BRING BACK THE SALMON
LAKE ONTARIO

To: Dr. Tom Stewart, Chair of the Lake Ontario Atlantic Salmon Science Review Team

From: Andy Todd (MNRF) and Matt DeMille (OFAH), Co-Chairs of the Lake Ontario Atlantic Salmon Restoration Program Steering Committee

October 15, 2014

Dear Dr. Stewart;

Restoring Atlantic Salmon to today's Lake Ontario is a very big idea which presents some big challenges with big rewards. The program partners are all working very hard to improve habitat, educate and engage our youth about conservation, grow and stock fish and conduct the science needed for success.
On behalf of the Lake Ontario Atlantic Salmon Restoration Program Steering Committee, we are pleased to receive the final science review report "**Proceedings of the Lake Ontario Atlantic Salmon Restoration Science Workshop".**

The science review represents a significant milestone in the restoration program and is an important part of the program's adaptive management cycle. We appreciate the time, energy and commitment to conduct this review. We would also like to acknowledge the generosity of the Great Lakes Fishery Commission, the Canadian Sportfishing Industry Association and all the participants from Canada and the US.

The Atlantic Salmon program review provides an opportunity to reflect on what we have learned and to plan for the next five years. The Steering Committee is considering the science advice and management implications and we expect to have an updated Five Year Program Plan before the new year.

Please extend our gratitude to the science review team and support staff.

Kindest regards

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Proceedings of the Lake Ontario Atlantic Salmon Restoration Science Workshop February 18–20, 2014, Alliston, Ontario

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Correct citation for this publication:

Stewart, T. J., Bowlby A., Wilson C. (eds.), 2014. Proceedings of the Lake Ontario Atlantic Salmon Restoration Science Workshop, February 18–20, 2014, Alliston, Ontario. Ontario Ministry of Natural Resources and Forestry, File Report LOA 14.08

Contents

Overview

A workshop was held February 18–20, 2014 in Alliston, Ontario to assess progress and identify knowledge gaps and management implications in the Lake Ontario Atlantic Salmon Restoration Program and to support a second workshop to review and update this program. The workshop participants presented preliminary findings from ongoing research and monitoring programs in support of Atlantic salmon restoration in Lake Ontario and shared experiences, knowledge, and perspectives among restoration partners and invited experts from other jurisdictions. To facilitate the next workshop, this report begins with a synthesis of key findings, hypotheses-of-effect, and management implications derived from the workshop presentations and discussions. The extended abstracts of the presentations, associated questions and answers, and facilitated discussion notes are reported approximating the order of the workshop agenda listed in Appendix A. The original detail questions posed to investigators are listed in Appendix B, and a list of participants is given in Appendix C. A post-workshop calculation of life stage performance corrected for stocking numbers is presented in Appendix D. Scientific names of fish species referred to in report are listed in Appendix E.

Acknowledgements

The concept for this workshop was initially proposed by Andy Todd and developed by a steering committee composed of Tom Stewart, Evan Hall, Kevin Loftus, Jack Imhof, Chris Wilson, and Chris Robinson. We would especially like to thank our visiting investigators and restoration practitioners Steve McCormick, Dave Cote, Rick Cunjak, Jim Johnson, Bill Ardren, and Roger Greil. Jason Dietrich facilitated the discussions, and Evan Hall and Nina Jakobi provided logistic support. Tim Johnson, Colin Lake, Chris Robinson, and Jack Imhof took notes of the workshop discussions. Mark Desjardins, Mark Heaton, Tim Johnson and Jerry Smitka provided helpful comments to the summary of findings and hypotheses-of-effect. Hospitality support was provided by the Canadian Sportfishing Industry Association. Funding for the workshop was provided by the Great Lakes Fishery Commission.

Summary of Findings, Hypotheses-of-Effect, and Management Implications

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Introduction

The following is a summary of findings, hypotheses-of-effect, and management implications synthesized after completion of the workshop by discussion among members of the workshop steering committee. As necessary, the steering committee sought technical review and clarification by appropriate workshop participants. The goal of the workshop was not to reach consensus, and it is important to acknowledge that not all participants would agree with the summary. The summary of findings is organized under two themes: **Culture and stocking strategies** and **Ecological influences** with hypotheses embedded in each theme. **Management implications** follow the summary of the findings.

Hypotheses-of-effect are derived from the adaptive management approach (Walters, 1986). In this context we see the hypotheses as:

- plausible mechanistic explanations for what was presented and discussed at the workshop.
- not proven, not certain, and not mutually exclusive.
- testable by adaptive management approaches or research experiments.

Restoration practitioners need to consider these hypotheses and make their own decision (individually and collectively) based on the weight of evidence and expert opinion on the likelihood of a hypothesis being true or not. Based on this judgement, practitioners will need to choose a suite of management strategies and weigh the associated potential risk and benefits.

Culture and stocking strategies

1. Because of the time involved to establish in-house broodstocks of the Sebago and Lac Saint-Jean strains, most stocking data pertain to the LaHave strain. It will require another 3–5 years of management and assessment before sufficient data are available to assess stocking performance for the other two strains. Preliminary data from Lake Ontario, most derived from Credit River monitoring, indicate that stocking of spring fingerlings (fry) accounts for the majority of the surviving adults observed. Fall fingerlings do not appear to have survived as well as spring fingerlings based on smolt sampling and captured returning adults. Fish stocked as yearlings were rarely seen in smolt traps or as returning adults (either in assessments or angling fisheries in New York and Ontario). These low catches could suggest poor survival or straying to un-monitored tributaries. As an indicator of the difference in performance among life-stages, using recent culture and stocking practices, it would be necessary to increase fall fingerling stocking numbers by a factor of 17.3 or spring yearling stocking numbers by a factor of 13.8 to achieve the same number of adults produced from stocking spring fingerlings (Appendix D). There are several hypotheses that may explain these observations:

    a. **Hypothesis 1**: After stocking, physiological smolt development and behaviour of spring fingerlings are more synchronous with the ecologically-optimum time for outmigration to the lake which improves their survival.

    b. **Hypothesis 2**: Spring fingerlings are stocked into better habitats than fall fingerlings and spring yearlings, improving their survival compared to fall fingerlings and spring yearlings.

    c. **Hypothesis 3**: Fall fingerlings have poorer survival because:

        i. their overwinter habitat is not suitable (either due the habitat conditions at the stocking site and/or their inability to move to more suitable overwinter habitat).

        ii. they are unable to adapt, due to timing or location of stocking, to the ecological conditions (temperature, flow, photoperiod) ultimately affecting physiological development and behaviour during smoltification, and they may spend a second winter in the tributary resulting in higher mortality.

        iii. they are stocked at too small a size affecting their ability to survive and develop as smolts.

    d. **Hypothesis 4**: Spring yearlings have poorer survival because:

        i. some fish are stocked at too small a size and/or are not physiologically or behaviourally adapted to stream conditions delaying or deferring their movement from the tributary to the lake resulting in higher mortality than natural smolts.

ii. some fish emigrate from the tributary very soon after stocking due to their larger size, flow conditions at the time of stocking, or development of physiological and behavioural traits of smolts in the hatchery. These fish do not survive in the lake due to high levels of predation and/or inadequate food resources during the early spring (March/April) when they emigrate.

iii. surviving fish do not imprint to monitored streams and are therefore not observed.

e. **Hypothesis 5**: Higher spring yearling survival on other systems (US waters of Lake Ontario, St Mary's River, Lake Champlain, other small inland systems) is due to the culturing of larger fish and/or delaying hatchery release until later in the spring (late May or early June). Later stocking may improve their ability to avoid predation due to larger size and lower density of predators, and/or they may benefit from increased food availability. These fish may not imprint to stocked tributaries.

f. **Hypothesis 6**: Stocking of fish too far upstream from the tributary mouth may reduce survival due to higher energetic cost of migration, increased vulnerability to predation, and potential disruption of the smoltification process.

Ecological influences

1. Restoring Atlantic salmon requires that they be able to complete their life cycle in the presence of other naturalized salmonids using the same tributaries for reproduction. A review of field and laboratory experiments suggests that competition with other salmonids in the tributaries is likely not a significant impediment to restoration or could potentially be managed or mitigated. There are several hypotheses that may explain these conclusions:

a. **Hypothesis 7**: Chinook and coho salmon juveniles pose a low competitive risk to Atlantic salmon juveniles as they are unlikely to impede growth, alter behaviour and/or increase mortality of juvenile Atlantic salmon

b. **Hypothesis 8**: Rainbow trout juveniles pose a moderate competitive risk to juvenile Atlantic salmon and may impede growth, alter behaviour and/or increase mortality of juvenile Atlantic salmon. Habitat conditions will mitigate the risks.

c. **Hypothesis 9**: Juvenile and resident adult Brown trout pose a high risk to Atlantic salmon juveniles through competition and predation, and will substantially impede growth, alter behavior and/or increase mortality of juvenile Atlantic salmon.

d. **Hypothesis 10**: In streams where multiple salmonid species are present, synergistic effects of competition and niche overlap may disproportionately impact juvenile Atlantic salmon juvenile performance more than predicted by simply adding the species effects together.

2. Upon leaving the tributaries, surviving Atlantic salmon are vulnerable to angling in the open-waters of Lake Ontario in both New York and Ontario. Currently, Ontario tributaries are closed to angling for Atlantic salmon. Available information suggests that fishery exploitation does not currently impede Atlantic salmon restoration success. The hypothesis that may explain this conclusion is:

   a. **Hypothesis 11**: Fishery exploitation rates on Atlantic salmon are very low. In the open-lake boat fishery this is due to a very low overall salmonid fishery exploitation rate and little fishing effort directly targeting Atlantic salmon. In Ontario tributaries, exploitation is low because Atlantic salmon are only caught incidentally by anglers targeting other species and are released.

3. Salmonid stocking levels are bi-nationally managed to maintain predator-prey balance to avoid over-consumption of alewife by predators. Available information suggests that Atlantic salmon do not pose a significant additional predator demand on alewife or substantially increase the risk of over-consumption of alewife. The hypothesis that may explain this conclusion is:

   a. **Hypothesis 12**: The very low abundance of Atlantic salmon relative to other alewife predators and the diverse diet of Atlantic salmon, including a high proportion of round gobies, results in very low predation pressure by Atlantic salmon on alewife.

4. Two potential impediments to successful reproduction of Atlantic salmon in Lake Ontario are thiaminase-induced reproductive impairment resulting from a diet high in alewife and the need for returning adults to find high-quality spawning and nursery habitat. In the upper reaches of the Credit River, there is evidence of successful wild Atlantic salmon spawning and wild-collected eggs with thiamine levels sufficient for survival. Small numbers of captured juvenile and adult Atlantic salmon do not assign to the genetic signature of stocked families and are therefore very likely wild fish. The hypotheses that may support these observations are:

   a. **Hypothesis 13**: Atlantic salmon have a diverse diet including a high proportion of round gobies which mitigate the amount of thiaminase in their diet. Thiamine deficiency in adult Atlantic salmon in Lake Ontario may only become apparent with an increase in the consumption of alewife or in the presence of other stressors (competition, barriers, long migrations to suitable habitat, elevated tributary temperatures) that increase the metabolic demand for thiamine.

b. **Hypothesis 14**: The habitat and ecological conditions in Lake Ontario tributaries are currently sufficient to support successful reproduction of Atlantic salmon.

Management implications

1. Culture and stocking practices

The workshop findings and discussions suggest a number of changes to culture and stocking practices that should be considered.

a. Update the stocking plan including specifying how many of each Atlantic salmon life stage and strain will be stocked and where they will be stocked across the watersheds. Include in the plan a policy on the fate of surplus eggs to ensure their stocking does not confound life-stage or strain assessments.

b. An increase in survival may be achieved by:

   i. increasing the size of each life stage stocked,

   ii. changing the timing and/or location of the stocking of fall fingerlings and spring yearlings to increase the development of physiological and behavioural traits similar to natural smolts,

   iii. delaying stocking of spring yearlings to later in the spring when nearshore predator densities may be lower and food resources may be higher,

   iv. emulating natural conditions in the hatchery (temperature, cover, flow, exercise regimes) for spring yearlings to synchronize physiological smolt readiness with optimum ecological smolt timing and improve the fitness of the fish.

c. If managers want to accelerate the development of the stream fishery they should consider culture and stocking practices that could support more rapid development of recreational fisheries (e.g. higher concentrations in some locations, stocking lower in the reaches, larger sizes of fish, penning of fish).

2. Adaptive management approach

The number and size of streams makes it difficult and expensive to do the required monitoring, experimental design, and data management with enough scientific rigor while also accommodating other fishery management programs and partner activities. The workshop findings and discussions suggest a number of changes to adaptive management approach that should be considered.

a. Improve experimental designs to test life-stage and strain effects by controlling for habitat differences in stocking sites, which will be easier to accomplish by studying fewer watersheds.

b. Improve the data management system and support for parentage analysis and origin assignment of survivors from field data by:

    i. assignment of dedicated staff resources for data base management,

    ii. adherence to data standards (naming conventions, data dictionary),

    iii. ensuring all relevant field monitoring data is entered into common data base which is broadly available and shared.

c. Improve documentation of stocking events by:

    i. increased tracking and standardized data recording including fish attributes (length, weight, physiological markers) at time of stocking,

    ii. precise and consistent recording of the geographic location of stocking events,

    iii. improved fine-scale monitoring of stocked tributary attributes (flows and temperatures).

d. Consider classifying some watersheds as (dedicated) research/assessment watersheds and others as restoration watersheds and develop assessment plans and protocols specific to each watershed category.

