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Quantifying the fluvial habitat needed for the re-introduction of Atlantic Salmon (*Salmo salar*) in Lake Ontario

Quantification de l'habitat fluvial nécessaire à la réintroduction du saumon atlantique (*Salmo salar*) dans le lac Ontario

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ABSTRACT

For extirpated Atlantic Salmon (*Salmo salar*) in Ontario, fluvial habitat for spawning and early growth would be required to re-introduce the Lake Ontario population. Based on a review of habitat suitability, the Ontario Ministry of Natural Resources identified three tributaries for restoration, Credit River, Duffins Creek and Cobourg Creek, all of which supported salmon historically. Based on a drainage area of 87,100 ha, the conservation targets for the Credit River were estimated to be 8.61 X 10^6 eggs and 3,631 female spawning salmon (1 lake winter; average 1.8 kg), assuming a conservation egg deposition target of 2.4 eggs/m^2. Conservation targets (number of female spawners) for the other two tributaries would be less. All accessible rearing habitat in the rivers could be essential for survival for three reasons: 1) allowable harm assessment indicated that population viability is sensitive to juvenile mortality; 2) only 3 of the original 27 rivers inhabited by salmon are targeted for restoration; and 3) identification of the whole river as important habitat is consistent with the proposed approach for inner Bay of Fundy salmon. Methods are proposed for identifying the amount of fluvial habitat needed if an adult population recovery target is identified on a lake basis rather than a tributary basis. Identification of important habitat in Lake Ontario proper could be deferred until more is known about migration routes and feeding areas. Residences (as defined in SARA) may apply to Atlantic Salmon for redds (egg incubation), but a Fisheries and Oceans Canada policy on residences is still pending. Based on known reproducing populations of other Salmoninae in Lake Ontario, suitable habitat for Atlantic Salmon is likely available, and re-introduction of this extirpated species is ecologically feasible.

RÉSUMÉ

Le saumon atlantique (*Salmo salar*), qui est disparu de l'Ontario, a besoin d'un habitat fluvial pour se reproduire et passer ses premiers stades de vie et, ultimement, reconstituer une population dans le lac Ontario. D'après un examen de la qualité de l'habitat, le ministère des Richesses naturelles de l'Ontario a ciblé trois tributaires où le saumon était observé autrefois, à savoir la rivière Credit, le ruisseau Duffins et le ruisseau Cobourg. Les cibles pour la Rivière Credit, dont le bassin hydrographique couvre 87 100 ha, sont de 8,61 x 106 œufs et de 3 631 femelles reproductrices (1er hiver dans le lac; moyenne de 1,8 kg), avec une cible de ponte pour la conservation de 2,4 œufs/m2. Les cibles pour la conservation (nombre de femelles reproductrices) pour les deux autres tributaires sont inférieures. L'ensemble de l'habitat d'alevinage accessible dans les rivières peut être essentiel à la survie de l'espèce et ce, pour trois raisons : 1) l'évaluation des dommages admissibles indique que la viabilité de la population est fonction de la mortalité chez les juvéniles; 2) seulement trois des 27 cours d'eau qui étaient habités par le saumon à l'origine sont visés; 3) la désignation de tout le cours d'eau en tant qu'habitat important est conforme à l'approche proposée pour le saumon de l'arrière-baie de Fundy. On propose des méthodes pour quantifier l'habitat fluvial nécessaire pour une cible de rétablissement d'une population adulte dans le lac plutôt que par tributaire. La désignation de l'habitat important dans le lac Ontario proprement dit pourrait être reportée jusqu'à ce que l'on en sache davantage au sujet des voies migratoires et des aires d'alimentation. Le concept de résidence (tel que défini dans la LEP) peut s'appliquer au saumon atlantique en ce qui concerne les nids (incubation des œufs), mais Pêches et Océans Canada n'a pas encore de politique à cet égard. Selon les populations reproductrices connues d'autres salmonidés du lac Ontario, il existe vraisemblablement un habitat approprié pour le saumon atlantique et la réintroduction de cette espèce disparue est faisable sur le plan écologique.

