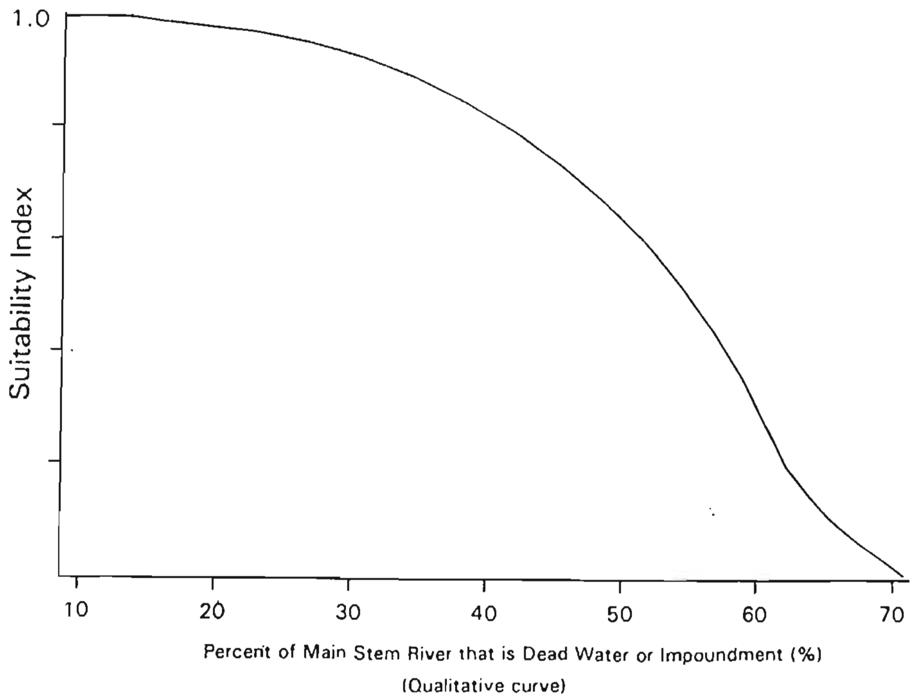


Figure 23. Proposed relationship between percent of mainstem river that is dead water or impoundment and habitat quality for Atlantic salmon fry; curve developed by reviewer.