3. Program communications and messaging

Based on the information in this review, program communication and promotion strategies should emphasize the difficulty of the task, commitment to improvement through monitoring and research, current evidence of wild production, ability of Atlantic salmon to co-exist with existing fish communities, and the potential for development of a fishery.

4. *Consider stocking locations identified in the stocking plan when developing habitat restoration priorities*

5. *Consider the implications of competitive risks to restoration outcomes and other watershed management plan objectives*

   The review of competitive risk in tributaries suggests that interactions that are identified as moderate or high risk can be mitigated by ensuring Atlantic salmon juveniles are provided habitat that favours them and where exposure to juvenile or adult brown trout or to multiple salmonine competitors is minimized. Competition with rainbow trout is best mitigated with habitat improvements to provide sufficient habitat for both species.

6. *Review vision and benchmarks*

   There is broad agreement that a self-sustaining population of Atlantic salmon would meet everyone definition of "success" but the program's vision, priority setting, focus and effectiveness is confounded by different interim (5, 10, 20, 40 years) definitions and benchmarks of "program success". Is there, or does there need to be amongst the partners, a common vision?

7. *Review potential implications of future development and climate change*

   Should development and climate change scenarios impact the management planning, long-term vision, and expectations? Is the habitat restoration/protection component of the program sufficient?

References

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Presentations

Introduction to the Workshop

Tom J. Stewart, Ontario Ministry of Natural Resources and Forestry, Lake Ontario Management Unit, RR #4, Picton, ON, Canada K0K 2TO

Abstract

Atlantic salmon were endemic to Lake Ontario before their extirpation in the late 19th century primarily due to stream habitat loss and over harvest (Dymond, 1965). A long-term plan to restore Atlantic salmon to Lake Ontario was developed by the Ontario Ministry of Natural Resources and Forestry (Miller-Dodd and Orsatti, 1995). The plan identified benchmarks for monitoring the success of the program over a 20-year period and recommended 5-year reviews. Although capacity and resource limitations delayed progress relative to the original schedule, the plan continues to guide the restoration of Atlantic salmon in the province of Ontario. The first review (Greig et al., 2003) concluded that the initial research phase of the program confirmed that restoration was feasible and recommended that the program move to a more management-directed restoration phase. The original restoration plan and benchmarks were confirmed along with several recommendations concerning approaches to restoration and associated new emerging science and monitoring needs (Greig et al., 2003). The program evolved quickly into a multi-partnered initiative promoted as "Bring Back the Salmon" (www.bringbackthesalmon.ca) with a timeline divided into 5-year intervals. In support of this phase, a revised science program was developed for Phase 1 (2006–2010) which included collaborative proposals directed towards answering priority questions to track restoration benchmarks and identify potential impediments (Jones et al., 2006). Again, capacity and resource limitations reduced the ability to fully deliver on the envisioned restoration, science, and assessment agendas. However, the program was substantially enhanced and remained focused on the key elements identified in these guiding documents. This workshop emphasized the **monitor** and **learn** phases of the adaptive management cycle (Figure 1). A second workshop will focus on the **plan** and **implement** phases. The approach to the workshop was to synthesize information by way of presentations answering questions grouped under five themes: survival benchmarks, strain and life stage performance, influence of culture practices, influence of habitat and abiotic conditions, and influence of species interactions. After each presentation, participants' questions and comments were recorded. Visiting experts provided constructive criticism of the monitoring and synthesis; insights from their own research or program experience relevant to the themes and questions; and additional insights, recommendations, or lines of investigation for the future. Facilitated discussions under each theme identified key monitoring and research needs, updated hypotheses, recommended improvements to monitoring or research, and discussed management implications and applications.

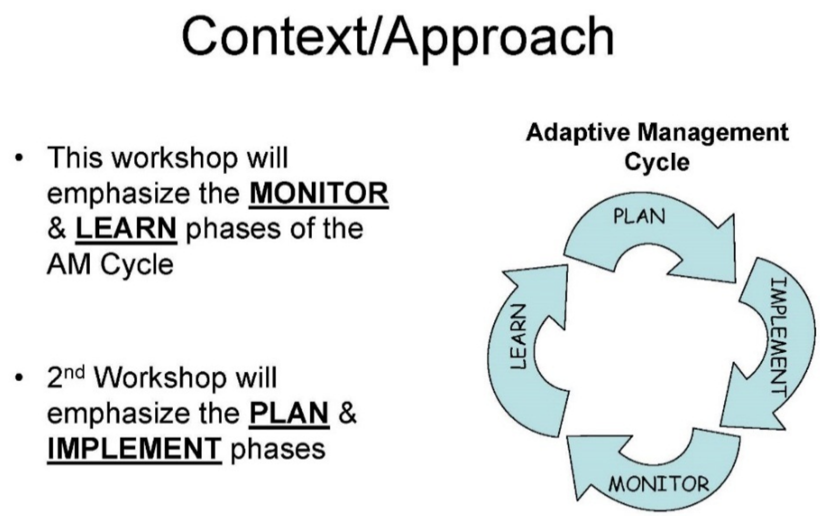

Figure 1. Context and approach to workshops in relation to the adaptive management cycle.

References

Greig, L., Ritchie, B., Carl, L., Lewis, C.A., 2003. Potential and strategy for restoration of Atlantic Salmon, in: Lake Ontario: A workshop report. Prepared by ESSA Technologies Ltd., Toronto, ON. Ontario Ministry of Natural Resources and Forestry, Lake Ontario Management Unit, Peterborough, pp. 39.

Jones, N.E., 2006. Atlantic Salmon Restoration and Research and Assessment Agenda. Report to the Atlantic Salmon Recovery Team: Mach 31, 2006. River and Stream Ecology Unit, Ontario Ministry of Natural Resources and Forestry, Trent University, Peterborough. pp. 40.

Miller-Dodd, L., Orsatti, S., 1995. An Atlantic salmon restoration plan for Lake Ontario. Ontario Ministry of Natural Resources and Forestry. Lake Ontario Assessment Internal Report LOA 95.08. Napanee, Ontario.

General discussion notes

A general discussion addressed the need to distinguish between science and management when discussing issues and next steps.

C: The emphasis of this workshop is to be the science.

C: Avoid prescribing specific management actions or programs, but do discuss management implications and general applications.

New York's Lake Ontario Atlantic Salmon Program: A Review of Opportunities, Constraints, and Management Actions

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Abstract

Atlantic salmon, once a major component of the Lake Ontario fish community, have been extirpated for over a century. Efforts to restore Atlantic salmon as a viable component of the fish community have, until recently, met with limited success. Three encouraging signs—an increase in angler catches in the lake, an increase of adult returns to tributaries, and documented natural reproduction in the Salmon River—suggest that environmental events and/or management actions are having positive effects. Reasons for increased survival and natural reproduction are unknown but could be associated with changing lake conditions, reduced reliance on alewife in the diet, or the strain(s) of Atlantic salmon now being stocked. In the tributaries, several limiting factors still exist including high stream temperatures, competition for spawning sites, and competition for juvenile rearing habitat, especially with steelhead. However, the evidence suggests that juvenile Atlantic salmon will displace juvenile steelhead in areas with water velocities exceeding 0.5 m/s that are preferred by both species. In New York, most Atlantic salmon stocking now uses the Sebago strain and most of the effort is directed at the Salmon River. The effort consists of stocking fall fingerlings and yearling smolts. Both life stages are marked (fall fingerlings with an adipose fin clip, smolts with an elastomer tag) prior to release into Beaverdam Brook and the Salmon River. The goal of the program is to develop a Lake Ontario egg source for Atlantic salmon that return to Beaverdam Brook while at the same time providing increased summer angling opportunities in the Salmon River.

General discussion notes

Q: Why in 2012 and 2013 were there not as many wild Atlantic salmon as predicted?
A: True, those were also the warmest summers in the last decade; a poor year for reproduction.
C: Low numbers or no rainbow trout, also.
C: Looking into options for mitigating temperature.

Q: What were the maximum temperatures in the Salmon River?
A: 74–75 °F and 71–72 °F when there were lots of fry.

Q: What was the size of the Atlantic salmon crossed brown trout hybrids?
A: 60–70 mm.

Q: What might have produced the increased level of reproduction in 2009–2011?
A: Don't know.
Q: How far upstream were the fish stocked?
A: 20km.

Q: What is the timing of the smolt immigration?
A: Don't know; fall fingerlings are not being tracked.

Q: Is the stocking data summarized?
A: Yes, not sure how it is available, but will follow up.

Landlocked Atlantic Salmon Restoration and Management in Lake Champlain.

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Abstract

Landlocked Atlantic salmon (LAS) are an important part of the Lake Champlain ecosystem and fishery. Native LAS were extirpated in the Lake Champlain basin approximately 150 years ago. In the 1970s, LAS were reintroduced to the lake through stocking of hatchery fish. This hatchery program supported by NY and VT, and USFWS continues to provide for a popular lake fishery. However, few fish return to tributaries to spawn. Effective sea lamprey control efforts over the past eight years have resulted in a large reduction of wounding rates on LAS. Fish passage and riparian habitat restoration efforts have provided access to key spawning habitat in VT and NY. Increased numbers of fish, survival to older age classes, and access to spawning and rearing habitat provide new opportunities to enhance the river fishery and natural recolonization of tributaries by hatchery-origin adults spawning in the wild. Lab and field experiments have been initiated in the Winooski River, VT and Boquet River, NY to increase river-runs of hatchery-origin LAS and to re-establish natural populations. Activities include physiology, genetic, morphometric, lab, and field studies focused on improving quality of hatchery fish by optimizing culture conditions and modifying stocking strategies to enhance survival, improve imprinting, and increase adult returns.

General discussion notes

Q: There was a difference in the condition factor of the smolt versus the parr. Is there a result on the comparative release of fry versus smolt?
A: Will have the results next year.

Q: Do you have any details like temperature and flow at the time of stocking?
A: Will be presenting some of that information tomorrow.

Q: Was the fry-stocking limit based on limited habitat?
A: No it was limited because of the shortage of broodstock and genetic tagging.
C: Cutbacks are at the fry stage.
C: Stocking was tried to be optimized based on habitat.
C: Targets are based on habitat.

Q: What is the surface area of Lake Champlain?
A: It is about 300 km^2.
C: If Lake Ontario was stocked at the same density as Lake Champlain it would require to the stocking of approximately 20 million fish per year.

Q: What are the adult return rates?
A: The creel survey starts next year. So far, 1 % return.
C: Large numbers returning about 100 % to a uniquely clipped non-site facility.

Lake Ontario Atlantic Salmon Planning Benchmarks

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Abstract

A long-term plan to restore Atlantic salmon to Lake Ontario (Miller-Dodd and Orsatti, 1995) identified benchmarks for the success of the program. The next series of talks (Bowlby et al., this workshop; Desjardins et al., this workshop) will evaluate whether the fingerling density (measured in the fall) has reached the benchmark of 5–50/100m^2 and evaluate the survival from fingerling to smolt relative to the benchmark of 20 %. Monitoring effort of surviving adults is minimal and sample size is low. However, the accumulated samples of surviving adults are sufficient for some preliminary evaluation of the origin of surviving adults (Wilson et al., this workshop). The stocking strategy has primarily been directed at stocking three life stages of fish—spring fingerlings, fall fingerlings, and spring yearlings—with average annual stockings in last 4 years of approximately 477,284, 199,184 and 86,843, respectively (Figure 1). Most of the fish have been stocked in the Credit River with about equal numbers in Cobourg Creek and Duffins Creek (Figure 2). A comparison of the number of observed adults by life stage relative to the number stocked will provide a direct quantitative evaluation of stocking strategies to inform management. Most of stocking to date, for which adult returns would be expected, has been limited to the LaHave strain.

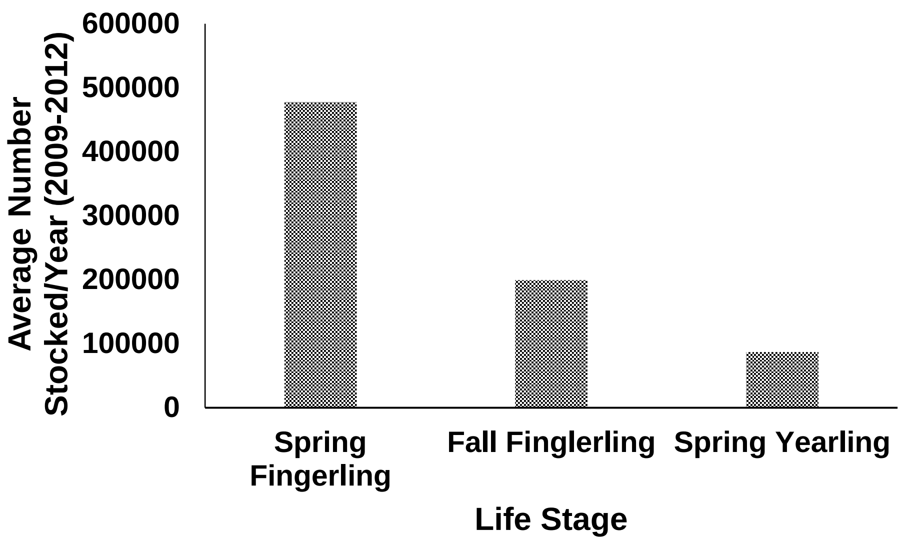

Figure 1. Average (2009–2012) number of Atlantic salmon stocked in Credit River, Cobourg Creek and Duffins Creek combined by life-stage.

