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Technology Transfer Workshop: List of Participants

	Name	Affiliation	Email
1.	Antcliffe, Bonnie	DFO, Vancouver	antcliffeb@pac.dfo-mpo.gc.ca
2.	Bain, Hugh	DFO, Ottawa	BainH@dfo-mpo.gc.ca
3.	Blanchfield, Paul	DFO, Winnipeg	BlanchfieldP@dfo-mpo.gc.ca
4.	Bradford, Mike	DFO, Vancouver	BradfordM@dfo-mpo.gc.ca
5.	Brousseau, Christine	DFO, Burlington	BrousseauC@dfo-mpo.gc.ca
6.	Clarke, Keith	DFO, St. John's	ClarkeKD@dfo-mpo.gc.ca
7.	DeBruyn, Ed	DFO, Burlington OGLA	debruyne@dfo-mpo.gc.ca
8.	Fallis, Bruce	DFO, Winnipeg	fallisb@dfo-mpo.gc.ca
9.	Franzin, Bill	DFO, Winnipeg	FranzinW@dfo-mpo.gc.ca
10.	Grant, Carole	DFO, Newfoundland	GrantCG@dfo-mpo.gc.ca
11.	Harper, David	DFO, Vancouver	HarperD@dfo-mpo.gc.ca
12.	Jacques, Jean-Guy	DFO, Quebec	jacquesjg@dfo-mpo.gc.ca
13.	Jones, Mike	MSU, East Lansing	jonesm30@msu.edu
14.	Kelso, John	DFO, retired, BC	jkelso@golder.com
15.	Mandrak, Nick	DFO, Burlington	MandrakN@dfo-mpo.gc.ca
16.	Metikosh, Serge	Golder Consulting	Serge.metikosh@golder.com
17.	Mills, Ken	DFO, Winnipeg	MillsK@dfo-mpo.gc.ca
18.	Ming, Debbie	DFO, Burlington OGLA	mingd@dfo-mpo.gc.ca
19.	Minns, Ken	DFO, Burlington	MinnsK@dfo-mpo.gc.ca
20.	Morry, Chris	DFO, Moncton	morrycj@dfo-mpo.gc.ca
21.	Paradis, Sylvan	DFO, Ottawa	ParadisS@dfo-mpo.gc.ca
22.	Perrault, Julie	DFO, Ottawa	PerraultJ@dfo-mpo.gc.ca
23.	Plante, Francois	DFO, Moncton	plantef@dfo-mpo.gc.ca
24.	Potter, Ted	DFO, Dartmouth	potter@dfo-mpo.gc.ca
25.	Pratt, Tom	DFO, SSM	PrattT@dfo-mpo.gc.ca
26.	Quigley, Jason	DFO, Vancouver	QuigleyJ@pac.dfo-mpo.gc.ca
27.	Randall, Bob	DFO, Burlington	RandallR@dfo-mpo.gc.ca
28.	Ridgway, Mark	OMNR, Peterborough	mark.ridgway@mnr.gov.on.ca
29.	Samis, Steve	DFO, Ottawa	samiss@dof-mpo.gc.ca
30.	Scruton, Dave	DFO, St. John's	ScrutonD@dfo-mpo.gc.ca
31.	Smokorowski, Karen	DFO, SSM	SmokorowskiK@dfo-mpo.gc.ca
32.	Stanfield, Les	OMNR, Glenora	Les.Stanfield@MNR.gov.on.ca
33.	Stoneman, Christine	DFO, Ottawa	StonemanC@dfo-mpo.gc.ca
34.	Wagner, Angie	ULERN, Sault Ste Marie	angie.wagner@saultc.on.ca
35.	Winfield, Nick	DFO, Ottawa	WinfieldN@dfo-mpo.gc.ca

Habitat-Specific Production in Inland Lakes

Pratt*, T., P. Blanchfield and M. Ridgway
Email: prattt@dfo-mpo.gc.ca

Estimating habitat-specific production rates is a difficult but crucial component of meeting Fisheries and Oceans Canada policy of 'no net loss of productive capacity of fish habitats' as outlined in the *Fisheries Act*. In three separate studies from north-western (Experimental Lakes Area), central (Turkey Watershed) and eastern (Swan Lake Research Reserve) Ontario, we used underwater snorkelling transects set perpendicular to shore in combination with DISTANCE software to estimate habitat-specific littoral zone fish densities. Habitat classes were broadly defined and based on simple physical habitat features such as substrate and the presence of vegetation and coarse wood. Passive fish traps (minnow traps, fyke nets, hoop nets) were concurrently fished in specific habitat types, and captured fish were weighed. These weights, when used in combination with the available density estimates and estimates of habitat availability, provided habitat-specific biomass estimates for each species. In all studies, habitat-specific production was estimated by multiplying habitat-specific biomass estimates with published species-specific production:biomass ratios to determine habitat production indices (HPI). Production was also estimated in two of the studies by conducting visual censuses and capturing and weighing fish over two time periods.

The underwater visual method for determining habitat-specific densities was validated by conducting a concurrent mark-recapture population estimate in the five Turkey Lakes Watershed lakes. The 95% confidence intervals from visual and mark-recapture population estimates overlapped for 90% of the species censused, indicating that our underwater visual method is capable of providing habitat-specific densities.Fish densities were significantly higher in structurally complex habitats, as beaver lodges contained higher densities of fish than all other habitats, and coarse wood and vegetation had higher densities than open habitats. HPI estimates demonstrated a similar pattern, with beaver lodges having significantly higher HPI estimates than vegetated, rocky or open habitats, and coarse wood habitats having significantly greater HPI estimates than open habitats. Production estimates too followed a similar pattern, but were more variable and there was no statistical difference among habitat types. We examined habitat fidelity (an assumption of our methods is limited movement among habitats), and found that fish captured in specific habitats were most likely to be recaptured in those habitats.

