Fisheries
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ufsh20

NSERC's HydroNet: A National Research Network to Promote Sustainable Hydropower and Healthy Aquatic Ecosystems

Karen E. Smokorowski [a], Normand Bergeron [b], Daniel Boisclair [c], Keith Clarke [d], Steven Cooke [e], Rick Cunjak [f], Jeff Dawson [e], Brett Eaton [g], Faye Hicks [h], Paul Higgins [i], Chris Katopodis [j], Michel Lapointe [k], Pierre Legendre [l], Michael Power [m], Robert Randall [n], Joseph Rasmussen [o], George Rose [p], Andre Saint-Hilaire [b], Brent Sellars [q], Gary Swanson [r], Nicholas Winfield [s], Roger Wysocki [t] & David Zhu [h]

[a] Fisheries and Oceans Canada (DFO), Science, Sault Ste. Marie, Ontario, Canada E-mail: Karen.Smokorowski@dfo-mpo.gc.ca

[b] Program in Hydrology, Institut National de Recherche Scientifique-Eau-Terre-Environnement (INRS-ETE), Quebec, QC, Canada

[c] Department of Biological Sciences, University of Montreal, Montreal, Quebec, Canada

[d] Fisheries and Oceans Canada (DFO), Science, Oceans and Environment Branch, St. John's, NL, Canada

[e] Department of Biology, Carleton University, Ottawa, ON, Canada

[f] Canadian Rivers Institute, University of New Brunswick, Fredericton, NB, Canada

[g] Department of Geography, University of British Columbia, Vancouver, BC, Canada

[h] Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada

[i] BC Hydro, Burnaby, BC, Canada

[j] Fisheries and Oceans Canada (retired); Katopodis Ecohydraulics Ltd., Winnipeg, MB, Canada

[k] Department of Geography, McGill University, Montreal, QC, Canada

[l] Department of Mathematics and Statistics, University of Montreal, Montreal, QC, Canada

[m] Department of Biology, University of Waterloo, Waterloo, ON, Canada

[n] Fisheries and Oceans Canada (DFO), Science, Burlington, ON, Canada

[o] Department of Biological Sciences, University of Lethbridge, Lethbridge, AB, Canada

[p] Centre for Fisheries Ecosystem Research, Fisheries and Marine Institute, Memorial University of Newfoundland, St. John's, NL, Canada

[q] Nalcor Energy, St. John's, NL, Canada

[r] Manitoba Hydro, Winnipeg, MB, Canada

[s] Fisheries and Oceans Canada (DFO), Habitat Management Policy Branch, Ottawa, ON, Canada

[t] Environment and Biodiversity Science Branch, Ottawa, ON, Canada

Available online: 19 Oct 2011

NSERC's HydroNet: A National Research Network to Promote Sustainable Hydropower and Healthy Aquatic Ecosystems

Karen E. Smokorowski
Fisheries and Oceans Canada (DFO), Science, Sault Ste. Marie, Ontario, Canada (Corresponding author: Karen.Smokorowski@dfo-mpo.gc.ca)

Normand Bergeron
Program in Hydrology, Institut National de Recherche Scientifique–Eau-Terre-Environnement (INRS-ETE), Quebec, QC, Canada

Daniel Boisclair
Department of Biological Sciences, University of Montreal, Montreal, Quebec, Canada

Keith Clarke
Fisheries and Oceans Canada (DFO), Science, Oceans and Environment Branch, St. John's, NL, Canada

Steven Cooke
Department of Biology, Carleton University, Ottawa, ON, Canada

Rick Cunjak
Canadian Rivers Institute, University of New Brunswick, Fredericton, NB, Canada

Jeff Dawson
Department of Biology, Carleton University, Ottawa, ON, Canada

Brett Eaton
Department of Geography, University of British Columbia, Vancouver, BC, Canada

Faye Hicks
Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada

Paul Higgins
BC Hydro, Burnaby, BC, Canada

Chris Katopodis
Fisheries and Oceans Canada (retired); Katopodis Ecohydraulics Ltd., Winnipeg, MB, Canada

Michel Lapointe
Department of Geography, McGill University, Montreal, QC, Canada

Pierre Legendre
Department of Mathematics and Statistics, University of Montreal, Montreal, QC, Canada

Michael Power
Department of Biology, University of Waterloo, Waterloo, ON, Canada

Robert Randall
Fisheries and Oceans Canada (DFO), Science, Burlington, ON, Canada

Joseph Rasmussen
Department of Biological Sciences, University of Lethbridge, Lethbridge, AB, Canada

George Rose
Centre for Fisheries Ecosystem Research, Fisheries and Marine Institute, Memorial University of Newfoundland, St. John's, NL, Canada

NSERC's HydroNet: Red Nacional de Investigación para Promover el Uso Sustentable de Energía Hidroeléctrica y Ecosistemas Acuáticos Saludables

RESUMEN: NSERC's HydroNet es un programa nacional colaborativo de investigación a cinco años que inició en el año 2010 e involucra a los sectores académico, gubernamental e industrial. El objetivo general de HydroNet es comprender los efectos que tienen las operaciones hidroeléctricas en los ecosistemas acuáticos y ofrecer herramientas científicas defendibles y transparentes tendientes a mejorar los procesos en la toma de decisiones que están asociados al uso de la energía hidroeléctrica. Diversos proyectos se encuentran insertos en tres grandes tópicos: 1) análisis ecosistémico de la capacidad productiva de los hábitats para peces (CPHP) en ambientes fluviales, 2) Modelación de meso-escala de la capacidad productiva de los hábitats para peces en lagos y embalses, y 3) predicción del riesgo de arrastre de peces hacia los embalses hidroeléctricos, en función del poder generador de las operaciones, combinando la ecología conductual y la ingeniería hidráulica. El conocimiento generado por HydroNet es fundamental para evaluar el balance entre la demanda por recursos hídricos limitados, para asegurar que la energía hidroeléctrica sea sustentable, que promueva la salud de los ecosistemas acuáticos así como también a la pujante economía canadiense.