INTRODUCTION

Critical habitat[1] is defined in the *Species at Risk Act* (SARA) as the 'habitat necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species'. For Atlantic Salmon *Salmo salar* in Lake Ontario, with the Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status of extirpated, this definition is specifically interpreted to mean the habitat necessary for recovery. In SARA, habitat for aquatic species is defined as 'spawning grounds, and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where species formerly occurred and have the potential to be reintroduced'. By this definition, habitat is identified based on the functions it provides for all life history stages.

Historically, Atlantic Salmon utilized many tributaries flowing into Lake Ontario for spawning and juvenile production. Parsons (1973), cited in COSEWIC (2006), listed 40 tributaries, 24 on the Canadian shoreline, and 16 on the United States shoreline. The Atlantic Salmon Federation (http://www.asf.ca/rivers/ontario.html) listed 17 tributaries on the Canadian shoreline (Fig. 1). Based on the extreme migration distance from the sea, time of spawning, and other evidence, many authorities believe that Lake Ontario salmon were lake-resident rather than anadromous, but this assumption remains conjectural (Dunfield 1985; COSEWIC 2006).

The quantification of habitat requirements for recovery of Lake Ontario Atlantic Salmon in this study is based on the assumption that Ontario salmon will have a lake-resident life history rather than an anadromous life history. The objective of this document is to extrapolate and apply methods for estimating conservation requirements (in terms of population goals and the associated habitat needs) of Atlantic Salmon from Atlantic Canada to Lake Ontario.

METHODS

NARRATIVE DESCRIPTION OF HABITAT REQUIREMENTS

River habitat requirements of Atlantic salmon for the different life stages (spawning, alevins, and parr), and habitat constraints to production, were summarized from Amiro (2006).

BIOLOGICAL CHARACTERISTICS

Biological characteristics of Lake Ontario salmon were obtained from the Ministry of Natural Resources (J. Bowlby, pers. comm.). A small sample (n = 29) of stocked salmon that returned as adults to Credit River in 1990 and 1991 was used to determine size and age at maturity.

[1] Subsequent to the Lake Ontario Atlantic Salmon Recovery Potential Assessment, the Canadian Science Advisory Secretariat advised and emphasized that DFO Science does not make Critical Habitat designations, but rather provides information and advice on habitat use, availability, requirements and threats for Species at Risk (DFO 2007). The description of habitat needs for Atlantic Salmon in this document is consistent with this advice. Critical habitat designations are based on policy and management decisions within the context of Recovery Strategies and Action Plans.

CONSERVATION TARGETS AND HABITAT QUANTIFICATION

Two approaches were identified to demonstrate methods for quantifying habitat requirements, a lake (population) approach and a river (habitat) approach. Both methods were based on conservation spawning requirements (number of eggs per square metre of fluvial habitat) extrapolated from the east coast of Canada. Conservation spawner requirements (number of eggs and female adult salmon per river) for anadromous Atlantic salmon were calculated by O'Connell *et al.* (1997).

Lake method: To quantify fluvial habitat requirements using the lake approach, a tentative conservation population target for the whole lake was determined. The amount of fluvial habitat needed to support this population was then estimated using literature information on conservation spawning requirements from Atlantic Canada, literature based fecundity, average female weight of hatchery returns of salmon from Lake Ontario, and an assumed sex ratio of 1:1.

No population estimates of Atlantic salmon were made in Lake Ontario historically. Observed abundance was inferred from anecdotal information in historical records (Dunfield 1985). The rough estimate of the historic abundance of salmon in Lake Ontario was used as a target for estimating the fluvial habitat requirements, to demonstrate the lake method.

River method: Using expert opinion, provincial and state biologists developed several selection criteria for identifying three candidate rivers for restoration. The criteria were comprehensive and included the following river attributes: substrate, thermal conditions, available spawning and nursery habitat, stream fragmentation (barriers), ground water input, base flow, ratio of base to peak flow, fishing pressure, abundance of competitors, stream productivity, anchor ice, stream gradient, forest cover and urban development (Greig *et al.* 2003).

