Methods of Measuring Productive Capacity in Canada: Summaries for review at a national workshop, October 15-16, 2007.

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2008

METHODS OF MEASURING PRODUCTIVE CAPACITY IN CANADA: SUMMARIES FOR REVIEW AT A NATIONAL WORKSHOP, OCTOBER 16-17, 2007

by

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ABSTRACT

Smokorowski, K.E., and Derbowka, D. 2008. Methods of measuring productive capacity in Canada: Summaries for review at a national workshop, October 15-16, 2007. Can. Tech. Rep. Fish. Aquat. Sci. 2815: iv + 158 p.

In response to a need identified by DFO's Habitat Management Program to develop national standards of measuring productive capacity of aquatic ecosystems, early in 2007 DFO Science began gathering and summarising the current methods used to measure productive capacity of aquatic systems affected by hydro development across Canada. Relevant method summaries were documented in this technical report for science review and debate at a National Methods Workshop held October 15-16, 2007. It is important to emphasize however that this technical report only provides a summary of methods with no scientific review. The products from this National Workshop were threefold: 1) a peer-reviewed Technical Report that summarizes existing methods for determining the productive capacity of fish habitat (this document); 2) a CSAS Proceedings Report (documentation of the workshop discussion, conclusions and recommendations: DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/002) and 3) a reference document (primer), explaining the basics of predictive habitat models "A Primer on Fish Habitat Suitability Models" (deKerckhove et al. *in prep*).

RÉSUMÉ

En réponse au besoin cerné par le Programme de gestion de l'habitat du MPO d'élaborer des normes nationales pour la mesure de la capacité de production des écosystèmes aquatiques, le secteur des Sciences du MPO a commencé, au début de 2007, à recueillir et à résumer les méthodes présentement utilisées pour mesurer la capacité de production des systèmes aquatiques touchés par l'aménagement hydro-électrique dans tout le Canada. Les résumés des méthodes pertinents ont été documentés dans ce rapport technique aux fins d'examen et de débat scientifiques lors d'un atelier national sur les méthodes tenu les 15 et 16 octobre 2007. Il est toutefois important de souligner que ce rapport technique fournit seulement un résumé des méthodes sans examen scientifique. Les produits de cet atelier national étaient triples : 1) un rapport technique approuvé par des collègues qui résume les méthodes actuellement utilisées pour déterminer la capacité de production de l'habitat du poisson (le présent document); 2) un rapport des délibérations du SCES (documentation de la discussion, des conclusions et des recommandations de l'atelier : Secr. can. de consult. sci. du MPO, compte rendu 2008/002); 3) un document de référence expliquant les notions élémentaires des modèles de prévision d'habitat, intitulé : « A Primer on Fish Habitat Suitability Models » (deKerckhove et coll. *en prép.*).

1. Background

DFO's habitat management program most frequently uses changes in habitat area (by type) as a basis for assessing the net change in productive capacity to achieve their objective of no-net-loss under the Policy for the Management of Fish Habitat (DFO 1986). These physical and biological descriptors are used as surrogate measures to assist in defining habitat productive capacity until ongoing research provides more precise tools.

However, large scale changes in habitat type which occur, for example, with the development of a new hydropower facility (e.g., transformation from lotic to lacustrine habitat, change in the fish community composition, modification of water parameters such as temperature, etc.) need the development of productive capacity assessment tools adapted to this type of project. These tools could take into account the inclusion of other parameters such as fish population data. In fact, the policy states that it is the productive capacity of habitat that must be measured, not simply the habitat itself, which would require the inclusion of a biotic measurement in the habitat accounting.

One of the most prominent large-scale habitat change developments is a large-scale hydroelectric development, the majority of which have recently been occurring in the Quebec region, although a few are in other regions (e.g., the Lower Churchill development in Labrador). In 2005 a workshop was held with the objective of reviewing methods proposed by Hydro Quebec to evaluate the effects of large hydroelectric projects on fish habitat (CSAS Science Advisory Report SAR-AS2005-038 – http://www.dfo-mpo.gc.ca/csas/Csas/status/2005/SAR-AS2005_038_E.pdf). The workshop was successful in establishing why proposed methods were not appropriate, including identification of approaches that were innovative and novel but requiring more development, but failed to reach a firm recommendation on what methods should be employed under what circumstances. The most problematic scenario was for assessing the reservoir after dam construction relative to the flooded rivers, streams, and lakes. Suggestions were made for method refinement which was tasked to Hydro Quebec, and a separate new method has been in development by Newfoundland and Labrador Hydro for the assessment of the new Lower Churchill waterpower facility.

In other parts of Canada, watersheds are affected by new hydro developments (albeit at a smaller scale, e.g., Ontario), or by significant changes in operational regimes of a hydro facility (e.g., via new regulation practice or redevelopment). Since all significant changes in flow management will affect the productive capacity of fish habitat, there is a requirement to assess the change under the terms of the no-net-loss policy. However, no national standard methods exist prescribing how to achieve the goals of the policy, resulting in different approaches by region and disparate sampling burdens being placed on proponents. The 2005 CSAS workshop report indicated that there were a number of outstanding methodological issues that could be addressed through a technical workshop involving national representatives from science, academia and habitat management. Advancement towards consensus on national standards (recognizing regional and habitat differences) was the main goal of this proposed workshop.

Early in 2007 DFO Science began gathering and summarising the current methods used to measure productive capacity (or an index thereof) of aquatic systems affected by hydro development across Canada. Regulating agencies and industry were contacted nation-wide to provide documentation of methods applied in river and reservoir systems using habitat based, biota based, and/or a combination of approaches. In addition, searches for applicable methods were conducted in the literature. Reviews were documented in this technical report for science review and debate at a National Methods Workshop. The purpose of the workshop was to scientifically review methods used to quantify productivity capacity of habitat impacted by hydroelectric operations. It is important to emphasize however that this technical report only provides a summary of methods with no scientific review. The workshop objectives identify the steps in the scientific review process and expected outcomes. Establishing criteria for evaluation of methods is critical as development of consistent standard methods will be a continuing and dynamic process. The workshop was run as a Canadian Science Advisory workshop on October 15-16, 2007, in Calgary, Alberta.

The objectives of the workshop were to:

Provide a science review of methods obtained from the primary literature, industry and elsewhere for evaluating the productive capacity of fish habitat for projects impacted by hydroelectric development and operations. The proposed approach included the following:

1. Review list of summarized methods and assess for completeness (any missing methods?);
2. Group methods according to general approach;
3. Evaluate the applicability of methods to DFO mandate and across systems and development scenarios. Identify systems and referral scenarios not covered;
4. Review, revise, and reach consensus on proposed criteria for evaluating the methods;
5. Select candidate methods for review using agreed-upon criteria;
6. Review selected methods according to criteria to ensure standard application of criteria against any future proposed or amended method;
7. Identify volunteers from workshop participants to evaluate remaining methods against criteria to form part of workshop report.

By presenting a comprehensive set of methods at the outset, the goal was to evaluate them on a relative basis and assess applicability to the range of systems and stages in the assessment process. By reaching consensus on criteria and approach for evaluating the methods, tools would be provided for habitat practitioners to scientifically evaluate new methods as they are proposed. If it is found that no suitable methods currently exist that are applicable under all situations (i.e. upstream before and after the dam or change in operation, downstream before and after the dam or change in operation), then the workshop would have advanced this issue by outlining the research needed to address the methodological shortcomings. These gaps could be addressed in future by the DFO Center of Expertise on Hydroelectric Impacts on Fish and Fish Habitat (CHIF) research agenda and/or as part of a proposed National Research Network to assess the impacts of altered flow regimes on riverine ecosystems (proposed NSERC's HydroNet). While the methods aimed to account for habitat change in the no-net-loss calculation, it should be noted that like the 2005 workshop, this workshop did not address the issue of the acceptability of trading one habitat type (e.g. riverine for lacustrine) or fish species for another, since that is a policy issue and not a matter for science.

Workshop Steering Committee

Dr. Karen Smokorowski, Lead
Dan Thompson, DFO Habitat Management
Dr. Robert Randall, DFO, Science
Mike Stoneman, DFO, NHQ Environmental Science
Christine Stoneman, DFO, NHQ Habitat Management
Jean Guy Jacques, DFO, Habitat Management

Workshop Conclusions

The list of methods was reviewed for completeness and some additions were suggested. The methods were grouped according to use and applicability for assessment and monitoring, and the only development scenario considered to be missing an appropriate method was how to assess the creation of reservoirs. However, no method handled connectivity of habitats or the impacts on estuaries, and all methods lacked adequate scientific validation of predictions. The criteria for evaluating methods were examined, modified, and consensus was reached, however, it was felt that the criteria should not be used to assess new proposed methods outside of a formal peer review process, particularly for large-scale projects. One method was reviewed under the criteria and was considered relatively robust for use in the referral assessment process. There was general agreement that the 'holy grail' of creating a national standard method or suite of methods was not feasible at this time. Because of the large spatial scale of hydropower impacts (whole watersheds), specific methods for measuring no-net-loss of productive capacity need to be peer-reviewed on a site-by-site basis in the future (see Proceedings: DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/002).

2. Approach

2.1. How Method Papers were Obtained

In late December 2006 as a response to the priorities identified by the Reservoir Science Breakout Group at the CHIF Workshop held on September 19, 2006, DFO-GLLFAS in Sault Ste Marie contacted 94 individuals from government, industry and academia, involved in the assessment of habitat productive capacity across Canada. Recognizing the need for both federal and industry input, a request for submissions was made to provide documentation of the methods currently being used to assess productive capacity in river and/or reservoir systems affected by hydroelectric development using habitat and/or biota-based approaches (see request letter Appendix A). Over the subsequent 10 weeks, 17 respondents provided either the requested documentation or the names of further potential contacts.

Additional methods were sought in two ways. First, the bibliographies of obtained methods documents were mined for other potentially useful papers. Papers identified in this manner were either obtained from the DFO Library in Winnipeg or were acquired from online resources. Cambridge Scientific Abstracts (CSA) and Google Scholar were used exclusively for this task. A number of different terms were used within the search engines, which included many derivations on ‘productive capacity’, ‘fish habitat’, ‘fish production’, and the like. Also, specific authors’ names were queried when it was warranted. Where the documents were not available online, the DFO Library was again used to acquire hard copies.

In total 88 documents were obtained from all sources. From these documents 26 did not provide information related to habitat productive capacity; 35 were related to habitat productive capacity, but were not methods or were duplicated; the remaining 27 documents were summarized for this report. Three additional methods were added to this report after the workshop participants recommended their inclusion. All documents were entered into a ProCite 5 database when hardcopies were obtained and grouped respectively as ‘Not useful’, ‘Related’, or ‘Summarized’.

2.2. How Method Papers were Summarized

Each document was summarized according to the system type to which it applied, the reason or objective for the assessment, the methods employed, the results obtained, and any relevant discussion that ensued. Any assumptions or assessments of validity of a given method were also noted in the summaries, provided that they were included in the body of the text. A section was also included at the end of each summary for any questions that were raised about the method during the initial summary process. Methods were categorized according to their use and applicability as follows:

1) Methods that can be used in environmental assessment to predict change in productive capacity from a change in habitat either via:

- habitat quality measures based on biotic parameters (change expressed in terms of habitat area), or,
- fish productivity measures (change expressed in terms of kg of fish per unit area), or,

2) Methods that can be used in monitoring or compensation studies (empirical studies):
   - fish productivity or diversity measures; or,
   - multi-trophic level / ecosystem project assessment.

No attempt was made to critically compare the strengths, weaknesses, or validities of any document reviewed. The purpose of this exercise was to collect as many methodologies as possible, in expectation that a future critical review process could provide scientific validation.

2.3. Challenges of the Summaries

The timing of the request for submissions coincided with winter holidays for many individuals and may have contributed to delayed response times. Overall only about 15% of contacted individuals replied to the submission request, resulting in larger time requirements searching through online resources. A number of the methods found as a result of searches were difficult to obtain given that they were grey literature reports. Since the invitation to the workshop was distributed in August 2007, a number of additional methods were provided for the review which indicates that other methods may be in existence that have not been included. The last minute reviews were conducted before the workshop, and three method summaries were added after the workshop.

3. Products

The products from this National Workshop were threefold: 1) a peer-reviewed Technical Report that summarizes existing methods for determining the productive capacity of fish habitat (this document); 2) a CSAS Proceedings Report (documentation of the workshop discussion, conclusions and recommendations: DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/002) and 3) a reference document (primer), explaining the basics of predictive habitat models "A Primer on Fish Habitat Suitability Modelling" (deKerckhove et al. *in prep*).

4. Method Summaries

4.1. Karr et al. 1986 – Rivers and Streams

IBI
Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., Schlosser, I.J. 1986. Assessing Biological Integrity in Running Waters. A Method and Its Rationale. Illinois Natural History Survey, Special Publication 5. See also: Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries

6(6) 21-27.
System Type and Method Classification
Rivers and streams. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
To develop a method to rapidly and inexpensively assess water resource quality using fish based indicators in a series of watersheds in Illinois and Indiana.
Methods & Design
• The accurate assessment of biotic integrity requires a method that integrates biotic response patterns and processes from individual to ecosystem level by defining an array of biological metrics. • IBI incorporates data from the entire fish community on 12 metrics in 3 categories. • The value of each metric is compared to the value expected at similar site, region, and size where human impacts are minimal. • Each metric is assigned a rating of 5, 3, or 1 depending whether it approximates, deviates, or strongly deviates from the expected value. • Sampling site is assigned to 1 of 6 classes based on sum of the 12 metrics. The highest score is 60 (a site without disturbance). The total score also provides qualitative label from excellent to poor. • Metrics assess attributes assumed to correlate with biotic integrity and together characterize underlying biotic integrity of the site. • Metrics are a function of integrity, but integrity is not function of the metrics. • IBI incorporates professional judgement in a systematic and sound manner and sets qualitative criteria to assess what is excellent versus poor quality. • Expectation criteria used to rate metrics will vary in stream size and region. • IBI works when the objective is to study biotic integrity at specific site and is suited to screening large number of sites to identify immediate issues or trends over time. • IBI can be used to interpret large amounts of data from complex fish communities. • IBI enables researchers to formalize professional judgements, which does not mean that it results in assessments that are more subjective than other “objective” methods such as diversity indexes. <u>Metrics Used</u> • Metrics reflect insights from individual, population, community, ecosystem, and zoogeographic perspectives. • Metrics are sometimes redundant as several may be sensitive to the same impact, together they are responsive to relatively small magnitude changes over broad range of degradation. • Relative sensitivity varies from region to region and no single metric is always reliable indicator of degradation. • Metrics are differentially sensitive to various perturbations and site

conditions can be determined with considerable accuracy. For example, municipal effluents depressed total numbers and altered trophic structure, whereas habitat alteration would most affect sensitive taxa.

Species Richness and Composition

- This category assesses species richness and composition compared to stream size and zoogeographic factors.
- Expected 'undisturbed' values are based on region, stream size, elevation, and gradient.
- Total numbers, number of intolerant species, and numbers of species in 3 major families (suckers, *Catostomidae*; sunfish, *Centrarchidae*; and darters, *Percidae*) are considered.
- Suckers and darters feed on benthic invertebrates, sunfish on midwater and surface invertebrates.
- These groups represent Ideal indicators due to relatively high species richness and broad distribution.
- Other families may be substituted where listed families are missing from region of interest. Substitutes should also have high species richness, broad distribution, and include 1 benthic and 1 non-benthic oriented family (3rd family from either). Consider sampling methods when choosing groups, for example, larger rivers might include larger species (eg. Suckers, catfish, etc).

***Metric 1- Total number of species*:** total number of fish species decreases with degradation. Do not include hybrids and subspecies in this count.

***Metric 2 – Number of darters*:** subfamily *Etheostomatinae* of *Percidae* as sensitive to degradation due to reproductive and feeding habitats in benthic habitats. In other regions number of sculpin species (*Cottidae*) may be substituted.

Metric 3 – Number of sunfish: Members of *Centrarchidae* (excluding black basses) responsive to degradation of pool habitat and instream cover. Salmonids could be substituted where other pool-dwelling species are required.

Metric 4 – Number of suckers: *Catostomidae* are intolerant of habitat and chemical degradation and their longevity provides a multiyear integrative perspective.

Metric 5 – Number of intolerant species: many families intolerant of a variety of disturbances and are first to be decimated after a disturbance. Species in metrics 2-4 may also be included in this group, but endangered or threatened species are not recommended. Metric should be restricted to 5 to 10% of most susceptible species to siltation, low flow, low DO, and toxic chemicals. These species should disappear by time stream degrades to "fair".

Metric 6 – Proportion of green sunfish: *Lepomis cyanellus* increase in abundance in degraded streams and may increase to dominant status and therefore is an appropriate species to measure the degree to which tolerant species dominate the community. May also weight this metric proportionally with other tolerant species present

Trophic Structure

- Energy base and trophic dynamics are assessed by this category.
- Alterations in water quality or habitat condition result in fish community changes due to changes in food resources.
- Species assigned based on feeding patterns as omnivores, insectivorous cyprinids, or piscivores.

Metric 7 – Proportion of omnivores**:** omnivorous species consume significant quantities of both plant and animal materials and have presence of long gut and dark peritoneum associated omnivorous ability. Diets contain at least 25% plant and 25% animal foods. Do not include omnivores that take no plants or possess short guts that occasionally contain plants. Dominance of omnivores occurs as specific food base degrades.

Metric 8 – Proportion insectivorous cyprinids: Tends to vary inversely with Metric 7. Relative abundance decreases with degradation, probably responding to variability in insect supply. In regions where insectivorous cyprinids are less dominant, the proportion of total insectivores to total individuals may provide better information, using 0-40%, >40-80%, and >80% for ratings 1, 3, and 5 respectively.

Metric 9 – ***Proportion of piscivores***: Includes adults of all species that are predominantly piscivores. Do not include opportunistic feeders that may take fish. Viable and healthy populations of top carnivores (e.g. smallmouth bass, walleye, pike) indicate a healthy ecosystem. Some species may feed on crayfish and frogs.

Abundance and Condition

- This category measures abundance, age structure, growth, recruitment, and conditions in a general rather than detailed way.

Metric 10 – Number individuals in sample: Expressed as CPUE, where effort can be expressed per unit area, reach length, or unit of time. Poor sites generally yield fewer fish. Relative CPUE assign scores among sites or at the same site sampled different times.

Metric 11 – Proportion of hybrids: Assesses extent to which degradation altered reproductive isolation, due to loss of normal barriers along habitat gradients (e.g. substrate types) that generally limit hybridization. May be common among cyprinids after channelization. Frequency of hybrids may increase more among some species. Difficult to determine from historical data.

Metric 12 – ***Proportion of abnormal conditions:*** Especially poor sites yield large numbers of fish in poor health. Parasitism, sterility, tumors, fin damage, other deformities increase as degradation increases.

Rating Metrics and Classifying Site

- Collecting and interpreting IBI is a hierarchical process.
- The process begins with defining the fish community of interest and choosing an appropriate sample design.
- All species in the region must be categorized for food requirements

and tolerance limits.

- After sampling, 12 metrics are compared to expected values and given 5, 3, or 1 rating. The sum of these values gives the total IBI score, which provides the qualitative label for site.
- Expectation criteria must reflect the same stream size and geographic region and be representative of "excellent" communities in undisturbed settings.
- Total numbers of fish and numbers in 3 key taxa (metrics 1-4) increase with stream size.
- Horton (1945) and Strahler (1957) are commonly used to indicate increases in stream size based on first, second, third, etc. order of the stream.
- Ecological discussions generally rely on 3 classes: headwater (1^{st} to 3^{rd} order streams), intermediate rivers (4^{th} to 6^{th} order), and large rivers ($\geq 7^{th}$ order).
- Area of watershed may be a more useful measure than stream order.
- When the total number of species is plotted as function of stream order (or watershed area) for number of relatively undisturbed sites, a distinct right-angle triangle is produced (best fit line). The hypotenuse approximates the upper limit of species richness. Migratory species and escapes from reservoirs are not included.
- Line with slope fit by eye to include 95% of sites was found to be a better measure of species richness than by linear regression.
- This line of maximum species richness is used to define "excellent" fish community for metrics 1 to 5.
- Similar lines are drawn for the 3 major taxa (darters, suckers, sunfish) and intolerant species, accounting for regional differences. For example, where no sunfish exist in the region, rating 5 to metric 3 was arbitrarily assigned because their absence does not indicate degradation.
- The line for specific taxa is unlikely to be smooth when few species are used. Data used to plot lines are based on individual sample, since communities are dynamic and several samples taken at different times from the same site will lead to erroneous conclusions.
- Metrics in "Trophic composition" and "Abundance and Condition" groups appear to vary less with watershed area, stream size, and region.
- 5 qualitative labels are Excellent, Good, Fair, Poor, and Very Poor with IBI ranges of 58-60, 48-52, 40-44, 28-34, and 12-22 respectively. A 6^{th} label called "No fish" was added to account for no captures at a site.
- Undefined ranges of scores between classes are used to make sure decisions are not based solely on IBI, but also gives careful consideration of expectation criteria.

Sampling methods and data quality

- Collection methods must be standardized and sample must reflect the community present.

- Multiple samples collected on same date should not be combined for IBI analysis.
- 4 problems affecting quality of data
    1. Purpose governs nature of data. Data collected for taxonomic purpose are accurately identified, but may not have reliable total counts.
    2. Gear, water conditions, and fish behaviour affect sample accuracy.
    3. The entire range of habitats must be sampled.
    4. Unrepresentative habitats adjacent to sample site will result in atypical samples. Data collected near bridges, river mouths, etc will be more typical of larger order streams.
- Biologists must ensure representative sampling by selecting appropriate gear, for example.
- Most sampling gear is not effective on fish <20mm in length, thus it is recommended to exclude this size range. Usually they prove to be YOY.
- Basic premise of IBI is that the entire community sample is in its true relative abundance without bias. If this assumption is violated, the reliability of IBI is reduced.
- Size of sample reach is another consideration. 100m is sufficient in simple headwater streams. In general, distances of 11 to 15 stream widths are adequate to sample two cycles of habitat (i.e. 2 riffle-run-pool and backwater areas).
- No single time of year best defined for sampling, but periods of low to moderate flow are preferred.
- Sampling guidelines should also be applied rigorously to historical data.

<u>Inappropriate uses</u>

<u>General Cautions</u>

- Management decisions using IBI must be made with guidance of biologist familiar with IBI and local fish fauna.
- It is dangerous to turn IBI calculations over to a computer as it eliminates the human decision making process.
- Management is needed at watershed level to fix problems identified by IBI, with solutions like fish stocking having limited lasting value.

<u>Sampling cautions</u>

- Representative samples are essential. The most common problems are having reaches too short and using inappropriate gear.
- All species present must be captured and their relative abundance must represent that of stream community.
- Must identify and count every specimen in sample, not just sport or commercial fish.
- Use historical data sets cautiously.

- Lines of maximum species richness are based on species collected at 1 site on 1 day. The accuracy of metrics 1 to 6 depend on this one sample richness.

Interpretation cautions

- Professional judgement is important at every level.
- Disease and condition are the most frequent data missing from historical sets, which influences metrics 11 and 12. Omitting a metric would require a rescaling of IBI and best approach may be to assign a 5 rating to missing data.
- IBI is not the last word in management, but is tool for interpreting complex biological data.
- Total IBI scores should differ by at least 4 points before a change in site quality can be said to exist. This will vary depending on site conditions and sample methods.
- When comparing sites in different regions, qualitative labels can be compared but quantitative IBI scores cannot.

Future Use

- Recommend 4 major developments →1) training in IBI, 2) creation of substitute metrics for other regions, 3) study of natural and anthropogenic variations of biotic integrity, and 4) documentation of distributional properties of IBI.
- Training should take place at 2 levels – how /why ecological concepts of IBI are used and resource managers need to recognize the importance of direct assessment of biotic integrity.
- IBI potentially useful in wide range of aquatic and marine environments, geographic regions, and taxa thus equivalent metrics must be found for these circumstances.
- Natural variation must be defined to distinguish anthropogenic variation in biotic integrity.
- Long term goal should be to treat IBI as statistic with sampling and other sources of variability.
- 3 more minor considerations for future use involve treatment of exotic species, scoring metrics related to trophic composition, and handling of one-species guilds.

Results & Discussion

- Several examples were provided of watershed where the method was used in Indiana and Illinois. The examples showed that decline in quality of fish communities across the range of classes paralleled by declines in measured indices. Selection of any one single metric alone would yield less reliable results than the array of metrics selected.

Assumptions

- Assumed fish sampled were a balanced representation of the fish community.
- Assumed site sampled was representative of the larger geographic area of

interest • Assumed scientist was trained and experienced with local fish fauna.
Assessment of Validity
• IBI satisfies all 6 criteria identified for biomonitoring programs by Herricks and Schaeffer (1985), which states measures must be/have 1. Be biological. 2. Interpretable at several trophic levels and connect with organisms not directly involved. 3. Sensitive to conditions being monitored. 4. Range suited for intended purpose. 5. Reproducible and precise within acceptable limits for data collected over space and time. 6. Variability of measures must be low.
Questions?

4.2. Rempel and Colby 1991 - Lakes

Rempel, R.S. and Colby, P.J. 1991. A statistically valid model of the morphoedaphic index. Can. J. Fish. Aquat. Sci. 48, 1937-1943.
System Type and Method Classification
Lakes. Predictive – fish production.
Reason for Assessment/ Objective
The purpose of this paper was to explain concepts of morphoedaphic model (MEM), describe this statistical model based on logarithmic transformation, and compare model predictions with Ryder's (1965) original morphoedaphic index (MEI).
Methods
• The original MEI model was a simple predictive tool that allowed the determination of annual fish harvest of lakes, based on mean depth, surface area, and total dissolved solids (TDS). The model was highly criticised, but widely used. *MEM Development* • Uses three variables – surface area, lake volume, and TDS. • Variables capture 2 properties related to lake productivity – thermodynamics and fertility. • Surface area and volume describe thermodynamics as heat retention depends on allometric properties of basin morphometry. • However, thermal dynamics of lakes are complex and not fully accounted for by these 2 variables, which affects generality and precision of the model. • Increase model precision can be achieved by partitioning data set to lakes with similar environmental conditions and latitude. • Increase generality could be achieved by broadening the range of lakes in

the model and including additional variables (e.g. latitude, epilimnion depth, lake temperature).

- Fertility is partially independent of basin morphology, and can be affected by watershed geomorphology, atmospheric deposition, point source inputs, and exchange rates.
- TDS is used to indicate fertility in MEM, but other correlates might better characterize fertility (phosphorus, chlorophyll *a*, primary/secondary productivity). Estimates of nutrient dynamics or loading might be useful variables.
- Decision to increase precision or generality is based on cost, management needs, or scientific objectives.

Data Conversion

- Ryder's (1965) data were converted into SI units.
- Volume (m^3) calculated from relationship → mean depth (m) = volume (m^3) x surface area $(ha)^{-1}$ x 10^4
- Annual harvest calculated from relationship → yield (kg/ha/yr) = annual harvest (kg/yr) x area $(ha)^{-1}$

Log-linear MEM model

- In log-linear form, Ryder's (1965) data described by →

  $$\log_e(\text{harvest}) = 0.840 \log_e(\text{area}) + 3.041;$$

  where harvest (kg/yr) is annual mass of fish caught and kept in the lake and area is in ha
- This relationship describes ≈ 95% of variation of fish harvested among lakes.
- Addition of volume (m^3), effects of morphometry better accounted for →

  $$\log_e(\text{harvest}) = 1.586 \log_e(\text{area}) - 0.564 \log_e(\text{volume}) + 7.666$$
- This equation indicates 97% of variation in fish harvest.
- Addition of TDS (mg/L), harvest predicted by

$$\mathbf{\log_e(harvest) = 1.588 \log_e(area) - 0.561 \log_e(volume) + 0.293 \log_e(TDS) + 6.184} \quad \text{(eqn 1)}$$

- This equation indicates 98% of variation in fish harvest.
- It has been suggested that TDS could be dropped as it accounts for only 1% of variation in data. Also suggested that volume could be dropped, as surface area adequate predictor on its own. However, their inclusion broadens the range of lakes that can be modelled to include atypical morphometry or TDS situations.

Non-linear MEM Model

- Lack of heteroscedacity in covariance matrix indicates coefficients of MEM are linearly additive, thus the model should also be equivalent in non-linear form.
- This idea supported by Bajdik and Schneider 1991 and confirmed by estimating parameters of MEM using non-linear regression
- Non-linear model form→

$$\mathbf{\log_e(harvest) = \log_e(area^{b1} \cdot volume^{b2} \cdot TDS^{b3} \cdot EXP^{b0})} \quad \text{(eqn 2)}$$

where b1, b2, b3 = slopes of log-linear model; b0 = intercept

- Equation 2 without logarithms →
  harvest = area$^{1.59}$ · volume $^{-0.56}$ · TDS $^{0.29}$ · EXP $^{6.18}$ (eqn' 3)
-

Results & Discussion

Comparison MEI and MEM

- MEI and MEM result in very close predictions of yield for original data set. Exploring equations cast into full exponential form reveals →
  MEI: $C = k(A^{1.45} \cdot V^{-0.45} \cdot T^{-0.45})$ (eqn' 4)
  MEM: $C = i(A^{1.59} \cdot V^{-0.56} \cdot T^{-0.29})$ (eqn' 5)
  Where C = harvest, A = area, T = TDS, D = depth, Volume (V) = D x A x 10^4; k = EXP$^{(4.48113)}$ = 88.3344; I = EXP ^{b0} and b0 = 6.18
- MEI closely related to MEM although TDS is assigned greater importance in MEI model.
- Predicted harvest differs little between statistically valid MEM and traditional MEI approaches.
- MEM allows error estimates, such as 95% confidence limits.

Relationship among variables

- Partial correlation (accounts for intercorrelation of variables) reveals surface area, volume, and TDS are independently correlated with harvest in descending order of strength
- Pearson (uncorrected) correlations indicate surface area and volume equally correlated with harvest, while TDS virtually uncorrelated.
- Uncorrected correlations lead to erroneous interpretation as there is strong intercorrelation between surface area and volume.
- Morphometric factors (surface area and volume) contribute 94.8 and 2.54% of variability in fish production while edaphic factor (TDS) accounts for only 0.64%

Application of MEM

- Evident that parameters reflect the data set chosen.
- In some ecoregions, edaphic factors play greater role than this data set which is based primarily on oligotrophic lakes.
- Can expand original MEI data with data based on new area.
- Original MEI data set is based on sound, long-term estimate of sustainable yearly harvest. Estimation of this harvest is the most difficult component of developing a model data set.

Approaches to comparing fish production

- Traditional MEI use compares fish production between lakes
- MEM model demonstrates difficulty in making interlake comparisons as area, volume, TDS slope, and model intercept all vary between classes of lakes.
- One approach could be to use multivariate regression techniques test for differences in slope and intercept.
- For example, take a single group of lakes where fishing pressure changes. The annual sustained harvest (for the 2 periods) could be expressed as separate dependent variables. Multivariate regression shows differences

among slopes of 2 time periods (low and high pressure). Results could be interpreted in terms of fishing pressure.

- Another example, compare 2 different groups of lakes with different fish community structure. Test community structure influence of sustained annual harvest by including dummy variable for lake "a" (=0) and lake "b" (=1). The significance of lake group variable can be determined and its percent contribution to explaining annual harvest estimated.
- Interpretation of residuals also aid in interpreting trends among lake classes.

Management Example

- MEM parameters were derived for 2 OMNR fisheries management data sets to show how Ryder's 1965 parameters may change.
- 2 groups of lakes differ with respect to MEM variables – sportfish lakes (smaller, more fertile) versus commercial lakes (larger, less fertile). As result, MEM parameters differ between 2 groups.
- Derived model for sportfish lakes →

$$\textbf{harvest} = \textbf{area}^{1.44} \cdot \textbf{volume}^{-0.49} \cdot \textbf{TDS}^{0.49} \cdot \textbf{EXP}^{4.49}$$

(r^2=0.84, p<0.0001)

- Derived model for commercial lakes →

$$\textbf{harvest} = \textbf{area}^{1.25} \cdot \textbf{volume}^{-0.26} \cdot \textbf{TDS}^{0.17} \cdot \textbf{EXP}^{3.00}$$

(r^2=0.98, p<0.0001)

- It is evident that TDS more important in smaller sport fisheries lakes.
- Comparison of predictions using MEI, MEM derived with Ryder's data set (MEM_R), and MEM derived using the sport fisheries data set (MEM_S) show MEM_S better fits data than other 2 models. Similar to commercial fisheries, MEM_C best fit observed yield than 3 other models previously mentioned.
- Increased precision is gained, while sacrificing generality, by partitioning data sets and deriving separate models for each group.

Outliers

- Issues affecting whether lakes were outliers for Management Example were:
  - Selective harvest and community structure: Fisherman harvest and keep greater diversity of fish in certain lakes can lead to altered predator/prey community structure.
  - Phosphorus loading: Higher natural and anthropogenic loading is associated with higher harvest. Lakes located further south have a long growing season. Some surrounding land more is fertile naturally.
  - Habitat degradation: noxious winter kills, recreation activities, etc. can impede natural production.
- With proper partitioning of data set and selection of meaningful variables, models can be derived allow managers to predict expected harvests with acceptably high level of confidence.

Assumptions
Not listed
Assessment of Validity
Not listed
References
Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94: 214-218. Ryder, R.A. 1982. The morphoedaphic index- use, abuse and fundamental concepts. Trans. Am. Fish. Soc. 111: 154-164.

4.3. Minns et al. 1994 – Great Lakes with potential adaptation to inland lakes

Index of Biotic Integrity
Minns, C.K., Cairns, V.W., Randall, R.G., and Moore, J.E. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. Can. J. Fish. Aquat. Sci. 51, 1804 – 1822.
System Type and Method Classification
Great lakes – potential adaptation to inland lakes. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
Great Lakes littoral zones To derive an IBI for fish in littoral zones of Great Lakes' Areas of Concern (AOCs), analyse the properties of the index and its metrics, and asses the IBI as an indicator of water quality and habitat condition.
Methods & Design
• Method based on work by Karr (1981, 1991) and Miller et al (1988) Sampling Method – detailed in Valere (1996) • 1988, 1989, 1990 extensive surveys of fish assemblages and their habitats in littoral zones of three Great Lakes AOCs • Electrofishing boat used to sample 100 m transects, running parallel to shore and following 1.5 m contour • Transects selected to represent fairly homogenous habitat type and to span range of available nearshore habitats • Sampling catch data recorded for occurrence, abundance, and total wet biomass by species • Seven groups of data spanning a range of ecosystem impairment and degradation were collected over three sampling years; Bay of Quinte in 1989 (1) and 1990 (2); Hamilton Harbour in 1988 (3) and 1990 (4); the Severn Sound sites of Penetang Harbour (5), Hog Bay (6), and Matchedash Bay (7) all in 1990 • Number of transects varied from 12 to 48 in different areas ▪ 1990 transects were subset of 1989 transects in Bay of Quinte; 1989 transects sampled once and 2 were selected for a second sampling in August

- 40 transects sampled 7 to 11 times in Hamilton Harbour in 1988 were revisited in 1990 along with 8 new transects
- Severn Sound sites only sampled in 1990
- Each site visited in 1990 had transects sampled 1 to 3 times during the summer

Selection of Metrics

- Review of existing literature led this study to group metrics in 3 categories (species diversity, trophic composition, abundance and condition)
- Raw IBI metrics were always expressed either as 1) sum of subset of species or individuals or 2) same sum expressed as percentage of total species presence-absence, abundance, or biomass.
- Review of existing literature and consideration of littoral fish assemblage features guided selection of metrics.
- 12 metrics were selected in three categories:

Species richness metrics

1. natives species (SNAT)
2. centrarchids (SCEN)
3. native cyprinids (SCYP),
4. nonindigenous species (SNIN)
5. turbidity intolerant species (SINT)

Trophic structure metrics

6. piscivores (PPIS),
7. generalists (PGEN)
8. specialists (PSPE)

Abundance and condition metrics

9. native numbers (NNAT)
10. native biomass (BNAT)
11. percentage nonindigenous by numbers (PNNI)
12. percentage nonindigenous by biomass (PBNI)

Analysis of Raw Metrics

- Summarized frequency of occurrence for raw species richness metrics.
- Cumulative percentage frequency tables were devised using whole database for all metrics.
- Redundancy examined among metrics using Pearson correlations.
- Principal components analysis performed using raw metrics as input.

Metric Standardization and IBI Formulation

- Standardized each metric so minimum value was 0 and maximum was 10 using the equation:

$$M_s = A + B \cdot M_R$$

If $M_s < M_{MIN}$, then $M_s = M_{MIN}$

If $M_s > M_{MAX}$, then $M_s = M_{MAX}$

- This equation expressed the standardized metric (M_s) as linear function of raw metric (M_R), which was the simplest model available.
- Minimum and maximum thresholds (M_{MIN} and M_{MAX}) defined the floor and ceiling respectively. Floor set to 0 for positive metrics. Ceiling set near 90-95th cumulative percentile of whole database.

- A high value for intercept (A) and negative slope (B) produced inverse function; high values of some metrics imply low biotic integrity (ie. low M_s values). 4 metrics had a negative impact on IBI scores – SNIN, PGEN, PNNI, and PBNI
- All raw metrics were treated as continuous variables
- Standardized metrics were summed and multiplied by $10/N_M$, where N_M was the number of metrics. IBI values were produced between 0 and 100 after this step.
- IBI values were put into range categories of equal-width: 0=no fish, >0-20=very poor, >20-40=poor, >40-60=fair, >60-80=good, and >80-100=excellent

Analysis of IBI Properties

- Assessed sensitivity of IBI to each metric by computing a reduced IBI using the other metrics and computing the difference between reduced and overall IBI (Reduced IBI = $10 \cdot (N_M \cdot \text{IBI}/10 - \text{Test Metric})/(N_M - 1)$). Variance of differences was an indication of the relative importance of individual metrics.
- For each metric, the ratio of the variance of differences within each range category to the total variance of differences provided measure of range sensitivity.
- IBI values were assed for normal distribution using (K-S) D statistic and other transformations evaluated for ability to produce normal distribution. IBI transformed before statistical analyses performed.
- IBI variability assessed in three ways: 1) seasonal means and standard errors where transects sampled ≥3 in a year, 2) mean and standard deviation of absolute IBI differences between pairs of samples collected within a few days of each other, and 3) Pearson correlations of transect mean values between years in Bay of Quinte (1989 vs. 1990) and Hamilton Harbour (1988 vs. 1990).

Relationship of IBI and Ecosystem and Habitat Conditions

- IBI was evaluated at 2 levels: 1) between ecosystems according to general conditions, 2) within ecosystems, among transects in relation to site-specific habitat features.
- First, seven groups of transect means were assigned as treatments in one-way ANOVA. Second, series of regression analyses and ANCOVA were performed to relate transect means to measures of vegetation abundance.
- To examine relationship between IBI and habitat features, used IBI and IBI* adjusted for proportion of numbers ($P_{N.OFF}$) and biomass ($P_{B.OFF}$) attributed to "offshore" fish species. [$\text{IBI}^* = \text{IBI} \cdot \{1 - P_{OFF}\}$, where $P_{OFF} = \{P_{N.OFF} + P_{B.OFF}\}/2$]

Results & Discussion

Raw Sampling Results

- Overall 45 species were sampled in electrofishing surveys.
- Total species richness (number of species) per data set was 17 to 30

- Of 654 samples, 13 had no fish caught
- Species frequency of occurrence ranged from 1 to 393, with 14 species occurring <10 times
- Mean number by species per transect ranged from 1 to 48.5
- Mean biomass by species per transect ranged from 0.001 to 11.145 kg
- Mean weight per individual ranged from 1 to 3184 g
- 5 most frequently occurring species were alewife, brown bullhead, yellow perch, pumpkinseed, and common carp.
- By number the top five species were alewife, yellow perch, brown bullhead, logperch, and emerald shiner
- By biomass top five were common carp, common carp x goldfish hybrids, brown bullhead, bowfin, and lake trout.
- Habitat data were recorded at a subset of transect locations for submerged macrophyte occurrence and abundance.
- In 1988, transects in Hamilton Harbour were assigned to 1 of 4 density classes: absent (n=15), sparse (n=7), moderate (n=10), heavy (n=8) following complete survey of macrophyte occurrence along the 1 m depth contour.
- In 1989, macrophyte biomass was estimated from duplicate quadrats and percent cover diver-estimated for 33 transects in Bay of Quinte.
- In 1990, detailed macrophyte stem density, composition, and percent cover surveys were conducted by divers at 72 transects across five areas surveyed.
- Stem density and percent cover means were lower in Hamilton Harbour and Bay of Quinte than 3 areas in Severn Sound
- Habitat transects covered full range of conditions present in electrofishing surveys across study areas.