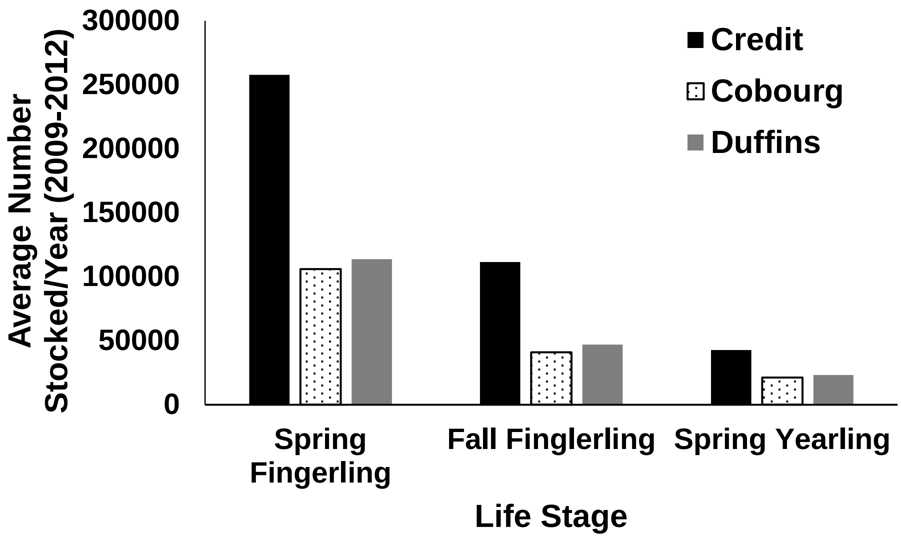

Figure 2. Average (2009–2012) number of Atlantic salmon stocked in Credit River, Cobourg Creek and Duffins Creek by life stage.

References

Miller-Dodd, L., Orsatti, S., 1995. An Atlantic salmon restoration plan for Lake Ontario, Ontario Ministry of Natural Resources and Forestry. Lake Ontario Assessment Internal Report LOA 95.08. Napanee, Ontario.

General discussion notes

Q: What is the mortality rate of kelts?
A: Don't know; of the seven adults captured at Duffins Creek weir, one may have been a repeat-spawner.

Q: What is a reasonable rate of repeat spawners in other wild populations?
A: Up to 30 % of egg deposition from repeat spawners on the Miramichi. Some are repeat spawners, some are alternate year spawners. Don't know the proportions.

Restoring Atlantic Salmon to Lake Ontario: Genetic Issues, Options, and Methods

Chris Wilson, Aquatic Biodiversity and Conservation Unit, Ontario Ministry of Natural Resources and Forestry, Trent University, 2140 East Bank Drive, Peterborough, Ontario

Abstract

As part of the effort to re-establish self-sustaining populations of Atlantic salmon in Lake Ontario, genetic tracking is being used to address information needs such as the performance of different stocking strains, optimal stocking life stages, juvenile survival, adult returns, and effectiveness of different experimental approaches and management strategies. As the restoration effort is a large-scale effort in adaptive management, information on the successes or failures of different management approaches is essential for long-term success.

For reintroductions or restoration of extirpated populations, the most commonly-recommended conservation action is to introduce a closely-related strain or population based on the assumption that these will be similarly adapted or suited to local habitats (Krueger et al., 1981; Meffe, 1995). Alternatively, donor sources may be sought that should perform well under the existing ecological and environmental conditions, relying on contemporary adaptations rather than historical relatedness (Moritz, 1999; Jones, 2003). In the absence of known genetic relatives, it is advisable to introduce several different strains with differing characteristics and follow up with field assessments to evaluate their relative success (Krueger et al., 1981; Jones, 2003).

The first of these options is being pursued by the Royal Ontario Museum (ROM), which is gathering genetic data from 19th century taxidermy mounts and archaeological samples. These data will be used to genetically characterize the historical Lake Ontario population with the goals of identifying either transplanted (historically-stocked) survivors in New England lakes or a closely-related contemporary population which could be used for reintroductions.

In the absence of known survivors or close relatives, the current restoration plan is using three source populations (LaHave River, NS; Sebago Lake, MA; and Lac Saint-Jean, QU) that differ in their ecology for life history, migration (anadromy/landlocked), and native ecological communities (Dimond and Smitka, 2005). A previous genetic study (King et al., 2001) also showed that these populations were quite genetically distinct from each other which enables their ready identification based on highly-variable genetic markers (microsatellite DNA). Based on the observed differences among the source populations using microsatellite genotyping, it should be possible to identify their contributions to wild populations for at least two full generations even with interbreeding between strains.

Genetic tagging is an integral part of the stocking program and assessment strategy (Figure 1). When broodstock fish first reach sexual maturity, each is PIT tagged and

genotyped using nine microsatellite DNA loci. As well as providing information on the genetic characteristics of each broodstock (source population) for strain assignment of wild fish, this provides the genetic “signature” of each adult Atlantic salmon used for producing fish to be stocked. Production families are made from single-pair matings within each strain, using each male and female only once and enabling genetic identification of their offspring through parentage analysis. In this way, all stocked Atlantic salmon are genetically “tagged” and identifiable to family as well as strain/source population. By stocking all members of a family at the same life stage (spring parr, fall fingerling, or yearling), genetic identification to family also gives information on the stocking success of each life stage.

The combined strain and parentage analyses provide information on the contribution of the different stocked strains and life stages to wild-caught juveniles and adult fish caught in either Lake Ontario or the stocked tributaries. In this way, genetic tracking is being used to inform result-based actions within the restoration plan by identifying optimal life stage(s) and strains for juvenile survival and adult returns. Furthermore, genetic tracking of stocked families also enables detection of wild (unstocked) Atlantic salmon (by identifying fish with either mixed-strain ancestry and/or parental exclusion from all stocked families), thereby providing measurable progress towards the long-term goal of population re-establishment.

In addition to the restoration plan, collaborative research efforts with university researchers are looking beyond identified information needs to pursue questions that are highly relevant to the restoration effort. As well as assessing life history differences among strains such as growth and maturity under shared environmental conditions, graduate students from several universities are investigating behavioural differences in interactions with introduced salmonids, differences in stress physiology and gene expression among the strains, and wild performance with significant implications for their potential fitness in the wild. These research partnerships have proven highly effective, and are providing valuable data that anticipate future information needs for the restoration effort.

Restoring Atlantic salmon to Lake Ontario is a long-term exercise in adaptive management and restoration ecology with many known and unknown challenges still remaining. Genetic tracking of stocked fish and identification of wild recruits is a key element for assessing the effectiveness of restoration efforts and is helping to inform and improve management practices. Results to date have confirmed the contribution of all stocked life stages to returning adults as well as potential evidence for wild recruitment.

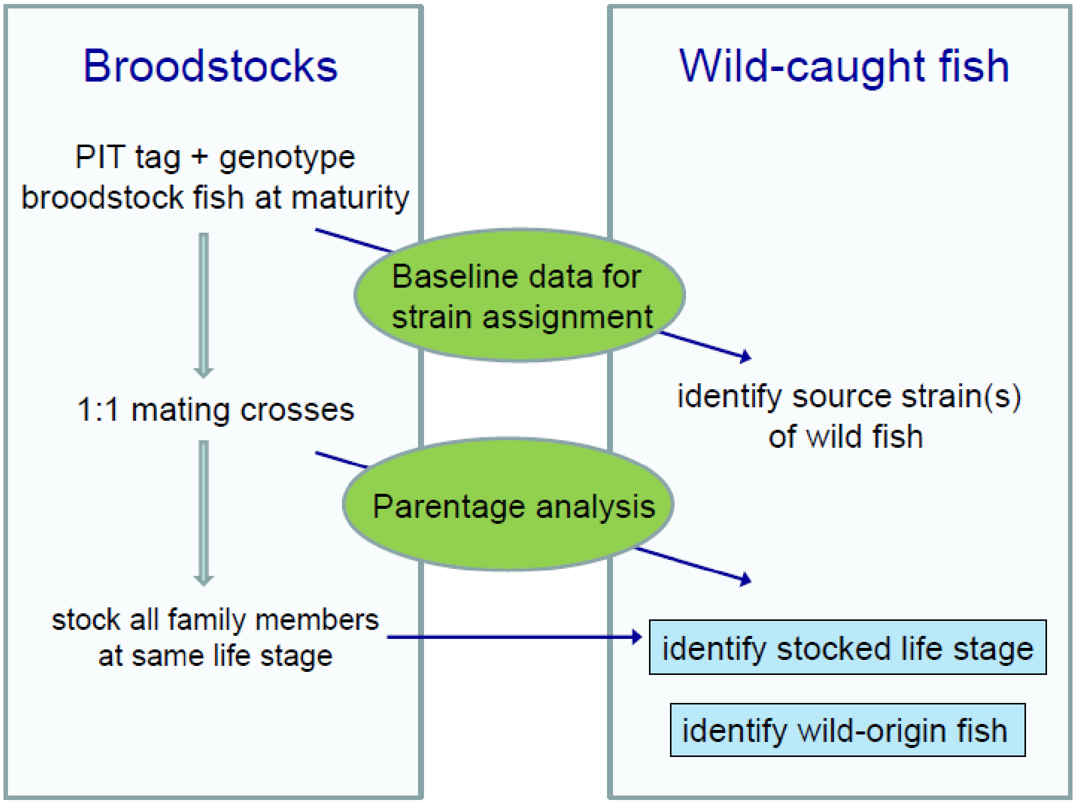

Figure 1. Overview of genetic tracking system to identify the origin (stocked or wild) of juvenile and adult Atlantic salmon captured in Lake Ontario and tributaries. Stocked fish are identified to source strain and life stage at time of stocking by strain and parentage analysis, respectively. Wild-origin fish are similarly identified by combined strain assignment and parentage analysis: fish identified as having mixed ancestry (assigning to more than one strain) must be wild-origin, and those that assign to a single strain but are rejected (excluded) from all mated parent pairs within that strain must be the result of successful wild mating between (previously-stocked) mature fish from that strain.

General discussion notes

Q: Is there comparative performance data for Atlantic salmon in offshore Lake Ontario?

A: Most of the information is from the US creel which indicates most of the fish caught there originate from the Sebago, NY strain. All we can say is that most of the fish are not from families that we have markers for.

Q: What life stage are NY Sebago fish stocked at?

A: Most likely yearling smolts but fish are not clipped

Q: Is the egg source from the Riviere aux Saumons?

A: Yes, for the last two years, but last year part of the collection is from Metabechuane and Ashupmushuan Rivers. There are concerns that the other population runs are less than 20K. Some research going on regarding the cross mating of populations, but it is too early to tell.

Performance of Stocked Atlantic Salmon Parr in the Credit River

Jim Bowlby, Ontario Ministry of Natural Resources and Forestry, Lake Ontario Management Unit, RR#4, Picton, ON, Canada K0K 2TO

Abstract

The objectives of this presentation are to evaluate survival targets for Atlantic salmon stocked as spring fingerlings, evaluate growth and potential to smolt, estimate overwinter survival, and evaluate the performance of two strains (LaHave, Sebago) in a paired stocking experiment.

Atlantic salmon were stocked (~20,000–40,000/site) as spring fingerlings (1–2 g) in May, 2008–2013 at 6–7 locations in the Credit River. Fish were captured at most of these sites by electrofishing in October and marked with Visual Implant Elastomer (VIE) colour-coded to age (0 or 1), site, and year. Some sites' fish were resampled about one week later, and based on recaptures the population was estimated. Fin tissue samples were collected from a subsample of Atlantic salmon for DNA analysis to determine strain, age, and life stage at stocking.

Density of age-0 Atlantic salmon in 2010 (Figure 1) exceeded the target density range (0.05–0.5 m^{-2}) of the Atlantic salmon restoration plan for Lake Ontario (Miller-Dodd and Orsatti 1995). These results were typical of other years.

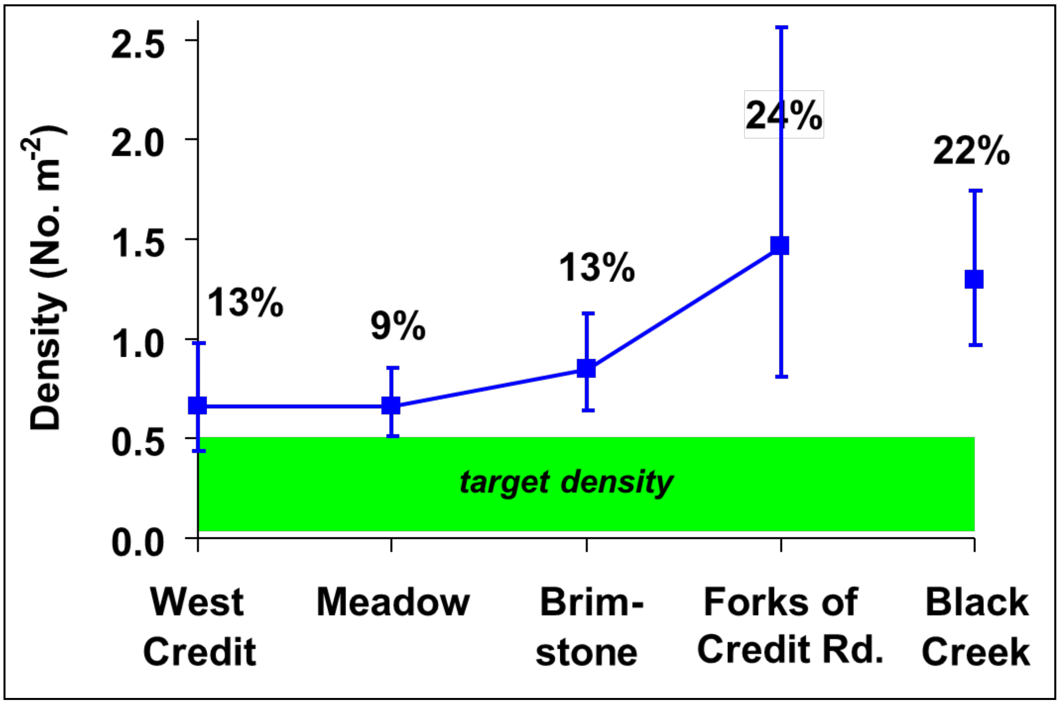

Figure 1. Density (± 95 %) of age-0 Atlantic salmon in October 2010 at sites in the Credit River (Meadow, Brimstone, Forks of the Credit Road) and two tributaries. Survival (%) since stocking in May 2010 in indicated above density.