In contrast to the lake population approach, the river approach started with an estimate of rearing area for each watershed, and then the numbers of spawners needed to saturate the habitat was estimated. Conservation targets for each river in Lake Ontario chosen for restoration were estimated using: 1) a regression between drainage area (ha) and fluvial rearing area (100 m^2) from Bay of Fundy rivers; 2) a conservation target of 2.4 eggs/m^2 from the literature (O'Connell *et al.* 1997; Chaput 2006); 3) relative fecundity for landlocked salmon from the literature (Warner and Havey 1985; Vélez-Espino and Koops 2007); and 4) size and age at maturity data for female salmon from Lake Ontario. Five assumptions applied to these estimates: 1) the regression assumes that the proportion of fluvial rearing area to drainage area is similar in the Lake Ontario and Bay of Fundy rivers; 2) all Ontario restoration tributaries are accessible to migrating salmon; 3) the conservation target egg deposition for anadromous salmon in eastern Canada applies to landlocked populations in Lake Ontario; 4) the fecundity of Lake Ontario salmon will be similar to salmon from landlocked populations in the State of Maine; and 5) size and age at maturity of a small sample of female salmon collected from Lake Ontario in 1990 and 1991 were representative of future populations. Assumptions will be discussed later.

In future, the conservation targets (population and habitat) could be revised using these methods if updated information on rearing area, size at maturity, fecundity and abundance data for Lake Ontario salmon becomes available.

RESIDENCE

Residence is defined in the *Species at Risk Act* as 'a dwelling place such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating [Section 2(1)]. Section 33 of SARA prohibits the damage or destruction of a residence of an endangered or threatened species upon listing, and of extirpated species if a recovery strategy has recommended the reintroduction of the species.

Fisheries and Oceans Canada (DFO) currently does not have a policy for identifying residences of aquatic species. However, it is likely that the concept of a residence will apply to some aquatic SAR. To scope this possibility, DFO conducted residence identification pilots for six aquatic species, including Inner Bay of Fundy Atlantic salmon. Results from the Bay of Fundy pilot case study were used to discuss potential residences of Lake Ontario Atlantic salmon.

RESULTS

NARRATIVE DESCRIPTION OF HABITAT REQUIREMENTS

Atlantic salmon are rheophilic, requiring flowing water for spawning and early rearing. Ranges in water depth, current speed, and substrate characteristics of fluvial habitat were summarized for the juvenile life stages by Amiro (2006):

Life stage	Water depth (cm)	Velocity (cm/sec)	Substrate
Spawning	17 – 70	<20 – 54	Gravel (little silt and sand)
Egg incubation	20 – 50	40 – 54	Gravel
Alevins (6-7 months post egg deposition)	18 – 82	5 – 48	Gravel, pebble
Fry (8-12 months post egg deposition)	<10 - 40	5 – 80	Gravel to boulder
Parr, age 1	20 - >300	4 – 80	Gravel to boulder
Parr, age 2	20 - >300	4 – 75	Gravel to boulder

As indicated in the above table, use of fluvial habitat (water depth, current) by juvenile salmon is flexible. Amiro (2006) noted in detail habitat constraints to salmon production. Of particular note: salmon are sensitive to water pH < 5.3, an upper lethal water temperature is 27.8^{o}C, and suitable habitat is a direct function of stream discharge. Obstructions and habitat fragmentation accounted for most of the losses of salmon habitat historically (50% loss prior to 1870, including the Lake Ontario population). Sedimentation and siltation negatively affects both egg survival and overwintering. Further details of the habitat requirements of Atlantic salmon are provided by Amiro (2006).

It was assumed that the above fluvial habitat requirements synthesized by Amiro (2006) would apply to Lake Ontario Atlantic Salmon. After one or two years of growth in the river habitat, juvenile salmon would become smolts, move into Lake Ontario, and mature after one or two years in the lake (Table 1).