<u>IBI Metric Selection</u>

- Disease and physical anomalies metrics were not considered as data were not collected from fish samples.
- Total species richness, total abundance, or total biomass metrics were not used as they are sums of assemblage components that measure opposite integrity features.
- SNAT was a strong indicator of ecosystem health.
- SNIN had a major impact on the fish assemblage, acting as a negative indicator.
- SCEN and SCYP are positive metrics typical of North American littoral areas and greater richness expected in undisturbed habitats
- Turbidity is an important factor in littoral areas and SINT had four intolerant species identified in catches.
- Trophic structure metrics based on proportion of total biomass. Generalists had wide range of diets. Piscivores had non-YOY diet consisting of predominantly fish and their low abundance was evidence of poor conditions. Specialists were determined if they did not fit the other classifications and their proportional abundance was positive assemblage

indicator
- Abundance and condition metrics based on numbers and biomass (NNAT and BNAT) and nonidigenous species as percent of total number and biomass (PNNI and PBNI)
- Number and biomass metrics used due to the wide variation in fish size among species encountered.
- Numbers and biomass of native species used instead of totals due to substantial influence of nonindigenous species.

<Detailed summary of further results presented in original paper>

Discussion

Appraisal of structure and performance

- Analyses of within and between ecosystems showed that the index responds well to general ecosystem quality and to the specific habitat variable of macrophyte cover
- Variability within transects showed index values were reproducible seasonally and between years and that acceptable level of precision could be achieved with modest sample sizes (3-5 per transect).
- Some differences with lotic IBI methods exist for this lentic IBI developed.
    - Great Lakes context, richness and abundance metrics need not be standardized for ecosystem size as was done for lotic environment.
    - 5 of 12 metrics here use biomass base as size variation among species is greater in lakes, compared to predominant use of abundance based metrics in lotic systems.
- Subjectivity of metric selection is a major unresolved issue for all IBI, although the three categories of species richness, trophic composition, and abundance and condition are an accepted framework.
- Species richness metrics were determined by taxonomic diversity of assemblages, and mostly same as Karr's selection. SNAT first choice, because of introductions and invasions SNIN was logical second choice.
- Centrarchid and native cyprinid used as metrics in many IBIs, are both well represented in Great Lakes. Their greater richness and abundance is sign of a more mature and stable condition, along with greater resources and habitat diversity.
- Most IBIs include richness of turbidity intolerant forms (SINT) as increased turbidity is a character of ecosystem degradation.
- Turbidity intolerant metric was weak due to few species assigned to the group, however future assignment to this metric may involve recent brain morphology research (Huber and Rylander 1992)
- Trophic composition metrics similar to other IBIs although used percent composition by biomass instead of numbers due to large variation in size.
- 3 trophic position categories used (piscivore, generalist, specialist)

differed from lotic IBIs, since membership to these guilds were presented as objective fact in other IBIs , yet reviewing the literature found diet information was anecdotal and contradictory. Range of fish size in littoral zone and changes in dietary preferences as fish grow added to uncertainty.

- Omnivore category (requiring diet of 25% plant material) was inappropriate as plants are rarely major diet item in lake fish
- Assigned some fish to piscivore group easily. The difference between generalist and specialist was difficult to discern objectively as numerical methods of diet analysis (e.g. Rachlin et al 1989) were beyond resources for most surveys and feeding patterns can change.
- A more objective assignment to trophic composition might be based on overall lifestyle using morphometric characteristics (e.g. Portt et al 1988) based on feeding and diet, life history, and reproductive guilds to form multidimensional species guild. Meanwhile, trophic assignments remain subjective.
- Abundance and condition metrics, only abundance metrics were commonly used in other IBIs. Biomass was added because of size variation and it's indication of energy flow in ecosystems
- Native and nonindigenous portions of biomass and abundance were used to avoid misleading inferences of ecosystem condition when biomass and abundance were high given 1) eutrophication increases biomass and productivity and 2) alien species can make up significant amount of biomass and abundance. Neither situation is healthy for the ecosystem.
- To account for negative impact of nonindigenous fish 2 negative, proportional metrics were added to indicate contribution to total abundance and biomass
- Metrics for hybrids and disease were not collected.
- Correlations among the metrics with IBI and PCA showed substantial redundancy in metrics. Range sensitivity analysis showed the degree and operational range individual metric contribution varied considerably. Redundancy could be considered essential as response of individual metrics to a variety of stresses is unknown.
- Inshore-offshore modifier (P_{OFF}) increased the ability to discern influence of local habitat conditions on littoral fish assemblages
- Increased presence of offshore species was an indicator of degraded littoral fish assemblages. While presence of piscivores was a sign of a healthy ecosystem, low levels of littoral piscivores was result of decreased vegetation and shoreline impairment.

<u>Ecosystem status within and between AOCs</u>

- Lotic IBI values express an upstream, catchment-wide integration of stresses and disturbances. Within lakes, particularly in areas like littoral zones, also integrate influence of local conditions, adjacent land use, and free flow of biotic and abiotic components.
- Significant correlations between IBI and macrophyte cover suggest

spatial integration was strongly influenced by local conditions.

- Four classes of factors influenced littoral fish assemblages: 1) exotic species abundance, 2) water quality, 3) physical habitat, and 4) piscivore abundance. Each factor may influence or be influenced by other factors.
- This four factor system supported by Scheffer's (1989) model for eutrophic, shallow freshwater ecosystems in Holland. Model supports the view that when nutrient inputs are low, a clear state is the only stable situation. When nutrient inputs are high, turbid state is outcome. With intermediate inputs, either state possible.
- Results show IBI for littoral fish assemblages influenced by all four factors.
- Piscivore and nonindigenous metrics showed significant relationship with physical habitat and water quality. PCA showed major contrast between numbers of nonidigenous fish and numbers of piscivores.
- Significant differences in survey areas, even after adjustment for cover, demonstrated importance of general water quality conditions.
- Scheffer's model can be applied to littoral regions and bays of Great Lakes. Eutrophication raised nutrients to intermediate levels allowing both clear and turbid states. Destruction of physical habitat, deliberate and assisted species introduction, and heavy fishing exploitation created favourable conditions for turbid state.

Future applications

- IBI developed in this paper is a logical expansion on those developed for lotic systems. A wider range Great Lakes littoral habitats needed to establish robustness.
- Present study sites border sedimentary land areas, granitic Shield need to be tested.
- Application to inland lakes requires metric revisions; wider use will require limits for some metrics to be adjusted and array of metrics may need to be changed.
- Conservation of rare or endangered species was not considered.
- Complementary indices could be developed to reflect human versus ecological interests

Assumptions

- While sampling occurred with 3 AOCs it was assumed that some sites represented healthy assemblages.
- In setting maximum threshold values for metric standardization, 90-95th percentile was assumed to be measure of levels attainable for any transect not subject to degradation.
- Standardization assumed that impairment of beneficial ecosystem uses was not universal phenomenon in AOCs surveyed.
- Assumed that the widest range of habitats possible was surveyed from the three AOCs, which would have included acceptable reference benchmarks. True "control" sites were unlikely to exist, however.

• Assumed for species richness that numbers of species within a specific taxa, within a guild, or that were native would decrease with habitat degradation. • Assumed that for trophic composition proportions of specialists and piscivores would decline while proportions of generalists and omnivores would increase with habitat degradation. • Assumed that proportions of individuals in silt sensitive reproductive guilds decreased, while evidence of disease, parasitism, and anomalies would increase with habitat degradation. • Assumed that native abundance or biomass could decline, even though total biomass may increase along with introduced species.
Assessment of Validity
• This littoral IBI met the 6 validation criteria set out by Karr et al (1986) for lotic systems, which were 1) biological based, 2) interpretable across trophic levels, 3) sensitive to ecosystem status, 4) responsive over range to intended use, 5) reproducible and precise, 6) low variability.
Questions?

4.4. Minns 1995 and 1997. – Rivers and Lakes

Minns, C.K. 1995. Calculating Net Change of Productivity of Fish Habitats. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2282, 37 pp. MInns, C.K. 1997. Quantifying "no net loss" of productivity of fish habitats. Can. J. Fish. Aquat. Sci. 54, 2463-2473.
System Type and Method Classification
Rivers and Lakes. Predictive – habitat quality.
Reason for Assessment/ Objective
To develop an equation that can calculate the net change in productive capacity of habitats affected by human development.
Methods
Definitions • **Productive capacity** = "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." – Policy for the Management of Fish Habitat, DFO 1986. • **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. • **Productivity** = the sum of production rates for all co-occurring fish stocks within a defined area or ecosystem; or sum of all production accrued by all stocks during the time of year they spend any part of their life history in that area or accrued elsewhere as a result of a strict requirement to use that area of habitat. *Measures and Indices of productivity*

- Three types – 1) direct measurement and summation of all fish present; 2) measurement of biological indices such as biomass, CPUE, sport or commercial yield, presence-absence; 3) surrogate habitat variables.
- 2 and 3 depend on prior studies to develop predictors.

Reference point for original conditions?

- 1800AD suggested as benchmark in Canada as substantial colonization and growth did not result in significant impacts until the end of this century, prior to which small-scale human impacts prevailed. This does not imply that restoration to those conditions is achievable, but that estimates can be made for comparison.

Framework for quantification

- Habitat productivity (P) composed of area (A) and unit-area productivity rate (p).
- $P = A \times p$
- No net loss isoline calculated for combinations of area and productivity rates that yield no net loss. Noted that substantial increases in productivity required for small decreases in available habitat area.
- Unit rate productivity (p) = sum of all fish species production using habitat area for all or part of lifecycle.
- Proponent responsible for habitats physically impacted project, but also any biologically connected areas.
- Many habitats have areas eliminated by previous development ($A_{eliminated}$) – proponent not responsible for compensation for previous development, however these are good areas for compensation plans.
- Development can create a loss of habitat (A_{lost}) or modify productivity of habitat ($A_{modified}$) – proponent responsible for lost and modified areas.
- To compensate lost or modified areas, proponent may increase productivity in modified or unchanged areas, or reclaim lost or eliminated areas.
- May also compensate for decreased productivity off site.
- To calculate net change in productivity requires estimates of current productivity (p_{now}), post-development productivity ($p_{modified}$), and maximum productivity (p_{max}).
- Direct measures of productivity (ie. sum of all fish production (kg) per year) is not practical - productivity indices and habitat surrogates can be used when backed with scientific evidence.
- More practical means of assessing productivity is through models, using various habitat parameters to predict productive capacity – models currently being developed.
- Another assessment of productivity can be made based on consensus judgement by experts backed with objective estimates, with productivity values assigned to p_{now} and $p_{modified}$. Generally p_{max} assigned value of 1, with others considered a proportion of p_{max} on a scale of 0 to 1.

Results & Discussion

Net Change Equations

- When proponent destroys habitat, productivity rate must be set at p_{max} regardless of current rate because productive capacity can no longer be restored.
- When proponent modifies productivity without loss of habitat, p_{now} used because future achievement of p_{max} is possible through modifications.

Net Change Without Compensation

- Net Change = Modification – Loss
- Net Change = ((Change in productivity) x (Area Affected)) – (Productive Capacity x Area Lost)

$$\textbf{Net Change} = ((p_{modified} - p_{now}) \cdot A_{modified}) - (p_{max} \cdot A_{lost}) \text{ (eqn' 1)}$$

- For net gain, $p_{modified} > p_{now}$
- If $(p_{modified} - p_{now}) \times A_{modified}) > (p_{max} \times A_{lost})$, then net gain occurs.
- Equation protects productive capacity while allowing human development
- If $p_{modified} < p_{now}$, then loss unavoidable unless compensation undertaken elsewhere.

Net Change With Compensation

- Net Change = Modifiaction + Compensation – Loss

$$\textbf{Net Change} = ((p_{modified} - p_{now}) \cdot A_{modified}) + ((p_{comp} - p_{now}) \cdot A_{comp}) - (p_{max} \cdot A_{lost}) \text{ (eqn' 2)}$$

- Compensation from stocking or artificial rearing is not desirable.
- Restoration involves increasing p_{now} towards $p_{max.}$

Adding Heterogeneity

- Areas impacted may contain several smaller areas of differing productivity

$$\textbf{Net Change} = \Sigma((p_{modified} - p_{now}) \cdot A_{modified}) - \Sigma(p_{max} \cdot A_{lost}) \text{ (eqn' 3)}$$

Implications of Equations

Areal mitigation and compensation ratios

- If set net change equation to 0, transition point between loss and gain can be determined and used to guide setting of compensation ratios

$$(p_{modified} - p_{now}) \cdot A_{modified} = p_{max} \cdot A_{lost} \text{ (eqn' 4)}$$

- Since p_{max} is defined = 1, rearrange (eqn' 4)

$$A_{modified} / A_{lost} = 1 / (p_{modified} - p_{now}) \text{ (eqn' 5)}$$

- As the difference in productivity rates in modified area increases, required mitigation ratio of modified to lost area can decrease.
- Maximum difference is 1 (p_{now} = 0 and $p_{modified} = p_{max}$) and gives area ratio of 1 , which is the equivalent of “like for like” requirement in policy
- If the difference in productivity is small, then compensation area ratio increases and supports current practice of asking for >1:1 area ratios in compensation projects
- Similarly using (eqn' 2) required compensation area (p_{comp}) can be obtained. Compensation required when losses compounded by decreased productivity in modified area. Assumed $p_{modified} < p_{now} < p_{comp}$ and $|p_{modified} - p_{now}| \approx p_{comp} - p_{now}$
- Rework equation 2 –

$$A_{comp} = A_{modified} + A_{lost} \cdot p_{max} / (p_{comp} - p_{now}) \text{ (eqn' 6)}$$

- This equation means compensation ratios usually greater then 1:1 and if no modified areas involved, then use eqn' 5

Conservation Targets

- If C is proportion of A_{now} that must be conserved to avoid further losses, then $C \cdot A_{now}$ can be substituted for $A_{modified}$ in Equation 1 to set conservation target

$$0 = (p_{modified} - p_{now})(C \cdot A_{now}) - p_{max} \cdot (1-C) \cdot A_{now} \text{ (eqn' 7)}$$

- Solve for C

$$C = p_{max} / (p_{max} + p_{modified} - p_{now}) \text{ (eqn' 8)}$$

- If $p_{modified} = p_{max}$, then minimum conservation proportions are 0.5 and 1 when $p_{now} = 0$ and p_{max} respectively
- Equation 8 defines minimum curve and is logically consistent with Policy goals for conservation and restoration
- Pristine areas with p values close to p_{max} given maximal protection
- Most appropriate application of conservation rule (eqn' 8) likely large ecosystem scales or in area habitat management plans as envisaged by the Policy.
- Conservation proportion (C) may be used as cumulative limit for habitat loss and alteration
- Can be affected by biased assignment of p values
- Essential that objective defensible methods be used to estimate areas and unit-area productivity

Other Considerations

- Where uncertainty exists, the proponent must prove alteration will not cause net loss.
- Endangered or rare species and/or habitats are more important and warrant extra consideration.
- Habitats must be considered for use by different lifestages of species present – e.g. loss of spawning habitat may not be offset by increased adult feeding habitat.
- Addition of time dimension to equation may be necessary for consideration of transient effects.
- Preferable to make system more productive for native fish species than invasive species.

Assumptions

- Assumed $p_{after} < p_{now} < p_{comp}$ and $|p_{after} - p_{now}| \approx p_{comp} - p_{now}$

Assessment of Validity

Not given

Questions?

4.5. *Randall et al. 1995 –Rivers and Lakes*

Randall, R.G., Kelso, J.R.M., and Minns, C.K. 1995. Fish production in freshwaters: Are rivers more productive than lakes? Can. J. Fish. Aquat. Sci.. 52, 631-643.
System Type and Method Classification
Rivers and Lakes. Predictive – fish production.
Reason for Assessment/ Objective
To address the hypothesis that fish population per unit area is greater in rivers than lakes using community fish production data from the literature. Second objective to determine if Boudreau and Dickie's (1989) model could be used to predict fish community production in lakes and rivers.
Methods
• Fish production or biomass data (all taxa) were available for 31 lakes and 62 rivers in the world wide literature. Lakes • Synthesised data from 20 lakes in Downing et al. (1990) and added additional 11 lakes found elsewhere in literature. • Average fish production and biomass from 19 small Ontario lakes were used as one data point; treated as replicates due to size and physical nature. Rivers • Used summarized data from Chapman (1978), Welcomme (1985), and Mann and Penczak (1986). • Where data from different tributaries of same river system were different with respect to number of species or densities, both were used. • Average biomass for several rivers in 6 U.S. states and from Ontario also used (Hoyer and Canfield 1991). Phosphorus concentrations in Ontario data set allowed comparisons with fish production in lakes and rivers. Both Lakes and Rivers • Avoided single species or single family production estimates if they only represented portion of the fish community. • Interested in total community estimates only as this was likely to better reflect carrying capacity. • Single species data were used only if they occurred allopatrically. Data Included • Mean biomass (B= kg/ha), annual production (P= kg/ha/yr), species richness (SR, total number species), density (D= number/ha). • Density was from time of sampling. • Standing biomass at time of survey used where average biomass was not available. • Population abundance estimated by mark-recapture or (particularly in rivers) removal method. • Production mostly estimated as product of growth rate (G) and mean biomass (B) using techniques by Chapman (1978).

- P/B ratios calculated from published estimates of mean biomass and annual production for entire fish community.
- P/B used to indicate growth or biomass turnover rate

Analysis

- Differences in fish density, biomass, and production between lakes and rivers were tested using nonparametric procedures (Mann-Whitney U-test).
- Correlations between production and biomass, density, and species richness were tested using standard regression analysis.
- Data log transformed for regressions, to stabilize variance and linearize relationship.
- If significant regressions found, then slopes and elevations tested using dummy variable (lakes =0, rivers =1), which was analogous to ANCOVA.
- When significant differences in elevation were found (not slopes), statistics were given separately for lake and river regressions and regression for the pooled (including the dummy variable – common slopes model).

Results & Discussion

- Fish production was higher in rivers than lakes, with range of 26 to 2800 (mean 273) kg/ha/year and 2 and 398 (mean 82) kg/ha/year respectively.
- Related variables of species richness, density, biomass all had higher averages in rivers.
- Differences significant for all community measures except richness (M-W U-test, p<0.05).
- Magnitude of differences: density 14 times higher, biomass 2 times higher, production 3 times higher in rivers; however, average fish weight was 7 times less in rivers.
- Fish weight was negatively correlated with density in rivers and lakes. Regression slopes in river and lake data were not significantly different, while intercepts were significantly different – indicates density 3.1 times higher in rivers. Slopes not significantly different than -1 (from Table 2)

Table 2. Regression equations relating fish density and fish weight.

Habitat	Model	R^2	n	p
Lakes	Log D = 4.48(0.37) – 1.01(0.29) log W	0.38	19	0.003
Rivers	Log D = 4.90(0.09) – 0.94(0.15) log W	0.50	42	<0.001
Pooled	Log D = 4.41(0.19) – 0.96(0.13) log W + 0.49(0.16) ID	0.74	61	<0.001

Note: D is fish density (no.Ha-1) and W is the mean weight (g) of the fish in the community. The regression for the pooled data included a dummy variable (ID) for lakes (0) and rivers (1). The coefficient of determination is adjusted for the number of parameters in the model. Standard errors for the regression coefficients are given in parenthesis.

- Differences in weight also affected P/B ratios – mean P/B was 1.7 times higher in rivers. P/B significantly (negatively) correlated with mean weight (W) in both rivers and lakes.
- Regression slopes of P/B on W were not significantly different, but

intercept coefficients were significantly different - indicates P/B ratios 1.5 times greater in rivers than lakes after adjustment for size.

- Biomass not only higher in rivers, growth of biomass significantly greater in rivers
- Production was not correlated with species richness, but was correlated with both density and biomass in both lakes and rivers. Fish densities – slopes and intercepts of regression between density and production were not significantly different. Slopes for regression of biomass on production not different, but intercepts did differ significantly.
- Thus for any given biomass, production was 2.4 times higher in rivers than lakes. Different intercepts reflect differences in P/B ratios.
- Coefficients of determination (R^2) for regressions relating production to density or biomass all >70%
- Boudreau and Dickie's equation predicting production was

  $\log_{10}P = \log_{10}a + b\log_{10}W + c\log_{10}B$;
  where P=production, W=weight, B=average biomass.

- This multiple regression was significant in both rivers and lakes. R^2 for pooled data was 0.89. Biomass was the dominant factor, but inclusion of weight increased R^2 by 9% for lakes, 12% for rivers, and 19% pooled (Table 5).

Table 5. Regression equations relating production to body size and biomass.

Habitat	Model	R^2	n	p
Lakes	Log P = 0.30(0.33) – 0.38(0.16) log W + 0.91(0.14) logB	0.83	11	<0.001
Rivers	Log P = 0.51(0.15) – 0.94(0.15) log W + 0.89(0.07) logB	0.80	42	<0.001
Pooled	Log P = 0.28(0.14) – 0.35(0.06) log W + 0.90(0.06) logB + 0.22(0.09) ID	0.89	53	<0.001

Note: P is production ($kg \cdot ha^{-1} \cdot year^{-1}$), W is the mean weight (g), and B is biomass ($kg \cdot ha^{-1}$). For the pooled data, ID is a dummy variable for lakes (0) and rivers (1). Standard errors for regression coefficients are given in parenthesis.

- Total phosphorus concentration was available in 12 lakes and 7 river data points. For the pooled data, biomass and phosphorus concentration was significantly correlated. Biomass was similar for any given phosphorus concentration in both habitats. Phosphorus levels were significantly higher in rivers than lakes.
- Higher production in rivers was related to significantly higher fish densities and biomass and smaller weight of fish.
- More energy would be required per unit area to support higher production in rivers, as energy cost for respiration in average river fish community is higher.
- Phosphorus concentrations and fish production are both higher in rivers, as phosphorus may have limiting role on processing allocthonous detritus and on autotrophic primary productivity.
- Productive capacity of habitat determines the amount of fish biomass supported; other factors determine its distribution among species and

individuals.

- Species richness on average was higher in rivers (not significantly) though this study did not indicate clear relationship between production and number of species present.
- Physical habitat characteristics affected fish size and density. Results show higher densities and smaller body size for rivers versus lakes.
- Highest densities of fish associated with fish communities with lower fish size. Low fish weight at high density explains why densities were 14 fold greater, but biomass only 2 fold greater in rivers.
- Energetic equivalence hypothesis predicts if animal requires a certain area to maintain its metabolic requirements then there would be a negative linear relationship between log density and log size (weight). Observed density and size relationship suggest biomass carrying capacity was reached in a number of sites, given that this relationship would not be expected to exist otherwise.
- Significant differences in intercepts were consistent with different productivities of lakes and rivers, and support the view that when production is summed for all species in the community, it approximates productive capacity.
- Different intercepts for P/B versus weight between lake and river data suggest that for any given mean weight, biomass turnover or growth is greater for rivers than lakes. This study indicates production can be estimated from biomass from both rivers and lakes, but P/B ratios must be adjusted for habitat and fish size.
- Differences in the intercept of Boudreau and Dickie's equation provided the best overall measure of production differences in lakes and rivers – indicated production was 1.7 times greater in rivers. Intercept in this equation is apparently dependant on habitat productivity and will also be influenced by how habitat area is measured, by the units of W and B, and possibly on whether production estimates are at the cohort, population, and community level.
- Boudreau and Dickie's regression method was a useful tool for estimating fish production, as reasonable estimates of population or community production can be determined from information on biomass and average fish size.
- Community level studies are desirable as total biomass is more likely to reflect carrying capacity. Community biomass can remain remarkably stable over time, and thus few estimates of biomass may be needed to provide approximate estimates of productive capacity.

Assumptions

- Assume fish production in both habitats limited by nutrients, and is thus regulated from the "bottom-up".

Assessment of Validity

- Results compared for consistency with results found in literature, for example:
    - o Watson and Balon (1984) also did not find a correlation between

species richness and production. o Schlosser (1990) supported the observation of higher densities and lower body size in rivers. o Animal body size and density correlation are well documented in literature (Peters 1983, Peters and Wassenberg 1983, Begon 1986, Bohlin et al 1994). Slope for fish communities in rivers and lakes not significantly different than theoretical value predicted by energetic equivalence hypothesis (Bohlin et al 1994).
Questions?

4.6. *Randall and Minns 2000 – Lakes and potentially Rivers*

Habitat Productivity Index
Randall, R.G. and Minns, C.K. 2000. Use of production per unit biomass ratios for measuring the productive capacity of fish habitats. Can. J. Fish. Aquat. Sci. **57**: 1657-1667.
System Type and Method Classification
Lakes and potentially rivers. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
1. Calculate species specific P/B (per year) ratios for 79 species of fish inhabiting freshwater systems of eastern Canada. 2. To use HPI (habitat productivity index = B x P/B) as a measure of habitat productive capacity.
Methods for P/B determination
Fish Database Sources • Life history traits of specific species were obtained from two databases (Port et al. 1991 and Minns et al. 1993) that determined length-at-maturity (L_{MAT}), maximum length (L_{MAX}), age-at-maturity (T_{MAT}), and maximum age (T_{MAX}) for 79 species of fish. These databases were combined into the LakeDB database. • Another database (Moore et al. 1998) containing data on fish productive capacity for 36 of the 79 species above was used to derive the *a* and *b* parameters for the length-weight regression $W=aL^b$. This database was known as CapacityDB. • The a and b parameters from CapacityDB were used to convert the lengths (L_{MAT}) and (L_{MAX}) from the LakeDB to weights (W_{MAT}) and (W_{MAX}) respectively for the 36 species common between both databases. Length-weight data for 5 other species was obtained from elsewhere in the literature. Finally, the remaining 38 species for which the coefficients were not known had their (W_{MAT}) and (W_{MAX}) estimated by regression. • CapacityDB was also used to estimate L_{MAX} for fish in each taxon based on the average 10 largest fish, which were then compared to maximum lengths in the LakeDB to test for consistency in species size data.

- Asymptotic lengths (L_{inf}) and weights (W_{inf}) were obtained from published database (FishBase 98, Froese and Pauly 1998). Parameters were available for 142 populations of 28 species. The maximum size of fish in LakeDB was compared to these asymptotic sizes.

Estimation of P/B ratios

- 3 databases used to estimate species-specific P/B ratios using life history info on W_{mat} (g) and longevity (years).

Method 1: P/B estimates using W_{MAT}

- P/B estimated using Randall et al (1995) allometric equation for fish inhabiting lakes and rivers →

$$\log P/B = 0.13 - 0.35 \log W_{MAT} + 0.18H$$

where W_{MAT} = weight at maturity (g) and H is habitat variable (0 for lakes, 1 for rivers)

- Partial slope of -0.35 with W_{MAT} consistent with exponent of within-fish subgroup based on allometric theory.
- Retransformed allometric equation for lake habitat was used to estimate P/B_W for all 79 species →

$$P/B_W = 1.32 W_{MAT}^{-0.35}$$

Method 2: P/B estimates using T_{MAX}

- Hoenig (1983) demonstrated that plots of total mortality versus T_{max} were negatively correlated for 3 taxonomic groups (molluscs, fish, cetaceans) and described by following equation →

$$\ln Z = 1.44 - 0.982 \ln T_{MAX}$$

where *Z* = instantaneous mortality rate (annual), T_{MAX} = maximum age in population.

- Regression parameters were similar for all 3 groups of animals, so a combined dataset was used for prediction.
- For balanced populations P/B ≈ Z, if mortality constant with age
- Therefore, equation can give first order estimate of population production, reworked in non-log form→

$$P/B_Z = 4.22 T_{MAX}^{-0.982}$$

- P/B_z applied to 75 of 79 species where T_{MAX} was known.
- The two methods were compared through Pearson correlation and validated with by interspecies correlation with field estimates of P/B from Downing and Plante (1993).

Results & Discussion

Life history characteristics

- L_{max} varied among species (52 to 1830mm). Many species were small and short lived (70% matured at age 3 or less).
- L_{mat} related to L_{max} by equation → $\log L_{mat} = -0.005 + 0.880 \log L_{max}$
- L_{max} and L_{inf} predicted from von Bertalanffy growth equation should be reasonably close, thus L_{max} (LakeDB) and L_{inf}(FishBAse98) were significantly correlated demonstrating that L_{max} provided approximation of L_{inf}. and sizes in LakeDB were approximately medial for each species.
- Corresponding equation for relationship W_{mat} and W_{max} for subset of

species was $\log W_{mat} = -0.762 + 0.931 \log W_{max}$

- Species specific L_{max} from LAkeDB were significantly correlated with maxima for 35 species calculated from CapacityDB, which is consistent with the hypothesis that maximum size can be estimated with the 10 largest individuals in a large sample.
- Analysis showed that all databases used provided similar trends in maximum size.

P/B Ratio

- The two methods of determining P/B (per year) ratios were significantly correlated with each other as was expected, though P/B_W values were lower than those calculated by P/B_Z.
- P/B_z values within bounds of 0.2 and 5, consistent with field observations of Downing and Plante (1993). P/B_w estimates were lower. Slope of $\log P/B$ on $\log W_{mat}$ was -0.19 for P/B_z, which was different than -0.35 used for P/B_w
- The P/B ratios calculated by both methods also correlated well with a subset of published P/B ratios for 9 species, in 24 populations, within 9 Canadian lakes from Downing and Plante's (1993) field study. This suggested that either species-specific method would be a useful predictor of actual P/B ratios, although the specific production coefficients determined by each method were less than those measured in the field.
- Theoretically, P/B estimates based on population size-at-maturity data were more accurate than species "average" size at maturity data.
- Downing and Plante (1993) reported maximum individual size of fish in populations and size-at-maturity for 16 of 24 populations (noted above) estimated using regression of W_{mat} on W_{max}. Little difference in coefficients of determination for regression of P/B on species versus population W_{mat}, thus little difference in predictors in this case.
- The reported biomass (kg/ha) from these 24 populations was multiplied by the species-specific P/B_W from this study to obtain specific production rates. The expected and observed production rates were significantly correlated. Species-specific P/B ratios increased predictive ability by 9% over the use of average P/B ratios.

Discussion

- When combined with field biomass data, species-specific P/B (per year) ratios could be used for production estimates.

Database characteristics and limitations

- P/B (per year) ratios from this report could be applied to fish inhabiting the Atlantic drainage basin of eastern Canada, and the 79 species examined comprised 48% of species in Ontario and a significant portion of Quebec, Newfoundland, and Maritime species as well.
- Generally life history traits were correlated as expected by life history theory, although limited diversity of taxonomic groups examined in this study may have been the reason for lower values of L_{mat}/L_{max} and $Z \times T_{mat}$ than values reported in literature.
- Covariance among life history traits was useful for determining W_{mat} and

first-order P/B coefficients for the diverse group of species considered in this study.

- Species-specific P/B ratios can be applied to population biomass, however this will result in approximate estimates of specific production as life history traits vary among populations of same species. This potential error will be higher in longer lived species.
- The authors advocated that generic species P/B ratios be used where population specific life history traits are absent. Where population-specific traits (such as W_{mat}) are known for a population and area, they should be used to estimate P/B (using the allometric equation) rather than generic species P/B coefficients.

Validation and calibration

- Validation of P/B ratios was achieved through intercorrelation of the two methods and comparison with published data.
- P/B ratios derived by the two methods were significantly correlated with each other.
- The P/B_W method was recommended for use over P/B_Z because 1) size-at-maturity or maximum size data is more readily available and 2) animal size and P/B relationships are established in the literature.
- Downing and Plante (1993) found P/B and weight were related with a -0.22 exponent for their whole data set. The subset of data used for validation in this study confirmed a -0.35 exponent after adjustment for biomass. This coefficient was consistent with that used to calculate P/B_W in this study and similar to findings of Dickie et al. (1987) and Boudreau and Dickie (1989) for within fish group coefficients. Further field validation is required.
- The proportionality coefficient of 1.32 was adjusted by a factor of 2 to 2.64, given that the P/B_W method consistently under estimated P/B ratios observed in the field.
- Underestimated because Randall et al (1995) allometric equation 1) used average fish weight instead of W_{mat}, and 2) was based on community measures of fish production, which has been shown to be marginally lower than population production when biomass is adjusted for (Downing and Plante 1993).
- The calibrated final equation to determine P/B from W_{MAT} data was

$$\mathbf{P/B_W = 2.64W_{MAT}^{-0.35}}$$

- The data in this study were based primarily on short lived species, so further validation on P/B ratios in this paper is required for the longer lived and larger fish in this study.
- River inhabiting fish and populations of young fish were expected to have higher P/B ratios, which may require upward adjustment to the values determined in this report.
- Additional adjustments based on water quality issues such as nutrient and temperature levels may also be required.

- Principles and methods of this paper may also apply to marine environments, but coefficients would need to be verified.

Methods for HPI determination

The species-specific P/B ratios calculated in this study were used with the average fish biomass (B) obtained from collected field samples to produce a first-order habitat productivity index (HPI) using the equation HPI = B x P/B

Sampling Method – detailed in Valere (1996)

- 63 transects in variety of Lake Erie (n=30) and Lake Ontario (n=33) habitats were sampled on three different occasions at monthly intervals during the summer of 1994.
- Fish samples were collected via boat electrofishing using 100m line transects where water depth was 1.5m in depth.
- Habitat types included coastal wetlands (with submerged macrophytes), harbour breakwalls, and exposed shorelines adjacent to harbours.
- The three visit average fish biomass (kg/ha) was calculated for each species at each transect.
- The average fish biomass per species was then multiplied by the species-specific P/B ratios identified in this paper to obtain the HPI (kg/ha/yr).
- HPIs were then summed across species and transects. Only transects that included an average of 5 fish were included in the analysis (n=54).

Results & Discussion

- HPI and biomass were strongly correlated (R^2 = 0.93), but varied due to differences in fish size. Biomass and fish size were predictors of HPI ($P<0.05$), confirming HPI was related to fish size.
- Residuals from HPI versus biomass regression were weakly correlated (r=0.27, P=0.05) with macrophyte abundance, which demonstrated that HPI was also related to habitat cover after adjustment for biomass.
- HPI provided a similar measure of habitat capacity as biomass, but also accounted for fish size. Higher HPI values were recorded for areas of similar biomass, but contained smaller fish sizes.
- HPI was a more direct measure of productive capacity than biomass alone and further investigation in this method is recommended.
- To increase sensitivity of this method, P/B could be adjusted for the size of fish in the catches rather than using the constant P/B ratios found in this paper. This possibility also requires further investigation.

Assumptions

- P/B (per year) equals Z, assuming populations are balanced and

mortality is constant with age. • It was assumed that fish weight was the most useful predictor of P/B. • HPI measure of productive capacity assumes 1) fish production is correlated with average fish biomass, 2) biomass is linked to habitat productivity, and 3) P/B is a refinement to population production by accounting for effects of fish size. • For biomass density calculations used in HPI determination, it was assumed that transect width was 10m and catch efficiency was 0.3.
Assessment of Validity
See validation and calibration section above
Questions?

4.7. Bradbury et al. 2001 - Lakes

Bradbury, C., Power, A.S., and Roberge, M.M. 2001. Standard methods guide for the classification/quantification of lacustrine habitat in Newfoundland and Labrador. Fisheries and Oceans, St. John's, NF. 60 p. *See also:* Minns, C.K. Meisner, J.D., Moore, J.E., Greig, L.A., and Randall, R.G. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Can. MS Rep. Fish. Aquat. Sci. 2328: xiii + 65p.
System Type and Method Classification
Lakes. Predictive – habitat quality (not applicable to reservoirs).
Reason for Assessment/ Objective
To provide a standardized approach for conducting habitat assessments on proposed developments impacting lacustrine habitat.
Methods
Rationale • Concepts adapted from the Defensible Methods approach (Minns et al. 1995; Minns et al. 1991), and based on Habitat Suitability Index (HSI) models of the USFWS (Terrell et al. 1982). • HSI = quantification of habitat requirements of various fish species and their different life stages, based on habitat preferences/utilization (from Bradbury et al. 1999) = surrogate of fish habitat productivity. • Four life stages were identified: 1) spawning, 2) young-of-the-year (YOY), 3) juveniles, and 4) adults. • Preferences for main physical habitat features including water depth, substrate and cover were reported as nil (rarely associated), low (infrequently associated), medium (frequently associated), and high (nearly always associated). • Often data were supplemented by studies from similar geographical areas,

and a number of limitations to associations are presented (e.g. predator avoidance, competition, prey availability etc.).

- The preference is to consider all species found within a project area. Where the number of species is high a guild approach may be considered. Guild is defined as a group of species that have similar habitat and life history requirements.
- A rational for grouping fish species into guilds must be explicitly stated.

Proposed quantification methodology

- Method requires completing a series of tables and documentation provides detailed step-by-step instructions.
- Lacustrine habitat is divided into 1) littoral (light penetrate to bottom), and 2) non-littoral zones (littoriprofundal and profundal zones + pelagic).
- Steps involve 1) identification of affected fish species, life stages + grouping into guilds if necessary; 2) assemble habitat requirements and compute HSIs for each species and life stage; 3) collect field data and classify habitat types and total surface area of each; and 4) calculate habitat equivalent units = area x habitat suitability.
- The documentation provides a step-by-step example for a lake being considered for a tailings pond (i.e. whole lake destruction).
- The approach can be used to quantify a HADD of fish habitat and could be used to assist in addressing fish habitat compensation to ensure NNL (by calculating total habitat identified and the amount of preferred habitat impacted by a development activity).
- For partial lake destruction it was noted that the portion of the lake not directly impacted by the proposed project will need to be considered to determine if the habitat impacted by the HADD is also present within remaining areas of the lake. It was recommended that for lakes <200 ha the entire lake should be sampled in the same manner; for lakes > 200 ha, 20% of the unimpacted lake area should be randomly sampled.

Appendix B – Field methodologies

- Field survey methods recommended by DFO are provided in Appendix B, although they are intended only as a guideline understanding that methods evolve, and depend on project and site-specific conditions.
- Develop a bathymetric map, identify maximum depth, calculate mean depth (volume/surface area) for littoral and non-littoral zones, and the SDI (a measure of the shape of the lake) as
    - $SDI = L/2(A)^{1/2}$ (where L = length of shoreline, A = surface area)
- Water chemistry should be assessed from a variety of stations to reflect overall lake conditions across habitat types. (nutrients, turbidity, DO, pH, contaminants)
- The Morphoeadaphic Index (MEI) should be calculated as an indicator of potential lake productivity:
    - MEI = TDS/Mean Depth
- Secchi depth should be taken to divide the lake in to littoral and non-littoral

zones
- Water temperature profiles should be taken at 1 m intervals.
- Details are provided on how to develop a bathymetric map, a substrate composition map, and for mapping aquatic vegetation cover.
- Guidelines are provided on how to obtain representative samples of all length-age classes and species of fish inhabiting lakes using a range of gear types (i.e. fyke nets, experimental gillnets, beach seines, wire cage traps, angling etc.), and covering all available habitat types.
- Since many factors can influence catch-per-unit-effort (CPUE), sampling should be standardized for season, time, location and duration of net sets, coupled with precise gear and deployment specifications.
- General biological characteristics, including species composition, relative abundance, population length and age structure will help determine potential habitat utilization (consulting Bradbury et al. 1999).

Results & Discussion

n/a

Assumptions

- assumes that frequency a species uses a habitat provides an indication of its importance to the species' well being and contribution to habitat productivity.

Assessment of Validity

References

Bradbury, C., Roberge, M.M., and Minns, C.K. 1999. Life history characteristics of freshwater fishes occurring in Newfoundland and Labrador, with major emphasis on lake habitat characteristics. Can. MS Rep. Fish. Aquat. Sci. 2485: vii+150p.

Minns, C.K., J.E. Moore, M. Stoneman, and B. Cudmore-Vokey. 2001. Defensible Methods of Assessing Fish Habitat: Lacustrine Habitats in the Great Lakes Basin – Conceptual Basis and Approach Using a Habitat Suitability Matrix (HSM) Method. Can. MS Rpt. Fish. Aquat. Sci.2559:viii+70p.

Terrell, J.W., McMahon, T.E., Inskip, P.D., Raleigh, R.F., and Williamson, K.L. 1982. Habitat suitability index models: Appendix A. Guidelines for riverine and lacustrine applications of fish HIS models with the habitat evaluation procedures. U.S. Fish and Wild. Serv. FWS/OBS-82/10.A: 54p.

Questions?

4.8. Randall and Minns 2002 - Lakes

Randall, R.G. and Minns, C.K. 2002. Comparison of a Habitat Productivity Index (HPI) and an Index of Biotic Integrity (IBI) for measuring the productive capacity of fish habitat in nearshore areas of the Great Lakes. J. Great Lakes Res. 28(2), 240-255.

See also:

Brousseau, C.M., Randall, R.G., and Clark, M.G. 2004. Comparison of Severn Sound fish assemblages in Hog Bay and Penetang Bay, 1990 and 2002, using two indices of productive capacity. Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2686, 21pp.

