# Proceedings of the DFO Workshop on Research Priorities to Improve Methods for Assessing Productive Capacity for Fish Habitat Management and Impact Assessment, Sidney, B.C., May 13-15, 1996

C.D. Levings[1], C.K. Minns[2] and F. Aitkens[3]
(Editors)

[1]Department of Fisheries and Oceans
Science Branch, Pacific Region
West Vancouver Laboratory
4160 Marine Drive
West Vancouver, B.C.
V7V 1N6

[2]Great Lakes Laboratory for Fisheries and Aquatic Sciences
Bayfield Institute
867 Lakeshore Road
PO Box 5050
Burlington, Ontario L7R 4A6

[3]2023 Meadow Place
Victoria, B.C. V8R 1R2

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# PROCEEDINGS OF THE DFO WORKSHOP ON RESEARCH PRIORITIES TO IMPROVE METHODS FOR ASSESSING PRODUCTIVE CAPACITY FOR FISH HABITAT MANAGEMENT AND IMPACT ASSESSMENT, SIDNEY, B.C., MAY 13-15, 1996.

Editors: C.D. Levings[1], C.K. Minns[2] and F. Aitkens[3]

[1]Department of Fisheries and Oceans
Science Branch, Marine Environment and Habitat Science Division
West Vancouver Laboratory
4160 Marine Drive
West Vancouver, B.C.
V7V 1N6

[2]Great Lakes Laboratory for Fisheries and Aquatic Sciences
Bayfield Institute
867 Lakeshore Road
PO Box 5050
Burlington, Ontario L7R 4A6

[3]2023 Meadow Place
Victoria, B.C. V8R 1R2

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CONTENTS

## ABSTRACT

Levings, C.D., C.K. Minns and F. Aitkens. 1997. Proceedings of the DFO Workshop on Research Priorities to Improve Methods for Assessing Productive Capacity for Fish Habitat Management and Impact Assessment, Sidney, B.C., May 13-15, 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2147: 109 p.

Recognizing the urgent need for scientifically defensible techniques for measuring changes in the productive capacity (PC) of fish habitats, DFO's National Coordinating Committee for the Environmental Science Program proposed a workshop to bring researchers and managers together to address this issue. DFO habitat managers and researchers from all regions convened at the Institute of Ocean Sciences, Sidney BC, May 13-15 1996, to discuss science priorities. Background and status papers on marine, estuarine, anadromous, and fresh water fish habitat research were given on results from each of the Regions, and are presented in these Proceedings. Work groups were struck to discuss priorities for future research. Ten themes emerged as the most important, as follows in approximate ranked order: Extension and technology transfer; Measurement of productive capacity; Mitigation, restoration, and compensation techniques; Ecosystem research; Technology for habitat characterization; Modeling of productive capacity and advancing understanding of the concept; Habitat mapping; Research on habitat alterations; Retrospective analyses; and Risk analyses. The recommendations of the Work Groups made it clear that while habitat science research priorities inevitably involve much broader questions than measurement of PC, the estimation of PC is central to the way DFO fish habitat management science does business. They also made it clear that a narrowly focused habitat research program that concentrated only on this topic will not meet contemporary needs which must involve consideration of protected areas, cumulative impacts, sustainable productivity, environmental quality, and biodiversity, in relation to the Fisheries Act, the habitat policy, and the recently-proclaimed Canada Oceans Act. There was a consensus at the workshop that a broad-based ecosystem approach is essential.

## RÉSUMÉ

Levings, C.D., C.K. Minns and F. Aitkens. 1997. Proceedings of the DFO Workshop on Research Priorities to Improve Methods for Assessing Productive Capacity for Fish Habitat Management and Impact Assessment, Sidney, B.C., May 13-15, 1996. Can. Tech. Rep. Fish. Aquat. Sci. 2147: 109 p.

Reconnaissant qu'il est impératif de disposer de techniques scientifiquement défendables pour mesurer les variations de la capacité de production des habitats du poisson, le Comité national de coordination du Programme des sciences de l'environnement du MPO a proposé l'organisation d'un atelier regroupant des chercheurs et des gestionnaires afin qu'ils se penchent sur cette question. Des gestionnaires de l'habitat du MPO et des chercheurs de toutes les régions se sont réunis à l'Institut des sciences de la mer à Sidney (C.-B.), du 13 au 15 mai 1996, afin d'examiner les priorités scientifiques. Des documents de base et des documents sur l'état d'avancement des recherches sur l'habitat des poissons marins, estuariens, anadromes et d'eau douce ont porté sur les résultats de chacune des Régions, et ils sont présentés dans ces comptes rendus. Les groupes de travail ont été amenés à examiner les priorités en vue de recherches futures. Dix thèmes sont apparus comme les plus importants et sont énumérés dans l'ordre d'importance approximatif suivant : extension et transfert technologique; mesure de la capacité de production; techniques d'atténuation, de rétablissement et de

compensation; recherches écosystémiques; techniques de caractérisation de l'habitat; modélisation de la capacité de production et avancement des connaissances du concept; cartographie de l'habitat; recherches sur les altérations de l'habitat; analyses rétrospectives et analyses des risques. Il est précisé dans les recommandations des groupes de travail que les priorités de recherche dans le domaine des sciences de l'habitat touchent inévitablement des questions beaucoup plus vastes que la mesure de la capacité de production, cependant l'estimation de ce paramètre détermine la façon dont on gère le secteur de la gestion de l'habitat du poisson du MPO. Ils ont également précisé qu'un programme de recherche sur l'habitat du poisson très pointu, axé seulement sur ce sujet, ne répondra pas aux besoins actuels qui doivent prendre en compte les aires protégées, les effets cumulatifs, la productivité durable, la qualité de l'environnement et la biodiversité par rapport à la *Loi sur les pêches*, à la politique de gestion de l'habitat du poisson et à la nouvelle *Loi sur les océans du Canada*. Lors de l'atelier, tous s'entendaient sur la nécessité d'une approche écosystémique à grande échelle.

ACKNOWLEDGMENTS

Many people helped with the planning, organization and facilitation of the workshop. Thanks are owing to Jill Bell, Institute of Ocean Sciences, and Kathy Vinton, Gibson and Associates, Victoria, for assistance with logistics at the Workshop. Mike McPhee, Quadra Planning Consultants Ltd., West Vancouver, acted as a facilitator for the Workshop and the organizers are also grateful for his guidance and advice when planning the meeting. Partial funding support was provided by the DFO Assistant Deputy Minister (Science) High Priority Fund. Members of the National Committee for Environmental Science (as it was constituted in FY 1995/96) who helped with planning the Workshop were Hugh Bain (National Headquarters), Ken Yuen (Chair, National Headquarters), Paul Kiezer (Maritimes), Martin Bergmann (Central and Arctic), Jean Piuze (Laurentian), Dave Scruton (Newfoundland), and Colin Levings (Pacific, main organizer).

PREFACE

Manuscripts in this Technical Report were not anonymously peer-reviewed. They were read by the Editors and edited only for clarification of meaning where needed. The discussions were transcribed from verbatim tapes made at the meeting, which are archived with Ms. Fran Aitken. The opinions expressed in the papers and discussions are those of the authors or speakers.

# EXECUTIVE SUMMARY

by C.D. Levings[1], C. K. Minns[2], and H.Bain[3]

The guiding principle of no net loss of the productive capacity (PC) of fish habitats is the cornerstone of the DFO Fish Habitat Management Policy (1986). The concept of "productive capacity" was developed by fish habitat managers when the Policy was formulated. A national habitat committee which included DFO scientists vetted the idea of PC but there was no rigorous review in the open scientific literature to determine if PC was measurable. However PC must be measurable in a scientifically defensible manner to make the Policy operational, since "if you can't measure it, you can't manage it". If measurement of PC is based on weak science, this would present a major technological problem for the Department. Those drafting the policy may have envisioned a qualitative concept, similar, perhaps, to the land capability ratings used by terrestrial habitat managers (e.g. Harper et al 1993). A more recent Policy directive to regional habitat managers from National Headquarters (May 25, 1995) dealing with projects which have the potential to harmfully, alter, disrupt, or destroy fish habitat heightened concerns over the measurability of productive capacity. Recognizing the potential difficulty of devising operational measures of PC, this directive allowed for the use of surrogates to PC: "...the effects of a project on the physical, chemical, and biological components of fish habitat will normally be assessed as surrogates for impacts to productive capacity"

Demand for tools to measure changes in productive capacity of fish habitat remains a priority issue for habitat managers. Since the Policy was released in 1986 substantial efforts have focused on how PC should be assessed and used as a management tool. Several national and international meetings have been held on this topic. e.g. Nanaimo (1987: Levings et al 1989), Burlington (April 1988), (unpublished workshop notes), Halifax (CAFSAC, 1990), and Canberra, Australia (Hancock, 1993) and there have been major advances in measurement of PC (e.g. Minns 1995). The DFO habitat program has been widely acknowledged as progressive towards sustainability and has received accolades from some workers (e.g. Brouha, 1993). However, without appropriate tools to measure PC, proponents and habitat managers are forced to make decisions based on unsubstantiated opinions and subjective arguments. The measurement of PC, the quantification of relationships between habitat features and fish production, remains : " the most important and most difficult aspect of fish habitat management' (Levings et al 1989).

Recognizing the urgent need for scientifically defensible techniques for measuring changes in the productive capacity of fish habitats, DFO's National Coordinating Committee for the Environmental Science Program in November 1995 proposed a workshop to bring researchers and managers together to address this issue. The proposed objectives of this workshop planned for September 1996 were to: (1) compare methods currently in use across the country, (2) determine the shortcomings of these from science and operational perspectives, and (3) reach a consensus on the directions of new research together with an

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[1] Department of Fisheries and Oceans, Science Branch Pacific Region, West Vancouver Laboratory, 4160 Marine Drive, West Vancouver, B.C., V7V 1N6

[2] Great Lakes Laboratory for Fisheries and Aquatic Sciences, Bayfield Institute, 867 Lakeshore Road, PO Box 5050, Burlington, Ontario L7R 4A6

[3] Environmental Science Branch, 200 Kent Street, Ottawa, Ontario, K1A 0E6

estimate of financial resources for priority work. However events overtook the planning. The Assistant Deputy Minister of Science's request for a strategic plan for the DFO Environmental Science by May 31 1996 forced the organizers to focus on research priorities. Hence DFO staff, habitat managers and researchers from all regions convened at the Institute of Ocean Sciences, Sidney BC, May 13-15 1996, to discuss the science priorities.

Scientific events and publications external to DFO again overtook workshop planning and the original agenda for work group discussions was changed. Recognizing some of the fundamental ecological differences between marine, estuarine, anadromous, and freshwater habitats, particularly the open nature of the first two areas, the original agenda suggested that Working Groups be struck to discuss specific recommendations for a research program to improve our capability to assess productive capacity for spawning and rearing habitats for freshwater, anadromous, estuarine, and marine species. However given that: (1) the recently published Habitat Research Plan (HRP) of the U.S. National Marine Fisheries Service (Thayer et al 1996) provided a model framework for discussing general fish habitat research needs, and (2) specific program recommendations with costs and timelines were no longer needed, the work groups struck at the workshop were given a more open mandate. Groups were charged with the task of developing generic research priorities for PC research, and given the option of using the HRP as a framework. The HRP recognizes the need for research in five priority areas: ecosystem structure and function, effects of habitat alteration, habitat restoration methods, impact and recovery indicators, and synthesis and information transfer.

The recommendations of the work groups are summarized in Table 1. There were ten themes that emerged as the most important, as follows in approximate ranked order:

1. Extension and technology transfer
2. Measurement of productive capacity
3. Mitigation, restoration, and compensation techniques
4. Ecosystem research
5. Technology for habitat characterization
6. Modeling of productive capacity and advancing understanding of the concept
7. Habitat mapping
8. Research on habitat alterations
9. Retrospective analyses
10. Risk analyses

The recommendations of the Work Groups made it clear that while habitat science research priorities inevitably involve much broader questions than measurement of PC, the estimation of PC is central to the way DFO fish habitat management science does business. They also made it clear that a narrowly focused habitat research program that concentrated only on this topic will not meet contemporary needs which must involve consideration of protected areas, cumulative impacts, sustainable productivity, environmental quality, and biodiversity, in relation to the Fisheries Act, the habitat policy, and the recently-proclaimed Canada Oceans Act. There was a consensus at the workshop that a broad-based ecosystem approach is essential. One of the work groups chose to use the HRP framework as a template for identification of more specific topics. The other three groups independently identified the requirement for a comprehensive program over and above measurement of PC.

Since the work groups were well represented by habitat managers it was notable that Science clients need a broad-based research program of ecosystem research with a focus on methods of measuring of PC.

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Thayer, G.W., Thomas, J.P., and K.V. Koski, 1996. The Habitat Research Plan of the National Marine Fisheries Service. Fisheries 21(5):6-10.

Table 1. Summary of main themes for priority fish habitat research, derived from written and narrative reports of the four Work Groups.

| Theme | Group A | Group B | Group C | Group D |
|---|---|---|---|---|
| Extension and Technology Transfer | Extension Activities (3 challenges) | Synthesis and information transfer (1 priority) | Environmental science needs to do a better job in transferring research results to habitat managers (3 recommendations) | Enhance communication between habitat managers and scientists (4 priorities) |
| Measurement of Productive Capacity | operational definition of productive capacity (3 challenges) | Indicators of habitat impacts and recovery (2 priorities) | Development of practical habitat management tools using defensible science (6 recommendations) | Science in support of habitat management (4 priorities) |
| Mitigation, Restoration, and Compensation Techniques | Development and evaluation of mitigation, restoration, compensation, and enhancement techniques (3 challenges) | Habitat Restoration and creation (3 priorities) | Testing mitigation/compensation techniques (3 recommendations) | Experimental validation of habitat restoration, enhancement and compensation methodology (one priority) |
| Ecosystem Research | N.E.I. (not explicitly identified) | Ecosystem Structure and Function (4 priorities) | Research on life history as it is related to habitat use (2 recommendations) | Ecosystem structure and function (3 priorities) |
| Technology for Habitat Characterization | Technology development for the characterization of habitat (4 challenges) | N.E.I. | N.E.I. | Managing area habitat systems and cumulative impacts (3 priorities) |
| Modeling of Productive Capacity and advancing understanding of the concept | Methodology to model productive capacity of habitats (4 challenges) | N.E.I. | Improve understanding of the concept of Productive Capacity (2 recommendations) | N.E.I. |
| Habitat mapping | Habitat characterization and data management (8 challenges) | N.E.I. | Habitat mapping (one recommendation) | N.E.I. |
| Research on Habitat Alterations | N.E.I. | Effects of habitat alterations (6 priorities) | N.E.I. | Scientifically defensible cause-effect research into specific habitat impacts |
| Retrospective Analyses | N.E.I. | N.E.I. | avoid reinvention and make sure recommendations implemented | retrospective assessment of habitat decisions to improve and fine tune decision making and other tools (3 priorities) |
| Risk Analyses | N.E.I. | N.E.I. | N.E.I. | incorporate explicit statements of uncertainty associated with habitat advice and information |
| Funding issues | N.E.I. | N.E.I. | N.E.I. | improve funding stability climate for planning and research |

DFO WORKSHOP ON RESEARCH PRIORITIES TO IMPROVE METHODS FOR ASSESSING PRODUCTIVE CAPACITY FOR FISH HABITAT MANAGEMENT AND IMPACT ASSESSMENT

May 13 - 15, 1996

Institute of Ocean Sciences

Sidney, B.C.

**AGENDA MAY 13**

Welcome and Introductory Remarks -- Hugh Bain

**Background Papers** (Chair: Hugh Bain)

1. Productive Capacity Estimates for Habitat Management Serge Metikosh, Habitat Management, Central and Arctic

2. Habitat Hydraulic Models in other Jurisdictions Dave Scruton, Science Branch, Newfoundland

**Synopsis of Current Methods in the Regions**

**Newfoundland**

Freshwater / Freshwater Anadromous Productive Capacity: *D.A. Scruton, J.B. Dempson, R.J. Gibson, and M.A. Barnes.*

Estuarine and Marine Carrying Capacity in Newfoundland and Labrador: *M.R. Anderson, J.T. Anderson, M.A. Barnes, and J.B. Dempson.*

**Laurentian**

Laurentian Region Habitat Sciences Program: Summary: *Gordon Walsh*

**Maritimes**

Assessing Productive Capacity of Maritimes Region Rivers to Produce Atlantic Salmon and Other Diadromous Fish: *Peter G. Amiro.*

Assessing the Productive Capacity of Fish Habitat: Synopsis of Methods Used in Estuarine and Marine Habitats: *D.C. Gordon Jr, P.D. Keizer, P. Lawton, R.J. Rutherford, and W.L. Silvert.*

**Central and Arctic**

Science for Fish Habitat Management: A Fresh Perspective: *C.K. Minns.*

Assessment of Productive Capacity for Canadian Arctic Seas and Estuaries: *Harold Welch.*

**Pacific**

Productive Capacity: Freshwater/Freshwater Anadromous: *I. Williams, M. Bradford, K. Shortreed, J. Hume, S. Macdonald, B. Holtby, G. Ennis, G. Logan, and H. Stalberg.*

An Overview of the Science Supporting Marine and Estuarine Fish Habitat Management in Pacific Region: *Colin Levings.*

**Final Discussion**

**Wrap-up and Preview of Day 2** (Mike McPhee)

**AGENDA MAY 14**

**WORKING GROUPS**

8:30 am Meet in Plenary -- overview of group discussion objectives and process

(Mike McPhee)

8:45 Breakout into Workshop Discussion Groups

Participants will be divided into groups:

Each discussion group will be led by a facilitator and assisted by a rapporteur.

Each discussion group begins by identifying key issues/topics in their area for further examination and discussion. The following discussion topics have already been suggested: a) development of practical habitat management tools using defensible science; b) protocols for habitat management plans and linkages with site-level referrals; and, c) testing of mitigation/compensation techniques.

10:00 Grouping and selection of priority items for further discussion. (Given time limitations a maximum of 5 topics per group is recommended).

**10:30-10:45 Refreshment Break**

10:45 Discussion of Priority Items

In each group, for each priority item identify:

- challenges (problems, concerns, what hasn't worked, what needs to change, etc.)
- opportunities (for overcoming challenges, what has worked, what does it make sense to continue, etc.)
- Final recommendations

| | |
|---|---|
| **12:30** | **Lunch** |
| 1:30 | Discussion of Priority Items continued |
| **3:00-3:15** | **Refreshment Break** |
| 3:15-4:30 | Discussion of Priority Items continued |
| 4:30-5:00 | Facilitator and rapporteur summarize key points from discussion which will form the basis for the presentation to the Day 3 Plenary. |

**AGENDA MAY 15th**

**PLENARY SESSION**

| | |
|---|---|
| 8:30 am | Participants reconvene in plenary. The rapporteurs for each working group will present a 15-minute summary of the key points and research recommendations from their group discussions. |
| **10:30** | **Refreshment Break** |
| 10: 45 | Final discussion |
| 11:45 | Concluding Remarks -- Hugh Bain |
| 12:00 | Workshop adjourns |

# NO NET LOSS IN THE 'REAL' WORLD

by

Serge Metikosh

Habitat Management

Central and Arctic Region

867 Lakeshore Road, Box 5050

Burlington, Ontario

L7R 4A6

## INTRODUCTION

The Habitat Management program is responsible for administering the habitat protection provisions of the *Fisheries Act* and implementing Department of Fisheries and Oceans' Policy for the Management of Fish Habitat. The concepts of *productive capacity* and *No Net Loss* are central to accomplishing this task. Habitat managers are constantly forced to make decisions based on relatively abstract definitions of these terms. Such decisions often appear to be inconsistent and are always difficult to defend when challenged. Setting research priorities to improve methods for assessing productive capacity must take into account the non-scientific/non-research aspects of delivering this program. In planning research priorities, science needs to be aware of the legislation and the policies that drive it, the science needed to support it, and the role that operational personnel must play to weave these components into something called habitat management. In the following paper I provide a brief summary of the habitat protection provisions of *Fisheries Act* and the Policy for the Management of Fish Habitat. I will also outline how the legislation and the policy are used together to manage habitat, my impression of our success in achieving no net loss, and what I believe to be needed research.

## LEGISLATION AND POLICY

### The Fisheries Act

The *Fisheries Act* is federal legislation dating back to the time of Confederation. It was established to manage and protect Canada's fisheries resources and applies to all fishing zones, territorial seas, and inland waters. It is also binding on federal, provincial, and territorial governments and by virtue of the Doctrine of Paramountcy it supersedes provincial legislation. The habitat protection and pollution prevention provisions of the *Fisheries Act* were included in the early 1970s. These appeared as general prohibitions that forbade the harmful alteration, disruption, or destruction of fish habitat and the discharge of deleterious substances. Section 35(1) and section 35(2) specifically deal with habitat protection. It is these two subsections that provide the legal basis for the habitat management program.

According to Section 35(1) the *harmful alteration, disruption, or destruction* of fish habitat (known as HADD) is prohibited. Note that this is a general prohibition for which there is no defense. It simply says anyone harmfully altering, disrupting, or destroying fish habitat is guilty of an offense. Section 35(2) however does provide a way out. It says that no one violates the prohibition of Section 35(1) if the Minister of Fisheries and Oceans has given them the authority to harmfully alter, disrupt, or destroy fish habitat. It is not mandatory for a proponent to have an authorization to proceed with a project. However, penalties consisting of fines of up to one million dollars and/or imprisonment provide proponents with the motivation to seek authorization.

### Policy for the Management of Fish Habitat

In October 1986, the federal Department of Fisheries and Oceans (DFO) released its Policy for the Management of Fish Habitat. The policy recognized that fish habitats constitute healthy production systems for Canada's fisheries resources and reaffirmed the need for their management and protection. The overall objective of the policy, was to obtain a **net gain** in the productive capacity of fish habitat. The objective is reached through achieving the following three goals:

1. **Conservation** of existing habitats;

2. **Restoration** of damaged habitat; and

3. **Development** of new habitats.

Conservation – the first goal towards achieving the net gain objective – requires that the current productive capacity of existing habitats be maintained through the application of the no net loss guiding principle. Under this principle, existing fish habitats are protected while unavoidable habitat losses are balanced with replacement habitat.

IMPLEMENTATION: THE LINK BETWEEN FISHERIES ACT AND POLICY

The requirement under the *Fisheries Act* for authority to harmfully alter, disrupt, or destroy fish habitat and the guiding principle of ***No Net Loss*** outlined in the Policy are used together to conserve and protect fish habitat.

The first choice is to avoid the harmful alteration, disruption, or destruction of fish habitat through mitigation (*actions taken during the planning, design, construction and operation of works and undertakings to alleviate potential adverse effects*). By definition, mitigation measures, if applied successfully, will avoid harmful alteration, disruption, or destruction of fish habitat (HADD). If HADD is avoided there is no violation of Section 35(1) of the *Fisheries Act*. No authorization is required.

However, if mitigation fails to prevent *HADD*, the proponent will require an authorization from DFO to avoid prosecution under Section 35(1) of the *Fisheries Act*. Authorizations are issued on the condition that the proponent implements measures to compensate (*replace natural habitat or increase the productivity of natural habitat*) for the habitat harmfully altered, disrupted, or destroyed as a result of the undertaking. Generally, no authorizations are issued without compensation or in cases where the loss of a specific habitat type is unacceptable.

The word **harmful** is critical to the application of Section 35(1) of the *Fisheries Act*. The alteration and disruption (and presumably destruction) of fish habitat can occur provided it is not harmful. Although fish habitat is defined by the *Fisheries Act*, there is no clear definition of what constitutes **harmful**. One way of approaching the problem is to interpret the *Fisheries Act* definition of habitat (*"spawning grounds and nursery, rearing, food supply migration and any other areas on which fish depend directly or indirectly in order to carry out their life processes)* as representing those physical features that, in addition to good water quality, provide for the basic life requisites of food, reproduction, cover, and the corridors that connect them. Then, any changes that adversely affect the abilities of the physical habitat to provide these basic life requisites can be considered a **harmful** alteration, disruption, or destruction of fish habitat. For example, if work on a shoreline changes the physical habitat such that it no longer provides food, then that activity can be considered *harmful*. At the outset, it would appear that this definition provides a simple way for consistently interpreting the word harmful; one that has some basis in science and could be applied in an operations context. However, after some serious "spin doctoring" the definition of HADD evolved into:

"... any **meaningful** change in one or more habitat components that **can reasonably be expected** to cause a **real** reduction in the capacity of the habitat to support the life requisites of fish." (Decision Framework for the Determination and Authorization of Harmful Alteration Disruption and Destruction of Fish Habitat. Final Draft, January 1996)."

Is anyone surprised?