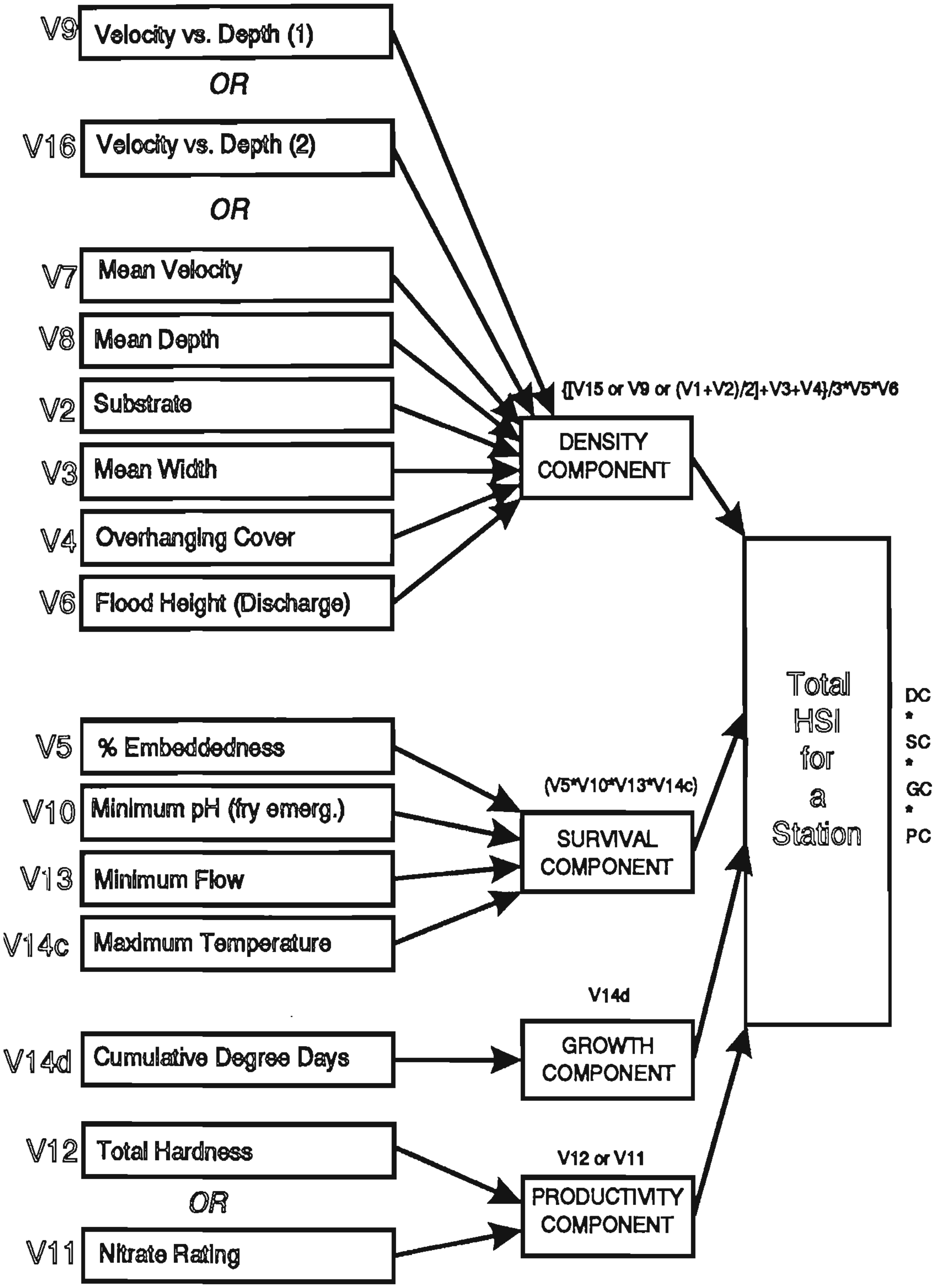


Figure 24. Schematic of the proposed Habitat Suitability Index (HSI) Model for salmon fry in riverine habitat in insular Newfoundland.

APPENDIX A

Matrices of potential variables for habitat assessment considering habitat types (environment), seasons, and life stages of Atlantic salmon as developed by workshop participants from Table 2 (pg. 28).

Table A-1. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** All Seasons

					ALL STAGES	
Variable	**Reprod.**	**Fry**	**Parr**	**Smolt**	**Growth or Productivity Water Quality**	**Survival Water Q.**
Substrate Rating						
Stream Width						
% Overhang. Cover						
Total Hardness					X	
% Embeddedness						
Max. Flood Height						
Mean Velocity						
Depth X Velocity						
Mean Depth						
Prox. to Spawn. Site						
pH						X
Nitrate Rating					X	
Minimum Flow						
Degree Days Growth					X	
Lethal Temperature						X
Deg. Days Incubation					X	
Air Temperature						
Land Use						
BOD					?	?
Habitat Type						
Dissolved Oxygen						X
Alkalinity					X	

Table A-2. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Summer

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating		X	X			
Stream Width						
% Overhang. Cover		X	X		X	May not be very important
Total Hardness		X	X			Could use alkalinity ?
% Embeddedness		X	X			
Max. Flood Height		X	X		X	For juveniles, data may be too stream type specific
Mean Velocity					X (pools)	
Depth X Velocity		X	X			
Mean Depth						
Prox. to Spawn. Site					X	
pH		X	X			
Nitrate Rating		X	X			
Minimum Flow		X	X			Space limits
Degree Days Growth		X	X			Age of smolt
Lethal Temperature		X	X			
Deg. Days Incubation		X				
Air Temperature						
Land Use						
BOD		X	X			or DO?
Habitat Type		X	X			
Maximum Pool Depth					X	
Pool Size					X	
Pool Cover					X	
% Instream Cover			X			
Dissolved Oxygen		X	X		X	