System Type and Method Classification

Lakes. Monitoring/compensation studies – fish.

Reason for Assessment/ Objective

To compare and contrast two fish assemblage measures of habitat productive capacity, where HPI was a surrogate for fish production and IBI was a measure of diversity and trophic composition. Proposed that both indices are needed to evaluate the quantitative (production) and qualitative (species composition) aspects of productive capacity.

Methods

Sample methods – see Valere 1996

- Habitat and fish surveys were conducted in 1994 in Lake Ontario and Lake Erie in 6 different locations that included three habitat types.
- Habitat types included coastal wetlands, harbours, and exposed shorelines.
    - 3 transects located inside and 3 outside harbour breakwalls for “harbour” habitat type
    - 3 transects to each side of harbour surveyed for “exposed shoreline” habitat type
- 63 line transects were run, with 30 in Lake Erie and 33 in Lake Ontario.
- Fish composition, size, and abundance obtained by electrofishing 63 line transects from May to October 1994 to obtain spring, summer, and fall samples of biomass for each habitat type; 189 samples obtained (=63 x 3).
- Sampling was conducted using 6.1m electrofishing boat (pulsed DC current, 120pps, 8 amps) at ≈1.5m depth contour along 100m transects parallel to shore.
- Species richness (#/transect), total number fish, and total biomass (g wet weight) were recorded for each transect.
- Fork length (mm) and wet weight (g) were recorded for sample catches up to 20 fish per species. If catch exceeded 20 individuals, then the remaining fish were batch weighed. Batch total weight and number of fish were recorded.
- Species richness = average number of species captured at each transect over three sample dates.
- Average fish weight (per transect) = total biomass of three sample dates divided by the total number of fish caught.
- Fish with weights less than literature weight-at-maturity were categorized as juveniles, ≥ weight-at-maturity were categorized as adults; batch samples based on average fish weight of sample.

IBI calculations – based on Minns et al 1994

- Based on 3 categories of 12 metrics:
  - Species richness metrics (numbers of)
    - natives species (SNAT)
    - centrarchids (SCEN)
    - native cyprinids (SCYP),
    - nonindigenous species (SNIN)
    - turbidity intolerant species (SINT)
  - Trophic structure metrics (percent biomass of)
    - piscivores (PPIS),
    - generalists (PGEN)
    - specialists (PSPE)
  - Abundance and condition metrics
    - native numbers (NNAT)
    - native biomass (BNAT)
    - percentage nonindigenous by numbers (PNNI)
    - percentage nonindigenous by biomass (PBNI)
- Piscivores consumed fish prey as adults, generalists had ominivorous diets, and specialists had specialized diets (insectivores, planktivores).
- Species were assigned to categories based on literature values.
- 4 metrics (SNIN, PGEN, PNNI, and PBNI) had a negative impact on IBI scores; the remaining 8 were positive.
- 2 IBI values were calculated for each transect – IBI based on total fish catch, and IBI* adjusted downward based on abundance of offshore species (i.e. high abundance of offshore species led to low IBI* score). IBI* was considered a more direct measure of resident fish.
- IBI score was calculated for each sample for each date (n=189) using software described by Stoneman (1998). Final IBI score = average of three IBI scores for each transect.

HPI calculations – based on Randall and Minns 2000

- Data from 3 samples per transect were pooled to calculate HPI.
- Biomass density estimated by assuming survey width of 10m and capture efficiency of 0.3.
- For each species, biomass (kg/ha) was calculated for the three samples.
- A production index for each species was determined as the product of average biomass ($B_{average}$) and species P/B ratio.
- P/B ratio was calculated as P/B = 2.64 $W^{-0.35}$, where W was the average weight of each species captured at each transect (total biomass/total number fish) rather than constant weight-at-maturity used by Randall and Minns (2000).
- Final HPI (kg/ha/yr) was calculated as sum of production indices of all species captured at the transect.
- HPI* was also calculated to exclude offshore species.

Habitat Measurements

- Macrophyte abundance and substrate type were measured during September and October at each transect.
- Macrophyte abundance measured by echo sounding the 100m transects, and dividing paper echograms into 10 segments.
- Percent bottom cover for each segment was estimated and averaged for whole transect, then correlated with visual estimate at time of survey.
- Substrate type was determined by Ekman dredge sample (sand or finer) or visual observation (more coarse substrates) at 2 locations for each transect.
- Substrate type was assigned to one of seven categories (mud, silt, sand, gravel, cobble, armour, bedrock) based on dominant substrate.
- Site exposure was measured from transects marked on hydrographic charts, digitized to show transect and shoreline.
- Fetch was measured at 16 compass points at 22.5 degree intervals and calculated using Scheffer et al. (1992) formula. Maximum fetch value obtained was used as measure of exposure at each transect.
- Surface water temp (ºC) and specific conductivity (µS/cm at 25ºC) was recorded at time of electrofishing, then averaged over three samples to obtain rough characterization of water temp and conductivity.

Statistical Analysis

- IBI square root transformed to achieve normal distribution.
- HPI $\log_{10}$ (x+1) transformed to achieve normal distribution.
- Transformed scored tested for fit with normal distribution using (K-S) D statistic.
- Compared HPI and IBI using correlation matrices to identify and quantify relationships among fish variables.
- Pearson correlation coefficients were tested for significance after Bonferonni adjustments for multiple comparisons.
- Scatterplots were used to visually compare IBI, HPI, biomass, and species richness. Locally weighted sequential smoothing used for showing trends in scatterplots.
- Compared HPI and biomass as assemblage measures in different habitat types, HPI regressed with biomass and residuals tested for significant difference among habitat types using one-way ANOVA.

Results & Discussion

- Results support the contention that to comprehensively evaluate productive capacity of fish habitat in species-rich near shore areas of Great Lakes, composite indices of productivity and diversity are needed.
- The use of only one index constrained conclusions about habitat use.
- Correlation between IBI and HPI were expected, however the relationship was not linear. IBI was closely related to species richness and HPI was closely related to biomass. Richness and biomass were not linearly correlated among samples.
- Community biomass was highest in harbour samples, due to high fish

abundance and large fish size. Richness was highest in coastal wetlands of each lake and IBI scores matched these trends.

- Ranking of habitat suitability depended on the metric used – productive capacity clearly had production basis, but needed to be qualified on basis of species produced. That is, specific habitat types attract some species and not others. To account for production and diversity components of productive capacity, both HPI and IBI need to be used respectively.
- Literature indicates more accurate predictions of production are made if both biomass and fish size used as predictors, which HPI does.
- HPI was related to habitat type, after adjusting for biomass, confirming that HPI accounted for fish size structure at different habitats. However, HPI was coarse surrogate for production, given electrofishing biased for larger fish size. Surveys significantly underestimated abundance of small fish.
- P/B adjustments may also need to be made for temperature in future studies.
- Without temperature and sampling rectifications, biomass and HPI were underestimated in coastal wetland.
- Further research using large-scale, whole ecosystem experiments is needed to fully evaluate HPI as production surrogate when based on biomass from localized habitats.
- IBI was qualitative, and viewed differences in fish community composition whereas HPI is determined by total biomass.
- Differences in IBI were consistent with varying levels of ecosystem degradation and site specific habitat quality; metrics linked to diversity and quality of habitat. It is reasonable to view IBI as a quality indicator at localized site and ecosystem scales.
- Individual metrics and influence of offshore species provided a tool for evaluating differences in communities between areas. Total biomass and HPI were not significantly different at coastal wetlands and harbours in both lakes. However richness and IBI were higher in both habitat types in Lake Erie than Lake Ontario, due to greater occurrence of centrarchids, greater native species richness (both habitats), and greater biomass of piscivores (coastal wetlands). IBI was a more informative indicator of habitat use by trophic components than richness, biomass, or HPI.
- IBI and HPI accounted for quantitative and qualitative components of productive capacity. Conceptualization was presented in a graph, with HPI (quantitative characteristics) on x axis and IBI (qualitative characteristics) on y axis. Highest productive capacity in upper right of graph, where indices of HPI and IBI were both high. In this study, coastal wetlands (shown on graph) rated higher than harbour breakwalls, due to diverse, natural, fish community reflected in IBI scores.
- Two axis approach was consistent with recent standards for assessing water quality.
- Nearshore data limitations:
    - Size selectivity of electrofishing and need for evaluation of relative

productivity of three habitats (mentioned earlier). o Sampling at coastal wetlands not replicated within lakes. o Only 2 harbours surveyed in each lake. o Transect samples from each habitat were pseudoreplicates. o Since data were collected in different geographic areas, spatial patterns may also affect catches. o Nevertheless, samples from different areas contrasted composition and abundance of catches and were useful in comparing IBI and HPI. • Despite limitations of field data, this study showed IBI and HPI are useful fish assemblage indices, but metrics need to be used together to fully measure productive capacity. Further work is needed to validate HPI and IBI use as surrogates for community production and diversity at local habitats – particularly at natural and altered exposed shoreline areas in Great Lakes.
Assumptions
• Assumed localized site biomass, averaged seasonally and adjusted for size to calculate HPI, was an index of site productivity.
Assessment of Validity
• HPI validated by comparison with whole lake estimates of fish production (in Randall and Minns 2000).
References
Valere, B. 1996. Productive capacity of littoral habitats in the Great Lakes: Field sampling procedures (1988-1995). Can. Manuscr. Rep. Fish. Aquat. Sci. 2384.

4.9. DeLeeuw et al. 2003. - Lakes

De Leeuw, J. J., Nagelkerke, L. A. J., Van Densen, W. L. T., Holmgren, K., Jansen, P. A., & Vijverberg, J. (2003). Biomass size distributions as a tool for characterizing lake fish communities. *Journal of fish biology, 63*(6), 1454-1475.
System Type and Method Classification
Lakes. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
Information on distribution of biomass over size classes, taxonomic, and trophic groups combined in biomass size distributions (BSDs). The objective of this study was to examine BSDs as an integrative indicator of ecological status that would allow characterization of fish communities.
Methods
Lakes & Sampling • Data from 2 Norwegian, 35 Swedish, and 8 Dutch freshwater lakes were used. Dutch lake data were stratified into shorter time periods of consistent total phosphorus concentration (TP). • Norwegian and Swedish lakes were sampled using standard gillnet

- procedures with multi-mesh Nordic series consisting of 12 panels (1.5m x 2.5m each) with mesh from 5 to 55mm.
- Pooled selection curve was flat for 1+ and older fish, so no selectivity corrections were made.
- Dutch lakes were sampled with bottom trawlnets with 3m beam and codend mesh size 10-12mm, towed by boat at speed of 1-2m s^{-1}.
- There was no temperature stratification in the shallow Dutch lakes, so fish were concentrated in lower layer, thus most 0+ and large portion larger fish were caught by trawlnets. A few pelagic and nearshore species biomass were underestimated.

Taxonomic and trophic group BSD

- BSD was constructed on basis of length-frequency data.
- Total length (L_T) was measured and converted to individual body mass using species-specific length-mass relationships.
- Total biomass per size class was estimated by summation of all individual body mass per size class.
- For trawled lakes, biomass was estimated directly (kg ha^{-1} swept).
- For gillnets, CPUE was used to estimate biomass, which is supposed to be proportional to biomass (g m^{-2} per night).
- Size was expressed as log_2 individual mass classes to condense large size classes relative to small size classes, which has advantage of making BSD more “stabilized” as variation becomes less erratic.
- Species were grouped at the taxonomic level of families.
- Trophic groups classified as planktivores, benthivores, and piscivores based on species- and size-specific diet studies. Herbivory was rare in these lakes and disregarded.

Community variables in relation to productivity

- Compared BSDs with a quantitative analysis of community variables.
- To do this the authors examined the relationship of TP with 1) biomass of taxonomic groups, 2) proportion taxonomic groups, 3) biomass of trophic groups, 4) proportion trophic groups, and 5) mean body mass (M, weighted by number fish per size class).
- Simple curves were fitted to the above relations, with significant relations ($P<0.05$) and marginally significant ($P<0.1$) relations shown.
- When a taxon was absent due to the location of the lake being outside of the species’ natural range, the 0-value for that species was excluded from the analysis.
- Lakes were excluded if they were in transition from marine to freshwater.
- Scandinavian and Dutch lakes were analysed separately due to different sampling methods. Gillnets are biased towards large fish and trawlnets are less efficient for larger specimens.

Growth & Mortality Affecting BSD

- Growth data for perch and bream used to explain how differences in BSDs could explain differences in growth and mortality.

- Theoretical ranges of BSDs were explored based on min and max growth rates and range of mortality rates, under the assumptions that recruitment, growth, and mortality were constant.

Results & Discussion

Taxonomic shifts

- BSDs show differences in taxonomic composition at family level.
- Scandinavian lakes showed a shift along the productivity gradient.
- Lowest TP lakes were dominated by salmonids (<8 µg L^{-1}).
- Percids, coregonids, cyprinids, and esocids were abundant in moderate TP (8-13 µg·L^{-1}) lakes.
- Cyprinids were more dominant and coregonids disappeared in higher TP (>13 µg·L^{-1}) lakes.
- There were some exceptions to the general pattern, but overall total fish biomass increased with TP for cyprinids, but decreased for salmonids and percids. Esocids showed a maximum at (15 µg·L^{-1}).
- Dutch lakes were not as diverse as Scandinavian lakes, and they did not display the general pattern between TP and taxonomic composition.

Trophic shift

- Most lakes were dominated by benthivorous fish.
- Only Scandinavian lakes of moderate TP were piscivore dominant.
- Dutch lakes with many percids or osmerids were dominated by zooplanktivores.
- Scandinavian lakes CPUE of planktivores increased with TP, while increase in planktivore was proportion only marginally significant. Increases were caused by the growing importance of planktivorous cyprinids and coregonids.
- Increase CPUE of piscivores (marginal significance) with TP was mostly due to an increase in pike.
- Benthivore proportion was at minimum where TP was moderate, reflecting salmonid presence at lower TP and increasing perch and roach at higher TP.
- Dutch lakes biomass and proportion benthivores increased with TP, due to large bream of high individual body mass.
- Piscivore increase with TP was only marginally significant, and explained by increase of pikeperch.
- Planktivores decreased, due to an increase in large benthivorous bream.

Size aspects

- Dutch lakes with large biomass of small percids and osmerids, peak biomass found in body mass classes 0 – 4, which is smaller than other lakes where peak biomass was found between classes 8 – 11.
- Scandinavian lakes usually had their peak biomass at intermediate body mass classes (4 – 9).
- In Scandinavian lakes the weighted body mass (M) of planktivores increased significantly with TP, caused by increasing size of cyprinids and

percids.

- In Dutch lakes, the M of planktivores increased with TP, caused by increased size of bream and the simultaneous decreased biomass of cyprinids, percids, and osmerids.
- Overall M of planktivores was greater in Dutch lakes (marginal significance).
- M of benthivores had a marginally significant quadratic relation with TP in the Scandinavian lakes, with a minimum at TP = 11µg L^{-1}, caused by decrease of large benthivorous salmonids, and an increase of smaller bodied cyprinids.
- Dutch lakes M of benthivores increased significantly with TP, exclusively caused by increase bream.
- M of benthivores in Dutch lakes was significantly higher than Scandinavian; taking into account that gillnets biased to larger fish size the difference between was probably even larger.
- Difference in M was clearly reflected in BSDs by the position of highest peaks.

Population dynamics and BSD

- To assess the extent growth and mortality affects BSD, population dynamics of perch and bream on BSDs were explored.
- Length at age data of slow and fast growing perch and bream were used to calculate instantaneous individual body mass increment (G) →
  $G = dM/M, dt = \ln (M_2M_1^{-1})$, where M is individual body mass
- Survivorship of size class M_1 to M_2 is $(M_2M_1^{-1}) - ZG^{-1}$, where Z = instantaneous mortality rate
- Therefore biomass ratio of adjacent size classes written as →
  $B_{M2}B_{M1}^{-1} = (M_2M_1^{-1})^{1-Z/G}$, where B = biomass of particular size class
- Peak biomass in BSD found at body mass where growth rate = mortality rate.
- Simulated BSDs for slow and fast growing perch and bream with Z = 0.4 (approximately natural) and Z = 1.0 (commercial fishing) also given.
- Growth rates of perch were more variable than bream, particularly at younger ages.
- Peak body masses differ by 2-3 body mass classes between fast and slow growing conditions.
- At higher mortality rates (Z = 1.0) peak body mass shifts to the lower size classes.
- Simulation holds under assumption of constant rates of growth, mortality, and recruitment.
- If assumptions are met, it is possible to infer growth differences from body mass classes where peak biomass is found.

Discussion

- Study shows that biomass size distributions BSDs can be used as integrative indicators for the ecological status of fish communities.
- Semi-quantitative results from BSDs (relative surface areas of taxonomic

or trophic groups and position of biomass peaks) are consistent with quantitative results from regression analysis of same variables. • BSDs can also give a first indication of population dynamics variables like growth and mortality. • Shifts in biomass of major taxonomic groups along a TP gradient are consistent with other studies. • Major shift in taxonomic composition was not observed in Dutch lakes, since they were at the extreme end of the TP gradient. • BSDs reflect trophic shifts in fish communities, like simultaneous abundance and size increase of benthivores in Dutch lakes. • BSDs can evaluate many aspects of fish community simultaneously (species and trophic diversity, importance of taxonomic and trophic groups, average sizes) and provide tool for summarizing complex information, like a fingerprint of individual fish communities. • Can be used for qualitative comparisons between communities where quantitative comparisons are difficult or impossible (e.g. because of differences in sampling methodology). • Can be used as a tool for comparison with (historical) reference state conditions. • Using multivariate techniques can further enhance BSD as a quantitative ecological quality assessment tool (Nagelkerke & van Densen, 2001).
Assumptions
• Simulation holds under assumption constant rate growth, mortality, and recruitment.
Assessment of Validity
• Not listed
Questions?

4.10. Manitoba Hydro 2003. –Rivers and Lakes.

Manitoba Hydro – CPUE and Benthic Inverts
Manitoba Hydro et al. 2003. Wuskwatim Generation and Transmission Projects. Numerous Volumes.
System Type and Method Classification
Lakes and Rivers. Monitoring/compensation studies – multi-trophic level.
Reason for Assessment/ Objective
This project was undertaken as an obligation to produce Environmental Impact Statements for the Wuskwatim Generation and Transmission Projects. The project focuses on the development of a 200 megawatt generating station on the Burntwood River, south west of Thompson, Manitoba.
Methods
• Existing aquatic environment is regulated system resulting from the Churchill River Diversion (CRD) in the mid 1970s. The baseline measurements used for this study are from this regulated system, not from a natural system.

- The assessment considers the construction and operation of the hydro facility and ancillary facilities (e.g. camp, lagoon, etc.) required to build or operate the project.
- Not possible to measure all components of the ecosystem so Valued Ecosystem Components (VEC) were selected for study, based on 1) importance to humans, 2) representative of a group of species, 3) good indicator of effects within a food web, 4) rare or endangered, 5) special ecological importance.
- 4 fish species were selected as VECs – lake whitefish, lake cisco, northern pike, and walleye. These species meet criteria listed above, are present throughout the sample area, and can be sampled with proven technology.
- Water quality was also selected as a VEC.
- Other aquatic ecosystem components were sampled to assess Project effects on VECs – Lower Trophic Levels (phytoplankton, attached algae and rooted aquatic plants, zooplankton, and benthic inverts); other fish species.
- Potential impacts assessed as direct impacts on VECs and other individual components, and indirect impacts occurring as a result of interactions among components within ecosystem (e.g., project reduces a prey species which indirectly affects the VEC of interest).

Assessment Approach

- Significance of impacts focussed on level of impact to VECs, based on the following criteria:
    1. Nature of effect (positive, neutral, negative)
    2. Magnitude of effect
    3. Duration of effect
    4. Frequency of effect
    5. Geographical extent of effect
    6. Reversibility of effect or Resilience of VEC
    7. Ecological context (is VEC sensitive to disturbance)
- Matrix was developed to guide assessment of impact significance based on 3 key assessment components - magnitude, duration, and geographical extent (2, 3, 5). Guidance of impact assessment further modified based on consideration of frequency of effect (4), assessor confidence in degree of impact, VEC resilience (6), and VEC ecological context (7).

Study Area

- Aquatic environment studies focussed on waterbodies directly affected by changing water levels and flows caused by development. Magnitude of physical change among reaches varied considerably.
- Water quality assessments extended further downstream, as water quality effects can extend beyond zone of direct flow impacts and because of local community concerns. Aquatic environment assessments were also

performed on proposed access road crossings.

- 4 reaches were identified for aquatic environment studies:
    1. Wuskwatim – 22 km reach corresponds with reservoir proper, with full-supply of 234 m ASL (above sea level)
    2. Falls - 1 km reach corresponds to immediate forebay of proposed generating station (GS), with raised water level of 234 m ASL
    3. Burntwood – 14 km reach affected by daily water level and discharge fluctuations of proposed GS superimposed over fluctuations caused by CRD and natural events.
    4. Opegano – 8 km reach affect by same fluctuations as above (3), although much reduced.
- 2 downstream reaches identified for additional water quality studies:
    5. Downstream of Opegano – above the city of Thompson.
    6. Downstream of Thompson – 100 km reach below the city of Thompson.

    One sample site above the impacted area was also used as a water quality reference.
- 8 stream crossings for proposed access road were identified for aquatic environment studies.

Water Quality Sampling (Volume 5, 5.2)

- Physical and chemical surface water quality variables were sampled in the field and analysed in the laboratory using recognized procedures.
- Open water samples were collected in 1999, 2000, 2001, while ice covered samples were collected during 2001, 2002.
- Not all parameters or all sites were sampled during each period; new parameters and sites were added as required.
- Sediments were collected for chemical analysis July 2001 and August 2002.
- Access road stream crossing water quality samples were collected June 2002, while tributaries were sampled September 2002.
- Results were compared to provincial and national guidelines and criteria for protection of aquatic and terrestrial wildlife, and human usage.
- Parameters measured included: TSS and turbidity, colour, DO, water temperature, nutrients, pH, hardness, alkalinity, TDS and conductivity, bacteria and parasites, major ions and trace elements, hydrocarbons, and radioactivity.

Aquatic Habitat (Volume 5, 6.2)

- Habitat assessment before development was compared to expected changes afterwards, along with changes in water and sediment quality, lower trophic levels forms basis of impact assessments on fish.
- Bathymetric and water velocity information was gathered in each of the 4 reaches during project planning. Aquatic habitat in reaches 1 to 4 surveyed and mapped in GIS-based system.
- Key characteristics: water level, level fluctuations, substrate type,

presence/absence rooted submerged aquatic plants, water velocity.

- Lacustrine classification differed somewhat from riverine with respect to water elevation and velocity.

Water Level

- Bathymetric surveys were conducted using differential global position system technology for lakes (Reach 1 and 4). Surveying emphasised nearshore areas and areas where bottom complexity was highest.
- Three dimensional lakebed maps were developed from which contours and water volume were determined.
- Water depth was standardized to lakebed elevation in meters above sea level (ASL) using daily water level record.
- Riverine surveys (Reaches 2 and 3) were conducted using kinematic Global Position System linked to an echosounder. Backwater inlets elevation determined using differential and kinematic positioning.

Substrate

- Substrate was interpreted from echo-sounder displays, with changes in sonar display showing changes in substrate.
- Changes were verified by Ekman or Ponar dredge, or a 20lb anchor device.
- Information was gathered on the location of substrate change, substrate classification, and associated boat route.
- Information was plotted on a map with the area between 2 consecutive substrate types classified as the first datapoint.
- GIS polygons were plotted by connecting the same-value substrate points, allowing area and perimeter calculations.
- Reaches 1 and 4 had a limited in number of transects due to the large size of areas, however supplementary substrate information was collected during lower trophic and fish community surveys.
- In Reaches 2 and 3 substrate data were collected at cross-sectional transects 500m apart. Transect density was higher where bottom complexity was higher. Areas adjacent to falls or in high water velocity were not sampled.
- Substrate was visually graded by particle size as boulder, cobble, gravel, sand, silt/clay. Compaction was characterized as hard or soft.
- Substrate data were combined into 5 possible classifications: Bedrock, Boulder/Cobble, Hard Silt/Clay, Soft Silt/Clay, and Flooded Terrestrial (last category included due to areas flooded by CRD with heterogeneous substrate of organic with silt/clay or rock).

Rooted Aquatic Plants

- Rooted submerged aquatic plant abundance, species composition, and distribution were recorded during boat-based surveys and supplemented during aerial surveys, then digitized into GIS polygons.
- Presence/absence was described with respect to physical conditions of wave energy using fetch, elevation, substrate slope, distance from shore, modelled water velocity, and water depth.

- Percentiles were determined from the frequency distribution of values where rooted aquatic plants were observed.

Water Velocity

- In Reaches 2 and 3 the magnitude and distribution of water velocity were estimated by 2 different hydraulic models: the Flow 3D model and River2D model respectively.
- Velocity categories classified into categories and digitized in GIS for area and aquatic habitat classification.

Habitat Classification

- Comprehensive hierarchical classification system was devised to provide a framework for assessing and describing habitat types, based on USGS (1998) and modified for this study area.
- Classification was divided for lacustrine (reaches 1 and 4) and riverine (reaches 2 and 3) habitats.
- Estimates of spatial extent of aquatic habitat types provided for existing and post Project conditions were based on extrapolations from topographic and bathymetric maps.
- Accuracy was reduced where shorelines have a relatively low slope.

Lacustrine habitat

- Classified using 1) water level, 2) substrate, and 3) presence/absence of rooted aquatic plants (from above).
- Water level variation was caused by irregular flow regime in system, so criteria were identified to describe habitat with respect to variable water levels.
- Daily water level fluctuations recorded post-CRD (1977 to 2001) were used to define entire range of fluctuation. Extreme water levels (above 95th percentile and below 5th percentile) were excluded.
- Water level classified into three zones
    1. Intermittently Exposed Zone – shore zone bounded by 5th and 95th percentiles of water level fluctuation recorded since 1977 (i.e. experienced dewatering from 5-95% of the time since 1977).
    2. Nearshore Zone – shore zone effectively wetted all the time with upper border 5th percentile of water level fluctuation and lower level was identified visually and defined from bathymetric data.
    3. Offshore Zone – all areas below Nearshore Zone.
- Each water level was further classified based on bottom substrate classification (Bedrock, Boulder/Cobble, Hard Silt/Clay, Soft Silt /Clay, Flooded Terrestrial) Flooded terrestrial substrate was not present in the Offshore Zone.
- Soft/silt Clay and Flooded Terrestrial substrates were further classified based on presence/absence of aquatic plants (i.e. No plants, Rooted Vascular Plants or Non-Vascular Plants)
- Some uncommon observations (e.g. shoals, filamentous green algae) were grouped with most similar classification.

Riverine habitat

- Classified using 1) water level, 2) position in river (i.e. mainstem vs.

backwater inlet), 3) substrate type, 4) presence/absence aquatic plants, and 5) water velocity

- Water level was defined as above, however only intermittently exposed zone (IEZ) and permanently wetted zones were used.
- The IEZ was estimated using the elevation of water surface from hydraulic data, and by estimating by projecting the centre of river surface profile laterally to the bank, and water levels calculated using a triangulated irregular network surface model.
- Each water level was further classified as mainstem versus backwater inlet.
- Further substrate and vegetation classifications were performed as above.
- Water velocity categories based on swimming efficiencies of fish species were applied to classification system for riverine habitats – Low = <0.5m/s, Medium = 0.5 to 1.5m/s, and High = >1.5m/s
- Riverine and lacustrine mapping performed and located using overlapping classification layers in GIS, with riverine including a 4th component of water velocity.

Stream Crossings

- Performed for 8 identified crossings after road route was determined.
- Streams were assessed 100 m upstream and 200 m downstream of the right-of-way when water level was high due to spring freshet.
- Habitat was classified by type, channel characteristics, water velocity, discharge, substrate, and cover. Potential habitats included were overwintering, rearing, and spawning.
- Assessed habitat value and sensitivity based on those outlined in Habitat Conservation and Protection Guidelines (DFO 1998)
- Used a conservative approach in that no waterway assigned a value of "no habitat".
- Habitat Value was assessed as Critical, Important, or Marginal based on 1) importance in sustaining fisheries, 2) productive capacity, 3) seasonal availability, 4) life stages supported, and 5) habitat diversity.
- Habitat Sensitivity was assessed as High, Moderate, or Low based on 1) immediacy of disturbance to fish, and 2) natural ability to recover.
- To facilitate habitat ranking, habitat requirements for fish species using or potentially utilizing these streams were assessed and Low to High scores were determined for spawning, overwintering, and rearing habitat in streams.

Lower Trophic Levels (Volume 5, 7.2)

- Algae were sampled in selected lakes along with water quality.

Phytoplankton

- Wet weight biomass (mg/m^3) was determined for each genus/species identified.
- Chlorophyll α concentration was also measured as relative measure of

phytoplankton biomass.

Attached Algae and Rooted Aquatic Plants

- Abundance, species composition, and distribution were assessed during boating surveys and confirmed using detailed transect samples and aerial surveys.

Zooplankton

- Collected with water quality using 63µm mesh net and identified to genus/species.

Habitat-based Community Assessment for Benthic Inverts ← potential use for productive capacity

- Provided a replicable, habitat-based, quantitative description of benthic invertebrate community abundance, composition, and distribution.
- The approach taken in the EIS focused on a broad-based description of invertebrate abundance in the range of aquatic habitat types to support the assessment of potential Project-related impacts to the fish community.
- Used as relative measure of habitat productivity; changes in abundance or composition may influence fish community or habitat quality.
- Samples were collected at most sites in 2 years during the fall (September to October) when invertebrate populations stabilize, to allow better inter-year comparisons.
- Most sites in Reach 1 were sampled in 1999, 2000, and 2001 with additional sites sampled in 1998; adjacent waterbodies to Reach 1 and sites in Reach 2 and 3 were sampled in 2001; reach 4 was sampled in 2000 and 2001.
- Sampling areas were chosen to encompass the range of habitats within the aquatic environment.
- 700 samples were collected from 1998 to 2001 along transects in each habitat type in each reach.
- Sampling sites were positioned along a transect that encompassed a number of habitat types.
- A 'tall' Ekman dredge (0.023m^2 opening) was used to sample lacustrine (reaches 1 and 4) habitats with both hard and soft silt/clay substrates
- A 'petit' Ponar dredge (0.023 m^2 opening) was used to sample riverine habitats (reaches 2 and 3) with bolder/cobble and both hard and soft silt/clay substrates.
- An air-lift sampler (0.032m^2 opening) was used in Reach 3 riverine habitats with bedrock and bolder/cobble substrates.
- 4 dredge or air-lift samples were taken at each site to determine within site benthic organism variability; the duration of air-lift sample was 10 seconds.
- Each replicate was sieved through 500µm mesh.
- Inverts were identified to major group and quantified.
- Density of each taxon was calculated as number of individuals per square metre.
- A subset of benthic invert samples from reaches 1, 2, and 3 was taken in September 2001, and was further identified to genus and/or species to

create an index of biodiversity for selected habitat types.

- Shannon-Weiner biodiversity index (SWBI) was calculated for 13 sites representing 5 habitat types in Reach 1, 9 sites representing 4 habitat types in Reach 2, and 23 sites representing 8 habitats in Reach 3.
- Species richness (=number of species in a community) and evenness (=distribution of abundance among species) were the 2 fundamental community characteristics used in SWBI calculations.
- Calculation:

Shannon-Wiener's index: $$H' = -\sum_{i=1}^{S} P_i \log p_i ,$$

Where: proportional abundance or percent importance, $(p_i) = n_i / N$ for the i^{th} species; S = total number of species; (n_i) = number of individuals of a species in sample; N = total number of individuals of all species in sample.

- Thus the value of H' is dependent upon the number of species present, their relative proportions, sample size (N), and the logarithm base. The choice of the base of logarithm is arbitrary (Valiela 1995) but in comparing indices the base used should be stated and be the same.
- Marked dominance of one species gives low diversity, while co-dominance of several species gives high diversity
- A more diverse community with many species has a higher probability of adapting to changes in environment.
- Drift traps provided supplemental qualitative survey where other methods were not possible due to safety concerns.

Fish Community and Movement Studies (Volume 5, 8.2)

- Several sources of information were explored including traditional knowledge (TK), existing published information, and environmental assessment studies.
- Traditional knowledge included information from local commercial fishers, domestic fishers, aboriginal Elders, and field assistants working with study team and was incorporated into knowledge and assessment of the existing environment.
- Pre- and post-CRD fish population information was very limited or non-existent for the study area, thus no previously published scientific studies were used to describe the current study area conditions
- Ecosystem based approach was used to assess potential effects of the Project on fish community, which incorporates water quality, aquatic habitat, and lower trophic levels.
- The field program was grouped into 6 primary components (habitat based, spring-spawning, fall-spawning, overwintering, tributary streams, and fish movements).

Habitat-based Community Assessment for Fish ← potential use for productive capacity

- Standard-gang index gillnets (6 panels, each 22.9 m long, ranging in size from 38 mm to 127 mm of stretched twisted nylon mesh) set to inventory lentic fish communities.
- Provided a replicable, habitat-based description of the fish community.
- In reaches 1 and 4, sites were chosen to sample available habitat types with emphasis on most common habitat types.
- In some cases, experimental gillnets were set in composite of habitat types, where overall designation was based on predominant habitat type over the length of net.
- Wuskwatim Lake supported commercial fishing, thus effort was limited to 200 fish per VEC species.
- In reaches 2 and 3 where there was an abundance of medium and high velocity lotic habitat, index gillnets were set in low velocity areas (mainly Reach 3 backwater inlets).
- Small tributary size at access road crossings required electrofishing.
- Species composition, relative abundance (% of total number caught), catch per-unit-effort (CPUE = number of fish per 100 m of net per 24hr period), size, age, condition, sex and state at maturity, and diet were obtained from index netting.
- This method sampled across the fish community while other procedures were fish VEC specific.

Spring Spawning

- Initially, TK identified potential spawning habitat for walleye and northern pike, then supplemented by results of field sampling.
- 2 to 4 hour sets of (76 to 12 7mm) twisted nylon mesh gill nets were used in mid-May to mid-June.
- Captured fish were assessed for sexual maturity to infer location of spawning habitat.
- Potential spawning habitat in tributaries and backwater inlets (and some mainstem locations) was assessed with larval drift traps and kick nets to capture eggs and larvae.

Fall Spawning

- Identified potential spawning habitat for lake whitefish and lake cisco initially using TK supplemented by field sampling.
- Onset of open water season, a modified neuston sampler was used from 1999 to 2002 in lentic habitats to capture emerging larvae.
- Floating drift traps were used from 2001 to 2002 in lotic habitats to capture larval cisco and whitefish.
- Radio-tagging information also used to infer potential spawning sites

Overwintering

- Effort was focused where project could adversely affect overwintering habitat.
- DO was measured by YSI meter and no gillnetting was conducted at anoxic sites (DO less than 3.0 mg/L).

- Gillnet gangs (2 nets, each 22.9 m long, 38 mm to 108 mm stretched twisted nylon mesh) were set under ice at 8 sites.
- Radio-tracking also helped to identify overwintering habitat for lake whitefish, lake cisco, and walleye.

Tributary Streams

- Assessed fish utilization of streams flowing into Reach 3 and streams crossed by access road.
- Species composition and abundance within downstream most 100 m of each stream flowing into Reach 3 were assessed September 2001 using a backpack electrofisher.
- Streams crossed by access road were sampled with 100 to 300 m sections in early spring 2002.
- DO was measured at 3 of 8 crossing sites in March 2002 for overwintering potential.

Fish Movement

- To assess the general movement of VEC fish between reaches in the study area and to identify important habitat by documenting concentrated movement of fish.
- Floy tagging of 1259 fish (69 lake whitefish, 361 lake cisco, 146 northern pike, 683 walleye) was performed (mostly in Wuskwatim Lake n=1057) and recapture data provided movement information.
- Radio Tagging of 14 walleye, 20 lake whitefish, and 8 cisco in Wukwatim Lake was performed in fall 1999 and 2000, and spring 2000. Fish were relocated using aircraft receiver.

Fish Quality (Volume 5, 9.0)

- Quality studies were performed to assess mercury concentrations, trace metal concentrations, whitefish cysts, and fish palatability

Results & Discussion

The results of this study were used to establish a baseline set of conditions for the aquatic ecosystems impacted the Wuskwatim Generation Project. It is worth noting again that results for aquatic ecosystems are based on existing regulated (rather than natural) conditions in the watershed, which was assumed to have stabilized 30 years post (CRD) hydro-development.

Potential impacts related to the construction and operation of the project were determined by comparing baseline ecosystem conditions with predictions of expected changes caused by the project. Expected changes were predicted using a pathways-of-effect model to assess direct and indirect ecosystem linkages.

Expected changes could produce positive, neutral, or negative results depending on the general life history, biology, abundance, and/or habitat use of each VEC fish species. Independent consideration was given to each VEC fish species with respect to expected changes in water quality, quantity and quality of habitat, invertebrate production, and forage fish production within spawning, feeding, and overwintering habitats for each of the 4 reaches identified.

An assessment of the overall impact significance was performed by considering the magnitude, duration, and geographical extent of the expected changes across reaches for each VEC species independently. The results of this assessment were used to produce the required Environmental Impact Statements.

The aerial extent of expected habitat changes was determined through GIS analysis. In brief, a small amount of habitat will be lost due to dam construction and a small amount of habitat will be disrupted at some stream crossings. Reduction in water level fluctuations in the main lake (reach 1) will convert some periodically exposed areas into permanently wetted habitat. Below Wuskwatim lake (Reaches 2 and 3) there will be a decrease in permanently wetted habitat during low flow periods.

It is worth noting again that the value of habitat in streams affected by the road crossings was assessed using criteria provided by DFO (1998), which includes provision for describing productive capacity based on habitat characteristics of the site (e.g., seasonal water levels and flows, presence of obstructions such as beaver dams).

There were 2 habitat-based community sampling procedures performed in this study – one for benthic invertebrates and one for fish communities. While the intent of using the results of these sampling methods as measures of change in productive capacity was not explicitly stated, this is likely the intended use given that 1) these methods link habitat types to measures of production, and 2) these methods were scheduled for replication during construction and operational phases of the project.

For the Fish Community Assessment, relative abundance, and catch-per-unit-effort were calculated for each species caught with the Standard-gang index gill nets, within each habitat type sampled, for each Reach identified in this study. Of note, CPUE for each VEC was used for comparing productivity of Wuskwatim Lake (reach 1) to other Manitoba water bodies – further lending support to CPUE being used to assess future changes within the current study area. Volume 5, section 8 summarizes the baseline results for the existing environment in terms of relative abundance and CPUE.

For the Benthic Invertebrate Community Assessment the mean total abundance, percent composition (of major groups), and species richness were calculated from the data. The Shannon-Weiner biodiversity index was also calculated for each habitat type survey in each reach. Calculations of expected changes in invertebrate abundance (numbers/ha) were performed based on expected changes in total habitat area. Volume 5, section 7 summarizes the results of the

existing environment for benthic invertebrates.
Assumptions
• It was assumed that the current regulated system had achieved a stable state more than 30 years post diversion, based on studies of other regulated systems (e.g. Long Spruce Forebay) and on stability of other non-biological parameters (e.g. erosion rates, water quality) within the study area.
Assessment of Validity
Not provided
Questions?
• Q: How is productive capacity of streams affected by road crossings being determined? A: Habitat at the streams was described based on criteria described in DFO (1998). Professional judgement (and observed fish catches) in conjunction with an understanding of seasonal water levels and flows, habitat characteristics, and other features (e.g., presence of obstructions), was used to classify the importance of streams to forage fish and large-bodied fish, including VECs. As the stream crossings affected a small amount of habitat that generally supported few fish, this qualitative type of assessment was felt to be appropriate. • Q: The value and sensitivity of habitats was determined for streams affected by road development, but there was no mention of the same being done for lacustrine or riverine habitats. Was this done? If so, how? A: Fish use of reaches 1-4 (those directly affected by the proposed Wuskwatim Generating Station) was described in detail in the EIS. For the VEC species, spawning, feeding and overwintering areas were described. Where these habitats overlapped with areas that would be affected by the project (e.g., due to altered water levels and flows), the impact assessment considered the degree to which these changes could affect the fish population in question. • Q: Since no VEC species were caught in streams affected by road crossings, were resident species considered when determinations of impacts caused by habitat alteration were made? A: Yes, use by non VEC species was described, and in general, fish were considered present based on the habitat assessment even if none were caught.

4.11. Jones et al. 2003. – Rivers and compensation channels

Hierarchical Framework of Functions
Jones, N.E., Tonn, W.M., Scrimgeour, G.J., and Katopodis, C. 2003. Productive capacity of an artificial stream in the Canadian arctic: assessing the effectiveness of fish habitat compensation. Can. J. Fish. Aquat. Sci. 60, 849-863.
System Type and Method Classification
Rivers, compensation channels. Monitoring/compensation studies – multi-trophic level.