Growth of Atlantic salmon in the Credit River watershed showed two patterns. Size at age was higher at sites in the main stem of the Credit River than in the West Credit River and Black Creek (Figure 2). A waste water treatment plant at Orangeville on the main stem likely enriches productivity in the Credit River. High growth of Atlantic salmon in the Credit River is consistent with smolting at age-1. Enrichment of Black Creek and the West Credit River is lower and most Atlantic salmon smolt at age-2.

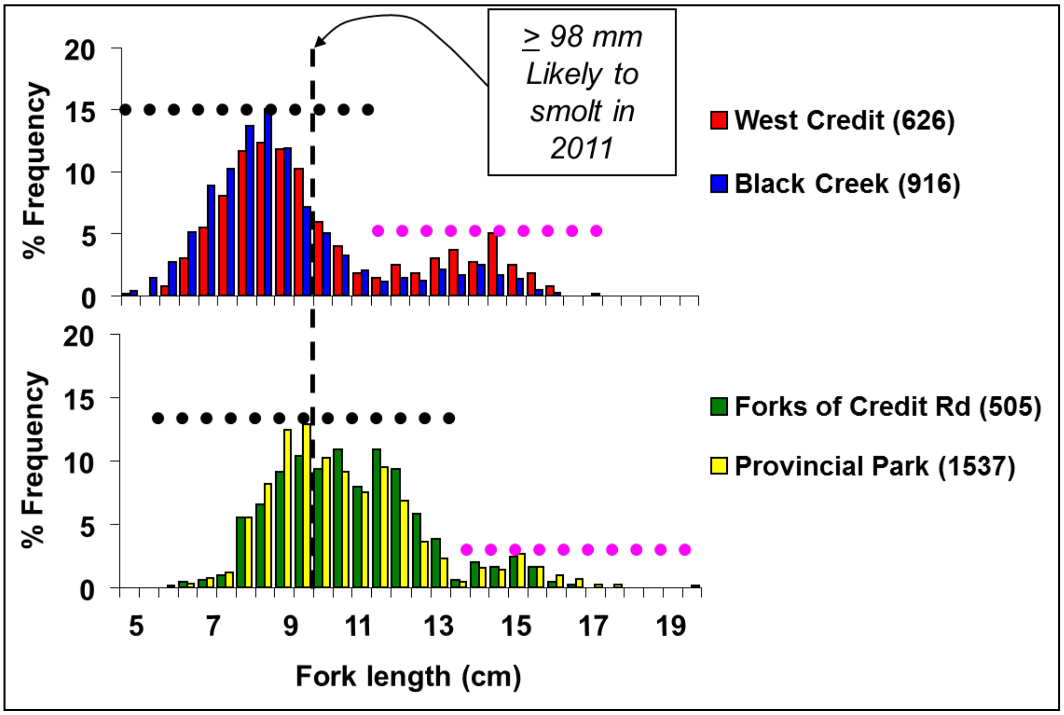

Figure 2. Fork length of Atlantic salmon in October 2010 at sites in the Credit River (lower panel) and two tributaries (upper panel). Age of Atlantic salmon is indicated by the dotted line (age-0: black, age-1: magenta [grey in print]). Atlantic salmon ≥ 98 mm were expected to smolt in 2011.

Overwinter survival and number of smolts in 2011 were estimated by stocking reach by fitting age-specific density data to a life history model. Estimates of overwinter (2010–2011) survival ranged 9.5–44.5 % among different sites, and averaged 20.7 % (Table 1). This was likely an underestimation due to emigration from the stocking sites, and this is currently being addressed with a PIT tagging study. The predicted number of smolts in 2011 was 4,026, which compared well with independent smolt trap estimates (Desjardins, 2014) of 4,017 smolts. However, the model overestimated the number of age-1 smolts and underestimated the number of age-2 smolts.

Site	First summer survival	Overwinter survival
West Credit	13.2 %	15.5 %
Forks of the Credit Road	23.9 %	9.5 %
Forks of the Credit Provincial Park	10.9 %	44.5 %
Black Creek	22.4 %	13.3 %
Mean	17.6 %	20.7 %

Table 1. Survival of age-0 Atlantic salmon in the Credit River stocked in 2010.

The relative survival and growth of LaHave and Sebago strain Atlantic salmon were evaluated with paired stockings of similar size and numbers of age-0 fish in the Credit River in 2013. Analysis was ongoing, and preliminary results showed no significant difference in survival between strains, but Sebago Atlantic salmon grew about 9 mm more than LaHave. We expect a 81% of age-1 Sebago Atlantic salmon to smolt in 2014 but only 39% of the LaHave.

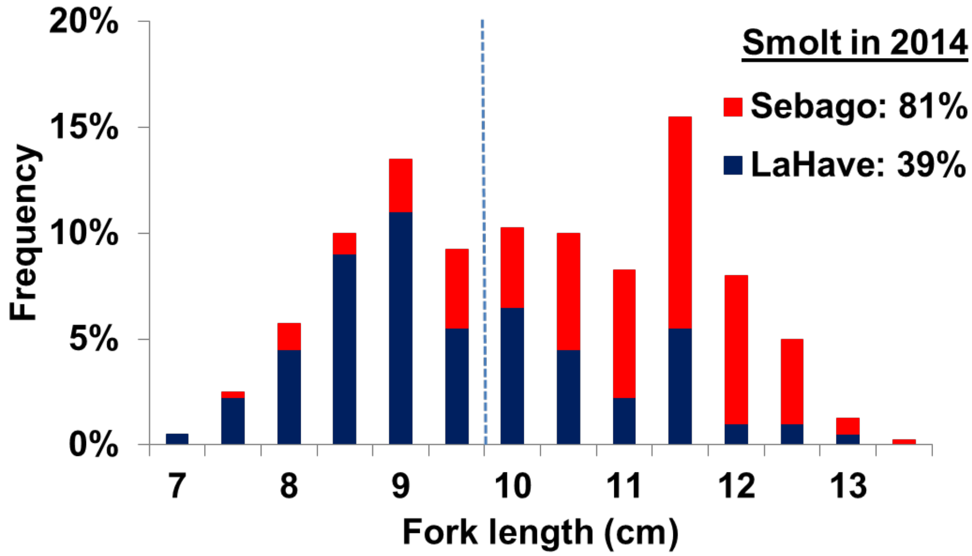

Figure 3. Fork length of Sebago and LaHave strain Atlantic salmon in the Credit River in October 2013. Atlantic salmon ≥ 98 mm were expected to smolt in 2014.

References

Desjardins, M. 2014. Assessment of Atlantic salmon smolt performance in the Credit River. *In*. Stewart, T. J., Bowlby A., Wilson C. (eds.), 2014. Proceedings of the Lake Ontario Atlantic salmon restoration science workshop, February 18–20, 2014, Alliston, Ontario. Ontario Ministry of Natural Resources and Forestry, File Report LOA 14.08

Miller-Dodd, L., and S. Orsatti. 1995. An Atlantic salmon restoration plan for Lake Ontario. Ontario Ministry of Natural Resources. Lake Ontario Assessment Internal Report LOA 95.08. Napanee.

General discussion notes

Q: Are there steelhead in the stream?
A: There are browns of moderate to high density.

Q: Is competition influencing survival?
A: Maybe, no data is available.

Q: Is the survival in the first year comparable to what was observed in Maine? Is this a reasonable comparison?
A: Maine reports targets as ranges. We require our targets to be reported as ranges.

Q: What may be the differences between the “meadow lands” site and the other sites that accounts for the higher growth?
A: There is likely higher overall productivity at the meadow lands site.

Assessment of Atlantic Salmon Smolt Performance in the Credit River

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Abstract

Monitoring Atlantic salmon throughout their life cycle is critical to the success of the Lake Ontario Atlantic Salmon Restoration Program. This information is necessary to choose "best" management strategies in the future. Collecting information while salmon are outmigrating to Lake Ontario is a critical fisheries reference point because it represents the outcome of stream life and allows biologists to compare stream and lake survival.

This is particularly important for the Restoration Program as it is implementing a stocking strategy that is exploring the use of three stocked life stages (spring fingerlings, fall fingerlings, and spring yearlings) and three strains (LaHave, Sebago, and Lac Saint-Jean). Assessing the relative contribution/survival of the strains and life stages will allow for the optimization of the stocking program. Selecting the best life stage and strain of Atlantic salmon to stock will in turn improve the chances for restoration.

Annual Atlantic salmon out-migrant sampling was conducted on the Credit River from 2011–2013. Collections utilized a 5 ft (152.4 cm) diameter Rotary Screw Trap (EG Solutions, Corvallis Oregon) deployed at the Meadowvale Conservation Area located approximately 26 river kilometers upstream from Lake Ontario. Sampling typically commenced during the first week of April and concluded during the first few weeks in June. Ideally, sampling would be consistent across years with deployment occurring before the beginning of outmigration with daily operation until catches dissipate. However, there were differences in sampling effort across years resulting from operational refinements and constraints. The numbers of days sampled in 2011, 2012, and 2013 were 51, 82, and 52 which yielded 227, 308, and 277 Atlantic salmon captures, respectively (Table 1).

Tissue was collected from the upper lobe of the caudal fin on all captured Atlantic salmon and sent to be genotyped at OMNRF's Aquatic Research and Monitoring Section's Genetic Lab. Genotyped field samples were compared against hatchery broodstock genotypes to determine strain, parentage, and stocked life stage following procedures outlined in these proceedings (Wilson, 2014a). Of the 812 samples submitted, strain and stocked life stage confirmations were made on only 622. The remaining 190 samples will be analyzed further to see if parentage can be confirmed (Table 1).

Characteristics of rotary screw trap catch 2011–2013

Abundance

Following the determination of parentage, the catch of the rotary screw trap was partitioned into planned stocked life stage (spring fingerling, fall fingerling, and spring yearling) and strain (LaHave, Sebago, and Lac St. Jean). Parentage assignments also provided the stocking dates for each of the subsequent families allowing for the further determination of smolting age.

Overall, the LaHave strain contributed more to the catches than the Sebago strain, and no fish from the Lac St. Jean strain have yet to be captured (Table 2). These results are not altogether unexpected. It should be noted that not all strains have been stocked equally since the beginning of the Restoration Program.

A LaHave River broodstock was developed in the 1990s while the program was in an earlier research phase. This strain is well-established, enabling the effective production of all life stages. The other two restoration strains (Sebago and Lac St. Jean) have only recently been introduced to the province’s hatchery system. Therefore, the development of broodstock and the subsequent production of all life stages for these strains have only recently been achieved. For example, spring fingerling and fall fingerling Sebago strain fish were not stocked into the Credit River until 2011 and would not have been detectable at the trap until the spring of 2012. Sebago and Lac St. Jean strain spring yearlings were not stocked until 2013 and, therefore, would only have been assessable with the gear in the spring of 2013, the last year of sampling included in this report. For details about relative stocking levels of the strains and life stages refer to Table 3.

The catch composition was also examined to determine the relative contribution of the stocked life stages. The most abundant stocked life stage captured was spring fingerlings which represents about 85 % of the catch. Catches of the more advanced life stages (fall fingerlings and spring yearlings) were considerably lower representing about 6 % and 9 % of the catch respectively. High catches of the spring fingerling stocked life stage are not unexpected as roughly 60 % of the fish stocked into the Credit River on any given year are spring fingerlings. The substantially-lower capture rates of the spring yearling and fall fingerling stocked fish are surprising as these fish were stocked at larger sizes, and survival to smolt should have been higher.

Also of interest is the age of smolting, as determined by tracking stocking dates of the genetically-marked families. When the age of smolting was examined across life stages, the spring fingerling stocking events yielded a higher proportion of 1-year-old outmigrants than did the advanced life stages. Seventy-three percent of the spring fingerling stocked fish captured at the trap were emigrating as age-1 fish. Conversely, seventy-four percent of fall fingerling stocked fish were emigrating in their second year. The spring yearlings, which were anticipated to all smolt within months of their stocking as age-1 fish, also had a high proportion (53 %) of 2-year-old outmigrants (Table 2).

These are interesting results, as there is a perceived trade-off between survival and yield across the life stages stocked. Although fewer individuals of the advanced life stages can be produced in the hatchery and subsequently stocked, their survival to smolting should be proportionally higher and their stream residence time shorter as they are stocked at a larger size. Likewise, although more spring fingerlings can be produced and, hence, stocked, their survival to smolting should be proportionally-lower and their stream residence time longer as they are stocked at a smaller size and likely experience higher levels of mortality.