Andre Saint-Hilaire
Program in Hydrology, Institut National de Recherche Scientifique–Eau-Terre-Environnement (INRS-ETE), Quebec, QC, Canada

Brent Sellars
Nalcor Energy, St. John's, NL, Canada

Gary Swanson
Senior Environmental Specialist, Manitoba Hydro, Winnipeg, MB, Canada

Nicholas Winfield
Fisheries and Oceans Canada (DFO), Habitat Management Policy Branch, Ottawa, ON, Canada

Roger Wysocki
Environment and Biodiversity Science Branch, Ottawa, ON, Canada

David Zhu
Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada

All authors are also members of the NSERC HydroNet Network, Department of Biological Sciences, University of Montreal, QC, Canada.

ABSTRACT: *NSERC's HydroNet is a collaborative national five-year research program initiated in 2010 involving academic, government, and industry partners. The overarching goal of HydroNet is to improve the understanding of the effects of hydropower operations on aquatic ecosystems, and to provide scientifically defensible and transparent tools to improve the decision-making process associated with hydropower operations. Multiple projects are imbedded under three themes: 1) Ecosystemic analysis of productive capacity of fish habitats (PCFH) in rivers, 2) Mesoscale modelling of the productive capacity of fish habitats in lakes and reservoirs, and 3) Predicting the entrainment risk of fish in hydropower reservoirs relative to power generation operations by combining behavioral ecology and hydraulic engineering. The knowledge generated by HydroNet is essential to balance the competing demands for limited water resources and to ensure that hydropower is sustainable, maintains healthy aquatic ecosystems and a vibrant Canadian economy.*

Introduction

The 470-plus hydroelectric facilities distributed across the country generate more than 60% of the electricity used by Canadians (Canadian Electricity Association 2009). The rising demand for energy and the interest in renewable energy will require additional facilities and increased production from the existing installations. Hydroelectric facilities have a direct influence on all physical, chemical, and biological processes that take place in aquatic ecosystems and, eventually, on their capacity to produce biomass (Poff et al. 1997; Rosenberg et al. 1997). Although progress has been made on several mitigation measures, ecological, economic, policy, and scientific challenges remain (Katopodis 2005). Though it is desirable that environmental stewardship attributes of hydroelectric facilities parallel their performance at producing electricity, achievement of the former objective is impeded by the difficulties associated with accurately estimating the effects of hydropower on aquatic ecosystems. A better understanding of the effects of hydroelectric facilities on the productivity and the biodiversity of communities is imperative to reconcile industrial and environmental water requirements.

Hydroelectric facilities transform natural lakes and rivers into reservoirs and regulated rivers. When discharge is regulated for hydropower, five main flow characteristics are affected, including magnitude, duration, timing (seasonality), recurrence frequency, and rates of change (Magilligan and Nislow 2001, 2005). All affect riverine biota directly and indirectly via short-term and long-term impacts on fish behavior and habitat (Richter et al. 1996; Clarke et al. 2008). Production rate ($kg \cdot ha^{-1} \cdot y^{-1}$) is generally taken as an integrated measure of the degree to which organisms fulfill the three key ecological functions that will ensure the perpetuation of their population: survival, growth, and reproduction. The importance of maintaining fish production is embedded within the *Policy for the Management of Fish Habitat* (the policy; Department of Fisheries and Oceans [DFO] 1986), which has been adopted by Fisheries and Oceans Canada and has as a first objective to protect the productive capacity of fish habitats (PCFH). In the policy, productive capacity is defined as "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" (DFO 1986). However, in application of the policy, numerous indices or surrogates have been used (e.g., habitat area with assumed suitability, biomass, or catch per unit effort), with the frequency of use in direct relation to the complexity of the measure (Quigley and Harper 2006). The result is that population or community production is rarely used as a measure of PCFH in application of the Fisheries Act (Smokorowski et al. 1998). In addition, the policy states that "no net loss of the productive capacity of habitats" (DFO 1986) is fundamental to the habitat conservation goal. Under this principle, DFO will strive to mitigate habitat changes to the extent possible and balance unavoidable habitat losses with habitat replacement on a project-by-project basis so that further reductions to Canada's fisheries resources due to habitat alteration, destruction, or disruption may be prevented.

Managers responsible for implementing this policy and proponents of projects (e.g., hydroelectric companies) must be able to estimate the productive capacity of an aquatic ecosystem before and to predict the productive capacity of this ecosystem after the realization of a project such that the principle of no net loss can be respected. The estimation of PCFH is complicated by the nature of this variable, which is the integration of the effects of numerous environmental conditions on the complete fish community. The productive capacity of fish habitats has most often been evaluated directly from measures of fish abundance or productivity (Randall et al. 1995; Randall and Minns 2000; Scruton et al. 2005). The difficulties in estimating fish production have inspired attempts to identify adequate surrogates or correlates of fish production (Rawson 1952; Ryder 1965; Oglesby 1977; Randall 2003), yet there is still no consensus on the methods and the metrics that should be used to estimate PCFH on a routine basis or on the variables that should be used to predict the effects of hydropower on PCFH with sufficient statistical precision (Smokorowski and Derbowka 2008; Smokorowski and Dutil 2008). Given its ecological significance and key role in the decision-making process, the productive capacity of fish habitats is taken as the central theme of the HydroNet research program.