Table A-3. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Spring

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating						
Stream Width						
% Overhang. Cover						
Total Hardness						
% Embeddedness						
Max. Flood Height				X		
Mean Velocity						
Depth X Velocity						
Mean Depth						
Prox. to Spawn. Site						
pH						
Nitrate Rating						
Minimum Flow						
Degree Days Growth						
Lethal Temperature						
Deg. Days Incubation						
Air Temperature						
Land Use						
BOD						
Habitat Type						
% Mainstem Impound.				X		
Dam Size (height)				X		
Turbine Type				X		

Table A-4. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Winter

Variable	Embryo Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating			X			
Stream Width						
% Overhang. Cover						
Total Hardness						
% Embeddedness			X			
Max. Flood Height						
Mean Velocity					X (pool)	
Depth X Velocity			X			
Mean Depth						
Prox. to Spawn. Site						
pH	X					
Nitrate Rating						
Minimum Flow			X		X	
Degree Days Growth						
Lethal Temperature	X					
Deg. Days Incubation	X					
Air Temperature	X		X		X	Relates to ice
Land Use						
BOD						
Habitat Type						
Ice Conditions	X		X		X	
Pool Depth					X	
Pool Size					X	

Table A-5. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Fall (identifies spawning areas)

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating	X					
Stream Width	X					
% Overhang. Cover						Could also use stream order
Total Hardness						
% Embeddedness	X					
Max. Flood Height						
Mean Velocity	X					
Depth X Velocity						
Mean Depth	X					
Prox. to Spawn. Site						
pH						
Nitrate Rating						
Minimum Flow						
Degree Days Growth						
Lethal Temperature						
Deg. Days Incubation						
Air Temperature						
Land Use						
BOD						
Habitat Type						

Table A-6. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Winter

Variable	Reprod.	Fry	Parr	Pre-Smolt	Adult	Comments
Substrate Rating		X	X	X		Very important
Stream Width		X	X			
% Overhang. Cover		X	X			
% Embeddedness		X	X	X		
Max. Flood Height		X	X	X		
Mean Velocity		X	X	X		
Depth X Velocity		X	X	X		
Mean Depth		X	X	X		
Prox. to Spawn. Site					X	
pH		X	X	X		
Nitrate Rating		X	X	X		
Minimum Flow		X	X	X	X	
Air Temperature		X	X	X		
Land Use		X	X	X		
BOD		X	X	X		
Habitat Type		X	X	X		
Ice (% Cover)		X	X	X		
Ice Thickness/Durat.		X	X	X		

Table A-7. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Growing Season

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating		X				
Stream Width		X				
% Overhang. Cover		X				
Total Hardness		X				
% Embeddedness		X				
Max. Flood Height[1]		X		X		
Mean Velocity		X		X	X	
Depth X Velocity		X		X	X	
Mean Depth		X		X	X	
Prox. to Spawn. Site		X				
pH						
Nitrate Rating		X				
Minimum Flow		X				
Degree Days Growth		X				
Minimum Temperature		X		X		
Maximum Temperature		X		X	X	
Lethal Temperature		X			X	
Deg. Days Incubation						
Air Temperature						
Land Use		X		X	X	
BOD						
Habitat Type		X		X	X	

[1] Flood height here is taken as sudden spates that stimulate emigration of smolts to sea and that could also displace fry from preferred habitat.

Table A-8. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Winter

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating	X	X				
Stream Width		X				
% Overhang. Cover						
Total Hardness						
% Embeddedness	X					
Max. Flood Height	X	X		X	X	
Mean Velocity	X	X		X	X	
Depth X Velocity	X	X		X	X	
Mean Depth	X	X		X	X	
Prox. to Spawn. Site						
pH	X					
Nitrate Rating						
Minimum Flow	X	X		X	X	
Degree Days Growth						
Minimum Temperature	X	X		X	X	
Maximum Temperature	X	X		X	X	
Lethal Temperature						
Deg. Days Incubation	X					
Air Temperature						
Land Use	X	X		X	X	
BOD						
Habitat Type	X	X		X	X	

Table A-9. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Riverine **Season:** Growing