BIOLOGICAL CHARACTERISTICS

A sample of adult Atlantic salmon that returned to the Credit River in 1990 and 1991 provided information on the biological characteristics of Lake Ontario salmon (Table 1). The salmon were initially stocked as age-1 fingerlings (90%) or as fry (10%). Of 29 returning adults, 41% were males and 59% were females. The majority of salmon (79%) returned after one winter in the lake; remaining salmon returned after two years in the lake. The average weight of the female 1 lake-winter (1LW) salmon was 1,838 g (SE 128.9).

Average relative fecundity of landlocked salmon from Maine was 1.29 eggs/g (Warner and Havey 1985). For estimating conservation targets, an average female weight of 1,838 g and a fecundity of 1.29 eggs/g were used.

CONSERVATION TARGETS AND HABITAT QUANTIFICATION

Lake method: Prior to 1800, the tributary rivers of Lake Ontario ‘abounded’ with salmon. One resident of the Credit River, reputed to be the best salmon tributary in Upper Canada, noted that salmon ‘swarmed’ the tributary so ‘thickly’ that they could be easily captured. Local First Nation fishers routinely captured several hundred fish nightly (Dunfield 1985). As noted above, approximately 40 tributaries of Lake Ontario were known to support spawning runs of Atlantic salmon (Parsons 1973).

Based on these historical, albeit anecdotal, records it is reasonable to assume that the Lake Ontario population was in the thousands (DFO 2009). Based on this reasoning, a tentative and somewhat arbitrary conservation target for Lake Ontario was set at 30,000 adult salmon. Assuming a 1:1 sex ratio, an average female weight of 1,838 g, 1.29 eggs/g, and a conservation target of 2.4 eggs/m^2, 15,000 female salmon would require about 1,500 ha of fluvial habitat for rearing.

Migration routes and habitat use in Lake Ontario, historically, are unknown.

River method: Using the habitat criteria from Greig *et al.* (2003) and available habitat data from Lake Ontario tributaries, three watersheds were selected for restoration – Credit River, Duffins Creek and Cobourg Creek (M. Daniels, Ontario Ministry of Natural Resources (OMNR), pers. comm.). All three tributaries were inhabited by salmon historically (Figure 1). Fishes currently inhabiting these rivers are given in Table 2. Two of these rivers have existing fish management plans, developed by OMNR and conservation authorities (Credit River and Duffins Creek), and a management plan is being developed for the third watershed (Cobourg Creek) (M. Daniels, pers. comm.). All three tributaries chosen for restoration had suitable habitat for all life stages as qualified above (Narrative Description of Habitat Requirements).

For the Bay of Fundy salmon rivers, the regression between drainage area (DA, ha) and rearing area (RA, 100 m^2) was: $\ln RA = -3.647 + 1.243 \ln DA$ (SE of estimate 0.116) (Figure 2). Using this regression and the Ontario drainage areas as predictors, the rearing areas for the Credit River and Duffins Creek were estimated to be 35,882 and 8,875 units of 100 m^2, respectively (Table 3). A rough estimate of the rearing area of Cobourg Creek was 6,000 units of 100 m^2 (Table 3). Assuming a conservation target egg deposition rate of 2.4 eggs/m^2, the conservation targets were estimated as 1) Credit River: 8.61×10^6 eggs and 3631 female spawners (age at maturity of 1LW); 2) Duffins Creek: 2.13 x 10^6 eggs and 898 adult 1LW female spawners; and Cobourg: 1.44 X 10^6 eggs and 607 1LW females. Together, these three tributaries would require 5,136 females and, assuming a 1:1 sex ratio, about 10,200 salmon in total to provide adequate spawning escapement to fully seed the rearing habitat.

All three tributaries targeted for restoration were inhabited by non-native salmonids (Table 2). Interactions with non-native and invasive species (AIS) was identified as the primary threat crucial to recovery of Lake Ontario salmon (DFO 2009). Potential sources of mortality include Early Mortality Syndrome related to alewife as prey, predation of Atlantic salmon juveniles by Chinook salmon, and competition for space and food. Other threats potentially affect Atlantic salmon in these tributaries as well (Table 4; DFO 2009).