Generally, habitat managers do not encounter difficulties in determining whether there is fish habitat present or whether a given activity results in a HADD. Most difficulties are encountered when assigning a 'value' to the habitat affected by the undertaking and determining the compensation measures. The value of a particular habitat type or its relative productive capacity is difficult to determine. There are no consistent methods. This becomes even more complicated when issues such as uniqueness, supply, and incremental loss become factors. Decisions are often based on a combination of science and intuition. They are rarely quantitative. Similarly, decisions on the appropriate compensation measures and the amount of compensation needed to achieve No Net Loss are generally made on the basis of professional judgement. In the majority of cases, the compensation measures implemented are a balance between what the habitat biologist considers reasonable and what the proponent is prepared to do. These too are rarely quantitative or defensible. Typical projects appear in the following table:

| **ACTIVITY** | **COMPENSATION** |
|---|---|
| Shore alteration<br>Infilling<br>Erosion control | "Soft" engineering<br>Structure<br>Substrate diversity<br>Shoreline vegetation<br>Aquatic macrophytes<br>Slope modification<br>Island construction |
| Water management structures<br>Small hydroelectric<br>Flood control | Reservoir regime<br>Flow regime<br>Structure<br>Substrate diversity<br>Channel modification<br>Fishways |
| Water course diversion<br>Channelization | "Natural" channel design<br>Channel modification<br>Structure<br>Substrate diversity<br>Riparian vegetation |

| ACTIVITY | COMPENSATION |
|---|---|
| Water crossings | Channel modification |
| Bridges and culverts | Riparian vegetation |
| Pi :lines | Structure |
| | Substrate diversity |

Such projects generally account for the bulk of the authorizations issued. For the most part these are small to medium in size and take no more than twelve to sixteen months to complete. It is tempting to suggest that the impact of these activities is trivial, yet incrementally they represent a major source of habitat loss. Ignoring the small ones in favour of the large ones will not lead to No Net Loss.

The projects listed above are also 'typical' because a set of compensation measures (albeit untested) is available. There are other projects such as those involving whole-lake destruction, conversion, or transfer of habitat type (e.g., changing flowing rivers into manipulated reservoirs), or wetland destruction, that are atypical in that compensation methods are largely unknown or unavailable.

In the absence of more quantitative procedures, the current approach to making habitat management decisions has worked reasonably well, particularly for the typical projects. However, where there is disagreement on the 'value' of the habitat or the compensation measures required, conflicts arise between the habitat manager and the proponent. Generally there is no simple resolution to these conflicts. Indeed, such disagreements are often resolved either by the courts or at the political level. Either way the result is rarely No Net Loss.

Is No Net Loss Achieved?

The short answer is, we don't know. However, it is unlikely that true No Net Loss of productive capacity has been achieved. At best it is possible that we are approaching No Net Loss of physical habitat. Nevertheless, it is not possible to determine whether mere replacement of physical habitat actually equates to the replacement of the habitat productivity originally lost. The nagging question yet to be answered is, Does construction of a new channel really replace the productivity of the existing channel lost to development? If achieving No Net Loss is unlikely, what has been achieved by the habitat program? There has been a tangible change in attitude and an increased awareness of the *Fisheries Act* and the importance of fish habitat. Mitigation measures that were at one time rare or appeared only when specified in permits or letters of advice are now routine. Fish habitat considerations have become major components of most project proposals. It is safe to say that since the implementation of the Policy the rate of habitat loss has declined.

Problems and Solutions

What are the reasons for being unable to determine if No Net Loss has been achieved? There are many. Some are related to the lack of supporting science, others are due to a lack of appropriate and well-defined policies. The ones I feel are the most important are summarized below:

- No consistent scientifically defensible quantitative method to determine productive capacity
- No consistent scientifically defensible quantitative method to assess habitat quality
- No link between quality and quantity of habitat and fish production
- Limited number of proven compensation methods
- No quantitative methods for assessing the effectiveness of compensation measures

The effort directed towards habitat research and policy development needs to be linked in order to resolve these problems. Policy must evolve from the science. Science must develop the tools that will permit habitat managers to make defensible decisions. This is a task for both the research and policy sides of the Department. Specific needs for both are outlined in the following table:

| **SCIENCE** | **POLICY** |
|---|---|
| Develop a quantitative scheme for No Net Loss accounting. | Relate habitat management to sustainable and achievable fish community objectives. |
| Develop simple but scientifically defensible tools for assessing habitat quality and quantity. | Develop unambiguous scientifically defensible policy to deal with whole-lake destruction. |
| Develop simple but scientifically defensible tools for linking habitat quality and quantity with fish production. | Develop unambiguous scientifically defensible policy to deal with wetland destruction. |
| Develop simple but scientifically defensible tools for predicting project impacts on productive capacity. | Develop unambiguous scientifically defensible policy to deal with habitat conversions. |
| Develop simple but scientifically defensible tools for compensating HADD. | Develop defensible procedures and policies to rationalize habitat losses with socio-economic benefits. |
| Develop simple but scientifically defensible tools for assessing the effectiveness of compensation measures. | |

## DISCUSSION

**Don Gordon:** I have a question on terms. When you started using the term *compensation*, I was thinking in terms of dollars, but the example you gave I see as mitigation measures. That is one viewpoint of the terminology.

The main point of my question is – are there actually any cases where you cannot mitigate, yet approval is given – if, in fact, the compensation is given in terms of money. For example, money can be used to buy habitat somewhere else, such as a salt marsh that will go into some type of land trust.

**Serge Metikosh:** I'll ask my colleague Jeff Stein to answer that. I think we've sold a lake here and there.

I guess you're right. One of the problems with the policy overall, going back to the terminology, is that there is a real confusion over what mitigation and compensation and so on are. If you read the policy, it very clearly says that compensation is the replacement of habitat, and mitigation is voiding the situation. The policy also says that generally speaking, we don't accept cash for habitat. Habitat isn't for sale. There have been times when, in order to get the biggest bang for the buck, we have had situations where we may not have done habitat compensation on-site. Why go out and fix a lake in the middle of nowhere that isn't broken and that doesn't help things out from a fisheries management perspective? In those cases, there have been situations where a certain sum of money has been accepted in order to do compensation in an area that's closer to where the fisheries resource would be of benefit to local residents.

**Otto Langer:** Serge, to some people on the Pacific coast – and, I get the impression, in Ontario also – no net loss means never having to say no. I didn't see the word *No* very prominent in any of your presentations or slides, and that concerns me. It's as though we take too much of an engineering techno-fix to everything. Any habitat is something we can compensate or mitigate. I almost read that into your presentation. Don't you think we need more science to say which habitats are highly productive or sensitive and therefore should not be compromised or touched?

**Serge Metikosh:** In those cases, Otto, it would be a lot easier to say No. We do say No. I tried to allude to that when we dealt with denying authorization, which is, in fact, a No as far as I'm concerned.

As to how often we say No and whether we say No often enough, that is largely a question of what we understand about the habitat. Quite frankly, it's very rare; I agree. Maybe it should be more often, but if we want to be able to say No, we'd better have our ducks in order to be able to make a defensible argument, and I would submit that we can't do that right now.

**Bob Wilson:** This is an observation more than a question. You've called for some tools. The problem with tools is that some tools work really well in some areas and in some cases, and not very well in others. I'd like to use as an example the shoreline armouring procedures you showed in your slides. A debate has been raging on the CoastNet List, which is one of these Internet mailing lists, about shoreline armouring procedures. The views seem to be pretty evenly split. Some people defend them quite strongly, and some people say that they are really destructive of what, on a beach, might be the intertidal zone. The moderators of the list seem to be saying that it depends on the type of beach and on the sediment source. If the sediment source is local, then maybe you're not going to have an intertidal zone; if the sediment source is far away, then maybe it's going to work and you're going to be left with habitat. This is a problem with tools. We get in our toolbox, as you said, a limited number of things that have been demonstrated to work, but they may not work everywhere.

**Serge Metikosh:** Absolutely, Bob.

**Bob Wilson:** You have to have some understanding with that.

**Serge Metikosh:** I couldn't agree with you more. Actually, I'm glad you made that point, because I always use the analogy of a toolbox. Do any of you people get the Time-Life books? You get a whole whack of them: How to Build a Patio, How to Wallpaper Your House. We're in the same situation with habitat management. At this point, we do have some tools. We have a whole whack of things in our toolbox. But I don't think we have the Time-Life manuals yet that say: If you're building a house here, this is where you use your Robertson screwdriver, this is where you use your ratchet, and this is where you use your saw. We don't have that. It's missing, and your point is a good one.

# HABITAT-HYDRAULIC MODELS: DEVELOPMENTS IN OTHER JURISDICTIONS

by

D. Scruton[1], J. Heggenes[2], S. Valentin[3] A. Harby[4] and T.H. Bakken[4],

[1] Department of Fisheries and Oceans
P.O. Box 5667
St. John's, NF
A1C 5X1
CANADA

[2]Department of Nature Conservation
Agricultural University of Norway
P.O. Box 5014
1432 As, NORWAY

[3]Division Biologie des Ecosystemes Aquatiques
Laboratoire d'Hydroecologie Quantitative,
CEMAGREF, 3 bis quai, Chaveau
CP 220, 69336 Lyon
Cedex 09, FRANCE

[4]SINTEF-Norwegian Hydrotechnical Laboratory
7038 Trondheim, NORWAY

# INTRODUCTION

As a result of the ever-increasing competition for available streamflow, a wide variety of approaches have been developed to assess the effects of an altered flow regime on aquatic biota. River flows are used for such projects as hydroelectric developments (river regulation, peaking flows, run-of-the-river, diversions), municipal and industrial water supplies, irrigation, aquaculture, and others. The underlying issue is that these types of projects strive to utilize a portion or all of the available water in a given stream resulting in reduction, regulation, and in some instances augmentation (diversions, peaking power production) of flows. These alterations in the flow regime can have serious impacts for riverine biota, particularly fish, consequently emphasis has been placed on conservation and protection of instream flow requirements while allowing acceptable use of available water. Habitat hydraulic modeling has increased in prominence as a preferred tool for allocation of river flows in some jurisdictions. This approach has largely replaced other 'standard-setting' methodologies and decision-making processes based primarily on hydraulic considerations and which have relied extensively on professional judgment.

Habitat hydraulic models essentially integrate changes in stream-channel hydraulics, which are related to discharge, with changes in physical aquatic habitat for biota of concern. The primary result of this type of model is a relationship between discharge and some expression of available habitat (e.g., usable area). Interpretation of usable area versus discharge functions allows for determination of optimum and critical flows for species and life stages and for identification of potentially limiting habitat conditions. These models are better at predicting habitat conditions for some life history requirements (e.g., spawning, rearing) than for others (e.g., migration). It is important to recognize that these modeling approaches have been developed as tools to allow for an evaluation of the incremental change in habitat in relation to flow to permit (i) assessment of tradeoffs and benefits between life stages and species, and (ii) negotiation between competing users. The key attribute of the habitat-hydraulic modeling approach is that the results are *incremental* which allows the practitioner to determine the relative change in available habitat with change in discharge.

In the context of productive capacity, some important definitions are applied to streamflow regulation. The US Fish and Wildlife Service defines *minimum flow* as the discharge required to maintain a combination of depth, velocity, and substrate conditions that permits continued (level not defined) life functions of selected species or life stages (Bovee and Cochnauer, 1977). Many historical and current flow regimes have striven to identify and provide some level of minimum flow. *Maximum flow* is defined as the discharge conditions that provide habitat conditions at the upper range of species tolerances, and exceedence of this flow would be detrimental to certain species and life stages. This concept applies to projects that may periodically (daily or seasonally) introduce excessive flows or where consideration of the requirements for periodic high flows (sediment flushing, channel maintenance) is included. *Optimum flows* are those that maximize available habitat quantity and quality for certain species or life stages at a given time period.

It is now widely accepted that a single minimum or optimum streamflow is a myth and there is a need to provide a dynamic flow pattern, variable within and between years. This variability in flow is required to provide the hydrological power to maintain channel dynamics and is also considered necessary to provide the seasonal fluctuations desirable to maximize available habitat as necessary for key life stages, which can vary temporally as well as spatially. The increased use and acceptance of hydraulic habitat modeling lies in the need to consider seasonal variability in habitat requirements and a recognition that it is not possible to optimize water allocation or use for all interests. Several recent developments in habitat-hydraulic models have recognized the need to include a temporal component in the analyses.

Biological criteria used in habitat-hydraulic models are necessarily those parameters that are directly related to streamflow and channel hydraulics and vary both laterally and longitudinally in a river. These include depth, velocity, substrate, and (occasionally) cover. These attributes are usually measured and modeled on fine spatial scales and are considered microhabitat criteria. Physical habitat attributes not related to discharge are not normally considered. In some models (e.g., IFIM), parameters that vary longitudinally in the stream (e.g., temperature, DO), considered to be macrohabitat variables, are included. Biological criteria are most often developed separately for individual species, specific life stages of a species, and occasionally for species groups (e.g., guilds) with similar habitat requirements. Species and life stages are selected, for the most part, based on (i) management criteria (important for economic or other criteria, e.g., recreational fish), (ii) indicator species (narrow tolerances; if conditions met for indicator species are assumed to be suitable for other species); (iii) rare and endangered species, and (iv) fish that are competition or forage for important species. Biological criteria can be taken from the literature, but there is increasing attention paid to development of site-specific criteria or evaluation of non-site-specific criteria for transferability. A wide variety of approaches are used to develop criteria, the most common being the underwater observation of fish position (and behaviour) and subsequent measurement of the habitat variables associated with that position. Similarly, a wide variety of methods are available to construct criteria curves or some other expression of habitat preference.

Development of biological criteria — and use in habitat-hydraulic models — involves a number of inherent assumptions that are often not met. Additionally, other biotic and abiotic factors that may be important in determining fish habitat preference are often not considered. These concerns about ecological validity, geographic transferability, seasonal variability, and the multiplicity of inter- and intra-specific interactions have led to extensive criticism of the methods, and in particular the biological models. While not intending to repeat these criticisms here, the habitat-hydraulic models in use in other jurisdictions will be discussed in the context of developments that have addressed shortcomings of current habitat modeling components.

This paper has been developed, in part, as a result of ongoing research in Newfoundland Region conducted under the Habitat Action Plan, Environmental Analysis component. Specifically, a Federal-Provincial effort is underway to test and evaluate a suite of instream flow needs (IFN) methodologies for use in the Region. This project is looking at a tier of approaches varying from standard setting approaches for planning purposes (e.g., Tennant's Method), to mid-range methods (e.g., Wetted Perimeter), to habitat-hydraulic modeling (e.g., IFIM). As part of this study, a comparison of three habitat-hydraulic models currently in use in various jurisdictions has been undertaken. The three models being evaluated are the IFIM (developed in the USA and extensively applied), HABITAT (recently developed in Norway), and EVHA (developed and used in France). This paper reviews the various concepts and application of the three models, discusses certain methodological advances being pursued, and compares and contrasts application of the three methods to modeling flow variation on a Newfoundland river (Pinchgut Brook).

IFIM: INSTREAM FLOW INCREMENTAL METHODOLOGY (USA AND ELSEWHERE)

The Instream Flow Incremental Methodology (IFIM) was developed by the US Fish and Wildlife Service in the late 1970s and has enjoyed widespread application in the USA and elsewhere. The process is managed by a series of computer programs (PHABSIM or the Physical HABitat SIMulation system) which link stream channel hydraulics with aquatic habitat utilization. IFIM is the concept and PHABSIM is the modeling vehicle. PHABSIM uses a number of hydraulic models including WSP ( a step-backwater method), MANSQ (a method employing Manning's equation), and IFG4 (uses rating curves and output from the other models). The requirement for field data collection varies with the hydraulic model used and the conceptual approach to modeling. For example, if IFG4 is used, detailed hydraulic transects (measurements of depth, velocity, and substrate) are needed at one flow and two sets of water-surface elevations are needed at contrasting flows.

There are a variety of approaches to modeling a river segment. The two most common are: (i) selecting and modeling a 'critical' or representative reach involving multiple transect selection within one or more reaches, and (ii) stratified selection where a single transect is placed in several reaches representing available habitat types, and transects are distributed according to the proportional availability of habitat types. As an example of this second approach, in Pinchgut Brook, Newfoundland, five habitat types were identified and a total of 14 transects were proportionally placed to represent these habitats along a 5.2 km reach.

Habitat models are normally expressed as habitat suitability functions (curves) for the variables depth, velocity, and substrate. Many different methods are used in collecting the data and computing the habitat preference functions. These functions are completed separately and the resulting curve coordinates are then used as input to the model. The model calculates a composite habitat suitability value from the univariate curves using several simple approaches (e.g., straight multiplication geometric mean, weighted average, lowest limit). Weighting factors can be determined statistically, but these must be determined outside of the PHABSIM. While available habitat may be computed for the component attributes, the most common output is an incremental curve depicting the weighted usable habitat area (WUA: total of wetted area times the combined suitability on a cell-by-cell basis) in relation to discharge. Weighted Usable Area has been defined by Bovee (1986) as the carrying capacity based on physical habitat conditions alone. Depending on the modeling approach adopted, the output can be weighted by the proportional distribution of habitat (types) in the river segment.

There are a large number of other components of the PHABSIM modeling system which can, for example, integrate temperature effects and allow a 'network' analysis. The model can depict spatial habitat maps (which have not been used as extensively as with HABITAT and EVHA) and a time series component has also been developed. Recently, a user-friendly menu-driven version of PHABSIM (RHABSIM) has been developed by T.R. Payne and Associates and is available as a commercial product.

There has been considerable debate as to the appropriate methods for data collection to develop criteria curves and, most recently, with particular reference to the need to consider available habitat in criteria construction. Previously curves were often constructed considering fish habitat use, subsequently adjusted by available habitat, in order to create 'preference functions.' In the USA, the increasing preference is to develop a sampling methodology that considers available habitat and not to explicitly adjust curves. One example of this approach, as applied at Pinchgut Brook, was to collect fish habitat use data using an *equal area sampling* method where all habitat types were sampled equally within two defined reaches. Curves were then constructed from the habitat use data only and were considered to adequately represent the range of available habitat.

Another issue, which has arisen as use of IFIM method has become more routine, is the requirement to construct river-specific habitat criteria and the costs (effort) associated with this activity. This has led the USFWS (NBS) to develop tests for criteria transferability in order to determine if available non-river-specific criteria may be used in an IFIM analysis. This has resulted in some criticism based on ecological considerations. It is also recognized that, in some instances, field efforts for transferability tests are not appreciably less than those required to develop river-specific information.

HABITAT (Norway)

HABITAT is a component of a large environmental modeling system (the River System Simulator or RSS) recently developed by a number of Norwegian institutions. HABITAT is a habitat-hydraulic model first developed in 1984 by the Norwegian Hydrotechnical Laboratory and the Norwegian Freshwater Ecology and Inland Fisheries Laboratory and is now included in the RSS. The modeling system is under continual development and refinement with the inclusion of additional components and capability. It currently uses the hydraulic model HEC-2 (US Army Corps of Engineers) but will be developed to accept input from any hydraulic model. HABITAT requires input from detailed transects for depth, velocity, and substrate collected at three contrasting discharges. Major efforts are currently underway to develop and implement 2-D and 3-D hydraulic models as optional routines in the HABITAT model. The model is normally run on one or several reaches containing representative habitat types in the modeled segment. Each reach is described in detail by a number of hydraulic transects (in principle at least 2, in practice usually from 5 to 20) spaced at frequent intervals as determined by topography, hydraulic, and biotic conditions (usually between 1 and 20 as a standard).

The initial development of the HABITAT modeling system involved application of habitat models that were appreciably different from those of IFIM and EVHA. Criteria are developed as habitat preference functions, species- and/or life-stage-specific, based on usage/availability data normally collected by underwater observations. Curves are developed after Jacobs (1974) and derived separately for (i) preferred, (ii) indifferent, and (iii) avoided habitat conditions. In the initial iteration of the model, habitat conditions were modeled independently for each attribute, with the explicit intention of NOT combining the component suitabilities. This was largely related to concerns as to interdependence of variables but was also considered to provide more detailed information for evaluation. In this sense, the effect of flow variation on the component variables can be used to identify rapidly changing habitat conditions as well as to illustrate discharge ranges that could be considered limiting. Owing to the large amount of output from this system, and the requirement for subjective interpretation of the results, recent development has focused on reducing the complexity of analysis (as an option). It is now possible to incorporate typical habitat suitability curves. As well, efforts have been directed at combined the results into a single index of available habitat (similar to the WUA) using (i) multivariate models (with statistically determined weighting of variables), and/or (ii) 3-D suitability functions.

The principle outputs of HABITAT include: (i) habitat suitability versus flow curves (initially curves of preference, indifference, and avoidance for each variable, now combined available habitat estimates are possible); (ii) spatial habitat suitability maps (a key output of the model and extensively used in the analysis); and (iii) time series of total available habitat. A habitat time series is a current major focus of the model development in order to address the static nature of discharge-habitat relationships. Time series allows the integration of the habitat simulation with available hydrological records (daily flow) to reconstruct a history of 'habitat events' (available habitat for a species or life stage at a particular time interval - daily, monthly or seasonally). Current development of the River System Simulator allows for production of duration curves for individual or composite (e.g., index) habitat or hydraulic parameters and provides standard spreadsheet operations which facilitate time series analyses.

EVHA (France)

The EVHA (EValuation de HAbitat) model was developed in 1985 by CEMAGREF, Laboratoire d'Hydroecologie Quantitative and was based on the same principles as IFIM. The hydraulic model is a step-backwater (one-dimensional) method and uses Limerinos equations for hydraulic calculations which provides refinement for use on streambeds of higher gradient and high to medium roughness. As for HABITAT, the model is normally run on one or more reaches containing habitat types that represent the river segment and each reach is described by several closely spaced transects. An important component of the field data collection is the requirement for construction of the topography (3-D) of the reach. The model requires one set of detailed hydraulic and topographic measurements. Measurements are collected at a required flow considering the range of desired modeling flows such that the surveyed flow would allow extrapolation from 20% to 10 times the surveyed flow. To model a river segment, the results are weighted by the length of the reaches within that segment as per IFIM.

Habitat models used in EVHA are the same as for IFIM, expressed as habitat suitability functions (curves) for the variables depth, velocity, and substrate. The model calculates a composite habitat suitability from the univariate curves, using straight multiplication (other options are not currently available in the software). The major output of the model is, as for IFIM, an incremental curve depicting the weighted usable habitat area (WUA) versus discharge. The model also depicts spatial habitat maps of a study reach (again a major component of the results for interpretation), and longitudinal or lateral profiles of depth, velocity, and available habitat.

A habitat time series analysis can be run using separate procedures. Improvement of the temporal component of the EVHA system is a current focus for model enhancement. Currently, three options are available, including (i) a habitat time series (as above for HABITAT), (ii) habitat duration curves, and (iii) continuous under threshold (CUT) duration curves. Habitat duration curves, which also have been used in other jurisdictions, are developed as for flow duration curves and depict the number of days over a study period in which available WUA was greater or equivalent to a WUA threshold value. The CUT (continuous under threshold) curves are also developed from hydrological principles and integrate the duration under which WUA is lower or greater than a given threshold. The output is a cumulative frequency curve of the sorted (longest to shortest) continuous periods where WUA was under a given threshold. This method is considered useful in the identification of minimum flow conditions for a critical life history period. One of the major limitations (and a criticism) of time series analysis is that biological criteria developed from one seasonal period are frequently applied across broad time scales.

In addition to developing the temporal component of EVHA, ongoing development of the model involves (i) improving the flexibility and sophistication of the habitat modeling component, and (ii) improving and implementing the hydraulic models (e.g., 2-D and 3-D approaches).

## RESEARCH NEEDS

It is widely recognized that there is a need to improve the physical and hydraulic simulation capabilities of these models. For simple, small, and straight streams one-dimensional approaches work well. For more complex systems (e.g., braided channels, meandering, deep channels) and where greater precision is required, research efforts have been focused on developing and refining 2-D and 3-D methods. This increased capability is considered important in modeling for species whose habitat selection is benthic in nature, such as the Atlantic salmon. For example, current 1-D models provide output for mean column velocity as opposed to predicting the range of velocities throughout the water column (particularly bottom velocities for benthic fishes).

Seasonal habitat requirements, and biological criteria to describe these needs, should be considered and incorporated into IFN assessments. Currently most biological criteria are developed during summer low-flow periods, in part for convenience, but also because conditions at this time are thought to be limiting for some species and geographic locales. Microhabitat availability, as a limiting factor, does not operate continuously and conditions at other time periods may be more important to survival. For example, in northern locales overwintering conditions may be more critical than summer conditions. In Newfoundland, winter flows are often equal to or lower than summer low-flow periods and there is additional loss of habitat due to ice formation. Concurrent with the need for seasonal (winter) biological criteria is the requirement for hydraulic models to predict conditions associated with ice formation.

Major criticisms of these habitat-hydraulic models continue to be the use of univariate curves, the inherent assumptions attached to their development, and the methods used to combine habitat preferences into a single index (in fact these concerns are why the designers of the HABITAT model initially did not want to combine the variables). Research is needed into the development of multivariate biological models or other means of addressing variable interactions. The habitat-hydraulic models would then need to be capable of using these multivariate approaches.

There is a need to consider other ecological factors affecting stream fish during an IFN process. As an example, food availability is often identified as a major limiting factor which may only in part be determined by hydraulic conditions. IFN studies should develop means of considering effects on food organisms (e.g., invertebrates or forage species) and several applications of IFIM have attempted to address the response of benthos to flow modification. IFN methods must also recognize that with stream fish populations, there are likely inter-relationships between recruitment limiting situations and carrying capacity limitations over time.

## CONCLUSIONS

Despite the inherent problems and concerns about the current state of the art in habitat-hydraulic modeling, these methods are IFN tools that permit the structured use of available knowledge in a problem-solving context. These methodologies are under continual development and model capabilities are constantly improving. Some of the ecological criticisms of these methods may never be adequately addressed. In the interim, until modeling has reached the state where satisfactory simulations can be used to reliably predict fish population response to varying and altered flow regimes, assessments should be conservative in order to protect the available resource.