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating			X		X	
Stream Width			X		X	
% Overhang. Cover			X		X	
Total Hardness			X			
% Embeddedness			X		X	
Max. Flood Height			X	X	X	
Mean Velocity			X	X	X	
Depth X Velocity			X		X	
Mean Depth			X		X	
Prox. to Spawn. Site			X		X	
pH			X	X	X	
Nitrate Rating			X	X		
Minimum Flow			X	X	X	
Degree Days Growth			X	X		
Lethal Temperature			X	X	X	
Deg. Days Incubation						
Air Temperature			X	X	X	
Land Use			X	X	X	
BOD			X	X	X	
Habitat Type			X		X	

Table A-10. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Lacustrine **Season:** Winter

Variable	Repro.[1]	Fry	Parr	Smolt	Adult	Comments
Habitat Type	X	X		X	X	
Substrate Type	X	X				
Thermal Regime	X	X		X	X	
Degree Days Growth						
Oxygen Level	X	X		X	X	
BOD						
Total Hardness						
Nutrient Levels						
Deg. Days Incubation	X					
Land Use	X	X		X	X	
Prox. to Spawn. Site						

[1] Refers only to possible spawning in lakes in inlet and outlet areas with suitable substrate.

Table A-11. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Estuarine **Season:** Spring

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Salinity				X		
Minimum Temperature				X		
Maximum Temperature				X		
Lethal Temperature				X		
BOD				X		
Oxygen Level				X		
Land Use				X		

Table A-12. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Estuarine **Season:** Summer

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating		NA	X			
% Embeddedness						
Mean Velocity high tide low tide			X	X	X	
Depth X Velocity			X	X		
Mean Depth			X			
Prox. to Spawn. Site	X		X	X	X	
Nitrate Rating						
Minimum Flow			X		X	
Degree Days Growth			X			
Lethal Temperature			X			
Air Temperature			X		X	
Land Use			X		X	
BOD			X	X	X	
Habitat Type			X	X	X	
Tidal Height			X	X	X	
Salinity			X	X		
% Aquatic Cover			X	X		
Slope		↓				

General Comments:

- Fry are not known to use estuarine environments in Newfoundland.
- No data available on use of estuaries by salmon in winter.

Table A-13. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Estuarine **Season:** Summer

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Salinity				X	X	
Minimum Temperature				X		
Maximum Temperature				X	X	
Lethal Temperature						
BOD				X	X	
Oxygen Level				X	X	
Land Use				X	X	

Table A-14. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Estuarine **Season:** Growing

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating			X			
Stream Width			X	X	X	
% Overhang. Cover			X			
Total Hardness						
% Embeddedness						
Max. Flood Height			X	X	X	
Mean Velocity: River			X	X	X	
Sea			X	X	X	
Depth X Velocity						
Mean Depth			X	X	X	
Prox. to Spawn. Site			X		X	
pH						
Nitrate Rating						
Minimum Flow			X	X	X	
Degree Days Growth			X	X		
Lethal Temperature			X	X	X	
Deg. Days Incubation						
Air Temperature			X	X	X	
Land Use			X	X	X	
BOD			X	X	X	
Habitat Type			X			
Temperature Stratif.			X	X	X	
Salinity Stratific.			X	X	X	

Table A-15. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Lacustrine **Season:** Winter

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Substrate Rating		X	X		X	
% Aquatic Cover		X	X		X	
Total Hardness		X	X		X	
% Embeddedness		X	X		X	
Depth X Velocity		X	X			
Mean Depth		X	X	X	X	
Prox. to Spawn. Site		X	X		X	
pH		X	X	X		
Nitrate Rating		X	X			
Degree Days Growth		X	X	X		
Lethal Temperature		X	X	X		
Air Temperature		X	X	X		
Land Use		X	X	X	X	
BOD		X	X	X	X	
Habitat Type		X	X	X	X	
Ice Duration		X	X	X		

Table A-16. Matrix of potential variables for habitat assessment, seasons, and life stages of Atlantic salmon, as developed by a workshop participant.

Environment: Lacustrine

Season: Growing Season

Variable	Reprod.	Fry	Parr	Smolt	Adult	Comments
Habitat Type		X		X	X	
Substrate Type		X				
Thermal Regime		X		X	X	
Degree Days Growth		X				
Oxygen Level		X		X	X	
BOD		X		X	X	
Total Hardness		X				
Nutrient Levels		X				
Deg. Days Incubation						
Land Use		X		X	X	
Prox. to Spawn. Site		X				

APPENDIX B

The three matrices of habitat values contained in this appendix (Tables B1 to B-3) were provided to reviewers after the workshop to use as sample data to help develop a single HSI value from individual suitability indices. The resulting contributions and interpretations provided by three reviewers are also included.