Our research provides many valuable insights for Fisheries and Oceans Canada Habitat Management Program. Structurally complex habitats contained the highest fish densities and biomass, and provided the greatest potential for production. Coarse wood habitats were 11.5, 4.5, and 3.3 times more productive than open, rock and vegetated habitats respectively. Given the variability in actual habitat-specific production estimates, the use of underwater visual methods for determining habitat-specific density estimates, in combination with published production:biomass ratios, provide a simple and effective method for estimating habitat-specific production.

Complexities in the Classification of Fish Habitat in Large Rivers with Implications for Estimates of Productive Capacity

William Franzin[1]*, Leon Carl[2] and Karen Smokorowski[3].
[1]Department of Fisheries and Oceans, Freshwater Institute, 501 University Crescent, Winnipeg, MB, R3T 2N6 Email: franzinw@dfo-mpo.gc.ca
[2] United States Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105-2807 Email: lcarl@usgs.gov
[3] Department of Fisheries and Oceans, Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1 Canal Drive, Sault Ste. Marie, Ontario P6A 6W4
Email: smokorowskik@dfo-mpo.gc.ca

This presentation is a compilation of work done in large rivers in Ontario and the Prairie Provinces. The complex nature of stream habitats at different scales is provided along with potential fishing approaches to sample across those habitat scales. We show four examples of sampling designs used in river sampling, the types of data that are produced by them and the sources of error and levels of confidence associated with riverine fish and fish habitat sampling. Two studies were conducted to estimate biodiversity while the other two assessed abundance and biomass. Most riverine fish communities are sampled using backpack or boat-mounted electrofishers. The effects of fish size, water depth and transparency/turbidity on capture success at constant power levels were modeled as part of one of the studies. These data indicate that a healthy amount of scepticism should be applied to interpretation of electrofishing results. All of these factors reflect on estimates of productive capacity of fish habitat in rivers based on fish captures. The following two tables summarize approaches to sampling riverine habitat and fishes over a broad range in scale.

Scaling Habitat Classification and Fish Use in Rivers:

Typology	River Scale		Fish and Fish Habitat Sampling Scale		Modeling
	Small	Large	Small	Large	
Geomorphology	Harder; higher slope	Softer; lower slope	Headwater species, geological substrates	Large river/lake species; ETD substrates	Below
Watershed	Primary: a few to 10s of kilometres, few stream orders	Secondary or tertiary: 100s of kilometres, multiple stream orders	Kilometre reference segments, habitat in metres^2, Communities, IBI, indicator species, etc., reference barriers	Reference segments, habitat in hectares communities, IBI, indicator species, etc., reference barriers	1-D models for hydrology, PHABSIM, River2D for habitat at reference sites
River mainstem, natural or man-made barriers	Hectometres to kilometres; stream widths<10m	Kilometres to 100s of kilometres; stream widths >10m	Reference Reaches Mesohabitats (riffle, pool, run, glide, pocket water) Metres^2 Fish guilds, reference barriers	Macrohabitats (inside / outside meander bends crossovers, backwaters and side-channels, hectares reference reaches by segment, fish guilds	1-D model for hydrology, PHABSIM, MESOHABSIM, River2D for habitat at reference sites
River or valley segment or reach, length variable, natural or man-made barriers	Dekametres	Kilometres	Microhabitats (HSI for depth, velocity, substrate, cover), guilds, species, life stages	Reference reach, microhabitats at metres^2 level, guilds, species, life stages	PHABSIM, River2D preferred
Site, 12-20 stream widths	Metres^2	Metres^2 to hectares	Microhabitats at metres^2 level	Microhabitats, at metres^2 level	PHABSIM, River2D preferred
Temporal Issues	Seasonal changes in hydrograph dramatically affect habitats at all levels of watersheds.				

Scaling Sampling Designs for Determining Fish Use of Habitat in Rivers:

Habitat Scale	River Sampling Units		Expected Fish Species / Biodiversity		Fishing Gears
	Small	Large	Small	Large	
Watershed	Tributary network by stream order; valley segments stratified random sampling (SRS) of tributaries by order or mean width	Valley segments, major tributaries; SRS by segment, revert to small scale up watershed tagging, telemetry	Mainly small fish species and specialists in local mesohabitats; low-moderate biodiversity, increasing down watershed, effects of barriers	More large fish species, high, variable biodiversity, distributions influenced by local habitat structure, pelagic (lake-type) species enter down watershed, effects of barriers	A variety: backpack, positioned array, push boat and large boat shockers, seines, passive gear (various nets, traps etc.)
River mainstem, natural or man-made barriers	SRS of habitat units such as mesohabitats, barriers	Large scale SRS of transects or macrohabitats, barriers, telemetry	Position of sample in watershed determines fish communities	Position of sample in watershed determines fish communities	Backpack to Large boat shockers, trawls, large seines, gillnets, traps etc.
River valley segment or reach, length variable, natural or man-made barriers	Random sweeps, habitat sampling	SRS of short transects or macrohabitats, possibly mesohabitats, barriers, telemetry	Biodiversity may be differentiated by mesohabitats, pool and riffle communities	Mesohabitats largely indistinguishable, community biodiversity organized among macrohabitats	Backpack, boat or push boat shockers, seines, traps, surrounding gears
Site, 12-20 Stream widths	Barrier netted sections, positioned arrays, grids	SRS of smaller scale, possibly mesohabitats, telemetry	Microhabitat variables become useful, HSI parameters may be determined	Microhabitat variables become useful, HSI parameters may be determined	As above, also in small streams, Hess-type samplers on microhabitat
Temporal Issues	Seasonal changes in hydrograph dramatically affect fish sampling at all levels of a watershed.				