Reason for Assessment/ Objective
Development of diamond mine in the Barrenlands of the Northwest Territories. The objective of this study was to assess YOY production of arctic grayling in an artificial channel relative natural streams and to examine the factors that explain differences in this growth (water temp, invert availability, physical habitat)

Methods

- 4000km^2 study area 100km north of the tree line in the arctic ecozone in the Northwest Territories.
- A 3.4km long artificial channel was created as a diversion that permitted the draining of two lakes for open pit diamond mines. This compensation channel restored watershed connectivity for migration and access to spawning and nursery habitats, primarily for arctic grayling.
- Pristine streams were used as reference sites representing natural conditions.

Sampling

- Data were collected in four summers (1998 to 2001).
- 20 natural streams throughout the study were surveyed for physical characteristics, fish community composition and abundance, and grayling YOY size just before out-migration.
- These natural streams were used as reference sites and selected based on the presence of visible water during aerial surveys in July.
- A subset of 9 of these 20 streams located close to artificial channel was additionally sampled for benthic inverts, water chem., woody debris volumes, substrate coarse particulate organic matter (CPOM), and epilithon.
- A subset of 2 of these 9 streams was further sampled for intensive fisheries and invert drift surveys.
- The artificial stream was sampled for all above parameters

Basic stream surveys (20 natural streams + artificial)

- Stream length, slope, bankfull width and depth, and substrate composition were determined from ground surveys, aerial photographs, and topographic maps.
- Substrate composition and aquatic vegetation cover were quantified along a transect perpendicular to stream flow.
- Substrate were classified as clay, sand, small gravel, large gravel, cobble, and boulder based on particle size.
- Mesohabitats composition quantified as percent length of stream (cascade, riffle, run, flat, pool, wetland, boulder garden, culvert)
- Grayling fry observed 21 to 24 days after spawning;
- Swim up dates were similar among streams and average lengths and weights of 11-13mm and 0.01g were recorded respectively
- Migration to over wintering habitat occurs in late August to early September at ≈50 days post swim-up, so YOY grayling mean mass represents significant percentage of year's growth at this time.

- Fish community composition and YOY grayling size determined by electrofishing in late summer, shortly before migration in 1, 2, 10, and 3 natural streams in 1998, 1999, 2000, and 2001 respectively. Fish were identified, counted, weighted, and measured (fork length).

Benthic stream surveys (9 of 20 natural streams + artificial)

- 3 replicate water samples were collected from each stream in late July and refrigerated until analysis. Total nitrogen (persulfate digestion) and phosphorus (persulfate oxidized samples by molybdate blue absorption) were determined.
- Woody debris volumes determined for debris >10 cm long along 40-150 m lengths of stream. Length and average diameter were determined and converted to volume estimates for each piece. Volumes were standardized to 100 m^2 areas of stream surface.
- Mean density of shrub stems located within 1 m of stream banks was determined along 40 to150 m transects along stream banks. Also quantified was the percentage ground cover by grass and shrubs along same transects. Similarly, percentage streambed cover was determined for aquatic macrophytes and bryophytes.
- 5 replicate samples of CPOM, epilithon, and benthic inverts were collected in late July from both riffles and pools.
  - CPOM sampled by inserting plastic jar (90mm deep x 80mm wide) into substrate. Within 48 hours, samples were washed to remove inorganic material and invertebrate cases, then sieved through 1mm mesh. Filtered organics were dried to constant mass.
  - Periphyton samples were scraped from the upper surface of randomly selected stones. Macroinvertebrates were removed and samples refrigerated for 2-4 weeks before being dried and weighed, then ashed and reweighed for ash-free dry mass.
  - Benthic invertebrates were sampled using a 0.093 m^2 Surber sampler, fitted with 250 μm mesh. Samples preserved with 70% ethanol and identified to genus or species (Nematoda, Turbellaria, and terrestrials identified to family or order). Following counting, samples were dried to constant mass and weighed.

Intensive stream sampling (2 of 9 natural streams + artificial)

- Temperature was recorded every 4 hours from freshet to late August using a HOBO temperature logger. 5 locations in the artificial stream and 2 locations in each of Polar-Vulture and Pigeon streams.
- Amount and composition of available cover for YOY grayling were visually estimated along transects perpendicular to stream axis. Stream divided into 10 m sections and transect placed randomly in each section. Cover types included depth, turbulence, rock, undercut, aquatic vegetation, and terrestrial vegetation and provided velocity refuge, visual isolation, and/or overhead cover.
- Drift sampled simultaneously at 2 locations using tri-net samplers (250 μm mesh). Sampling conducted on 4 dates at 3 times during each day (dawn, noon, dusk). Sampling conducted in relatively shallow water close to fish

collection to reflect organisms available to grayling. Nets wetted for 30-45 minutes to filter 3-6m^3 of water. Samples were preserved in 70% ethanol and after counting, were dried to constant mass and weighed.

- Drift invertebrates were classified as large or small based on body mass. Head capsule width, as an indicator of body mass, was measured for Chironomidae and Simuliidae larvae in subset of drift samples from each date in 2000.
- In the artificial and Polar-Vulture streams, total fish density and biomass was estimated in late July 1998-2000 using three-pass removal method using electrofishing equipment. Habitat was stratified as riffles and pools.
    - Captured fish were identified, counted, weighed, and measured for fork length.
    - Population estimates were made separately for Arctic grayling (juvenile and YOY) slimy sculpin, and burbot.
    - Each stream section had total fish biomass estimated as product of mean individual mass and number of fish estimated in that section.
    - Mean mass of YOY grayling were determined several times from swim-up to shortly before out-migration in the artificial and 3 natural streams.
    - YOY grayling diet was determined by identifying 19 taxa from stomach contents that were classified as large or small based on body size. Head capsule widths for Chironomidae and Simuliidae larvae were measured from random stomach subsets from each sampling period in 2000.
    - Some reference streams from the literature (Jones et al. 2003) were included for comparison of food habits of YOY grayling in the artificial stream

<u>Bioenergetic model and simulations</u>

- Bioenergetic modelling assessed temperature effects on YOY grayling in artificial and natural streams (Wisconsin model configured for age 0-grayling)
- Input were average daily temperature from swim-up to August 23 and respective mean mass of YOY grayling on sample dates
- Simulations adjusted for food consumption (P value) to meet observed final mass using respective temperature regimes
- Model simulations determined what the YOY grayling final mass would be if natural temperature regimes were substituted into the artificial stream
- Simulations also determined the final mass if the P value in artificial stream substituted into natural stream
- Effect of Temperature on growth:

$$Growth_T = \frac{\{|OBS_{ART} - PRE_{Part\ \&\ Tnat}|\}}{\{OBS_{NAT} - OBS_{ART}\}} \times 100\%$$

where OBS_{NAT} and OBS_{ART} = observed YOY grayling mass on August 23 in natural and artificial stream respectively

where $Pre_{Part\ \&\ Tnat}$ = predicted mass of grayling using P value from artificial stream (P_{art}) and temperature regime from natural stream (T_{nat})

- Effect of food availability of growth::

$$Growth_F = \frac{\{|OBS_{ART} - PRE_{Pnat\ \&\ Tart}|\}}{\{OBS_{NAT} - OBS_{ART}\}} \times 100\%$$

where OBS_{NAT} and OBS_{ART} = observed YOY grayling mass on August 23 in natural and artificial stream respectively

where $Pre_{Part\ \&\ Tnat}$ = predicted mass of grayling using P value from natural stream (P_{nat}) and temperature regime from artificial stream (T_{art}).

- Conducted sensitivity analysis by changing P value and activity multiplier by 25, 50, & 100%

Statistical Analysis

- Employed one-sample hypothesis testing using data from general benthic stream surveys to compare artificial and natural streams
- Compared average value in artificial stream with distribution of values among natural streams
- If limited natural streams were sampled for a variable, then general linear model followed by Tukey's multiple comparison used to compare artificial and natural streams
- ANCOVA used to assess if YOY differed in condition among streams and years (mass data square root transformed)
- Used K-S test for normality and Lavene median test for homogeneity of variances
- $\alpha = 0.05$ significance level for all tests (Bonferroni adjustments made when required)

Results & Discussion

Assessing artificial stream as productive fish habitat

- Based on hierarchical framework of functions focused on production of YOY grayling
  1. Successful migration
  2. Successful spawning
  3. Successful hatching
  4. Successful growth
- Each function required to compensate for lost habitat and achieve NNL of productive capacity for Arctic grayling
- Reference streams provided standards to measure artificial channel against.
- Artificial stream met or approached expectations regarding migration of adult grayling through the watershed [function 1 met]. While fish passages throughout the stream were effective for grayling and lake trout, sculpin and burbot appeared unable to ascend one of the culverts [function 1 not met for other species] suggesting that their populations had become fragmented.
- Quantitative spawning success was not measured, but YOY qualitatively

estimated by visual observation of large numbers in lower end of stream where spawning occurred [function 2 & 3 apparently met].

- Growth and production of YOY grayling suggested nursery habitat quality deficient with respect to food production, physical habitat, or water temperature [function 4 not met]

<u>Growth of YOY Arctic grayling [function 4]</u>

- Water temperature in artificial stream 1ºC colder than natural streams. Bioenergetic simulations suggested summer water temperature had little influence on growth however, accounting for only 11% of YOY grayling mass.
- Bioenergetic simulations indicated 80% of difference in YOY growth between natural and the artificial stream explained by differences in food consumption
- Natural streams were well vegetated, while artificial stream supported little aquatic macrophyte, algal, or riparian vegetation. Lack of vegetation resulted in lack of organic matter input in artificial channel
- Habitat required for aquatic and terrestrial plants not available to colonize; may require successional processes to establish
- High flows in spring may scour and erode any available vegetation habitat
- Lack of terrestrial and aquatic plants leads to low CPOM and woody debris, which reduces food and substrate for aquatic invertebrates.
- Density and biomass of benthic inverts much reduced in artificial stream, leading to lower densities of drift. Head capsules of chironomids smaller in artificial stream suggesting food limitation. Heavy pulses and bed scour likely damage invert assemblages and hamper establishment and growth of inverts.
- YOY grayling rely heavily on select aquatic insect larvae, particularly chironominds and simuliids and strongly avoid microcrustacea, nematodes, and mites
- Chironomids and simuliids in grayling stomachs were larger than available in drift, indicating foraging based strategy.
- Forage base for grayling is limiting their growth in artificial stream.
- In the natural stream, YOY grayling were larger in the warm, dry year when macroinvertebrates were plentiful. Epilithon abundance was also low during same year, perhaps due to increased macroinvertebrates. The opposite was true in cool, wet years.
- In the artificial stream, grayling growth and climate relationship was greatly muted, masked by the effect of limited food production (i.e. system was unable to respond to favourable warm, dry conditions due to lack of food and substrate for macroinvertebrates)
- Relative to reference streams, habitat complexity at large and small scales was considerably reduced in the artificial stream, which was fairly straight and lacked or was deficient in several mesohabitat types
- Size and composition of inverts in YOY grayling diets in natural and the artificial streams had little difference, despite poor growth in artificial

stream suggesting that YOY grayling may have to expend more energy to obtain food requirements. This would lead to poor growth. • Sensitivity analyses of bioenergetic models indicated 50% increase in activity multiplier resulted in 2-fold reduction in body mass; extra swimming could contribute to observed differences. However, the model was twice as sensitive to changes in food consumption • Scarcity of organic matter in artificial stream limited overall growth and productivity of benthic inverts, leading to poor growth and production of YOY grayling. • Growth of young fish can have significant implications at population level, directly affecting productive capacity by reducing survival during their first winter and reduced recruitment into the breeding population. End of summer mass for YOY grayling in the artificial stream was half that observed in natural streams.
Assumptions
• Reference streams were assumed to represent the range of natural stream structure and function in the region
Assessment of Validity
Not listed
Questions?

4.12. Jones and Tonn 2004 – Streams and Compensation Channels

Jones, N.E. and Tonn, W.M. 2004. Enhancing productive capacity in the Canadian Arctic: Assessing the effectiveness of instream habitat structures in habitat compensation. Trans. Am. Fish. Soc. 133, 1356-1365.
System Type and Method Classification
Streams. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
Examined the effectiveness of 4 types of habitat structures (ramps, V-weirs, vanes, and groins) at increasing productive capacity for Arctic grayling and other fish in a 3.4 km artificial stream as part of regulatory program to compensate for lost habitat.
Methods
• Employed a modified before-after-control-impact (BACI) design to determine changes in density, biomass, and growth of fish at 2 spatial scales in the immediate area of structures and in the stream as a whole. *Study Area* • 3.4km long artificial stream located in Barrenlands of Northwest Territories in Southern Arctic Ecozone • The artificial stream originally had a limited number of habitat types, constrained by steep and high banks with a single channel and about half

was featureless, sandy flats.

Habitat Structures

- Structures built at upstream and downstream reaches, while the central portion was avoided for safety reasons.
- In the upper 1 km, 5 groins and 2 ramps were added.
- 6 V-weirs and 2 vanes were added to the downstream end.
- Built with aggregate from eskers in the region, no wood was used in the structures as large woody debris is not normally found in the region.

Design

- Structure-scale assessments quantified density, biomass, and growth rate using adjacent unmodified sections of the artificial stream as reference.
- Whole-stream scale used summer conditions pre-manipulation (1998) and following 3 summers for measures of post-manipulation conditions (199-2001).
- 3 nearby natural streams were used as reference.

Structure-scale assessment

- Arctic grayling were first observed beginning of July with the yolk sac still visible.
- All fish out-migrate in late August to over-winter in nearby lakes.
- Total fish density (fish/m^3) and biomass (g/ m^3) were estimated using the 3 pass removal method (Zippin 1958), performed twice at each structure – July 20 and August 20, to incorporate changes in habitat use with increasing age-0 Arctic grayling size.
- Block nets were erected to prevent immigration and emigration during fishing.
- Reference sections were located upstream and/or downstream of sections with structures (≈10m).
- Some references were shared among several structures. At least 3 reference sections for each structure type studied.
- In August 2000, 5 groin structures electrofished as a unit because fish densities were too low at individual sites.
- Fish were identified, enumerated, weighed (g), measured (fork length), and released.
- Section volume was determined from mean depth at 5 to 10 transects perpendicular to flow multiplied by mean width and section length for each section.
- Population estimates were made separately for grayling, slimy sculpin, and burbot using CAPTURE software.
- Biomass was determined by multiplying mean individual fish mass by number of fish estimated in the section.
- ≈90% of estimated numbers of fish were typically captured in each section.
- Each structure used t-tests with Bonferroni adjustments to determine if differences in density and biomass between manipulated and controlled sections were significant.
- Used mass and length data to determine if structures affected growth of

age-0 Arctic grayling from July 20 sample date. Grayling movements were too extensive later in season to provide accurate assessment of structure effect on growth.

- At each structure type, t-tests with Bonferroni adjustments were used to determine if mean mass of age-0 Arctic grayling differed between treatment and reference sections.

Stream-scale Assessment

- Between 1998 and 2001 analogous assessments of density and biomass of age 0 Arctic grayling at whole stream scale were conducted.
- Both spatial (artificial vs. natural) and temporal (before vs. after) comparisons were considered.
- Estimated fish density (fish/m^3) and biomass (g/ m^3) in artificial and nearby Polar-Vulture stream in 1998-2000 using previously described electrofishing methods.
- 14 sample sections (60-100m in length) in artificial stream were surveyed, incorporating several habitat structures in each.
- In Polar-Vulture stream 10 sections were sampled (30-75m in length).
- In both streams, half the sections represented fast-flowing habitat and half were slow-flowing.
- Same sections were sampled each year.
- 75% of estimated numbers were typically captured in each section.
- Specific growth rate (SGR) was estimated for artificial and 3 nearby streams (Polar-Vulture, Pigeon, Polar-Panda) by →

$$SGR = [(\log_e M_2 - \log_e M_1) / (t_2 - t_1)] \times 100$$

Where M_1 and M_2 are mean mass Arctic grayling shortly before swim-up (early July) and shortly before out-migration (late August) respectively: t_1 and t_2 are days of the year for those two samplings

- All stats used Kolmogorov-Smirnov test for normality and Levene's test for variance homogeneity.
- Data were log-transformed when required
- 0.05 used as critical level of significance with Bonferroni adjustment made when required.

Results & Discussion

- 80% and 52% of fish in the artificial stream were age-0 Arctic grayling in July and August respectively; remainder were slimy sculpin and burbot.
- Composition in reference streams was similar.
- Highest densities grayling occurred in the last 700m of artificial stream where most spawning occurred.
- Strong negative relation was found between size and downstream location in artificial stream (upstream fish were larger).

Structure-Scale Assessment

- Structures maintained their form during the study, even after an estimated 100 year flood in the spring of 1999.
- Density in late July was higher at all structure types than at reference

sections.

- Biomass was also higher at all structures except groins.
- Growth of age-0 grayling was comparable to reference sections by late July.
- By late August, density and biomass were reduced at both reference and structure sites.
- Ramp 1 was an exceptional situation – Density was 2 fold higher than other structure sites, 4 fold higher than reference sections.
- Biomass and density remained higher at Ramp 1, even though they were reduced at other structures by late August.
- Despite relatively higher densities at Ramp 1, fish were 20% larger than reference sites by late July.
- All structures were effective at attracting fish, evidenced by higher densities than reference sites suggesting structures provided appealing characteristics.
- YOY experienced a shift in habitat use from July to August, reducing density by 10 fold and biomass by 4 fold at structures during this period.
- Reduction was greater at veins and groins – provided quiet, shallow backwater habitat shortly after swim-up, but as grayling grew they moved to deeper, midchannel habitat.
- Despite higher densities of fish, growth did not experience density-dependent reduction, suggesting structures provided energetically favourable microhabitats.
- Longitudinal gradient in density, with higher densities at downstream end of artificial stream was like due to spawning adults concentrating at downstream end.
- Greater growth observed at upstream end possibly a result of density dependent growth or likely the result of lake outlet supporting higher density and biomass of benthic filter-feeder prey species in first 100-400m of stream.
- This gradient contributed to the difference in growth rate between groins and ramps compared to vanes and V-weirs, rather than any superiority of structure.
- Ramp 1 was anomaly due to its decreasing of water depth, which resulted in higher water velocity and favourable conditions for black fly larvae. In turn these larvae supported higher densities of fast growth grayling.

Stream-scale Assessment

- Spawning stock size in the artificial stream increased over time.
- Fish densities differed among years and between streams.
- Density decreased in both artificial and natural systems from 1998 to 1999, and increased substantially in 2000.
- Polar-Vulture stream supported higher densities than artificial and proportional difference increased over time.
- Biomass was also affected by year and stream; lower overall in 1999 than 1998 or 2000.

- Difference in biomass was consistently higher in Polar-Vulture with relative difference increasing over time.
- Density and biomass were typically higher in fast-flowing than slow-flowing sections in both streams.
- SGR differed among years with the highest in 1998 and lowest in 2000 for all streams.
- Relative growth difference was larger between artificial and Polar-Vulture after structures were built.
- SGRs from natural streams were greater than SGRs from artificial streams.
- Density and biomass in artificial stream varied considerably between years.
- Same trends were found in Polar-Vulture, indicating climate conditions contributed to variation.
- Differences in density and biomass between artificial and Polar-Vulture stream increased after habitat structures installed.
- Initial construction of artificial stream exposed areas of permafrost that melted and eroded, carrying organics into the stream. Erosion is now stabilized and organics have been processed or washed out, which likely explains unexpected increase in difference in growth rates between artificial and natural streams.
- SGR varied considerably among years, strongly affected by climate-related variables.
- SGR was highest in the year prior to construction, but this was also true for the reference stream reflecting favourable conditions.
- Stream scale differences in growth rate (like density and biomass) between natural and artificial streams increased following addition of structures, thus there is no evidence to indicate instream structures increased productive capacity of artificial stream 2 years after installation.

Assessing Effectiveness

- Comparing density, biomass, and growth relative to nearby reference sections showed clearly that structures increased local densities without corresponding density-dependent cost in growth.
- Observations suggest age-0 Arctic grayling opted for a foraging strategy that reduced movement from habitat structures.
- Structures provided refuge, isolation, and cover, reduced energy demands on positioning, predator vigilance, foraging, or territoriality.
- Saw no evidence of stream scale enhancement in age-0 Arctic grayling in absolute sense or in comparison to reference streams.
- Suggests grayling simply drawn from featureless reference sections to structurally enhanced sections, a simple redistribution of animals without increase in numbers, growth, or survival.
- Fundamental paucity of organic matter was more limiting than structural deficiencies at stream wide scale.

Assumptions

Not listed
Assessment of Validity
Not listed
Questions?

4.13. B.C. Hydro 2004. - Reservoir.

BC Hydro. 2004. Jordan River Water Use Plan, Monitoring Program Terms of Reference, Diversion Reservoir Fish Indexing. 25-31.
System Type and Method Classification
Reservoir. Monitoring/compensation studies – multi-trophic level.
Reason for Assessment/ Objective
Operational change limiting the reservoir drawdown flexibility (and ultimately active storage) by imposing operational constraints.
Methods
• Rationale was that the decrease in seasonal and daily reservoir fluctuations and bulk decrease in pelagic volume would increase both establishment of littoral zone and mitigate against reducing rainbow trout condition factors. • Therefore, the reservoir was regulated to have maximum drawdown to minimum elevations as follows: o Minimum normal elevation of 376 m: 1 July – 30 September. o Minimum normal elevation of 372 m: 1 October – 30 June. *Summary of hypotheses* • H1→ reduced reservoir drawdown does not increase rainbow trout condition. • H1a → changes in reservoir first order productivity indicators occur independently of reservoir operation. • H1b→ Changes in fish condition occur independently of reservoir first order productivity indicators. • Relationship between fish condition and reservoir operation was to be evaluated. • First order productivity indicators include chlorophyll, phosphorous, and temperature. • Fish condition was defined as size and weight characteristics at age for rainbow trout. • The results of this study will evaluate effects of extensive drawdown on reservoir productivity indicators and fish condition. • End of review period information will be evaluated to determine if constrained reservoir operations should continue. *Approach* • Fish condition assessed using repeated gill-net and gee-trap surveys set at index sites in the reservoir in late August/early September every year,

coinciding with typical low-reservoir operations.

- Six years of data will be collected under recommended minimum operations.
- One-time opportunistic summer drawdown below 372m for 2 weeks is planned within first 5 years of monitoring period (or planned for year 5).
- Annual assessments will replicate site locations, timing (daily and annual), prevailing conditions of weather and operation, and inflows as best as possible.
- Initial assessments considered the relative impact gill-net sampling had on population and if a perceived risk was found, sampling intensity was reduced.

Site and gear selection

- Prior to sampling, gillnet and gee-trap sites were mapped for repetition throughout study.
- Sampling gear to meet RISC standards to ensure comparisons with other system data are valid.
- Gillnet sets targeted habitats used by each life history stage of rainbow trout – littoral zones, tributary confluence, instream habitat.
- Field period was used to test set times to optimise key interests of effectiveness and impact reduction.
- 2 pelagic zone sites were selected for monitoring of temperature and oxygen levels.

Gillent and Gee-trap Surveys

- Fish observations were made by gillnet and minnow trap.
- 2 gillnet sites were sampled proximal to rainbow trout habitats.
- 5 minnow traps were deployed in littoral zones and tributary confluences near each gillnet site.
- 2 x 6 panel variable mesh gillnets (300ft length, 8ft depth) were set within littoral zone – 1 floating and 1 sinking at each site.
- Set times ≈3-4hrs to reduce population level impacts.
- Early morning surveys helped to ensure temperature and habitat use factors were controlled over years.
- Gee-traps were set overnight with standardized baiting.
- Timing for gillnet and gee-trap were constant over entire study.
- Fish caught were measured and weighed.
- Scale samples were taken from each individual. A portion of mortalities were kept to calibrate scale ages using otoliths. Care was taken to minimize mortalities.

Environmental monitoring

- Temperature, weather conditions, time and date, reservoir level (rising or falling), and estimated stream flow were documented for each site.
- Temperature, light, oxygen profile, secchi depth were completed at each pelagic site.
- Duplicate water samples were taken 1-2m below surface with vertical

water sampler for gillnet and pelagic sites, to sample total and dissolved phosphorus and chlorophyll a.
- Standardized forms were developed for data collection and data entry.

Analysis and Reporting

- Length and weight data by age-class were integrated into Fulton condition factor →

$$K = (W_w / L_s^b) \cdot 10^5$$

Where K = Fulton condition factor; W_w = weight (g); L_s = standard length (nose to caudal peduncle, mm); b = slope of species length-weight relationship.

- Acceptable length-weight relationship 'b' for rainbow trout is 2.990 for lentic and 3.024 for lotic systems (Anderson and Newman 1996).
- One in five scale-aged samples was also aged using otoliths.
- Correction factor was derived by comparing 2 ageing methods and applied to all scale aged samples.
- Comparative analysis of condition factor and population age structure between years was conducted each year, with a comprehensive analysis to be conducted after reservoir test drawdown.
- Sample size expected to be relatively low (n<40), thus statistical power expected to be low.
- Water quality was compared annually, with significance tests conducted between sites to see if trends prevail.
- After 6 years, if the monitoring program suggests no increased benefits from regulated drawdown, then more flexible operating options will be sought at end of review period.

Results & Discussion

Methods only

Assumptions

- Condition factor of rainbow trout was assumed to be coincidental with reservoir drawdown and associated with high temperature and low oxygen during summer.
- Extent of drawdown assumed primary driver of fish condition.

Assessment of Validity

Not listed

References

Anderson, R.O. and Neumann, R.M. 1996. Length, weight, and associated structural indices. Pages 447-481 in Murphy, B.R. and D.W. Willis, eds., Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Questions?

- How many gillnet sites were established - 2 per habitat type, or 2 total covering all habitat types?
- Why only consider rainbow trout?

4.14. Lewis 2005 – Potential hydro developments in B.C.

Lewis, A. 2005. Developing Measures for the Aquatic Habitat Attribute in BC Hydro's 2005 Integrated Electricity Plan. Ecofish Research Ltd. report prepared for BC Hydro.
System Type and Method Classification.
Hydro developments. New site screening method.
Reason for Assessment/ Objective
Objective is to incorporate environmental impacts into consideration of electricity portfolios.
Methods
• Ideally, individual projects sites would incorporate consideration of environmental impacts with a direct measure that quantifies impacts on productive capacity. • However, this type of measure typically takes years to collect and/or is not available for new development sites. • The site of a large hydro-electric project (Site C) was assessed with numerous studies decades ago, but now those studies are outdated ecologically and methodologically. • Therefore assessments are now forced to use more generalized measures based on basic physical data available to individual projects. • Green Energy Study (GES) for BC (Sigma 2002) inventoried potential small hydro run-of-river projects ranging in size from 500kW to 47 MW. • 67 of 97 proposed projects used in the Integrated Electricity Plan (IEP) overlap the Sigma database. • GES provides information usable to estimate potential effects on fish habitat including: streamflow (mean annual, cms), penstock length (m), head (elevation difference from intake to powerhouse, m), fish presence, drainage area (km^2), length of transmission line (km), length of access road (km). • Above variables can be used individually or in combination to describe effects of small hydro on aquatic environments. • For 30 projects where data are not available, it was deemed necessary to assume parameters were the same as other 67 projects. Surface Area • Primary measure derived from GES is surface area of potentially impacted habitat. • Fish production is usually defined on aerial basis because area is a convenient index of spatial extent and ecosystem production can be compared when scaled to size. • Surface area is a key element in the operational definition of habitat productive capacity and is identified in regulatory policies and guidebooks. • Surface area can be modified by factors that describe quality-based aspects of fish habitat.

- Stream surface is area is derived from GES by length x width of affected habitat areas.
- Stream length is restricted to the section most affected by the project. For small run-of-river this section is the diversion section, where water is withdrawn but where continuous flow is provided.
- In case of Site C there is no water withdrawal, but the dam will impound 83 km of river and 23.9 km of tributaries in upstream section.
- Width is known for Site C and its tributaries, so area was calculated as 3970 ha.
- Width is known only for small number of the projects, but remainder can be estimated from data from Ministry of Waters, Lands, and Air Protection (MWLAP).

Width prediction

- Wetted width is predicted from mean annual streamflow through a power relationship of form $x = aQ^b$, where x = hydraulic parameter of interest (width, depth, velocity), a = coefficient, Q = flow, and b = power function.
- Relationship is expressed in log form and plotted on log-transformed axes.
- Typical values of the exponents are 0.26 for width, 0.40 for depth, and 0.34 velocity.
- Downstream relationships are developed by analysing different stations, analogous to comparing streams of different mean annual flow
- MWLAP collects data on standing stock per unit area by species and variables such as wetted width and flow. This database is composed of streams ranging from 3 to 370 cms, which overlaps the range of mean annual flows in GES
- Streams in MWLAP database have gradients <5%, contrasted with >5% gradients of typical small hydro project sstreams.
- Other sources of width and flow data include 2 published studies of streamflow, 1 from Pacific Northwest (75 streams) and 1 from New Zealand (73 streams).
- The consistency of relationships across regions was evaluated and confidence in relationships was assessed by comparing MWLAP data from 139 sites to these 2 datasets.
- BC data were restricted to downstream station data, but were collected from 65 streams with up to 10 stations per stream.
- Width and streamflow collected from 11 small hydro projects in BC were also compared to published data sets. Although methods of data collection and analysis differed among 11 streams, it was expected that trends in exponent values would differ minimally.
- Relationship of streamflow to wetted width was determined for the above 4 data sets.
- MWLAP data lay between trend lines predicted by New Zealand and

Pacific Northwest datasets, while the small hydro dataset from 11 streams lay within spread of values of MWLAP data.

- There was insufficient small hydro stream data to confidently evaluate differences with MWLAP. Thus MWLAP dataset predictive equation will be used recognizing that future validation may be required →

  Stream width (m) = 5.51 x mean annual flow$^{0.534}$ **(eqn 1)**

Penstock length

- The combined length of the tunnel and penstock from intake to powerhouse at potential small hydro sites was reported as penstock length. It was assumed that this was a reasonable estimate of the length of stream in the diversion section.
- The lengths were correlated, but actual lengths of the diversion were likely longer than estimated by GES since actual small hydro projects are built in less steep sections than those examined by GES.
- The GES mean penstock length was compared with actual proposed penstock lengths for 13 projects in the IEP, and the intercept and slope of the 2 datasets were used to derive equation for estimating length of stream channel in diversion section

  Diversion length (km) = 0.80 (GES penstock length (km)) + 1.93 **(eqn 2)**
- For projects in IEP without corresponding penstock length and flow data in GES database, the average aquatic habitat surface area based on 67 projects was used. Eventually these will be corrected using project-specific data, but the above equation was expected to provide a reasonable estimate.

Habitat Quality Factors

- Significant relationships between fish production and physical variables are rarely measured in practice. Practitioners usually correlate standing stock (biomass per unit area) with physical variables and assume abundance is closely linked with production (e.g. production/biomass ratio is constant).
- Numerous examples in literature show that physical habitat variables are correlated with productivity in BC, thus potentially can be used as indicators of habitat quality.
- GES database was examined to determine if variables could be derived to use as indicators of habitat quality.
- Additional physical variables can be calculated using available drainage basin area, mean annual flow, head, and diversion length.
- Water yield can be calculated as mean annual flow divided by drainage area.
- Stream gradient can be calculated as head divided by diversion length.
- MWLAP database was used to examined efficacy of water yield and stream gradient variables by determining strength of their relationship with productive capacity, as inferred by standing stock estimates.

- MWLAP database provided limited evidence that these variables are linked to standing stock
- Significant relationship between biomass per unit area and water yield existed →

  Biomass [g/100m^2] = 652(Water Yield [L/s/km^2])$^{-0.31}$
  (eqn 3)
- Relationship explains 26% of variance in biomass.
- Since data from Site C were unavailable, evaluating productive capacity through water yield was not possible at this site.
- Stream gradient plays role in structuring fish distributions. In B.C. the rule-of-thumb is that stream reaches >20% gradient rarely support fish.
- However, in step-pool habitats of lake headed streams, trout and char may be found at steeper gradients
- The typical GES diversion section gradient is 14.5%, which implies over half the streams support fish.
- Literature has limited support for the hypothesis that gradient determines trout standing stock, but suggest many variables acting together cause such pattern. Thus, steam gradient does not provide a useful habitat quality weighting factor.

<u>Fish Presence</u>

- Small hydro projects typically avoid major impacts to fish habitat as they are often located in headwater tributaries in canyons, which contain natural barriers to fish passage.
- These streams don't directly provide fish habitat, however they do contain nutrients and inverts that indirectly support fish production. Therefore, they are governed by same regulations for protection of productive capacity.
- In the case of fishless streams, risk of development is expected to be very low as direct mortality of fish is eliminated, invertebrates can tolerate short term dewatering, and all risk comes in form of downstream effects. Downstream effects are not considered in detail in this report because 1) all options affect downstream habitat and 2) geographic scope of downstream habitats is difficult to define and increases the complexity of comparisons.
- To acknowledge different risk to habitat by small hydro developments, habitat measures are modified by binary variable (1, 0) with developments on fishless streams assessed a value of '0' indicating the risk is minimal.
- Fish presence data are available in GES, but have not been validated with project specific data.

<u>Aquatic habitat attribute measures</u>

- Based on information on individual projects and the ability to extrapolate effects from basic physical data, measures were proposed to represent potential risk to fish habitat from development.
- Focus was primarily on small hydro developments, as the have direct effects on fish and basic physical data are available.

- Measures for aquatic habitat impacted include:
    - Measure A – describes dewatering impacts from diversion created by small hydro. Calculation →
      Area = stream width [eqn 1] * diversion length [eqn 2] / 10000
    - Measure B – describes back water effects of large hydro projects (Site C only)/ Calculation →
      Area = 3970 ha
    - Measure C – describes back water effects at small hydro projects. Calculation →
      Area = stream width [eqn 1] * weir height / diversion length [eqn 2] / 10000
    - Measure D – describes footprint of dam for all projects. Calculation →
      Area = stream width [eqn 1]^2
    - Measure E modifier based on fish presence. Calculation →
      Fish presence modifier = (0 or 1)
    - Measure F – describes impact of stream crossings (roads, transmission, pipeline, etc). Calculation →
      Area = [(pipeline, penstock, tunnel length + access road length) * 550 + transmission line length * 500] / 10000
- To determine the area of aquatic habitat affected by development (ha) appropriate measure variants must be selected, combined, and calculated from resource options database.
- Calculations required by resource option as follows:
    - Run-of-river small hydro → (A + C +D) * E + F
    - Large hydro → (B + D) * E + F
    - Natural gas, coal, wind, geothermal → F
    - Biomass, cogen, Power Smart → none
- Above calculations can be used to compare aquatic habitat impacts of different resource options.
- From a conservative, science-based perspective these calculations should not be used due to uncertainties and data gaps.
- However, the challenge for 2005 IEP is to provide the best measure possible with available information.
- Measures are expected to be relatively accurate as they measure surface area.
- Should be defensible providing qualitative issues are also considered.

Results & Discussion

<u>Uncertainties and Data Gaps</u>

- 3 key uncertainties
    - First – accuracy of input data. Addressed to some extent by derived correction factor like that is used for diversion length
    - Second – accuracy of prediction of habitat effects. Reliability of extrapolations from MWLAP database to projects in IEP is

unknown. Need to collect additional data to refine equation o Third – Comparability of measures between resource options. Cannot easily be addressed even if available data were collected. Ecological equivalency is unknown for calculation of backwater effects for small and large hydro projects. Reflects scale of impacts and lack of understanding of impact thresholds
Assumptions
Assessment of Validity
Questions?

4.15. *Santucci et al. 2005. – Rivers impounded by low-head dams.*

Santucci, V.J. Jr., Gephard, S.R., and Pescitelli, S.M. 2005. Effects of multiple low-head dams on fish, macroinvertebrates, habitat, and water quality in the Fox River, Illinois. N.A. J. Fish Manage. 25: 975-992.
System Type and Method Classification
Rivers impounded by low-head dams. Monitoring/compensation studies – multi-trophic level (operational change only).
Reason for Assessment/ Objective
To examine effects of low-head dams on aquatic biota, habitat, and water quality in a 171 km reach of a midwestern U.S. warmwater river fragmented by 15 dams into a series of free-flowing and impounded habitats.
Methods
Site locations • Sampled fish, macroinvertebrate communities, and habitat quality at 40 stations from mid-July to early September 2000. • Biota and habitat were sampled concurrently. • All stations were 0.8 km long and consisted of the entire river width and adjacent riparian areas. • 30 stations were located within 1km of Fox River Dams – 15 upstream of dam and impounded areas and 15 in free flowing areas downstream. • No sampling was conducted within 100m of dams due to safety concerns. • 10 additional stations were located in middle reaches of 5 between dam segments – 2 stations per segment, 1 located at 30% and 1 at 60% of total segment length in either free flowing or impounded habitat. *Fish samples* • Fish were sampled with three methods. • Boat electrofishing runs began at upstream boundary and went downstream along each bank for 30 minutes (total time = 1 hr/station) • Wadable habitat was sampled with generator powered backpack electrofishing using relative proportion of habitat abundance for 30

minutes per station.

- Seining was conducted at 3 locations per station in habitats of wadable depth with sand, silt, or gravel substrates. The seine was deployed in single 30.5m arc along the riverbank and retrieved to shore.
- Fish larger than 200mm total length were identified to species, measured (nearest mm), weighed (nearest g), and examined for anomalies. Smaller fish were preserved and processed in lab.

IBI

- Characterized fish communities using IBI and abundance of harvestable-sized sport fish
- Values of IBI ranged from 12 to 60, with higher values indicating better biotic integrity.
- Streams were classified into categories representing A) unique (51-60), B) highly valued (41-50), C) moderate (31-40), D) limited (21-30), and E) restricted aquatic resources (12-20) based on IBI scores.
- Sport fish abundance was estimated from boat electrofishing catch for fish greater than minimum harvestable size limit – index included top predators.

Fish distribution

- Data from the present study and 14 other surveys conducted between 1980 and 1999 were used to examine affect of dams as barriers to upstream movement of fish.
- Identify species limited by dams, determined species present between dam segments and visually examined distribution pattern over entire study area

Macroinvertebrate samples

- Macroinvertebrates were sampled from wadable habitats using kicknets and hand picking for 1 hour per station.
- Kick nets were 250mm x 457mm rectangular steel frames fitted with 500 µm mesh, and were used to sample small substrates (silt, sand, gravel), water surface, and water column.
- Forceps were used to pick inverts from arbitrarily selected submerged rocks and woody debris.
- Allocated sample time to various macrohabitats (riffle, run, shoreline) based on a visual estimate of the aerial coverage of habitat within station.
- Deeper, offshore habitat was sampled with ponar dredge (152mm x 152mm opening) from a canoe.
- 5 substrate grabs taken along 1 upstream transect and 1 downstream transect for 10 grabs per station.
- Transects ran perpendicular to thalweg in water >1.5m depth.
- Grab contents were washed and sieved through 500µm mesh.
- 3 impoundment stations were not sampled due to inability of the ponar to sample large gravel and cobble substrate.
- Samples were preserved then sorted and counted in lab. Identified all individuals to genus except for chironomid larvae, where 1/3 subsample

was used for identification when numbers exceeded 15. Identities assigned to all chironomids in the sample based on taxa proportions of the subsample.

MCI

- Multimetric macroinvertebrate community index (MCI) was used to characterize communities from wadable habitats.
- This seven-metric index developed for Fox River based on USEPA rapid bioassessment protocols (Barbour et al. 1999).
- Intolerant taxa metric was made up of organisms with tolerance rating of 4 or less based (range = 0-11) based on an Illinois tolerance list.
- Illinois MBI (version of Hilsenhoff 1987 biotic index) provided overall community tolerance rating based on mean tolerance values weighted by organism abundance (Hite and Brockamp 1992). .
- MBI ≥7.5 represented restricted aquatic resources and community with limited diversity, few intolerant forms, and predominance of tolerant organisms (Bertrand et al. 1996).
- Clinger organisms were filter-feeding insects permanently attached to substrates and were considered intolerant of poor water quality.
- Range of MCI values was 0 to 700, with higher score indicating higher quality community.
- MCI was not appropriate for comparison to other studies or gauging ecological health of other rivers as only Fox River data were used in its creation.
- MCI provided a useful measure documenting relative differences in macroinvertebrate communities among Fox River stations.
- MCI was positively correlated with IBI ($r = 0.82$, $P = 0.001$).