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## DISCUSSION

**Larry Anthony:** This question is for Hugh [Bain]. I don't know about others in the room, but I've been jotting down a lot of points in the form of questions and comments. I was just wondering what mechanism there's going to be for further discussion on some of the things that Dave is talking about, for example. Have you thought about that in protocol?

**Hugh Bain:** We were hoping there would be enough time between talks. We're allowing about ten minutes, but we have a fairly heavy schedule today. I think that's all we should allow, unless you have some other ideas.

**Larry Anthony:** Maybe some of these things will come up during the workshops or the plenary sessions. I have a number of them, but I don't want to take time away from other people. If we don't have time or they don't come up, maybe we should just jot them down and forward them.

**Ken Minns:** Has there been any explicit attempt with any of these hydraulic models to build a population model that examines the dynamic consequences of these flow fluctuations to the populations? My corollary to that would be: how do you know that any particular factor is either critical or limiting?

**Dave Scruton:** I don't believe there are actual components within these models to address those issues. One of the reasons for these habitat time series is to look at how these flow conditions may affect the life history or, in some senses, the population level. As you know, these models have been notorious in terms of their failure to predict a relationship between wetted usable area and any measure of population biomass or density. There is a gap there that needs to be addressed.

**Gordon Ennis:** I suppose this is a discussion point, Dave. I had the opportunity some years ago of taking a number of IFIM courses. One was a modeling course, with Ken Bovee and Bob Milhouse. In addition to the HABTAT model, they had a model called HABTAV. I think it's relevant to this workshop in that this model introduced another variable. Rather than the velocity of where the fish were most of the time, you could add another velocity; we used the velocity of where it would move to feed. These juveniles were typically on the bottom or very close to it, and then they'd move up higher to catch insect drift. When we used the HABTAV model the preferred flows for these fish, in the Brown River, moved from about 10 cfs (with HABTAT) to 110 cfs (with HABTAV). It was a dramatic difference, and reflects the sensitivity of the models to velocity, and the more realistic HABTAV model which can utilize both a holding and a feeding velocity.

That's a species criteria factor, and it basically spoke against the fact that the best way to provide juvenile habitat, since most of the day juveniles don't like a lot of velocity is to dry up the stream. It showed that when you become a little more ecological and consider more of the life history of a fish on a daily basis, you get a completely different answer. IFIM has been very good in terms of some of the debates in bringing this out and types of research to do, but in terms of manuals, if you will, of habitat productive capacity, it points out some of the complexities and difficulties of the job at hand.

**Don Gordon:** I think it's very valuable to proceed, as you are, by looking at this from the viewpoint of comparing different models, particularly bringing in people working in other jurisdictions. I would assume that at some stage you will be able to do a comparison between how these three different models operate in terms of the data they require, the value of their output, the costs of running them, etc. That would be a very valuable output, particularly in terms of understanding the limits under the conditions in which they can be applied.

**Dave Scruton:** As I mentioned, this work is ongoing, and that's certainly one of the major intentions. We intend to look at a full range of comparisons of the models, even dealing with the costs of implementing data collection and that kind of thing. The first output from this will be presented in June in Quebec City, and it will address the field data collection needs and the results looking at IFIM, which is fairly non-intensive in terms of its data needs versus the other two models, which require quite a bit more data collection. That's the first output, and as I mentioned, two or three of the other major components will be addressed, we hope, in this year of the work.

# FRESHWATER/ANADROMOUS PRODUCTIVE CAPACITY: NEWFOUNDLAND REGION

by

D.A. Scruton[1], J.B. Dempson[2], R.J. Gibson[1], and M.A. Barnes[3]

Department of Fisheries and Oceans

Science Branch

P.O. Box 5667

St. John's, NF A1C 5X1

[1]Experimental Sciences Division, Marine Habitat Research Section

[2]Pelagic, Shellfish and Salmonids Division, Salmonids Section

[3]Marine Environmental and Habitat Management Division, Habitat Evaluation Section

# INTRODUCTION

The insular Newfoundland fish community is characterised by euryhaline species. Salmonids (Atlantic salmon, brook trout, and to a lesser degree Arctic char, brown trout, and rainbow trout) are the primary species of recreational and commercial importance and are those for which most attention is directed in terms of habitat management and stock assessment advice. As insular Newfoundland is depauperate of fish species, there is reduced interspecific competition allowing salmonid species to occupy a wider range of habitats than would be found in other regions. Thus, in insular Newfoundland, salmonids make extensive use of both fluvial and lacustrine habitats during their various life history stages in freshwater, making it necessary to develop region-specific knowledge of habitat requirements. In Labrador, there are additional obligate freshwater species including lake trout, lake and round whitefish, and others that need to be considered. Aboriginal concerns in relation to fisheries and habitat are an important consideration. As well, the relative importance of fish species in the recreation/commercial/ aboriginal fisheries is different in Labrador. Carrying capacity and productive capacity must be quantified with reference to the fish community as well as to other biotic variables and physical-chemical factors.

The major habitat perturbations affecting freshwater and anadromous habitats include hydroelectric development (e.g., flooding, river regulation, interruption of migration), mining (e.g., habitat losses due to tailings disposal, water withdrawal), forest harvesting (e.g., sedimentation, warming, altered hydrology), linear developments (e.g. road crossings), stream diversions, and others. In the region, the major issues involving productive capacity and compensation have involved the loss of running water (e.g., river regulation and impoundment) and standing water (e.g., tailings disposal, lake dewatering for site construction).

Management needs for measurement of productive capacity relate most closely to the issue of habitat compensation as per the No Net Loss guiding principle of DFO's Policy for the Management of Fish Habitat. Current practice in the Newfoundland Region is for referrals to be reviewed and a harmful alteration, disruption, or destruction (HADD) determination to be completed by habitat managers. A determination of *no* HADD leads to permitting and identification of mitigations in a letter of advice. A determination that a HADD will occur leads to (i) a requirement for issuance of an authorization, (ii) development of a compensation plan, or (iii) a CEAA review. The requirement for development of a compensation plan is a *Fisheries Act* requirement and not specifically related to the environmental assessment process. The application of the concept of productive capacity to habitat loss/compensation issues has, to date, necessarily relied on the use of proxy approaches, primarily replacing habitat on a quantitative basis (unit for unit). In practice, there has been minimal consideration of habitat productive capacity except in the sense that there is an intention to compensate within habitat types.

## MEASURING PRODUCTIVE CAPACITY

Newfoundland studies are partitioned into three categories for measuring or predicting total fish productivity, after Minns (1995).

### I. Measurement of productivity (direct)

Total returns of adult Atlantic salmon are available from 18 rivers (3 rivers in Labrador), including the 3 largest systems. On 11 rivers, 10 or more years of data are available. Estimates of smolt production, and thus information on marine survival, are available from 6 rivers. Estimates of total salmon 'production' are scientifically defensible and have the potential for providing absolute information on potential fish production losses due to habitat perturbations. Current productivity, however, may not adequately reflect the natural (theoretical maximum) productivity of a population. Target spawning requirements have been developed for some Atlantic salmon rivers in Newfoundland. This interim approach uses average smolt production parameter values applied to fluvial and lacustrine habitats, along with river-specific biological characteristics of the salmon stocks, where available. Continued refinement of river-specific spawning requirements using alternative stock-recruitment approaches are currently being explored.

A moratorium on commercial salmon fishing (Labrador excluded) has been in existence since 1992. This has allowed estimates of marine survival and total stock production to be obtained in the absence of confounding influences associated with directed marine fisheries. Adult salmon production resulting from increased spawning escapements owing to the commercial moratorium, in some cases increasing by a factor of three, will first become apparent in 1997.

Limitations to these studies include: the inability to enumerate nonmigratory salmonid (or other) species; limited coverage throughout the province; relatively high cost; inability to predict partial losses resulting from habitat perturbations; and, recognition that current levels of productivity may have little bearing on the productive capacity of a system.

II. Measurement of indices of productivity (indirect)

In the absence of fish counting facilities, various indirect indices are used to infer information on salmon production and status of stocks for stock assessment and habitat management advice.

Recreational salmon catch data, in conjunction with angling exploitation rates, allow estimates of plausible ranges in adult salmon production to be derived. Estimates are routinely used to infer salmon stock status and can be used to advise on possible impacts associated with habitat perturbations.

Differences between spring and fall mark-recapture surveys for salmon (and trout) have been used to estimate smolt production from headwater lakes on one specific river system. This provides alternate estimates of lacustrine smolt production for Newfoundland waters. Stock-recruit relationships have been developed using estimates of spring population size in lakes with counts of adult salmon in previous years. These relationships could have utility in predicting subsequent loss of juvenile and adult production associated with any habitat perturbations affecting spawning escapements and changes in marine survival.

Quantitative electrofishing is often used to assess changes in juvenile fish production in response to changes in habitat quality. It has also been used to assess impact predictions from projects undergoing formal environmental assessment, including mitigation measures to minimize/eliminate impacts. Various habitat attributes are measured and recorded but are not otherwise incorporated into any modeling process associated with electrofishing surveys. Electrofishing has been a major tool in measuring salmonid densities/biomass in relation to habitat attributes in the Experimental Rivers project (below).

Microhabitat techniques involving snorkelling observations of juvenile fish and subsequent measurement of microhabitat variables associated with fish holding positions have been used to develop biological criteria for use in habitat-hydraulic modeling studies.

Currently, for the purposes of environmental assessment, fluvial *salmonid* habitats are classified using a system introduced by Beak Consultants in the late 1970s. This system identifies four habitat types based on visual identification (aerial survey) of key habitat features (flow, depth, substrate, gradient). The four types are: 1 spawning/rearing, 2 rearing, 3 migratory (rapids), and 4 standing waters. DFO strives to maintain conservation of habitat types, on a project-by-project basis. Lakes are considered primarily on an areal basis only, however, few projects have involved destroying lake habitat (other than flooding to create a larger reservoir). Habitat compensation or mitigation is assessed within the two major habitat types (fluvial/lacustrine) and there has been no attempt to consider trade-offs between rivers and lakes.

III. Measurement of habitat variables and development of predictive models

An Experimental Rivers Project was initiated in 1984 to (a) determine egg depositions required to optimise smolt production; (b) develop models to determine Atlantic salmon and brook trout productive capacity; and (c) to derive stock-recruitment relationships for the experimental rivers in terms of evaluating the appropriateness of the current target value of 240 eggs$\cdot$100 $m^{-2}$ of fluvial habitat. (See Amiro, this volume).

Salmonid biomass has been quantified in various habitat types in three 3rd-order experimental rivers located in the southeastern part of the island, and in one 4th-order river on the southwest coast. Systems were stratified into various reaches, corresponding to stream order, and sub-sampled according to riffles, flats, and pools as well as lakes. In conjunction with the population estimates, physical and chemical characteristics of stations were measured. The most important habitat attributes have been identified.

In all rivers there is a positive correlation between any index of substrate coarseness (cobble, rubble, and boulders) and densities of salmon parr. Substrate is the most important predictive variable, although it has to be considered in conjunction and interacting with other variables. Densities and biomass are negatively correlated with stream width and range of discharge. Water chemistry has significant effects on fish production, and in Newfoundland where waters are generally acidic and low in nutrients, experimental stocking has shown that where the pH is relatively high and phosphates and nitrates have enriched a system, the biomass and production of juvenile salmon may be several times higher than would be found in similar streams without enrichment.

Both juvenile salmon and the various stages of brook trout have been shown to migrate considerable distances up very small streams (2nd or 1st order), to use headwater lakes or to colonise areas above spawning sites, so that such habitat is important. In addition, smolts of salmon and anadromous trout may use estuarine habitats, which are especially important for anadromous trout. Estuaries are also used by salmon parr, which may later smoltify, or return to the river to overwinter.

Habitat requirements and the physiology of Atlantic salmon and brook trout are well known, although productive capacity of habitats and intra- and inter-specific interactions are only generally predictable, since biotic and abiotic factors interact in complicated ways, and stock-recruitment relationships are poorly understood. Currently, models exist which can relate salmonid densities to various habitat attributes. The potential exists to predict changes in densities, or biomass, resulting from modifications to various habitat characteristics. At present, however, these results are limited to the specific reaches within rivers for which data have been collected. Work is continuing on the applicability of extrapolating results to the entire river as well as identifying and rectifying problems associated with the transferability of models to other river systems.

## ONGOING RESEARCH

### I. Experimental ponds

Objectives: (a) To understand factors affecting salmonid production in lacustrine habitat; (b) to increase production of all trophic levels in an experimental lake, and (c) to develop models to predict changes in production at various trophic levels associated with varying levels of lake fertilization.

Methods: Monitoring started in 1977 with documentation of physical, chemical, and biological (plankton, benthos, and fish) conditions. Whole-lake fertilization (nitrogen and phosphorus) began in 1991 with various studies of the food chain, nutrient loading, and hydrogen ion loading continuing through 1995.

Results: Rapid increase in primary production with initiation of fertilization in 1991. Some evidence for increased abundance of chironomids with slower responses found in gastropods, mayflies, and dragonflies (primary food organisms of salmonids). Diet changes observed in salmonids. Numerical response in the salmonid populations (primarily brook trout) has lagged behind that of the invertebrate prey, with substantive increases in recent years.

Application: There are insufficient data to develop predictive models for responses to nutrient enrichment at the present time. Various existing models are inappropriate for insular Newfoundland as most model parameters typically lie below the ranges of data upon which models were constructed. Models, when developed, could potentially be used to assess production gain or loss, and to determine carrying capacity levels for all trophic levels.

### II. Lacustrine rearing

Objectives: To identify constraints to utilization of lacustrine habitats by juvenile Atlantic salmon and to develop low-technology approaches to augment watershed production potential.

Methods: Controlled releases of both swim-up fry and fall-fed fingerlings to lacustrine areas. Evaluate consecutive and non-consecutive stocking strategies.

Results: Smolt production of 53 to 130$\cdot$ha$^{-1}$ obtained from artificial seeding of lakes in contrast to 7 to 15 smolts$\cdot$ha$^{-1}$ documented from natural seeding. Current data are insufficient to determine optimal stocking levels required to achieve lacustrine carrying capacity.

Application: Lacustrine stocking and rearing techniques could be employed as a stock rehabilitation or mitigation measure required as a result of habitat perturbations (loss) in productive capacity of fluvial habitat. This would involve stocking replacing physical habitat which is low on the tier of compensation options.

III. Spatial and temporal utilization of lacustrine habitat

Objectives: To identify and quantify the relative abundance of salmonids, with emphasis on juvenile Atlantic salmon, in different lentic habitats, and to associate results with modifying current target spawning requirements for Newfoundland river systems.

Methods: Systematic sampling of various lentic habitats at different times of the year in both small (< 100 ha) and large (> 8000 ha) lakes.

Results: Relative abundance varied significantly among lentic habitats. Season effects were also identified. Salmon were most abundant in littoral areas, however, non-littoral benthic and pelagic zones could represent up to 40% of the catch. Utilization of different lentic zones can be size- and age-specific. Similar spatial patterns of use have been identified in both small and large lakes.

Application: Lacustrine areas must be considered when quantifying productive capacity of Newfoundland river systems. Relative abundance estimates (catch rates) could be compared with 'standards' derived from systems where current target spawning requirements have been met or exceeded.

IV. Relative production from fluvial and lacustrine habitats

Objectives: To assess the utility of scale characteristics for differentiating salmon parr from fluvial and lacustrine habitats and estimating relative production of smolts from each habitat type.

Methods: Various classification and maximum likelihood estimators were used to estimate the habitat rearing origin of 'mixed' or unknown samples of smolts and one sea-winter salmon. Simulations were carried out to evaluate the suitability of the known origin classification data to estimate the habitat origins.

Results: Significant differences in scale circuli characteristics exist in salmon parr from fluvial versus lacustrine habitats. Results of the analyses suggest a high affinity for lacustrine utilization with 75% or more of the estimated production associated with lacustrine rearing.

Application: The applicability of this approach should be tested in other systems. The potential exists to provide alternate estimates of relative production from various habitat types in insular Newfoundland systems characterised by both fluvial and lacustrine habitat. Baseline scale characteristic data from wild salmon also have utility in identifying salmon escapees from aquaculture facilities in proximate areas.

V. Habitat-hydraulic modeling

Objectives: To develop a tier of region-specific methods to assess projects that propose to alter the flow regime of rivers.

Methods: Test and evaluate a variety of habitat-hydraulic models in river systems representing the range of hydrological conditions and fish species in Newfoundland. Develop habitat criteria to support these models.

Results: Ongoing. Three commonly applied models provided comparable results and predicted a similar response of communities to changes in flow. Habitat criteria are similar to published material and reflect a wider range of use related to lack of inter-specific competition.

Application: These results will be structured into a set of Federal-Provincial criteria that will be the standard for assessing future project affects on river hydrological regimes. Criteria will allow for the consideration of new methodologies as they become available.

VI. Habitat improvement/restoration research

Objectives: To evaluate the effectiveness of habitat improvement and restoration techniques for use in Newfoundland, specifically with application to juvenile Atlantic salmon habitats.

Methods: Through a combination of scientific evaluation of habitat improvement projects undertaken by public groups and experimental (manipulation) research, determine appropriate techniques and evaluate fish response to implementation.

Results: A variety of techniques have been successfully used to restore and improve habitat with fish species responding positively to the habitat features provided.

Application: Results will be used to determine the appropriateness of techniques for use in habitat compensation projects, use of methods to increase productive capacity of natural habitats, and also to evaluate the relative importance of certain habitat attributes.

## HABITAT IMPROVEMENT RESEARCH

### Pamehac Brook Restoration project

For example, there has been a major effort at evaluating the restoration of Pamehac Brook. Pamehac Brook had been diverted to facilitate water borne transport of pulpwood. This resulted in the de-watering of 12 km of quality salmonid rearing habitat. Creation of dams on headwater lakes and other infrastructure created other migration barriers. A major effort was undertaken in 1990 tc restore this river. The river was rediverted back into its natural streambed and migration barriers related to forestry infrastructure were removed. DFO undertook pre (1990) and post (1991, 1992 and 996) project monitoring. Results in 1996 indicated, based on an increase in habitat area coupled to increased fish biomass, an 18 fold increase in 'habitat productive capacity' from pre-restoration conditions.

VII. Fisheries-forestry research

Objectives: To evaluate the effectiveness of riparian buffer strips in the protection of the productive capacity of headwater watersheds.

Methods: As part of a multidisciplinary research study, effects of forest harvesting on streams with different buffer strip treatments pre- and post-harvesting will be contrasted, to determine relative benefit of buffer strip width in maintaining habitat quality.

Results: Ongoing. Detrimental effects on sedimentation, water temperatures, and woody debris dynamics were apparent after small-scale harvesting in the watershed. Fish response has included movement from the affected reach.

Application: Results will be used to determine the effects of harvesting on productive capacity in small headwater systems, benefits of riparian leave strips, and indices will then be developed to transfer results to other locales in insular Newfoundland.

HABITAT COMPENSATION - SEAL COVE RIVER CASE STUDY

In 1987, the Newfoundland Department of Transportation proposed destroying a 162 m section of fluvial salmonid habitat to accommodate highway construction and, as per DFO's Habitat Policy, were required to compensate for this loss through construction of a replacement section of stream. DFO undertook a research program to assess the effectiveness of this project in achieving habitat compensation. This involved (i) assistance in the design of the replacement habitat, (ii) evaluation of key habitat attributes before and after the habitat loss/replacement construction, and (iii) determination of subsequent utilization of the replacement habitat by resident fish.

Plans for the compensatory habitat considered (i) availability and relative abundance of habitat types in the existing stream, (ii) fish species and age classes using the natural stream, and (iii) the local preferences with respect to recreational fisheries. As a result, a decision was taken to develop habitat features in the compensatory habitat that would benefit adult salmonids, primarily brook trout. The resulting habitat design included provision of a number of large holding pools with cover features (artificial undercut bank).

Detailed habitat surveys and fish populations were conducted before and after construction of the compensatory habitat. Results indicated the project increased habitat area, a result of sinuosity designed into the replacement stream, and pool habitat area also increased, related to constructed features. Total habitat area increased by 20% (162 to 195 $m^2$), while pool area more than doubled (0.73 to 1.71 100 $m^2$ units), while mean depth increased by 29 % (13.6 to 17.6 cm). Fish biomass increased 2.1-fold by three years after construction. There was a shift in utilization from Atlantic salmon fry to older brook trout (1+ and greater). Using biomass as a proxy for productive capacity, and considering the increase in area (habitat quantity), there was a 2.58-fold increase in productive capacity associated with the project.

This project was the first major development in the province after introduction of the Policy for the Management of Fish Habitat and was pursued as a regional model for application to similar compensation projects and to evaluate the benefits of artificially created habitats. This project demonstrated a number of challenges and problems in implementing the DFO Habitat Policy and in particular, the productive capacity concept. Productive capacity measurement is problematic in that the intent is to measure the capacity of the habitat and not fish production. In practice, fish production (biomass), at a specific point in time (summer low flows), was used as a surrogate for productive capacity. This project has also resulted in a number of recommendations that will be applicable to future habitat compensation projects in Newfoundland and elsewhere.

## FUTURE RESEARCH REQUIREMENTS

A number of requirements for future research have been identified with respect to measurement of productive capacity. These recommendations include a number of region-specific needs but also address conceptual issues that are broader in context. Recommendations also reflect the realities of fiscal restraint currently affecting Fisheries and Oceans. Recommendations include:

- continuation of relevant long-term monitoring and modeling projects;
- evaluation of application of regional prototype models to the spectrum of river types and biological assemblages in the region;
- use of habitat manipulation studies (including fertilization) to assist in identifying attributes driving fish production;
- evaluation of restoration and compensation initiatives to determine the benefits of measures undertaken;
- determination of the relative importance of habitat attributes at the micro, meso, and macro-habitat level; and,
- improvement of microhabitat models for use in instream flow assessments, including multivariate approaches and other considerations of habitat 'structure' (e.g., seasonal variability).

Of primary importance is to ensure that methods developed and knowledge gained are practical, scientifically defensible, and will be implemented (i.e., tools that have resource or time constraints will likely not be widely applied) and of use to habitat managers.

## REFERENCES

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## DISCUSSION

**Otto Langer:** On your Seal Cove Highway work, have you had 1-in-50-year flood event yet? You probably don't have to answer. My comment is that before we can consider these as compensation accomplished, I think we have to look at it in the long term. Sometimes it looks great. We monitor it for a few years, and then all hell breaks loose 10 years later. We've seen that happen a number of times on the west coast. We generally recommend against in-stream compensation works in most projects.

**Dave Scruton:** I agree. We're hoping to have the opportunity to try and monitor this over the long term. Again, it depends on access to dollars. This site is right below a culvert, so there is some buffering of hydrological effect as a result of that situation. Another aspect of this work that's unrelated is that it's in a provincial park and subject to some angling pressure, so that's going to affect how we interpret results into the future, as well.

**Martin Bergmann**: Dave, have you or your group had opportunities to work with some of those mega-projects that deal with both marine and freshwater areas, or are they distinct enough that the impacts aren't in both areas.

**Dave Scruton**: Most of the approaches that we have taken to dealing with them have been fairly distinct to this point in time. Voisey's Bay will be the big exception. We'll be dealing with every aspect of impact and environment in that project, and it will be addressed cohesively.

**Glen Hopky**: I want to follow up on Otto's question. I have a comment for the scientists to think about. When we finalize compensation agreements and the like, often one of the things that comes into play is the Act of God clause at the end of it, which stipulates that at some flood frequency the proponent either assumes some further obligation for sustaining that productive capacity or not. Of course, the classic example is one we had on the Oldman River basin last June when, in some reaches of the basin, we had a 1-in-3,500-year event, and it just blew everything away. The question really comes down to at what point do you consider productive capacity having been sustained? That's just a comment I wanted to make because I think it's an important one to look at that goes to the durability of the work you're doing and to the way in which you manage the issue from a department perspective in the long term.

**Dave Scruton**: Just as an aside, we did have a major problem with the initial creation of habitat involving in-filling some of the pools with some of the substrate material we added. The proponent did agree to incur the cost to remedy those situations. Again, that was on a very tight timeframe. I don't know if they would be prepared to undertake that kind of remedial activity again. This project was consummated in a formal compensation agreement.

# ESTUARINE AND MARINE CARRYING CAPACITY IN NEWFOUNDLAND AND LABRADOR

by

M. Robin Anderson[1], John T. Anderson[2], Marvin A. Barnes[3], and J. Brian Dempson[4]

[1]Marine Habitat Research, Environmental Sciences Division

[2]Fisheries Ecology, Ocean Ecology Division

[3]Habitat Evaluation, Marine Environment and Habitat Management Division

[4]Salmonids, Pelagic Fish Division,

Science Branch, Fisheries and Oceans Canada

PO Box 5667

St. John's NF

A1C 5X1

# INTRODUCTION

Until recently in Newfoundland and Labrador there has been relatively little activity in coastal waters that required evaluation under the *Fisheries Act* or CEAA. This is rapidly changing with the initiation of numerous small-scale activities, ranging from sea urchin harvest to sewage disposal, and of several large-scale projects around the region. Proposals for activities in estuarine and coastal waters are currently evaluated on a case-by-case basis for habitat alteration, disruption, or destruction (HADD). This involves a careful evaluation of the fisheries and fish habitat in the local area of the proposal and an assessment of the potential for habitat damage. The focus of this assessment is primarily on physical disturbance of the habitat. A determination of 'no HADD' leads to permitting and mitigation advice as required. A determination of HADD calls for an authorization, a compensation plan, and in the most severe cases, a CEAA review.