Coastal Exposure as a First-Order Predictor of the Productive Capacity of Near Shore Habitat in the Great Lakes

R.G. Randall*, C.K. Minns and C.M. Brousseau, Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences,
P.O. Box 5050, 867 Lakeshore Road, Burlington, Ontario, 7R 4A6.
Email: RandallR@dfo-mpo.gc.ca

Regression tree analysis with coastal exposure (fetch distance) as a predictor of fish biomass was used to evaluate the productive capacity of near shore habitat in the Great Lakes. Regression tree models were developed using survey data collected at coastal wetlands, harbours and natural shorelines in 1994 (n=100) and validated using data from other areas surveyed in other years (1990 to 1999, n = 273). Coastal habitat characteristics that influence fish distribution, including the occurrence and abundance of submersed macrophytes, water temperature and substrate characteristics were related to maximum fetch distance in a consistent manner in the model and validation data sets. Three classes of macrophyte density (absent, moderate and dense cover), were predicted from substrate size and fetch distance: plant cover was highest where the predominant particle size was fine (silt or smaller) and maximum fetch was < 12.6 km. Fetch was a significant predictor of the biomass of three species (*Lepomis gibbosus, Perca flavescens, and Alosa pseudoharengus*), each with different habitat preferences, and two fish community indices (Index of Biotic Integrity [IBI], and the Habitat Productivity Index [HPI]. IBI and HPI were used as measures of the diversity and production components of habitat productive capacity, respectively. For all fish response variables, classification was improved if fetch was used together with associated habitat attributes as predictors. The degree of resolution of habitat classification (number of classes that were discernible) was limited to 2 to 4 classes, depending on the fish response variable. Proportional reduction in error for the regression trees ranged between 0.30 and 0.76. Four classes of *Lepomis* habitat were determined and validated, but the number of habitat classes for *Perca* and *Alosa* was less. For the whole fish assemblage, four habitat classes were identified using IBI and HPI together in a two-axes approach for evaluating productive capacity, along with fetch and water temperature as predictors. Knowledge of site exposure and the associated habitat covariates can be used to determine and map first-order estimates of coastal habitat productive capacity in the Great Lakes.

Riverine Habitat Classification in Newfoundland and Approaches to the Measurement of Habitat Productive Capacity and/or Surrogates, for Stream Salmonids

Scruton, D.A.* and K.D. Clarke, Fisheries and Oceans Canada, Science, Oceans and Environment Branch, P.O. Box 5667, St. John's, NL A1C 5X1 CANADA
Email: scrutond@dfo-mpo.gc.ca

It is well recognized that the spatial and temporal dynamics of habitat quantity and quality are a major determinant of fish production and fish populations. Riverine ecosystems are particularly dynamic owing to the stochastic nature of precipitation events and anthropogenic influences either dampening (e.g. regulation) or exacerbating (e.g. hydro peaking, urbanization) this variability. The habitat requirements of a particular fish species will vary from location to location owing to differences in biotic (e.g. species complexity, inter- and intra-specific competition, predation, food availability, etc.) and abiotic (e.g climate, geomorphology, hydrology, etc.) conditions. Habitat requirements for fish may also vary seasonally or on shorter time scales as they progress through different life stages and often the relative location of habitats (e.g. adjacency) is important. Further, the habitat requirements of a species can be defined at different scales (microhabitat, meso-habitat, river reach, watershed). Conceptually, it is also thought that fish populations may be controlled by habitat limiting events or conditions embraced in concepts such as 'critical habitats' and habitat 'bottlenecks'. All of these influences will confound and complicate efforts to measure habitat productive capacity (HPC).

In Newfoundland, the classification of stream habitat has evolved from a macro-habitat based approach (the Beak habitat classification system, circa 1979) to a tiered approach embracing macro-habitat, meso-habitat (e.g. run, riffles, pool, etc.), and microhabitat (e.g. depth, velocity, substrate) scales. These habitat classification strata will be discussed in the context of methods to identify and measure physical habitat attributes towards quantification of habitat. Considerations unique to Newfoundland including a depauperate fish community, co-existence of resident and anadromous populations, Salmo-centric focus, dilute and low fertility of waters, and the high proportion of water on the landscape are described. The various metrics and/or surrogates, including fish-based and habitat based measures, that have/can be used to describe or quantify habitat productive capacity will be discussed. Issues associated with temporal (diel, seasonal) and spatial variability in fish habitat utilization, and the definition and measurement of habitat productive capacity, is discussed using examples from fluvial salmonid habitat studies in Newfoundland. Two-dimensional habitat hydraulic modeling will be presented as a tool to examine effect of flow changes on habitat productive capacity and to demonstrate sensitivity to habitat criteria (models) used. Habitat supply based fish population modeling will be presented as a means of integrating habitat productive capacity across life stages, meso-habitats, and considering the marine life phase of anadromous fish. Fluvial habitat productive capacity will be discussed in the context of the workshop themes: (i) sensitivity and standardization of HPC measures; (ii) HADDs and thresholds; (iii) habitat compensation; and (iv) risk and uncertainty in the measurement of HPC. Finally, the classification of fluvial habitats in Newfoundland will be discussed in relation to the Habitat Management program's 'Risk Management Framework..'

Production Dynamics of Salmonids in Newfoundland: Investigating the Role and Linkages of Lucastrine and Fluvial Habitats

Clarke* K. D. and D. A. Scruton
Science, Oceans and Environment Branch, Department of Fisheries and Oceans
P.O. Box 5667 St. John's, NF A1C 5X1
Email: clarkekd@dfo-mpo.gc.ca

Freshwater fish communities of insular Newfoundland are generally characterised by a depauperate fish assemblage and low production when compared to their mainland counter parts. The species present are all hyposaline and are generally dominated by salmonids. This reduction in species has been hypothesised to allow for an expansion of useable habitat such that salmonids extensively utilise both lacustrine and fluvial habitats for production and many of the classical habitat associations derived from the literature are only very generally applicable. The linkage between these habitats is poorly understood and we tend to manage them as separate entities, although they are often highly linked from a population viewpoint. To further complicate the matter it has been shown that individuals within these low productivity systems do not always exhibit a high habitat affinity and large inter-habitat migrations, occurring on a variety of spatial and temporal scales, do occur.

The situation described above has a number of consequences when managing habitat within the Newfoundland and Labrador Region. Since most species found in Newfoundland systems use both lakes and streams, either inter-changeably within the same year or during a specific stage of their life cycle, the question arises as to which of these very distinct habitats are more important to the overall production of the population. Furthermore, due to this plasticity in habitat utilisation, situations may arise were development resulting in the alteration of one habitat type into another or compensating for one habitat type with another would benefit from an estimate of production 'equivalency' between the differing habitat types.