RESIDENCE

Using inner Bay of Fundy Atlantic salmon as a pilot study, three types of potential residences were proposed for Atlantic salmon: spawning/incubation residences (redds), parr shelters (home stones) and adult staging pools. The physical appearance, function and period and frequency of occupation were described for each type of residence (A.J.F. Gibson; Appendix I). Recent discussion, however, has focussed on residence as being a ‘constructed’ structure. If this definition is confirmed, home stones and staging pools would not be eligible as residences. Redds as constructed residences would potentially apply to Lake Ontario tributaries (e.g., Credit River). However, the results of the pilot case studies have not yet been applied to inner Fundy salmon, or to any other fish species, as the development of a DFO policy on residences is ongoing.

DISCUSSION

Methods and information for estimating the amount and quality of habitat needed for the restoration of Atlantic salmon in Lake Ontario were extrapolated from stock assessment procedures used for anadromous Atlantic salmon in eastern Canada (O’Connell *et al.* 1997; Amiro 2006). The premise of this document is that the long-standing knowledge of Atlantic salmon conservation in eastern Canada can be used as a reasonable benchmark to guide salmon restoration in Lake Ontario. For extrapolation, however, key assumptions of this approach need to be tested, and the knowledge gaps need to be addressed, before the methods can be calibrated and applied with confidence to the spawning and rearing tributaries of Lake Ontario.

Both the lake and river methods of estimating habitat requirements were based on the assumption of an egg deposition target of 2.4 eggs/m^2. A spawning egg deposition rate of 2.4 eggs/m^2 is used as a conservation target to saturate fluvial habitat with salmon eggs to maintain healthy populations of salmon for most regions in eastern Canada (O’Connell *et al.* 1997; Chaput 2006). Whether or not this egg deposition target applies to Lake Ontario tributaries needs to be tested with stock-recruitment data, but 2.4 eggs likely provides a reasonable but rough benchmark to guide restoration until more data become available.

For the lake method, a tentative target of 30,000 adult salmon was identified to demonstrate the method of quantifying fluvial habitat needs based on a population recovery target as a starting point. The target population size was chosen arbitrarily, as no historic records of population size of salmon in Lake Ontario were available. If this method is used, a target population size for restoration would have to be decided by consensus by a panel of experts, using the anecdotal information available and other information (lake productivity, abundance of non-native salmonids). Once a target population abundance is identified, the quantity of fluvial habitat needed for spawning and rearing could be back calculated from knowledge of sex ratio, fecundity, female body size and a target conservation egg deposition rate as demonstrated in this study. A minimum target population size for recovery could be based on a proportion of historical abundance (e.g., 20% of historical abundance), or an estimate of effective population size (DFO 2009). The recovery target for Lake Ontario should be considered on a whole-lake basis rather than a tributary basis (DFO 2009).

For the river method, the quantity of fluvial habitat for each of the three tributaries targeted for restoration was estimated by assuming that the drainage area-fluvial habitat regression from the Bay of Fundy rivers was applicable to Lake Ontario tributaries, and by assuming that all available habitat, rather than subsections, was essential for recovery. Both assumptions need to be tested. First, correlations between fluvial habitat and watershed drainage area would be different for different regions, depending on river gradient, geology, riparian vegetation, land use, and other factors. The regression, if used, would have to be tested and calibrated for tributary streams of the north shore of Lake Ontario. Alternatively, and preferably, the quantity of fluvial habitat could be measured directly. Secondly, the assumption that all available fluvial habitat is needed for recovery was based on three factors: 1) only three tributaries were selected for the restoration program in Ontario, compared to 27 tributaries that were known to be inhabited with salmon historically; 2) threats to survival of Atlantic Salmon in the streams would be significant (e.g., competition and predator-prey interactions with non-native salmonids); 3) viability of the population is sensitive to survival during early life (> 7% reduction in survival of fry would jeopardize population survival and future recovery; Vélez-Espino and Koops 2007). Considering all fluvial habitat as essential, rather than subsections, is consistent with the approach proposed for Bay of Fundy salmon (Amiro *et al.* 2003). For Lake Ontario salmon, survival of juveniles in different habitats from spawning to outmigration as smolts needs to be quantified in view of the number of threats that potentially affect Ontario populations.