At present, habitat information is used in only a few stock assessments for finfish. Sea survival indices for Atlantic salmon have been developed, based on a measurement of the area of preferred temperature in the northwest Atlantic available to adult salmon for over-wintering in a given year. This index has been found to apply to certain rivers in Newfoundland and Scotland. Another relationship has been developed to model the sea survival of salmon from the Conne River based on the timing of the smolt run. In this case the greatest returns are seen with the earliest smolt runs.

## CURRENT ISSUES FOR HABITAT MANAGEMENT

A large number of highly diverse referrals are being evaluated by Habitat Management at the present time. Large projects include offshore oil exploitation and exploration (Hibernia environmental effects monitoring [EEM] program, Terra Nova environmental impact statement [EIS]), exploratory drilling (Port-au-Port and White Rose), mining (Voisey's Bay nickel mine, Labrador audit sampling and EIS), and decommissioning (Argentia US naval base, Long Harbour phosphorus plant). Medium- and small-scale referrals include smaller mines (Hope Brook EEM, several new mines on the Baie Verte Peninsula, potential placer mining on the north coast), pulp and paper EEMs (Cornerbrook, Stevenville, and Grand Falls-Windsor), sewage outfalls in small communities, construction, refinery and oil trans-shipment sites (Come-by-Chance, Hibernia), harvesting (rockweed, kelp, urchins, etc.), and aquaculture (Baie d'Espoir: salmonids; coastal bays and inlets: mollusks and cold water finfish).

## OTHER CLIENTS AND PARTNERS

Marine Habitat Research and other Science Branch sections also receive direct questions about productive capacity and fish habitat. In many cases these questions lead to fruitful collaborative research and partnerships. These referrals/collaborations fall into three areas:

Coastal inventory and habitat mapping: community development groups (Shelbourne County NS, model), environmental groups, oil-spill response agencies and oil companies, Parks Canada and the Protected Areas Association;

Habitat disturbance: offshore oil (Hibernia), aquaculture (local aquaculturalists and the provincial government); and

Technology development and marine industries: remote sensing, acoustics, acoustic tag miniaturization (Lotek Marine); acoustic seabed classification

(Questar Tangent); high resolution acoustics, and benthic community evaluation (Guigne International).

RELEVANT RESEARCH

Research relevant to the definition and prediction of the productive capacity of coastal marine habitat can be grouped under three broad headings:

Autecology of key species/communities,

Inventory and classification of habitat types and disturbance regimes, and

Modeling of productive capacity based on 1 and 2 above.

All are critical to providing habitat management with useful tools for habitat evaluation. Several projects in Newfoundland Region address one or more aspects of these needs.

HABITAT INVENTORY

The longest-running project, the Placentia Bay (also Conception Bay) Habitat Sensitivity Mapping Project under the Brander Smith Initiative of the Green Plan, is designed to collect and map existing information about the sites in Newfoundland most at risk from an oil spill. More recently, several community-based coastal inventory projects have been initiated (Baie Verte, Port-au-Basques). We are also collaborating with Environment Canada and the Geological Survey to reduce duplication and cover a wider area.

BENTHIC DISTURBANCE

Two projects address impacts of disturbance on benthic habitats. One, the trawling impacts study, deals with offshore areas on the Grand Banks (Fisheries Ecology with Habitat Ecology, Maritimes Region), and the second dealt with iceberg scour in the nearshore as a mimic of human-induced benthic disturbance (Marine Habitat Research with C-CORE, Memorial University of Newfoundland, the Canadian Museum of Natural History, and Moss Landing Marine Lab, California). This study of iceberg scours near the coast of the Avalon Peninsula indicates that they are transient in nature. We conclude from this that in these extremely high-energy environments the natural disturbance regime results in communities that recover rapidly (within a year) from major disturbance events.

HUMAN DISTURBANCE

Two new projects to study the effects of offshore oil exploitation on the surrounding habitat are getting underway with the imminent activities at Hibernia (Marine Habitat Research with Habitat Ecology, Maritimes Region).

AQUACULTURE CARRYING CAPACITY/SITE SUITABILITY

Three types of projects are ongoing in this area:

An assessment of existing models for application to Baie d'Espoir salmonid aquaculture projects (in collaboration with Habitat Ecology, Maritimes Region).

Determination of the physical characteristics of small bays and coves as they influence the occurrence and resuspension of toxic phytoplankton

(Fisheries Ecology, Oceanography, and Ocean Sciences Center [OSC] of MUN). Results to date indicate that small inlets in the region can be classified into one of three or four types depending on their physical features, such as their flushing characteristics, and that the behaviour of these systems with respect to toxic blooms can then be predicted.

Mapping of toxic algal blooms and coliform bacteria distributions with shellfish closures (Marine Habitat Research).

It is our objective to combine the information obtained in these last two projects with models of fetch and exposure developed in our Placentia Bay mapping project to create a site-suitability-indexed map of the Island for shellfish aquaculture.

HABITAT ECOLOGY OF FISH IN NEARSHORE ENVIRONMENTS

The habitat requirements and distribution of two species of fish of commercial importance (capelin and cod) are currently being studied in Newfoundland Region. Both projects deal in part specifically with the physical habitat requirements for each species in the coastal environment. These two projects are examining the habitat requirements for capelin spawning (Pelagic Fish Section) and for juvenile cod (Fisheries Ecology Section) that use the nearshore for the first years of development.

The study of nearshore habitat use by juvenile cod is a good example of the multidisciplinary approach to questions of this nature. The study involves development of several acoustic mapping and fish quantification tools in conjunction with direct sampling and autecological studies of habitat use by young cod of different ages. This project will not only provide information on the habitat preferences of nearshore fish, which can be used in evaluating habitat classification schemes, but it will also provide development and testing of the acoustic interpretation tools, which will allow us to develop comprehensive maps of nearshore habitat from sonar readings aboard our coastal boats.

CONSTRAINTS, CONCERNS, AND CAVEATS FOR NEWFOUNDLAND

Before summarizing Newfoundland Region's proposed and potential directions for future research, we would like to raise several points that members of this workshop should consider as we develop the goals for further research into productive capacity.

First, there are specific physical constraints on the productive capacity of coastal Newfoundland waters. These shape the structure of intertidal and subtidal communities and determine the broad range of species distributions. Ice is one of these key factors. The species composition of nearshore benthic communities can be separated into two broad groups. The south coast of the Island is characterized by temperate species, while the other areas are primarily arctic fauna and flora resistant to the annual appearance of sea ice. Another key factor in our Region is the regular occurrence of cold temperatures in most nearshore surface waters (-1.8 °C). It is suggested that these cold temperatures result in the migration to deeper waters of the juvenile fish in the winter months. Certainly they are the reason that only Baie d'Espoir is suitable for salmonid culture.

The second constraint under which we operate is the limited database for inventory. In such a large region, we know relatively little about the species distributions, habitat preferences, and community ecology of our nearshore environments. We do not even have a complete inventory of physical conditions and substrates of these waters. Clearly we must fill in these gaps and, as you have seen, several of the regional projects include new ways of collecting this information on a broad scale.

Thirdly, application of a measure of productive capacity to assessment of the habitat implications of human activity in fish-bearing waters is not straightforward. We are not going to be able to simply produce a map with different colored areas for management purposes that says red = highly productive habitat, green = bare rock, etc. The concept has very different meanings for different species or situations. For example, in Baie d'Espoir where all of the Region's salmonid aquaculture takes place, the term "carrying capacity" can have several meanings and hence several ways of being assessed.

For the aquaculturalists, it can be a measure of how many fish can be carried per cage, which is a function of the size of the fish, temperature, season, etc., or a measure of how many cages can be placed per site, which is a function of site specific physical and chemical conditions.

From a habitat management perspective, the issues of concern may be nutrient loading and eutrophication potential, or oxygen depletion and benthic disturbance resulting from the cages. How many fish can be farmed at a given site before detrimental effects on the surrounding habitat occur? How long will those effects last? Where will those effects be felt?

From a fisheries biology/stock protection point of view, questions will focus on the effect of escapees on the wild populations. Will their presence affect the survival of the native salmonids? by predation on the smolts? by competition for food or spawning sites? by displacement from optimal habitat?

Not all of these questions can be answered by the same body of research. We need to understand the nature of the questions we are asking and the types of answers required from our research on coastal habitat in order to direct our work toward tractable and practical prediction of "productive capacity." It is clear from the above examples that we are interested in more than just straight mapping of standing biomass or primary and secondary production in habitats of different physical characteristics. We will need to be able to predict how these communities respond to disturbance, be it physical (e.g., dredging or dumping), biological (e.g., harvesting, introduction of foreign species or stocks), or chemical (e.g., eutrophication, oxygen depletion). We will also need to evaluate these questions on the appropriate scales of space and time. Species distributions, behaviour, and production vary both between seasons and between years, as does the disturbance regime. How will this variability affect our ability to measure or predict "productive capacity"?

## FUTURE DIRECTIONS

To provide habitat managers with comprehensive habitat information and models of productive capacity for the marine environment, several lines of research should be pursued.

Habitat inventories must be built up to provide the spatial basis for habitat evaluation models and for predicting the effects of human disturbance. These inventories should include not only the physical, chemical, and biological characteristics of the habitats but also the present and past resource use.

Autecology of important (economically, ecologically, genetically, etc.) species and their habitat use must be studied to provide the foundation and support for realistic models of productive capacity.

Disturbance regimes and the response of species, populations, and communities to disturbance must be quantified to provide the background for evaluation of the environmental consequences of human activities in marine environments.

Models must be developed and tested of habitat classification, habitat suitability, productive capacity, and disturbance regimes and responses that tie into the habitat inventories and provide answers to questions of relevance for habitat managers.

The tools and technology to accomplish these tasks must be developed. Few of us will have the luxury of visiting all potential sites for a first-hand look at the habitat types, so broad-scale survey techniques and remote-sensing capabilities must be developed. These include acoustic bottom classification and fish enumeration and identification, and aerial and satellite imagery. We need the software to handle and interpret the massive amounts of data these technologies can provide and the software for spatial modeling of the information. Also we need the technology to evaluate the movements of fish in natural habitats and in response to human-induced disturbances.

Finally these lines of research must be integrated to provide the most up-to-date capabilities and a national approach to the definition of productive capacity.

## DISCUSSION

**Larry Anthony**: I really want to applaud you and your colleagues on this presentation. It was very good.

I have a number of questions, but first and foremost in my mind is this: You referred to the consultative process, partnerships, and so on in your region. How is this accomplished? What type of dialogue do you have between habitat managers and your scientists and your clients? And who leads those discussions?

**Robin Anderson**: It varies with the client, and it varies with the questions of concern.

In the case of small projects, somebody will phone me and ask a question. We will then discuss whether more research is required or what is known. I'm thinking of kelp harvesting, for example. In the case of larger projects, I have to use the template that Don Gordon has developed for his PERD work with the oil and gas industries in the Maritimes region. Don has put in place for his PERD projects – and this is what we have done with our PERD projects associated with Hibernia – a steering committee that is composed of representatives from the industry, scientists involved in the projects, and various managers who have an interest in the application of the research results. This is to make sure everybody is saying what they need out of this project. Industry is saying that they would like to see it develop in this direction, Habitat Management is telling us what tools they would like to see, Environment Canada is providing input, and the provincial people and the fisheries people are all invited to sit on this steering committee. These people direct the general process of development of these programs. These are quite large scale, and they involve a number of investigators. The scientist would have primary control over individual projects within this, but the recommendations of the steering committee focuses the research in the direction that the industry, Science, and Habitat Management would like to see happen. I think all the credit for this has to go to Don Gordon.

# LAURENTIAN REGION HABITAT SCIENCES PROGRAM: SUMMARY

by

Gordon Walsh
Department of Fisheries and Oceans
Maurice Lamontagne Institute
850 route de la Mer
Mont-Joli, Québec
G5H 3Z4

## INTRODUCTION

In the Laurentian Region, we recognise the importance of supporting the Fish Habitat Management Program and targeted research with a long-term basic research program. This work remains essential in order to understand factors that determine the nature of the habitat and to develop reliable models to predict and assess risks to it.

The funding base for the Region's Habitat Sciences Program has not allowed a long-term research program to be set up to develop tools for fish habitat managers to measure production capacity.

For this reason, the Habitat Sciences Program consists of targeted, short-term research projects designed to assess the impacts human activities have on the Region's marine environment and the risks they represent to it. As regards production capacity research, habitat management advice must be based on the results of work carried out in the Department's other regions or available in the literature.

Projects under the program were designed based on environmental challenges in the Region, clients' most pressing needs, and available funding. All projects under the program are supported by external funding sources, and they will all wind up in 1996-97 when the funding ends.

The following section briefly describes each project. I will then present the methods employed by fish habitat managers in the Region, and finish with a statement of the program's prospects for the coming years.

## PROJECT DESCRIPTIONS

### RISK OF INTRODUCING UNDESIRABLE SPECIES IN BALLAST WATERS

The modernization of merchant vessels and increase in ocean-going traffic have greatly aggravated the problem of introducing harmful aquatic organisms throughout the world (Carlton 1985, 1987, 1989; Williams et al. 1988; Hallegraeff et al. 1990). In Canada, three species have succeeded in establishing themselves in the Great Lakes in recent years; the zebra mussel *Dreissena polymorpha* (Hébert et al. 1989), the cladoceran *Bythotrephes cederstroemi* (Berg and Garton 1988), commonly called the water flea, and the fish *Gymnocephalus cernua* (Lehman 1987).

No regulations apply to vessels using the ports of the St Lawrence estuary and gulf. Only optional guidelines for vessels plying the St Lawrence Seaway have been published by the Canadian Coast Guard following pressure brought to bear by the Great Lakes Fishery Commission. The guidelines recommend that ships change ballast water on the high seas, outside of Canadian waters, or, if weather conditions do not permit this to be done entirely safely, that they stay within a well-defined zone of the St Lawrence channel.

Discharging water ballast in this zone could, however, lead to harmful aquatic organisms establishing themselves in the gulf and to disastrous consequences for fishery resources and aquaculture activities (Carlton, 1987; Williams et al. 1988). These ships could also represent a risk of biological and bacterial contamination of the food chain and fishery resources. In addition, the work of Williams et al. (1988) would indicate that sediments present in ballast tanks can carry some benthic organisms that are either encysted or in the form of spores. Hallegraeff et al. (1990) confirmed this hypothesis by finding microalgal spores and cysts in tank sediments of vessels bound for Australia.

The main goal of this project is to develop a transportation and introduction model to assess the risk of introducing harmful aquatic organisms through taking on and discharging liquid ballast and sediments in the St Lawrence estuary and gulf.

The specific objectives are to:

1) draw up a list of marine organisms and ports of origin that pose the greatest threat to the St Lawrence estuary and gulf;

2) describe technical aspects and current practices related to taking on and discharging ballast water and sediments in the St Lawrence estuary and gulf;

3) assess the role of water from ballast tanks in transporting harmful marine organisms, as well as how effectively the organisms are eliminated when water is changed.

4) draw up a model to calculate the probability of different chains of events, from taking the organisms aboard at the last port of origin to transport conditions and aspects of the discharge.

ASSESSING THE IMPACT OF OCEAN DUMPING OF DREDGED SEDIMENT

Dumping dredged sediments near ports, wharves, navigable channels, fish migration routes and certain fishing and aquaculture zones constitutes a physical disruption that affects organisms, their habitat and their productivity. This type of disturbance can manifest itself throughout ecosystems and have short-, medium- and long-term effects. Until now, these impacts have been little known and it is difficult to assess them in a context of uncertainty, i.e. taking into account the confidence limits of the results, in order to determine the sites, the time of year and the operating conditions likely to minimize their harmful effects.

The general goal of the project is to provide managers of the marine environment and, in particular, those in charge of ocean dumping and fish habitat, with the knowledge and tools required to improve enforcement of current and future regulations. The specific objectives of the project are to:

1) assess the short- and long-term impacts of ocean dumping of dredged sediment on the productivity of benthic communities and habitats in a coastal environment;

2) produce a manual on models and methods to predict the behaviour of material dumped at sea in order to compare the respective environmental and financial impacts of ocean disposal options.

IMPACTS OF HYDRO-ELECTRIC DEVELOPMENTS

The overall goal of this project is to acquire the necessary scientific information to contribute to an assessment of the specific and cumulative impacts of the change in freshwater discharge rates on the marine environment of the Hudson drainage basin. A number of hydroelectric projects have already been completed (La Grande Complex and the Churchill-Nelson and Moose River systems); others have been the focus of an environmental assessment (Great Whale, Eastmain, Laforge, Brisay); and several more are in the planning stage (Nottaway-Broadbeck-Rupert, Conawapa, Moose River). Several of these projects significantly alter the dynamic of freshwater discharge from rivers into the marine environment, but the physical oceanography of the region is dependent on freshwater discharge, ocean currents, ice cover, and changes in solar radiation and winds (Prinsenberg 1986). Prinsenberg (1988) estimated the annual flow of fresh water into James Bay and Hudson Bay at 21 x $10^3$ $m^3s^{-1}$ from a total drainage basin of 3.1 x $10^6$ $km^2$. According to this calculation, melting of the ice layer in spring contributes twice as much fresh water as outflow from rivers and run-off (Prinsenberg 1988). Great Whale River alone has an average annual rate of 655 $m^3s^{-1}$ (Prinsenberg 1977), which leads to the formation in spring, under the ice, of a large plume 1 000 $km^2$ in area and 3 to 5 m thick (Ingram and Larouche 1987; Lepage and Ingram 1991).

Knowledge of the Hudson drainage basin ecosystem is still limited and it is currently dangerous to evaluate the real extent of specific and cumulative impacts of the alteration in freshwater discharge rates on the marine environment. Available information is mostly descriptive and limited to areas under development. Sponsors have carried out a number of impact studies on the land and aquatic environment but studies on the marine environment are rare and selective. What are the biological, chemical and physical processes that influence the resource? What are the relationships between these processes? How can hydroelectric development influence the dynamic of these processes? What are the impacts on productivity and the availability of the resource?

It was with reference to these parameters that the following objectives were set for the project:

- Model cumulative impacts of the regulation of freshwater discharge on general water circulation and the ice cover of Hudson Bay;

- Determine distribution patterns of chlorophyllian pigments throughout Hudson Bay in order to be able to assess the sensitivity of different areas to possible impacts of hydroelectric projects;

- Assess the availability of nutrients in relation to oceanographic processes and the resulting distribution of primary and secondary plankton production on coastal waters in eastern Hudson Bay and the richer waters of the Hudson Strait.

- Acquire basic data on phytoplankton and zooplankton communities, fish larvae and the distribution of macrozooplankton and pelagic fish in the same region; and

- Assess the contribution of terrestrial carbon from land systems like that of the Great Whale River to biological production in a coastal environment.

Cumulative impacts are defined here by Peterson et al. (1987): "There is a cumulative effect when at least one of the following circumstances prevails: 1) the continual addition from a single source at a faster rate than that at which it dissipates of a material, force or effect; and 2) the combined effects of the coming together of two or more materials, forces or effects that individually are not necessarily cumulative".

The program's main seagoing mission took place in September 1993. Three moorings made in August 1992 in the north-eastern channels of Hudson Bay were retrieved and the data analysed. A grid of stations situated along the eastern coast of the bay and in Hudson Strait were sampled for phytoplankton, zooplankton, ichthyoplankton and nutrients. A hydroacoustic system made it possible to obtain echograms of the distribution of macrozooplankton and pelagic fish. Plankton samples were also taken in the Great Whale River region for a study on how terrigenous carbon is incorporated into the food chain. The sample and data analyses are almost completed and publication of the results of the project as a whole will continue in 1996-97 and 1997-98.

## CLIENTS OF THE PROGRAM

A number of external and internal clients can benefit from the results of the program:

### EXTERNAL CLIENTS

Federal and Provincial Departments: Federal departments and agencies (Environment, Indian Affairs and Northern Development, Public Works and Government Services, Transport), provincial departments (Quebec Department of the Environment and Wildlife) and Environmental Assessment Commissions (federal, provincial or joint) can use the program's products to assess the state of the marine environment and the environmental acceptability of development projects or activities that can have impacts. In particular, this includes managers responsible for applying acts and regulations concerning the environment and ocean dumping (Regional Ocean Dumping Advisory Committee - RODAC).

Industrial Sponsors: Industrial sectors, particularly ocean transportation and dredging companies, can use program results to assess the impacts of their activities on the marine environment. Consultants and firms specialising in sample analysis that are mandated by these sponsors can also make use of the results of the program. Electric utilities (Hydro Quebec, Ontario Hydro and Manitoba Hydro) can also use the results to assess impacts on the marine environment.

Environmental Groups: Environmental groups can use the program's results to assess impacts and to develop their position for the purposes of environmental assessment processes.

Natives: Native groups can use the program's results to assess impacts on the harvest and develop their position in relation to hydroelectric development projects. They also take part in some research work.

Special Programs: A number of research programs can also be considered to be clients of the Marine Environment Program, given that the program contributes directly to attaining their objectives and satisfying their respective clients. These special programs are: 1) Green Plan - Habitat Action Plan; 2) St Lawrence Vision 2000 Program; 3) Green Plan - Toxic Substances; 4) Green Plan concerning the management of ocean dumping regulations; and, 5) Green Plan - Ocean dumping research fund.

Public: Members of the public, fishers and other users of the marine environment, as well as organizations that protect and promote the environment or socio-economic development, can refer to the program's products for information or to carry out projects to enhance, develop or capitalize on the marine environment or fishery resources.

INTERNAL CLIENTS

Fisheries and Oceans senior managers and fishery, fish habitat, inspection and Canadian Coast Guard managers: Managers can put the tools, research results and scientific advice to work to: 1) assess the effectiveness of programs and policies designed to improve or protect the quality of the marine environment; 2) draw up and apply the acts and regulations in their field in a discerning and enlightened manner; and 3) develop the Department's regional and national position on all issues relating to the quality of the marine environment.

DFO Scientists: Scientists can use the results to support current impact hypotheses, improve impact prediction and monitoring ability, refine and gauge impact assessment models and develop research programs adapted to relevant environmental challenges.

## METHODS USED FOR HABITAT MANAGEMENT

The following information was provided by Laurentian Region fish habitat managers, who make decisions to protect, preserve and enhance fish habitat within the framework of regulatory procedures or in the capacity of advising department.

Based on the availability of information, a subjective decision is made as to whether there will be or has been a harmful alteration, disruption or destruction of fish habitat.

Lost productivity is determined based on the experience of the analyst and scientific advice. The evaluation is most often qualitative, i.e. negligible, minor or significant. It may be quantitative if specific habitat types are measurable (e.g. beach area used by capelin).

To determine if no net loss has been achieved or is actually attainable, subjective decisions are made as to the expected duration of the impacts and to what degree the habitat will return to its original state. An evaluation is made as to whether or not proposed mitigation and compensation are state of the art, as well as whether or not the monitoring program examines all the necessary parameters and is of sufficient duration. All major projects should have a contingency plan to upgrade the mitigating or compensating measures used to alleviate negative effects.

## PERSPECTIVES AND CONCLUSION

The Habitat Sciences Program projects end this year. Current and future budgetary constraints will make it difficult to begin new projects as of the coming fiscal year.

Obviously, it will not be possible to put in place a basic research program in the coming years. The program will have to continue to concentrate on the Region's major challenges, which will be determined based on knowledge of environmental problems in the Region and in consultation with the program's main clients.

The fact remains that research requirements exist. Managers need working and decision-making tools, and scientists need to improve their knowledge of the processes that influence habitats to help them to weigh risks and predict the impacts of human activities on the Region's marine environment.

Apart from improved knowledge of the ecosystem's structure and function, scientific information on the nature of habitats is also required, on a spatial scale that is useful for fish habitat managers. Acquisition of local data on habitats will therefore have to be planned for threatened habitats. Use of the Geographic Information System (GIS) will have to continue.

Finally, there is a need to monitor the success of measures to protect, preserve, restore and enhance fish habitat that are implemented by sponsors to conform to managers' recommendations.

The coming years will be crucial for the program's development, which will depend upon external funding possibilities and in particular on the forging of partnerships.

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DISCUSSION

**Robin Anderson:** Gordon, your second-to-last slide made some very important points. First of all, that we need the collaborative research to be addressing these questions, and secondly that the issues of space and temporal scale need to be addressed. General models for the Gulf are not going to apply to issues for habitat management. If nothing else we reiterate that throughout the workshop, I think we will have made some progress. That would be very helpful.

**Gordon Walsh:** I agree. Thank you.

**Martin Bergmann:** Gordon, you referred to the hydroelectric projects and that B-based resources weren't going to be available anymore to address those. Is the provincial government going to be doing more in that area in the future? Does that fall in line with DFO's management in terms of these mega-projects?

**Gordon Walsh:** I don't think so. From the provincial point of view, all the assessments of hydro development projects lie on the proponent's shoulders. There is no one else doing anything; we're the only ones, besides Hydro Québec.