Size

Biological data (fork length and weight) were collected on all trapped individuals, and the information was partitioned by strain, life stages, and smolt age to see if certain strata outperformed with respect to these parameters. The results also seem to indicate an enhanced performance of the spring fingerling stocked fish. These results are tentative, however, as not all life stage comparisons could be made due to a lack of spring yearling Sebago fish in our collections.

Individuals of both strains that were stocked as spring fingerlings produced larger outmigrants following one year of growth in the stream (smolt age-1) than did those age-1 fish that were stocked as spring yearlings (Figure 1). LaHave age-1 spring fingerling smolts were significantly larger (Kruskal-Wallis $H\ [1,246] = 30.5, p < 0.0001$) and heavier (K-W $H\ [1,246] = 23.1, p < 0.0001$) than LaHave age-1 spring yearling smolts (Figure 1). Although no Sebago spring yearlings were captured for a similar comparison, the mean weight of spring yearling Sebago fish as recorded from hatchery staff at the time of stocking ($\mu = 24.6$ g; Table 3) is substantially smaller than the mean weight ($\mu = 44.8$ g) of age-1 spring fingerling Sebago outmigrants captured at the trap the same year.

Sebago spring fingerling stocked age-1 outmigrants were also larger (K-W $H\ [1,170] = 5.89, p = 0.01528$) and heavier (K-W $H\ [1,170] = 6.40, p = 0.0114$) than fall fingerling outmigrants of the same age and strain (Figure 1). There was, however, no significant difference between LaHave stocked spring fingerlings, stocked age-1 outmigrants, and the fall fingerling outmigrants of the same age and strain.

Differences in size and weight between spring fingerling and spring yearling stocked fish were not evident in 2-year-old smolts (LaHave strain only); however, differences were detected between spring fingerling and fall fingerling age-2 smolts for both strains. This reflects the fact that there was no apparent change in size between 1- and 2-year-old fall fingerling fish. The other life stages were significantly larger following their second year in the stream.

Overall, spring fingerling size was high indicating good growth rates, particularly Sebago strain spring fingerling stocked fish. Sebago spring fingerlings displayed tremendous growth and were significantly larger (K-W $H\ [1,529] = 4{,}41, p = 0.036$) and heavier (K-W $H\ [1,529] = 24.7, p < 0.0001$) than LaHave stocked spring fingerlings.

It is unclear how the quality of the stocking locations for the different life stages may impact the relative growth rates. What is clear is that spring fingerlings are stocked into some of the finest habitat the watershed has to offer and their growth rates are sufficient to outgrow the hatchery product of a similar age.

Timing

For comprehensive sampling, trapping would ideally commence well in advance of downstream movement and continue until most fish have left the system. Due to project constraints, our sampling period was more compressed, usually beginning during the first week of April and concluding during the first few weeks in June. We can only speculate on the numbers and characteristics of any outmigration that occurred outside of the sampling window.

The timing of the catch has been relatively consistent across all three years sampled. The dates of peak catch and the dates on which 50 % of the catch have been collected generally fall in the first or second week of May (Figure 2). The consistent nature of the yearly catch provides confidence that we have sufficiently sampled the majority of the outmigration and that the fish captured during this period offer an adequate representation of the Atlantic salmon outmigration in general.

When the timing of out migration was examined across strata, patterns emerged that may provide insight regarding the relative contribution of certain life stages. The majority of fish from the advanced life stage stocking events (spring yearling and fall fingerlings) appear to outmigrate prior to the peak outmigration of spring fingerlings (Figure 3). The spring fingerling outmigrants dominate in last half of the sampling event. Perhaps, fish of the advanced life stages are outmigrating prior to trap deployment, resulting in lower-than-expected catch numbers. This may be the case more for the spring yearling stocked fish and especially for those spring yearlings that are outmigrating soon after being stocked as age-1 fish. Catches of age-1 spring yearlings appear to proceed catches of the age-2 fish (Figure 3). Stocking of the spring yearling fish frequently occurs prior to the commencement of outmigrant sampling. Stocking commonly occurs in early to mid-March, almost a month prior to sampling (Table 3).

Also of interest is the relative timing of the outmigration of the two strains examined. Individuals of the Sebago strain appear to outmigrate somewhat later than LaHave strain fish (Figure 4). Fifty percent of the catch of LaHave fish were obtained by May 5, whereas the same index was not reached until May 15 for Sebago individuals.

Variation of the date of outmigration likely has consequences. It has been suggested that there is an optimum time for outmigration. The optimum time would see young fish arrive in a lake environment that has adequate food resources and a satisfactory number of predators. Arriving either too early or too late could impact lake survival regardless of the outcome of the stream phase. More work needs to be done to determine the optimal smolting period for Lake Ontario and its watersheds.

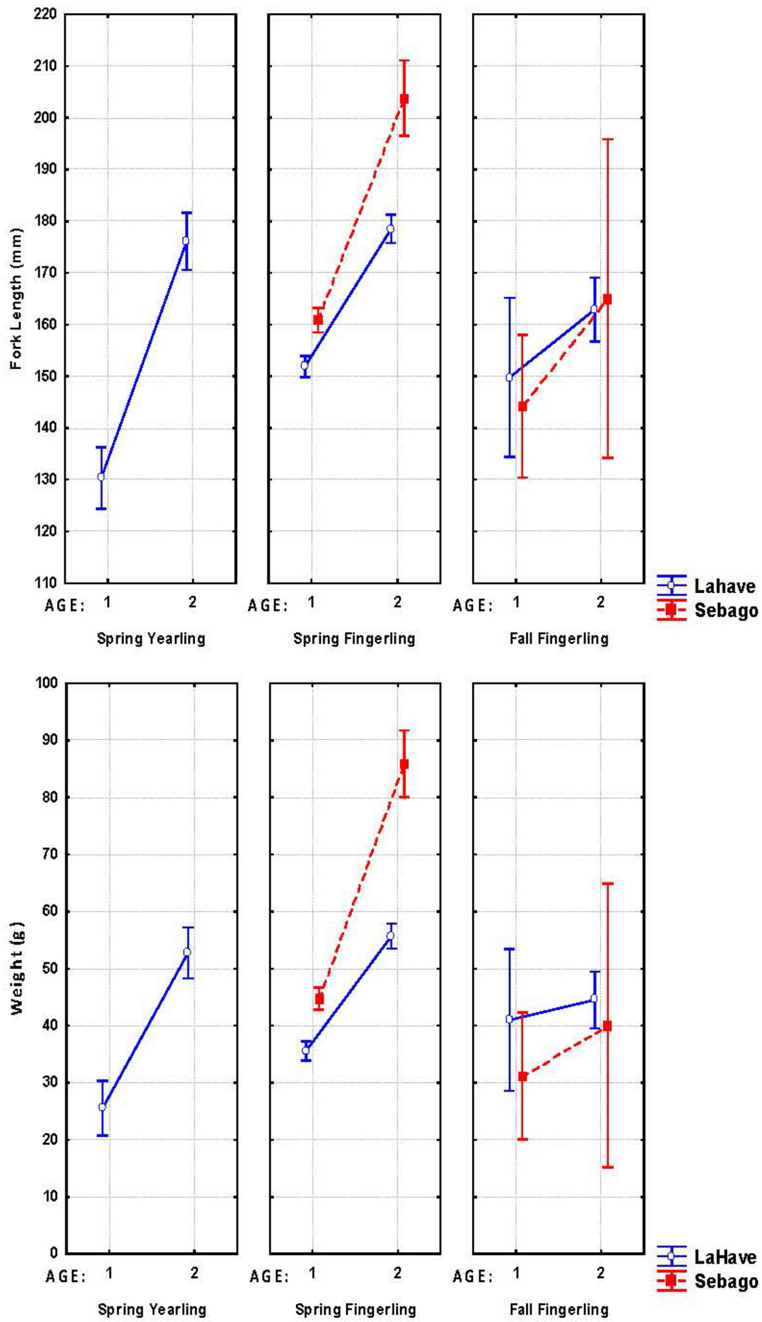

Figure 1. Mean fork length and weight of LaHave and Sebago strain Atlantic salmon captured in Rotary Screw Trap. Vertical bars denote 95 % confidence limits. Figure is partitioned by stocked life stage and smolting age.

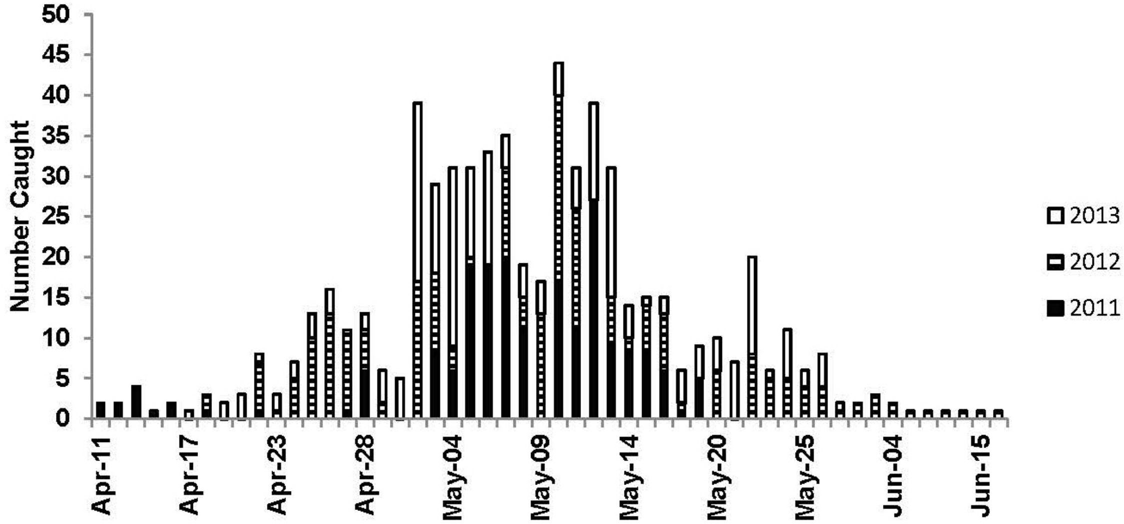

Figure 2. Combined catch of Atlantic salmon by date of capture for the 2011–2013 sampling periods. Strains and life stage combined.

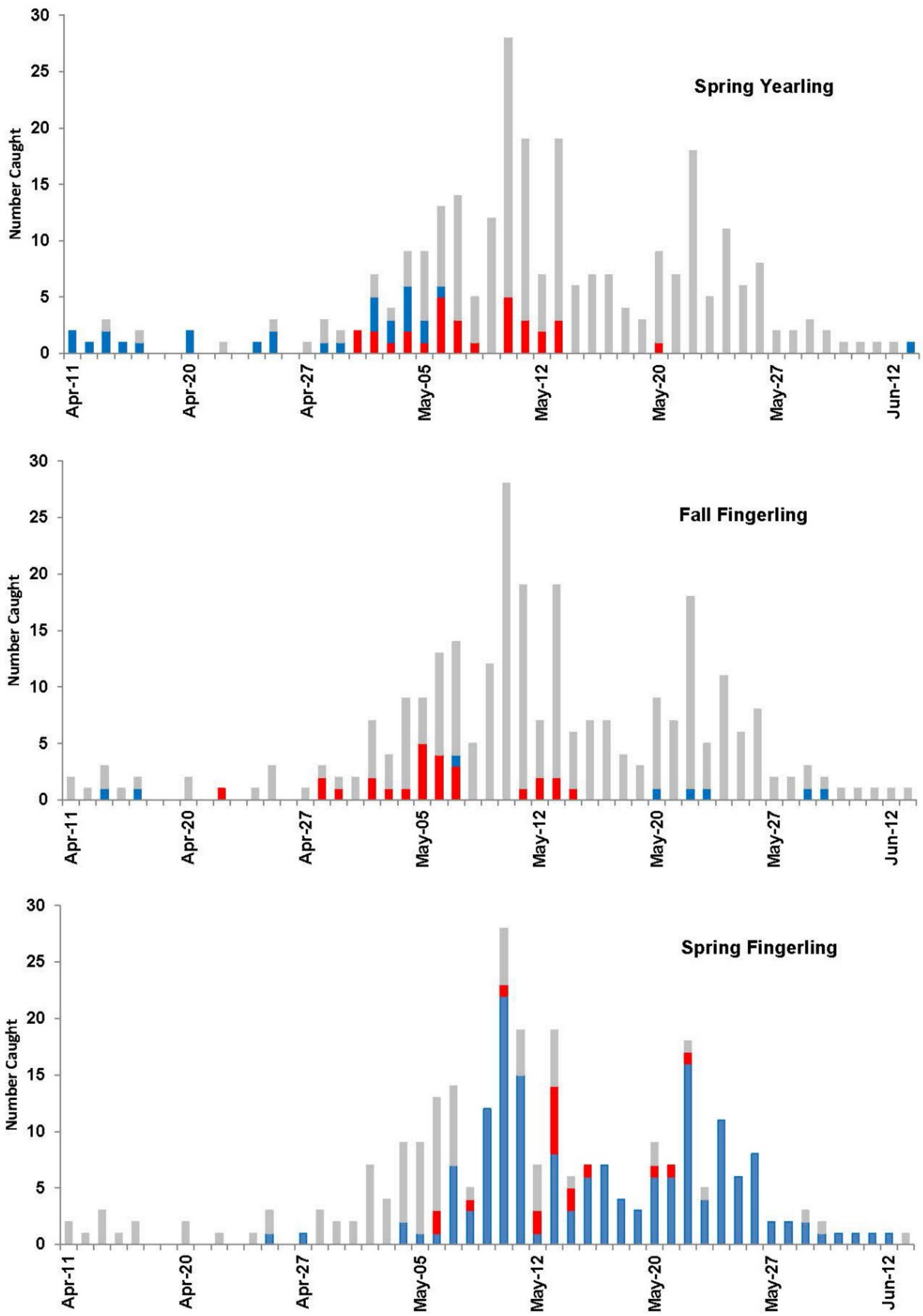

Figure 3. The cumulative catch of spring yearling, fall fingerling and spring fingerling Atlantic salmon by date form 2011–2013 (strains combined). Blue columns [medium grey in print] denote age-1 fish, red columns [dark grey in print] signify age-2 fish, and grey columns [light grey in print] indicate catches of other life stages.