Table B-1. First example of a data matrix.

Variable	0.00	0.01 - 0.30	0.31 - 0.60	0.61 - 0.90	> 0.90
			Suitability Index		
Substrate Rating					X
Stream Width					X
% Overhanging Cover					X
Total Hardness			X		
Percent Embeddedness					X
Max. Flood Height			X		
Mean Velocity			X		
Depth X Velocity			X		
Mean Depth			X		
pH			X		
Nitrate Rating			X		
Minimum Flow				X	
Deg. Days Growth			X		
Lethal Temperature		X			
Deg. Days Incubation			X		
Land Use					X
Habitat Type					X

Table B-2. Second example of a data matrix.

Suitability Index

Variable	0.00	0.01 - 0.30	0.31 - 0.60	0.61 - 0.90	> 0.90
Substrate Rating		X			
Stream Width		X			
% Overhanging Cover		X			
Total Hardness					X
Percent Embeddedness		X			
Max. Flood Height					X
Mean Velocity					X
Depth X Velocity					X
Mean Depth					X
pH					X
Nitrate Rating					X
Minimum Flow			X		
Deg. Days Growth					X
Lethal Temperature					X
Deg. Days Incubation					X
Land Use					X
Habitat Type					X

Table B-3. Third example of a data matrix.

	Suitability Index				
Variable	0.00	0.01 - 0.30	0.31 - 0.60	0.61 - 0.90	> 0.90
Substrate Rating					X
Stream Width					X
% Overhanging Cover					X
Total Hardness		X			
Percent Embeddedness					X
Max. Flood Height		X			
Mean Velocity				X	
Depth X Velocity				X	
Mean Depth				X	
pH		X			
Nitrate Rating		X			
Minimum Flow				X	
Deg. Days Growth		X			
Lethal Temperature				X	
Deg. Days Incubation		X			
Land Use					X
Habitat Type					X

Participant #1

The following paragraphs detail a method to determine a productive capacity HSI value. Different variables can be classified into categories by their decreasing order of influence upon the productive capacity of the riverine environment for salmon. The first group includes hydrodynamic and geologic variables:

stream width or stream order;
mean depth and mean velocity (or depth * velocity);
habitat type;
maximum flow height;
minimum flow;
% embeddedness; and
substrate rating.

The second group includes climatic variables:

% overhanging cover;
degree-days incubation;
degree-days growth; and
lethal temperature.

The third group includes physical and chemical variables:

total hardness;
pH;
nitrate rating;
land use; and
BOD.

This aggregation of variables assumes that the model is static, not dynamic. To determine the actual hierarchy of the three groups or of the variables within a group, it is necessary to adjust the model with existing data sets. One approach would be to use density of age 0+ fish as the dependent variable in a regression analysis utilizing either a single or multivariate approach. Additional variables such as slope, ice scour, and permeability of substrate could be added to group 1 and a variable for light intensity to group 2.

Lastly, a fourth group of biological variables could be added (for regression analysis), and would include percent overhanging cover, proximity to spawning site, biotic index, and density of salmon parr and other species.

This approach (regression analysis) is necessary to help understand the relevance of identified variables, how they interact with each other, and when one variable becomes a limiting factor. If regression analysis is not used to estimate productive capacity in an undisturbed river, a coefficient could be attributed to each of the three groups of variables:

Group 1:	hydrodynamic and geological = 0.5;
Group 2:	climatic = 0.3;
Group 3:	physical and chemical = 0.2.

Since the hierarchical order of variables within a group is not known, a simple approach would be to assume that they are the same (although we know this is not true), and thus use an arithmetic mean of the variables within the group. To determine the productive capacity HSI, the weighted mean of the three variables groups is calculated; i.e.,

$$HSI = 0.5\,\frac{\sum SI(\text{group 1})}{N_1} + 0.3\,\frac{\sum SI(\text{group 2})}{N_2} + 0.2\,\frac{\sum SI(\text{group 3})}{N_3}$$

where N_i = number of variables in group i.