Habitat quality

- Habitat quality was assessed with qualitative habitat evaluation index (QHEI – OEPA 1989).
- QHEI is visual observation index designed to provide empirical, quantified evaluation to important lotic macrohabitat characteristics.
- QHEI includes 7 principal metrics and a number of metric components and has been shown to generate scores that are strongly correlated with fisheries assessment data.
- QHEI was used to evaluate habitat quality in impounded and free-flowing areas because 1) impounded areas retain characteristics of slow-flowing river, 2) habitat indices are not available for impoundments, 3) free-flow condition would be restored after dam removal if chosen as a river restoration alternative.
- Each station was surveyed twice by canoeing or wading – first to draw a map of macrohabitat features and second, to score individual metric components.
- Index scores >60 (max 100) indicate good quality habitat with diverse fish communities.
- Scores <46 indicate severely degrade habitat with poor quality fish

communities.

- Scores between 46 and 60 indicate degraded habitat.
- Water quality was monitored at 11 downstream free flowing and 11 upstream impounded stations.

Statistical Analyses

- Fish, MCI and AHEI indices and individual metric scores among station types were compared with a one-way ANOVA and Tukey's multiple comparison test.
- Arcsine transformation was used to normalize the variance.
- Pearson's product moment correlation was used to assess the relation between fish and invertebrate communities and habitat quality.
- Repeated measures ANOVA was used to compare water quality parameters between habitat types.
- To assess whether effects of multiple dams were cumulative, linear regression was used to examine the relation between upstream-downstream distance and several measured variables.

Results & Discussion

Fish Community

- Fish community quality as determined by IBI scores was higher in free-flowing reaches than impounded areas above dams, but did not differ within free-flowing reaches or impounded areas.
- Free-flowing reaches on average were characterized as highly valued B-quality (41-50) streams and impounded areas were characterized as limited value D-quality (21-30) streams.
- Mean catch of harvestable size sport fish was higher at downstream and mid-segment free-flowing stations than upstream and mid-segment impounded stations.
- Higher values were recorded in free-flowing areas for: 1) overall and harvestable-size sport fish abundance, 2) number of suckers and intolerant fish species, 3) species richness, 4) percentage of insectivorous minnows.
- Impounded areas contained a predominance of tolerant and omnivorous fish species.
- Dams altered the distribution of 1/3 of fish in Fox River by acting as barrier to upstream movement.
- 15 species with truncated distributions were found only in lower portion of river.
- 10 species with discontinuous distributions were not found above lower-most dam with 5 more species limited to lower portions of river.
- Species with discontinuous distributions were found in upper or lower river, but rarely/ not at all in central river where there was a high density of dams and urbanization.

Macroinvertebrate Communities

- Free-flowing habitat supported higher-quality communities than impounded areas.

- Mean MCI scores were similar within free-flowing and impounded habitats, but free-flowing downstream and mid-segment stations had MCI scores twice as high as upstream and mid-segment impounded areas.
- Free-flowing areas had higher percentage of Ephemeroptera-Plecoptera-Trichoptera (EPT) individuals and clinger organisms and higher EPT richness.
- Overall taxa richness and chironomid percentages were similar among stations.
- Mean numbers of intolerant taxa were higher at midsegement free-flowing stations than free-flowing stations closer to dams or in impounded areas.
- Below dams had a higher density of filter feeders.
- Impounded areas typically had highest MBI scores and 8 of 15 upstream impounded stations had scores ≥7.5 which indicates poor invertebrate assemblages.
- Invertebrates were extremely limited in open-water impounded areas, with few taxa present and predominantly made up of tolerant oligochaetes and chironomid larvae.

Aquatic habitat quality

- Differed substantially between free-flowing and impounded areas.
- Mean QHEI scores were higher in downstream and mid-segment free-flowing stations than upstream and mid-segment impounded areas, though scores were similar within free-flowing and impounded habitats.
- Free-flowing stations were characterized by good habitat quality; impounded areas were characterized as severely degraded.
- Contributing to degraded status of impounded areas was the absence of riffle and run habitats.
- Calculation without riffle and run metric still showed higher scores in downstream and mid-segment free-flowing stations than upstream and mid-segment impounded stations.
- Good quality instream habitat was available throughout free-flowing portions of the river, even where banks were stabilized with concrete or riparian vegetation was minimal or absent.
- Strong positive relationship between QHEI and IBI and QHEI and MCI scores, which attest to usefulness of QHEI as subjective stream habitat assessment tool and underscore the importance of habitat quality to lotic fish and macroinvertebrate communities.

Assumptions

None given

Assessment of Validity

None given

References

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. 1999. Rapid bioassessment protocols for use in streams and wadable rivers: periphyton, benthic macroinvertebrates, and fish, 2nd edition. U.S. Environmental

Protection Agency, Office of Water, EPA 841-B-99-002, Washington, D.C.
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Hite, R.L. and Brockamp. D.W. 1992. Effects of livestock wastes on small Illinois streams: lower Kaskaskia River basin and upper Wabash River basin. Illinois Environmental Protection Agency, Report IEPA/WPC/92-114, Springfield.
OEPA (Ohio Environmental Protection Agency). 1989. Biological criteria for the protection of aquatic life. Volume III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Ohio Environmental Protection Agency, Columbus.

Questions?

4.16. Scruton et al. 2005. – River and compensation channel.

Biomass Surrogate

Scruton, D.A., Clarke, K.D., Roberge, M.M., Kelly, J.F., Dawe, M.B. 2005. A case study of habitat compensation to ameliorate impacts of hydroelectric development: effectiveness of re-water and habitat enhancement of an intermittent flood overflow channel. J. Fish. Bio. 244-260.

System Type and Method Classification.

River and compensation channel. Monitoring/compensation studies – fish.

Reason for Assessment/ Objective

Rose Blanche River, Newfoundland - New hydroelectric development.

To evaluate the rewatering and physical enhancement of a flood by-pass channel in compensating for the loss of fluvial habitat due to hydroelectric development. The objectives were to determine (1) the stability of the constructed habitat features in the compensatory channel, and (2) if fish production (biomass surrogate) replaced that lost due to the project (i.e. achievement of NNL).

Methods & Design

- A hydroelectric facility was built on the Rose Blanche River in Newfoundland in 1998 that destroyed 570 units (each $100m^2$) of fluvial fish habitat due to flooding. Modification of a 1.2 km long intermittent flood by-pass channel was performed to compensate for lost spawning and rearing habitat by the installation of a box culvert that ensured controlled flow ($0.4\ m^3s^{-1}$ low flows and $0.9\ m^3s^{-1}$ high flows) from the reservoir all year round.
- Physical modifications to the channel were performed to increase available microhabitats for resident adult and juvenile brook trout and Atlantic salmon.
- Compensation channel effectiveness was determined by comparing

estimated fish biomass (productive capacity surrogate) between main stem lost and compensation habitat.

- Meso-habitat distribution surveys were conducted in the compensation channel annually during summer low flows from dam pre-construction (1998) through post-construction (1999-2002) with habitat classifications based on Beak's classification scheme for salmonid fluvial habitats.
- Beak Consultant's fluvial habitat classification for salmonids in Newfoundland (from Table 1):

  Type I: Spawning and Rearing
  Good spawning and rearing habitat with pools for older age classes; Flows – moderate riffles 0.1 to 0.3 m^3s^{-1}; Depth – shallow 0.3 to 1.0 m; Substrate – gravel to small cobble and some boulders

  Type 2: Rearing
  Good rearing habitat with spawning in isolated pockets, good feeding and holding areas for older fish; Flows – riffles, runs 0.3 to 1.0 m^3s^{-1}; Depth – shallow 0.3 to 1.5 m; Substrate – cobble and rubble, some boulders and bedrock, gravel in pockets

  Type 3: Migratory
  Poor rearing and no spawning, primarily a migration "corridor"; Flows – fast turbulent, rapids chutes, small falls >1.0 m^3s^{-1}; Depth – variable 0.3 to 1.5 m; Substrate – boulders, bedrock

  Type 4: Rearing and over-wintering
  Rearing no spawning, shelter and feeding for older fish, over wintering function; Flows – slow 0.1 to 0.15 m^3s^{-1}; Depth – variable ≥ 1.0 m; Substrate: sediment, sand, organics, interspersed with boulders and bedrock, macrophytes may be present

- The main stem habitat was surveyed prior to flooding in 1998 and was entirely Beak Type 2. The surveys were used to assess changes in the distribution and stability of mesohabitats post-construction.
- Electrofishing was conducted in summer 1998 at low flow to collected pre-construction baseline data in the main stem prior to flooding. The compensation channel did not support fish production prior to development, due to seasonal flow fluctuations with periods of dryness.
- Post-construction electrofishing was similarly conducted twice annually (July and August, October) in 2000, 2001, and 2002 to determine fish density, biomass, age and size distribution, and in season growth.
- Three locations [lower, middle, upper] were selected in each of the compensation channel and main stem with a number of sites sampled at each [lower=3 sites, middle=2 sites, upper=2sites]. Electrofishing was conducted using a backpack electrofisher and employing a successive removal method.
- Barrier nets were erected at each site to prevent immigration and

emigration from the site. A minimum of three sweeps were conducted in an upstream direction and fork length, weight, and ageing (by scale sample) information was collected.

- Population estimates were calculated using Microfish 3.0 software with a maximum likelihood estimator at each site for 1) all fish, 2) all fish by species, and 3) separately for YOY and older age classes. Only summer electrofishing data were used for spatial comparison and comparison to pre-development data
- Total fish biomass was compared between the compensatory channel and the main stem to demonstrate how fish production evolved 3 years post construction.
- Brook trout density (all fish and YOY) was used to demonstrate response to habitat attributes, which were designed to benefit brook trout.
- All fish were marked or tagged during electrofishing to determine site fidelity and migration between channel and main stem.
- Inter-annual survival (no units) and fish production (biomass per year) calculations were conducted for each site.
- Fork length distribution was used to demonstrate within year movement between reaches.
- To determine that NNL of habitat productive capacity had occurred, estimated total fish biomass gained in the compensatory channel in 2000, 2001, and 2002 was compared to the total biomass lost due to dam construction.
    - Lost total biomass was calculated as the product of the lost area (570 units) and average total fish (brook trout only, as they were the only resident fish in the destroyed habitat) biomass (g m^{-2}) from pre-construction surveys.
    - Gained compensatory fish biomass was calculated as the product of the newly acquired area (100 units) and the average total fish (brook trout and Atlantic salmon) biomass (g m^{-2}) in each year.

Results & Discussion

Habitat Distribution

- Immediately after construction, spawning habitat in the compensation channel increased due to directed construction efforts. Due to natural scouring of the substrate subsequently after construction however, spawning habitats (Type 1) were reduced from 72.5% to 32.7% and redistributed, leading to an increase in rearing (Type 2) and over wintering habitats (Type 4).

Fish Biomass

- Total fish biomass in the compensation channel increased each year while it decreased in the main stem, although the changes were not significant when tested with ANOVA ($P>0.05$).
- Differences in total biomass between main and compensation channels were only significant in 2002, with greater biomass in the compensation channel.
- Total fish biomass within the compensation channel was > the upper

reach > middle reach > the lower reach. Differences were significant between upper and lower reaches in 2000 only (K-W one way ANOVA, p=0.029).

Fish Density

- Brook trout density was consistently greater in the compensation channel than main stem, but only significantly higher in 2002.
- YOY density increased in both main stem and compensation channel.
- Increases were significant in each year.

Fork Length Distribution

- Distribution indicated greater numbers and wider size distribution in compensation channel for brook trout than Atlantic salmon.
- Good production of smaller size classes and good representation of larger sizes of brook trout.
- The proportion of Atlantic salmon increased through study period.
- Fork length distribution in three sub areas of compensation channel demonstrated within season movement of brook trout and possible immigration.
- Influx of larger individuals in lower reach in autumn was probably from the main river, as there was no major sign of outmigration from other reaches.

NNL Determination

- From comparing estimated total fish biomass (g) in the compensatory channel with the estimated lost biomass in the main stem, it was apparent that NNL was approached 2 years after construction (92% of pre-construction biomass) and a net gain was achieved by year 3 (128% of pre-construction biomass).
- Fish production increased each year after the channel was developed.
- In this study a low ratio of replacement habitat versus lost habitat (1:5.7) resulted in a net gain of habitat productive capacity (biomass surrogate) after 3 years.

Assumptions

- Pre- and post electrofishing assessments assumed that 1998 was a representative year.

Assessment of Validity

Not assessed

Questions?

- How big were the electrofishing sites (width, flow, etc.)? Were any spots too deep to fish?
- How much of the gained productivity in the compensation channel was due to Atlantic salmon?

4.17. Pearson et al. 2005. –Rivers and Lakes (compensation assessment).

Pearson, M.P., Quigley, J.T., Harper, D.J., and Galbraith, R.V. 2005. Monitoring and Assessment of Fish Habitat Compensation and Stewardship Projects: Study, Design, Methodology and Example Case Studies. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2729: xv + 124 p.
System Type and Method Classification
Rivers and Lakes. Monitoring/compensation studies – multi-trophic level.
Reason for Assessment/ Objective
This study examines a 3 level strategy for monitoring and evaluating fish habitat for compensation and stewardship options (1. Routine monitoring; 2. Site effectiveness monitoring; and, 3. Program effectiveness evaluation). This review will focus on level 2, site effectiveness monitoring, which emphasizes paired before-after control-impact experimental designs and statistical analysis to determine whether NNL has occurred in larger or more complex projects.
Methods
Site Effectiveness Monitoring • Measures biological effectiveness of compensation projects are quantified in terms of net gain or loss. • 3 objectives at this level – o 1) to verify that the project was implemented as approved/designed, o 2) to quantify net change in habitat productive capacity, and o 3) to document how the project affected social values in the community. • This monitoring applies quantitative experimental design and statistical analysis to larger compensation and stewardship projects and those posing a significant risk to the resource. Objective 1 - Verify the project was implemented as approved/designed *What to measure* • Area, configuration, materials, and project integrity using rigorous methods. *How to measure* • As-built and post project surveys are required and must permit precise area calculations. • Important in compensation projects where compensation ratio (compensation area:HADD area) is used in NNL calculations. • Detailed survey methods for streams (Kondolf & Micheli 1995, Newbury & Gaboury 1993), subtidal areas (Robinson et al 1996), and estuarine habitats (Hunter et al 1983, Williams 1993) were not described in this study, but appropriate literature was cited for reference. Objective 2 - Quantify net change in habitat productive capacity. • 2 aspects in determining net change are 1) overall area of change, and 2)

the magnitude of change per unit area of a variable. These allow the evaluation of quantity and quality of habitat.

- A multi-metric approach with many variables and rigorous techniques are required within framework of formal experimental design and statistical analysis

What to measure

Abundance, Density, and Production

- Biomass is measure of tissue weight per unit area, and production is the generation of tissue weight per unit area per unit of time.
- Both can be calculated for a species, taxonomic group, guild, trophic level, or life stage and are better index of habitat quality than simple abundance.
- Production estimates often rest on estimates of density (abundance per unit area).
- Abundance should be measured using standard methods (e.g. quadrat counts, mark-recapture).
- Indirect indices are more easily measured (CPUE, transect counts), and can be used following calibration to direct estimators of abundance.
- Target species production is always of central interest, and direct estimates (smolt emigration, biomass accumulation) should be made, although this can be difficult with acceptable precision.
- Periphyton, macroinverts, and macrophytes are important in food production and cover sources and their biomass and production rates are often a better measure of productive capacity than fish production.
- Estimates of abundance, density, and/or production must be combined with area measurements to account for compensation ratio to estimate total abundance, production or biomass at each site.

Individual-based biotic variables

- Assessments often overlook individual performance, but differences in body size, condition, growth, parasites, and behaviour reveal important insights to the mechanisms involved behind population scale variables.
- These measures have high statistical power relative to population based measures.
- Recommend measuring growth rate and condition of target species due to sensitivity to change.
- Less mobile and easily measured taxa (e.g. inverts) should be included as they are likely most sensitive.
- Methods will usually require individually marked animals which can be incorporated into estimations of abundance using mark-recapture. .

Community structure and diversity

- Community structure can be very sensitive to ecological change.
- Can be readily quantified using similarity indices and measures of diversity.
- Calibrated multi-metric indices (IBIs) use community structure to compare sites against regional baseline for specific habitat types.
- IBI may be ill suited to regions where fish diversity is naturally low, but IBIs based on macroinverts or periphyton may prove useful in these areas.
- Recommend using regionally calibrated fish and macroinvert IBIs or development of other multi-metric indices of ecosystem function as per guidelines recommended in Jackson et al. (2000) or the Canadian Aquatic Biomonitoring Network (CABIN - Environment Canada 2004, including the reference condition approach – Reynoldson et al. 1997).

Water Quantity

- The pattern of a site's water levels and currents over time (hydrograph) is a fundamental determinant of its habitat.
- In streams fluvial process physically shape habitat and change in discharge can alter types and amount of habitat.
- In wetlands and intertidal zones the frequency and duration of inundation controls plant community structure and mobility of animals.
- Best information is from continuous data collection using a data logger.

How to measure it

- Method details (for all types of monitoring) are not listed in this paper, but a list of useful references is provided on page 29 (Table 3) organized by variable and habitat type.

Objective 3 – Document affected social values in the community.

- Opinion survey methods with analysis of data using contingency tables (chi-squared test).

Experimental Design

- Quantitative experimental designs are required to establish if an observed changed is due to a project's impact.
- The type of design this paper advocates is a Before, After, Control, Impact (BACI) experimental design. Requires variables be measured before and after project at both control and impacted sites.
- BACI is simplest spatially-nested design with controls at local and distant scales.
- This paper provides a background on some general considerations for good experimental designs.
- A Table is provided for the minimum number of **replicates** recommended for different sampling methods commonly used for several variables.
- With respect to **statistical power**, this study points out that many

environmental impact assessments require an 80-100% change in a measured variable to detect a change. A solution is listed that weighs risk of type 1 and 2 errors at the design stage:

1. establish an effect size that must be detectable (e.g. 25% change in biomass).
2. establish ratio (k) of α to β based on perceived risk of committing type 1 and 2 errors
3. Set $\alpha=k\beta$ and starting with $\alpha=0.05$ apply power analysis to determine necessary sample size to achieve $\alpha=k\beta$
4. Adjust α and recalculate. Repeat iterations trading off cost against risk of errors.

- With respect to selecting **control sites** recommended using 1 local and 2 distant sites, which allows spatial nesting to examine fish movement on local abundance and insurance in case of problems with one control site.
- Control sites should be 1) similar in character to pre-impact project sites to increase study's power to detect change, 2) appropriate distance from project site relative to distances moved by target species, and 3) free from confounding influence (e.g. other HADD)
- Recommend that regional reference sites established on trial basis for 1 or 2 common habitat types (to be used as common control sites for projects in a given habitat type).
- With respect to **frequency and duration of monitoring**, it was recommended that 2 years of pre-project sampling be conducted to gain some measure of inter-annual natural variance. Also recommend minimum of 3 sampling periods per year for biotic variables to provide replication
- Post project monitoring should extend for 10 years of 2 life cycles of target species. Recommend 3 pulsed, 2 year periods (in years 1 and 2, 5 and 6, 9 and 10 for immediate, short term, and medium term effects respectively). This allows statistical testing of NNL for each period and provides valuable information on recovery rates and avoids averaging impact over the 10 year period.

<u>BACIP Designs</u>

- BACI designs constitute the best available family of experimental designs for assessing human impacts on natural ecosystems.
- Observed trends at a project site can be legitimately attributed to on or off-site influences.
- Addition of spatially nested control sites at a hierarchy of scale (watershed, segment, reach) permit identification of off-site factors influencing the site.
- Can be applied to any numeric value with several assumptions.
- 2 main methods of analysis:
    - (1) **Paired BACI models** (BACIP)focus on difference in mean values between control and project sites before and after project implementation (Stewart-Oaten and Bence 2001).

- Control sites are used as covariates to reduce effects of large-scale temporal variation affecting both control and project sites.
- Major advantage is that mean values of variables at control are not assumed to be the same as project prior to construction – assumed difference between them is constant.
- (2) **ANOVA models** differ in using replicated control sites to estimate variation among natural sites.
- ANOVA tests for time (before versus after) by treatment (control versus project) interactions.
- These models were criticized on theoretical grounds and are not recommended except when pre-impact data are not available and there is no alternative.
- Assumptions of BACIP designs include additivity, independence, and identical normal distributions and homogeneous variances (see below).

<u>Application of BACIP</u>

- Applied to any variable for which one can estimate values before and after project implementation (e.g. Density, biomass, growth rate, fish condition, trophic levels, habitat attributes, or regionally calibrated IBI).
- For **Restoration Projects**
  - Impact of project (I) on given variable estimated by →

    $I = D_B - D_A$ (eqn 1)
  - where $D_B - D_A$ are difference of mean values at restoration and control sites before (B) and after (A) the project is implemented (Stewart-Oaten et al. 1986).
  - When separate effects are operating at different scales using local and distant control sites →

    $I = (D_{B,\,Cd} - D_{A,\,Cd}) - (D_{B,\,Cl} - D_{A,\,Cl})$ (eqn 2)
  - where Cd is distant control site(s) and Cl is local control site
- For **Like Compensation Projects**
  - Assessing NNL requires additional steps.
  - Must determine the actual compensation ratio.
  - Eqn. 1 is applied to the HADD and appropriate equation (1 or 2) applied to compensation site.
  - Net change (NC) is then calculated →

    $NC = (CR \cdot I_{Comp}) + I_{HADD}$ (eqn 3)
  - where I_{Comp} and I_{HADD} are changes in variable at HADD and compensation sites and CR is ratio of compensation area to HADD area
  - When NC ≥0, NNL of variable has occurred.
  - Net change is a function of both habitat area and productivity and should integrate both elements where possible (i.e. parameter is “per unit area”).
  - Where parameter is not in area-specific terms and cannot be expanded by CR, then it can be used as weight of evidence to support NNL determination.

- For **Unlike Compensation Options**
  - When like compensation is not possible, the next option is to create or enhance a different type of habitat conducive to different life history stage or species.
  - When production of different species must be traded off, decisions should compare impact of HADD and compensation sites on production of the same, later life history stage of the species involved.
  - Ideally this is the adult stage, as growth and survivorship are integrated across all life stages and habitats.
  - For anadromous species, smolt production is the preferred stage.
  - This approach requires good estimates of survival between life history stages in different habitats and knowledge of limiting habitat.
  - BACIP should also be applied to variables common to both habitats (e.g. macroinvertebrate or periphyton biomass).
  - Weakness may be that these variables are not related to productive capacity in the same way across habitats.
- When there is no "before" data:
  - BACI designs cannot be applied without pre-project data.
  - The best option is a After-Control-Impact (ACI) that compares project values directly to control site using ANOVA.
  - In compensation projects, control sites are assumed to estimate conditions in the HADD site if the impact had not occurred.
  - Differs from BACIP where control sites used to factor out large scale temporal changes common to both sites.
  - Success judged in amount of difference (D) in mean values of variable (X) between control site (c), compensation project site (p), and modified areas in HADD site (m) that still have habitat value →

    $$Dx = Xc - Xp - Xm \quad \text{(eqn 4)}$$
  - As in equation 3, the compensation site variables should be expanded by CR where appropriate.
  - NNL is achieved where $Dx \leq 0$ and precision is calculated in the form of confidence limits.
  - For non-compensatory habitat creation, control sites act as reference sites which the creation project is designed to emulate.
- With respect to **Data Analysis**
  - To interpret a finding one must know size of difference test is capable of detecting and minimum difference that is biologically important.
  - Statistical significance is meaningful only so far as if reflects biological significance.
  - BACIP design uses paired t-tests or more commonly Welsh t-

tests.

- o Separate tests can be made for each of 3 after periods (immediate, short, and medium terms).
- o When no effect is found, a simple examination of confidence intervals around the mean is a reliable way of assessing adequacy of sampling post hoc. Confidence intervals for BACIP can be determined from →

  $(D_B - D_A) \pm t_{df} \cdot SE$
- o When observations are in categories, contingency tables can be used to examine patterns using chi-squared analysis.
- o When assumptions for t-tests are badly violated, other non-parametric methods may prove useful – the Wilcoxan paired sample U test and Spearman rank correlation coefficient.

Results & Discussion

- Several case studies were presented demonstrating the use of BACIP design in Site Effectiveness Monitoring to determine NNL of productive capacity

Assumptions

- BACIP design has 3 main assumptions
  1. Additivity: Difference in variable's value between control and project site must be constant within period of time.
     - Commonly violated (eg. Where value of site variable always a fraction of other site's variable regardless of absolute numbers)
     - Careful selection of control site can minimize risk of violating this assumption
     - Data transformations can often correct this violation
  2. Independence: Observed values from different sampling dates must be independent
  3. Normal distribution and homogenous variance: Deviations from expected mean difference between control and project must be normally distributed with constant variance among sample times and sampling periods
     - Can be corrected with modification to t-stat, transformations, and interpretation

Assessment of Validity

Not listed

References

Environment Canada. 2004. Invertebrate biomonitoring field and laboratory manual for running water habitats. Environment Canada, Pacific and Yukon Region.

Jackson, LE. Kurtz, J.E., and Fisher, W.S. Editors. 2000. Evaluation guidelines for ecological indicators EPA/620/R-99/005. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Reynoldson, T.B., Norris, R.H., Resh, V.H., Day, K.E., and Rosenberg, D.M. 1997. The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic invertebrates. J.N. Am. Benthological Soc. 16: 833-852.
Stewart-Oaten, A., Murdoch, W.W., and Parker, K.R. 1986. Environmental impact assessment: “pseudoreplication” in time? Ecology 67: 929-940.
Stewart-Oaten, A., and Bence. J.R. 2001. Temporal and spatial variation in environmental impact assessment. Ecol. Monographs 71: 305-339.

Questions?

- o How do you measure individual growth rate and condition of invertebrates, or incorporate invertebrates into a mark-recapture study (as recommended in the ‘individual-based biotic variables’ section)?

4.18. *Alliance Environment 2005a. – Rivers and Lakes (Hydro Quebec).*

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ALLIANCE ENVIRONNEMENT INC. 2005a*.* Partial diversion of the Portneuf River. Environmental monitoring of the operational phase, 2004. Productivity of fish populations in lakes along the course of the Portneuf River. Report submitted to Hydro-Québec. 78 p. and appendices.

System Type and Method Classification

Rivers and Lakes. Monitoring/compensation studies – fish.

General Description of the Project

In the fall of 2002, the Portneuf River was partially diverted to increase the flow of two Generating Stations on the Betsiamites River. To do so, the Itomamo Dam was built on the Portneuf River (Figure 1). The average annual flow diverted is 9.5 $m^3 \cdot s^{-1}$ and a minimum flow of 1 $m^3 \cdot s^{-1}$ is provided at the dam site. To minimize the impact on overall productivity of brook trout, a series of mitigation measures was applied in the river (construction of a fishway, spawning beds for brook trout, flow deflectors) and in lakes ("compensation lakes") in the Portneuf and Sault-aux-Cochons Rivers watersheds (construction of spawning and rearing areas for brook trout, and stocking of brook trout).

Aspects of the fish community, with special emphasis on harvestable biomass of brook trout, were assessed in the Portneuf River before diversion in 2000-2001-2002 (reference state) and after diversion (2003-2004-2005). The compensation lakes were assessed before enhancement in 2003-2004 (reference state) and after enhancement (2005).This program will continue until 2012.

Reason for Assessment/ Objective

- Describe the fish community composition present in affected (main) water bodies
- Determine fish species relative abundance and yield compared with the reference state (2001 study)
- Compare length, weight, condition factor, age, growth, fertility, sexual

maturity and mortality of brook trout and white sucker (main species) with the reference state.

Methods

Stations and sampling

- Net fishing was conducted in the same water bodies as reference state study:
  - The Portneuf and Sables rivers
  - Portneuf, Bacon, Dégelis, Emmuraillé, Patien, and Sage Lakes
  - Tableau Lake was used as reference lake
- Sampling was performed August 3–11, 2004, similar to period used in 2001 for reference state
- 3 stations with lentic flow were located in Portneuf River; 1 located upper reach (KP 118), 2 stations located in lower reach (KP 38 and KP 62). Stations were isolated from each other by impassable obstacles. These sites were located in free access and areas used by outfitters
- 1 station was sampled in the Sables River, (near KP 16) in free access territory.
- Lakes Portneuf (KP 169-185), Bacon (KP 162-165), Dégelis (KP 149-154), and Emmuraillé (KP 138-142) were located in areas used by outfitters.
- Lakes Patien (km 133-137) and Sage (130-131) located in free access area
- Impassable obstacles limit fish movement between lakes Dégelis and Bacon, and between lakes Patien and Emmuraillé.
- Chain formed by lakes Dégelis, Chailly and Emmuraillé was considered one water body for management purposes.
- Tableau Lake was chosen as the reference lake because:
  - Located near study lakes in same watershed
  - Possess a fish community identical to the sample lakes (white sucker and brook trout only)
  - Brook trout stocking is not performed
  - Surface area and depth similar to Lake Dégelis
  - Water quality similar to other lakes
  - Overharvesting not a known problem, seldom visited by outfitter clients
  - Beaver dams limit fish movement with Portneuf River
  - Is not influenced by the partial diversion of the Portneuf River.
- Sampling in Tableau Lake allowed documenting of natural variability.

Gear

- Experimental gill nets (22.8 m long and 1.8 m in height) consisted of 6 panels of multifilament gill nets (25 to 76 mm stretched mesh)
- Installed in the littoral zone, in preferred brook trout habitat (less than 6 m in depth).
- Nets were set perpendicular to shoreline with fine mesh nets alternately positioned between gear to face shore and offshore areas.

- In lakes, nets were placed in same locations as 2001. In rivers, some nets were moved where water depth was too low.
- Effort at each station was determined by 1) effort applied for reference state and 2) by target number of catches.
- Minimum 100 brook trout were targeted for lakes Dégelis, Emmuraillé, Tableau, and southern part of Lake Portneuf.
- Sables and Portneuf rivers, a minimum of 50 brook trout were targeted to assess required POTSAFO parameters for monitoring river in 2005.
- No minimum sample was established for other fish species in other water bodies.
- Exploratory fishing was also performed using minnow traps to ensure representation of fish species present. Minnow traps were systematically positioned near each experimental gill net.
- All gear was hauled after 18 to 25 hours, including one night. Unit of effort is net-day or trap-day.
- Position of fishing gear was identified using a GPS device to ensure installation in same location as reference state.

Measurements and samling

- Information recorded: species, total length (to the nearest mm), weight (precision of 0.1 g), sex (male, female, undetermined), sexual maturity stage based on Kesteven chart

Fishing yields

- CPUE and BPUE calculated for each species harvested and fishing stations.
- Individuals of atypical weight were identified using linear regression. Weight/total length relationship for each fish species established using regression calculated with *Systat 11.0* software.
- Weight of atypical fish based on visual examination of regression line and outliers was adjusted using the regression equation.
- Weight was estimated from the equation when it could not be measured in the field.
- Where individual length and weight not measured in the field, the median species weight for a given water body was estimated for purposes of calculating the BPUE.
- Mean length, mean weight, Fulton's condition factor, and length distribution were also determined by fishing station and sex of individuals (males, females, immature and undetermined).
- Fishing stations located in the lower reach of the Portneuf River (KP 38 and KP 62) were grouped together for analyses to increase the sample size (same as reference study).
- Specimens caught in minnow traps were excluded from analyses, except for growth curves.

Condition

- Fulton's condition factor was calculated based on a species-specific size interval to minimize variability attributable to length.
- Parameter makes it possible to assess fitness.
- Size intervals used to calculate condition factor were the same as used for reference state:
  - white sucker: 150-349 mm;
  - longnose sucker: 100-299 mm;
  - brook trout: 100-299 mm.
- Intervals were arbitrarily established in 2001, taking care to keep sufficient number specimens to ensure representative results.
- Fish whose weight was adjusted (outliers) were not considered in the calculation of average condition factor.

Percentage of small individuals

- Proportion of small individuals was determined (recruitment index) to assess brook trout and white sucker recruitment.
- Percentage of individuals meeting specific criterion was calculated for each species:
  - Brook trout - proportion of age class 1+ selected as criterion
  - White sucker - proportion of 1+ and 2+ selected as criterion.
- YOY (0+) were not considered in recruitment index as they were virtually absent from catches.

Sex ratio

- Sex ratio was calculated for brook trout and white sucker.

Fecundity

- Ovaries of mature females were taken from brook trout caught in Portneuf, Dégelis and Tableau lakes along with Portneuf and Sables rivers.
- Brook trout fecundity analyses - total egg count performed for each pair of sampled gonads. Only normally developed eggs counted.
- Abnormal values (*outliers*) were determined by considering 1) total weight to fecundity and 2) total weight to gonad weight relationships. Abnormal values were excluded from analyses.
- Linear regression between total number of eggs and total weight of each female was used to represent fecundity.
- Mean fecundity for fixed weight of 100 g was calculated.

Age and growth

- Otoliths and scales were taken from all brook trout specimens, while pectoral fin rays were taken from white suckers in Portneuf, du Dégelis and Tableau lakes.
- Sub-samples of 100 individuals of each species in Dégelis, Tableau, and northern and southern portions of Portneuf lakes were used for

determining age. A sub-sample of 50 brook trout was used at other stations.

- Sub-sampling followed the Ketchen procedure, based on size structures (Ricker, 1980).
  - All specimens of the least abundant age classes (smallest and largest specimens) were selected for age determination
  - Sub-sample was completed by random selection of fixed number within each 10-mm length class.
  - After age determination, an age-length key was used to attribute age to any specimen not classified.
- Brook trout ageing was performed in accordance with MRNFP procedures.
  - Initially, 2 independent age determinations were made for all specimens.
  - If a difference in attribution of ages was found, a second independent age determination was performed.
  - If disagreement persisted, no age was attributed to specimen concerned.
- 10% of brook trout and white sucker age determinations were validated by experts and showed a concordance of 88% for brook trout and 90% for white sucker.
- Brook trout scales from Lake Bacon were examined for the same sub-sample as otoliths to determine age determination concordance with otoliths, as age determination for reference state was only performed with scales. 88% concordance indicated reference state ages were comparable to the present study.
- The age structure was determined for brook trout and white sucker when free of abnormal cases in length-age relation.
- Mean catch age, sexual maturity age, and mortality rate were calculated.
  - Lysak method was used to determine weighted mean age at sexual maturity.
  - Annual mortality rate was estimated using catch curves.
- For growth analysis, mean lengths were determined for each age class.

Data Analysis

- Comparison with reference state was conducted for each analysis to identify changes in biological characteristics of fish populations.
- More nets were used in 2004 than 2001 for Portneuf River and Sables River. Additional nets did not significantly alter yields, therefore they were not excluded when comparing yield between two years.

Length distribution and Age

- Contingency tables were used to compare brook trout and white sucker length and age structures for each water body for reference state and this study.
- Contingency coefficient determined using Pearson chi-square, where p≤

0.05 indicated size or age structure depended on sampling year.

- Classes with <5 individuals over both years were excluded from calculations to avoid bias of statistical results.

Condition Factor Comparison

- *t* -test was used to compare condition factor of reference state and current study for given fish species in given water body.
- When data were not normally distributed after transformation, a *Kruskal-Wallis* non-parametric test was used.

Fecundity Comparison

- ANCOVA was used determine significant differences between reference state (2001) and current study (2004) for fecundity-body weight relationships of brook trout.
- Steps required to verify conditions of ANCOVA
    - Identification of abnormal values
        - Visually identified on graph
    - Linearity and significance
        - Verified using simple linear regression
    - Homogeneity of variance and normal distribution
        - Homogeneity of variance assessed visually by plotting residual versus predicted values
        - Data for fecundity-female weight log transformed to make variance homogeneous
        - Normality of distributions verified using Lilliefors test
        - Lilliefors test also applied to ANCOVA model residuals, separately for each year and each lake.
- Differences in regression lines were tested: test for homogeneity of slopes and differences in intercept values.
    - homogeneity of slopes
        - Homogeneity of slopes not tested directly with ANCOVA.
        - General linear model (GLM) used determine if slope of fecundity-female weight relationship different for 2 years sampled →

*Fecundity = constant + year + length +year*length*

        - If P>0.05 for *year*length* term then slopes of regression lines were considered similar
    - Comparison of intercepts
        - ANCOVA was used to determine differences between intercepts of 2 regression lines (when lines were parallel). If P≤0.05 for constant term, the intercept was different for the 2 years sampled.
        - Example for the fecundity - body weight regression: if homogeneity of slopes indicates lines were parallel and intercept comparison indicates a significant difference, then

regardless of length, fish always present higher fecundity in one year than in another.

Sex ratios and percentages of small individuals

- Differences in percentages of males, females and small individuals between 2 sample years were assessed using test for equality of proportions, where p-value was based on the two-sample *z* test.

Growth Comparisons

- To determine difference in mean length at age between reference state and current study a GLM was performed →

Logarithm of length = constant + age + year (2001 or 2004) + age year*

- Log transformation was applied to length to normalize the distribution.
- "*age*year"* term is growth indicator for a year. If $p<0.05$ for this term indicates mean length at age is different for 2 sampling years. When test is significant, *t* test was done to compare mean lengths at each age for 2 years sampling to determine age at which lengths differ.
- All brook trout between 1+ and 3+ selected for this analysis, except Portneuf River where individuals aged 1+ to 4+ were selected.
- For white sucker, individuals aged between 2+ and 9+ were kept for analyses in lakes Portneuf and Tableau, whereas individuals aged between 2+ and 7+ were selected in Lake Dégelis.
- This selection of individuals was necessary because there were too few individuals in certain age classes, and retaining age classes with too few individuals would cause bias in the statistical results.

Results & Discussion

Comparison of relative abundance, relative biomass, numerical yields (CPUE) and catch rate by weight (BPUE) with respect to the reference state.

- Brook trout relative abundance increased in lower Portneuf River, the Sables River and Lake Emmuraillé compared to reference state.
- White sucker benefited by decreased brook trout relative abundance in all other water bodies, including the control Tableau Lake.
- CPUE reflected same changes as relative abundance. Noted that CPUE increased nearly threefold and twofold in Sables River and Emmuraillé respectively, in comparison to reference state.
- Portneuf River, Lake Tableau (reference), Lake Portneuf and Lake Bacon exhibited greatest decreases in numerical yields, of 7.4, 10.0, 11.4 and 16.1 trout/net-day respectively.
- Brook trout relative biomass subject to same changes as relative abundance, except relative biomass decreased in Sables River
- Brook trout catch rates by weight (BPUE) follow same trend as numerical yields (CPUE), except Lake Dégelis with increase of 0.37 kg/net-day while numerical yield decreased by 1.8 trout/net-day.
- Increased white sucker relative abundance in 70% of water bodies

compared to reference state, including control lake. CPUE increased in the same water bodies, except Lake Tableau and Bacon. • Lakes Sage, Portneuf and Patien showed highest increases of 5.9, 7.2 and 30.6 suckers/net-day respectively compared to reference state. • Relative biomass increases less pronounced than relative abundance for white sucker. Increases observed in upper Portneuf River, Sables River, and lakes Bacon, Patien, Sage and Tableau (control). • Increase in catch rates by weight also observed in upper Portneuf River, Sables River, and lakes Dégelis, Emmuraillé, Patien, Sage and Tableau (control).
Assumptions
Not listed
Assessment of Validity
Not listed
Questions?

Figure 1 – Map of watershed showing the Portneuf River and location of the Compensation Lakes.