In summary, to apply methods for estimating habitat requirements from the east coast to Lake Ontario will require additional research to address knowledge gaps: habitat-dependent survival of salmon for all life history stages, during both river and lake residence; age and size at maturity, sex ratios and fecundity of adult Lake Ontario salmon; migration routes and habitat use in Lake Ontario; and population productivity and smolt yield for different egg deposition rates.

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Table 1. Biological characteristics of Atlantic salmon captured in the Credit River during 1990 and 1991. Data from Ontario Ministry of Natural Resources (J. Bowlby, pers. comm.)

Number	Year	Strain	TL (mm)	Weight (g)	Sex	Age stocked	Lake years
1	1990	Grand Lake	535	1500	M	1	1
2	1990	Grand Lake	575	1820	M	1	1
3	1990	Grand Lake	593	1800	M	1	1
4	1990	Grand Lake	575	2325	F	0	1
5	1990	LaHave	528	1330	F	1	1
6	1990	LaHave	549	1950	F	1	1
7	1990	LaHave	560		F	1	1
8	1990	LaHave	560		F	1	1
9	1990	LaHave	560		F	1	1
10	1990	LaHave	563	1625	F	1	1
11	1990	LaHave	566	1450	F	1	1
12	1990	LaHave	570		F	1	1
13	1990	LaHave	572	2050	F	1	1
14	1990	LaHave	583	1675	M	1	1
15	1990	LaHave	589	2000	M	1	1
16	1990	LaHave	595	1725	F	1	1
17	1990	LaHave	603	2000	M	1	1
18	1990	LaHave	610	2010	M	1	1
19	1991	LaHave	595	2250	F	1	1
20	1991	Grand Lake	515		M	1	1
21	1991	Grand Lake	550		M	1	1
22	1991	Grand Lake	725	4400	F	1	2
23	1991	Grand Lake	748	4250	M	1	2
24	1991	Grand Lake	750	4000	M	1	2
25	1991	Grand Lake	819	5500	F	1	2
26	1991	Grand Lake			F	1	2
27	1991	Grand Lake	617	3336	M	0	1
28	1991	Grand Lake	635		F	0	1
29	1991	Grand Lake	747	5500	F	1	2

Age group	Mean weight	(SE)
Female: 1 lake winter	1838	(128.9)
Female: 2 lake winter	5133	(366.7)
Female: pooled	2737	(480.8)

Table 2. Physical size and fish species inhabiting Credit River, Duffins Creek and Cobourg Creek, the rivers proposed for Atlantic salmon restoration in Lake Ontario.

Description	Credit River	Duffins Creek	Cobourg Creek
Location (mouth)	43°34'56" N 79°42'31" W	43°51'10" N 79°3'44" W	43°57'53" N 79°11'6" W
Watershed Area (km^2) [1]	871	283	
Discharge ($m^3 sec^{-1}$) [2]	8.12	2.82	1.89
Cohabiting species[3]	57	33	28
Cohabiting salmoninae[3]			
Salvelinus fontinalis	√	√	√
Salmo trutta	√	√	√
Oncorhynchus kisutch	√		√
Oncorhynchus mykiss	√	√	√
Oncorhynchus tshawytscha	√		√
SARA Listed Species			
Anguilla rostrata	√?		
Clinostomus elongatus	√	√	

[1] watershed area from fisheries management plans (OMNR, pers. comm.; Cobourg not available)
[2] mean monthly discharge. Credit : Water Survey of Canada station 02HB002 at Erindale, 795 km^2, 47 yrs; Duffins: WSC station 02HC006 at Pickering, 249 km^2, 45 yrs; Cobourg: WSC station 02HD019 at Cobourg, unknown km^2, 2 yrs; data from: www.wsc.ec.gc.ca/staflo/index_e.cfm?cname=main_e.cfm
[3] cohabiting species from fisheries management plans (Credit and Duffins); Ontario Aquatic Map Explorer database (Cobourg)(A. Doolittle, pers. comm.)