To investigate the variety of functions provided by these habitats with respect to salmonid production, habitat based production estimates and movement patterns within two very different Newfoundland freshwater systems was compared. The first study system is a small headwater system located in western Newfoundland, which is inhabited by brook trout as its only fish species. The second system studied is located on the Avalon Peninsula with easy access to the marine environment. The latter has a diverse fish assemblage, by Newfoundland standards, with six species, brook trout, brown trout, Atlantic salmon, American eel, rainbow smelt, and three-spine stickleback, all with a variety of anadromous and non-anadromous life history strategies. Extensive movement between lakes and streams was observed in both systems with some movements being associated with changes in life history stage and others having a seasonal pattern. Production estimates are presented within each habitat or meso-habitat as appropriate. Information on temporal habitat use and movement is also presented to investigate the relative role each of these major habitat classes has on the productive capacity of salmonids in Newfoundland.

A Bioregional Model for Predicting Thresholds of Change for Lake Ontario Tributary Systems

Les W. Stanfield*, (Ministry of Natural Resources, R.R. # 9, Picton, ON KOK 2T0; 613/476-3255; FAX 613/476-7131;Les.Stanfield@MNR.gov.on.ca)
Bruce Kilgour, and (Jacques Whitford Environment Limited, 2781 Lancaster Road, Ottawa, ON, K1B 1A7; 613/738-0708; Fax: 613/738-0721; bkilgour@jacqueswhitford.com)

Ecosystems are organized hierarchically with large-scale features such as hydrography, geology, topography, climate and natural disturbance history having a primary influence on determining the finer-scale features such as channel form, structure, riparian conditions, and biological composition. Landuse modifies the landscape, which in turn modifies the physical and chemical features at a stream site, and thus the biological condition. Landuse-related decisions cannot be justified without knowledge of how landuse affects biophysical properties of streams. The first challenge to this task is understanding the relationship that catchment features impose on the streams and how the overall pattern of development influences these features.

The overall objective of this project is to quantify the effect of landuse on stream health, using techniques that quantify the scales of effect and identify the pathways of the disturbance. This phase of the analysis is intended to characterize the reference state for a variety of biophysical properties of wadable streams. Further, we wish to quantify the effect of a composite of disturbance on stream health and to explore the degree to which thresholds of change exist within these systems. We will focus on the fisheries metrics in this report.

Since 1995, biophysical data (fish, inverts, instream habitat, temperature etc) have been collected on wadable streams flowing into the Lake Ontario basin using the OSAP protocol (Stanfield et. al., 1996). Recently a GIS application (ALIS) was developed by the MNR to characterize mainly the landscape conditions for each site. Many of the landscape features are measured from within the drainage basin for each site which is developed for each site using a DEM. For each of the 700 sites, biophysical data and GIS information (drainage area, geology, landuse, slope, stream length and climatic conditions) were summarized. Once summarized, we developed two composite metrics to include in the analysis. The baseflow index (BFI) was calculated for each site by summing the composite score for each geology class and its rating of contribution to baseflow. The percent imperviousness was estimated by summing the product landclasses and their impervious ratings.

Canonical correlation analysis (CCA) was used to illustrate the general relationships between fish communities and landscape features. Indices of fish community composition (i.e., ordination axis scores, total fish community biomass, richness, and brook trout biomass) were modeled (multiple regression) in relation to catchment area, slope of the stream reach, BFI, and imperviousness. We also visually examined plots of indices of fish community composition, in relation to percent imperviousness, for thresholds of disturbance.

The ordination analysis demonstrated that salmonids, lamprey and sculpins were generally found at sites with high amounts of forest cover and high baseflow. Sites with low forest cover, but more urban and agricultural landuses had few salmonids, lampreys or sculpins. The ordination also showed that sites with high slope/elevation had higher proportions of brook trout and brook sticklebacks, while sites with larger upstream catchments had fewer brook trout , and more pumpkinseeds and rainbow darters.

One multivariate index of fish community composition (the first ordination axis) showed a very strong threshold response to imperviousness. Significant changes in indices of fish community composition were evidence where forest cover was reduced to around 20%. Below that threshold there was considerable variance in the data, suggesting that local landuse and instream habitat were influencing the fish community to a greater degree in those areas.

The multiple regression models were stronger for the multivariate indices of community composition ($R^2 = 0.36$ to 0.39) than for the species richness ($R^2 = 0.17$) or the brook trout model ($R^2 = 0.31$). Variations in each index of the fish community were at least in part related to imperviousness, and variations in all but one index were related to catchment area. BFI explained variations in two multivariate indices of composition, and in brook trout biomass, while slope explained variations in three indices of composition.

We were able to estimate the reference condition for each site using the predictive multiple regression models, and hindcasting the expected "historical" condition assuming no development. Hindcasting with these multiple regression models is one way to evaluate the sensitivity of indices of composition to disturbance on the landscape. For each site, we also determined the deviation from the expected historical condition in an undisturbed state and classified each site as to whether it was within 1, 2 or 3 standard deviations from its estimated "historical" or "reference" condition.

Within the Lake Ontario dataset, there were 45 species of fish that were infrequently found and that were not used in the multivariate ordination procedure because of their rarity and potential influence on ordination output. Those species, however, have been "projected" onto the multivariate ordination, providing an opportunity to explore the landscape conditions that might be suitable for these taxa.

Next steps include developing similar models for metrics of instream habitat, temperature and invertebrates. Preliminary results of invertebrate work indicate that indices of benthic community composition respond in similar ways to the same list of landscape variables as do fish communities, although they appear to be less sensitive than the fish metrics used here. Managers will be able to plot site data against the background condition, to assist with diagnosing local verses far effects.

Finally, these results provide rationale for identifying those sites that at present are below thresholds of change for the fish communities that are more likely to be influenced by local features of habitat and biological interactions. Research will now focus on developing an understanding of which local habitat features are important influences on the fish communities and how best management practices (i.e., adjacent landuse and riparian vegetation condition) influence the biophysical conditions of these sites.