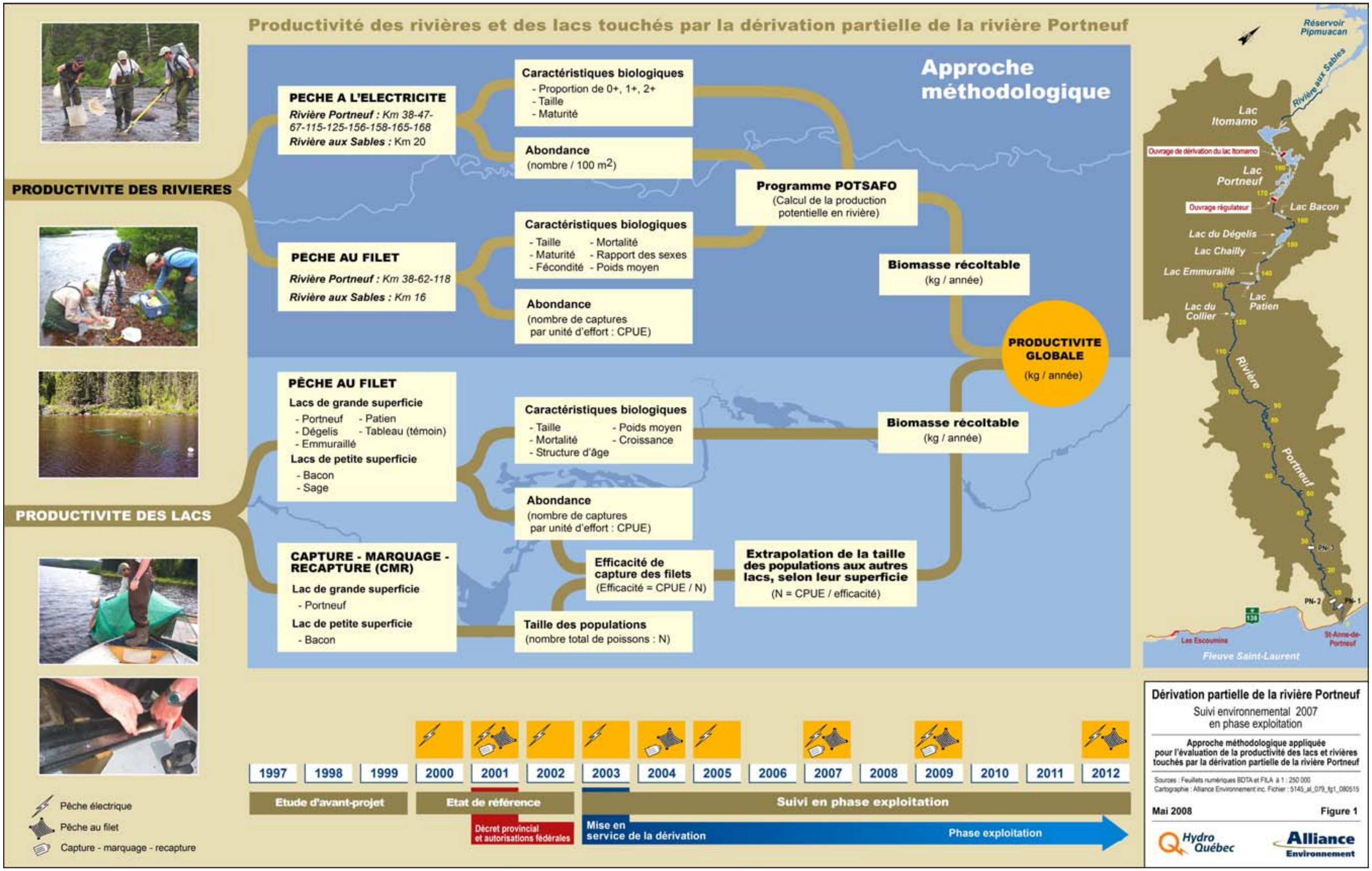

Figure 2 - Summary of the methods used for assessing harvestable biomass in the Porteuf River and lakes along the river.

4.19. Alliance Environment 2005b. Lakes (Hydro Quebec).

B
ALLIANCE ENVIRONNEMENT INC. 2005b. Partial diversion of the Portneuf River. Environmental monitoring of the operational phase, 2004. Productivity of fish populations in lakes along the course of the Portneuf River. Report submitted to Hydro-Québec. 78 p. and appendices.
System Type and Method Classification.
River and Lake. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
• General project description, map of Portneuf watershed and diagram of sampling program available in Alliance 2005a summary. • Objectives are to establish 1) abundance and density of brook trout and white sucker, 2) harvestable biomass of brook trout (maximum sustainable yield or MSY), and 3) compare these values to values the reference state. • Catch efficiency of gill nets was established once the abundance was known. This catch efficiency was then used to estimate fish abundance in lakes where no estimate existed (no CMR conducted).
Methods

<u>Stations and dates</u>
• CMR (catch mark recapture) was conducted during summer low flow in July, when brook trout circulation between fluvial and lacustrine environments was lowest.
• Multiple recapture method established by Chapman modified Schnabel (1938) and developed by Darroch (1958) was used.
• 2 lakes were selected for sampling, lakes Bacon and Portneuf.
    o Lake Portneuf used as reference for lakes with large surface areas (lakes Dégelis, Emmuraillé, Patien and Tableau),
    o Lake Bacon used as reference for Lake Sage.
• Lake Bacon was sampled during July 6 –16, 2004.
• Northern portion of Lake Portneuf was sampled during July 17–26, 2004
• Southern portion of Lake Portneuf was sampled during July 27 to August 8, 2004.
• Northern and southern portions were sampled to conduct efficient sampling of the entire Lake Portneuf.
 	
Gear and strategy
• Alaska trap nets and line fishing were used to catch brook trout and white sucker.
• A leader installed perpendicular to shore and set at centre of the opening, which was facing the bank. In some cases, the leader was moved to increase trap catch efficiency.
• Trap position was noted using a GPS and the date and time of trap setting and raising were noted.
• Traps were visited once a day and line fishing was conducted for rest of the day.
• A pair of two-way fyke nets was also installed at entrance of Lake Bacon

to identify presence of fish movement between Portneuf River and Lake Bacon, which could strongly influence the population estimate for Lake Bacon.

- Fyke net could not be installed at Lake Bacon outlet because of high velocity.
- Marking of fish was modified every three days to determine if catch probability changed over time. Changes in catch probability are indicators of change in catch vulnerability among marked fish, potentially associated with emigration or immigration.
- Fyke nets were not required in Lake Portneuf because of a fish-way present at the outlet of the lake. Monitoring of this fish-way in 2003 implied circulation between the river and the lake was negligible during the summer (July).
- Marking of fish modified every 5 days during this time (July 2003) to determine changes in catch probability. Marks were different in northern and southern portions of Lake to determine movement within the lake
- For each catch, the species, total length (nearest mm), previously marked fish (recaptures), and fish marked on the catch day was noted.
- Before marking the fish, the instruments were disinfected.
- Fish were placed in tank containing oxygen-enriched water and were redistributed over the lake's littoral zone after measurement to mix them into unmarked population.
- Fish enmeshed or found dead were measured, weighed, sexed, and sexual maturity was determined.
- Fyke net catch was treated same as those from Alaska trap nets, then released in the direction of their destination. Only fish entering the lake were marked.
- Fish caught by line fishing were treated same as those from Alaska trap net catches.
- In total, 6 Alaska trap nets and 2 fyke nets were installed in Lake Bacon and 24 trap nets (12 in each portion) were installed in Lake Portneuf.
- Effort for entire sampling duration was
    - 60 trap-days and 15 hours of line fishing in Lake Bacon
    - 108 trap-days and 24 hours of line fishing in the northern portion of Lake Portneuf
    - 144 trap-days in the southern portion of Lake Portneuf, (total of 252 trap-days and 24 hours of line fishing in Lake Portneuf)

Density and abundance estimates

- Schnabel method (modified by Chapman) was used to calculate abundance of brook trout and white sucker populations in lakes Bacon and Portneuf.
- Described by following formula:

$$N = \frac{\Sigma\,(C_t \cdot M_t)}{\Sigma(R_t + 1)}$$

- where N = population abundance estimate, Ct = number of fish catches, Mt = number marked during previous samplings, and Rt = number recaptured, all at time t (Ricker, 1980).
- Confidence interval obtained from R considered as Poisson variable
- The following conditions were required for a reliable assessment of the population (Ricker, 1980):
    1. Population studied is closed;
    2. Marking does not affect catch probability or mortality rate;
    3. Fish do not lose their marks;
    4. Marks are easily identifiable;
    5. Marked fish randomly mixed in the population after release.
- To determine if conditions were met, cumulative population estimate was calculated each day. If estimate became stable over time, then population is closed, but if it increased the population may be considered open.
- Population estimates for brook trout and white sucker in Lake Bacon, and for white sucker in Lake Portneuf increased steadily over time, despite a narrow confidence limit. This indicated violations of conditions (1, 2 and/or 5).
- Fyke nets at Lake Bacon inlet indicated that populations were open. Only a portion of fish movement was recorded by fyke nets, as they do not block the entire immigration and no fyke nets could be installed at outlet.
- Final estimates for brook trout in Lake Portneuf were valid as conditions appear to have been met (cumulative estimates stable over time).
- 1% marked brook trout and white sucker from northern portion moved to southern portion of Lake Portneuf, with very limited influence on abundance estimate.
- Population estimate of white sucker in northern and southern portions of Lake Portneuf increased over time, which may indicate marked fish less likely to be caught than unmarked fish.
- Sampling study was conducted continuously over a short period, meaning other methods to determine population estimate could not be used (eg. Bailey's, Jolly-Seber's)
- Assuming fish behaviour did not change during the study, the initial population abundance was estimated using simple linear regression of Schnabel cumulative estimates, which increased in linear fashion.
- All white suckers under 120 mm (ages 0+ and 1+) were excluded from estimate calculations in Lake Bacon and Lake Portneuf because of insufficient recaptures (potentially due to effects of marking).

Density estimate in other lakes

- Brook trout and white sucker density in lakes Portneuf and Bacon were used to establish catchability of nets, allowing calculation of densities in the other lakes studied.
- Following equation associated fish population density with net fishing:

$$N = \frac{CPUE}{q}$$

- Where N = population density (# of fish per hectare), $CPUE$ = # fish caught per unit of effort (ie. net-day), and q = catchability of experimental nets.
- Population abundance was obtained by multiplying fish density (number/ha) by the lake's surface area.
- Catchability of nets was different in lakes Portneuf and Bacon, thus it was decided to attribute mean catchability obtained in Lake Portneuf to lakes Dégelis, Emmuraillé, Patien and Tableau (lakes with a large surface area).
- Catchability of Lake Bacon was applied to Lake Sage (lake with a small surface area).
- CPUE for lakes was adjusted by excluding all white suckers under 120 mm.
- Estimated population abundance corresponds to brook trout population ages1+ to 4+ and white suckers ages 2+ to 11+
- Catchability of net fishing determined in this study was applied to CPUE for 2001, to assess population densities prior to the diversion (i.e. reference state).
- Same methodology was applied to adjustment of CPUE for white sucker.

Biomass and MSY assessment

- MSY (max sustainable yield or 'harvestable biomass') was estimated using the Cadina method (*in* Troadec, 1977), modification of Gulland method (1971), which is applicable to exploited populations.
- Equation is →

$$MSY = 0.5 \cdot Z \cdot B_{mean}$$

- where Z = total instantaneous mortality, and B_{mean} = mean annual biomass.
- Z was calculated using the curve of natural log of number catches by age (Ricker, 1980), where age was determined for fish caught by net fishing.
- Mean annual biomass was calculated from the population abundance estimate obtained from CMR campaign.
- Estimated total number of fish was divided among age classes of harvestable size, (from 1+ to 4+ for brook trout).
- This distribution was based on total instantaneous mortality rate according to following equation →

$$Nt = No \cdot e^{(-Z \cdot t)}$$

- where Nt = # survivors of cohort at age t, No = # of individuals at age 0, t = age in years, Z = total instantaneous mortality rate.
- To determine proportion of individuals in each age class, arbitrary value of 100 individuals assigned to No. The proportion applicable to each age class was used to determine the number of fish in each age class based on the population abundance estimate.
- Mean annual biomass (biomass in July, for this study) was calculated using mean weight associated with mean length for each age class.
- Mean weight was determined from the length-weight relationship of fish caught during net fishing.
- Mean length-at-age was established using age readings taken from fish

caught during net fishing.

- Total biomass each age class was calculated by multiplying the number of fish in the age class by the mean weight (kg) of said class.
- 0.5 yr was added to the variable *t* for all age classes to account for growth over the year.

Results & Discussion

Density and abundance estimates Bacon and Portneuf

- Population estimates were based on Schnabel method in Lake Bacon and Lake Portneuf.
- Where Schnabel population estimates did not reach a plateau, regression lines were added along with the confidence interval.
- Table 1 presents results based on 1) Schnabel method for brook trout in Lake Portneuf and 2) on modified Schnabel for brook trout and white sucker in Lake Bacon and sucker in Lake Portneuf.
- Density estimates for Lake Bacon were about 2 times higher then Lake Portneuf for brook trout and 4 times higher for white sucker.
- Density estimate for brook trout and white sucker were higher in the southern portion of Lake Portneuf compared with northern portion.
- Catchability of net fisheries also differed between the 2 lakes.

Density estimates in other lakes

- Brook trout density highest to lowest - Lake Bacon (38.93 trout/ha), Lake Sage (25.16 trout/ha), Lake Emmuraillé (20.50 trout/ha). Similar densities were observed between Lake Dégelis (19.60 trout/ha) and Lake Portneuf (14.52 and 19.38 trout/ha) and between Patien (12.47 trout/ha) and Tableau (12.38 trout/ha)
- White sucker density – Highest in Lake Sage (83.70 suckers/ha) and Lake Bacon (42.17 suckers/ha). Lowest density was control LakeTableau (6.11 suckers/ha). Density in other water bodies ranged from 10.59 to 16.99 suckers/ha.

MSY assessment

- Highest MSY observed in southern (505 kg/yr) and northern (327.2 kg/yr) portions of Lake Portneuf
- Lowest MSY observed in Lake Sage (5.9 kg/yr).
- MSY of 18.56 to 53.86 kg/yr calculated for small surface area lakes (ie, Bacon, Sage and Patien) approached MSY calculated for compensating lakes with similar surface area (ie Larose and Belle-Isles).

Density and MSY compared to reference state

- Brook trout density
    - o Lake Portneuf, Lake Bacon and Lake Tableau (control) were significantly lower than the reference state.
    - o Lake Emmuraillé significantly higher than the reference state.
    - o Lakes Dégelis, Patien and Sage remained similar to the reference state.
- Brook trout remained the most important species in Portneuf and Dégelis.

- Lake Bacon was dominated by brook trout at the reference state, but now was dominated by white sucker.
- A significant increase in white sucker density was observed in northern Lake Portneuf and Lake Sage. In all the other water bodies, white sucker density remained similar to the reference state.
- Brook trout MSY declined in southern Lake Portneuf, Bacon, Sage and Tableau (control), but significantly increased in lakes Dégelis and Emmuraillé
- Total brook trout MSY in study lakes does not significantly differ between the reference state (1,254 kg/yr) and this study (1,295 kg/yr).
- The control lake (Tableau) showed significant decrease of 34% in harvestable biomass (MSY) of brook trout compared to reference state.
- The project does not appear to have had a significant effect on brook trout or white sucker populations because 1) significant changes were also observed in the control lake and/or 2) uneven changes were observed for various water bodies.
- MSY should be 3017kg/yr in lakes studied if using Valin method, based on impact study by Hydro-Québec (2000).
- When results were compared to the reference state, MSY using Valin method overestimated yield calculated from the biomass estimates by 76% to 904% depending on the lake.
- It is necessary to review requirements for maintaining brook trout production (as stipulated by the province of Québec), since the overall value of 9,729 kg/yr for lakes and rivers combined does not correspond to the reference state and is not realistic.
- MSY estimates calculated for the river using POTSAFO method and for lakes during this study indicate that all values used for impact study were overestimated.

Assumptions

- Assuming fish behaviour did not change during study

Assessment of Validity

Not listed

Questions?

Table 1: Results from fish population abundance estimates, including the 95% confidence interval, for Lakes Bacon and Portneuf.

Lake	Species	Abundance estimate (number of fish)	Density estimate (number/ha)	Efficiency of capture by net [F]
Bacon[A]	Brook trout	1 842 (1 614 to 2 069) [E]	38.93 (34.13 to 43.74)	1.01 (1.16 to 0.89)
	White sucker [D]	1 995 (1 775 to 2 214)	42.17 (37.53 to 46.81)	0.38 (0.42 to 0.34)
Portneuf – north portion [B]	Brook trout	13 196 (12 491 to 13 837)	14.52 (13.75 to 15.23)	2.36 (2.49 to 2.25)
	White sucker [D]	9 622 (8 758 to 10 487)	10.59 (9.64 to 11.54)	3.92 (4.30 to 3.59)

Portneuf – south portion[C]	Brook trout	18 427 (17 505 to 19 272)	19.38 (18.40 to 20.27)	1.63 (1.72 to 1.56)
	White sucker [D]	14 245 (9 523 to 18 968)	14.98 (10.01 to 19.95)	2.61 (3.92 to 1.95)

A Area of 47.3 ha.
B Area of 908.6 ha.
C Area of 951.0 ha.
D Excluding individuals less than 120 mm (aged 0 and 1+).
E In parenthesis: 95% confidence interval.
F Efficiency of of capture defined as the number of fish per net (CPUE) divided by the density of fish per hectare.

4.20. Alliance Environment 2006. –Rivers (Hydro Québec).

Alliance Environment Inc. 2006. Partial diversion of the Portneuf River. Environmental monitoring of the operational phase, 2005. Report submitted to Hydro-Québec. 62 p. and appendices.

System Type and Method Classification

Rivers and Lakes. Predictive – fish production.

- General project description, map of Portneuf watershed and diagram of sampling program available in Alliance 2005a summary.
- Partial Diversion of the Portneuf River
- Objectives were to 1) describe the evolution of juvenile fish densities and biological characteristics of brook trout in the Portneuf and Sables Rivers and select tributaries using electrofishing; and 2) Assess brook trout productivity in these rivers.

Methods

- Productivity assessment of the entire watershed of Portneuf and Sables rivers combines productivity of lakes and sections of the rivers. Electrofishing was the only method used in 2005, while other sampling methods were also employed in previous years.

Stations and dates

- Electrofishing was conducted during summer low flow using MRNFQ's standard methodology for assessing juvenile salmonid density (Caron and Ouellet 1986; Lachance and Bérubé 1999a).
- 2005 sampling was conducted from July 19 to August 1 (same as in 2001, 2002, and 2003).
- 9 fishing stations in Portneuf River in 2002 and 2003 were surveyed again in 2005. Stations were distributed in homogenous sections (section 2, 4, 5). Canyon area (section 3) was not sampled due to limited access and fishing sites. Section 1 was not sampled due to its remoteness from the flow closure point and it is not significantly affected by project impacts.
- Stations were surveyed at 2 tributaries (P5 and P6) in the first 500m from the mouth as they are used by brook trout for spawning and rearing. P6 had habitat improvements built in 2003.
- 1 station was selected in Sables River located between Lake Itomamo and Pipmuacan reservoirs, and was only accessible by helicopter.
- At each station electrofishing was carried out in several standard size ($100m^2$) plots.

- 6 plots per station in Portneuf River were sampled for a total of 54 plots. 28 plots were established in Sables River, 6 plots in tributary P5, and 4 plots in tributary P6.
- With the exception of P6 (where 2 plots were visited in 2002 and none 2003), all plots were surveyed the same as in 2002 and 2003.
- 2 plots were moved in 2005 as water levels too low compared to previous years, and moved a maximum of 100m upstream or downstream and were selected based on comparable habitat.
- Plots were located along a riverbank or island shore and measured 20m long by 5m wide for maximum bank coverage.
- Plots were distributed in stream environments (rapids or sill) and lentic environments (meander, pool, channel) to cover available types of rearing habitats and were representative of flow conditions at each station.
- 18 additional plots were surveyed in Portneuf River in 2005 (2 per station) at distance 5m from riverbank, positioned adjacent or near riverbank plots to compare densities in the river centre. Habitat quality for juvenile brook trout was documented in each plot. River centre plots had to contain minimum number of shelters, thus 100% sand or gravel sites or sites lacking woody shelter/aquatic vegetation were excluded.
- Total of 111 plots were surveyed in 2005 (93 riverbank and 18 river centre).
- 3 closed plots were sampled, while the rest were open plots.
- Closed plots made it possible to assess capture efficiency to determine a correction factor, which was applied to all results from open plots to estimate total number of fish present.

Gear and sampling strategy

- Electrofishing performed with portable device, direct current ≈150W applied with varying voltage depending on conditions
- 3 crew members were present, 1 to operate device and 2 to collect fish with kick nets.
- Electrofishing was only performed where velocity <1.0m/s and maximum depth <100cm.
- Closed plots with 3 sweeps of electrofishing, with ~20 minutes between sweeps. A single sweep was performed in open plots.
- Number of catches in closed plots should ideally diminish from 1 sweep to the next. Fine-mesh seine nets (10 x 10mm) were used to contain closed plots, with rocks placed bottom of seine prevent escapement.
- Sweeps were conducted from downstream to upstream, ensuring coverage entire $100m^2$. Attention was paid to areas below riparian shrub cover, logs, and rocks to target preferred shelter for juvenile trout.
- Each sweep was fixed to 20 to 30 minutes depending on quantity of shelter to ensure comparable fishing effort.
- Catches were identified by species and counted. For brook trout, total length was measured (nearest mm). If >75mm, the fish was sacrificed and taken to lab to identify sex and maturity. Sacrificed fish had otoliths removed to determine age. If <75mm, brook trout were released, except for 9 individuals to remove otoliths for ageing.

- Each plot was characterised using following parameters: flow type (stream or lentic), % cover of substrate based on particle size, average depth (nearest cm) taken from 4 corners and centre, velocity at 60% height of water column using current-meter, % aquatic and riparian vegetation cover, % woody debris cover, and water temperature.
- Each plot was GPSed to ensure surveys were carried out in same locations. Visual cues on riverbank were installed along the length of each plot.
- Age readings for brook trout >75mm using MRNFQ procedures. Only otoliths were used in 2005 as they are easier to determine age than with scales.

Fish density assessment

- Total number of fish in closed plots was assessed using the Zippin method (1958).
- Based on results obtained in each sweep of closed plots, a fish catch probability was established. Using catch probability allows estimate of proportion of population caught and total number of fish in the plot by using formulas →

Proportion population caught = (1-(1-catch probability)$^{N\ sweeps}$)
Total # estimate (Zippin) = N Total of catches / proportion of the population caught

- Catch probability was calculated using Armour et al. (1983) equations; Zippin equations (1958) were used to calculate population estimate and standard deviation of this estimate.
- Based on results of each plot, it was possible to assess capture efficiency by calculating ratio number of individuals caught in the first sweep compared to total number estimated using Zippin method →

Capture efficiency = N catch on 1st sweep / N Total estimate (Zippin)

- Mean capture efficiency for all closed plots was used to assess total # fish present in open plots →

N Total estimate = N caught in open plot / mean capture efficiency of closed plots

- Results were expressed in terms of density (total # fish / 100m^2)
- Statistical analyses (Systat 11.0) were carried out to compare mean brook trout densities in 2005 with 2000, 2001, 2002, and 2003 data. Comparisons were made by watercourse and habitat type. Multiyear comparisons were carried out between sections (2,4,5) in Portneuf River.
- Analyses were repeated for other fish species.
- Multiyear comparisons took into account all fish stations, except where stations were not surveyed every year.
- Within year (2005) brook trout densities were compared between watercourse, habitat type, and (Portneuf only) upper and lower reaches
- Analyses were performed using parametric (ANOVA followed by Tukey multiple comparison) or non-parametric (Kruskal-Wallis followed by Tukey-

Kramer multiple comparison) depending on if values met criteria for normality (Lilliefors test) and homogeneity of variance (Levene test)

River productivity & POTSAFO method

- POTSAFO software was used to assess brook trout productivity.
- This program (developed by MRNFQ) is based on the biological characteristics specific to brook trout populations to estimate their productive capacity.
- Model parameters are juvenile mean density by habitat type (stream vs lentic), proportion of 0+ and 1+ in catches, proportion of mature females per age group, mean weight of mature females, sex ratio, and natural mortality per age group. Calculations are summarized by the following equations→
    1. Habitat surface area x juvenile mean density = total # juvenile
    2. Total # juvenile x proportion 0+ and 1+ = total # 0+ and 1+
    3. Total # 0+ and 1+ / survival rate from egg = Total # eggs required
    4. Total # eggs required / # eggs per reproducer = # reproducers required
    5. Total # eggs x integrated survival rate = total adult production
    6. (Total adult production – # reproducers required) x mean weight = harvestable biomass

Rationale for parameters

- Juvenile densities and proportions 0+ and 1+ were determined by electrofishing in 2005.
- % mature females per age group was calculated by combining results of net fishing carried out 2004 (Portneuf river stations only) and 2005 electrofishing.
- Values of other parameters were derived from net fishing conducted in 2004. The method improves representation as net fishing had greater proportion of individuals age 2+, while electrofishing had virtually none.

Density of juveniles

- Juvenile densities in each section of Portneuf were used as they better reflect local variations in abundance.
- Values obtained in homogenous section 2 were extrapolated to adjacent sections (1 and 3) as the latter were not electrofished. Assumed based on field observations, section 2 better represented section 1 and 3 juvenile densities than sections 4 and 5 would have.
- Section 3 corresponds to canyon with supercritical flow and low brook trout densities as a result.
- Section 1 contained successive impassable obstacles and potential competitor species that limit brook trout.

Proportion 0+ and 1+

- Determined from examination size structure obtained at each station and age readings carried out during the study. 0+ group collected in 2005 corresponds to individuals <70mm length, whereas 1+ group ranged from 70 to 130mm.

Proportion of females per age group

- Difficult to assess, so used 2 scenarios. First scenario (comparable to results in Montmorency river) = 0% mature females at 1 of age, 75% at age 2, 95% at age 3, and 100% at age 4. Second scenario based on recent results (2004 and 2005) indicate later maturity of fish = 3% mature females at age 1, 70% at age 2, 88% at age 3, 100% age 4
- Lowered maturity at ages 2 and 3 was explained by smaller size of 0+ and 1+ noted during electrofishing, as slower growth causes delayed sexual maturity.

Mean weight of mature females and sex ratio

- Assessed only by net fishing in 2004. Electrofished specimens were not considered due to low yield of age 2 and older individuals, which would underestimate mean weight of mature females.
- Similarly, sex ratio from electrofishing appeared to be unbalanced and not constant over the years.

Fecundity

- Derived from egg counts from females caught in Portneuf (n=31) and Sables (n=43) rivers in 2004 and were very similar to females caught in Portneuf, Degelis, and Table lakes in the same year.

Natural mortality by age group

- Default values from Montmorency River consider valid for use in this system, as parameters are difficult to assess.

Results & Discussion

- Potential harvest in 2005 was similar to 2003 but lower than 2002, despite significant juvenile densities in 2005. This is explained by the later maturity scenario than in previous years, which induces reduced adult production.
- There was also a significant drop in mean mass of females which reduces egg production in the population.
- Nevertheless, the harvestable biomass in 2005 remains comparable to that assessed for the reference state (2000 to 2002).
- Overall productivity of Portneuf River assessed for first 3 years of operational phase monitoring (2003 to 2005 – 3346 to 4002 kg/yr) was similar to the 3 reference years (2000 to 2002 – 2844 to 4635 kg/yr).
- The harvestable biomass assessed during the impact assessment was well above that measured during reference state, because the draft design was based on theoretical yield values applied to quality of rearing habitat, which overestimated harvestable biomass.
- The overestimate was explained by an abundance of competing species not accounted for in Portneuf River.
- Reference state harvestable biomass values were more realistic than theoretical values assessed in the draft design and will be used as comparative basis for entire operational monitoring program.

Assumptions

- Assumed most juvenile brook trout were found in the first 5m of width from edge of riverbank based on survey work in Sault aux Cochons River in

2001, which showed 90% caught <2.5m from riverbank compared to 10% caught between 2.5 and 5m from riverbank.

- This study showed 80% individuals were caught within first 5m, which was significantly higher than the centre of river.
- Brook trout productivity calculated using 5m wide riparian strip along each bank, total width of 10m for both banks. Furthermore, a correction factor of 10% was applied to juvenile densities during electrofishing to account for possible underestimate since centre of river habitat was not considered.
- Mean juvenile densities recorded increased by 10% when applying POTSAFO.
- Number of harvestable adult individuals (age 2+) per year was converted to harvestable biomass (kg/yr) by applying mean weight of 80g for Portneuf and 60g for Sables River based on 2004 fish netting data. Age 2+ was selected as it corresponds to the population segment taken by sport fishers.

Assessment of Validity

- Not listed

References

ARMOUR, C.L., K.P. BURNHAM et W.S. PLATTS. 1983. *Field methods and statistical analyses for monitoring small salmonid streams.* U.S. Fish Wildl. Serv. FWS/OBS-83/33. 200 p.

CARON F. et G. OUELLET. 1986. *Méthodologie d'inventaire des saumons juvéniles au Québec*. Ministère du Loisir, de la Chasse et de la Pêche, Direction faune aquatique. Non paginé.

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ZIPPIN, C. 1958. *The removal method of population estimation*. Journal of Wildlife Management, 22 (1) : 82-90.

Questions?

- Q: Productive capacity is used as a term for brook trout production, not a measure of the habitat's natural maximum production of all fish species present. Could this method and data collected be used to assess total fish production on a per habitat basis over time? A: There was some confusion and lack of consistency among agencies on the terminology used. Depending on the documents, we were asked to measure brook trout productivity, harvestable biomass, potential production, etc. What was measured actually is harvestable biomass pre and post diversion, given the current trout biomass and population dynamic.
- Q: Why was 10% decided as an appropriate correction factor? A: This correction factor was added after a request from the provincial agency, to take into account habitat not sampled in the centre of the river.
- Q: Why decide on brook trout alone as an indicator of overall river productivity? A: This is what is requested from both provincial and federal authorization.

4.21. Larose et al. 2006. – Lakes (Hydro Québec).

Larose, M., Belles-Isles, M., and Bérubé, A. 2006. Partial diversion of the Portneuf and Sault aux Cochons rivers – Environmental monitoring of the operational phase, 2005 – Compensation of brook trout habitat in lakes. Report submitted to Hydro-Québec by GENIVAR. 135 pages + appendices
System Type and Method Classification
Lakes. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
• General project description, map of Portneuf watershed and diagram of sampling program available in Alliance 2005a summary. • This study reveals the first year of monitoring of compensation lakes following establishment of reference state in 2003 and 2004. • Main objectives were to 1) gather recreational fishing data to establish history of exploitation, 2) monitor changes in fish populations with respect to the reference state to establish relationship between biomass and indices of abundance (CPUE and BPUE), 3) monitor effectiveness of habitat enhancements and characterize spawning habitat, and 4) monitor use of enhanced habitat for fry rearing and breeding
Methods
• In 2003 and 2004 Hydro Quebec carried out habitat enhancement and brook trout stocking in lakes Isolète, Castle, Piper, Brume, Bouchard and Travers to compensate for habitat loss caused by partial diversion of Portneuf and Sault-aux-Cochons rivers. *Recreational Fish Monitoring* • Recreational fishing data were collected in 2005 by outfitters (Isoète, Bouchard, Travers lakes), by the manager of Forestville ZEC (Castle, Piper, Brume lakes), and by vacationers at Lake Brume. • Protocol, tally sheet, weigh scale, and measuring board were provided and a GENIVAR technician explained objectives and procedures for data collection to the people involved. • Three more visits by the technician were conducted through the summer to remind participants of objectives and procedures. • Baseline fishing data previous 2003 taken from usual monitoring conducted by managers of ZECs and outfitters. *Recreational Fishing Data* • Historical fishing data were analyzed using Schaefer (1954) and Fox (1970) models. • These models were used to predict long-term potential yield (MSY), where total annual effort data were plotted on x –axis and corresponding success plotted on y-axis. Slope and y intercept of the least squares regression were used to solve model equations. • Schaefer model→ **$MSY = -0.25 \cdot a^2/b$** Where: a = y-intercept, b = slope of regression of

success on effort

- Fox model →

$$\mathbf{MSY = -(1/d)\cdot e^{(c-1)}}$$

Where c = y-intercept; d = slope of line of Ln (success) as function of effort

Monitoring change in brook trout populations

- Reference state data collection carried was out in 2003 and 2004 using 2 methods: 1) Experimental gill nets to determine the main characteristics of population dynamics and, 2) catch-mark-recapture (CMR) using different gear types (Alaska trap net, floating trap net, fyke net) to determine abundance in different lakes.
- Traps were used for the CMR as this study necessitates low mortality caused by gear.
- Experimental gill nets were used because of their greater effectiveness in lakes and population dynamic studies require a large number of specimens.
- Post-reference (i.e. post-stocking) data collection in 2005 used Alaska trap nets only as significant mortality (potentially caused by other gear types) would influence future abundance results and because these nets provided better yield than other trap types used in 2003-2004.
- 2005 sampling was conducted to 1) determine population abundance 2 years following the habitat enhancements and 2) verify whether a relationship existed that would allow CPUE to predict future abundance or density.
- Although 2005 study did not specifically sample for population dynamics, certain data were used to refine the values obtained in 2003-2004.

Gear and effort

- Fishing was conducted in July and August.
- Alaska trap nets were fitted with 2 wings and square opening (2.4m x 2.4m) with cylindrical body held open by 2 aluminium hoops (1m and 0.75m diameter). Total gear length was 7m and each wing was 15m long. 6mm mesh for trap and wings.
- Effort = 40 trap days, with 8 nets set for 5 days in each water body.
- Nets were positioned close to shore at depth between 0 and 3m.

Capture and Marking

Trap nets were raised and specimens identified by species, counted, measured (total length) and marked with an adipose clip.

- Number of recaptured specimens was noted for each trap.
- Scales were collected for aging of 50 unmarked specimens.
- Individuals were released at random in different locations around lake so they evenly mixed into population.
- Dead or dying fish were measured and weighed.

Processing and analysis of data

Yield-abundance relationship

- relationship for trap fishing yield and number of fish and relationship for trap fishing yield and trout density were calculated for each water body.
- Trap fishing yield was expressed as number of catches/trap day, adjusted

to 24hour trap-day.

- Relationship between fishing yield and abundance or density were determined via linear regression.

Biology

- average age of catches was based on mean age of specimens sampled.
- Growth in length was estimated using an age-based length curve
- *Von Bertalanffy's* equation was used to describe curve:

$$L_t = L_\infty(1-e^{-k(t-t0)})$$

Where L_t = total length at time (t) corresponding to age in years; L_∞ = maximum theoretical length of fish if mortality were null; k = Brody growth coefficient=Walford slope, which is the rate that speed of growth decreases with age; t_0 = theoretical age at null length

- These calculations were carried out with back calculations of length using scales of captured specimens using VoNBIT software.
- *Instantaneous mortality (Z)* calculated from Ricker (1980) curve for catches, which corresponds to the slope of relationship between natural log of catches and age of catches.
- Total Z as determined based on total of all catches. To estimate age of all captured individuals, an age length key was devised for Castle, Piper, Brume, Bouchard, and Travers lakes.
- Age groups considered for total mortality were 2+ to 6+ for Isoète, 1+ to 6+ for Brume, 1+ to 4+ for Castle and Travers, and 2+ to 5+ for Piper and Bouchard.
- *Instantaneous natural mortality (M)* determined by 2 theoretical methods based on population parameters. Mean mortality of 2 methods was used as an assessment of natural mortality.
- Method 1 → auximetric plot of mortality as function of L_∞. Relationship of mortality vs. L_∞ was established from 43 salmonid populations in the FishBase data base, where these parameters were found.
- Method 2 → Quinn and Deriso (1999) model. Derived from the fact that natural mortality is inversely related to longevity.

Population equilibrium index

- Relative Stock Density (RSD) and Proportional Stock Density (PSD) population equilibrium indices permitted distribution of captured specimens according to standardized length class intervals.
- Quantitative descriptors of length frequencies allow the comparison of size structure of different populations of same species.
- PSD equation →

$$PSD = [(n\ catches \geq 250mm) / (n\ catches \geq 150mm)] \times 100$$

- RSD equation →

$$RSD = [(n\ catch\ per\ class) / (n\ total\ catch)] \times 100$$

Evaluation of abundance, biomass, and MSY

Fish Count

- Schnabel (1938) equation modified by Chapman (1952) was used to estimate the population of each lake.

- Used for population estimates in lakes with closed populations and permits some violation of basic conditions, particularly with respect to catchability.
- Schnabel-Chapman equation →

  $$N = \Sigma(C_tM_t)/(R+1)$$

  Where N = number of individuals in population; Ct = number fish caught during day of fishing; Mt = number fish marked and present in lake; R total number of fish recaptured since start of fishing
- Confidence interval was calculated for 1/N since its distribution is more symmetrical
- Thus variance of 1/N →

  $$Var(1/N) = R / (C_tM_t)^2$$

- Then confidence interval of 1/N obtained→

  $$C.I.(1/N) = 1/N \pm [1.96 \times \sqrt{Var(1/N)}]$$

- Then confidence interval of N calculated →

  $$C.I. (N) = [1 / L.C.I (1/N), 1 / U.C.I (1/N)]$$

- Number of dead fish in fishing gear, those recorded for recreational fishing, and estimate of natural mortality for 5 fishing days were added to the population estimate.
- Fishing gear mortality was derived from fishery statistics.
- Evaluation of number of captured specimens subject to natural mortality was based on following equations →

  $$N_5 = N_1e^{-M\cdot t}$$

  Where N_5 = number fish on day 5 of fishing; N_1 = number of fish on day 1 of fishing; M = instantaneous natural mortality; t =time (year)

Biomass and MSY

- MSY (or harvestable biomass) was estimated based on Cadima method (1977), which is modified from Gulland method (1971) and is applicable to exploited populations.
- Cadima equation →

  $$MSY = 0.5 \times Z \times B_{av}$$

  Where Z = total instantaneous mortality; B_{av} average annual biomass
- Average annual biomass was based on results of the CMR count according to the Schnabel method.
- Total number of fish broken down into different age groups was based on total instantaneous mortality according to the equation →

  $$N_t = N_0e^{-Z\cdot t}$$

  Where N_t = number of cohort survivors at age t; N_0 = number of individuals aged 0; t = age in years; Z total instantaneous mortality
- Assuming an arbitrary value of 100 individuals at N_0, the proportion applicable to each cohort was applied to the total number of individuals in the lake to determine representatives of each age group at time of fishing.
- Age group breakdown allows the calculation of biomass by applying an

average length determined by Von Bertalanffy growth curve to each individual in each group. The mass was determined for each individual based on this length using mass-length relationship established by experimental catches from 2003-2004.

- Average annual biomass was determined to be biomass present in lake at beginning of year, after recruitment of individuals from 1+ cohort at the start of summer.
- Average annual biomass was calculated based on biomass results at time of fishing and by determining (for each cohort) the number of individuals that should be present in the population at the beginning of year, which was based on the total instantaneous mortality rate.
- Average size of individuals for each class (at beginning or end of year, as applicable) was determined using Von Bertalanffy growth curve and individual mass attributed using length-weight relationship.
- To verify MSY variability, lower and upper intervals calculated by taking confidence limits established by Schnabel method as total number of individuals

Effectiveness of enhanced habitat and spawning habitat characterization

- Monitoring the integrity of enhanced habitat and characterization of spawning habitat were conducted in fall, shortly after brook trout breeding.
- To verify the integrity of enhanced habitat, the structures built in 2003 were visited to describe general condition, presence of erosion, and their accessibility to fish.
- Spawning sites were characterized by % cover of various particle sizes, substrate condition, depth, flow velocity, surface area.
- Surface areas of measured spawning sites match areas dominated by gravel, which were areas of high potential for brook trout breeding.
- Zones with high deposition of fines were subtracted from surface area measurement.
- Description of cover for various particle sizes applies to the entire enhanced surface area, including sedimentation zones where applicable.

Use of enhanced habitats

Method 1

- Fry sampling was conducted by electrofishing (open stations and variable surface area) at enhanced reaches of tributaries to lake Isoète, Castle, Piper, Brume, and Travers.
- Specimens were identified, measured, counted, and released at site.
- In lakes, near shore sampling was conducted with seines at enhanced sites.
- Inventories were semi-quantitative to evaluate site for brook trout use, but not for density.

Method 2

- Count of brook trout redds after spawning at enhanced sites.
- In streams the inventory was conducted on foot and in lakes, by diving.
- Number of redds observed, number of redds sampled for eggs, and number containing eggs were noted.
- Kick net was used to verify the presence of eggs when redds were difficult

to detect. Surface area was sampled and the number eggs were recorded when the kick net was used.

Results & Discussion

Evaluation of biomass, abundance, MSY

Fish population estimate in Lakes

- 1830 fish were caught from 6 water bodies in CMR study.
- Of total 1332 marked brook trout, 438 were recaptured, representing 32.9% recapture rate.
- Recapture rate, which was 2 to 4 times higher than 2003 and 2004, allowed fairly precise evaluation of number of fish in most lakes, despite 5 day effort compared to 10 day effort in previous years.
- Despite high overall recapture rate, Bouchard and Castle lakes showed recapture rates too low to predict population abundance from Schnabel equation.
- High water temperature likely affected the success of catches.
- Abundance of brook trout using Schnabel method corresponds to individuals vulnerable to trap net.
- This size equates to individuals 1+ in age, thus evaluation was representative of real number of fish 1+ and older in the lakes.

Adjustment for mortality

- Unadjusted result from Schnabel method was corrected to reflect mortality during 5 day CMR study (from traps, sport fishing, and natural).

Evaluation of biomass

- Lake Isoète MSY estimated at 1.49 kg/ha/yr using Cadima equation based on biomass present in lake, which was higher than Schaefer (0.89kg/ha/yr) and Fox (0.65 kg/ha/yr) methods based on historical fishing data
- Cadima method was more representative as was based on 2005 biomass, where Schaefer and Fox were based on recreational fishing data (some of which was collected prior to enhancement of spawning areas in 2003).
- Increased reproductive success through enhancement of spawning habitats along with stocking permitted more significant recruitment, altered population dynamics, increased biomass, and ultimately higher MSY.
- Schaefer and Fox methods were strongly influenced by fishing yields prior to habitat enhancements.
- MSY calculated from 2005 abundance estimates was influenced by stocking in 2004, but that influence will diminish in years to come.
- Recreational fishing yield in 2005 was 1.06 kg/ha/yr; given MSY of 1.49 kg/ha/yr the water body does not appear to have been exploited beyond its productive capacity.
- Castle Lake MSY was not determined in 2005 due to insufficient recaptures for CMR-Schnabel method, nor for Schaefer or Fox methods due to limited recreational fishing data.
- Piper Lake MSY = 4.25 kg/ha/yr, though no estimate could be made for

Schaefer or Fox methods due to limited recreational fishing data. Current recreational fishing yield is 0.64 kg/ha/yr, which is clearly lower than MSY.