HydroNet was awarded funding in 2010 from the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Network Program (SNG) and the NSERC Collaborative Research and Development Program (CRD) to undertake a 5-year research program focusing on the definition of standard approaches to estimate PCFH, the identification of the best indices to represent PCFH, and the identification of key variables related to hydropower that affect PCFH. Study sites are distributed nationally (Figure 1), as are the fisheries and aquatic scientists that comprise the network. HydroNet's research program was developed based on industry and government priorities, and an ongoing feedback process will continue to ensure its relevance (Figure 2). Partners directly involved with HydroNet include Fisheries and Oceans Canada (DFO Habitat Management Program), Manitoba Hydro, B.C. Hydro, and Nalcor. Satellite partnerships have subsequently been formed with DFO Science (through the Center of Expertise on Hydropower Impacts on Fish and Fish Habitat, CHIF) Brookfield Renewable Power Ltd., and numerous provincial government agencies. Here we describe the objectives of HydroNet, provide an overview of the ongoing and future research activities that will be conducted by the network, and describe some lessons learned from implementation of the first presampling year. This article is part of a series in *Fisheries* that is focused on NSERC Strategic Networks that are currently active in Canada and have specific relevance to fisheries and aquatic science (see Hasler et al. 2011 for introductory article).

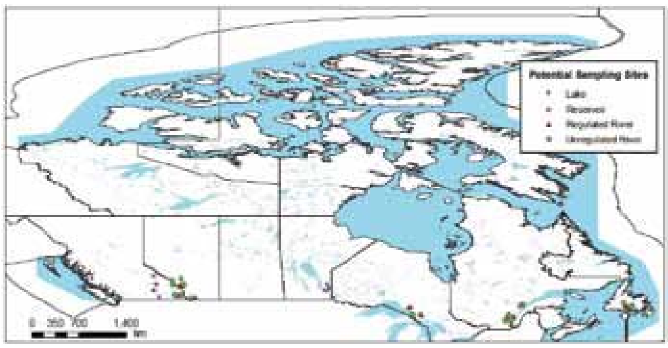

Figure 1. Map of Canada showing the distribution of the short list of potential sampling sites categorized as lake, reservoir, regulated river, and unregulated river.

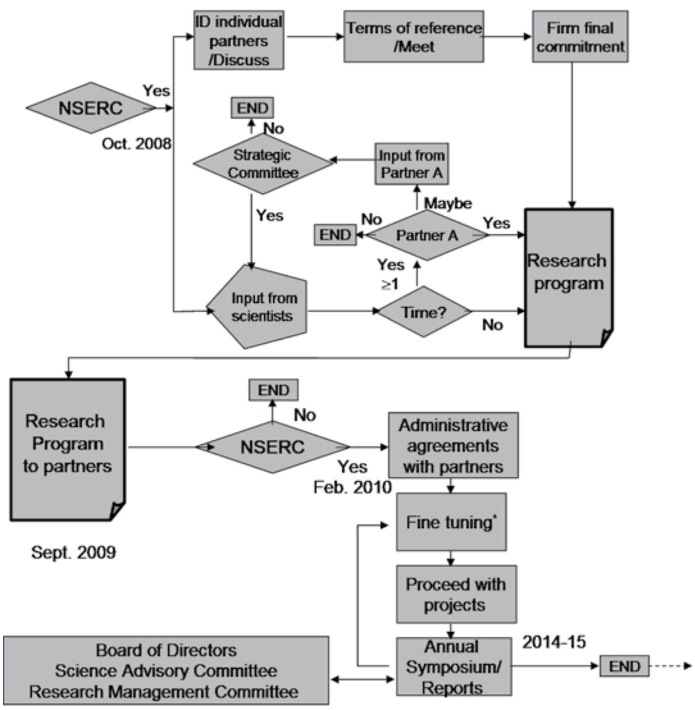

Figure 2. Schematic of the interactive process between academia, government, and industry used to develop the final NSERC proposal and how this interactive model will continue through the term of HydroNet.

HydroNet Objectives

The general objective of NSERC's HydroNet is to promote sustainable hydropower in Canada via a better understanding of the effects of hydroelectric operations on aquatic ecosystems. Through coordinated national efforts, NSERC's HydroNet will supply new knowledge about the effects of hydropower on abiotic and biotic processes. Science-based practical solutions will provide industry and government resource managers with new tools to assess, mitigate, and minimize potential impacts on aquatic ecosystems, improve the decision-making process associated with hydropower operations, and reduce conflict among stakeholders. By working to achieve the goal of sustainable hydropower in Canada, NSERC's HydroNet's specific objectives include the following:

- improvement of approaches to estimate and model physical drivers of the productive capacity of fish habitats;
- definition of standardized protocols capable of estimating the productive capacity of fish habitats;
- identification of the relative importance of chemical, physical, and biological drivers of the productive capacity of fish habitats and of large-scale (ecosystem-level) and small-scale (habitat patches) environmental conditions on this variable;
- improved understanding of the effect of hydropower on key biological processes (e.g., effect of flow modifications on egg survival, relationship between environmental conditions affected by hydropower and fish growth, effect of the loss of connectivity of habitats on tropic linkages, effect of trash rack design, and reservoir management on fish entrainment in turbines);
- comparison of the productive capacity of fish habitats and its environmental determinants over a range of ecosystems (regulated and unregulated) for which PCFH must be estimated to assess the effect of hydropower on fish;
- development of modeling approaches that will facilitate the routine estimation of the effect of hydropower on the productive capacity of fish habitats.