# ASSESSING PRODUCTIVE CAPACITY OF MARITIMES REGION RIVERS TO PRODUCE ATLANTIC SALMON AND OTHER DIADROMOUS FISH: *REVIEW OF METHODS USED AND UNDER DEVELOPMENT*

by

Peter G. Amiro

Diadromous Fish Division

Maritimes Region

PO Box 550

Halifax, Nova Scotia

B3J 2S7

## INTRODUCTION

This presentation reviews the methods being used by the Diadromous Fish Division to assess productive capacity of rivers to produce diadromous fish in the Maritimes Region, and also methods utilized by the Habitat Management Division to assess site-specific habitat impacts on freshwater and diadromous fish. Research directed to advise managers of habitat issues that impact on the conservation of diadromous fish is also reviewed. This presentation concentrates on research and assessment methodologies dealing with anadromous Atlantic salmon and does not address habitat documentation.

## BACKGROUND

The Maritimes Region includes New Brunswick, Nova Scotia, and Prince Edward Island. Diadromous fish research in the Diadromous Fish Division is directed to the anadromous species including; Atlantic salmon (*Salmo salar*), gaspereau (*Alosa pseudoharengus* and *aestivalis*), striped bass (*Morone saxatilis*), Atlantic silversides (*Menidia menidia*), smelt (*Osmerus mordax*), and the catadromous American eel, (*Anguilla rostrata*). Habitat research within the Diadromous Fish Division is directed to these species and is concentrated in providing engineering advice on fish passage, impact assessment for broad-scale deleterious actions (e.g., pH), and assessment of the status of stocks relative to the productive capacity of the rivers.

The operational translation of the potential productivity of rivers to produce Atlantic salmon that complies with the definition of conservation by the 1980 United Nations Environment Program is the deposition of 2.4 eggs per square metre of fluvial habitat and 368 eggs per hectare of lacustrine habitat. The definition is:

". . . that aspect of renewable resource management which ensures that utilization is sustainable and which safeguards ecological process and genetic diversity for the maintenance of the resource concerned. Conservation ensures that the fullest sustainable advantage is derived from the resource base and that facilities are so located and conducted that the resource base is maintained." 1980 United Nations Environment Program (Anonymous 1991).

This definition implies that the productive capacity of the system is taken into consideration and that it be managed for fullest sustainable advantage.

Atlantic salmon, because of their requirement for non-impacted habitat, passage, and water chemistry, has been the principal species used to develop and test habitat, access, and chemistry models. In the course of these investigations many stream-dwelling species are routinely encountered and recorded. The interaction of habitat and production of gaspereau was researched on the Saint John River, New Brunswick, above Mactaquac Dam, and the interaction of freshwater habitat on the production of eels has only recently been initiated on the Atlantic coast of Nova Scotia.

## ASSESSMENT OF PRODUCTIVE CAPACITY

Models (mathematical and statistical representations of population response to physical and chemical environments) that predict the suitability of habitat to support specific fish species are not as valuable – but more readily derived – as models that predict fish populations. Population estimates may be standardized to habitat suitability indices but the conversion of suitability indices to populations is not trivial. An attempt to do this for chinook salmon was reported by Bartholow et al. (1995).

Estimation of productive capacity is complex. The term "capacity" infers some compensatory or decompensatory mechanisms within the ecosystem (e.g., interaction of habitat and biology). Production models assume equilibrium at some spatial and temporal state and possibly some optimum exploitation point for every condition of the model.

A conservation mandate implies that for systems too complex to model, some minimum level of input is required to maintain an acceptable probability of sustainability. Chaotic systems require some assessment of the requirements for the most stable stage in the system (Wilson et al. 1994). Hopefully there is agreement that in both process models and chaotic systems, similar critical levels of input (i.e., spawning escapement, habitat, and mortality) are required for sustainability. Effective management of a resource must take into consideration the uncertainties involved in the modeled system, bias decisions on the side of conservation, and adapt quickly to change using unbiased information (Ludwig et al. 1993).

Productive capacity of rivers to produce anadromous Atlantic salmon is currently assessed on at least two scales, a macro-scale approach involving complete drainages and salmon stock complexes, and a micro-scale approach involving site-specific information. In both cases, data concerning the physical and chemical properties of the habitat and biological parameters of the animal are combined to assess the productive capacity of the system or site to produce Atlantic salmon. These methods are summarized in Table 1 and explained, in brief, below.

## MICRO-SCALE MODELS

Micro-scale models are not widely used to assess Atlantic salmon resources in the Maritimes Region. There is an abundance of density data on juvenile Atlantic salmon, the result of a various electrofishing practices. However, at present there are no high-resolution, precise, ($R^2$>75%) habitat-to-juvenile salmon models. A high-resolution model capable of predicting unit area populations is difficult to define because of sampling error (both systematic and experimental), under-distribution of juvenile salmon, and variation in habitat strategies used by Atlantic salmon. Tactics used to compensate for these factors are to subdivide stocks (rivers) into biologically similar areas (e.g., salmon fishing areas, tributaries, stream orders), use of additional dependent variables, and increased sampling efficiency and coverage. Transportability, statistical robustness, and economic viability of these tactics are the main stumbling blocks to rapid development of micro-scale models of productive capacity. Site specific population index information can and does play a role in generalizing the direction and magnitude of changes in Atlantic salmon populations. Site-specific juvenile salmon density data have played a critical role in influencing management actions to decrease losses of specific salmon stocks.

The potential that micro-scale models could play in the maintenance of habitat, restoration of habitat and assessment of habitat degradation has provided adequate reason for priority research of micro-scale habitat models. The instream flow incremental methodology model has previously been tested for Atlantic salmon in the Maritimes Region (Shirvell and Morantz, 1983). The principal research location for development of these models in the Maritimes Region is the Catamaran Brook Project. This is a multi-disciplinary study of the effects of controlled forestry harvesting on the stream habitat, chemistry, fish, insect and associated animal populations to a tributary to the main Southwest Mirimichi River in New Brunswick. Existing habitat models such as and PHABSIM have been tested using these data (Bourgeois et. al. 1996). A multi-disciplinary approach to habitat research of streams is being practiced and event-driven (e.g. winter ice conditions) complex models, involving the complete assemblage of stream dwelling species, are suggested as better approaches to account for variance in production and environmental impacts (Cunjak 1995).

The percent habitat saturation (PHS) index for salmonids (Grant and Kramer 1990) is a site-specific measure of use, relative to productive capacity, by salmonids in streams based on density-dependent growth and/or mortality. Considerable controversy exists concerning the territoriality assumptions in this model and therefore it has not been accepted in regional assessments as a single assessment technique.

Elson's 2.4 egg deposition model (Elson 1957) and his "normal index of abundance" (Elson 1967) for underyearlings, small (<10.0 cm) and large (>10.0 cm) parr of 28.7, 23.9, and 14.4 $100^{-1}m^2$, respectively, have provided site-specific targets for unaffected populations as determined by a standard sampling protocol. The universality of these densities has been questioned. However, as mentioned earlier when faced with declining populations, index electrofishing data has played a critical role in influencing management decisions.

Expert opinion and results of electrofishing are often used by habitat management field staff to assess the fish production status of a site. These assessments are often not vetted and sometimes may not be substantiated by recorded data other than the electrofishing, and may only be documented by a photograph.

## MACRO-SCALE MODELS

The most basic productive capacity model for Atlantic salmon is the Elson 240 eggs•$100m^{-2}$ rule for egg deposition rate to achieve optimum smolt production. In this instance 'optimum' refers to maximizing the number of smolts from a minimum number of eggs deposited in 'rearing' habitat. Although this relationship has been examined many times, as yet no better generalization has been derived to replace it. Problems associated with this standard are: 1) definition of 'rearing' habitat, 2) deviation from the techniques used to estimate rearing habitat, 3) deviation from biological parameters of the stocks of salmon used to derive this standard.

A developing basin-wide approach to productive capacity for Atlantic salmon is stock and recruitment (SR) models. SR models have been published for about five stocks in Atlantic Canada, four of these are Maritimes Region rivers: Saint John River above Mactaquac, NB; LaHave River above Morgan Falls; North River, Vic. Co., NS; and Margaree River, Inverness County, NS. Fundamental to SR analysis by traditional methods is the acceptance of a compensatory or decompensatory model. No mechanism for decompensatory process has been shown for Atlantic salmon producing two year and older smolts. Data sets showing decompensatory effect could also be explained by non-stationarity in the data and parameters. However, management parameters derived from some of these analyses are similar to those obtained by other methods (e.g., 2.4 eggs), while other analyses indicate significant change from the operational interpretation of conservation. Resolving these differences has been a focus of stock assessment research.

Low-resolution ($R^2$ of 30-70%) site-specific production estimation modeling provides the bridging between site-specific models and stream-based or basin-wide production models. To be useful, attributes measured for inclusion in basin-wide models must be objective, readily attainable, and measured with known bias. These attributes may be measured using different techniques for the site-specific model than basin-wide model. The calibration between the two methods must be assessed. The macro-scale Atlantic Salmon Regional Acidification Model (ASRAM) (Korman et al. 1994), a habitat-sensitive, life history and pH toxicological simulation model, uses the approach of parameterizing the micro-model and scaling up to the macro-model using ecological unit-area- weighted stream gradient to ortho-photographic measured stream gradient for the habitat component (Amiro 1993). It assumes that the data used to calibrate the biological compensatory mechanisms are measured in the presence of competitor and predator species and that these relationships are consistent over all projections.

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Table 1. Methods used to assess productive capacity of Maritimes Region rivers for Atlantic salmon.

| Name | Publication Source | Atlantic salmon applications | |
|---|---|---|---|
| | | **Source** | **Problem** |
| **Micro-scale models** | | | |
| PHABSIM: Physical habitat simulation model | IFIM: instream flow incremental methodology | Bourgeois et al. 1996 | WUA not correlated with density. |
| | Bovee 1982 | Shirvell & Morantz 1983 | Temporal change in habitat selection. |
| PHS: Percent habitat saturation | Grant & Kramer 1990 | Bohlin et al. 1994 | Independence of territory size and density. |
| Elson's Normal Indices of Abundance | Elson 1967 | Widely used in assessments. | Assumes derived at optimum production point. |
| | | | Similar productivities and sampling strategy. |
| Expert opinion | | Widely used for stream alteration permits and impacts. | Subjectivity |
| **Macro-scale models** | | | |
| Elson's egg deposition rate "2.4" | Elson 1957 | Widely used in assessments. | Assumes similar measurement techniques and definition of 'rearing' habitat. |
| Stock and recruitment Ricker or | Ricker 1975 | Chadwick 1982 | No demonstrated decompensatory mechanism. |
| Beverton & Holt | | | Complete data sets are few. |
| | | Chaput & Jones 1992 | |
| ASRAM: Atlantic salmon regional acidification model | Korman et al. 1994 | | Within-reach emigration of parr assumed to equal migration of parr. |
| | | | Assumed consistency of competitor and predator relationships. |

DISCUSSION

**Gary Logan:** Why would you use an egg deposition rate, and is that 2.4 over 100 square meters right. It's not per square meter?

**Peter Amiro:** It's 2.4 per square meter. Did I have per 100?

**Gary Logan:** Why would you use an egg deposition rate instead of going to a biomass of some sort, or a smolt per unit area?

**Peter Amiro:** Because it's easier. Bob studied that very subject at one point. I think that's the simplest answer. That's a scaling issue, is it not. The 2.4 relates to the use of the habitat by parr. The parr have a mean size at age, and that mean size at age has a mean weight. So you can scale the whole thing to biomass.

Now, if you're asking about the interaction with other species, you heard Dave Scruton talk about that this morning. In many of these streams there's not a lot of competition by other species. If there were, it would be a good point. Bob Randall actually had a look at that at one point. Perhaps you could ask Bob about that one.

**Greg Bonnell:** On the west coast, with Pacific salmon there are two aspects that we're considering more now – genetic diversity, as you mentioned in the definition, and the effect of carcasses on providing nutrients to streams. That's turning out to be a really big thing these days. I wonder if you've addressed those areas in your work.

**Peter Amiro:** Well, we have no carcasses in our streams. But we're working on a publication on genetic diversity. Our hypothesis, I guess, would be that the minimum sufficient conservation limit is that number in the population where you get significant loss of genetic diversity. Our proposal is that for every third-order stream, you have a population. ICES has now determined that populations are the randomly mixed spatially or temporally isolated breeding groups. How many of those can be in a river? We're hypothesizing that there could be one for every third-order stream or greater. That's a conservation limit that you don't go below.

The effective population size is 50 times the amount of mix, and we're doubling that – we're going 50 to 100. That's 100 for every third-order or greater. Josh Korman and I have just done a paper on this. We looked at threats to conservation and yield in a simulation framework, taking in management error and process error over a thousand simulations. Curiously enough, when we applied it to the two rivers we have, there was an intuitive feeling that that was a good minimum level. We just postulated this because we needed some number. It turns out that for habitats that are impacted, like acidic habitats, that minimum conservation level is very close to what the system can produce. There are no surpluses, so every recruit is required to be a spawner. For the others, that number was quite low and less than 2.4. So these were for non-impacted systems. What we're proposing is that the optimum target is somewhat like MSY but that reduced your risk of going below this conservation limit.

What we're trying to do now in all our assessments and in all our advice to managers is to express everything in terms of risk. That way somebody else can decide how risky they want to be, and we in Science can stay reasonably clear about expressing our uncertainties to management.

# ASSESSING THE PRODUCTIVE CAPACITY OF FISH HABITAT: SYNOPSIS OF CURRENT METHODS USED IN ESTUARINE AND MARINE HABITATS, MARITIMES REGION

by

Donald C. Gordon Jr[1], Paul D. Keizer[1], Peter Lawton[2], Robert J. Rutherford[3] and William L. Silvert[1]

[1]Marine Environmental Sciences Division, BIO

[2]Invertebrates Division, St. Andrews Biological Station

[3]Habitat Management Division, Halifax

## INTRODUCTION

This regional summary is structured to address four questions:

1. How is productive capacity being measured at present?

2. What are the successes and problems?

3. How were the methods developed and are they scientifically defensible? and

4. Are they acceptable and usable by fish habitat managers?

We assume the following definitions:

- **Productive Capacity**: The maximum natural ability of a habitat to support healthy fish or grow aquatic organisms upon which fish depend.

- **Productivity:** The current yield of a habitat. This is often less than the productive capacity due to natural limiting factors and/or human impacts.

- **Fish:** Used as a general term to refer to commercially or recreationally important marine fish, invertebrate, plant, and mammal resources.

It should be stressed that these definitions are very broad and mean different things to different people. Ecologists tend to take a more aggregated approach and think in terms of productivity at a given trophic level or for the total system (in units of carbon or energy), while resource managers often think in terms of individual species (in units of numbers or biomass of fish).

There are several general points to stress about estuarine and marine habitats in general and the Maritimes Region in particular:

- Diversity of types (depth, light, substrate, etc.)

- Extensive area

- Poorly defined and mapped (physical, chemical, and biological features)

- Importance of physical oceanographic exchange processes

- Concern for migratory species (fish, mammals, birds, etc.)

It should also be stressed that we should not think just in terms of fish when considering habitat. Habitat is also important because of its role in supporting wildlife, providing recreation, treating wastes, supporting aquaculture, supporting non-commercial species, providing non-renewable resources, etc. DFO has many clients beyond the fishing industry. We must also consider other issues, such as integrated coastal zone management, cumulative impact assessment, marine conservation strategies, as well as the requirements of the proposed Canada Oceans Act.

In addition to the above definitions, for comparative purposes we add the following definitions for terms that are commonly used in human activities such as aquaculture.

- **Carrying Capacity**. The ability of a habitat to support shellfish culture from natural food (e.g., phytoplankton and detritus). It is usually expressed as biomass of cultured species per unit area that can be supported on a sustained basis.

- **Holding Capacity**. The ability of a habitat to assimilate the wastes produced by finfish culture supported by feed. It is usually expressed as biomass or numbers of fish per unit area that can be held on a sustainable basis without causing unacceptable adverse effects on other system components.

## MEASUREMENT OF NATURAL PRODUCTIVE CAPACITY

This is a quick review of past and current programs that have addressed various aspects of the productive capacity of estuarine and marine habitats in the Maritime Region under natural conditions. There is a wealth of information because of a long tradition in marine ecological research.

### FIELD STUDIES

Many estuarine and marine programs in our region have included the measurement of productivity at some trophic level(s) of the ecosystem. Since most of the systems studied have been unstressed, most measurements are probably good estimates of productive capacity. Ecologists have worked primarily at the lowest trophic levels (e.g., phytoplankton, zooplankton, benthos) while fisheries scientists have tended to work with specific resource species (e.g., cod, lobster, scallops) near the top of the food web. These studies have been conducted over different spatial scales ranging from individual saltmarshes and mudflats to large regions on the continental shelf. There are many examples and an extensive scientific literature.

Perhaps the greatest effort at a system level has been devoted to studies of primary productivity. In the coastal system, the most important primary producers are phytoplankton, macrophytes (both intertidal and subtidal including eel grass), saltmarshes and sediment microflora (both intertidal and subtidal). As a result, much is known about the levels, distribution, seasonal cycles, and limiting factors of primary productivity in the Maritimes Region.

As an example, the productive capacity of different regions in the Bay of Fundy has been estimated from the average rates of annual production for different plant forms and habitat areas (Prouse et al. 1984). The total annual primary production for the entire Bay is estimated to be 1124 x $10^3$ tonnes C. Of this about 96% is derived from phytoplankton with macrophytes, benthic microalgae and saltmarshes contributing about 2%, 1%, and 0.6% respectively. The dominance of phytoplankton production reflects the large area of water compared to the other habitats as well as the very high phytoplankton productivity rates in the less turbid outer Bay. In the intertidal zone, production is dominated by the other forms of vegetation.

Due to program cuts, current field programs measuring marine productivity are much reduced. Some continuing effort is being given to measuring the productivity of macrophytes and phytoplankton; little is being done with saltmarshes and sediment microflora. The macrophyte work is focused on southwest Nova Scotia and is driven by the rockweed harvesting issue in both Nova Scotia and southwestern New Brunswick.

The most extensive continuing program is the use of remote sensing by the Biological Oceanography Section at BIO to map chlorophyll concentrations and calculate phytoplankton productivity in coastal waters. Expertise in this field has been developed while conducting global studies of oceanic production under the JGOFS program of the IGBP. Increasing emphasis is now being given to the coastal region of Atlantic Canada from George's Bank to Labrador. Two sources of information are being used: 1) ocean color satellites (there will soon be three in orbit); and 2) the airborne CASI sensor. Satellite data should produce two maps a month for the entire region at a spatial resolution on the order of 1 km. The CASI sensor will provide greater resolution for coastal embayments. Both programs will involve some groundtruthing to improve algorithms for calculating productivity from chlorophyll. There also is a need to separate the sediment signal in turbid coastal areas. This new technology will provide extensive synoptic geographic coverage of phytoplankton productivity at low cost. The methodology developed should be of value to other regions.

While not a direct measurement of productive capacity, there has been a growing emphasis on describing and mapping estuarine and marine habitat, especially benthic habitat. The new technology available for doing this includes multibeam (swath) bathymetry, side scan sonar, ROXANNE, acoustic and video systems. Habitat concerns are of increasing interest to geologists in the Geological Survey of Canada, Atlantic who are keen to apply new mapping technology to habitat issues. As a result, there are several new collaborative projects underway involving benthic ecologists, geologists, and engineers. Many of these projects are aimed at identifying important spawning, nursery, and feeding habitats for key species such as lobster while others are directed towards general habitat mapping on the continental shelf. Hopefully, this new initiative will help correct our current poor understanding of the kinds and distribution of benthic habitat. Similar initiatives are underway in the Newfoundland Region. These mapping initiatives will help form the basis for developing more realistic quantitative estimates of productive capacity in the future.

Also of note is the existence of a coastal inlet database and classification system called CEICE for the region (Gregory et al. 1993). This compilation of basic physical information is also available electronically.

THEORETICAL STUDIES

Numerous modeling programs over the years have contributed to our understanding of the productive capacity of natural habitats. One of the best known of these has been the development of size-structure theory of aquatic ecosystems by Sheldon, Sutcliffe, Kerr, Dickie, Platt, Silvert and others (Silvert 1996). Beginning with the development of techniques to measure particle size in seawater, it has been demonstrated that the biomass of pelagic food chains is relatively constant at all trophic levels, usually within a factor of two, from bacteria to whales. This means that it is possible to predict the productive capacity at one trophic level from productivity measures made at other levels, for example predicting fish production from phytoplankton production. The same theory has also been applied to benthic systems by Schwinghamer (1981) with similar results, except that there are three peaks in the biomass spectrum with intervening valleys, instead of a continuous spectrum. These peaks are caused by the physical structure of sediment habitat (the smallest organisms live attached to the sediment particles, the intermediate-sized in the interstitial spaces, while the largest live on the surface or burrow through the sediment particles). This size-structure theory was developed in DFO and has been widely applied around the world in both marine and freshwater environments (Duplisea and Kerr, 1995; Sprules and Goyke, 1994). However, application within DFO today is limited.

In the 1980s, two projects developed highly aggregated (both biologically and spatially) carbon flow simulation models of complete ecosystems. The Cumberland Basin ecosystem model was developed with the assistance of European scientists to explore the potential impacts of tidal power development (Gordon et al. 1986). It contains the most important physical, chemical, and biological processes driving temperate estuaries. The Grand Banks ecosystem model, based on size-structure theory, was developed to explore the potential effects of large oil spills on the Grand Banks ecosystem and later developed into a generic continental shelf model, called the Theoretical Microcosm, with improved representation of the benthic system (Silvert 1993). This model is being used to study the dynamics of benthic-pelagic coupling.

These models can be used to provide estimates of productive capacity at different trophic levels in units of organic carbon as well as exploring the potential impacts of environmental change on large taxonomic groupings (e.g., the effects of changing freshwater runoff on phytoplankton production). The development and application of whole ecosystem models is not being actively pursued in the region at this time. The value in past projects has been mostly the learning exercise in constructing them but they have considerable potential in habitat management. These models are generic in nature and can be readily adapted to other geographic regions by changing the physical driving forces.

## ASSESSING THE IMPACT OF HUMAN ACTIVITIES ON PRODUCTIVE CAPACITY

Our region has a long history of research on effects of human activities on estuarine and marine habitats and the important resource species they support. These include studies of both contaminants and physical habitat alterations. Examples include petroleum hydrocarbons, chlorinated hydrocarbons, heavy metals, radionuclides, nutrients, drilling wastes, causeways, tidal power development, seafloor disturbance (e.g., mobile fishing gear), phycotoxins, and sedimentation (e.g., aquaculture wastes). These efforts have not been measuring productive capacity directly but have developed knowledge of how human activities may be reducing it, which is needed as background information for all habitat management activities.

### FIELD STUDIES

Three current projects have been developed to address habitat management questions and funded through the Sustainable Fisheries program of the Green Plan, the latter two in collaboration with the Newfoundland Region.

- Impacts of macrophyte harvesting
- Impacts of finfish aquaculture wastes
- Impacts of mobile fishing gear

### THEORETICAL STUDIES

It is essential to understand physical oceanographic processes of mixing and exchange when considering the productive capacity of estuarine and marine habitats. Physical scientists in our region (Loder, Greenburg, Tee, Petrie, Budgen, etc.) have developed a series of numerical simulation models for inlets, bays, and the entire continental shelf. Some are quite simple while others are quite detailed in respect to both spatial resolution and forcing functions included. These models are state-of-the-art and constantly getting better.

The Cumberland Basin and Grand Banks ecosystem models referred to above can be used to assess the potential impacts of certain human activities on the productive capacity of coastal ecosystems. However, because of the high degree of biological and spatial aggregation required by such holistic models, they do not provide the resolution usually needed to address the questions asked by habitat managers. Therefore in recent years more attention has been given to developing more focused impact-assessment models for use in environmental management.

Two current modeling projects are designed to address management issues:

- Impacts of drilling wastes on shellfish (George's Bank drilling issue)

- Impacts of finfish aquaculture wastes on coastal habitat

The finfish aquaculture modeling work has focused on salmonid culture in southwestern New Brunswick. A series of interactive numerical models (FISH, POINT, FARM, SETTLE, AND WQM) have been developed that operate at different temporal and spatial scales (Silvert 1992). These address the impacts of oxygen consumption in the water passing through the cage, sedimentation of organic wastes (ungrazed food and feces) to the seafloor, and eutrophication of receiving waters from nutrient release.

These scientific models have been incorporated in a prototype decision-support system (DSS) where they can easily be applied and interpreted by managers (Silvert 1994a). This prototype runs on a PC and is available to anyone interested in examining it. The next step in its development is to construct a graphical user interface so that it can be linked with electronic databases of georeferenced physical data (depth, current velocity, bottom conditions, etc.) for the waterbody of interest.

Much of the attention of the modeling work to date has been given to understanding the capacity of a given coastal system to assimilate the wastes released from cultured finfish. That is, how many fish can go into the water before unacceptable adverse effects are experienced in other parts of the system. Using existing models and databases, estimates of salmon holding capacity have been made for about 150 coastal inlets in Nova Scotia and New Brunswick (Silvert 1994b).

Simple models have also been developed to compare the potential effects of fish farms with other sources of organic matter and nutrients (Strain et al. 1995). More attention must be given to deciding what constitutes a significant effect on overall productive capacity. For example, what degree of nutrient elevation are we willing to tolerate within a given system?

## SUCCESS AND PROBLEMS

The many successes of the regional program include:

- Extensive bibliography of reports and papers that relate to the concept of habitat productive capacity.

- Extensive databases of habitat characteristics and the organisms they support.

- Large number of site-specific and generic numerical models.

- Extensive scientific expertise on both freshwater and marine habitat.

- Ability for Science to provide sound and timely advice on a wide range of habitat issues.