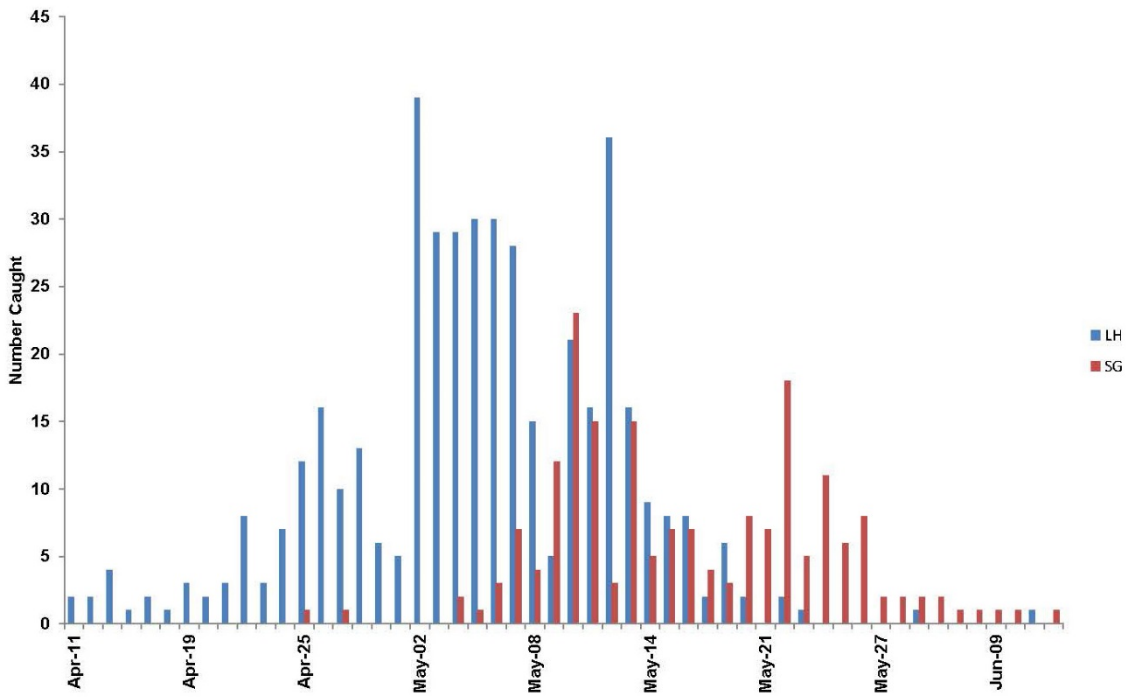

Figure 4. Combined catch of Atlantic salmon by date of capture for the 2011–2013 sampling periods. Catch includes all life stages and is partitioned between strains. (LH = LaHave; SG = Sebago).

Year	Days Sampled	Atlantic Salmon Catch	Number with Confirmed Parentage	Number with Unconfirmed Parentage
2011	51	227	195	32
2012	82	308	219	89
2013	52	277	208	69
Total	185	812	622	190

Table 1. Sampling summary of Rotary Screw Trap operations from 2011–2013 showing yearly Atlantic salmon catch, the number of those fish with confirmed strain and parentage assignments, and numbers with strain and/or parentage unresolved.

		Stocked Life Stage		/	Smolt Age			
		Fall Fingerling		Spring Fingerling		Spring Yearling		
Year	Strain	1	2	1	2	1	2	Total
2011	LaHave	2	16	106	44	7	20	195
	Sebago							
2012	LaHave	2		40	47	1	1	91
	Sebago	4		124				128
2013	LaHave		9	73	36	19	10	147
	Sebago	1	1	41	18			61
Total		9	26	384	145	27	31	622

Table 2. Breakdown of the Rotary Screw Trap catch from 2011–2013. Catch was partitioned by strain, life stage stocked, and age at time of smolting.

Year	Strain	Life Stage Stocked	Numbers Stocked	Mean weight	Month Stocked	Distance stocked upstream from Rotary Screw Trap [a]
2009	LaHave	spring fingerling	223,325	1.1	May	
		fall fingerling	150,216	8.4	Oct / Nov	
		spring yearling	31,886	13	April	~29km, 40km
2010	LaHave	spring fingerling	321,538	1.2	May	
		fall fingerling	91,814	8.7	Oct / Nov	
		spring yearling	43,140	15.4	March (late)	~23km, 29km, 40km
2011	LaHave	spring fingerling	126,646	1.1	May / June	
		fall fingerling	63,488	5.3	Oct	
		spring yearling	45,907	17.9	March (early)	~40km
	Sebago	spring fingerling	115,695	1.1	May	
		fall fingerling	49,668	8.7	Oct	
2012	LaHave	spring fingerling	124,978	1.5	May / June	
		fall fingerling	31,022	6.9	Oct	
		spring yearling	29,175	15	Feb(late) / March (early)	~29km, 40km
	Sebago	spring fingerling	125,254	1.5	April / May	
		fall fingerling	59,181	8.9	Sept	
2013[b]	LaHave	spring yearling	11,391	13.4	March (mid)	~40km
	Sebago	spring yearling	8,833	24.9	March (early)	~14km
	Lac St.Jean	spring yearling	19,757	13.8	March (early)	~14km

[a] Distance of stocking location upstream from rotary screw trap is only provided for spring yearling stocking events. The timing and location of stocking events for spring fingerling and fall fingerlings are considered less impactful on catch numbers as it is assumed that these life stages will not out migrate soon after being stocked.

[b] Note that only the spring yearlings were included in the table for 2013 as this was the only stocked life stage stocked in 2013 that was vulnerable to the gear.

Table 3. Stocking information for each strain and life stage of Atlantic salmon for the Credit River between 2009 and 2013. Note that only data from 2009 onward is presented, as 2009 represents the oldest stocking event that may have been captured with the Rotary Screw Trap due to the occurrence of both 1- and 2-year-old smolts. Also included is the distance upstream (river kilometers) of the spring yearling stocking events relative to the location of the Rotary Screw Trap.

General discussion notes

Q: What are the length equivalents for the report weights of stocked fish?
A: An 8 g fish is approximately 9 cm which is a typical spring fingerling.

Q: How mobile are the life stages?
A: They are very mobile. In the first year they stay put between the spring and the fall. We are using a pit wand to look at movement.

Ancestry of Adult Atlantic Salmon in Lake Ontario Tributaries: Strain and Life Stage Assessment

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Abstract

Key questions for the Lake Ontario Atlantic salmon restoration effort are to determine which life stages should be stocked to promote recruitment to a returning adult population, and which ecological and genetic "best bet" strains are most successful in the lake and tributary environments. This is of particular interest for what strains and life stages are most effective in generating adult returns as fish that return as adults have successfully navigated the full gauntlet of biotic and environmental challenges/selection pressures and are well-suited to pass on their genes to a new, wild generation.

To determine the relative contributions and success of the stocked strains and life stages, genetic tracking is being used to assess the relative contributions and success of the three strains of Atlantic salmon being stocked into Lake Ontario tributaries, as well as the three life stages (fry, fall fingerlings, and yearlings) being stocked for each strain. Although the number of adult Atlantic salmon captured to date is still limited (Table 1), the genetic data are providing valuable information on the contributions from the different stocked strains and life stages.

Figure 1 shows the contributions of the stocked strains to adult Atlantic salmon in Lake Ontario and assessed tributaries. The majority of Atlantic salmon sampled from NYSDEC creels assigned to the Sebago strain, but were not Ontario-stocked fish. (These assigned to the Sebago strain, but were excluded from all genetically-marked Sebago families.) Similarly, samples provided by DFO from western Lake Ontario grouped more closely with the Sebago than LaHave strain (Figure 1). As only the LaHave and Sebago strains were used for baseline comparisons, it is also possible that these fish are from a similar stocking source such as West Grand Lake which is stocked by USFWS, but for which we do not have baseline data. In contrast to the NYSDEC creel results, almost all adult Atlantic salmon captured in Ontario tributaries assigned to the LaHave strain, indicating successful adult returns from the Ontario stocking program (Figure 1).

The genetic ancestry (strain assignment) for captured adult Atlantic salmon is summarized in Figure 2 by location and year. As the Ontario stocking effort relied on the LaHave strain while the Sebago and Lac Saint-Jean broodstocks were being developed, the LaHave strain has had the greatest number of adult returns to date (Figure 2) as well as the most information on stocked life stage contributions (Figure 3). Similarly, the substantial number of adult Sebago (or related) fish from 2009 onwards largely reflects samples from NYSDEC creels (Figure 1; Figure 2) with only low numbers of New York Sebagos showing up in Ontario tributaries. At present, it is too soon to compare the success of the different strains being stocked in Ontario as the first returning Sebago adults from Ontario were only seen in 2013 (Figure 2), and Lac Saint-Jean juveniles have

been stocked too recently to expect to see returning adults before the fall of 2014 at the earliest. Figure 2 also shows fish with ambiguous ancestry, although some of these are data-deficient (inconclusive); others show genetic strain assignments indicative of mixed ancestry, assigning equally well to the LaHave and Sebago strains. Based on the capture years and only recent maturity of the Ontario Sebago broodstock, these adult fish cannot be descended from Ontario-stocked Sebago strain fish. These adult fish must therefore have resulted from wild matings between Ontario-stocked LaHave strain fish and New York-stocked Sebago (or similar) Atlantic salmon (Figure 2).

To date, only the Credit River has provided sufficient numbers of adults to begin to assess contributions of the different stocked juvenile life stages to adult returns. Figure 3 shows life stages at stocking for adults captured in the Credit River that were assigned to the LaHave strain. “Unresolved” adults in 2007 and 2008 represent fish stocked before tracking stocked fish by family (life stage) had begun; similarly, “unresolved” adults captured in 2009 were likely either 2-year stream residents or spent an additional year in Lake Ontario. From 2009 onwards, the greatest number of returning adults were stocked as fry (spring parr) although stocking of both fall fingerlings and yearlings has also provided returning adults (Figure 3). It should also be noted that Figure 3 shows the actual numbers of adults assigned to the stocked life stages, and has not been adjusted for stocking effort (numbers stocked at each life stage). Adults captured in 2011 and 2012 that are shown as “no parents” assigned to the LaHave strain but were excluded from all stocked families by parentage analysis. Similarly, fish indicated as “unresolved” in 2012 and 2013 assigned to the LaHave strain, but showed poor fits (multiple mismatches) to stocked families. These data are indicative of the success of the Ontario stocking effort as well as providing the first information on wild recruitment resulting from Ontario rehabilitative stocking.

Adult samples to date

year	Credit	Cobourg	Duffins	NY creel	Lake Ontario	anglers	other
2007	1						
2008	34	2					
2009	37	4		18			
2010	5	11		41	13		
2011	44	13		16	8	4	
2012	21			10	10		2 (SV*)
2013	22	1	4	4			1 (Bow)

Table 1. Summary of existing adult samples to date, showing numbers of adult Atlantic salmon captured by year, location, and source. Adults from Shelter Valley (SV) in 2012 were encountered as part of a survey for American eel, but were not sampled. Bow = Bowmanville Creek (opportunistic sample).