HydroNet Research Themes

The research program of NSERC's HydroNet comprises three complementary project themes: (1) ecosystemic analysis of productive capacity of fish habitats in rivers, (2) mesoscale modeling of the productive capacity of fish habitats in lakes and reservoirs, and (3) predicting the entrainment risk of fish in hydropower reservoirs relative to generation operations by combining behavioral ecology and hydraulic engineering. Each of these themes is outlined in the following sections, and projects imbedded under each theme are described in Table 1. Complementary projects supported by DFO CHIF and led by DFO scientists, as well as the first of what is hoped to be an expanding network of satellite projects, are also described in Table 1.

Theme 1: Ecosystemic Analysis of the Correlates of Productive Capacity of Fish Habitats in Rivers (Projects 1.1–1.10, 4.2, 4.5, and 5.1, Table 1)

The key objectives of this theme are to (1) assess the relationship between indices of the productive capacity of fish habitats (catch per unit effort, density, biomass, etc.) and large-scale environmental conditions (nutrients, water temperature, geomorphology, etc.) in rivers with average annual discharge less than 300 $m^3 \bullet s^{-1}$, (2) compare such relationships among types of ecosystems (regulated and unregulated rivers), (3) identify the environmental conditions that explain a significant proportion of the variations in indices of PCFH either within or among types of ecosystems, and (4) unveil the effect of environmental conditions (many affected by hydropower) on key biological attributes such as egg survival, fish growth, food web structure, and fish passage.

Theme 2: Mesoscale Modeling of the Productive Capacity of Fish Habitats in Lakes and Reservoirs (Projects 2.1–2.3, Table 1)

The objectives of this theme are to (1) develop sampling protocols to estimate indices of PCFH on a routine basis in different types of ecosystems and habitats (weed beds, sandy beaches, sublittoral, deep pelagic, etc.), (2) develop and compare relationships between various indices of PCFH and environmental conditions estimated for different types of habitats in each ecosystem, and (3) identify the indices of PCFH that correlate best with estimates of fish production. This project will model ecosystems as a mosaic of habitat patches defined by relatively homogeneous environmental conditions (water depth, substrate composition, macrophyte cover, etc.). The use of habitat patches is expected to solve many of the problems that affect the validity of the estimation of PCFH, such as the identification of the best sampling protocol (to be used as a standard methodology), number and diversity of sampling sites, and number of fish species and life stages that should be studied to adequately estimate the effect of hydropower on PCFH. Indices of PCFH, such as catch per unit of effort, fish density, biomass, growth, and production rate, will be estimated during 3 years in two ecosystems (one lake and one reservoir). Interannual variability in fish production rate will be estimated to define clearer patterns of long-term PCFH, an element that is central to the concept of PCFH but that is rarely estimated in the actual application of the Fisheries Act.

Theme 3: Predicting the Entrainment Risk of Fish in Hydropower Reservoirs Relative to Generation Operations by Combining Behavioral Ecology and Hydraulic Engineering (Projects 3.1, 3.2, 4.1, 4.3, and 4.4, Table 1)

Fish entrainment is the process in which fish are displaced from reservoirs by water diversion through turbines or other water release structures at dams. This can result in injury or death and reduce productivity of reservoir fish populations. Assessing fish entrainment risk at new hydropower intakes is one of the requirements of the Canadian Environmental Assessment Act, and managing entrainment effects is an important regulatory consideration at all operating hydroelectric facilities in Canada. Despite the importance of entrainment on regulating fish populations, there is no widely accepted systematic way to assess the risk of resident fish entrainment. The objectives of this theme are to (1) develop and parameterize a model of entrainment risk relative to biotic characteristics (species, sex, size, spawning population) and dam operations that could serve as an approach for future entrainment risk assessments in Canada and beyond and (2) conduct laboratory physical testing to assess the performance and suitability of mitigation alternatives.

Example Case Studies of Ongoing Projects

Here we present three case studies as examples of research activity in each of the three themes.

Theme 1 Case Study: Long-Term Physical Transformations of Regulated Riverine Habitats

The overall objective of this project is to generate physical habitat data (broken down by habitat types and reaches) across pairs of dammed and unregulated (reference) rivers across Canada, which will help explain observed patterns in fish productivity. The Mississagi River, Ontario, below the Aubrey Falls hydroelectric facility was selected for the case study because of the availability of data (Figure 3). Objectives of the study

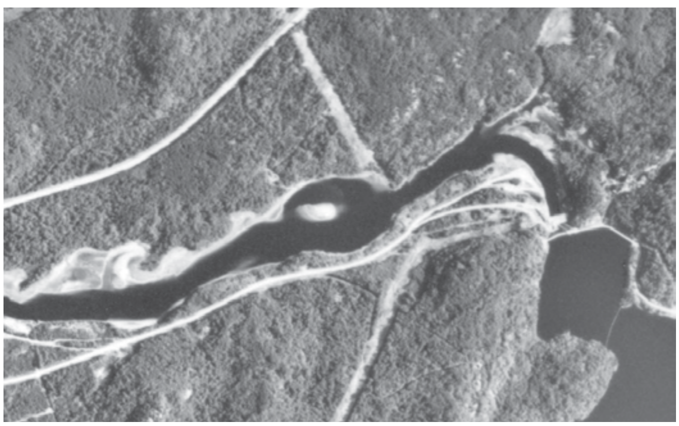

Figure 3. Digital, ortho-rectified aerial photograph of the Mississagi River below the Aubrey Falls Generating Station, Mississagi River, Ontario (1992).