- Excellent working relationship and communication mechanisms have been developed between Science and habitat management including provision of timely advice, program review meetings, seminars, design of research programs, development of management models, workshops to address specific management questions, etc.

However, there are some problems which include:

- The rapid loss of scientific expertise and supporting infrastructure for research. There are more issues to address but fewer people and resources to tackle them.

- The difficulty of getting the results of research incorporated into the habitat management process at both the federal and provincial levels. Part of the problem is that scientists do not always provide the data in a form that can be used by managers, while part is due to the reluctance of managers to accept new and better ways of doing things.

Another problem is the lack of time for managers to consider and evaluate the usefulness of new approaches.

In general for Maritimes Region fish resources, while species life histories are generally well-known and amenable to synthesis for habitat manager's needs (e.g., Harding 1992), it remains difficult to close life history cycles in a spatial sense. Thus, fisheries scientists find it difficult to provide advice on the population or stock consequences of habitat impacts in defined areas such as spawning sites. Many marine species have prolonged pelagic larval dispersal phases or migrations at subsequent life history phases which compound the problem of ascribing population or stock production consequences from habitat alterations at specific geographic sites. Science is now beginning to develop more spatially-explicit single-species population and harvesting models. This effort, together with the further definition of species distribution by life history phase mapped into georeferenced databases, should provide a better basis for providing scientifically-defensible advice to habitat managers.

## HOW GOOD ARE THE METHODS

Most if not all the methods that have been developed are well founded and have been subjected to peer review before publication. It is essential to always remember that numerical models are only crude approximations of nature and should only be applied to the questions they were designed to address.

Our habitat program has developed in close cooperation with habitat programs in other jurisdictions, in particular the Gulf of Maine in collaboration with US habitat scientists (e.g., Langton et al. 1996 and Stevenson and Braasch 1994). Similar US and Canadian research initiatives are under development within the marine fish and invertebrates fisheries science programs. Particularly for benthic invertebrate resource species (e.g., lobster and scallop), research is increasingly focused on explicitly linking species distributions to physical and biotic habitat characteristics.

HOW USEFUL ARE THE METHODS TO HABITAT MANAGERS

The current procedure followed by regional habitat biologists in Habitat Management when dealing with referrals is basically to follow all the species potentially affected through their life cycles and assess the physical, chemical, ecological, and environmental variables that control or limit production. The assessment is then compared to the potential impact of a proposed project to see if it will move a variable to a limiting level or worsen one that is already limiting. If it does, the project has to be mitigated or compensated as required. The process is similar for violations. Planning and restoration initiatives look at the current situation to determine what, if anything, limits the population and then works to alleviate these factors one by one.

Regional assessments, however, are carried out in several different ways ranging in complexity:

- Not considering habitat at all and just regulating the activity or assessing it on other environmental aspects.
- Opinion based on a few minutes of looking at the site.
- Angling or fishing success.
- Presence of a species (i.e., no fish, no habitat).
- Expert opinion from trained observers who look around and process the information in their heads.
- A defined, documented methodology.

For most staff none of these methods have very much science behind them and the inconsistency hurts the program.

Three years ago we were faced with learning to apply these assessment methodologies to coastal habitats with which we were not too familiar. To educate ourselves, develop management scenarios for court, and document our decisions for CEAA, we developed a series of species/habitat guidelines. The guidelines consist of extensive literature searches that define the limits of controlling variables such as temperature, salinity, water depth, substrate, etc., for each life stage. This information is then reviewed by Science and their professional opinions added to fill in the gaps and interpret the information. The initial four species profiles for lobster, herring, mussel, and scallop, developed as an Atlantic zone initiative, were released in hard copy (Harding 1992, Stewart 1994, Stewart and Arnold 1994a and Stewart and Arnold 1994b). The more recent species/habitat guidelines, nineteen in number, are maintained as electronic files so they can be updated as new information comes to our attention.

These guidelines are used extensively by the habitat management biologists but we lack clear definition of the optimum and acceptable ranges for each variable and we are now correcting this oversight. The other problem was how to assess complex communities supporting fish such as the rocky intertidal zone, mud flats and salt marshes. These complex community guidelines are now being written and hopefully can be used in combination with the species/habitat guidelines as departmental standards for regulating human impacts and to bring a higher level of consistency to our assessments.

From a management perspective the assessment of productive capacity must have the following characteristics:

- Be determined without reference to the population level. Several things that can limit a population are not habitat concerns (e.g., over-fishing).
- Consider habitats for all species of value in the ecosystem. We do not manage particular stocks (in streams we consider Atlantic salmon, brook trout, alewife etc.) and our objective is to optimize production overall.
- Consider all habitats (e.g., migration, spawning, nursery, rearing, food supply and anything the fish depend on directly or indirectly).
- Consider the whole watershed or range of the species (e.g., follow through the life cycle) but be detailed enough to be site-specific.
- Define the ranges on each variable for optimum production and acceptable levels.
- Be simple and quick enough to use, be practical for quick screenings, yet scientifically sound for major assessments. We need a management tool, not a scientific study procedure.
- Be able to distinguish significant changes for monitoring purposes.
- Be able to be done by trained field staff, including fisheries officers doing impact monitoring.

We have developed an excellent working relationship between Science and Habitat Management in our region. Many of the research programs are designed specifically to address questions raised by management. Joint projects are undertaken. Every attempt is made by Science to respond to requests for advice. Every effort must be made to continue this relationship, which is the envy of other DFO regions, despite recent reorganization and resource cuts.

However, there is still room for considerable improvement. There remains a significant gap between the models developed by Science and the approach that Habitat Management takes on a day-to-day basis. A considerable effort has to be made cooperatively to ensure that the best science is used at all times in management decisions. This is much more difficult in the habitat management side of DFO operations than in the fisheries side and much less attention has been paid to it. We need to explore new and better ways that existing and anticipated data and models can be better used by managers. We also need to define and secure funding for new habitat science projects to develop the kind of information and tools needed by managers.

In the future, referrals are going to play a relatively smaller role in DFO habitat management while there will be a greater role for watershed and coastal management. This will put even greater importance on our ability to transfer our scientific knowledge to managers who will be outside DFO and to incorporate it into area-wide management plans.

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# SCIENCE FOR FISH HABITAT MANAGEMENT: *A FRESH PERSPECTIVE*

by

Charles K. Minns

Great Lakes Laboratory for Fisheries and Aquatic Sciences

Bayfield Institute

867 Lakeshore Road

PO Box 5050

Burlington, Ontario   L7R 4A6.

## INTRODUCTION

As governments continue reducing their expenditure and staffing levels, and redistribute responsibilities for conservation and protection, the need for well-focused habitat research is heightened. In the Department of Fisheries and Oceans (DFO), Science has a responsibility to provide (i) scientific evidence of impacts and changes affecting fish and their habitats, (ii) defensible methodologies for managing stocks and sustaining habitats, and (iii) timely, independent, technical advice.

Here I outline a framework to guide habitat science in support of DFO's legislative and policy mandate to conserve and protect fish and fish habitat. I have drawn extensively on our freshwater experiences in Central and Arctic Region, particularly in the Great Lakes. We are actively engaged in research to develop simple methods of estimating fish production in nearshore fish communities and habitat-based models to predict productivity. We are also increasingly involved in efforts to develop habitat assessment tools for development sites and area ecosystems.

This report (a) reviews the mandate which habitat science must serve; (b) outlines the requirements for a science framework fulfilling the mandate; (c) describes efforts to develop and implement a framework, Defensible Methods for Assessing Fish Habitat, in Ontario; (d) examines the requirements for a research agenda and suggests two parallel tracks, reactive and proactive; (e) offers an interim implementation strategy; and (f) concludes with a set of strategic recommendations.

## MANDATE

Habitat science has several facets of mandate to serve, including implementation of legislation and policy, identification and evaluation of new and cumulative problems affecting the sustainability of the resource, application of an ecosystem approach, and execution of excellent, influence-free systematic science. In addition, government scientists and managers have moral and ethical responsibilities to the resource itself and to the wider public interest.

### THE FISHERIES ACT AND THE POLICY FOR THE MANAGEMENT OF FISH HABITAT (1986)

The Act and the Policy together provide the majority of the legislative impetus for fish habitat science in DFO. Under the Act, any action causing a "harmful alteration, disruption, or destruction" (HADD) of fish habitat requires an authorization. Little science effort has been directed to providing formal definitions of what constitutes a HADD.

The Policy has received great attention in Canada and influenced thinking beyond fish, beyond our borders. The principle of 'no net loss of productive capacity of fish habitat' requires a quantitative basis for implementation. The goals of conservation, restoration, and development are clear and unequivocal. The policy expects implementation at both the development site and ecosystem area level. Much of the fish habitat research conducted in Canada invokes the Policy as inspiration. However reviews of habitat referrals and proposed area habitat management plans show that science has been having little impact on habitat management. The Policy also contains implicit links with efforts to achieve ecological sustainability.

## ECOSYSTEM APPROACH

A key effort to instill sustainability ideas, the 'Ecosystem Approach' emerged in the Great Lakes basin and is now the focus of the Great Lakes Water Quality Agreement binding Canada and the United States to restoring the health and integrity of the whole basin (Christie et al. 1986). The approach is best seen as a three-step pyramid (Minns 1995a): Society rests on a bedrock of natural ecosystems and the economy rests upon, and depends on, the other two. Remove some economic bricks and parts of the economy may slump. The ecosystem and society steps stay intact. Remove too many ecosystem bricks and the whole pyramid may slump or collapse. For DFO, the bedrock ecosystems are the fish and their habitat; the society consists of all who are sustained by the health of the ecosystem, including fishermen and anglers; and the economy consists of the fisheries, sport and commercial. Ecosystem health is not a flexible trade-off among the three elements.

## HABITAT ISSUES

Assessing site-specific development activities is the main business of fish habitat managers and biologists. Assessments consider the likelihood of a HADD and authorizations use the no net loss (NNL) guideline for compensation. These activities may be large or small, few or many. They can include diamond mines, hydroelectric dams, or nuclear power plants, as well as marinas, shoreline protection, stream crossings, or ma'n'pa docks at the cottage. The typical lacustrine referral involves minimal information and virtually no analysis. The spatial extent and structural form of most proposals are rarely quantified. Physical aspects often get the most attention and potential indirect effects usually receive scant attention.

Other habitat issues are not site-specific. Issues like acid rain, climate change, and exotics (invaders and introductions) are not treated as habitat management. Other, more pervasive issues also have a substantial habitat management dimension. In North America, 40% of the freshwater fish species are at risk or worse. Habitat loss and exploitation are the top reasons for past extinction. Conservation of fish biodiversity is a habitat issue and needs attention before more species reach the brink. Developments tend to be tackled on a piece-meal basis and the aggregate effects are rarely considered. Cumulative ecosystem change (CEC) is a habitat issue, especially in the context of the area fish habitat management plans envisaged in the Policy.

There are urgent priorities. First, the goal of natural sustainable fisheries will require that both stocks and habitats are managed, i.e., conserved, restored, and protected. Unambiguous, quantitative fish community productivity targets and complementary fish habitat supply targets will help contain over-exploitation and over-development. Second, the emphasis in habitat science needs to be shifted from reactive to proactive if HADD is to be properly assessed and the NNL objective shown to be achieved. This will mean that more effort is explicitly directed to devising practical management tools but not by reducing the input of good science. Habitat science also needs a stable context to sustain research studies and experiments. There are no instant answers and funding mechanisms and priorities, which change frequently, diminish the potential for strategically useful products.

DFO's reduced commitment to freshwater habitat science is risky. Significant salmonid fisheries on both coasts depend on events in freshwaters. Freshwater fish habitat science has often been a source of innovation and insight for marine ecosystems. Ecological issues that are difficult to study in the oceans can be tackled in freshwater ecosystems and the wisdom flows downstream. Many problems threatening or endangering fish and fisheries were first seen in freshwaters; how well we treat freshwater fish and habitat is an indicator for marine fisheries. Other departments and agencies in Canada and elsewhere simply do not have the expertise and experience assembled over decades by DFO.

## A FRAMEWORK FOR ADDRESSING HADD AND NNL

The agenda for habitat science should flow from a framework addressing the Act and the Policy. That framework must have a defensible scientific grounding with quantification of HADD and NNL being central elements. Since the Policy was promulgated, too little attention has been given to putting a numerical assessment framework in place. The focus has largely been on process which while important will be impotent if science-based implementation tools are absent. Science is needed to define HADD and NNL and to define productive capacity in practical terms.

### WHAT IS A HADD AND WHAT IS ITS RELATIONSHIP TO NNL?

Court decisions have largely shaped DFO's approach to defining HADDs. It is time that HADD was measured as changes in fish productivity using scientific criteria. What constitutes a significant HADD should be defined. Of course, the spatial and temporal frame of reference has to be defined at the same time. The same process should apply for quantification of HADDs and NNLs. Ideally a net loss would constitute a HADD.

### WHAT IS PRODUCTIVE CAPACITY?

The Policy states that productive capacity is "the **maximum natural** capability of habitats to **produce** healthy fish, safe for human consumption or to support or produce aquatic organisms upon which fish depend." The three bolded, underlined words are the key to the strength and effectiveness of the policy. The wording is consistent with an ecosystem approach to habitat management.

At the population level, 'produce' refers to production, "The total elaboration of new body substance (collective growth of all individuals) in a stock in a unit of time, irrespective of whether or not it survives to the end of that time" (Ricker 1975). At the guild, community, assemblage, or ecosystem level, 'produce' refers to productivity, a summation of production rates of all biotic populations within an ecosystem, an aggregation of habitat units and types. Productivity can be defined for units of habitat, referring to portions of life history of subsets of the biotic assemblage.

Reference to Elton's trophic pyramid and its modern equivalent, the particle-size spectrums of biomass and production, clearly shows how the productivity of the fish depends on the productivity of the whole ecosystem. Thus the productivity of fish and the productivity of ecosystems are inseparable and must be assessed as a whole.

Direct measures of productivity will always be a luxury. Other indirect, surrogate indicators (biotic and abiotic) must be tested and documented (Minns 1995b). The goal should be to rely primarily on mappable habitat indicators, reserving direct biological assessments for audits, exceptional circumstances, and research validation of habitat indicators. We are using species richness, biomass, etc., as indicators of productivity while making direct productivity estimates to confirm their utility. We are using habitat potential indicators (depth, substrate, vegetation, cover, fetch) and performance indicators (phosphorous, temperature, turbidity) to predict productivity.

## CALCULATING NET GAIN/LOSS

Minns (1995b) has devised a quantitative scheme for accounting for No Net Loss. This approach shows that relative indicators of productivity, like the habitat suitability index (HSI) models in the U.S. Fish & Wildlife Service habitat evaluation procedures (HEP), can be used to compute net-change balances. The key elements of the net-change equation are based on requirements that the proponent be charged for the maximum productivity (productive capacity) of any area destroyed and credited for the difference in productivities (after versus before) of any areas modified:

$$\text{Net Change} = A_{MODIFIED} \cdot [P_{AFTER} - P_{NOW}] - A_{LOSS} \cdot P_{MAX}$$

Alternative formulations were rejected as unworkable; they were either too stringent or too lax. The scheme is quantitative and can be generalized from homogeneous to heterogeneous habitats. The equation can be used to determine compensation or modification to loss ratios for areas adjusted for productivity rates. The equation leads to a conservation rule which logically supports the goal of conservation in pristine areas while allowing some flexibility in highly degraded areas where the Policy's restoration goal is uppermost:

$$\text{Percent Conserved} = P_{MAX} / [P_{MAX} + P_{AFTER} - P_{NOW}]$$

The equation can be applied to any fish habitat issue. In place of the traditional subjective haggling about relative habitat values, the net-change equation provides a quantitative framework for disaggregating the assessment into constituents which can be assigned values using objective scientific methods.

## TOOLS FOR HABITAT MANAGEMENT

The specifications for the development of effective tools for use in habitat management are relatively straightforward: a) They must be simple and pragmatic but also scientifically defensible; b) They must be quantitative, consistent, reproducible, easy to use, and well-documented; c) They must promote the shifting of the work-load onto the proponents – proponents will know what is expected and assessment biologists will know how to judge the proposal; d) They must be applicable to assessing site developments and to the formulation of area fish habitat management plans – site referrals should be assessed in the context of area plans; e) They must place emphasis on mappable habitat-based predictors of productivity – productivity potential is mainly determined by physical habitat attributes while actual productivity performance within the potential is mainly determined by chemical conditions and loads and by biotic interactions. Indicators of potential are needed to estimate maximum productivity (productive capacity) and indicators of performance to estimate current productivity; f) They must be developed by design not by chance.

## DEFENSIBLE METHODS OF ASSESSING FISH HABITAT

The title **'Defensible Methods of Assessing Fish Habitat' (Def-Meth)** encompasses an effort to develop a comprehensive tool-kit for lacustrine fish habitats in Ontario, particularly in the coastal zone of the Great Lakes. The prototype work targeted site-specific developments in the lower Great Lakes (Minns et al. 1995). The prototype was built onto the net-change equations (Minns 1995b). Once the initial work was completed, the potential for application to a wider range of site-specific developments was obvious as was the potential for using defensible methods in area fish habitat management plans. The phrase **'Defensible Methods'** symbolizes the central philosophy of the framework which is to devise a set of assessment tools backed by published assumptions, techniques, and data. The tools should specify what the data requirements are, how to collect the data, how to analyze the data, etc. The task of our scientific research is to develop and test the tools.

## ATTRIBUTES OF DEFENSIBLE METHODS

Minns et al. (1995) presented a prototype of Def-Meth. We use a literature-based database of habitat requirements and life history characteristics by life stage of all species occurring in the Great Lakes to generate habitat suitability models for each species. The habitat features are depth, substrate, and cover. Using distributional data, species lists are derived for target areas. Species can be grouped using thermal, trophic, and endemy criteria and pooled suitability matrices generated. The accumulation of species' preferences leads to higher suitability indices where species richness is greater. Life stage requirements are assessed separately. Combined with GIS-based estimates of areal supply by combinations of habitat features, weighted usable areas (WUA) are computed for each fish group and life stage. Weighting criteria based on fish community objectives and consensus on the relative criticality of life stage requirements allow the WUAs to be pooled. WUAs are computed for pre- and post- development scenarios and the difference represents an estimate of net gain or loss.

The framework is extensible. New species can be added, new assessment criteria, and new habitat features can be added. We are working on a species-based productivity rate index using standard life-history parameters. A software package is being developed to make the analyses simpler. The method can be used to assess habitat supply for single species but assemblage-based assessments are more robust. The suitability indices can be validated via comparisons with field measures or indices of productivity in research programs. The computations can also be performed to generate indexed suitability maps for area habitat management plans.

## APPLICATIONS OF DEFENSIBLE METHODS

The applications are real-world situations which allow us to challenge and develop different aspects of Def-Meth. There are three site-specific projects: a) LaSalle Park Marina in Hamilton Harbour where renovation of a recreational marina has been undertaken with addition of substantial habitat restoration features. This is part of a fish and wildlife restoration plan which is itself part of the Remedial Action Plan for the harbour, a Great Lakes Area of Concern (AOC); b) Burlington West Island(s) where islands with substantial habitat features are being examined as an alternative to further shoreline hardening; and c) Westside Marsh where the net-change equation has been the basis for brokering a compensation agreement. There are three area fish habitat management plans (AFHMPs) which are a various stages of execution in Hamilton Harbour, Severn Sound, and the Bay of Quinte, all AOCs. In each case Def-Meth will be used to devise development screening maps for nearshore habitats using a Red-Yellow-Green color scheme to signal different degrees of protection and levels of development scrutiny. At each site extensive habitat inventories have been gathered. The AOC applications will also explore the potential for a banking/trading scheme using net gains as currency. We are also examining the data needed to build AFHMPs for Lake Erie in support of a binational lakewide ecosystem management planning process.

## LINKS TO POPULATION DYNAMICS

Little effort has been directed to linking fish population dynamics to the supply of suitable habitat. Fisheries assessments are mainly dynamic with habitat ignored or implicitly assumed to be static. Habitat assessments are mainly static. Fish productivity is determined by the supply of suitable habitat and any one of several density-dependent mechanisms may be the limiting factor at any moment. Different limiting factors produc populations with different characteristics. Hence, proving that particular habitats are critical is difficult.

Existing official interpretations of the Policy suggest that habitats are easily classified into one of three types - I, II, and III. This classification is invalid as it is based on static assumptions and takes no account of differences in the supplies of various stage-specific habitats at different locations. For example, in developing the fish habitat restoration plan for Hamilton Harbour, experts assumed that spawning habitat was the critical factor limiting the population of northern pike and that young-of-the-year (YOY) habitat was the next most important. Results obtained with a dynamic population model linked to habitat supply estimates suggested that YOY was the most limiting habitat with adult space being a close second (Minns et al. 1996 in press). The model also suggested that spawning habitat was very unlikely to have ever been limiting.

## LINKS TO COMMUNITY DYNAMICS

Despite much evidence of the need for an ecosystem approach to fisheries management, fisheries is still primarily a single species discipline, focused mainly on stocks and little on habitat. Habitat supplies determine potential productivity but biotic interactions strongly affect outcomes. These biotic interactions are mediated by habitat overlaps, and closer attention to the extent of these overlaps should help measure the relative strengths of the interactions. In the mainstream aquatic ecosystem literature, concepts like 'cascading chains of productivity' and 'top-down/bottom-up control' emphasize the role of linkages throughout the food-web binding the flows of energy and nutrients. As fish are at or close to the top of the trophic pyramid in aquatic ecosystems, their productivity is inevitably tied to the productivity performance of the whole ecosystem. Hence whole-ecosystem estimates of primary and secondary productivity can be useful guides to the potential size of fisheries.

# RESEARCH REQUIREMENTS

Traditionally DFO research has gravitated toward an academic view of science with practical applications as a spin-off. This view is now being supplanted by a management perspective wholly focused on science with immediate application to problem-solving. Neither extreme is desirable. Given DFO's mandate, an applied approach should be emphasized. This should mean that more DFO habitat science effort is directed to the appropriate spatial and temporal scales and contexts where problems exist rather than using the problems as justification for isolated efforts far down the system hierarchy. This is consistent with the need for an ecosystem approach.

There is a need for more research looking at the productivity dynamics of whole ecosystems and for research with realistic time-frames. It is unlikely that the complex dynamics of fish stocks with multiple cohorts can be unraveled with programs lasting one or two years. The allocation of research resources must balance the scientists' obligation to do good science and the managers' demand for instant, simple answers to complex questions.

Where DFO habitat science responded to the perceived immediate needs of habitat biologists assessing development projects, little effort went into building reusable tools. Otherwise habitat science has paid no heed of management needs. Reviews like this workshop tend to create reactive agendas, shopping lists, which divert attention from a proactive agenda with the potential to tackle a far wider range of problems. If the role of DFO science in habitat management is to be enhanced, the next program of habitat science needs to ensure at least a 50:50 allocation of resources between reactive and proactive agendas.

THE REACTIVE AGENDA

In the Central and Arctic Region, the majority of the reactive issues come from larger scale activities. This list could probably be expanded indefinitely, but reactive topics can be prioritized using retrospective surveys of referrals by habitat type, by development type, by data availability, by frequency.

The list of larger scale issues included: a) Mining (diamonds, uranium, metals) impacts in pristine areas both during the exploratory phase when test drilling can pollute many sites and during operations where whole-lake destruction is a likely outcome; b) Hydroelectric schemes which convert river sections into lakes and interrupt the river's continuum; and c) Headwater compensation plans where upstream modifications are applied in relatively pristine areas to offset large alterations in the lower reaches of rivers. This issue involves the quantification of NNL, the appropriateness of off-site compensation, and establishment of lake versus river productivity equivalencies.

THE PROACTIVE AGENDA

- **Develop and validate practical habitat management tools for site assessments and area habitat planning:** These are tools which i) are well-documented and easy to apply, ii) minimize the need to collect new data, and iii) place the main technical onus on the proponents. To support these tools, there is a need for systematic experimental testing of many of the mitigation and compensation activities that are now routinely accepted on faith. In most instances in freshwaters, the efficacy of these measures is unknown. For now the tools will still primarily be static ones.

- **Population and community dynamic models where density-controlling mechanisms are explicitly formulated with estimates of the supplies of suitable habitats:** Limiting factors will vary and will likely explain much of the variability in stock-recruitment models. As with past stock-recruitment models, accumulation of an array of habitat-driven population models for species with diverse life-history strategies will lead to the identification of combined habitat and stock management strategies. Such models will allow DFO to better estimate sustainable harvests, to use stock viability analyses for conservation management and reserve design, and to allow for large-scale effects such as long-term climatic fluctuation and change.

- **Spatial and temporal distributions of productivity:** needs to be given more attention. In lakes, we need clearer evidence of the on- /off-shore productivity gradients allowing a better prioritization of conservation measures. In larger river systems, we need to learn more about the levels and longitudinal patterns of productivity.

- **Validate indicators of productivity:** The usefulness and limitations of biomass, density, species richness, size-structure, etc., need to be established. Measurement of production rates will be a luxury. Research on fish-habitat links will have to use biotic indices like these as dependent surrogates in models.

- **Develop new habitat measures:** The range of direct indicators needs to be expanded with more emphasis on measures such as slope and fetch which can be obtained from mapped data. In addition, indirect structural and compositional indicators are needed to address issues of contiguity and connectance.

IN THE INTERIM . . .

The kinds of research outlined in the reactive and proactive agendas will take time to complete and translate into habitat management procedures. What can be done in the interim?