- Brume lake MSY estimated 0.63 kg/ha/yr, which was double 2003 estimate. MSY similar to Schaefer method (0.64 kg/ha/yr), but larger than Fox method (0.48 kg/ha/yr) based on fishing statistics. Current fishing yield was 0.24 kg/ha/yr, which means that water body was not exploited beyond its productive capacity. Note that individuals captured in trap nets were generally smaller and less vulnerable to recreational fishing.
- Lake Bouchard MSY estimated at 1.17kg/ha/yr, where it was 0.73kg/ha/yr in 2004. 2005 MSY may be influenced by 2004 stocking. Schaefer and Fox methods could not be calculated. Therefore, it appears fishing exceeds natural productive capacity and that further fishing would deteriorate unless stocking and habitat improvement program continues.
- Travers Lake MSY estimated at 1.35kg/ha/yr represents threefold increase over value for 2003. Value was also higher than Schaefer (0.62 kg/ha/yr) and Fox (0.43 kg/ha/yr) methods. 2005 recreational fishing yield was 0.78kg/ha/yr, so water body was not exploited beyond productive capacity.

Relationship between yield and abundance/density

- Relationship of trap net fishing (CPUE) and number of fish present in lake and between CPUE and density of lake fish had low r^2 values (0.11)
- CPUEs vary on daily basis and were likely influenced by environmental factors and/or sample sites, thus not very reliable in this context.

Assumptions

Not listed

Assessment of Validity

Not listed

Questions?

- Q: For Lake Bouchard, what is the current fishing yield that supports the notion that natural productive capacity is being exceeded? A: The fishing yield for the period 1992-2005 is 1.64 kg/ha. For the year 2005, it was 4.00 kg/ha.

4.22. Bérubé 2006 – Rivers and Lakes (Hydro Québec)

Bérubé, M. (2006).

System Type and Method Classification.

Rivers and lakes. Predictive – fish production.

Reason for Assessment/ Objective

New hydro development on the Romaine River

Methods

- First step to assessing fish production was to determine numerical and weight fishing yields

- CPUE (used for numerical yields) BPUE (used for weight yields) were calculated for each gear type used for sampling study area
    - For gillnets – CPUE = number of fish caught / number of days fished.
    - For seine nets – CPUE = number of fish caught / number of seine hauls.
- Gillnets were all multipanel experimental gillnets set from the shore for 24 hrs. Sizes: 45 m X 2.4 m, 6 panels, mesh sizes: 25, 38, 50, 64, 76 and 102 mm.
- Seines were 22.9 m X 1.5 m. Pouch had 1 mm mesh and sides 3 mm mesh.
- For electrofishing – abundance per unit of surface area (CPUA) as preferred to abundance per unit effort (CPUE).
- Electrofishing was conducted in tributaries.
    - Survey stations could either be "open patches" or "closed stations".
    - Closed stations were $100m^2$ and surrounded by a fine-mesh seine net. 3 or 4 passes were made to catch largest number of specimens possible.
    - Open patches had no seine net enclosures. Only 1 pass was made with the electro-fisher. Based on first pass in closed stations, possible to estimate total population in open stations using Leslie method described in King (1995).

<u>Romaine River</u>

River Biomass Calculations

- Estimate of instantaneous biomass (B_0) is a precondition for determining production.
- Estimate obtained from the linear model in Randall et al. (1995 – Table 2 pooled equations used because of better R^2).
- The model 1st calculates fish density in the river using:

Log D = 4.41 – 0.96Log W +0.49 (eqn' 1)

$$\log D = 4.41 - 0.96 \log W + 0.49$$

Where D=density (#/ha), W average weight (g) of the fish *community*.

- B_0 was based on density value obtained from equation 1 and the relative abundance ($CPUE_i$) and average mass of each fish species ($_i$) in the catch sample as follows:

$$B_0 = \Sigma(CPUE_i * D * W_i) \text{ (eqn' 2)}$$

- Model uses gillnet data to determine B_0 from in water strata deeper than 1.5m and seine data for water strata less than 1.5m

Production

- Boudreau and Dickie's (1989) equation used in Randal et al. (1995 – Table 5) was used to calculate production (P) using B_0 and average weight

$$P = 0.28 - 0.35 \log W + 0.90 \log B_0 + .022 \text{ (eqn' 3)}$$

Where P=production (kg/ha), W=average weight (g) of fish community, B_0 fish biomass per unit surface area (kg/ha) at specific instant of year

- By subbing equation 1 into 2 and then subbing equation 2 into equation 3 the following relationship is obtained:

$$\mathbf{P = 0.28 - 0.35LogW + 0.90Log(\Sigma(CPUE * 10^{4.41 - 0.96LogW + 0.49} * W_i) + 0.22}$$
(eqn' 4)

- Fishing data used for estimating average mass of fish and fish yield were modelled on laws of probability applicable to frequency distribution.
- Monte Carlo simulation was then run to generate several thousand random results to determine variability and robustness of this model (eqn' 4) using @RISK 4.5 software. First step was entering Romaine River catch data from 2004 and 2005 surveys, grouped irrespective of their sector of origin.

Production by species

- Species production was based on relative biomass (%) from gillnet and seine catches by sector (i.e. Romaine site 1 to 4). Seine fishing catch was used for zones where water was ≤1.5m; gillnet catch was used for deeper water.

Annual production

- Total annual production ($kg \cdot yr^{-1}$) was determined by multiplying production ($kg \cdot ha^{-1} \cdot yr^{-1}$) by the surface area of habitat concerned, either littoral zone (≤1.5m depth) or deeper zone (>1.5m depth).

<u>Tributaries</u>

Calculation of Biomass in tributaries

- Performed in three stages – 1) determine efficiency of electro-fishing, 2) convert numerical yield into absolute density (#/ha) and instantaneous biomass (kg/ha), then 3) convert instantaneous biomass into production (kg/ha/yr) and total annual production (kg/yr)
- Electrofishing efficiency was calculated as the ratio of CPUE to absolute density of fish in an open patch using the following equation:

Efficiency (%) = CPUE / D *100 (eqn' 5)

Where D=absolute fish density based on Leslie method

- The Leslie method generates the ratio of CPUEs during time interval *t* (C_t/f_t) to cumulative catches during time *t* (ΣC*adjusted*)
- The slope of the resulting line represents the potential catch (q)
- Point of intersection of the line with the abscissa gives the estimate of initial population (N_0), or total quantity of fish possible to catch in given stretch of water (King, 1995).
- For all closed stations, as per the Leslie Method, regression was performed on the CPUE vs. cumulative catch over four net passes which generated a straight line whose slope is catchability and the x-axis intercept is an estimate of absolute number (N_0). Number of fish caught in

the first pass was divided by N_0 to obtain first pass fishing efficiency.

- This efficiency was assigned by extrapolation to all stations (open and closed) to determine numerical density (#/ha) and weight density (#/ha * average mass) for each species in the tributaries.

Production, Production by species, and Annual production

- The exact same equation (eqn' 3) and methods used for the determination of these parameters in the Romaine River were used for tributaries.

<u>Lakes</u>

Calculation of biomass in lakes.

- All lakes were sampled using gillnets only. Gillnets were all multipanel experimental gillnets set from the shore for 24 hrs. Sizes: 45 m X 2.4 m, 6 panels, mesh sizes: 25, 38, 50, 64, 76 and 102 mm.
- Procedure was similar to Romaine River, where B_0 is generated using Randall et al. (1995) linear model for lakes:

  LogD = 4.41 – 0.96LogW (eqn' 6)

  Where D= density (#/ha), W = average weight (g) of *community*, (note coefficient and dummy variable (ID) has been dropped from egn' 1 to create eqn' 6)
- Model was applied separately to each lake surveyed, since fish communities differ considerably from one lake to another
- $B_{0\ was}$ calculated for each species in the sample using equation 2 (above) and was calculated separately for pelagic (>4m depth) and littoral (<4m depth) zones.

Production

- Procedure similar to Romaine River, where production was generated using linear model for lakes:

  $$P = 0.28 - 0.35LogW + 0.90Log\ B_0 \quad \text{(eqn' 7)}$$

  Where P=production (kg/ha), W=average weight (g) of fish community, B_0 fish biomass per unit surface area (kg/ha) at specific instant of year (note coefficient and dummy variable (ID) has been dropped from egn' 3 to create eqn' 7)
- By subbing equation 6 into equation 2, then subbing equation 2 into equation 7, the following equation is obtained:

$$P = 0.28 - 0.35LogW + 0.90Log(\Sigma(CPUE * 10^{4.41 - 0.96LogW} * W_i)$$

(eqn' 8)

- Average production value of all lakes was determined and applied to all planned flooded areas. Variability of the resulting value was determined by means of Monte Carlo simulation, factoring in law of probability relating to average mass and biomass of fish in surveyed lakes
- Despite considerable variation between lakes, the average was used for all lakes in all sectors to estimate lake production in the whole study area.

Production by species

- Based on relative biomass (%) of each species in all gillnet samples from lakes in Romaine 2, 3, and 4 sectors.
- Catch sample from nets dropped to average depth of 4m or less determined by-species production in the littoral zone.
- Nets dropped >4m depth determined the value of pelagic fish.
- In Romaine 1, relative biomass of fish caught in traps in Lake No. 106 determined the type of lacustrine community affected by project.

Annual Production

- Production ($kg \cdot ha^{-1} \cdot yr^{-1}$) was multiplied by the surface area (ha) of habitat concerned to determine annual production.
- In Romaine sections 2-4, the relative surface area of shallow (≤4m) and deepwater (>4m) environments of lakes were calculated by applying the factor obtained for the 14 lakes from which samples were netted (64% and 36% respectively).
- Romaine sector 1, all lakes were shallow.

<u>Future Conditions</u>

Romaine River

- Current calculated production per unit surface area and by species in various sectors of Romaine River were used to estimate future production.
- Expected change in flooded surface area and reduction in flow rates post construction determined fluctuation in annual production.
- A correction factor must be applied to consider change in water temperature attributable to the reservoirs.
- The correction factor was determined from a model that determines growth rate of the main fish species by incorporating water temperature into calculations.

Tributaries

- Fish production in tributaries flooded by reservoir was given a null value under future conditions.

Lakes

- Fish production in lakes flooded by reservoir was also given null value under future conditions. Change in the environment are expected to benefit some species at expense of others, depending on tolerance to new conditions.
- Fish community will adopt a new structure specific to reservoirs, somewhat different than lakes.

Reservoir

- Once a balance is reached, fish production in the reservoir will be equivalent to lake production
- Monitoring in Nordic environments show fishing yields stay at same level

after reservoir construction, however the fish community will change and bedominated by few species adapted to the new habitat.

- Conditions in Caniapiscau reservoir are similar to what is expected in this study, thus was used as basis for future conditions for Romaine River.
- Fish community of Caniapiscau reservoir (lake trout data excluded) was used to determine the relative biomass of fish in future Romaine Reservoir.
- Applying this biomass value to calculated lake production, the production by species expected to be present in flooded conditions can be estimated i.e. lake whitefish, northern pike, white sucker, longnose sucker, burbot and lake chub

Mesohabitat-based Approach

- To take into account the transformation of fluvial habitats, this approach was adopted to predict how physical habitat changes influence the structure of fish communities and fish abundance.
- Preference was given to data based on frequency of use of various habitats in study area.
- Only main sections of Romaine River that maintain fluvial characteristics after construction are factored into calculations, since they will not be flooded and turned into reservoir.
- Summer feeding habitat use index (S) was calculated by sector for each species (i), using BPUE as follows:

$$\mathbf{S_i = BPUE_i} \text{ (eqn' 9)}$$

- The highest value (S_i max) was used to weight preference (h) on scale of 0 to 1 using formula:

$$\mathbf{S_{hi} = S / S_i\ max} \text{ (eqn' 10)}$$

- For each typical habitat identified, both shallow (≤1.5m depth) and deepwater (>1.5m depth) zones were considered.
- Habitats were also subdivided according to presence/ absence aquatic vegetation.
- 11 typical habitats were identified (footnote points to table that defines habitat types, table not present in this paper).
- Type of gear used was considered with gillnet results used for deepwater and seine and/or trap fishing used in shallow water.

Weighted production index

- WPI is the product of $\mathbf{S_{hi}}$ and surface area of habitat concerned.
- Difference between WPI under future conditions versus WPI under current conditions, expressed as percentage, yields the value for change in productive capacity.
- Correction factor incorporating temperature was assigned to the WPI value to determine the influence of temperature on future condition.

Temperature and production

- Results of modelling the hydrological regime at 5 stations across

downstream and upstream portions of the Romaine River show water temperature increases more slowly in spring and summer and will cool down more slowly in fall and winter. • Romaine sector 1 (downstream from the dam), the average water temperature will be lowered post construction, but will be higher in other sections. • Temperature is a key variable in fish growth and production and its influence as determined by means of equations modeling growth rates of the main fish species. • Model generates a correction factor (%) that can be incorporated into both macro- and meso-habitat approaches. • Approach outlining optimum growth equations outlined in GENIVAR (2007a). Calculations for each species were made for all 365 days in the year, once for current and once for future conditions. Average difference between them is the correction factor to be applied to production under future conditions.
Results & Discussion
• Not translated or summarized.
Assumptions
• Assumed hydrological conditions in reservoir were too different from those in tributaries for current fish populations to be maintained post construction
Assessment of Validity
• Not listed
References
GENIVAR 2007. *Complexe de la rivière Romaine. Faune ichtyenne. Habitats et production de poissons. Rapport sectoriel.* Préparé pour Hydro-Québec Équipement. Québec, GENIVAR société en commandite. 212 p. et ann. King, M. 1995. *Fisheries Biology. Assessment and Management*. Cambridge (MA), Fishing News Book. 341 p. Randall, R.G., J.R.M. Kelso et C.K. Minns. 1995. « Fish production in freshwaters: Are rivers more productive than lakes? » *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 52, p. 631-643.
Questions?

4.23. Quigley and Harper 2006. – Rivers.

Fish & Periphyton Biomass, Invert Density, Riparian Cover
Quigley, J.T. and Harper, D.J. 2006. Effectiveness of fish habitat compensation in Canada in achieving no net loss. Environmental Management **37**(3), 351-366.
System Type and Method Classification
River. Monitoring/compensation studies – multi-trophic level.
Reason for Assessment/ Objective
To investigate the effectiveness of compensation habitats in achieving NNL of

current habitat productivity by measuring both the area and the productivity of compensatory habitats in systems affected by a variety of projects including hydro development.

Methods & Design

- Compensation projects were randomly selected from 5 provinces (BC, MN, ON, NB, NS) that were completed between 1994 and 1997. Field observations were conducted from May to October in 2000 and 2001.
- 2 to 4 treatment sites were located within the HADD of each project ("like for like habitat" and "increasing like habitat productivity" compensation options). Where HADD and compensatory habitats were spatially distinct ("like for unlike habitat" compensation option), 2 to 4 treatment sites were selected in each and the data were pooled to develop mean responses.
- 2 to 4 reference sites *not* located within the impacted area were selected for each project.
- Modified compensation options were based on the DFO Habitat Policy (1986, 1998).
- HADD and compensatory habitats occurred in in-channel riverine and riparian habitat categories.
- Evaluation consisted of determining the aerial extent of habitat change along with the productivity change per unit area. Compensation ratios were calculated from total surface area gains to losses.
- Four productive capacity surrogates were chosen to measure the change in habitat productivity at both treatment and reference sites. Sites were netted off and response variables were quantified per unit area.
- The four surrogates were:
    1. Periphyton biomass: 5 rocks were sampled along a mid-channel transect via stratified random sampling. Attached sediment was rinsed off with a washbottle. PVC tubing of varying diameters (dependant upon substrate size) was cut to 3.8cm lengths and held against the sampled rock. A cordless drill equipped with a nylon brush was used to emulsify the periphyton from within the area defined by the PVC tube. Emulsified periphyton was rinsed into sample bottles and quantified by filtration ($g \cdot m^{-2}$) in the laboratory.
    2. Macroinvertebrate density: 5 Surber samples were taken randomly from each site and macroinvertebrate density ($numbers \cdot m^{-2}$) and diversity were recorded.
    3. Fish biomass: For each site, a back-pack electroshocker was used to sample fish using a two pass removal method to calculate density. Biomass ($g \cdot m^{-2}$) and diversity were recorded.
    4. Aerial cover of riparian vegetation: 5 locations per site were selected using a stratified random sample along a parallel transect to the channel. 1 m^2 quadrats were used to measure percent cover and diversity of woody and non-woody vegetation.
- Treatment response variables were weighted by the compensation ratio (compensation area : HADD area). For example, where compensation exceeded HADD area by factor of 1.2, mean treatment response variables were multiplied by 1.2 to estimate total production. Many projects had

less than 1:1 ratios, so artificial ratios of 1:1 and 2:1 were also used to determine effects of larger compensation ratios on the achievement of NNL.

- Change in productivity was measured by comparing mean response variables between treatment and reference sites. In-channel and riparian components were evaluated separately.
- Net gain was achieved if one or more treatment response variables were significantly greater then those observed in the reference sites and the remaining response variables did not differ.
- A net loss was achieved if one or more reference response variables were significantly greater than those observed in the treatment sites.
- NNL was achieved if response variables were not significantly different between treatment and reference sites.

Results & Discussion

- Data were visually inspected for normality and homogeneous variances.
- Heterogeneous variances were minimized with log transformations.
- Analysis of variance was used to compare treatment and reference response variables.
- Least-squares means were used for means in graphical presentations.
- Values reported as means ±1 SE and all tests were considered significant at $P \leq 0.05$.
- 16 compensation projects evaluated across Canada (BC =7, MN =3, ON = 2, NS =1) representing 13% of total number authorisations (N =124) issued during 1994 – 1997. Mean age of projects = 4.3 years
- HADDs and compensatory habitats occurred in 2 habitat categories: in-channel and riparian
- Compensation techniques included: riparian revegetation, channel creation, and habitat complexing (e.g. boulder addition)

<u>In-channel habitat</u>

- 58% projects had HADD areas larger than authorised; 8% with smaller than authorised HADDs.
- 50% of projects had compensation habitat smaller than required; 17% were larger than required.
- Overall, 75% of projects had larger HADD areas and/or small compensation areas than authorised.
- As a result, 64% projects had smaller compensation ratios than authorized. Mean ratio required was 6.8:1, while the actual ratio achieved was 1.5:1.

<u>Riparian</u>

- Trends very similar to In-channel habitat

<u>Habitat Productivity</u>

- 63% of projects resulted in a net loss of productivity (mean compensation ratio 0.74:1), 25% achieved NNL (mean compensation ratio 1.08:1), and 12% achieved a net gain (mean compensation ratio 4.8:1).
- Where treatment response variables were multiplied by the 1:1 artificial

compensation ratio, 44% of projects would still have resulted in a net loss of production, 56% would have achieved NNL, and 0% would have achieved net gain. Where 2:1 artificial compensation ratio was used, 19% of projects would still have resulted in a net loss, 50% NNL, and 31% with a net gain.

- A difference in mean periphyton biomass was detected in 50% of projects where it was sampled, a difference in macroinvertebrate density in 25%, and a difference in fish biomass was detected in only 8% of projects.
- Riparian habitats were more difficult to compensate as 57% resulted in net loss and 0% achieved a net gain.
- No differences in diversity of fish or invertebrates between treatment and reference sites were observed for any project, whereas 3 projects had differences in diversity of riparian vegetation.

Discussion

- Inherent ecosystem variability meant differences had to be large in order to detect a response, thus NNL may have been assigned to projects that did not achieve this goal. Results can be considered conservative.
- More replicates would have assisted in detecting differences in habitat productivity, but gross disparity in physical area of compensation versus impacted habitat made it unlikely that equivalent productivity was achieved by replacing only a small portion of the habitat lost/altered.
- Even if compliance was 100%, it was unlikely that compensation projects would achieve NNL. DFO aims for minimum compensation ratio of 1:1, while 50% of projects in this study would not achieve NNL at this ratio.
- Minns and Moore (2003) advocated a ratio of 2:1; this study showed a substantial proportion of projects still did not achieve NNL at this ratio.
- Present study showed projects were successful at achieving net gain characterised by ratios of 5:1.
- Based on the simple metric of habitat area, it appears Canada should be achieving a net gain. Actual compensation areas were much less than required and actual HADD areas were larger than authorized.
- NNL also not being achieved temporally or functionally, as compensation takes place after HADD occurs, coupled with time lag until compensatory habitat achieves desired ecological function.
- Ability to detect changes and power of statistical analyses would be greatly improved if reference sites and quantitative pre-impact data were routinely required for compensation projects and rigorous experimental designs were employed in monitoring programs.
- Fact that differences in diversity of species were not detected was due to tendency of projects to implement in-kind compensation.
- In general, compensation sites were selected opportunistically rather than based on ecological bottlenecks and potential for success, which negatively influenced compensation success.
- This paper quantitatively examined 4 components of fish habitat, at 3 trophic levels, to determine efficacy of compensatory habitat in replicating habitat quality.

• Lower trophic level indicators were more responsive and/or less variable, and were better at representing gross differences in habitat productivity than fish biomass. • Invertebrates and periphyton are rarely measured in actual assessments of compensatory projects. • Typically fish biomass or vegetation cover is used to infer habitat productivity. However, the four methods used to quantify fish habitat productivity in this study provided a holistic view of changes in habitat quality through three trophic levels. • Habitat alteration does not impact a single species in isolation of others. • Fish could be poor indicators due to mobility, cyclical populations, exposure to confounding influences, and divergent life histories. • Selecting one surrogate method would have led to erroneous conclusions about habitat productivity in many cases in this study, thus the array of indicators was preferable.
Assumptions
• Not listed
Assessment of Validity
• Not listed
Questions?
• How close to shoreline were riparian transects located? • Were treatment and reference sites selected randomly? • What were the sizes of habitat surveyed? • What if the reference sites selected were already more productive than the treatment sites prior to the HADD? • Was habitat classified as the aerial extent alone, or was some type of habitat classification performed at a finer scale? Were similar habitat types compared between treatment and reference types?

4.24. McCarthy et al. 2008. – Rivers, Streams and Lakes (Lower Churchill Development)

Newfoundland Labrador Hydro - Habitat Utilization Indices
McCarthy, J.H., LeDrew, B.R., and LeDrew, L.J. 2008. A Framework For Aquatic Habitat Classification and Quantification for Large Northern Ecosystems: Application to the Proposed Churchill River Power Project, Churchill River, Labrador, Canada. Am. Fish. Soc. Symp. 49: 1041-1057.
System Type and Method Classification
Lakes, rivers and streams. Predictive – habitat quality.
Reason for Assessment/ Objective
Churchill River Power Project - New hydro development To develop a framework for HADD determination that provided a local estimation of productive capacity based on relative species utilization of habitats within a large watershed containing multiple species.

To achieve the objectives of the no net loss principle, a method was required to quantify fish productivity or to provide an index value which applies to the variety of habitats within a proposed development area and to predict productivity for any new habitat created (i.e. reservoir).

Methods & Design

Habitat Classification

- Habitat classification of the watershed affected by the development was performed and delineated 9 habitat types in the main stem, tributaries (>4m width at mouth), and small streams (<4m width at mouth) of the watershed based on depth, water velocity, and substrate type. Habitat types (H_1 to H_9) listed below
    - Lacustrine
        - H_1 Littoral zone (coarse, medium, fine) - Main stem
        - H_2 Profundal zone - Main stem
    - Riverine
        - H_3 Slow velocity – Main stem
        - H_4 Slow velocity – Tributaries
        - H_5 Intermediate velocity – Main stem
        - H_6 Intermediate velocity – Tributaries
        - H_7 Fast velocity – Main stem
        - H_8 Fast velocity – Tributaries
    - Stream
        - H_9 Small streams (riffle, run, pool, pocket water, rapid, +2?)
- Lacustrine habitats (H_1 and H_2) were differentiated by Bradbury et al.'s (2001) protocols, which used mean secchi depth to distinguish littoral and profundal zones. The littoral zone was further divided into sub-habitats based on the dominance of coarse, medium, and fine substrate types (no delineation provided).
- Riverine habitats (H_3 to H_8) were based on aerial surveys and ground-truthed cross sections.
- Stream habitats (H_9) were based on aerial photo and map interpretation accompanied by detailed ground truthing following the standard procedures established for Newfoundland and Labrador by Sooley et al (1998).
- Mean habitat characteristics were described for each habitat type in terms of averages for depth (m), velocity (m/s), and substrate percentage (%bedrock, %boulder, %rubble, %cobble, %gravel, %sand, %mud).

Baseline Data Collection

- All data were collected during ice free conditions from June to September. This method was designed for application to large watersheds with multiple fish species. The project area examined in this paper consisted of the entire lower Churchill River watershed.
- Catch data were obtained using a field sampling program that employed a variety of sampling gear (gill nets, fyke nets, electrofishing, angling, baited trawls, baited minnow traps) appropriate to species and

life cycle stage for each of the habitat types identified. The baited trawl and minnow trap methods yielded low catches and were not used in utilization index calculations, thus only 4 gear types were used in CUI determination.

- Adult, juvenile, and YOY life cycle stages for collected species were distinguished (see below).
- Available databases also provided extensive information on the watershed; gillnet collections (1976 -1977) (Ryan 1980), electrofishing from tributaries (1978-1979) (Beak 1980), main stem, tributary, and small stream collections (1998-200) (AGRA 1999; AMEC 2000, 2001), substrate analysis (Jacques Whitford Environment 1999).

Catch-based utilization indices (CUI)

- Methodology has intentionally defined the indices as 'utilization' and not 'suitability' since the latter rely heavily upon microscale preference of depth, velocity, substrate, and cover. Relative utilization of each habitat type is based on actual mean catch data (gm/effort) from each habitat type.
- Mean catch-per-unit-effort (CPUE) data (gm/set) were collected by species and life cycle stage for each of the 4 potential gear-types across all habitat types identified.
- Mean CPUE also incorporates inferences of sample size and variability since they are being used to represent the population, not the sample.
- The upper 95% confidence interval for each mean-catch was used to represent species utilization of the habitat type to address possible uncertainty of the catch data representing actual carrying capacity of the habitat (Minns and Moore 2003) and to avoid under-estimates of the population mean.
- Depending on whether all gear-types were used during sampling, up to 4 CUI's were therefore calculated for each habitat type. The highest of these 4 CUIs was used to represent the utilization index for the given habitat type. Where no gear-type was capable of sampling a given habitat type (e.g. fast velocities), a literature-based utilization index (LUI) was applied.
- To ensure assumptions considered regarding similarity of gear types to capture life cycle stages equally, each gear type treated separately.
- The upper 95% confidence limit of population mean for each gear type across habitats was normalized, with highest mean catch assigned the highest catch based habitat utilization index (CUI) of 1.00, with the other habitat CUI's calculated based on their mean-catch value relative to the highest.
- A schematic of the method is presented in the figure at the end of this summary.

Step One: Life Cycle Stages

- 4 life-cycle stages were imposed on the above CUI determination method for all captured species. These stages were young-of-year, juvenile, adult, and spawning.

- The stages were determined in the databases based upon maturity and length-at-age information. Juvenile and adult distinction was made when 50% of samples collected were mature. Where maturity data were not collected, literature values were applied to the length-at-age database.
- Habitat utilization indices for the spawning life-cycle stage could not be identified in the database, so substrate alone was used to identify potential spawning habitat. Spawning LUI's were calculated as the product of literature based preferences (not suitable=0, low suitability=0.33, medium suitability=0.66, high suitability=1.00) and the availability (substrate percentage) of substrate within each habitat type in the riverine system. Spawning LUI's were summed for each substrate type to provide a total LUI for each habitat type.
- A similar method was employed for lucustrine habitat types, where spawning preferences for littoral habitat types (coarse, medium, fine) identified by Bradbury et al (1999) were multiplied with the proportion of each said littoral sub-habitat type available within the area surveyed. The so derived sub-habitat utilization indices were summed to provide the total LUI for the littoral zone habitat. The same was done for profundal habitat.

<u>Step Two: Species Utilization Indices</u>

- The mean of the four utilization indices determined for each species' individual life-cycle stages (YOY, juvenile, adult, spawning) for a given habitat type was calculated and used as the single habitat utilization index (HUI) for the whole species.
- If a particular species life-cycle stage utilized only a single habitat type exclusively (defined as critical habitat), then the mean utilization index of all four life-cycle stages was not calculated. Instead, the utilization index for the critical habitat was used as the HUI for the given species.

<u>Step Three: Life History Guilds</u>

- To reduce the relatively large number of species present in the system, four guilds were identified based on shared life history strategies, similar habitats, and expected response to habitat alteration. These guilds were Large Piscivores, Salmonids, Large Benthic Feeders, and Prey Species. All captured species were included in these guilds.
- The species with the highest HUI for each given habitat type within the guild was used as the guild's representative for said habitat type. At this point each habitat type had 4 utilization indices associated with it, one for each guild.

<u>Step Four: Composite Habitat Utilization Indices</u>

- The mean of the four guild indices for each habitat type was used as the Composite HUI for the habitat type.
- The Composite HUIs were multiplied by the current total habitat areas to produce Composite Habitat Equivalent Units.
- Similar calculations can be conducted using predicted future habitat allowing for the comparison between current and future Composite Habitat Equivalent Units for HADD determination.

- Potentially lost habitat units are quantified at their full amount and not multiplied by an index as per Minns (1997) recommendation.

Results & Discussion

- This approach is similar to the Habitat Evaluation Procedure used by the U.S. Fish and Wildlife Service (1980, 1981).
- Species Habitat Utilization Indices were generated for each species life cycle stage found in the project area, which were used to quantify habitat units in the affected watershed. Despite assumptions and limitations (below), it was asserted that the utilization indices derived in this report represented actual habitat utilization by the species in question for this project area.
- Recent attempts at quantifying productive capacity use species-specific P/B ratios, used to calculate a habitat productivity index (HPI) (Randell and Minns 2000) that estimates productive capacity regardless of aerial extent of habitat.
- In Newfoundland and Labrador however, habitat is used as unit of measurement for management, assessment, and regulation. Has advantage over fish populations, being relatively stable over time, defined in intuitive terms, and tangible resource for negotiations.
- Habitat-based management validity rests on accurate definitions and measurements. Indices in this paper used average fish biomass within study area to provide standardized utilization for each species life cycle stage.
- Very difficult to relate compensation options, design, and success to HPI until final monitoring is implemented
- Habitat classification and validation in this study demonstrated that main stem and larger tributary velocities were outside species preference ranges documented in the literature.
- Existing habitat type definitions (i.e. Beak) were not applicable to the habitat types identified in this study area. Added effort in classifying habitats in this study avoided under estimates of habitat utilization derived using Beak's classification.
- Species were found using non-typical habitat in this study, which would not have been detected if strict literature values or empirical models were used for species utilization/ preferences
- This framework used project specific fish capture data to produce productive capacity indices for a variety of habitat scales and types in a consistent and conservative manner.

Assumptions

- Assumed fishing pressure on the system was negligible, thus catch rates represented maximum carrying capacity.
- Assumed that sampled substrate for spawning was representative of that present in each habitat-type, as most sampling was done in slow, shallow areas. Other factors (eg. velocity, depth) not considered may have also impacted spawning habitat by limiting utilization. This assumption would have overestimated spawning utilization for each habitat.

• Assumed that sampled habitats contained the variables required to sustain the population at current levels. • Assumed that utilization during ice-free conditions was representative of annual patterns. • Assumed that sampling results represented utilization through each habitat type, given that certain gear could not be deployed in certain habitat types (eg. gillnets in fast velocity water) • Assumed that the combination of gear-types used captured all life-cycle stages. • Assumed sampling covered the most active daily period of species present (e.g. dawn and dusk sampling) • Assumed data were collected from all habitat types present • Fish were not sampled on the scale for habitat utilization by individuals • Fish were only collected for habitat types in the project area
Assessment of Validity
• Not listed
Questions?
• How intensive was field sampling in each habitat type (temporal and spatial)? • How often were LUI's used? • Was the sampling data collected in this study included with the listed databases, or was it collected in addition to these databases? • Could a single species belong to more than one guild?

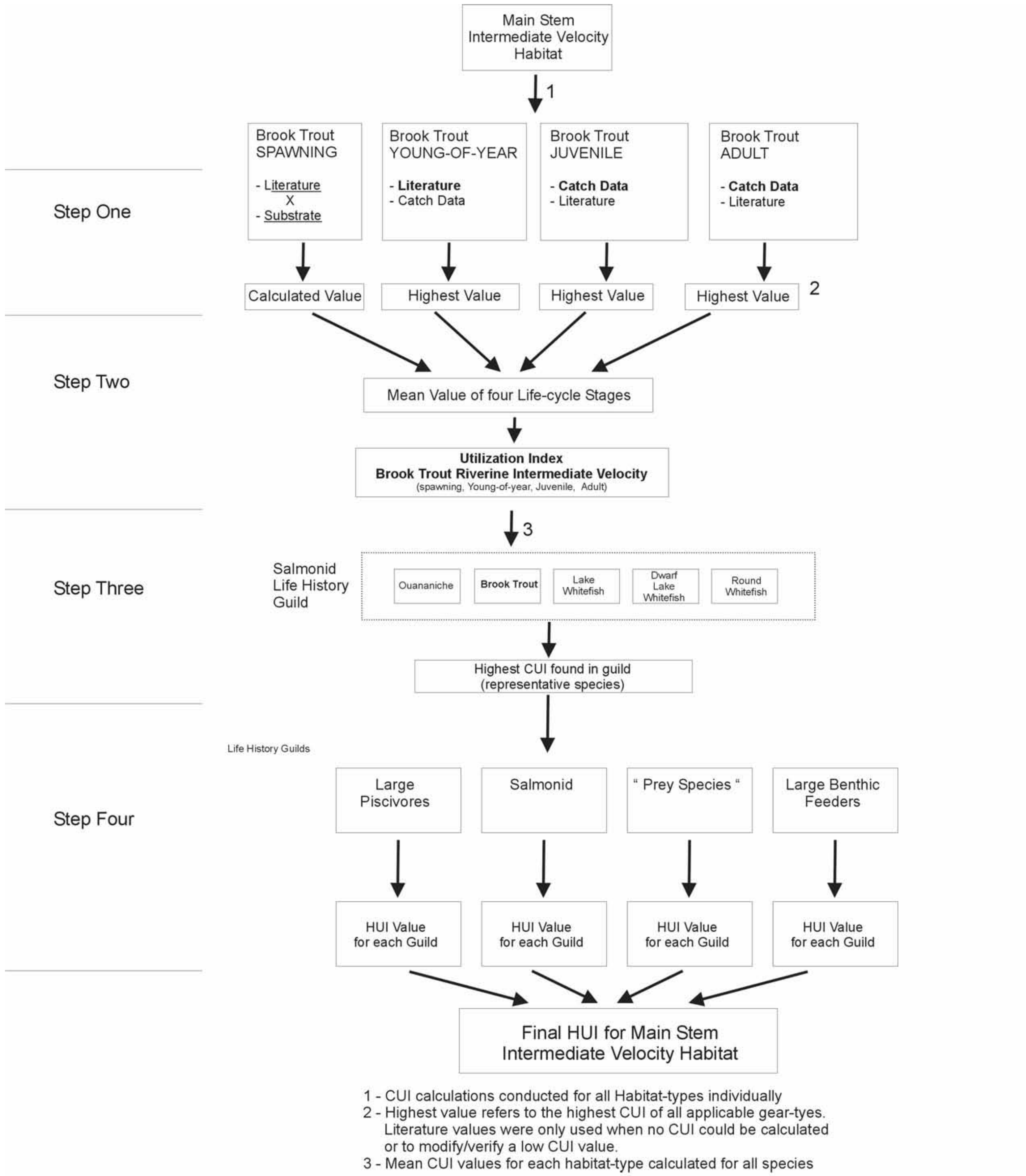

Figure 3. Illustrative calculation of composite habitat utilization index (HUI) as it relates to the mainstem intermediate velocity habitat, lower Churchill River. (from McCarthey et al. 2008).

4.25. McCarthy et al. 2006 - Rivers

McCarthy, J.H., Grant, C.G.J., and Scruton, D. 2006b. DRAFT - Standard methods guide for the classification and quantification of fish habitat in rivers of Newfoundland and Labrador. Can. Manuscr. Rep. Fish. Aquat. Sci. xx
System Type and Method Classification
Rivers. Predictive – habitat quality.
Reason for Assessment/ Objective
The full provisions of the *Fisheries Act* and *Species at Risk Act* (SARA) require a broader habitat assessment system than what has historically been used in Newfoundland and Labrador (i.e. formerly a focus on salmonds). This method outlines a riverine habitat classification/quantification system which will standard and replace the Beak (1980) salmonid dominated system used by habitat managers and fisheries biologists in Newfoundland and Labrador (NL) over the past 25 years.
Methods
• Over 20 habitat survey methods were reviewed and aspects of those relevant to NL were used in the development of the new classification system, but the new system has the important addition of tying habitat to biological criteria. • The method describes typical habitat and incorporates biologically meaningful ranges of physical parameters for all species, life stages and habitat preferences as outlined in Grant and Lee 2004 (based on water velocity, depth, substrate composition and cover). • As necessary to fill in knowledge gaps, data were supplemented by studies from similar geographical areas, and a number of limitations to associations are presented (e.g. temperature preferences, predator avoidance, competition, prey availability, water chemistry effects etc.). • Knowledge of over-wintering habitat use was very limited. • The habitat classification system was comprised of three hierarchical levels, each providing progressively more detail about the habitat, the choice of which depends on objectives. • Examples are provided describing when the use of each level of assessment (i.e. no assessment, coarse level, intermediate level, fine level assessments) is appropriate. • Generally, increasing levels of assessment are required with increasing levels of risk of the development (i.e. operational statements = no assessment; low risk = coarse assessment; medium or high risk developments = intermediate level assessments; changing natural flow patterns or impacts on large river systems = fine level assessments). • Detailed examples are provided for the use of each level to arrive at habitat preference ratings for each species and life stage (based on velocity, depth and substrate type) and the habitat suitability ratings for the habitat in question. *Example of an intermediate level assessment* • This level requires conducting field surveys or validating habitat measurements by experienced staff.

- Habitat measurements are compared to habitat preferences according to Grant and Lee (2004) – example provided for longnose dace spawning habitat criteria.
- Guidelines are provided for spatial coverage of habitat measurements in the field (dependent on the size of the river in question).
- Based on measurements, habitat ‘preference’ ratings for longnose dace spawning were calculated (using preference data from Grant and Lee 2004).
- The overall habitat suitability values were based on an average of the velocity rating and substrate rating in each habitat type assessed.
- The calculations are completed for all species and life stages present, and the highest suitability value for the four life stages (spawning, YOY, juvenile, adult) would be used as the species-specific value for that habitat type.
- Alternatively the mean of the 4 life stages could be calculated to obtain a suitability value, or, species considered to be of importance from a resource user perspective may be given greater consideration.
- Total Habitat Equivalent Units (HEU) = habitat suitability values x overall area of each habitat type.
- HEU is calculated for each species and each habitat type for the reach in question.
- Cover (substrate, woody debris, aquatic vegetation, overhanging vegetation, undercut banks, turbulence, concealing depths) can be added as a third preference rating involved in a final habitat suitability rating.
- A similar calculation of HEU can be performed on predicted future habitat so that the difference between the current and future habitat utilization could be considered the HADD.

Fine level assessments require the addition of instream flow assessment methodologies and more site-specific field investigations of fish use of habitat.

- Development projects which will change the flow require an instream flow needs assessment (IFN).
- A hierarchy of IFN approaches is outlined in the document ranging from simple (e.g. desktop approach to setting fixed minimum flows) to very complex (e.g. incremental methods in which fish habitat is quantified as a function of stream discharge).
- The hierarchy generally includes: 1) hydrological methods, 2) hydraulic rating, 3) habitat simulation, and 4) holistic methods.
- **Hydrological methods** use readily available hydrological data and prescribe a fixed proportion of available flow on an annual, seasonal or monthly basis (e.g. Tennant’s method). These are considered to be relatively easy to use with low resource requirements but are only considered a first level analytical tool and are not considered appropriate for establishing flow requirements for specific projects.
- **Hydraulic rating methods** consider quantifiable relationships between the quantity and quality of some instream resource such as fish habitat and river discharge (e.g. wetted perimeter vs. discharge), where the breakpoint is selected as a discharge threshold below which habitat quality can become seriously degraded.