TABLE 1. Projects being conducted under each theme of HydroNet. Theme 0 is networking, themes 1–3 are described in the text of the article, theme 4 is CHIF-funded projects, and theme 5 is related to a satellite project that recently joined HydroNet

No.	Title	Lead	Objectives
0.1	Networking	Dr. Boisclair, University of Montreal	Structuring, coordinating, integrating, expanding, and communicating network research activities
1.1	PCFH in rivers	Dr. Boisclair	Provide metrics of PCFH, quantify the role of environmental conditions on habitat use (by species and life stage), test the hypothesis that habitat quality models vary with fish density
1.2	Chemical drivers of the PCFH	Dr. Rasmussen, University of Lethbridge	Assess regional differences (or latitudinal similarities) in nutrient–fish community relationships. Determine whether river vs. lake differences are related to depth
1.3	Flow regime of natural versus regulated rivers	Dr. Lapointe, McGill University	Characterize the impacts of river damming on a variety of ecosystem-related metrics of river flow regime alteration
1.4	Effects of dams on the thermal regime of rivers	Dr. St-Hilaire, Institut National de Recherche Scientifique	Compare thermal regimes of regulated and unregulated rivers, develop geostatistical models to estimate temperature variability from physical metrics, compare statistical vs. deterministic models at one site
1.5	Long-term physical transformations of regulated rivers	Dr. Lapointe, McGill University	Assess impacts of hydro dams on downstream habitat structure: morphologic, hydraulic and sedimentary conditions, riparian conditions, wetted channel, etc.
1.6	Winter stressors for fish in river: effects of flow regulation	Dr. Hicks, University of Alberta; Dr. Cunjak, University of New Brunswick	Quantify winter regime of rivers to identify environmental stressors that directly influence fish habitat and productive capacity. Distinguish how those stressors vary in regulated vs. unregulated systems in different regions
1.7	Egg survival in response to river regulation	Dr. Cunjak, University of New Brunswick	Determine whether salmonid egg survival and alevin development are related to hyporheic water quality dissolved oxygen (DO) and how this varies with depth, river stage, and winter flow regulation
1.8	Thermal stability downstream of hydroelectric structures	Dr. Power, University of Waterloo	Use oxygen stable isotopes analysis of otoliths to determine average fish thermal habitat use and how differences in temperatures experienced due to river regulation (vs. unregulated rivers) manifest in fish condition and growth
1.9	Effects of regional differences in fish biodiversity on fish production and trophic structure	Dr. Rasmussen, University of Lethbridge	Establish how PCFH is influenced by fish biodiversity, how this differs among geographic regions, and how it affects trophic relationships and habitat use by different species. Determine the effect of system fragmentation on PCFH
1.10	Hydraulic and biological evaluation of upstream sturgeon passage at the Vianney-Legendre Fishway	Dr. Cooke, Carleton University	Combined biological and hydraulic assessment of a fishway that does successfully pass sturgeon to inform the design of future fish passage facilities in Canada
2.1	Hydroacoustic mapping of physical conditions at the scale of habitat patches	Dr. Rose, Memorial University	Use hydroacoustic survey methods to map the bathymetry, bottom type, any special habitat features (e.g., macrophytes), fish distribution, and densities at the scale of habitat heterogeneity
2.2	Detailed physical mapping of shallow areas of lakes and reservoirs at the scale of habitat patches	Dr. Bergeron, Institut National de Recherche Scientifique	Use and refine airborne mapping techniques previously developed for fluvial environments in shallow lake and reservoir shoreline environments to map aquatic habitat such as substrate size, depth, and water temperature
2.3	Metrics of productive capacity in shallow areas of lakes and reservoirs	Dr. Boisclair, University of Montreal	Develop relationships between metrics of PCFH and environmental conditions at a mesohabitat scale, estimate the relative effect of conditions (local, contextual, biotic, abiotic) on habitat use, comparative analysis of habitat use models with different sampling strategies (time of day, gear)
3.1	Hydraulic component: developing a model of entrainment risk based on hydraulic conditions and forebay geometry	Dr. Zhu, University of Alberta	Investigate thermal and hydraulic conditions upstream of four hydro dams of varying size, operation, and configuration to develop an entrainment risk framework for fish and assess the applicability of computational fluid dynamics modeling as a tool to predict entrainment risk
3.2	Biological component: strategies to reduce entrainment risk based on fish behavior and thermal requirement	Dr. Cooke, Carleton University; Dr. Power, Waterloo	Identify the biotic and abiotic factors that influence entrainment risk for key fish species in one reservoir, including the thermal biology of fish. Integrate hydraulic and biological components to develop a model of entrainment risk relative to biotic characteristics and dam operations
4.1	Thermal aspects of fish entrainment risk in Kinbasket reservoir with relevance to other large hydropower facilities in Canada	D. Patterson, DFO	Directly linked to project 3.2 by providing scientific support and equipment, this project will determine how reservoir thermal properties vary seasonally and with respect to hydropower operations to influence entrainment risk for a variety of key fish species
4.2	Longitudinal and lateral responses in riverine communities to altered seasonal flow regimes	K. Clarke, DFO	Assess the impact of the loss of connectivity among habitats, both longitudinal and lateral, by focusing on ecological process and function and by quantifying linkages among abiotic factors and associated biotic responses (primary producers, invertebrate prey, and fishes)

TABLE 1. (continued).