Estimated productive capacity for the three matrices (Tables A-1,2,3 in Appendix A) of SI values using the above approach are as follows:

Table A-1	Table A-2	Table A-3
HSI = 0.71	HSI = 0.63	HSI = 0.63

Participant # 2

Example 1: Based on SI values in Table A-3

Habitat descriptor (physical) gives habitat potential

Substrate rating	1
Width	1
Embeddedness	1
Depth * Velocity	0.75
Habitat type	1

$$\frac{\sum_{i=1}^{N} SI_i}{N} = \frac{1 + 1 + 1 + 0.75 + 1}{5} = 0.95$$

Production and Rate Modifiers give modified potential

% Cover	1	
Hardness	0.2	} Use lowest of these as both measure nutrients
Nitrate	0.2	
Degree-days	0.2	
Land use	1	

$$\frac{\sum_{i=1}^{N} SI_i}{N} \times \mathit{Habitat\ potential}$$

$$= \frac{1 + 0.2 + 0.2 + 1}{4} \times 0.95 = 0.5$$

Lethal Modifiers give actual potential = aggregated HSI

pH	0.2
Lethal temperature	0.75
Max. Flood height	0.2
Minimum flow	0.75

Since these act independently to kill fish, modified potential is multiplied by survival rate (HSI) for each factor.

$$0.57 \times 0.2 \times 0.75 \times 0.2 \times 0.75 = 0.013$$

(A very poor salmon habitat).

Example 1 (Revised): Move measures of maximum flood height and minimum flow to habitat descriptor (physical)

Habitat Descriptor

Substrate rating	1
Width	1
Embeddedness	1

Depth * Velocity	0.75
Habitat type	1
Max. flood height	0.2
Minimum flow	0.75

$$\frac{\sum_{i=1}^{N} SI_i}{N} = \frac{1 + 1 + 1 + 0.75 + 1 + 0.2 + 0.75}{7} = 0.$$

Production and Rate Modifiers

% Cover	1	
Hardness	0.2	Use lowest of these as both measure nutrients
Nitrate	0.2	
Degree-days	0.2	
Land use	1	

$$\frac{\sum_{i=1}^{N} SI_i}{N} \times \mathit{Habitat\ potential}$$

$$= \frac{1 + 0.2 + 0.2 + 1}{4} \times 0.81$$

$$= 0.60$$

Lethal Modifiers

pH	0.2
Lethal temperature	0.75

$$0.6 \times 0.2 \times 0.75 \times = 0.09$$

Example A: $\mathit{simple}\ \frac{\sum \mathit{individual\ SIs}}{N} = 0.64$

These examples demonstrate the difficulty of using aggregation procedures. A number of not very precise SI curves are obtained, some of which are different measures of an ill-defined habitat characteristic and clearly not independent, and some arithmetic is executed with them to arrive at a single value. The resulting HSI is very sensitive to the method of aggregation: thus, you can get any answer that you want. This is very worrisome. Some variables are more important than others; yet, how do we weight them? "Expert" opinions can be used; however, without using a multiple regression technique, there seems to be no alternative.

The scale approach to grouping is another possibility (grouping variables as to whether they apply to the site). Sites are presumed to have homogeneous conditions, but is this true of stations? Are sites equal to stations? Other variables obviously apply to longer reaches of rivers; perhaps the entire river. A scale approach was not attempted because it is subject to the same biases and uncertainties that the more functional approach also suffers from. The functional grouping exposes the underlying controls on salmon production better than the scale approach. The exercise leaves me worried; I tend to agree with White's (1990) appraisal.