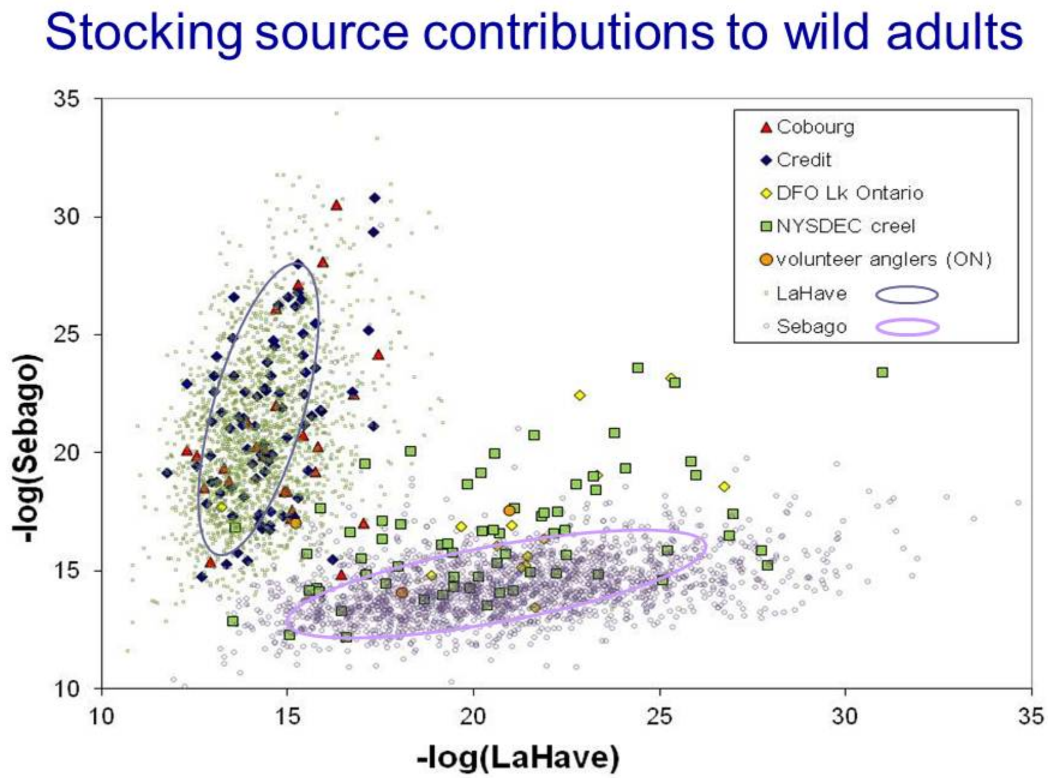

Figure 1. Scatterplot of $\log_{10}$ likelihood assignment probabilities of wild-caught adult Atlantic salmon in Ontario and New York waters of Lake Ontario to the LaHave and Sebago strains. The location of each symbol shows the probability of its genotype occurring by chance from each potential source strain. Blue and lavender ellipses [black and grey in print, respectively] show the 90 % confidence ellipses for genotypes for the LaHave and Sebago broodstocks, respectively. Small green squares and lavender circles [both light grey in print] show individual genotypes for broodstock adults from each respective strain). Red triangles [dark grey in print] show adult Atlantic salmon captured in Cobourg Brook; blue diamonds [black in print] indicate adults captured in the Credit River; yellow diamonds [light grey in print] indicate adults captured by DFO in Lake Ontario; green squares [light grey in print] indicate adults sampled in a NYSDEC creel from New York waters of Lake Ontario; and orange circles [light grey in print] indicate samples provided by volunteer anglers in Ontario.

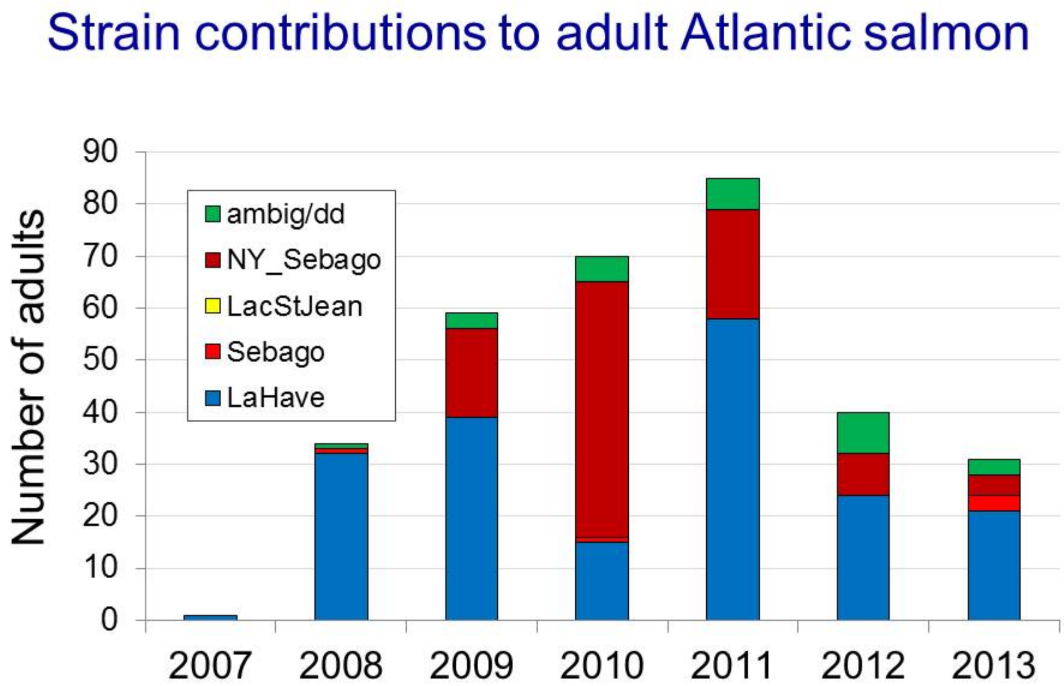

Figure 2. Strain contributions to adult Atlantic salmon in Ontario and New York by year, based on genetic strain assignment. Fish shown as “New York Sebago” were assigned to the Sebago strain but were excluded from being Ontario-stocked fish based on parentage analysis (family exclusions).

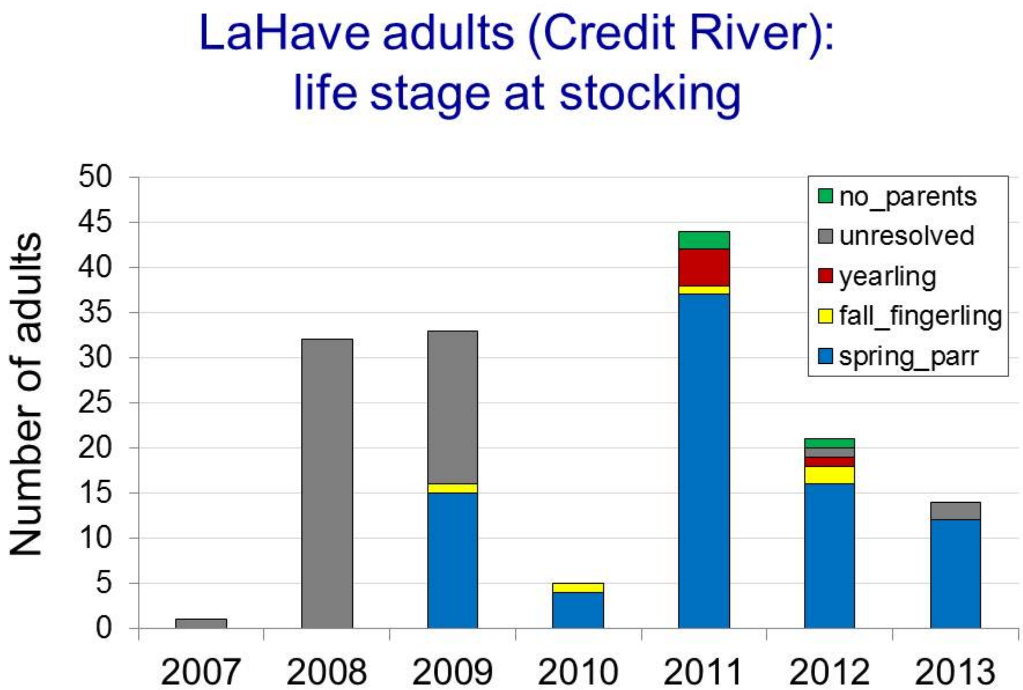

Figure 3. Contributions of different stocked life stage to adult LaHave strain fish captured in the Credit River. Unresolved fish from 2007 to 2009 represent fish stocked before the genetic family tracking program was initiated. Fish marked as "no parents" (shown in green [medium grey; top layer of 2011 and 2012 in print]) were excluded from all stocked families but were confirmed as having LaHave ancestry by strain assignment.

General discussion notes

C: The goal is to re-establish self-sustaining populations in Lake Ontario tributaries in sufficient numbers to support a recreational fishery.

C: Still too early to say how different strains are performing.

C: According to NYSDEC, angler catch rates of Atlantic Salmon increased by 6 times and harvest increased 20 times in 2009.

C: Genotyping showed NY creel fish were Sebago strain (i.e. what they stocked); meanwhile adults in Credit and Cobourg were LaHave. In other words, NY anglers catch NY stocked fish and Ontario samples Ontario stocked fish.

C: All salmonid catch rates (not just Atlantic salmon) jumped up after 2009, suggesting that whatever caused the change in catch rates was not just influencing Atlantic salmon.

Q: Are your returns adjusted for the number stocked?

A: No, but Marc Desjardin’s talk suggests that there are still disproportionately more survivors from fry.

Understanding Factors that Influence Atlantic Salmon Outmigration Patterns from Trap Operations Conducted from 1989–2012

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Abstract

From 1989–1995 in Wilmot Creek and from 2011–2012 in the Credit River, Atlantic salmon outmigration was monitored at a counting fence and auger trap, respectively. Note that early attempts to operate an auger trap and keyhole trap in the Credit River generated very low catches and are not reported here. One intent of the early studies on Wilmot Creek was to quantify outmigrant survival to maturity, but with only one adult being confirmed as an adult return, survival was zero. Other studies will evaluate survival of various sizes of stocked fish to outmigrants in the Credit River. Therefore, this study will focus on evaluating the relative survival and factors that influence survival from stocking to outmigration in these two systems for the anadromous LaHave River strain and, where available, the landlocked Grand Lake strain. Note that targets in the Atlantic salmon management plan refer to measures in terms of smolt survival, etc. However, since no information was collected to determine whether out-migrants were undergoing the smoltification transformation, the degree to which these results measure this process can only be inferred.

For this analysis, daily outmigrant catches of Atlantic salmon are plotted and compared with simple estimates of stream temperature and discharge. Photoperiod and growing degree-day data are not available for these streams. Catch data are converted to survival estimates based on the number of fish stocked and a conversion of catch statistics to total numbers of outmigrants based on measured estimates of trap efficiency, where available, or the mean efficiency of the devices (Table 1).

As a result of many factors, including the fact that the weir was in a trial period, efficiency rates varied from 2–60 % efficiency over the years of operation. The total number of outmigrant Atlantic salmon also varied widely, with the first and third years of operation clearly having the highest success rates (Table 1). Atlantic salmon tended to migrate in early May during the rising limb of both temperature and flows (Figure 1; Figure 2). The anadromous fish consistently outmigrated about a week earlier than the landlocked strain. After 1991, the number of Atlantic salmon captured at the Wilmot weir declined dramatically in concert with improvements in weir operational procedures. Similar analysis on the Credit River (Figure 3) also determined that the Atlantic salmon migrated in early May, although it is too early to determine whether the landlocked and anadromous strains showed similar differences in timing.

While rising temperature and discharge were correlated with outmigration, there were clearly other factors at play. Others have shown that Atlantic salmon outmigration is more closely correlated with stream-growing degree-days and/or cumulative photo period

(Saunders and Henderson, 1970). There was greater survival of outmigrants that were larger for both strains, although there were clearly insufficient data for the landlocked strain to infer patterns (Figure 4a), and there was no clear pattern in survival and median date of outmigration (Figure 4b). Fish condition varied considerably from year to year which resulted in an index of health being implemented in 1992, the year that only 55 % of fish were deemed to be in a visibly-healthy state (Table 2). Fish that routinely passed through the weir that had fungus, most scales missing, and eroded fins, although the degree to which these observations reflected smoltification processes versus other sources of stress was not evaluated. In recent years, health was assessed using a gill colouration category that suggests that, overall, the fish are in a good state as they pass through the screw trap (Table 2).

The program would benefit from a clear understanding of why the 1989 outmigration was so much greater than any other year. However, detecting patterns to explain variation in outmigrant survival and subsequent adult returns is challenging because of the high variation in both predictor and response variables, variation in methods, and the short duration of sampling. Initially, the program was exploratory and, therefore, methods in both hatchery and assessment techniques varied, making causal pathways difficult to discern. Anecdotally, the 1989 spring was late to arrive and extended well into May. Coincidentally, the largest fish ever stocked were in this year. Finally, the efficiency of the weir was not quantified during this first trial year, such that it is likely that the use of the mean efficiency rate likely underestimates the true size of the outmigrant population. This analysis does not consider the age of fish outmigrating, which likely changed as the size of fish stocked declined. This is supported by the observations from 1995, where 101 fish were captured, even though no yearling Atlantic salmon were stocked that year. In fact, failure to outmigrate soon after stocking may be sufficient to explain the declines in outmigrants since fish would have been forced to compete with the other salmonids for a full year and natural mortality could be extensive in this crowded system.

There are clearly lessons to be learned for current initiatives to evaluate outmigrant survival and patterns. The Wilmot Creek outmigration study was intended as a long-term project with the first five years directed at methods development. Researchers and managers should consider the implications of changing stocking practices and varying annual resources in current/future initiatives so that understanding does not depend on long-term data sets that can be compromised, while still providing an understanding of the main causal pathways. Finally, we would recommend either a rethinking of the smolt-to-adult survival target that relies on measuring smolt numbers that, to date, have not been quantified or that relates to outmigrant counts that presume preparedness for lake survival.

Year	Species	Number marked	Number recaptured	Weir efficiency	Comments
1990	Rainbow trout	272	13	4.8	Two efforts: 1 nursery, one at hwy 35 / 115
1990	Coho salmon	46	1	2.2	
1992	Coho salmon	159	95	59.7	Captured in weir released upstream
1993	Rainbow trout > 160 mm	429	98	22.8	Spring marking > 1 km upstream
1993	Coho salmon	29	1	3.5	Spring marking > 1 km upstream
1994	Rainbow trout > 140 mm	250	34	13.6	Spring marking > 1 km upstream
1994	Coho salmon	160	23	14.3	Spring marking >1 km upstream
Average				17.3	

Table 1. Synopsis of efforts to calibrate the counting fence on Wilmot Creek.