An Area-Per-Individual (API) Model for Identifying HADD Thresholds in Fish

C.K. Minns, Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, PO Box 5050, 867 Lakeshore Road, Burlington, Ontario L7R 4A6
Ph/Fax: 905-336-4874/6437
Email: minnsk@dfo-mpo.gc.ca

How limited supplies of suitable habitat influence the size and dynamics of fish populations is the key to determining the harm arising from habitat alteration, disturbance, and destruction (HADD). There may be four basic relationships between habitat supply and fish performance: linear (a one-to-one relationship between habitat supply and fish response), fragile (small decreases in habitat produce big fish changes), resilient (large habitat decreases must occur before significant fish declines occur), and threshold (a sigmoid relationship where initial habitat losses produce little change but then small changes produce large changes in fish). Fish habitat management practice is primarily based on the linear model with some intuitive precautionary leaning to the fragile model. Empirical evidence suggests the resilient or threshold models are more likely outcomes in nature. However, it is unlikely that the form of particular relationships or significant harm can be identified by simple inspection of habitat information alone. Dynamic population models provide an integrated quantitative framework for examining fish-habitat linkages and their consequences for productive capacity. Simple habitat assessment schemes are unlikely to discern life history bottlenecks and hence identify critical habitats whose loss will lead to a HADD. While our knowledge of most fish species is incomplete, science has developed a formidable understanding of population dynamics and the role habitat supply might play. A simple multi-stage population model for a freshwater fish is presented as a basis for examining how population size and structure respond to changes in life-stage specific habitat supplies. Central to the model development are the well-known relationships between population density and body size seen in all biota, including fish; the inverse of a density-size relationship is area-per-individual (API). Animals, and plants, have minimum space requirements for completing their life histories and the inverse size-density curves provide benchmark estimates of space needs. The life history rate processes and space requirements of spawning, yoy, and one+ life stages in fish are considered. For fish there are many *a priori* expectations regarding rate processes and space use that can guide model development and parameterization. Links between area-per-individual (API) of available suitable habitat and life stage processes provide a means for estimating habitat requirements and identifying potential productivity bottlenecks. Life history strategy affects the dynamics of populations and the patterns of life-stage habitat requirements. The patterns of fish life history strategies are well-known. How habitat quantity can affect population success is examined. Results are presented for a representative lake fish species (lake charr, *Salvelinus namaycush*). A sensitivity analysis indicates that yoy habitat is most limiting for lake charr followed closely by adult and with spawning habitat a distant third. This result contradicts the instinctive bias of most fish habitat biologists towards protecting spawning habitat. The order of yoy and adult habitats in limiting population performance can be changed by altering the relative amounts of life stage habitat supply. Approaches to parameter estimation for API models are explored. The uncertainties and limitations associated with an API approach are discussed. The API approach may be extended to more complex life histories and should be broadly applicable. More complex assessments can consider habitat quality and the operation of ideal-free distribution (IFD) rules. This fish-habitat modeling points to the need for fish habitat management to be targeted more at a population or ecosystem scale and away from the site-level. The model illustrates the difficulties involved in identifying population thresholds related to habitat supply and the importance of acknowledging uncertainties and natural variability in decision-making.

Web Mapping Tool for Fish Species at Risk in Ontario

Mandrak, N.E.*[1], A. Doolittle[2], C. Bakelaar[1], P. Brunette[2], K. Gray[2], and D. Ming[2].
[1] Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, ON L7M 3W2.
[2] Ontario-Great Lakes Area, Fish Habitat Management, Fisheries and Oceans Canada, Burlington, ON L7M 3W2.
*mandrakn@dfo-mpo.gc.ca

The Species at Risk Act (SARA) aims to protect fish and wildlife species at risk from becoming extinct or lost from the wild with the ultimate objective of helping their numbers to recover. To protect SAR and their habitat, it is necessary to have an understanding of their distribution, abundance and life history. Currently, there is no single database that houses this information. A user-friendly fish SAR intranet site is under development to provide easy access to relevant information (e.g. COSEWIC reports, recovery strategies) and a mapping tool for fish SAR. The mapping tool will provide the capability to produce maps of the known distributions of fish SAR at regional (i.e. tertiary watershed) and local scales (i.e. stream segments). The mapping tool is based on a distribution database currently containing over 200,000 records for all species in Ontario primarily from OMNR lake and stream inventories, Royal Ontario Museum, DFO and Canadian Museum of Nature. In addition, modeling based on landscape and in-stream attributes will be undertaken to predict the occurrence of fish SAR in unsampled stream segments. The intranet site will be used by DFO Fish Habitat Management and its partners to review proposed development projects for potential impacts to fishes and fish habitat. The site will assist in expediting the review process by providing geo-referenced, up-to-date information on fishes, including fish SAR and their recovery plans, so that informed decisions can be made to minimize impacts on fish SAR.

Development of an Instream Flow Screening Tool and Guidelines for Small Hydro in the Pacific Region

Bradford, M.[1]* and T. Hatfield[2]. [1]DFO and Cooperative Resource Management Institute, Simon Fraser University, Burnaby (mbradfor@sfu.ca); [2]Solander Ecological Research, Victoria.

Recent directives by the Provincial government to expand the network of small (<50 MW) hydro projects has resulted in over 300 applications that need to be reviewed by environmental agencies. To facilitate the processing of these applications in a timely fashion the development of guidelines and screening tools was deemed desirable.

Small hydro projects are often the run-of-the-river design. Water is diverted via a low head dam and penstocks around a high gradient reach of the stream before passing through a power house and returning to the stream channel. The diversion reach can range from a few hundred metres to 5-10 kilometres. The proportion of water that can be diverted from the channel for generation is a critical element of the financial viability of the project.

The fishery resources of these streams varies from being fishless tributaries of larger fish-bearing systems, to being habitat to populations of trout and other game fishes. With the exception of some species of concern, most streams do not support high value resources.

Instream flow guidelines were developed after a lengthy series of meetings and workshops which highlighted the lack of experience of the application of the *Fisheries Act* and the habitat policy for instream flows in the Region. Although there was a hope that a single instream flow method could be used to determine HADDs and the need for s35 authorizations, it soon was realized that this was a complicated problem and simple solutions were not likely.