The net-change equation can be applied now for the assessment of referrals. Some orientation workshops could introduce the concepts to operational staff. Proponents would have to provide the spatial information for a site broken down by habitat types. Expert panels could be used to devise best-judgment estimates of productivity values for each habitat type as well as for mitigation and compensation measures. These interim arrangements would be published in technical reports. In most instances, this interim approach would be substantially more scientific and objective than the qualitative methods currently used by proponents and assessment biologists. The workshops would also provide an effective mechanism for clarifying the assessment procedures and solidifying the research agendas.

RECOMMENDATIONS

•**Manage Both Fish and Fish Habitat:** Human development is encroaching on natural ecosystems everywhere as we over-exploit the natural productivity of many fisheries. The loss and degradation of fish habitat undermines the productivity we seek to exploit for food and profit. We must begin to manage habitat supply to sustain ecosystem productivity as we strive to manage stocks to sustain yield.

•**Put In Place Interim Procedures:** Use the net-change equation as a guide for applying a quantitative approach to referrals. Substantial science input will be needed to put an interim quantitative process in place.

•**Emphasize the Proactive Research Agenda:** Rather than chasing shifting priorities in response to referrals, concentrate on developing and validating scientific tools to standardize the assessment process.

•**Emphasize the Development of Practical Tools:** Methods requiring extensive new data and complicated calculations will not be used. If the assessment tool has a rule book with worked examples and software and training is provided, proponents will use it. Building tools will require that science and habitat management work together. The transfer of science does not occur when articles are published in the Canadian Journal of Fisheries and Aquatic Sciences.

•**Do Science to Support Practice:** DFO Science is applied science, directly addressing the management problems stemming from the mandate. There will be no end-point. As new understanding and data arise, old tools will be changed and new tools devised.

•**An Annual National Habitat Workshop**: DFO's habitat science will benefit from a regular sharing of results and experiences. Cross-fertilization benefits the science and DFO. The annual aquatic toxicology workshop serves as a guide to success. For too long the scientists have been isolated in the regions and headquarters relies too heavily on one-page summaries.

•**Multi-year Funding and End-Use Accountability**: Accept that good science needs a stable platform to operate effectively. Provide the funding over a reasonable time horizon, e.g., 5+ years. Stop trying to reinvent the program each year and bogging it down with time-wasting reports and reviews. Assess the investment by the products and their application at the end of the program.

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## DISCUSSION

**Robin Anderson:** Ken, I have a question about your net-change model. There are two situations that I've wondered about in terms of how we deal with them. I'm not sure how they fit into your models.

First, there are situations where you don't see a change in net productivity of the system but you do see a change in species composition, so you're moving from a shift in highly desirable fish from a fishery perspective, for example, to fish that are less desirable.

The second situation is where you might actually see an increase in productivity of the system as a result of human activities, eutrophication being the primary example.

**Ken Minns:** If a productivity increase is due to eutrophication, it does not meet one of the three key criteria — 'natural.' There is usually some consequence of eutrophication in other aspects of the fish community. There's no free ride. You don't just crank it up and get more of everything equally. There are differential changes.

About the community structure question . . . You're saying that you compute a net change of zero but you get a compositional shift?

**Robin Anderson:** Yes.

**Ken Minns:** We've dealt with that by using the defensible methods approach, breaking the analysis down into fish groups and applying weights based on your fishery objectives. If the site is a brook trout stream and you want it to be brook trout, then you weigh that more heavily in the analysis, both pre- and post- assessments. Other groups would have less weight. The adjusted net-change calculation should show a deterioration if there is a change in the preferred fishery.

**Robin Anderson:** My concern about that, however, is that it brings it back to the subjective evaluation, because you decide, based on some . . .

**Ken Minns:** Yes, but I don't think there's any scientific way of deciding *a priori* what the fishery objectives should be. We tried to do that in the preliminary trial runs. I'd come in and say, "These are the rules for fishery objectives," and people would be all over us. You can't come up with a universal rule that will apply in every single situation. So it seemed to me the best way is to have management agencies determine their objectives. There are also client groups and user groups to consider. You can negotiate the objectives and come to some consensus. The only rule we require for the net-change calculation is that you have to apply the same rule to the pre- and post- assessments. So you're stuck. Whatever you said you wanted before, you want after as well.

**Glen Hopky:** Ken, as you know, the department is engaged in a process of devolution of habitat provisions to the inland provinces. In some ways, Ontario and DFO have been on that path for almost ten years now, with the letter of intent. I'll direct this to Serge as well. In the context of the models you've developed and the relations you've had with Ontario in the last few years, to what extent do you feel they've had a role in participating and developing and nurturing these ideas and the management tools that go with them? Have you seen any opportunities or hindrances in that respect?

**Ken Minns:** When you talk about agencies, there are usually two levels, senior management and working.

**Glen Hopky:** I'm thinking of the MNR [Ontario Ministry of Natural Resources].

**Ken Minns:** Okay. At a working level, we have MNR people involved in the development of defensible methods. They've participated in the workshops we've held, and we're getting a reasonable buy-in. We're also getting a buy-in from consulting companies and people like that. They're desperate for consistent methodology that they can apply.

Speaking for myself, it seems to me that if you go to the high management level at MNR, they're also going through a devolution. We're talking about passing the responsibility down to the province; the province is already dealing it away in their revised planning act. They're not going to accept that responsibility; they're just going to sweep it through to a lower level of government that doesn't have the resources to do a good job.

**Glen Hopky:** So I guess the questions is, how do you see something like a defensible method working in a multi-tiered structure?

**Ken Minns:** If the federal level does pass down the responsibility, it should do so while at the same time outlining how to execute that responsibility. There should be a set of rules about delegation and what we'll expect. I think the feds should hold them accountable for that as well. There should be a reporting requirement. You could do that through the area habitat management plans. Require them to have a series of plans and report on them on an annual or three-, four-, or five-year basis. We should ask them what net gain or loss they have achieved in each habitat management area over time.

# ASSESSMENT OF PRODUCTIVE CAPACITY FOR CANADIAN ARCTIC SEAS AND ESTUARIES

by

Harold Welch

Freshwater Institute

501 University Crescent

Winnipeg, Manitoba R3T 2N6

## SOME PROPERTIES OF ARCTIC MARINE AND ESTUARINE ECOSYSTEMS

Arctic shelf marine systems differ from those of our other two coasts in only one qualitative way: the presence of seasonal and/or permanent ice (and even here, the Labrador coast overlaps with the Arctic). Otherwise they differ only quantitatively from temperate systems, in that their waters are colder, primary production is lower and extremely pulsed due to a narrow time window for light input, heterotherms are longer-lived, most homeotherms experience very different seasonal habitats as a result of migration, and biodiversity is lower.

Ice does more than simply influence other habitats; ice is a habitat in itself. For lower trophic levels, seasonal sea ice supports a sub-ice algal community that contributes about 10% of the total annual primary production (Welch et al. 1992). For upper trophic levels, ice is a preferred habitat for arctic cod (*Boreogadus saida*), which may feed heavily on ice-associated invertebrates that in turn are supported by ice algae. Marine mammals and sea birds are strongly influenced by the presence or absence of sea ice. Polar bears (*Ursus maritimus*) depend upon ringed seals (*Phoca hispida*) for food, which they access via sea ice (Stirling and Oritsland 1995). Ringed seals themselves are adapted to seasonal and permanent pack ice, where they maintain breathing holes in winter, and have special ice habitat requirements for birth lairs in March-April (Smith 1987).

Arctic estuaries also differ from temperate estuaries in that ice plays a more important role. The MacKenzie River estuary is unique because in winter there is ice ridging at the flaw lead between fast and pack ice. This ice ridging acts as a dam that retains buoyant freshwater shoreward of the ridge, freshening the estuary and the seasonal ice cover (MacDonald and Carmack 1991), although the biological significance of this effect has not been studied. In Hudson Bay, hydroelectric dams have altered the annual hydrograph, reducing spring-summer flows and increasing winter flows, with unknown but potentially significant effects on sea ice cover, currents, and biology (Bunch and Reeves 1992).

Arctic estuaries are important to anadromous fish, especially arctic char (*Salvelinus alpinus*) in the eastern and central Arctic, and dolly varden char (*S. malma*) west of the MacKenzie River. These fish overwinter in freshwater with estuaries used both as passageways and as feeding areas. A few rivers, primarily in Hudson Bay and the western Arctic, also produce other anadromous species such as broad whitefish (*Coregonus nasus*).

Biodiversity decreases with increasing latitude, reducing ecosystem flexibility. When diversity is high there are usually a number of species within a trophic level or feeding guild that are somewhat interchangeable, but when diversity is low, as in the Arctic, there are often key species whose function within the system cannot be replaced by other (non-existent) species. Examples are the arctic cod, a keystone species that mediates much of the energy flow between herbivorous crustacea and top predator mammals and birds. Other examples of key species whose functions cannot be replaced are the pelagic predatory amphipod (*Themisto libellula*), ringed seals, and the clam *Mya truncata*, the primary prey for walrus (*Odobenus rosmarus*).

Arctic marine and estuarine habitats are very patchy, caused by factors such as underwater topography, tidal currents, and winds. Flaw leads where the land-fast ice meets open water, commonly known as the floe edge, change location somewhat both seasonally and inter-annually, and are part of the mosaic of patchy habitats.

Locations where ice cover is annually prevented by oceanographic conditions are called polynyas, and have special significance as habitats. If they are very large, as is the Northwater in Baffin Bay, they sustain phytoplankton production long before the normal mid-summer bloom (Welch, Conover, Legendre, unpubl.). Thus their total productivity may be higher than that of surrounding waters. They also serve as refugia for air-breathing mammals and birds, allowing overwintering to occur in locations that otherwise would not sustain winter populations of certain species such as walrus, beluga, and eider ducks.

Especially in arctic seas, the assessment of productive capacity must include the understanding that feeding locations are often remote from the original source of production. Phytoplankton, zooplankton, and even arctic cod may be advected hundreds of kilometers to be fed upon by concentrations of top predators. This influences how we define habitat.

## THE HABITAT ISSUES

Industrial development along the arctic coast is relatively rare, but usually high profile. Because of the high start-up and operating costs, they tend to be big operations and transportation is an integral problem, as for example:

Two metal mines in the high Arctic, Nanisivik on Strathcona Sound, Baffin Island, and the Polaris Mine on Little Cornwallis Island, produce lead-zinc concentrate for export to Europe via the icebreaking transport *M.V. Arctic*, which also brings supplies in to the mines. There is elevation of metals concentrations locally but probably not at levels that harm biota (Fallis 1982). A parallel issue has been ice-breaking by the *M.V. Arctic* and associated Coast Guard ships, which interferes with hunter travel and probably affects the distribution of narwhal and beluga at the ice edge in spring (Cosens and Dueck 1993).

Oil and gas exploration in the 1970s resulted in increased ship traffic in the eastern Northwest Passage and Beaufort Sea, along with subsea drilling activities in the Beaufort. As a result, the Lancaster Sound region was subjected to intensive environmental study 1976-1979 (Sutterlin 1982) and became the subject of the first regional land-use plan in the Canadian Arctic (Department of Indian Affairs and Northern Development 1991). The Beaufort Sea likewise was intensively studied. Petroleum development involves the obvious risk of oil spills, which not only interfere directly with fish, birds, and marine mammals, but could damage nearshore and ice habitats (Sergy and Blackall 1987). Release of oil beneath the ice would impact the sub-ice community directly and be practically impossible to control, since ice breakup and drift in early summer would transport spilled oil long distances (Bobra and Fingas 1986).

Transportation of mining and petroleum products by pipeline and sea is a necessary alternative to wheeled transport. The Polar Gas project proposed to transport natural gas via pipeline from Melville Island eastward to Resolute, across Barrow Strait, and thence down Boothia Peninsula and the Keewatin to southern markets (Boyd et al. 1977). Another scheme, the Arctic Pilot Project, proposed to transport Melville gas through the eastern NWP via liquefied natural gas tankers, with a variable but high number of passages through the sensitive Lancaster Sound region (Mansfield 1983).

## YIELD TO HUMANS

Hunting and fishing activities are not usually considered a habitat impact requiring assessment of productive capacity. This is arguable because changes in a given population, especially for top predators, can directly affect the populations of either competing or prey species. Ringed seals and polar bears are especially good examples since man harvests both species. Increased kill of bears would increase the abundance of ringed seals and the demand on arctic cod, whereas increased take of ringed seals would reduce the productivity of bears and reduce the demand on arctic cod. The relative abundance of seals and bears therefore constitutes an important habitat parameter for both species plus lower trophic levels via "top-down" effects. It should be recognized that for the next several decades, the main human-induced impact on arctic marine and estuarine species directly used by people will be that caused by hunting and fishing.

## PAST RESEARCH ON THE PRODUCTIVE CAPACITY OF ARCTIC MARINE HABITATS

To my knowledge there has been no work on arctic marine habitats aimed specifically at relating habitat quality to productive capacity in order to facilitate the management of environmental impacts, with the possible exception of the BIOS oil spill experiment on north Baffin Island (Sergy and Blackall 1987). However, there has been some work relating productive capacity to habitat variables, and on the production of the offshore marine ecosystem, as shown by the following examples.

Ringed seal densities and reproductive success are correlated with ice habitats (Smith 1987; Furgal et al. 1996 in press). Polar bear densities are in turn closely correlated with the densities of their ringed seal prey, allowing the prediction of one from the other (Stirling and Oritsland 1995).

Research on ice algae (Welch and Bergmann 1989; Welch et al. 1991) and ice-associated invertebrates (Pike and Welch 1990; Siferd et al. in review) has provided the tools to predict biomass as a function of light, snow cover, ice thickness, and water depth.

The trophic dynamics of an entire Canadian arctic marine system has been assessed only for the Lancaster Sound region (Welch et al. 1992, and unpubl.). Rates and distribution of primary production are fairly accurate, as are estimates for the most abundant top predators, but intermediate trophic levels such as benthos, zooplankton, and arctic cod are poorly known.

## CURRENT ATTEMPTS TO MEASURE PRODUCTIVE CAPACITY IN ARCTIC SEAS AND ESTUARIES

In the Central and Arctic Region, the largest research component is on stock assessment, stock identification, and life-history parameters of fish and marine mammal species important to man, including anadromous chars and whitefish, beluga, walrus, ringed seals, and bowhead. For most of the projects some degree of habitat utilization is built in. Various techniques are used to quantify the types of habitat used at various life-history stages. Examples include the use of tags to monitor animal activity, migration, and presence in different habitats; micropixie (proton induced x-ray emission) analysis of otoliths to determine time spent in fresh, estuarine, and marine habitats; research on the relationships between types of snow/sea ice habitat and ringed seal birth lairs; and photographic surveys of marine mammals for stock assessment, with incidental information on habitat use.

There is a small program on the productivity of the entire arctic marine ecosystem, an effort to understand the trophic structure and function of the system producing marine mammals, fish, and seabirds. This is a direct assessment of habitat productive capacity, since it looks at things like the production of benthos on various bottom types, the production of microalgae in sea ice, and the influence of water and ice conditions on phytoplankton production.

## WHERE DO WE GO FROM HERE?

Realistically, most of our arctic marine and estuarine science will continue to be focused on stock assessment. We can let the animals themselves define the productivity of habitats and then use some measure of productivity, abundance, growth, or even condition factor to assess the productive capacity of that habitat. There must, therefore, be dialogue between those doing stock assessments and habitat managers. Habitat variables can often be built into stock assessment projects in order to provide habitat managers with information on the productivity of specific habitats.

There is also a need for a better understanding of the structure and function of arctic seas and estuaries, because this information underpins all subsequent assessment of habitat valuation and impacts (Thayer et al. 1996). I believe that one of the best ways to do this is to develop a trophodynamic model, because:

1. It clearly defines the sources of primary production at the base of the food web.

2. It quantifies the production of populations, which is usually the item of interest when assessing various impacts on a given system.

3. It defines and quantifies the energy flows between populations, identifying keystone and other species that are of particular importance to a given fishery resource.

4. It applies over a large area, acting as a sort of habitat integrator.

5. It can be modeled at any level of complexity. One relatively simple model, Ecopath II (Christensen and Pauly 1992), has been used to quantify marine ecosystem productivity throughout the world, and would be a useful tool to compare productive capacity of different marine locations.

Some disadvantages are:

1. It requires a large quantity of data and inevitably many values are taken from the literature, possibly leading to large errors.

2. It is practically impossible to quantify even the majority of populations in a marine shelf or estuarine system (however, if one's interest is in one or a few top predators, this may not be a serious drawback).

3. Because it integrates over a large area, it may not be a sensitive tool for assessing the productivity of small areas of special habitat. However, if habitat is to be totally lost, an energy flow model can specify how much primary production (and hence productivity of higher trophic levels) will be removed.

I am not suggesting that we should be pursuing "ecosystem understanding" as "science for science's sake." Rather, the questions we ask about habitat productive capacity are dependent upon the level of understanding we have already achieved, and here are two arctic examples.

The first is the coastal ecosystem. Our level of knowledge about the food web structure and productivity of important species is rudimentary for two or three of the best-known areas and practically non-existent for the rest of the arctic. Therefore basic ecosystem research is a valid, indeed essential, activity in support of habitat questions.

The second example is small arctic lakes, for which we have a good understanding of basic ecosystem structure, energy flow, and physical characteristics. Habitat managers have a problem – the impact of small-diameter diamond-drill cuttings on arctic lakes (joint government/industry workshop, Yellowknife, 9-10 May 1996). What effect does the resultant suspended sediment have on the productive capacity of lakes? Because of our existing knowledge base, which already tells us where the sediment will travel, the response of phytoplankton to light, and the importance and distribution of benthos, we are able to formulate very specific research questions: What is the effect of turbidity on the light regime? What is the effect of sediment on benthos production? The questions we ask, therefore, depend upon our previous knowledge base.

In conclusion, let me reiterate that arctic marine and estuarine ecosystems are poorly known, that most research will be focused on stock assessments, and that increased communication, backed by hard funding decisions, will be required between habitat managers and science if managers are to have adequate future knowledge of habitat productive capacity.

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## DISCUSSION

**Buster Welch:** I have a question for Hugh Bain. Hugh, could you give us a one-minute rundown on headquarters' policy as to what we do about freshwater research? If I bring a graduate student on to look at drill cuttings, am I going to get cut off at the knees in six months, or am I going to be able to keep him going?

**Hugh Bain**: Your regional research director is the one to go for that kind of ruling, rather than hands-on direction from headquarters.

**Buster Welch**: I was thinking specifically of devolution. Are we still going to have freshwater research?

**Hugh Bain**: Yes, there will still be freshwater research.

# PRODUCTIVE CAPACITY FRESHWATER FRESHWATER/ANADROMOUS PACIFIC REGION

by

Ian Williams[1], Mike Bradford[1], Ken Shortreed[1], Jeremy Hume[2]
Steve Macdonald[1], Blair Holtby[1], Gordon Ennis[3], Gary Logan[3], Heather Stalberg[3]

[1]Department of Fisheries and Oceans
Science Branch, Marine Environment and Habitat Science Division
West Vancouver Laboratory
4160 West Marine Drive
West Vancouver, B.C. V7V 1N6

[2]Department of Fisheries and Oceans
Cultus Lake Salmon Research Laboratory
4222 Columbia Valley Highway
Cultus Lake, B.C. V2R 5B6

[3]Department of Fisheries and Oceans
Habitat Enhancement Branch
555 West Hastings Street
Vancouver, B.C. V6B 5G3

## INTRODUCTION

Productive capacity research for freshwater habitat in the Pacific region has taken two paths that differ in scale and purpose. At the watershed and population level, the relationship between the amount and quality of habitat and the production of salmonids has been an important component of analysis of optimal escapement levels and harvest rates. At a more local scale habitat managers have required estimates of the capacity of specific habitats in order to assess the effects of various kinds of development on the productivity of aquatic habitats.

## HABITAT CAPACITY FOR FISHERIES MANAGEMENT

Productive capacity of freshwater habitat for anadromous fish has been extensively studied since the 1950s. Spawning habitat of B.C. and Washington State sockeye was examined in the early 1950s with the goal of understanding the potential production from habitat. Since that time there have been many studies of both spawning and rearing habitats of salmon. Models that have attempted to characterize fish production from habitat have generally worked for the habitats used for the development of that model, but had poor transferability to other systems. There is evidence from genetic studies in Alaska that fish populations less than 30 km apart can be genetically different, indicating the potential for local adaptation, thus explaining at least part of the difficulty in exporting habitat based models. This supports the concept that fish habitat is inseparable from an extremely complex ecosystem of which it is a part.

A significant amount of the efforts of Freshwater Habitat Science is directed at or linked to identifying the productive capacity of anadromous salmonid habitat. For the purposes of this forum we will present a summary of relevant Science programs by habitat type and life history stage.

### A. Migration Habitat

Recent concerns over the potential stress to returning adult sockeye salmon from high water temperatures in the Fraser River has prompted a research program comprised of monitoring water temperatures in the mainstem and tributaries with the development of a predictive model for water temperatures during the period of upstream migration. This model provided 10 day predictions twice-weekly during the 1995 season. Predictions were within 0.8°C using Environment Canada weather predictions, and error dropped to 0.6°C using actual meteorological data after the fact. The issue then was, how does this relate to sockeye production?

Cumulative exposure to temperatures above 18°C during migration of Early Stuart sockeye adults as they migrate upstream appears to influence returns of adult fish. A stress index was calculated by accumulating degree days between 18 and 20°C with degree days above 20°C doubled to reflect the curvilinear response to very high temperatures. There is a significant relationship between this stress index and estimated return per spawner for 13 years of data, suggesting the importance of migration habitat to salmon productivity.

### B. Spawning habitat

Productive capacity estimates were used by the Fraser River Task Force in 1987-88 to define a target for rebuilding Fraser River sockeye. Productive capacity of spawning habitat for sockeye was considered to be the equivalent of 12,000,000 spawners. This was estimated to have a potential for producing 30,000,000 sockeye. An interim production target of 20 million sockeye was established and rebuilding has proceeded faster than expected. Since these initial estimates we have been working on gaining a better understanding of the processes affecting productivity and production. This has occurred in two areas in the Fraser Basin, Stuart-Takla and Horsefly River.

The Stuart-Takla area is the location of a multi-disciplinary, multi-agency Fish/Forestry research program targeted at understanding ecosystem processes affecting productive capacity. While coastal-based fishery/forestry interaction research has been conducted since the early 1960s, the relationship between forest harvesting and the productive capabilities of aquatic habitats in B.C.'s interior are poorly understood. A new research project was initiated in 1990, on six tributaries of the Stuart/Takla watershed to improve our understanding of the productive capacity of interior habitats and to assist in the development of fish/forestry/wildlife guidelines. Following the proven pattern of previous research, this project incorporates long-term (7+ years), integrated, multi-disciplinary approaches. Participants from a number of agencies are involved, including the B.C. Ministry of Forests (MoF), Fisheries and Oceans Canada (DFO), Carrier Sekani Tribal Council, B.C. Ministry of Environment (MoELP), Canadian Forest Products Ltd. (CanFor) and several of B.C.'s universities.

During the first five years of the project before harvesting commences, the natural fluctuations and ecosystem processes associated with many biological and physical variables have been monitored. The productive capacity of the habitats occupied by sockeye salmon during their spawning, incubating and rearing life history stages are under investigation. Linkages between biological production and physical components of the watersheds are being studied including suspended sediment, bedload, solar radiation, hydrology and organic debris. These variables are directly linked to stream habitat quality and are controlled by many factors including the presence of the spawning sockeye salmon themselves. Redd construction alters gravel quality and changes stream morphology. Salmon carcasses provide nutrients of a marine origin which provide a foundation for the primary and secondary production within the watershed.

The Horsefly River study is targeted at understanding the dynamics of sockeye spawning in a major river system in order to identify the productive capacity of a large (64 km) spawning ground. Traditional analysis using spawner/recruit analysis has provided no insight into an optimum escapement for the Horsefly/Quesnel system which has grown from a few thousand sockeye to a production of 8,000,000. Escapement goals have been habitat based, including both spawning and lake rearing, however the task force goals were based on crude estimates of spawning habitat utilization. The current study uses a 1:20,000 scale digital map base combined with air photo interpretation of spawners at a 1:500 scale. Slope analysis was compared to spawner distribution and density. Airborne remote sensing techniques were developed to estimate water depth in order to identify potential dewatering over winter, and will be used to examine sediment transport through the system. Analysis indicates that the productive capacity of this system was probably reached in 1993 and any increase above the 1993 escapement of 2 million will not result in a further increase in production.

C. Rearing Habitat

a. Lakes.

Studies of the productive capacity of lakes for producing juvenile sockeye salmon has be underway for at least 30 years. A photosynthetic rate (PR) model has been developed which can be used to predict rearing capacity based on lake carbon production. The model allows predictions to be made after 1-2 years of limnological surveys, and its predictions agree closely with juvenile abundance data. A strong correlation between maximum smolt biomass and lake carbon production is used to validate the use of the PR model in B.C. sockeye nursery lakes. Some work has been done on littoral zone but this area has not been studied enough to determine its role in the productive capacity of sockeye or other salmon species. Based on this limnological 'nderstanding of sockeye producing lakes a number of them have been successfully fertilized. The addition of nitrogen and phosphorous nutrients has successfully increased the productive capacity of lakes in B.C., Alaska and the former Soviet Union. Nutrient additions increase phytoplankton and zooplankton production and biomass. Higher levels of zooplankton food produce larger smolts and increase their in-lake survival. Increased smolt numbers and the higher ocean survival from larger smolts translate into increased adult abundance. Results from lake enrichment studies demonstrate how fish stock productivity and habitat productivity are linked.

b. Streams.