Table 3. Drainage (ha) and rearing area (units of 100m²) of six inner Bay of Fundy rivers, and regression estimates of rearing area for two Lake Ontario rivers.

Region and river	Drainage Area (DA, ha)	Rearing Area (RA)	Estimate of RA[2]	Conservation Target	
				Eggs[3] (10^6)	Females[4]
Bay of Fundy					
Stewiacke	61,900	27,014			
Salmon (Colchester)	38,977	13,468			
Great Village	11,252	2,587			
Portapique	12,119	3,309			
Parrsboro	7,130	1,747			
River Hebert	22,248	6,062			
Maccan	36,674	10,587			
Lake Ontario					
Credit	87,100		35,882	8.61	3631
Duffins	28,300		8,875	2.13	898
Cobourg[5]			6,000[5]	1.44	607

[1] accessible rearing area excludes low gradient habitat (< 0.12 %; Amiro *et al.* 2003)
[2] from regression of ln RA = -3.647 + 1.243ln DA (SE of estimate 0.116)
[3] based on conservation target of 2.4 eggs m^2 (O'Connell *et al.* 1997).
[4] assuming 1.29 eggs/g (Vélez-Espino and Koops 2007; Warner and Havey 1985), and an average weight of 1838 g for 1 Lake Winter (1 LW) females (Table 1)
[5] No estimate of drainage area for Cobourg was available. Rearing area was estimated (roughly) as the ratio of discharge Cobourg to Duffins (0.67) times the rearing area of Duffins; conservation targets are approximate

Table 4. List of threats to Atlantic salmon survival in the three Lake Ontario tributaries targeted for restoration. Ranks (high, medium, low and unknown) are tentative.

Threat	Credit River	Duffins Creek	Cobourg Creek
Competition for spawning habitat	H	H	H
Competition for juvenile habitat	H	H	H
Early Mortality Syndrome	U	U	U
Habitat (thermal, water quality & physical)	H	M	M
Barriers [1]	H	M	M
Fishing [2]	M	M	M
Predators	L	L	L

[1] handling mortality
[2] bycatch and catch and release mortality

Figure 1. Map of rivers in Ontario and New York historically inhabited by Salmo salar (from the Atlantic Salmon Federation (http://www.asf.ca/rivers/ontario.html)).

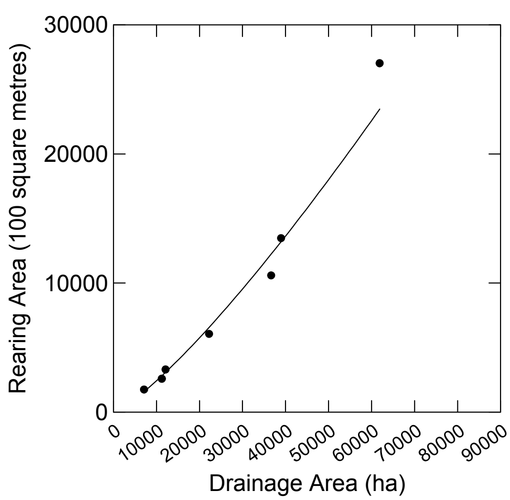

Figure 2. Relationship between drainage area (ha) and total rearing area (100 m^2) of seven inner Bay of Fundy rivers. Fitted line is a power function. Data for drainage and rearing areas were from L. Marshall and P. Amiro, DFO, BIO, Dartmouth (pers. comm.).