We then focussed on a simpler question: could a screening tool be devised for the initial application (with limited information being available) that would indicate if instream flows were likely to be an issue for fisheries agencies? The tool would ultimately be web-based and have accompanying guidebooks for data collection and processing and would allow the proponents to determine the status of the project themselves.

We settled on the following principles:

1. Projects meeting the screening guidelines would not incur a HADD and would not need a s.35 authorization for flow diversions at or less than the guidelines.
2. The screening would be based on limited site-specific data, and would thus be relatively risk-adverse.
3. Projects not passing the screen would most likely require more information to allow a site-specific evaluation
4. The screening tool would distinguish between fish and non fish-bearing waters, and would be less restrictive for fishless streams.
5. A 100% diversion was not permitted (i.e. dry channel below dam)
6. The post-project instream flow regime would have as many of the attributes described by the recent Instream Flow Council book as possible, including the maintenance of minimum flows as well as higher flows required for riparian connectivity, channel maintenance and other ecological functions.

The screening tool that we developed was based on monthly median flows estimated from limited site-specific hydrology data and regional analyses. For fish-bearing streams a sliding scale of allowable diversion rates was developed, with the lowest diversions being permitted in the low-flow months. This recognizes long-standing concerns about low flows during late summer in many areas, and limitations to fish by low flows in winter in the Interior and northern regions. Greater diversions were permitted in high flow months. We also imposed a cap on the maximum diversion rate, so that flood flows would not be captured by the project, and would travel through the diversion reach.

For fishless streams we set the minimum flow for all months as the median flow for the lowest month in order to assure connectivity; the maximum diversion cap again allowed high flow events to occur in the diversion reach.

On average, these flow rules allow for about 20-30% of the annual flow to be diverted in fish-bearing streams, and over 50% in fishless ones. It was recognized that these rules might be very conservative in some streams and that many projects would not pass the screen successfully. In these cases more site-specific information will be required to evaluate the effects of the altered flow regime on fish and fish habitat. However, the screening tool does force some level of rigour and consistency in data collection, and does help to identify the periods when there is the greatest potential conflict between instream flow needs and other water uses.

Experimental Manipulation of Habitat Capacity in Inland Lakes

Smokorowski, K.E.[1], T.C. Pratt[1], W.G. Cole[2], and J.R.M. Kelso[3].
[1]Great Lakes Laboratory for Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, 1 Canal Dr., Sault Ste. Marie, Ontario, P6A 3K6
Email: smokorowskik@dfo-mpo.gc.ca and prattt@dfo-mpo.gc.ca
[2] Ontario Forest Research Institute, Ontario Ministry of Natural Resources, 1235 Queen St., E., Sault Ste. Marie, Ontario, P6A 2E5 Email: bill.cole@mnr.gov.on.ca
[3] RR#1, Site 78, Compartment 6, Oliver, BC, V0H 1T0. Email : jkelso@golder.com

The *Fisheries Act* protects fish habitat from any work or undertaking resulting in its harmful alteration, disruption, or destruction (HADD) through a policy of No Net Loss of the productive capacity of fish habitat. To achieve the goal of this policy when a HADD is authorized, habitat enhancement or creation must be used to compensate the loss of habitat productive capacity. Woody material (e.g. brush bundles, root wads, tree drops) and other fish habitat structures (e.g. reefs, wetlands) have been placed in lakes and streams, often with the explicit goal of increasing fish production, or to compensate for a HADD. However, the success of habitat enhancements is rarely assessed from a biological perspective (i.e. by measuring changes in fish biomass or production resulting from designed changes in habitat). One assumption underlying these compensation decisions is that habitat availability and quality are directly related to fish production. To test this assumption, a whole-lake habitat manipulation (wood removal and habitat additions) experiment was conducted to determine the effect of nearshore habitat perturbation or enhancement on the fish communities in a suite of small aquatic systems.

In three experimental lakes (< 25 ha each) in the Algoma region of Ontario, we decreased nearshore habitat diversity (2 in 1999, 1 in 2000), and referenced the changes in biological metrics to an unperturbed system and to pre-manipulation conditions in each experimental system. Habitat manipulations mimicked the effects of human encroachment into aquatic habitat (e.g. cottage development) by reducing the complexity of physical habitat available to fish in the nearshore areas. At a workshop attended by managers and scientists, it was determined that a 50% alteration of the shoreline within a lake would be considered a HADD. Consequently, coarse woody debris was removed from 50% of the nearshore area (50% of total shoreline distance, to a depth of 2 m or 10 m from shore) in the three systems. Additionally, in one of the lakes a portion of the same nearshore bottom substrate was covered with a water/gas permeable geotextile cover (1999). In three other experimental systems (2 gravel pit ponds and 1 quarry pond – considered to have sparse natural habitat variability) in Southern Ontario, we increased habitat diversity (2 in 2000, 1 in 2001) and referenced changes to an unperturbed system and to pre-manipulation conditions in each experimental system. Habitat enhancements were designed to represent typical Habitat Management compensation for a HADD, and included re-grading littoral slope and planting wetland vegetation, creating a rock-rubble reef, and adding tree-brush bundles.

While fish response was the main indicator of interest, an ecosystem approach was adopted to help clarify the mechanism(s) behind any observed change in fish parameters. Consequently, water chemistry, phytoplankton chlorophyll a, zooplankton, invertebrates on wood, and chlorophyll a in periphyton on wood, as well as fish catch-per-unit-effort, mark-recapture abundance, biomass, production, and habitat-specific distribution were monitored. A modified BACI ANOVA design was used in the analysis whereby each system in each year was assigned to a category of either 'Before or After' (time) and 'Control or Impact' (treatment) with the resulting 'treatment x time' interaction as the statistic of interest. A significant interaction would indicate that the experimental systems responded differently over time than unperturbed control systems and that our habitat manipulations affected the Impact systems. Due to an unrelated fish kill in our "habitat addition" control system, we used the lake control systems as our control in the BACI ANOVA. As this analysis provided a coarse measure of impact, we also conducted analyses that might allow detection of more subtle effects within an impact system.