Work on the productive capacity of streams for coho and chinook salmon is currently being with the goal of finding methods to rapidly assess streams for their potential to produce juvenile salmon. Coho juveniles rear in streams for 1-2 years, and available evidence suggests that the amount and type of rearing habitat in the stream is the main limiting factor for the production of smolts. The most accurate estimates of smolt production potential are obtained from detailed surveys of individual habitat units, however, this is not feasible when estimates for the many hundreds of coho streams are required for watershed or regional planning purposes. As an alternative, the potential of using readily available sources of information (from maps or discharge records) to predict smolt production was assessed. Only stream length and to a lesser extent latitude were useful in predicting smolt yields. It was concluded that forecasting mean smolt yield at the regional level was possible (i.e. by averaging across many streams), however, for a single stream the precision of a prediction is poor, and a more detailed approach is required.

Such a detailed approach has been attempted using information collected from the Carnation Creek fish-forestry project. A model that involves a set of linked density-independent and density-dependent models involving both growth and survival has been developed. The inclusion of growth or fish size allow for the possibility that fish quality is an important modifier of survival. The inclusion of growth processes also allows for indirect interactions across time and space. The results suggest that large changes in coho production associated with clear-cut logging in Carnation Creek, a small coastal stream on the west coast of Vancouver Island, were driven by temperature changes in late winter and were not associated with physical habitat change at all. In fact coho production has continued to increase despite extensive loss of summer habitat through dewatering and loss of large organic debris (winter habitat). These interactions could not have been anticipated through a simpler model.

D. Ecosystem approach.

Integrating processes such as those above into a beginning of an ecosystem approach to resource management is enormously complex and difficult. We believe that the Integrated Fraser Salmon Model is such a beginning. Freshwater Habitat has been funded by the Fraser River Action Plan to build an integrated salmon model for the entire Fraser Basin. This is a dynamic model built in GIS-type software with many layers allowing complex processes such as those discussed above to be easily integrated into a model for all six species of salmon. The objective is to reduce complexity and provide managers with tools for incorporating habitat into DFO's salmon management plan. This model is built on a spatial platform of 1:20,000 digital maps. Currently there is

1500 maps loaded and an intelligent river network of some 550 salmon streams has been completed.

The model is based on the life history of Fraser salmon. It includes most of the major DFO databases. A harvest management sub-model has been integrated into this model as well as a migration component. This tool will structure some of the complexity in ecosystems, thus providing a better understanding for Stock Assessment, Harvest Management as well as Habitat Management and will assist in defining the linkages between these disciplines as they relate to the productive capacity of large watersheds such as the Fraser.

## PRODUCTIVE CAPACITY FOR HABITAT MANAGEMENT

Habitat Management generally attempts to work conservatively so that productive capacity likely has been maintained, and in general the poorer the data base the more conservative the decision. The current vision of many in the fisheries community is the concept of ecosystem management. Ecosystem management is tied to understanding productive capacity and progressing from concept to implementation will require a focused effort toward understanding complexity in these systems. Further, this complexity has lead to the realization that risk averse or conservative management is the most appropriate process for dealing with the no net loss of the productive capacity of habitats supporting the fisheries resource.

A lack of concrete information on productive capacity forces us to use surrogates such as area, depth contours, etc. Habitat 'productive capacity' related information is determined on the basis of quantitative, semi-quantitative and qualitative methods and on experience and knowledge of the investigator. Bio-standard information of the Habitat and Enhancement Branch (HEB) is often pragmatically useful, especially when tied to compensation agreements related to monitoring and further actions if fish production objectives are not achieved.

Examples of current approaches to issues include:

- Infilling of shallow water habitat in Kootenay Lake by the City of Nelson. Here we looked at increasing the complexity/variety of habitat to achieve no net loss.

- Revelstoke Dam hydro expansion project involving entrainment into turbines. A general bio-standard model was applied to determine the amount of new spawning habitat required to offset loss.

- Kemess South Mine project includes eliminating 17 km of dolly varden and bull trout habitat. Two dolly varden populations involved will be transplanted to two barren watersheds. Three fishways on a barren stream will provide access to spawning and rearing habitat for Bull Trout. Additional spawning and rearing habitat will be constructed. Some of monitoring and maintenance activities have in-perpetuity requirements with the proponent responsible for setting up a sufficiently sized fund using normal B.C. Mines Act protocols.

- There are over 9000 stream crossings per year in Northeast B.C. creating potential sediment problems impacting productivity of streams. Even with best available mitigation there is a risk of sediment release. There are at least two ways to approach this dilemma. First, We make it clear to the proponent that sediment is a deleterious substance and that sediment releases are unacceptable. Any release could result in prosecution. Secondly, we continue to stress the need for the best development plan possible to minimize if not avoid sediment releases. In the case of unavoidable HADDs we, a priori, require compensation efforts to be tied to the severity of sediment releases. A draft management model was developed using an adaptation of a published dose response model. The model was designed to apply to all types of sediment inputs and applies simple mathematical weighting factors to after the fact monitoring data to determine level of risk using severity of effect, duration of habitat impairment and hydrological season of release. Management actions are tied to resultant risk categories.

HEBs Habitat Inventory unit is currently working on a plan to deliver overview data from a large georeferenced fish and fish habitat database to Fisheries and Oceans users. This database is an inventory of the salmon streams in B.C. and includes salmon escapements, enhancement activities, habitat areas and constraints to production.

HEB is also working proactively to form partnerships with communities, municipalities and regional districts in the lower Fraser Valley as well as on Vancouver Island where urbanization is considered a serious threat to salmon habitat. This is an important step in bridging the credibility gap that all governments are faced with when dealing with 'enlightened' stakeholders. The Fraser River Action Plan (FRAP) has developed habitat management plans for the major watersheds in the Fraser Basin.

Generally, Fisheries and Oceans has addressed major habitat issues in an acceptable manner, it is the small incremental impacts that concern us. In spite of an attempt to manage conservatively a panel of fish habitat managers and scientists from Oregon, Washington, B.C. and Alaska all agreed that we are and will continue to lose the habitat base coastwide if we continue the status quo (American Fisheries Society, Sustainable Fisheries Conference, Victoria, B.C., April 1996). Clearly better tools are needed to enhance our ability to achieve no net loss of productive capacity. There is a serious problem within DFO with respect to the decline in resources. We will have difficulty marshaling appropriate resources to tackle the issues of productive capacity.

## WHAT OF FUTURE RESEARCH?

There are two diametrically opposed views on this. One view in the research community is that we need to construct more detailed, multiple factor models to fully understand the dynamics of production in different biogeoclimatic zones of the Pacific Region. We collectively know little about production in interior zones of the north and south with the result that we can give little guidance to such activities as the provincial Watershed Restoration Program. That research would involve intensive, long-term studies focused on paired watersheds and would include detailed multidisciplinary investigations of the interactions among biological and physical processes. Investigations must be based on the needs expressed by habitat managers and industry representatives and be based on good statistically supported experimental designs. However, Habitat management cannot wait for the results of these long term studies, therefore an important component of this approach is the delivery of tools in a timely fashion to address the current needs of management.

A summary of the second view begins by noting the strong relationships between habitat area and production, suggesting that space might be the overriding determinant of production. The 'best' strategy for maintaining wild fish production would then seem to be maintaining as much space as possible while protecting its structural diversity. Such a strategy might involve no research component at all because understanding production is not required for its maintenance. Foregoing research would free up valuable resources for public acquisition and protection of riparian zones and freshwater.

Both concepts are valid providing they are applied in an appropriate manner. However, our task is to focus on the first, particularly on the delivery of scientifically defensible tools for habitat managers.

## DISCUSSION

**Heather Stalberg:** This is actually a question for Gordon Ennis. I'm wondering if there has been a change with respect to compensation. It was my understanding that we didn't look at deleterious substances. Can you speak to that with respect to the overhead on stream crossing?

**Gordon Ennis:** We're looking at suspended sediment, and it's very controversial. There is no final decision on how to treat it. It can be a deleterious substance, but it can also be a HADD. The sediment is clogging up rearing space of invertebrates or is settling on substrates where fish spawn, lowering the survival rate of present or future eggs. In that sense, it's a HADD. There are so many stream crossings in northeast B.C. We use the best methodology possible in terms of the industry so the sediment is reduced, without a great concern physiologically. If there's important habitat downstream, the option is to say no, and charge if they cross, or have a crossing method. It's pretty hard to find a method that doesn't create some sediment. In a few cases where we've been worried about the risk of sediment we've taken the approach of the best method possible, monitoring, and if triggers are exceeded, then we'll go into compensation. All that is determined up-front.

We've been concerned, too, with the possibility of that approach being a due-diligence argument for people who don't go through the process of getting proper approvals, etc. I think this Region will be doing a lot more discussion before we regularize how to deal with it.

# AN OVERVIEW OF THE SCIENCE SUPPORTING MARINE AND ESTUARINE FISH HABITAT MANAGEMENT IN PACIFIC REGION, WITH EMPHASIS ON RESEARCH ON PHYSICAL CHANGES

by

Colin Levings

Department of Fisheries and Oceans

Science Branch, Marine Environment and Habitat Science Division

Coastal and Marine Habitat Science Section

West Vancouver Laboratory

4160 Marine Drive

West Vancouver, B.C. V7V 1N6

## INTRODUCTION AND BACKGROUND

This paper provides a brief chronological summary of the development and application of scientific knowledge of marine and estuarine fish habitats in the Pacific Region, with emphasis on information needed to assess change due to ecosystem effects. Before the 1970s, most of the concern for the physical disruption of fish habitat in the Pacific Region was focused on freshwater habitats. In 1973, rearing chinook salmon were found in the Fraser River estuary and analysis of their food habits showed that they were part of an estuarine food web. This triggered an episodic response (sensu Healey and Hennesey 1994) in the research and management systems. Both systems responded with programs that continue to this date as research projects or management protocols.

Pacific Region includes more than 27 000 km of shoreline with diverse habitats such as protected estuaries, open ocean beaches, island archipelagos, and fjords that penetrate deep into the coastline. The estuarine landscape in the Pacific Region holds the most threatened fish habitat because of the demand for flat land at tidewater for industrial and urban development, and therefore much of the emphasis in the region has been on management of estuarine fish habitat. However marine shorelines are also affected by industry, especially by the forest industry which uses the ocean for log storage and transport, notably along the northern coast of B.C. In the past decade, the rapid growth of non-salmonid, invertebrate, and plant harvesting has emphasized the need to define habitats for a wide variety of species, including inshore rockfish, lingcod, herring, eulachons, smelt, sea urchins, several species of clams, sea cucumbers, shrimp and prawns, crabs, and marine plants such as kelp and pickleweed. Open-coast shorelines are exposed to the constant threat of oil spills; a tanker from Alaska transits the coast about every second day of the year.

## PHASE I: THE DISCOVERY PHASE IN THE 1970S

As mentioned above, estuarine rearing of salmon was first documented in the Fraser River estuary in 1973. Research and management studies were then set up in the Fraser, Squamish, Nanaimo, Skeena, Cowichan and other estuaries to investigate the impacts of port development, log storage, airport expansion, and marina construction on fish habitat. An Estuary Working Group was established involving a number of Federal agencies and this group oversaw the preparation of a number of "Status of knowledge" reports for specific estuaries (eg Fraser River estuary; Hoos and Packman, 1974). At the same time, detailed research was launched and subsequently published in scientific journals. The research addressed some of the major hypotheses concerning the function of estuarine habitat for salmon. The role of estuaries for smoltification, food provision, and refuge was explored in detail by DFO Pacific researchers, by staff of the Westwater Research Centre at the University of B.C., and by estuarine ecologists at the University of Washington. The researchers agreed that estuaries provide vital functions for rearing salmonids, especially ocean-type chinook, chum, and some stocks of sockeye and coho. Trophodynamic research showed that estuaries were detrital-driven systems so that heterotrophy was the dominant production process with most of the carbon arising from seagrass, marsh, microbenthic algae, and riparian input from the watershed. The refuge function has been examined in more recent studies.

Results from this research set the stage for DFO fish habitat management policy in B.C. estuaries and also answered questions of immediate and local priority. For example, log storage was moved from one side of the Nanaimo estuary to the other and the extension of the third runway at Vancouver International Airport was kept off the intertidal area of the Fraser River estuary. Information in scientific journals was used by Environmental Assessment and Review Process panels (e.g., Roberts Bank), by task forces such as the one concerned with log storage on the coast, and by habitat managers at numerous locations on the coast.

PHASE II: ESTUARINE DEPENDENCY AND POLICY CHALLENGE IN THE 1980S

The ecosystem research conducted in Phase I needed to be bolstered by demographic studies. In 1981 scientists were asked to design a program that 'proved' the importance of estuaries to salmonids. The null hypothesis was: *There is no difference in salmon survival with or without an estuary.* This hypothesis was tested with an experimental release of juvenile chinook salmon at the Campbell River estuary. Results showed that survival to catch and escapement was best when juvenile salmon experienced an estuary, but that ocean conditions could also affect survival. The experiments did not investigate differences in survival between habitat types within the estuary (e.g., mudflats vs. sandflats vs. eelgrass beds). Technology to track movement and residency of individual fish on small spatial scales (<1 km) and time periods (<24 h) in small fishes (<2 g) was not available then, and is still not available.

In about 1980, habitat managers asked scientists to investigate the feasibility of fish habitat restoration in estuaries. Pilot-scale experiments were therefore conducted by DFO science staff with marsh and eelgrass transplants, initially at the Fraser and Nanaimo river estuaries, and managers tested other techniques, such as dike breaching, at other estuaries. Managers also requested the involvement of scientists as partners in a major restoration/compensation project at the Campbell River estuary. In collaboration with a forest company that was building a dry-land log sort, DFO designed and assessed functional aspects of the restoration project for a five-year period (1982-1986). The research program yielded evidence for density-dependent growth of wild chinook fry in the estuary, which validated the need for habitat restoration. However, because this particular chinook stock—and many others in the Pacific Region—is supported by large hatchery releases, further work is needed to determine the productive capacity of estuaries for hatchery fish.

The Fraser River estuary is the most intensively managed estuary in the region and possibly in Canada. The Fraser River Estuary Management Program (FREMP) was established in 1985 and continues today with DFO as one of the major stakeholders in the program. Habitat managers and the North Fraser Harbour Commission developed a three-level color-coding system (red - stop, no development; yellow - caution, possibly development with compensation; green - development with compensation) using quality of fish habitat as an index. Quality was assessed by the manager's interpretation of function and value of the habitat, using information from research papers. The entire shoreline of the estuary was qualitatively inventoried and color-coded using slope, substrate, vegetation, and industrial use as the characteristics for coding. A provincial estuarine habitat-mapping scheme was also employed, but is rarely used in day-to-day management. In 1995, FREMP struck a habitat review committee to enable stakeholders to ask for review and possible change of coding at specific sites. A representative of the Science Branch was asked to represent the Department on this committee and continues this role at present.

Compensation and restoration are two important management strategies used in the Fraser River estuary by DFO and FREMP, together with the color-coding scheme. In 1992, under the auspices of the Fraser River Action Plan, a ledger-book database was developed by habitat managers to see if net gain had been achieved with these strategies. Results showed a small net gain of marsh habitat (about 6 ha) but very large net loss in subtidal, mud/sand flats, and riparian zones (Kistritz, 1996). A functional audit, in direct support of the HADD issue, was also conducted under the auspices of the Fraser River Action Plan Science program at eight representative marsh transplant sites. This audit showed that replacement of functional values was not achieved at several sites, and also identified some general procedural issues such as lack of performance criteria, monitoring, and responses to failure (Levings and Nishimura, 1996).

PHASE III INTEGRATION, ATTRITION, AND EXPANSION OUT OF ESTUARIES IN THE 1990S

Coastal fish-habitat research activities in the Pacific Region entered an era of attrition in the early 1990s. However, relatively short-term projects, such as the work conducted in the Fraser River estuary under FRAP, have continued in the southern part of the region. Results of past applied research were integrated into management plans of estuaries other than the Fraser (e.g., those proposed at Squamish and Campbell River), but no new ecological or process-oriented work was launched. Habitat management prescriptions are often negotiated with industrial groups or, in some cases, debated in the courtroom. In both instances habitat managers (HMs) use scientific data generated some years ago to develop defensible positions.

Researchers in the 1990s became more involved in integrated coastal-zone management as another mechanism to distribute knowledge and help HMs influence other stakeholders. At the request of HMs, researchers served on committees with provincial agencies to ensure that DFO's interests were represented in the development of coastal inventories (e.g., the Provincial/Federal Resource Inventory Committee). As a key stakeholder on the coast, it was important for DFO to make sure that incoming data were usable by HMs. International obligations under the Strait of Georgia-Puget Sound initiative were also attended to. The rapid growth of the net-pen aquaculture industry in the Johnston Strait region has led to a requirement for new data on ecological effects, but few studies have been conducted by DFO researchers.

Some recent short-term work has been done in direct support of the Sustainable Fisheries Green Plan (Habitat Action Plan [HAP], Environmental Analysis) and the proposed Canada Oceans Act (COA). Studies under HAP have focused on development of new GIS tools for use by HMs and have provided a consolidation of existing habitat data in literature surveys, thus improving data accessibility. Other initiatives have investigated past and contemporary methodology for inventory of coastal habitats and have compared groundtruthing, aerial photography, and remote sensing. The HAP-sponsored work has emphasized the use of published data to provide a value-added component. For example probability density functions have been developed to provide a tool for relating the distribution of juvenile salmon to salinity in estuaries. A fish habitat atlas for the Baynes Sound region was developed as a prototype for other productive embayments. COA funding enabled a study of the possibility of accidentally introducing non-native species through ballast water disposal.

PHASE IV SOLUTIONS TO CURRENT PROBLEMS AND EMERGING ISSUES

Coastal habitat researchers cannot give the required attention to all topics in this vast coastal region nor address emerging issues in depth. This has sometimes resulted in shortfalls of site-specific knowledge and delays in providing timely advice. Solutions could involve collaboration between scientists and managers. An example might be better coordination of habitat monitoring so that temporal trends in area (hectares, $m^2$) could be tracked, for example, by using remote-sensing surveys. Better integration of freshwater, coastal, and ocean research and management is also required; a watershed approach to stock and habitat management is needed. More than a decade ago this strategy was suggested for the Cowichan River watershed, but was never implemented. In this respect, a review of past decisions and processes would also be instructive. As the old adage says, "Those who do not learn from history . . .".

Several current priority areas of coastal work in the Pacific Region have been identified as of direct and immediate importance to HMs, and as such merit attention in this review. First of all, because of the increasing encroachment of urban and industrial development on the shoreline, particularly in the Strait of Georgia, HMs have identified a need for applied research on buffer zones. For example, how close to high tide mark should road construction, which is often accompanied by sediment sloughing, be allowed? Another topic, closely linked to the HADD issue, is our lack of understanding of how fish use natural, restored, and compensated habitats as interacting units. We need to bring the concepts of landscape ecology into fish habitat management plans. Another emerging need is the incorporation of underwater remote sensing of fish habitat, especially substrates and seagrass beds, for important marine invertebrates and fish. 'Fisheries geomatics' needs to be continued and strengthened. Finally, the value-added component of past work needs continual nurturing. For example, the development of ecological criteria documents by scientists and publication in the peer-reviewed literature would be of benefit to HMs, who need to interpret scientific information when writing guidelines. Examples might be documents describing the key elements of an estuary management plan, factors involved in setting up marine buffer zones, or siting criteria for log storage operations to minimize impact on marine ecosystems. Establishment of marine protected areas (MPAs), as allowed under COA, may enable the long-term preservation of critical marine and estuarine fish habitat in the region. However, the actual utility of MPAs for harvesting refugia and for maintaining biodiversity has yet to be proven in our region, and may be the biggest challenge ahead.

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Otto Langer, Rod Bell-Irving, and Steve Macfarlane provided constructive comments on an outline of this paper.

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DISCUSSION

**Glen Jamieson:** Perhaps it's unfair to ask you this, Colin, but I'm hearing that ecosystem dynamics are very complex and that structure and function are so important, but what I'm not hearing is anything about marine protected areas or refuges or things like that. How do you compare areas that are obviously perturbed and disrupted? What's your control? Don't you need something to do that against? What are the implications of not having it?

**Colin Levings:** We have compared disrupted estuaries to intact estuaries [see background reference list]. It's a very useful approach. I found it very difficult to sell, however. There's so much site-specific information needed at a particular estuary that we often have to focus there. For a more balanced scientific approach, we should use reference habitats more often. Steve [Macdonald] and others have used that approach in contaminant work.

The marine protected areas are going to be important. NGOs are just waiting for the [proposed] Canada Oceans Act to pass so they can apply to make some of these estuarine areas marine protected areas. I don't know how we're going to deal with that, but that's probably going to happen in a couple of months.

## APPENDIX I: ATTENDEES BY REGION

Pacific Region:
**Bell-Irving, Rod**, Habitat and Enhancement Branch, Vancouver
**Bradford, Mike** , Science Branch, West Vancouver Laboratory
**Bonnell, Greg**, Habitat and Enhancement Branch, Vancouver/Victoria
**Conlin, Kevin**, Habitat and Enhancement Branch, Vancouver
**Delaney, Peter**, Habitat and Enhancement Branch, Vancouver
**Ennis, Gordon**, Habitat and Enhancement Branch, Vancouver
**Jamieson, Glen**, Science Branch, Pacific Biological Station, Nanaimo
**Karanka, Eero**, Habitat and Enhancement Branch, Prince Rupert
**Langer, Otto**, Fraser River Action Plan, Vancouver
**Levings, Colin**, Science Branch, West Vancouver Laboratory
**Logan, Gary**, Habitat and Enhancement Branch, Vancouver
**Macdonald, Steve**, Science Branch, West Vancouver Laboratory
**Miller, Lana**, Habitat and Enhancement Branch, Vancouver
**Naito, Brian**, Habitat and Enhancement Branch, Vancouver
**Shortreed, Ken**, Science Branch, West Vancouver Laboratory
**Stalberg, Heather**, Habitat and Enhancement Branch, Kamloops
**Williams, Ian**, Science Branch, Pacific Biological Station, Nanaimo
**Wilson, Bob**, Science Branch, Institute of Ocean Sciences, Sidney

Central and Arctic Region:
**Bergmann, Martin**, Science Branch, Freshwater Institute, Winnipeg
**Cairns, Vic**, Habitat Management Branch, Bayfield Institute, Burlington
**Hopky, Glen**, Habitat Management Branch, Freshwater Institute, Winnipeg
**Majewski, Dorothy**, Habitat Management Branch, Freshwater Institute, Winnipeg
**Metikosh, Serge**, Habitat Management Branch, Bayfield Institute, Burlington
**Minns, Ken**, Science Branch, Bayfield Institute, Burlington
**Randall, Bob**, Habitat Management Branch, Bayfield Institute, Burlington
**Stein, Jeff**, Habitat Management Branch, Freshwater Institute, Winnipeg
**Welch, Buster**, Science Branch, Freshwater Institute, Winnipeg

DFO Headquarters, Ottawa:
**Bain, Hugh**, Environmental Science Branch
**Burgess, Steve**, Habitat Management Branch
**Nadeau, Richard**, Habitat Management Branch
**Robinson, Dave**, Habitat Management Branch

Laurentian Region:
**Walsh, Gordon**, Science Branch, Institute Maurice-Lamontagne, Mont-Joli

Maritimes Region:
**Amiro, Peter**, Science Branch, Halifax
**Anthony, Larry** Habitat Management Branch, Moncton
**Gordon, Donald C.**, Science Branch, Bedford Institute of Oceanography, Dartmouth
**Lawton, Peter**, Science Branch, St. Andrews Biological Station
**Rutherford, Bob**, Habitat Management Branch, Halifax

Newfoundland:
**Anderson, Robin**, Science Branch, St. John's
**Anderson, John**, Science Branch, St. John's
**Barnes, Marvin**, Habitat Management Branch, St. John's
**Dempson, Brian**, Science Branch, St. John's
**Finn, Ray**, Habitat Management Branch, St. John's
**Gibson, John**, Science Branch, St. John's
**Scruton, Dave**, Science Branch, St. John's

# APPENDIX II: WORKING GROUP PARTICIPANTS

**Group A**

Facilitator: Steve Macdonald

Rapporteur: Marty Bergmann

Robin Anderson

Steve Burgess

John Gibson

Glen Jamieson

Eero Karanka

Bob Randall

Jeff Stein

Ken Shortreed

Ian Williams

**Group B**

Facilitator: Vic Cairns

Rapporteur: Peter Delaney

Larry Anthony

Mike Bradford

Gary Logan

Richard Nadeau

Brian Naito

Bob Rutherford

Dave Scruton

Buster Welch

**Group C**

Facilitator: Don Gordon

Rapporteur: Brian Dempson

Peter Amiro

Gordon Ennis

Ray Finn

Glen Hopky

Serge Metikosh

Dave Robinson

Heather Stalberg

**Group D**

Facilitator: Hugh Bain

Rapporteur: Colin Levings

John Anderson

Marvin Barnes

Greg Bonnell

Peter Lawton

Dorothy Majewski

Lana Miller

Ken Minns

Gordon Walsh