- **Habitat simulation methods** detail incremental change in quantity and/or suitability of instream habitat in relation to flow modification by integrating hydrological, hydraulic and biological variables through simulations and models of varying types of sophistication (often through commercial software). These methods are often complex, time consuming, and expensive, but allow more room for negotiation between competing uses and more attention to life stages/species that are of special concern.
- The most well developed and widely used model is the Physical Habitat Simulation System (PHABSIM) and a description of this method and its limitations is provided.
- **Holistic methods** use an ecosystem approach to refine flow modifications and involve multi-disciplinary assessments in a complex nature.
- Any flow changes must be monitored for effectiveness in a rigorous, scientific manner, allowing feedback into future flow modification decisions.
- **Natural flow paradigm (NFP)** recognizes that river systems depend on their natural dynamic character (variability in magnitude, frequency, duration, timing, and rate of change in flow) and is now considered a fundamental principle (by DFO and others) to consider when developing a managed flow regime.
- **Ecosystem Base Flow (EBF)** considers that extreme low flows can result in very limited habitat area and is intended to ensure that no increase in frequency or duration of these events occur by identifying low flows below which all water withdrawals should cease.

Large Northern Ecosystems

- Specific habitat utilization indices, based on actual catch-based data, is being applied to large northern rivers in Labrador, since most literature based habitat preferences are not applicable in large rivers.
- See summary of McCarthy et al. 2006a.

Results & Discussion

- This document outlines a methodological approach and therefore does not contain any results or discussion.
- A summary is provided presenting the rationale behind some decisions and potential problems or difficulties with this method.
- Cautions are provided regarding the potential need to refine and validate the classification scheme in some situations.
- It is acknowledged that the system will likely be improved as it is implemented, monitored and evaluated.
- In the Appendices, a glossary of terms is provided, as is a summary of suggested riverine survey methods, including:
    - Study site/sampling location – selection and mapping.
    - Habitat surveys – timing, photographic records, measuring gradient, velocity, discharge, substrate mapping, depth, riparian vegetation, streambanks, streambank stability, and cover (including aquatic plants).
    - Fish sampling – accessing local knowledge, existing data, and/or direct

sampling. Direct sampling must attempt to capture all length-age classes of fish by using a variety of gear types in a wide range of habitats at various times of the day and year. Descriptions of various gear types and guidelines for deployment, guidelines for conducting spawning surveys, and fish measurements are provided. o A summary of identified biological 'preference' criteria for freshwater fish species in NL is provided.
Assumptions
Assessment of Validity
References
Beak. 1980. Fisheries resources of tributaries of the lower Churchill River. Prepared by Beak Consultants Limited for the Lower Churchill Development Corporation, St. John's, Newfoundland and Labrador. Grant, C.G.J. and Lee. E.M. 2004. Life history characterization of freshwater fishes occurring in NL, with major emphasis on riverine habitat requirements. Can. Manuscr. Rep. Fish. Aquat. Sci. 2672: xii+262p.
Questions?

4.26. Jones and Yunker 2007. - Rivers

Jones, N.E., and Yunker, G.B. 2007. Riverine Index Netting Manual of Instructions. Interim Manual V.2. Ontario Ministry of Natural Resources River and Stream Ecology Unit, Peterborough, ON.
System Type and Method Classification.
Rivers. Monitoring/compensation studies – fish.
Reason for Assessment/ Objective
RIN provides an interim provincial standard for assessing large-bodied fish populations and communities in non-wadable rivers in Ontario. RIN is applicable across a range of physical and chemical river conditions, enabling comparisons between waterbodies regardless of differences in flow, turbidity, conductivity, or depth.
Methods
• Gillnets are 0.9 m deep by 30.5 m long, with 7 panels of monofilament mesh ranging from 38-127 mm configured in one of 4 possible manners. Final design will be based on the AFS standard and chosen in 2008 after further field testing (supplier info is provided). • Nets are to be set perpendicular or some angle (< 45° downstream) to shore for 18±2 hours. A 2 person crew is required. • Water velocity should be < 0.5 m/s; river width > 30 m; water depth > 0.9 m. • Survey occurs between July 1 – October 1 to avoid autumn increases in flow, leaf fall, and macrophyte die-off. • Community-wide survey – no criteria for temperature or depth.

- Typical sets are at 14:00-16:00 hrs; lifts are 8:00-10:00 hrs in the order they were set.
- Sample size depends on desired precision and catch rates – it was recommended that 20-40 net sets are used in each system, or until an adequate biological sample size is reached. A RIN support Spreadsheet is available to calculate relative standard error (RSE):

$$RSE = \frac{SE}{\bar{x}} = \frac{s}{\sqrt{n} \times \bar{x}} \qquad \text{(Eqn. 1)}$$

- Spatial limits depend on the system's physical characteristics and species of interest.
- Within the limits the river can be stratified into segments of relatively homogeneous habitat over the large scale, with the minimum length of river to be sampled = 5 km.
- Sampling should be conducted in a stratified random design, without replacement. Spacing between nets depends on river length with a minimum spacing of 250 m.
- Nets can be placed on either side of the river, but only in the middle if the width is > 200 m.
- Pre-survey of sites is recommended and a detailed map including sampling sites, access, navigational hazards and bathymetry should be prepared. Standard RIN Sample and Species and Fish Sample forms are available. Individual forms are required per net.
- The documentation outlines permitting requirements for fish collections, requirements for cleaning nets between waterbodies, fish disposal plans, fish release guidelines, preparing public information notices and safety cautions.
- All sport fish should be sampled for fork length, total length, round weight, sex and maturity. All other species should be sampled for length. A scale sample and at least one other secondary ageing structure (opercles, cleithra, otoliths) should be collected (a list of preferred ageing structures by species is provided).
- Additional data that can be collected include visceral fat, gonad wet weight, fecundity samples and stomach samples.
- Fish tissue samples can be taken and frozen for later contaminants analysis (protocol provided in an appendix).
- Data are compatible with the software package FISHNET 3.0 (currently only available to OMNR staff).
- A hypothetical case study is presented involving monitoring of a river before and after a flow modification, including spatial and temporal design and statistical power considerations.

Results & Discussion

- The development of this method arose as a result of a literature review and workshop on Methods for Sampling Fishes and their Habitats in Ontario's Flowing Waters (Jones and Kim 2005; Jones et al. 2005).
- The literature review provides an assessment and applicability of various methods for sampling fishes in various stream types, identifies gear limitations and bias, habitat assessment methods, sampling considerations

for standardization with particular emphasis on applicability to flowing waters in Ontario. • The subsequent workshop had the objective of setting direction on where research should focus efforts to learn more about sampling fishes and their habitat in flowing waters of Ontario. • The conclusion was that no one method was applicable to all types of systems and management questions. Standardization, precision and accuracy need to be given greater consideration in routine assessments, better guides should be provided to aid in selection of methods for fish and habitat sampling. • It was evident that few methods were available for the assessment of Ontario's flowing waters (aside from clear, wadable systems), and the development of this method arose as a result of the identified need.
Assumptions
n/a
Assessment of Validity
• This method underwent two years of testing and workshops and was modified based on field experiences. It was acknowledged that future modifications may be required as the method is used further and the authors welcome feedback from all users.
References
Jones, N.E, and Kim, N. 2005. Methods for sampling fishes and their habitats in flowing waters: a literature review. River and Stream Ecology Unit. Ontario Ministry of Natural Resources, Peterborough. 72 p. Jones, N.E., Mandrak, N.E., and Kim, N. 2005. Methods for sampling fishes and their habitats in Ontario's flowing waters. Proceedings of the flowing waters working group workshop. Kempenfelt Centre, Barrie, Ontario, April 10-11, 2005. 19 p.
Questions?

4.27. Smokorowski et al. 2007. - Rivers

Smokorowski, K.E., Metcalfe, R.A., Jones, N, and Finucan, S. 2007. Methods used to assess change in productivity of the Magpie River due to a change in ramping rate.
System Type and Method Classification
Rivers (partially wadable). Monitoring/compensation studies – multi-trophic level.
Reason for Assessment/ Objective
Fisheries and Oceans Canada (DFO), Ontario Ministry of Natural Resources (OMNR), and Brookfield Power Corporation Limited, are collaborating on a long-term, Adaptive Environmental Assessment and Management (AEAM) experiment to test whether regulating the rate of change of water flow (or ramping rates, $m^3 \cdot s^{-1} \cdot h^{-1}$) through hydro dam turbines can provide a more favourable environment for fish, while allowing energy production to be maximized.
Methods
Project Management

- The Project Management Team is composed of one representative from each agency section involved, namely, DFO, Ontario Ministry of Natural Resources (OMNR), and Brookfield Power Corporation. The purpose of the Management Team is to address all non-science issues related to the project.
- The Study Design Team is composed of representatives from DFO, OMNR (Renewable Energy Section, Aquatic Research and Development Section, Northeast Science and Information Section and Wawa District Office), Ontario Ministry of the Environment (OMOE), and industry, who have the experience and expertise to contribute to the science of this study (not all members are directly involved in the study). The purpose of the Study Design Team is to ensure that the experimental design is rigorous, and qualifies as sound science to satisfy the project's objective.

Design

- The Repeated Before/After Sampling at Control and Impact Sites (BACI) is being used in this study. The design requires that the ecosystem components under investigation in the experimental system – the Impact Site – be measured before and after the impact occurs, and that the same ecosystem components be measured in a similar but un-manipulated system – the Control or Reference Site – during the same period.
- A Hypothesis-of-Effect diagram and workshop were used to determine what aspects of the ecosystem to study to determine the effect of ramping rate changes.
- The experimental site is the Magpie River, Wawa, Ontario, on the 40 km stretch between Steephill Falls and Magpie Falls generating stations. The reference (control) river is the unregulated Batchawana River, located approximately 160 km south of the Magpie River, Ontario. Both rivers drain into Lake Superior.
- The Magpie River has a minimum (baseflow) requirement of 7.5 $m^3 \cdot s^{-1}$ and the maximum discharge through the turbines is 44 $m^3 \cdot s^{-1}$, and has a similar mean annual flow as the Batchawana River (22.7 $m^3 \cdot s^{-1}$). At minimum flow most areas of the river are too shallow for effective boating and navigable only by canoe.
- The rivers were spatially stratified and a random sampling design was implemented.
- The experiment included three years baseline data collection (with verification of a high power to detect an effect should one occur through power analysis) before the experimental change in flow occurred.
- Once baseline conditions were established on both rivers, all ramping restrictions were removed and power production at the Steephill Falls generating station can fluctuate as rapidly and as often as desired by the power generator (transition October 2004).
- Monitoring will continue on both systems to attempt to detect an effect from unrestricted ramping (the 'after' or experimental phase, 2005-2007).
- If an effect is detected, restrictions on ramping may be incrementally reinstated in an attempt to balance ecological and energy needs (evaluation phase).

Habitat and Hydrology

- Physical habitat parameters studied include temperature, bathymetry, bankfull width, channel slope, cross-sectional area and depth, entrenchment ratio, floodprone width, substrate heterogeneity and roughness, velocity (average and bottom) and wetted perimeter.

- Fluvial geomorphological parameters are being measured at a series of sites along the Magpie and Batchawana Rivers to elucidate the influence of ramping rate magnitude on downstream flow and sediment regimes.
- Three sites distributed longitudinally downstream of Steephill Falls Generating Station are being used to define the extent of the downstream 'zone of influence', the point on the stream beyond which the influence of ramping is fully attenuated.
- In addition, one site upstream of Steephill Falls GS and two sites on the Batchawana River (including a Water Survey of Canada gauging station), bounding the study section, will provide reference data on flow, sediment, and thermal regimes under natural conditions. The spatial extent of attenuation under various ramping rates will be identified, recognizing potential differences between flow, sediment, and thermal regimes.
- Water level and water temperature are measured at each gauging station and turbidity (a surrogate for suspended sediment) at the downstream stations.
- Field measurements of flow velocity ($m \cdot s^{-1}$) at different water levels was used to establish a rating curve for each gauging station, allowing the transformation of water level measurements to values of velocity and discharge ($m^3 \cdot sec^{-1}$).

Fish community

- A series of hypotheses related to fish species richness and diversity, community structure, population age class structure, individual fish condition, and total fish biomass were developed.
- A variety of methods were initially attempted on the river (trap nets, gill nets, hoop nets, boat and backpack electrofishing, angling) and many proved to be unsuccessful in terms of obtaining fish data with reasonable levels of variability.
- Backpack electrofishing the wadable portions of the river provided the most consistent and reliable data and the Design Team recommended focussing effort on obtaining these data only. Data provided a high power to detect a 10% change in catch per unit effort (area based: 73-85% power in slow habitat, 96-99% power in fast habitat).
- Backpack electrofishing sites were in a stratified random design, marked with GPS and permanent physical markers, and then fished in each year of the study.
- The river was too large to use blocking nets (average width 45 m, range up to 100 m, depth varied > 1 m with ramping), so data were considered relative keeping rate ($4 \ s \cdot m^2$), effort and power similar among sites and years (statistically validated).
- Sites were 100 m in length and all areas < 60 cm in depth were fished (at lower flows this allows the majority of the river area per site to be fished).
- Habitat was classified as either 'fast' or 'slow' (verified through velocity measurements) and fished in an upstream direction using standard 'back-and-fourth' electrofishing techniques.
- Fish density in these rivers was low and one netter per shocker was found to be adequate to capture turned fish – so crews of 4 were used, 2 per river bank.
- Once a habitat segment was completed detailed area measurements were taken (length and multiple widths drawn on a detailed map). Habitat notes included air and water temperature, substrate composition and the presence of any vegetation, woody material, or other debris (rare in these rivers).

- All fish were identified and counted in the field, and most non-YOY were preserved for later processing in the lab. Data collected included species, fork-length, weight, maturity, sex, and collection of otoliths and scales (if present).
- The following data will be used to detect any effect from the change in operating regime:
  - species richness and diversity (mainly used as descriptive indices, but can be tested using multi-way ANOVA or non-parametric equivalent)
  - Catch per unit effort (CPUE = number of individuals per area shocked, by species; summed = total fish community CPUE. Multi-way ANOVA or non-parametric equivalent on upstream-downstream differences between rivers)
  - Index of biomass (mean weight x CPUE, by species; summed = total fish community biomass. Multi-way ANOVA or non-parametric equivalent on upstream-downstream differences between rivers)
  - population age structure (proportion of population in each age class, provides indication of year class strength and recruitment)
  - fish growth (mean weight at age, comparing subsequent years gives annual growth by cohort; combining gives population growth)
  - fish condition (length-weight relationships, ANCOVA; Fulton's K factor)
  - Any of the above parameters may be included in a multiple-before-after-control-impact (MBACI) ANOVA model.
  - The main factors of our model were Treatment (Trt – ramping change or control), and Before-After (Time), with Sites (S) nested within Treatment, and Years (Y) nested within Time. The complete ANOVA model included the terms Trt, Time, Trt × Time, S(Trt), S(Trt) × Time, Y(Time), Y(Time) × Trt. The key term is **Trt × Time**, tested using S(Trt) × Time MS instead of the residual MS, which measures any change associated with the ramping change (Keough and Quinn 2000).

Invertebrate community

Rock bags

- Rock bags were used to determine the relative abundance and diversity of invertebrates colonizing artificial substrates longitudinally along each river, between rivers, and among years.
- The bags were constructed out of 5.1 cm (2") trap-net mesh 122 cm (48"). The two ends of the 18" length were woven together to form a cylinder. One end was tied off and sewn together, while the other end was left open but had a woven cord through the top mesh with a sliding Duraflex cinch.
- The rock-bag size was based upon those used by the Maine Department of Environmental Protection's benthic invertebrate study (Davies and Tsomides 2002 http://mainegov-images.informe.org/dep/blwq/docmonitoring/finlmeth1.pdf, last accessed February 28, 2006).
- Five sites were selected in riffle areas below the dam and one site in the unimpacted zone above the dam. Sites were spaced along a similar longitudinal distance on the reference system. Six rock bags were randomly placed at each site.
- Specific location (GPS), air temperature, water temperature, width of river, field crew, date and time were recorded at each site. As rock bags are designed to mimic the natural substrate of the river, the bags were filled with rocks of representative size found along the shoreline at the site of placement.

- To calculate average substrate size at the site, 10 rocks were haphazardly chosen from the bank and measured along the median axis for diameter and replaced on the river bank. Submerged rocks were then cleaned off by scrubbing with a wire brush and placed into the bag until it reached a weight of 7 kilograms (+/- 0.5kg), a weight designed to minimize chance of loss due to high flows, yet allow lifting for placement and retrieval. The actual number of rocks used and weight of each bag was recorded. As the rocks were placed in the bag, 5 diameter measurements were also taken along the median axis so that a mean rock diameter per bag could be produced.
- The bags were randomly placed in the riffle, ensuring a minimum distance of 3m from one to the next and that they were placed in sufficient depth to allow for water level decreases.
- Bags were left in the river for a period of approximately 60 days, a sufficient length of time for full colonization to reach fluctuating taxa richness, abundance and biomass (Mason et al, 1973; Shaw and Minshall 1980).
- Bags were lifted in order from downstream to upstream with a fine mesh d-frame net held downstream to capture dislodged invertebrates. Bags and rocks were thoroughly cleaned and contents were preserved in 70% ethanol.
- The laboratory enumeration technique and subsampling method was based on guidelines provided by Environment Canada's National Water Research Institute for area-based sieve splitting (http://www.ec.gc.ca/eem/pdf_publications/English/Revised_subsampling_guidance.pdf, last accessed September 10, 2007) which was originally described by Cuffney et al. 1993 (http://www1.usu.edu/buglab/forms/sortproc.pdf).
- All invertebrates were identified to the level of Family.
- Relative density was calculated as number of individuals per bag.
- Taxa richness (number of taxa) and diversity (PIE – probability of interspecific encounter – an evenness measure) were also calculated.
- Results were analyzed via straight parametric statistics (ANOVA) and using an MBACI ANOVA.
- Preliminary results indicate that invertebrate density did not change as a result of ramping, but diversity has decreased.

Invertebrate drift

- The objectives were: 1) to measure the effect of abrupt flow changes on invertebrate drift in a river regulated for hydropower generation, 2) to determine if any effects are attenuated with distance from the dam, and 3) to compare these results with an unregulated reference river.
- Three sites were used on each river, spaced 6.5 km apart, starting 3 km from the dam. Sites were sampled simultaneously during two full ramping cycles, and over a similar time period on the reference river.
- Net sets were of short duration: 0.5 hour for constant flow, 0.25 hr for changing flow. The exact time of each net set was recorded to allow for calculation of flow through net.
- Depth and velocity were recorded at the beginning and end of each net set.
- With the use of 2 nets, sampling was continuous during the full low-up-high-down ramping cycles.

- Invertebrate sampling was similar to the rock bag processing described above.
- In addition, the residual sample was dried and weighed and then ashed and weighed to obtain an estimate of the amount of unidentifiable organic and inorganic material in the water column.
- Data obtained included invertebrate richness, diversity (PIE), density (Number $\cdot 100m^{-3}$) and ash weight (inorganic matter$\cdot 100m^{-3}$) and ash-free-dry-weight (organic matter$\cdot 100m^{-3}$).
- Preliminary results indicate that there is an increase in both the number of invertebrates and drifting organic and inorganic matter during up ramping relative to other flow conditions.

Cross-sectional transects

- The standing crop of invertebrates was sampled in cross-sectional transects in the Magpie River and a series of unregulated rivers to determine: 1) What are the habitat conditions and community characteristics of invertebrates in natural streams and the Magpie River on transects from the shore to deeper areas of the river, 2) Why do we see these community patterns?, and 3) What does these mean for the fishes? Samples along the transect taken near the shoreline will be wetted only at high flows, the low flow channel will be continuously wet, and samples in-between will experience wetting at some intermediate level of duration and frequency.
- Three transect sites were established from shoreline towards center of the river, in areas where relatively small change in discharge (double – max = 44) translates into a change in wetted area.
- Transects were sampled at low flow and again at high flow to get as wide a representation as possible of the invertebrate community in the wet-dry zone vs. the permanently wet zone.
- On the unregulated systems transects began at the shoreline and went as deep as reasonable for sampling.
- Benthos was sampled using a standard Surber sampler for 2 minutes. Depth and velocity were taken at each net.
- Invertebrates were preserved in 75% ethanol and, in most cases, the entire sample was later identified to the species level, but the sample could be sub-sampled if needed.
- The data will be used to understand production of benthic invertebrates in natural and regulated streams. Specifically, what is the functional river width?
- Benthic invertebrate densities in natural rivers tended to be highest in the shallow water; whereas, in the Magpie densities were highest in the deepest parts of the channel (that associated with the low flow reg of 7.5 cms).
- The area of Magpie stream bed that is frequently wetted and dewatered harbour mainly tolerant benthic invertebrates e.g., oligochaeta, nematodes, and gastropods.

Food webs (in collaboration with U. Waterloo – J. Marty and M. Power)

- A stable isotope approach was applied to identify the effects of flow regulation and ramping rate flow regime on the sources of carbon supporting the food web (d13C) and on the food web structure (d15N).
- Aquatic vegetation, terrestrial vegetation, aquatic and terrestrial invertebrates, and fish were collected for carbon and nitrogen stable isotope analysis.

- On each river the upper control site and two downstream sites were sampled both 2 years before and 2 years after ramping change.
- Samples were kept frozen until they were dried at 50°C and ground into powder.
- Results are given using the standard δ notation with $\delta=[(R(_{sample}/R_{reference}) - 1] \times 1000$, expressed in units per thousand (‰) and $R={}^{13}C/{}^{12}C$ or ${}^{15}N/{}^{14}N$ (Verardo et al. 1990).
- Precision on stable isotope measurement was calculated as the standard deviation of a series of repeated samples signatures.
- Both isotopes can reveal complexity of food webs through number of food resources and food web length.
- Preliminary results indicate that both river regulation and changes in ramping regime affect stable isotope signatures of organisms and therefore food web C source and length.

Results & Discussion

The study is ongoing and 2007 is the final year in the experimental phase. Results are therefore preliminary and will not be outlined here in detail. All sampling programs are yielding results that have low variance and a high probability to detect an effect from a change in operational regime, should such a change occur. Any sampling effort that did not yield useful data was dropped early in the project and was not described in this summary. Final results will be reviewed at the annual Design and Management Team meetings in April 2008.

Overall, it is expected that this project will result in the following:

- The ecological responses to effective ramping rates can be applied to other systems.
- The information about the relationships between fish communities and their habitats that will be gained from the mechanistic studies will improve our understanding of the underlying processes of change and associated linkages.
- Results will be incorporated into provincial and federal waterpower guidelines and policy, facilitating science-based decisions regarding ramping at hydroelectric facilities.
- In addition, methodologies developed will be incorporated into monitoring programs for Water Management Plans at existing and newly developed hydroelectric generation facilities in Ontario.

Assumptions

Assessment of Validity

References

Keough, M.J., and Quinn, G.P. 2000. Legislative vs. practical protection of an intertidal shoreline in Southeastern Australia. Ecol. Appl. **10**: 871-881.

Mason W.T., Lewis, P.A. and Weber, C.I. 1985. An evaluation of benthic macroinvertebrate biomass methodology field assessment and data evaluation. Environ. Monit. Assess. **5**: 399-422.

Shaw, D.W., and Minshall G.W. 1980. Colonization of an introduced substrate by stream macroinvertebrates. Oikos 34: 259-271.

Verardo, D.J., P.N. Froelich, & A. Mcintyre 1990. Determination of organic carbon and nitrogen in marine sediments using the Carlo-Erba NA-1500 Analyzer. Deep-Sea Res. **37**: 157-165
Questions?

4.28. Anderson et al. 2006. - Rivers

Ecological Dynamic Models
Anderson, K.E., Paul, A.J., McCauley, E., Jackson, L.J., Post, J.R., and Nisbet, R.M. 2006. Instream flow needs in streams and rivers: the importance of understanding ecological dynamics. Front. Ecol. Environ. 4(6): 309-318.
System Type and Method Classification.
Streams and Rivers. Predictive (in theory) – Ecological dynamics.
Reason for Assessment/ Objective
A tool is required to assess instream flow needs for populations and communities that takes into account dynamic feedbacks among physical and biological components of the river environment. Integrating ecological dynamics in streams and rivers into IFN assessments is essential to make progress towards process-oriented holistic IFN assessments.
Methods
• At the core of hydrological and habitat-based IFN methods is that ecological tolerances of target organisms exist for physical habitat features that vary with flow, and that these can be quantified as habitat suitability curves. • Habitat suitability curves combined with detailed physical habitat models predict how weighed useable habitat area varies over a range of discharge levels, assumes a linear relationship between habitat area and population biomass, and assumes that curves are independent of flow conditions. • These key assumptions have little empirical support, receive much criticism, and have been empirically demonstrated as false (e.g. Vilizzi et al. 2004; Holm et al. 2001). • Habitat preferences based solely on habitat are not static and change in response to numerous abiotic and biotic factors, all of which can change with flow. • Habitat preference models based on bioenergetics or behaviour can incorporate organism responses to biotic components of the environment (e.g. food availability, competition, costs of swimming, predation), have been successfully validated at microhabitat scales (reviewed in Rosenfeld 2003), but still often ignore changing preferences across the life cycle. • Crucial feedbacks between populations (population dynamics) are affected by environmental forcing (including feedback between flow and factors that depend on flow), affect recruitment and survival rates, and ultimately population abundance. • Population dynamics are also driven by spatial and temporal variability – changes that can occur at local and landscape scales and at immediate and decadal scales respectively. • Recent advances in ecological modelling of streams and rivers can address

some of these issues and are reviewed by the authors:

- o Dynamic energy budget (DEB) models (Kooijman 2000; Nisbet et al. 2000) use differential equations to describe rates at which individuals distribute food energy among competing demands (growth, maintenance, reproduction etc.), but also allow feedbacks among bionergetics, conspecific densities, resource populations and the local environment, and provide a means to connect these processes to population dynamic outcomes. DEB-based population models need further development in the area of spatially explicit problems across a riverscape.
- o Spatial scales over which population dynamics are regulated by variability in ecological processes can be described by characteristic length scales. Length scales are especially important for rivers due to effects of longitudinal transport of materials and organisms, and can provide a useful means to compare spatial scales of management effects to relevant processes to preserve population and community viability (see Table 2).
- o Response length is a length scale that measures the effects of a local environmental disturbance on distant populations (Anderson et al. 2005).
- o Minimum habitat lengths refer to requirements for populations to be able to balance production with downstream losses in rivers, and usually increase with increasing downstream dispersal, indicating the importance of quantifying dispersal response to changing flow conditions (Lutscher et al. 2005).
- o Population persistence over landscapes requires careful consideration of habitat arrangements and landscape geometry (e.g. Eby et al. 2003). Predicting the influence of flow regime changes on viability or community structure over large scales may require integrating population dynamic-models with map-based models of physical processes (Ganio et al. 2005).
- o Temporal environmental variability is often incorporated into process-oriented ecological models as a forcing function affecting changes in dynamic rates. Tools available are most often limited to closed environments or local effects in open environments. Integrating both spatial and temporal variability in flow effects on population and communities remains a challenge.

Results & Discussion

The authors conclude by indicating that many ingredients required to couple ecological dynamics to the physical environment in a process-driven framework exist, but reiterate 4 topics where further research is required. Ecologists can provide practical assistance to managers seeking IFN assessments with increased predictive power and transferability across time and space by integrating rates of interactions between organisms and their environment into a framework to determine IFNs.

Assumptions

Assessment of Validity

References

Anderson, K.E., Nisbet, R.M., Diehl, S. Et al. 2005. Scaling population responses to spatial environmental variability in advection-dominated systems. Ecol.

Lett. 8: 933-943.
Eby, L.A., Fagan, W.F., and Minckley, W.L. 2003. Variability and dynamics of a desert stream community. Ecol. Appl. 13: 1566-1579.
Ganio, L.M. Torgersen, C.E., Gresswell, R.E. 2005. A geostatistical approach for describing spatial pattern in stream networks. Front Ecol. Environ. 3: 138-144.
Holm, C.F., Armstrong, J.D., and Gilvear, D.J. 2001. Investigating a major assumption of predictive instream habitat models: is water velocity preference of juvenile Atlantic salmon independent of discharge? J. Fish. Biol. 59: 1653-1666.
Kooijman, S.A.L.M. 2000. Dynamic energy and mass budgets in biological systems. Cambridge, MA: Cambridge University Press.
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Nisbet, R.M., Muller, E.B., Lika, K., et al. 2000. From molecules to ecosystems through dynamic energy budget models. J. Anim. Ecol. 69: 913-926.
Rosenfeld, J. 2003. Assessing the habitat requirements of stream fishes: an overview and evaluation of different approaches. T. Am. Fish. Soc. 132: 953-968.
Vilizzi, L., Copp, G.H. and Roussel, J.M. 2004. Assessing variation in suitability curves and electivity profiles in temporal studies of fish habitat use. River. Res. Appl. 20: 605-618.

4.29. Various. - Streams and Rivers.

Model Category: Predicting fish abundance from habitat variables.

E.g.

Bowlby, J.N. and Roff, J.C. 1986. Trout biomass and habitat relationships in southern Ontario streams. Trans. Am. Fish. Soc. 115: 503-514.
Fausch, K.D., Hawkes, C.L., and Parsons, M.G. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. Gen. Tech. Rep. PNW-GTR-213. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 52 p.
Bradford, M.J., Taylor, G.C., and Allan, J.A. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Trans. Am. Fish. Soc. 126: 49-64.

System Type

Streams and Rivers. Predictive – habitat quality.

Reason for Assessment/ Objective

Reasons are varied and range from the desire to predict standing crop from measurable characteristics of the environment, to identifying habitat variables linked to fish biomass or production to allow for directed stream improvement efforts or predict the impact of a detrimental change, identification of limiting habitat factors, or allowing more cost-effective region-wide management of fish populations by using readily available sources of data.

Methods

- Specifics vary but the premise is the same, which is to link fish to habitat in a quantitative manner.

- Capture fish using a quantitative technique (e.g. electrofishing in a grid pattern, or using pass-removal techniques with barrier nets, to quantify biomass, abundance or a relative index thereof) and record physical habitat attributes for each sample.
- Physical habitat can include quantification of primary production and/or benthos (food supply), instream cover, space (width, depth), substrate characteristics, water quality, water temperature, velocity, groundwater input etc.
- Some models use categories of habitat variables such as: drainage basin variables; channel morphometry and flow variables; habitat structure, biological, physical, and chemical variables; a mix of the first 3 types; or, weighted useable area (see Bovee 1982). Many examples of models developed under each category are described in Fausch et al. (1988).
- Some suggest excluding highly correlated variables to avoid redundancy.
- Usually some type of regression (stepwise forward linear, logistic) is used to identify which variables are significantly correlated with fish abundance or biomass (often by species or life stage). The final set of habitat variables account for the greatest amount of variation in the fish measure.
- Resulting models are considered predictive of fish biomass or abundance according to the significant variables which then identify suitable habitat.
- Reduced set of variables can then be included in subsequent analyses (e.g. discriminant function analysis) to classify sites by amount of fish present (i.e. good to poor).
- While not always conducted, it is important to validate the model developed with an independent set of data (i.e. use habitat to predict fish measure and then see how prediction matches reality).
- Quality of model can be judged based on sample size, coefficient of determination, degrees of freedom, and validation using independent data (to assess accuracy at another time or place).

Results & Discussion

Fausch et al. (1988) identified 6 problems with models, largely arising from minimizing or ignoring sampling or statistical problems while developing the model. The most common problems in model development and testing include:

- Inadequate sample size. Data measured at too few locations for too few dates to encompass the range of variability in fish or habitat variables.
- Procedures used to fit linear regression models assume that the independent habitat variables are measured without error. This assumption is often violated it is suggested that sensitivity analysis be conducted to determine how the model would change if habitat variables changed by an amount reflecting measurement error.
- How to choose the best model – facilitated by some statistical procedures (e.g. stepwise regression) but it is important not to pick a model solely based on the coefficient of determination as it will increase as variables are added (in multiple regression) which can result in unwieldy models. Presenting alternative models that take into considerations ease and expense of measuring habitat variables is also suggested.

- Few investigators attempted to test or validate models to determine if they are accurate in another time or place.
- Using habitat models to predict what will happen in the future or at another place but the existence of significance does not assure that the prediction will be useful. Misuse of models should be minimized by presenting ranges of values measured for habitat variables and recommending that future applications do not extrapolate beyond the range. Without experimentally changing habitat variables and measuring response there is a risk that the assumption that a change in a habitat variable caused an observed change in fish is false.
- If experimentation is possible, it is a good way to test if hypotheses about mechanisms underlying the response of fish populations to habitat are sound.

For models to be useful to managers, variables need to be able to be affected by management practices.
Precise models can be developed for specific cases, but more general, less precise models based on ecoregions can also be useful.

Assumptions

- A major biological assumption common to all models is that the fish population is limited by the set of habitat variables included in the model.
- Fishing, interspecific competition, or predation might be limiting the standing crop below what the environment can support, and these factors should be considered, limited, or accounted for.
- Large risk arises when one researcher takes a published model and applies it to another location at another time without first evaluating and testing the model to determine whether it applies under the new conditions.

Assessment of Validity

References

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Inf. Pap. 12, FWS/OBS-82126. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 248 p.

4.30. Parasiewicz 2007. - Rivers

Model Category: MesoHABSIM

Parasiewicz, P. 2001. MesoHABSIM: A concept for application of instream flow models in river restoration planning. Fisheries 26(9): 6-13.
Also see:
Parasiewicz P. 2007a. The MesoHABSIM model revisited. River Research and Applications, 23(8): 893-903.
Parasiewicz P. 2007b. Using MesoHABSIM to develop reference habitat template and ecological management scenarios. River Research and

Applications, 23(8): 924-932. Parasiewicz P. and Walker, J.D. 2007. Comparison of MesoHABSIM with two microhabitat models (PHABSIM and HARPHA). River Research and Applications, 23(8): 904-923.
System Type
Streams and Small Rivers. Predictive – habitat quality.
Reason for Assessment/ Objective
MesoHABitat SIMulation (MesoHABSIM) model design builds on Instream Flow Incremental Methodology (the physical side of fish-habitat relations) but applies to larger-scale habitat that will accommodate biological data collection more relevant to the scale of management decisions (large frameworks for river restoration).
Methods

• Instead of intensively sampling a few representative sites, the survey of physical habitat should determine the spatial extent of mesohabitats (i.e., riffle, run, pool, backwater etc.) in the study area under multiple flow conditions.
• As flow changes so does the distribution of hydro-morphological units (e.g. increasing flow = increasing runs).
• Need to identify high-, medium- and low-gradient sub-reaches, and then the habitat within those as described in Table 1 (e.g. riffle, run, etc.), combined with random sampling of magnitude of depth, velocity and presence of cover = mesohabitat type.
• Collection of physical data at a larger spatial scale requiring fewer resources (e.g. 2 km per day hiking wadeable stream; 7 km per day boating a larger river).
• More effort-intensive is the fish collection survey. Transferability of habitat use models among similar rivers is being explored.
• Species-specific (or community specific) habitat suitability is key. Use standard methods and multivariate statistics (e.g. multivariate logistic regression) to quantify mesohabitat level biological criteria and habitat quality assessments.
• The quality of a section or river reach can be defined by quantifying habitat areas with probabilities higher than 50% at various flows (or other options presented).
• Habitat rating curves for specified units can be constructed by plotting suitable habitat area, or weighted useable area, or landscape metrics against discharge.
• Biological response to individual restoration measures are simulated by manipulating the quantity or quality of mesohabitats and spatial or temporal variation of flow.
• Simply stated, MesoHABSIM is an aggregation of three models (described in detail in Parasiewicz 2007a):
  o A hydromorphologic model that describes the spatial mosaic of fish-relevant physical features.
  o A biological model describing habitat use by animals.
  o A habitat model quantifying the amounts of usable habitat and

relating it to flow.

- An example of an application is provided for the restoration study on the Quinebaug River, MA and CT (in Parasiewicz 2001) and is begin applied to the Upper Delaware River in New York and Pennsylvania to test applicability to large rivers (Parasiewicz 2007).
- Parasiewicz and Walker (2007) compared the output of MesoHABSIM for the Quinebaug River to that obtained using PHABSIM (Physical Habitat Simulation Model – microscale model, univariate habitat-use criteria and substrate based channel index) and using HARPHA (microhabitat model using multivariate criteria including a range of cover attributes).
- Model designs were chosen to reflect similar effort in data collection and computation.
- Habitat was mapped using cross sections, a hydraulic model was developed, habitat based suitability curves were generated from fish survey data, and the habitat model was developed to predict the amount of weighted usable area (WUA) for each site at different flows. WUA for the fish community was calculated by summing the species-specific WUAs weighted by species proportions expected in the target community and the results were used to create flow-habitat rating curves. (details available in Parasiewicz and Walker 2007).
- Model verification studies used to confirm whether predictions from different models are similar included comparing spot observations of fish density to suitability indices for the same location. Verification will also analyze the interpretation output of the models at the management scale to determine if conclusions are similar.
- Model outputs were analyzed at both the site and study scales. Flow-habitat rating curves were visually compared focusing on relative position and shape of each species' curve within each site and in the entire study area.
- A series of key questions were formulated (e.g. which site had the greates amount of suitable habitat?) and answers given by each model were compared using Spearmans rank correlations.

Results & Discussion

- Theoretical concept of modeling a river system at a mesohabitat scale of resolution, emphasizing biological requirements and includes large-scale spatial coverage.
- Method permits the quantitative evaluation of management scenarios from the perspective of the aquatic community in the entire river.
- Mesohabitat scale precision is more efficient for capturing biological data as fish are captured within their range of diurnal mobility, which also facilitates model validation (and may improve transferability across systems relative to microhabitat models).
- Recognizes the fauna react to the environment at different scales related to the size and mobility of the species as well as time of use (roughly corresponding to functional habitat).
- Of the 3 models, MesoHABSIM was the only one that showed a significant regression between predicted probabilities of fish presence and the

numbers of fish caught in the area. • At the study-segment scale the shapes of the rating curves for all models differed, although the order of species was similar between MesoHABSIM and HARPHA. At the site scale differences are more prominent. • Differences could lead to varying conclusions about the magnitude of available habitat, the inflection points of rating curves, the habitat stability, the species-habitat dominance structure, and the relative suitability of specific sites. • If a microhabitat model is used it is critical that there is demonstration that underlying assumptions are met. Instream and overhead cover and the placement of transects have significant impacts on results and subsequent decisions. The quality of the biological model (development and testing of suitability criteria) should be given particular attention when applying any physical habitat model.
Assumptions
Assessment of Validity
Questions?

5. References (not including summarised papers)

DFO, 1986. Policy for the Management of Fish Habitat. Communications Directorate, Fisheries and Oceans Canada, Ottawa, Ont.

DFO, 2005. Fish Habitat Considerations Associated with Hydro-Electric Developments in Quebec Region. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/038.

DFO. 2008. Workshop to compare methods to quantify the productive capacity of fish habitat impacted by hydro operations; October 15-16, 2007. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/002.

Appendix A: Original email request for methods.

Originally sent December 20, 2006. Reminders sent January and February 2007.

Hello,

You are receiving this email because of your involvement in the DFO-CEA MOU, or with the DFO Center of Expertise for Hydro impacts (CHIF), or have worked directly with me on a hydro issue, or are known to work in streams and rivers. I apologize if you have received this request more than once, and I thank you in advance for any help you provide.

In response to the priorities identified at the CHIF Workshop held on September 19, 2006, DFO-GLLFAS in Sault Ste Marie has initiated an exercise that will document the methods used to measure productive capacity of aquatic systems affected by hydro development. We are interested in collecting documentation of these methods, particularly for those currently being used to assess productive capacity for upstream and downstream systems in both pre- and post development scenarios. Methods are being sought for river and reservoir systems using habitat based, biota based, and/or a combination of approaches. A final report will be produced summarizing each method's rationale, applicable systems, sampling procedures, experimental design, any assumptions made, along with the resulting data, metrics, and how the data were used to assess change. This report will not make recommendations on which method(s) should be employed as the national standard, but will be used as a background document to focus this debate at a proposed National Methods Workshop. Furthermore, this report will neither attempt to re-analyze data or perform any meta-data analyses.

DFO-GLLFAS is asking for your assistance in providing documentation of the methods used or recommended by your organization to assess productive capacity (or index thereof) prior to and post-hydroelectric development. We would greatly appreciate any articles documenting the methods that you are willing to share from the primary literature, grey literature, and/or internal publications. We recognize that the holiday season is very busy for most people, but we were hoping to have the literature collected by the middle of January, 2007. Please feel free to submit electronic or hardcopy versions to the respective addresses or fax number listed below, or to provide a citation for us to obtain on our own.

Thanks and have a great holiday season,

Karen

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