By the 6th year of our experiment, any changes that were appearing to emerge in earlier analyses disappeared, and all parameters tested under the BACI design were not significant. At no time in our analyses over the years did we detect an effect on water chemistry, chlorophyll a, or invertebrates on wood. Earlier analyses indicated that fish community shifts were occurring in the wood removal lakes, whereby catch of smaller fish decreased, and catch of larger fish increased, supporting the hypotheses that habitat complexity serves as cover from predation. This effect is no longer significant. In addition, it appeared that some minnow species known to be more sensitive to perturbation (e.g. *Notropis* sp.) disappeared from our lakes, but in 2003 one of the species was again captured in our impact lakes. In the habitat addition systems, it appeared that the wetland creation was having a significant and positive effect on the fish community (biomass and production), but in 2003 total biomass decreased to below pre-manipulation conditions. While it now appears that the rock-rubble reef addition is having a positive influence on fish catch and biomass, this effect is currently not significant relative to controls. At no time did we detect a change in total fish biomass resulting from habitat manipulations; supporting the theory that total fish community biomass is one of the more stable parameters in aquatic systems.

These results do not provide support for the assumption that habitat supply is directly related to productive capacity, nor do they support the perception that a 50% habitat perturbation constitutes a HADD. Our design was not conducive to detecting a functional relationship between habitat alteration and fish response. Our results also do not provide insight into what type of physical habitat creation is more effective than another in enhancing productive capacity. The level of effort required to obtain a reliable abundance estimate from mark-recapture is large even in our relatively small and manageable systems. The resulting one-number-per-system-per-year also reduces the power to detect an effect from such a measure. Fish catch per unit effort in most cases was a reasonable surrogate for abundance, so the recommendation is that a standardized netting program used in conjunction with measures of biomass would be adequate for monitoring purposes. The transient and ephemeral results provide support for the need of long-term monitoring to avoid adopting erroneous conclusions. In fact, the results presented here could change with additional years of data since we included a maximum of only four years post-treatment monitoring to date. If financing long-term monitoring is an issue, we recommend conducting a focused, standardized effort in alternate years to extend the timeframe of monitoring at a similar overall cost.

The Decline and Recovery of a Lake Whitefish (*Coregonus clupeaformis*) Population From Winter Drawdown in a Small Boreal Lake

Blanchfield*, P., K. Mills, D. Bodaly and S. Chalanchuk
Email: blanchfieldp@dfo-mpo.gc.ca

Water level fluctuations are one of the most important disturbances affecting aquatic systems. For temperate or boreal reservoirs, the drawdown of water occurs during the winter when precipitation is low and power generation demand high, such that water levels do not replenish until the following spring. Reservoirs are often subjected to other perturbations that confound the direct link between physical habitat manipulation and changes in fish populations. Given this, whole-lake experimentation can be a powerful tool to clearly demonstrate the impacts of physical habitat on fish populations. A winter drawdown experiment was conducted on Lake 226 at the Experimental Lakes Area to examine the impacts of water level fluctuations on fish and fish habitat. The focus was on the lake whitefish population, and the goal of the drawdown was to mimic the type of impacts typical of hydroelectric reservoirs.

The main study took place over six years, with data collection occurring one year prior to drawdown, during the three years of drawdown and two years of recovery. A control structure was built at the outflow of Lake 226 and water levels were reduced from December to February of 1994-1996. The first water level reduction decreased water levels by 2 m, and over the subsequent two winters, water levels were reduced by 3 m. The drawdown exposed large portions of the littoral zone that resulted in decreases in lake surface area and lake volume by up to 24% and 45%, respectively.

Automated fish-positioning systems were employed to document the movement of lake whitefish during the spawning season. The results showed that whitefish typically spawned in shallow water on specific substrate types, and that these spawning shoals were exposed during the winter drawdowns. The drawdown of water after whitefish spawning resulted in complete recruitment failure for each year of drawdown, something that had never been observed for the previous 29 years in which the Lake 226 whitefish population was studied. Survival also showed significant declines during the years that Lake 226 water levels were drawn down, most likely related to anoxic overwinter conditions. The lack of recruitment and low survival resulted in an 80% decline in whitefish abundance compared to pre-manipulation levels.

The recovery of the Lake 226 whitefish population did not conform to expectations of a rapid recovery based on results from exploited populations. Instead, we observed weak year classes, poor condition and minimal increases in abundance. There are numerous reasons why the Lake 226 whitefish population did not recover as expected. The production of small year classes in poor condition may have been related, in part, to the disruption of the food supply and overall changes in the lake due to drastic loss of littoral habitat. In summary, poor environmental conditions likely hampered the ability of whitefish to rebound once drawdown was relaxed.

The research presented here advances our understanding of the negative impacts of winter drawdown on lake whitefish populations and suggests various recommendations for Fish Habitat Management when dealing with fluctuating water levels. Perhaps a more important point to emphasise is that our expectation of lake whitefish population recovery, based on exploitation studies, was not met. This finding underlines the fact the recovery of fish populations that have declined due to loss of habitat will be fundamentally different than those recovering solely from exploitation. This study highlights the fact that whole-lake manipulation can provide a strong demonstrative tool linking fish habitat destruction to declines in fish populations, as well as the complexity of population recovery due to ecosystem processes.

Fish Habitat Compensation in Canada: A Detailed File Review and Analysis of Past Evaluations

D.J. Harper* and J.T. Quigley
*Author to whom correspondence should be addressed; Email: harperd@dfo-mpo.gc.ca

An evaluation of the performance of Fisheries and Oceans Canada (DFO) in achieving no net loss (NNL) through habitat compensation was initiated in 2000. As part of this evaluation, a literature review and a file review were conducted.

For the literature review, studies that evaluated the effectiveness of habitat compensation projects in achieving NNL in Canada between 1986 and 2002 were compiled and reviewed. Data from these studies were pooled to summarize findings relating to the fish habitat compensation projects that have been assessed.