Appendix I. Application of the Residence Concept to Atlantic salmon (*Salmo salar*) (DRAFT)

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Canada's *Species at Risk Act* defines a residence as "a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating". For Atlantic salmon, at least four life stages use dwelling places that meet the criteria for being a residence. These residences are redds (used by eggs and yolk-sac fry), home stones (used by juvenile salmon in freshwater) and staging or holding pools (used by adults). Each of these locations is habitually occupied during part of the salmon's life cycle. These locations are essential to the successful performance of specific, crucial functions of the salmon's life-cycle. Details and rationale follow.

Redds

Atlantic salmon deposit their eggs in excavated depressions called redds (Gaudemar *et al.* 2000, Wedemeyer 2001). Eggs are deposited in the redds from late October to early December and are occupied until spring (roughly mid-May or June) when the fry emerge and begin feeding (Danie *et al.* 1984). Redds protect eggs and alevins from disturbance, currents and predators. Disturbance of salmon eggs after water hardening and prior to the eye stage can kill the eggs (Wedemeyer 2001). Salmon in rivers live in a fluvial environment and currents can displace eggs or alevins into unfavourable habitat if not sheltered from the currents. Redds fill this function by providing hydraulic eddies that capture expressed eggs and, after being covered over with gravel by the adult salmon, provide interstitial space for water flow and oxygen for the incubation of the eggs and development of alevins prior to emergence from the redd as early-feeding fry (Danie *et al.* 1984). Redds also provide protection for eggs and alevins from predators. Redds are typically about 2.3 and 5.7 m^2 in size, and consist of a raised mound of gravel or dome under which most of the eggs were located, and an upstream depression or 'pot' (Gaudemar *et al.* 2000). Burial depths are about 10 to 15 cm^2. Redds are typically constructed in water depths (Beland *et al.* 1982) of 17 to 76 cm and velocities (Beland *et al.* 1982) between 26 to 90 cm/s^2.

Home Stones

Atlantic salmon parr in fluvial habitat are found in riffle-run areas typically with cobble and boulder, are often stationary and occupy territories associated with home stones (Heggenes 1990). Maintaining position in a fluvial environment, which is necessary to avoid being swept into unfavourable habitat, requires either a high energy expenditure or shelter from the currents. Salmon parr use eddies and spaces around rocks (home stones) or instream debris as shelter from currents. These areas are used for feeding, growth, shelter from currents and as cover for predator avoidance. Salmon parr are territorial and defend these spaces from other salmon parr (Keeley and Grant 1995, Cutts *et al.* 1999a). Occupancy (prior residency) is a key determinant for successful defence (Cutts *et al.* 1999b). Although salmon may change home stones intermittently, movement may be limited. For example, in a study of movement of young-of-the-year salmon during July and August, 61.8% of the fish moved less than 1 meter during the study period (Steingrimsson and Grant 2003). Ability to obtain and defend a territory has been linked to age-of-smoltification (and hence age-at-maturity, a key life history parameter) via growth (Cutts *et al.* 1999a). Home stones associated with the individual positions of all ages are typically less than 20 cm in summer, and up to 40 cm in diameter in autumn (Rimmer *et al.* 1984).

Staging Pools

Although spawning does not occur until late fall, adult Atlantic salmon may enter the rivers in either the spring, summer or fall, and then typically remain in freshwater until they spawn. Ascension of rivers typically occurs in three phases, the second being a relatively long residency period (Bardonnet and Bagliniere 2002) that can range from about one month to over 6 months. During this time they stage in pools and these pools are used routinely year after year. Adults may stay as long as 2 to 3 months in a single pool (Webb 1989). These pools dissipate energy, provide cover and shelter from predators, provide low-flow areas that enable salmon to remain in freshwater without a large energy expenditure, and can also provide thermal refuges if the pools are fed by ground water. Holding pools are well documented for many rivers because they are the favoured location for salmon anglers, and many are identified on the 1:50,000 National Topographic Series maps. Low numbers of holding pools has been considered a limited factor for some salmon populations (Frenette *et al.* 1975).

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