Example 2: Based on SI values in Table A-1

Habitat descriptor

Substrate rating	0.2
Width	0.2
Embeddedness	0.2
Depth * Velocity	1
Habitat type	1
Max. flood height	1
Minimum flow	0.75

$$\frac{\sum_{i=1}^{N} SI_i}{N} = \frac{0.2 + 0.2 + 0.2 + 1 + 1 + 1 + 0.75}{7} = 0.62$$

Production and Rate Modifiers

% Cover	0.2	
Hardness	1	Use lowest of these as both measure nutrients
Nitrate	1	
Degree-days	1	
Land use	1	

$$\frac{\sum_{i=1}^{N} SI_i}{N} \times \mathit{Habitat\ potential}$$

$$= \frac{0.2 + 1 + 1 + 1}{4} \times 0.62$$

$$= 0.50$$

Lethal Modifiers

pH	1
Lethal temperature	1

Example B: $0.5 \times 1 \times 1 = 0.5$

The result seems reasonable -- probably a shallow, wide, stream section with fine consolidated substrate?

There were no lethal modifiers in this example, and in reality, they are probably rare conditions. They do pose the question about possible compensatory responses on the part of the salmon stock. It can be assumed that lethal modifiers act over a wide area. However, there are almost certainly temperature refugia due to ground water inflows and cool tributaries. The lower density remaining is likely to grow faster and experience reduced mortality. Should effects of lethal modifiers be down-weighted?

Example 3: Based on values in Table A-2

Habitat descriptor

Substrate rating	1
Width	1
Embeddedness	1
Depth * Velocity	0.75
Habitat type	1
Max. flood height	0.45
Minimum flow	0.75

$$\frac{\sum_{i=1}^{N} SI_i}{N} = 0.85$$

Production and Rate Modifiers

% Cover	1	
Hardness	0.45	Use lowest of these as both measure nutrients
Nitrate	0.45	
Degree-days	0.45	
Land use	1	

$$\sum_{i=1}^{N} \frac{SI_i}{N} \times 0.85 = 0.62$$

Lethal Modifiers

pH	0.45
Lethal temperature	0.2

$$\textit{Aggregate HSI} \quad 0.62 \times 0.45 \times 0.2 \times = 0.06$$

Very poor habitat due to the lethal conditions of pH and temperature.

$$\textit{Example C}: \quad \textit{simple} \ \frac{\sum \textit{individual SIs}}{N} = 0.65$$

Again, the result is very sensitive to the method of aggregation. The lethal modifiers exert a very large influence on the aggregate rating.

Participant # 3

I distributed the variables into three categories:

Category 1 - Stream morphology

Territory	Substrate rating
	% Embeddedness
	Stream Width
	% Overhanging Cover
Discharge	Flood Height (Annual Variation)
	Minimum Flow - summer
	Minimum Flow - winter
Depth*Velocity	Mean velocity
	Mean Depth
	Depth * Velocity
	Habitat type

Category 2 - Survival

Water Quality	
fry	Lethal Temperature
embryo	pH
	Degree Days Incubation

Category 3 - Scaling suitable habitat

Productivity	Hardness
	Nitrate Rating
	Degree Days Growth
	Land use

Example 1: Based on SI values in Table A-1

Category 1 - Stream morphology

Territory	Substrate rating	0.2	
	% Embeddedness	0.2	
	Stream Width		0.2
	% Overhanging Cover	0.0	

Territory SI = mode (of variables) = 0.2

Discharge	Flood Height	1.0
	Minimum Flow - summer	0.6
	Minimum Flow - winter	0.5

Discharge SI = minimum (of winter, summer flow variables) = 0.5
(expect limited variability)

Depth*Velocity	Mean velocity	1.0
	Mean Depth	1.0
	Depth * Velocity	1.0
	Habitat type	1.0

Depth * Velocity SI = mode (of variables) = 1.0

Category 2 - Survival

Water Quality			
fry	Lethal Temperature	1.0	
embryo	pH		1.0
	Degree Days Incubation	1.0	

fry SI = minimum (of variables) = 1.0
embryo SI = minimum (of variables) = 1.0

Category 3 - Scaling suitable habitat

Productivity	Hardness	1.0
	Nitrate Rating	1.0
	Degree Days Growth	1.0
	Land use	1.0

Scaling SI = mode (of variables) = 1.0

Assessment: There is good water quality. Low flows reduce density but not through extended periods of lethal temperatures, probably because of shade. Flood flows, depth/velocity, and habitat are all suitable. Substrate is not suitable for fry territories or embryo survival. With a width of approximately 1 m and 100% overhanging cover, the site is rated as unsuitable. Winter survival of embryo and fry are low due to embedded substrate and low flows. Fry territories and embryo survival are limited because of the poor substrate and low flows. Thus, although it is potentially productive, the overall the quality of the habitat at the site is poor, and I would expect low fry densities in late summer.