No.	TItle	Lead	Objectives
4.3	Fish behavior in relation to trash racks	Dr. Enders, DFO	Evaluate the performance of trash rack designs from both a hydraulic and biological point of view, analyze the behavioral response of fish approaching trash racks in flume experiments, and monitor entrainment and impingement of fish on the trash racks at a hydro dam
4.4	Numerical investigation of turbulent flows through trash racks in open channels and closed conduits	Dr. Ghamry, DFO	Numerical investigation attributed to the closed conduit trash rack model, for use in providing insight into the effects of the trash rack bar spacing and bar geometry on the flow pattern velocity distribution for closed conduit flows
4.5	Evaluating changes in productive capacity of mountain streams as a result of flow diversions for small hydro development	Dr. Bradford, DFO	Establish the underpinnings of a scientifically defensible approach to evaluating changes in productive capacity of small streams by examining the sensitivity of predictions of optimal flows to the assumptions of a British Columbia instream flow model and levels of sampling intensity. Examine alternative metrics for flow–habitat relations
5.1	Experimental determination of ramping rate effects on downstream biota: Magpie River, Ontario	Dr. Smokorowski, DFO	Use a before–after–control–impact design to assess the impacts of changing from restricted ramping rates to unlimited ramping rates at a peaking hydroelectric facility. Impacts to be assessed on hydrology, geomorphology, fish, invertebrates, food webs, and economics

were to (1) refine methods for classifying and mapping riverine habitat features using high-resolution optical data sources, (2) identify and synthesize methods for quantifying riverine habitat complexity from habitat units, and (3) refine analytical methods for detecting long-term changes in riverine habitat. The first two objectives required a review of the literature and assessment of the suitability of habitat classification metrics for other HydroNet sites. Here we focus on the third objective, which involved an analysis of changes in habitat over time of a 50-km reach downstream of the dam. Channel morphology and riparian vegetation between 1945 and 2009 were mapped using digital, ortho-rectified aerial photographs (1945, 1948, 1965, 1974, 1992), IKONOS, and Landsat satellite images (1985, 2002, 2009). Trends in historical discharge records were also analyzed (1946 to present) using a cumulative departure analysis (Klemes 1978). The Indicators of Hydrologic Alteration software (IHA7; The Nature Conservancy) was also used to document 33 statistics of hydrologic alteration for the site.

Though a change of state (e.g., from a wandering to a meandering or braided channel) would have been possible based on geomorphic theory and the degree of change in the hydrologic regime (both natural and imposed), the case study reach did not change state as a result of flow regulation (the dam was commissioned between 1966 and 1969) or because of long-term shifts in mean annual discharge. However, instream habitat decreased in complexity, with increasing mean annual discharge between 1960 and 1990. For example, floodplain islands were converted to bars through the loss of shrub cover. Lateral connectivity increased between adjacent riparian wetlands and the main channel and through the loss of forest and shrub vegetation at the channel edge, implying an increase in area of divergent flow and in slackwater zones (Figure 3). Such an increase in area of divergent flow may provide more hydraulic refuge for fish. However, refuge provided by structural elements such as vegetation (aquatic, emergent, and terrestrial), large substrate, and associated flow patterns can be lost by decreasing the area of convergent flow. Field studies scheduled for 2011 will test the effects of changes in divergent flow on fish habitat. Preliminary results are consistent with the contention that very low sediment loads and the presence of bedrock outcrops make rivers in the Canadian Shield slow to recover from hydrologic disturbance but resistant to morpho-sedimentary change compared to rivers that drain higher energy, sediment-rich catchments. On a decadal time scale, analysis of changes in the two horizontal dimensions indicated that the most responsive elements of the mesoscale habitat units are the riparian communities. These communities expanded and contracted with shifts in the hydrologic regime. These measurable effects have implications for smaller scale instream habitat features and aquatic inhabitants that have yet to be quantified.

Theme 2 Case Study: Metrics of PCFH in Shallow Areas of Lakes and Reservoirs

Estimation of PCFH in lentic ecosystems faces numerous challenges. First, these ecosystems are often large, which implies intensive sampling. Second, lakes and reservoirs consist of spatially heterogeneous mesohabitats defined by various environmental conditions (depth, temperature, substrate composition, etc.). Third, fish of different species and life stages may require different habitat types for the different ecological functions (survival, growth, reproduction). Fourth, habitat use may vary through time (seasonally or diurnally). Although the transformation of a river or lake into a reservoir has significant and complex effects on physical habitat, quantifying such changes or their effects on the fish community can be difficult.

The specific objectives of this NSERC CRD are to (1) improve our ability to partition large lentic ecosystems into a mosaic of mesohabitats, (2) augment our understanding of the role played by different types of mesohabitats for different fish species and size classes, and (3) gain knowledge about daily variation in fish habitat use. Surveys will be conducted in one lake (Manigotagan Lake) and one reservoir (Lac du Bonnet) in Manitoba. Multifrequency hydroacoustics and telemetry will be used to map water depth, bottom type, aquatic macrophyte cover, fish density and movements, with conventional techniques used to quantify temperature, and provide samples of substrates and macrophyte cover in these ecosystems. Sampling gears possessing different selectivity (i.e., gill nets, seines, fyke nets) will be used to assess habitat use by fish in the littoral and pelagic zones during day and night.

This project will allow us to propose optimal sampling designs to map physical and biological attributes of large lentic ecosystems. This work will also aid the development of predictive tools by identifying the relative effects of different types of environmental conditions (from local to landscape variables) on habitat use by fish. Similarities in habitat use models for combinations of species and life stages are expected to provide guidelines to define fish guilds (of similar habitat requirements) that may facilitate the development and transferability of habitat use models and, hence, the estimation or prediction of PCFH in lakes and reservoirs.