Only ten studies were conducted within this timeframe. These studies have assessed a total of 103 compensation projects, representing less than 4% of the compensation projects in Canada. Most of the studies employed qualitative methodologies when assessing compensation projects, limiting the inferences that can be drawn from them. Of the assessments conducted, 88% were a combination of qualitative file reviews and compliance assessments; 11% were effectiveness assessments; and 1% was research. Combined, the compensation projects in these studies created and/or restored 493,205 m^2 of fish habitat to off-set losses of 1,142,648 m^2. There was an estimated net loss of 649,443 m^2 of fish habitat.

The majority of the compensation projects assessed were a result of impacts to estuarine and marine habitats. The development activities that were associated with the greatest percentage of compensation projects included urban development and forestry. Post-construction monitoring of the compensatory habitat was required for only 51% of the projects. The mean duration of the monitoring period was 3.6 years. Sixty-four percent of the compensation projects achieved NNL.

For the file review, files relating to 124 *Fisheries Act* Section 35(2) authorizations issued by DFO for the harmful alteration, disruption, and destruction of fish habitat (HADD) in Canada from 1994 to 1997 were collected and reviewed. Data extracted from the files were pooled to summarize findings relating to fish habitat compensation projects. Proponent compliance and the effectiveness of the compensation projects in achieving NNL were determined.

The loss of fish habitat as a result of the authorized HADDs was 419,562 m^2 while the gain as a result of compensation was 1,020,388 m^2. The mean compensation ratio per project (compensation area:HADD area) was 1.27:1. A quarter of compensation projects had a compensation ratio that was less than 1:1. In-channel and riparian habitats were the most frequently impacted. Urban development and roads and highways resulted in the greatest loss of habitat. The compensation options that were most often selected included creation of in-kind habitat (50%), increasing in-kind habitat productivity (22%), and creation of out-of-kind habitat (12%). The mean duration of post-construction monitoring programs associated with the authorizations was 3.7 years. There was a 43% compliance rate with monitoring requirements. Determinations of NNL could only be made for 17 authorizations as a result of poor file quality, poor proponent compliance with monitoring requirements, and the qualitative assessment procedures used in the monitoring programs. Improvements in file management and the use of scientifically-based, quantitative monitoring programs are required to ensure that the assessment of NNL is possible.

Studies evaluating the effectiveness of habitat compensation in achieving NNL are essential to adaptive management. Future studies should aim to employ quantitative methodologies when assessing NNL rather than the qualitative methodologies used in the past. Resource managers and scientists should work together to develop a national evaluation program through which the attainment of the conservation goal of NNL can be assessed on an ongoing basis.

Effectiveness of Habitat Compensation in Canada

J.T. Quigley* and D.J. Harper, Fisheries and Oceans Canada, Habitat and Enhancement Branch, 200-401 Burrard Street, Vancouver, BC
* Author to whom all correspondence should be addressed, quigleyj@pac.dfo-mpo.gc.ca

Canada contains approximately one quarter of the world's wetlands that support a rich biodiversity of over 198 fish species. Approximately one seventh (20 million ha) of Canada's wetlands have been lost in the last century. In North American freshwaters, 73% of fish extinctions can be attributed to habitat alterations. In response, Fisheries and Oceans Canada (DFO) enacted the habitat provisions of the *Fisheries Act*. A "harmful alteration, disruption, or destruction to fish habitat" (HADD) cannot occur unless authorised with legally binding compensatory habitat to off-set the HADD. Canada's conservation goal is no net loss of the productive capacity of fish habitats (NNL) provided by the *Policy for the Management of Fish Habitats* (Habitat Policy). DFO's performance in achieving its conservation goal has never been evaluated on a national scale.

We investigated 52 habitat compensation projects across Canada to determine biological, physical, and chemical compliance with authorisation specifications. We further evaluated the effectiveness of compensation habitat in off-setting losses in habitat productivity at 16 projects across Canada. Periphyton biomass, invertebrate density, fish biomass and riparian vegetation density were used as indicators of habitat productivity and compared between reference and compensation sites.

Of the 52 projects investigated, compliance with biological requirements was the lowest (58%) and compliance with chemical requirements the highest (100%). Approximately 86% of authorisations had larger HADD and/or smaller compensation areas than authorised. These were not small differences. On average, HADDs in riverine habitat were 389% larger than authorised. Consequently, 45% of in-channel compensation projects and 72% of riparian projects resulted in net losses in habitat area. Probable *Fisheries Act* violations were prevalent at 50% of the projects. Multiple regression analyses indicated violations were negatively associated with the occurrence of a DFO field inspection, providing empirical support for increased monitoring.

Of the 16 projects evaluated for effectiveness, approximately 12% achieved a net gain in habitat productivity. These projects were characterised by mean compensation ratios (compensation area:HADD area) of 5:1. Twenty-five percent of projects achieved NNL and 63% of projects resulted in net losses in habitat productivity. These projects were characterised by mean ratios of 1.1:1 and 0.7:1 respectively. We demonstrated that artificially increasing ratios to 2:1 was not sufficient to achieve NNL for all projects. Our ability to replicate ecosystem function is clearly limited. This illustrates that compliance does not ensure ecological success.

Habitat compensation, as currently implemented in Canada, is at best slowing the rate of habitat loss. Increasing the amount of authorised compensatory habitat in the absence of institutional changes will not reverse this trend. Improvements in both compensation science and institutional approaches are recommended to achieve Canada's conservation goal. Limited success in achieving NNL does not erode or invalidate the value of this goal of the Habitat Policy. Rather, it provides the impetus for change. It is critical for Canada's fisheries resources that DFO engages in adaptive management to build on successes and learn from past mistakes.

Recommendations to improve success include larger compensation ratios, creation and documentation of the functionality of compensation habitats prior/concurrent to HADDs, maintenance programs, increased monitoring and enforcement, and attention to limiting factors on a watershed basis. However, it is important to acknowledge that compensation does not mean never having to say no to development proposals. Some habitats may not be possible to compensate for. Failure to acknowledge the limitations of compensatory science will hamper Canada's efforts to conserve fish habitat.