MODEL - HSI = minimum (of sub-category SI) = 0.2

Example 2: Based on SI values in Table A-2

Category 1 - Stream morphology

Territory	Substrate rating	1.0
	% Embeddedness	1.0
	Stream Width	1.0
	% Overhanging Cover	1.0

Territory SI = mode (of variables) = 1.0

Discharge	Flood Height	0.5
	Minimum Flow - summer	0.8
	Minimum Flow - winter	0.7

Discharge SI = minimum (of winter, summer flow variables) = 0.7
(expect annual variability due to floods)

Depth * Velocity	Mean velocity	0.5
	Mean Depth	0.5
	Depth * Velocity	0.5
	Habitat type	1.0

Depth * Velocity SI = mode (of variables) = 0.5

Category 2 - Survival

Water Quality		
fry	Lethal Temperature	0.1
embryo	pH	0.5
	Degree Days Incubation	0.5

fry SI = minimum (of variables) = 0.1
embryo SI = minimum (of variables) = 0.5

Category 3 - Scaling suitable habitat

Productivity	Hardness	0.5
	Nitrate Rating	0.5

Degree Days Growth	0.6
Land use	1.0

Scaling SI = mode(of variables) = 0.5

<u>Assessment</u>: There is suitable but not exceptional productivity. Substrate and minimum flows are suitable for a high density of territories, and embryo survival. Suitability is moderate based on depth, velocity, and habitat type. Although minimum flows do not limit territories, flood discharges do and annual variability in densities is likely to be high. Winter temperatures and spring pH reduce embryo survival. In addition, the site reaches lethal temperatures for fry in summer. Because of the effects of poor water quality on embryo and fry survival the habitat quality of this site is poor. If the temperature problem could be mitigated by nearby cool water refugia, then habitat quality would be good.

MODEL - HSI = minimum(of sub-category SI) = 0.1 - no refugia
MODEL - HSI = minimum(of sub-category SI) = 0.5 - refugia

<u>Example 3: Based on SI values in Table A-3</u>

<u>Category 1 - Stream morphology</u>

Territory	Substrate rating	1.0	
	% Embeddedness	1.0	
	Stream Width		1.0
	% Overhanging Cover	1.0	

Territory SI = mode (of variables) = 1.0

Discharge	Flood Height	0.3
	Minimum Flow - summer	0.8
	Minimum Flow - winter	0.7

Discharge SI = minimum (of winter, summer flow variables) = 0.7
(expect annual variability due to floods)

Depth * Velocity	Mean velocity	0.9
	Mean Depth	0.8
	Depth * Velocity	0.9
	Habitat type	1.0

Depth * Velocity SI = mode (of variables) = 0.9

Category 2 - Survival

Water Quality		
fry	Lethal Temperature	0.7
embryo	pH	0.3
	Degree Days Incubation	0.1

fry SI = minimum (of variables) = 0.7
embryo SI = minimum (of variables) = 0.1

Category 3 - Scaling suitable habitat

Productivity	Hardness	0.3
	Nitrate Rating	0.3
	Degree Days Growth	0.4
	Land use	1.0

Scaling SI = mode (of variables) = 0.3

Assessment: There is low productivity and a short growing season. Substrate and minimum flows are suitable for a high density of territories, and embryo survival. Suitability is high based on depth, velocity, and habitat type. Although minimum flows do not limit territories, flood discharges cause high annual variation. Winter temperatures and spring pH reduce embryo survival. However, the site does not reach lethal temperatures for fry in summer. If one only considers the effects of poor water quality on embryo survival the habitat quality of this site is poor. However, dispersing fry should survive well at this site. The morphology of the site makes it excellent fry habitat (0.7) and the scaling variables and flood height indicate that there may be weak and strong year classes and that it may take more than 2 years to produce a smolt at this site.

MODEL - HSI = minimum (of sub-category SI) = 0.3 - no embryo SI
MODEL - HSI = minimum (of sub-category SI) = 0.1 - embryo SI