Theme 3 Case Study: Biological and Hydraulic Aspects of Entrainment Risk

Fish entrainment is the process in which fish are nonvolitionally displaced from reservoirs by water diversion through turbines or other water release structures at dams. To date, most of the efforts to quantify and reduce entrainment have focused on downstream migrating salmonid smolts. Considerably less research has focused on adults, particularly resident populations of fish, despite the fact that some populations represent important recreational and First Nations fisheries. Fish entrainment is a function of flow hydraulics and the behavioral characteristics of fish using habitats near dams and adjacent to intake structures. Many studies have failed to fully incorporate hydraulics into fish entrainment studies because of the difficulty in accurately measuring three-dimensional flow fields with standard hydraulic methods. This significant knowledge gap has resulted in little guidance being available for optimizing entrainment mitigation actions.

Consequently, this project is focused on the integration of hydraulic and biological components of resident fish entrainment risk to develop a generalized framework for assessing their entrainment risk. Computational fluid dynamics (CFD) models will be used to study the intake-induced velocity field for different types of reservoirs (high dams vs. run-of-the-river types), different dam forebay geometries and intake arrangements/conditions, reservoir temperature stratifications, as well as hydropower operations. An engineering field program will also be conducted to study some site-specific issues, and the field measurements will be used to calibrate CFD models. At one key reservoir (i.e., Kinbasket), biological data will be collected to understand the spatial ecology and thermal biology of burbot (*Lota lota*) and bull trout (*Salvelinus confluentus*) using acoustic telemetry. Telemetry studies were initiated in 2010 and 240 depth- and temperature-sensing transmitters were deployed (see Figure 4). Toward the end of the 5-year project the validated CFD models will be used to guide the design of the field biological assessment of fish response to flow hydraulics and assist in the definition and evaluation of both fish entrainment risk models and mitigation alternatives for generating stations and dam operations. Collectively this work will enable the development and parameterization of a model of entrainment risk relative to biotic characteristics (sex, size, spawning population) and dam operations that could serve as a model for future entrainment risk assessments in Canada and beyond. The proposed study will help industry and DFO to assess fish entrainment, reduce entrainment risk, and optimize physical mitigation measures.

Application and Significance

One determinant of Canada's sustainable development and future economic strength is its ability to face the rising demand and cost of energy. Hydropower generation may help to meet this challenge because water is plentiful in much of Canada, yet the challenge will be to maintain the physical and biological integrity of aquatic ecosystems. NSERC's HydroNet will provide new knowledge and tools to ensure the sustainable development of hydropower in Canada.

The projects conducted under NSERC's HydroNet will train a large number of young scientists. The perspective, hands-on experience, knowledge, and skills that they will gain will provide a better understanding of the effects of hydropower

Figure 4. Graduate student Lee Gutowsky (Carleton University) releases a tagged bull trout (*salvelinus confluentus*) that will be tracked for 3 years using a whole-lake telemetry array as well as a fine-scale three-dimensional positioning array in the forebay of Mica Dam in Kinbasket Reservoir, British Columbia.

on aquatic ecosystems, augment their capacity for finding solutions to challenges, and improve present and future academia–industry–government relationships. NSERC's HydroNet is a multidisciplinary and multi-institutional partnership that will promote the exchange of ideas, expertise, data, and solutions among scientists and managers from all regions of Canada. NSERC's HydroNet will also constitute a structure that will foster interactions with North American (e.g., Conte Anadromous Fish Laboratory–U.S. Geological Survey; Rushing Rivers Institute, United States) and European (e.g., CEDREN, Norway; CEMAGREF, France) research groups having similar interests.

Lessons Learned

HydroNet is a new network and has had only one, very important, presampling field season to date. On a practical side, though ideal sample designs can be achieved in proposals, in reality site selection has been one of the most challenging tasks. Of the hundreds of hydroelectric dams in Canada, only 16 regulated sites currently remain on the list of potential candidate sites. Many were eliminated due to large size/high flows, insufficient access to the river, and the inability to comparatively sample the systems. Finalization of site selection is pending an analysis of hydrological data yet to be obtained and consideration of potential confounding factors (flow, temperature, nutrients, etc.). The proposed design for the reservoir modeling project had to be reduced by eliminating replicate reservoirs due to the sheer size of candidate systems coupled with the desire to maintain complete spatial coverage. Finally, on-site testing of sampling options has been key to developing robust standard methods to be used for the duration at all sites.

Maintaining the collaborative, cooperative, and integrative nature of a network may be the biggest challenge of a national research network. A clearly defined common goal brings cohesion to the network, and creative collaborators allow the adaptation of activities to move the science forward faster. Communication is critical to maintain linkages among projects, achieved via meetings of project committees, a research management committee, a science advisory committee, semiannual workshops, and annual symposia. The personal qualities of our collaborators and partners are expected to preserve the cohesion among scientists and projects.

Conclusion

The broad impacts and management of flow regulation across Canada requirecooperation and coordination among producers and regulators. Hydroelectric companies have as an objective to produce affordable energy required to support the Canadian economy while protecting ecosystems and, in particular, preserving PCFH. Government agencies have as a mandate to protect the integrity of ecosystems, biodiversity, and productive capacity. The knowledge gained and tools produced by NSERC's HydroNet will help partners to fulfill their respective mandates while, in the future, significantly reducing the effort, time, and money required to ensure that the development of new hydroelectric facilities and the modifications of existing installations will preserve the productive capacity of aquatic ecosystems (Egan 2005). Information garnered should also refine future research questions and approaches to issues that HydroNet cannot currently study; for example, rivers with flows greater than 300 $m^3 \bullet s^{-1}$. The knowledge developed collaboratively with industry and government will help to reduce and resolve conflict by developing robust and transparent decision support tools that are based on the best available biological data. Such knowledge is essential to improve the balance of competing demands for limited water resources and to ensure that hydropower is sustainable and maintains healthy aquatic ecosystems and a vibrant Canadian economy.

Acknowledgments

NSERC's HydroNet is funded by the NSERC Strategic Network Grant program, NSERC Collaborative Research and Development Program, Fisheries and Oceans Canada, Manitoba Hydro, B.C. Hydro, and Nalcor. We thank the members and partners of NSERC's HydroNet. Provincial agencies contributing to the network include the Ontario Ministry of Natural Resources, the Quebec Ministry of Natural Resources, and Manitoba Water Stewardship. Case studies presented were written by first project lead plus James John Luce, who contributed to case study 1. Shannon O'Connor, the network manager, provided valuable information on the details of the network components. The map of potential sampling locations was provided by the network database manager Carolle Djima. The Canadian Aquatic Resources Section of the American Fisheries Society coordinated the preparation and publication of this manuscript.

References

CEA (Canadian Electricity Association). 2009. Electricity Generation in Canada by Province and Fuel Type, 2009 in TWh. Available from http://www.electricity.ca/industry-issues/electricity-in-canada/industry-data.php (accessed September 2011).

Clarke, K., T. C. Pratt, R. G. Randall, D. A. Scruton, and K. E. Smokorowski. 2008. Validation of the flow management pathway: effects of altered flow on fish habitat and fishes downstream from a hydropower dam. Canadian Technical Report of Fisheries and Aquatic Sciences 2784:vi +111p.

Department of Fisheries and Oceans. 1986. Policy for the management of fish habitat. Department of Fisheries and Oceans, Ottawa, Ontario, Canada.

Egan, T. M. 2005. Good stewards: industry and government work to protect fish and their habitat. Hydro Review 24(5):16–23.

Hasler, C. T., G. C. Christie, J. Imhof, M. Power, and S. J. Cooke. 2011. A network approach to addressing strategic fisheries and aquatic sciences issues at a national scale: an introduction to a series of case studies from Canada. Fisheries 36(9): 450–453.

Katopodis, C. 2005. Developing a toolkit for fish passage, ecological flow management and fish habitat works. Journal of Hydraulic

Research 43:451–467.
Klemes, V. 1978. Physically based stochastic hydrologic analysis. Advances in Hydroscience 11:285–356.
Magilligan, F. J., and K. H. Nislow. 2001. Long-term changes in regional hydrologic regime following impoundment in a humid-climate watershed. Journal of the American Water Resources Association 37:1551–1569.
Magilligan, F. J., and K. H. Nislow. 2005. Changes in hydrologic regime by dams. Geomorphology 71(1–2):61–78.
Oglesby, R. T. 1977. Relationship of fish yield to lake phytoplankton standing crop, production and morphoedaphic factors. Journal of the Fisheries Research Board of Canada 34:2271–2279.
Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, J. R. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime—a paradigm for river conservation and restoration. Bioscience 47:769–784.
Quigley, J. T., and D. J. Harper. 2006. Effectiveness of fish habitat compensation in Canada in achieving no net loss. Environmental Management 37:351–366.
Randall, R. G. 2003. Fish productivity and habitat productive capacity: definitions, indices, units of field measurement, and a need for standardized terminology. Canadian Science Advisory Secretariat Research Document 2003/061.
Randall, R. G., J. R. M. Kelso, and C. K. Minns. 1995. Fish production in fresh waters—are rivers more productive than lakes. Canadian Journal of Fisheries and Aquatic Sciences 52:631–643.
Randall, R. G., and C. K. Minns. 2000. Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitats. Canadian Journal of Fisheries and Aquatic Sciences 57:1657–1667.
Rawson, D. S. 1952. Mean depth and the fish production of large lakes. Ecology 33:513–521.
Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10:1163–1174.
Rosenberg, D. M., F. Berkes, R. A. Bodaly, R. E. Hecky, C. A. Kelly, and J. W. M. Rudd. 1997. Large-scale impacts of hydroelectric development. Environmental Reviews 5(1):27–54.
Ryder, R. A. 1965. A method for estimating the potential fish production of North temperate lakes. Transactions of the American Fisheries Society 94(3):214–218.
Scruton, D. A., K. D. Clarke, M. M. Roberge, J. F. Kelly, and M. B. Dawe. 2005. A case study of habitat compensation to ameliorate impacts of hydroelectric development: effectiveness of re-watering and habitat enhancement of an intermittent flood overflow channel. Journal of Fish Biology 67:244–260.
Smokorowski, K. E., and D. Derbowka. 2008. Methods of measuring productive capacity in Canada: summaries for review at a national workshop, October 15–16, 2007. Canadian Technical Report of Fisheries and Aquatic Sciences 2815: iv + 158p.
Smokorowski, K. E., and J. D. Dutil. 2008. Proceedings of the workshop to compare methods to quantify the productive capacity of fish habitat impacted by hydro operations. Canadian Science Advisory Secretariat Proceedings Series 2008/002, Ottawa, Canada
Smokorowski, K. E., K. J. Withers, and J. R. M. Kelso. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects. Canadian Technical Report of Fisheries and Aquatic Sciences 2249: vi + 74p.