	N	Good	Some fungus/ gill paleness	Poor Health	Mortalities
1989	3407	98 %	< 1	< 1	< 1
1990	281	89 %	3	7	< 1
1991	570	99 %	< 1	< 1	< 1
1992	392	55 %	24	22	10
1993	111	97 %			3
1994	861	81 %	11	2	6
1995	150	76 %	17	7	8
2011	237	89 %	11	0	0
2012	338	98 %	0	0	2
2013	310	97 %	2	< 1	1

Table 2. Fish Condition, as measured at the Wilmot Counting fence 1989–1995 and from the Credit River screw trap (2011–2012).

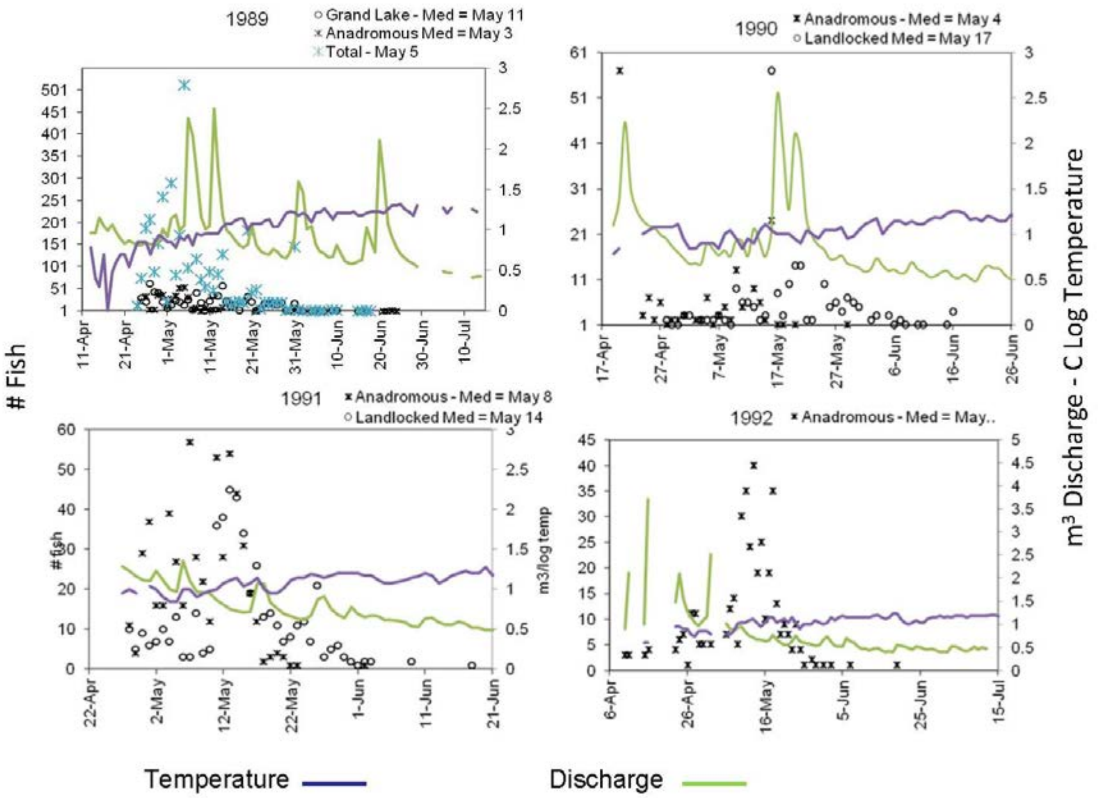

Figure 1. Relationship between Atlantic salmon smolt outmigration, temperature, and discharge in Wilmot Creek, Ontario during 1989–1992.

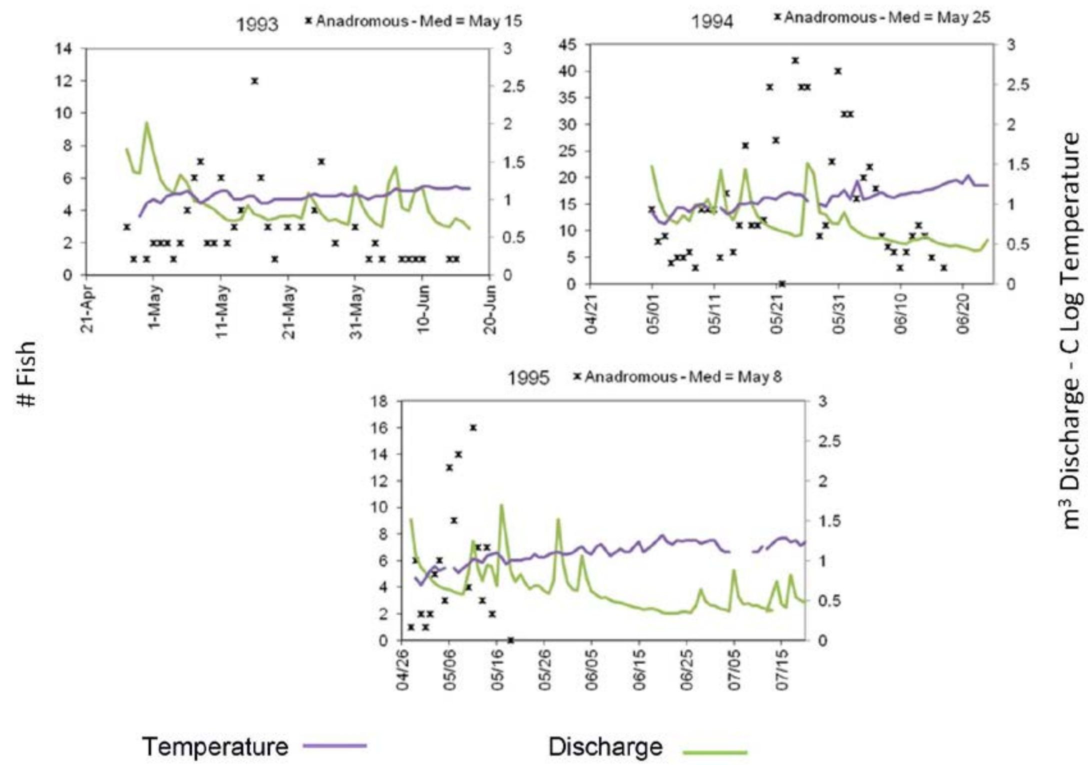

Figure 2. Relationship between Atlantic salmon smolt outmigration, temperature, and discharge in Wilmot Creek, Ontario during 1993–1995.

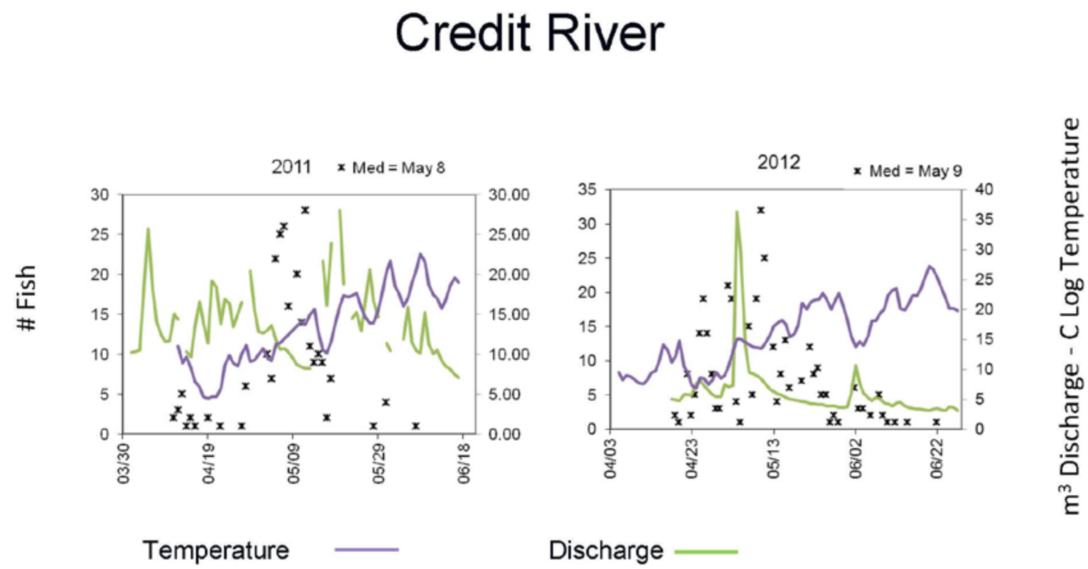

Figure 3. Relationship between Atlantic salmon smolt outmigration, temperature, and discharge in the Credit River, Ontario during 2011–2012.

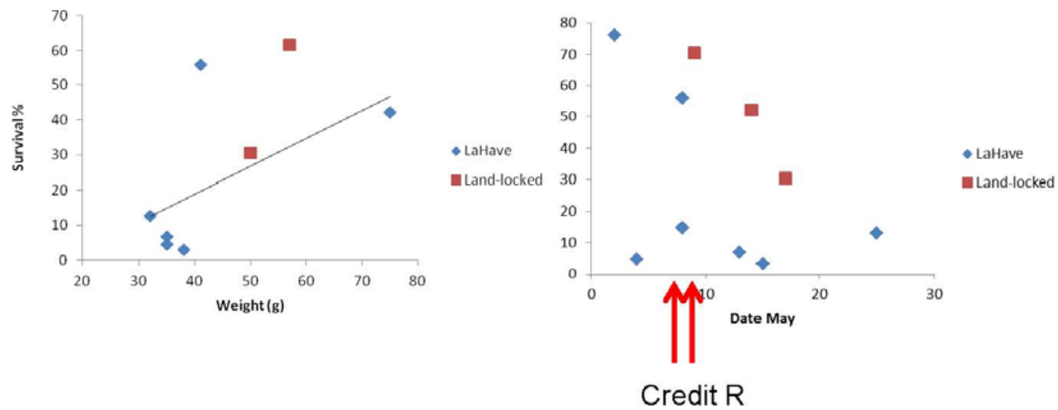

Figure 4. Relationship between estimated smolt survival, weight at stocking and peak date of smolt out migration in Wilmot Creek, Ontario during 1989–1995. Arrows show comparable dates for surveys conducted on the Credit River (Desjardins, this workshop).

References

Saunders, R.L., Henderson, E.B., 1970. Influence of Photoperiod on Smolt Development and Growth of Atlantic Salmon (*Salmo solar*). Journal of the Fisheries Research Board of Canada. 27, 1295–1311.

General discussion notes

C: Wilmot Creek's counting fence ran 1989–1995. It ran as soon as possible in spring (early April after spring freshet) through June. All fish captured were enumerated.

C: Efficiency of the weir is 17.3 % (range 2.2 to 59.7, varied by year and by species).

C: Using efficiency estimates, survival estimates are 3–13 % for Atlantic Salmon. Interestingly, in 1989 and 1990, before they figured out "BMP" for operating the weir, their survival estimates ranged from 47–61 %. Les has little faith in those numbers.

C: A combination of temperature and discharge influence the timing of outmigration.

C: Outmigration peaks first half of May. Anadromous strains from LaHave leave earlier than landlocked Grand Lake strains.

C: An exceptionally cold spring in 1989 coincided with high survival. This climatic pattern relative to weir timing has never been replicated.

Facilitated Discussion I

Knowledge gaps

- Further analysis of existing genetic data are needed to assess for extent of wild production. A number of samples do not map to known lineages; they are potentially wild fish.
- We should consider using grandparentage analysis to ID natural reproduction.
- We should track length, weight, and condition factors of yearlings, extend adult assessments and engage partners to collect standardized data.
- Radio telemetry and PIT tagging array can be used to examine fall fingerling/yearling/smolt movement and survival.
- There is an opportunity to look for wild production prior to spring fingerling stocking or pulse stocking on alternate years.
- Where is the juvenile survival bottleneck?
- What is the ideal length and weight for hatchery production by life stage?
- Different life-stage data may be useful for research.
- Downstream passage survival at barriers for juvenile and adult should be examined.
- There is a gap between adult assessment and adult return timings.
- How much variability is there for survival across habitats?
- General improvements to data management need focus.
- We should increase resolution in culture practice and stocking location related to parentage analysis, pending practicality and feasibility.
- Monitoring and evaluation criteria within hatchery should be enhanced, looking for condition factor and timing of stocking, via an adaptive management framework.
- What are fish culture BMPs?

Management implications

- We are exceeding our stocking density benchmarks for spring fingerling and fall fingerling stocked fish.

- Preliminary estimates of the survival of smolt for spring fingerling and fall fingerling stocked fish are below target.

- Preliminary results indicate that spring fingerling (fry) stocking is accounting for most of the surviving and returning adults. Performance indicators corrected for the number stocked (Appendix D) confirm the higher performance of spring fingerlings.

  Yearling stocked fish are not evident in the smolt traps and are rarely observed as adults. This may indicate insufficient monitoring of yearling outmigration or poor survival.

Drivers of Seasonal Survival and Condition in Wild Juvenile Atlantic Salmon

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Abstract

My research focus is field-based, with an applied science emphasis. There are three areas of focus involving the wild Atlantic salmon:

1. Natural stressors (winter, ice, floods, high temperature).

2. Anthropogenic impacts (hydroelectric operations, forestry).

3. Ecosystem and food web dynamics.

In the Miramichi River in central New Brunswick, the largest producer of wild salmon in eastern Canada, the annual discharge peaks are snowmelt driven with lowest water levels measured in September and February, on average. Natural flow variation is critical for adult (upstream) movement, winter survival (eggs and parr), and for smolt emigration (spring). Summer streamflow was important for determining thermal regimes for growth and survival of juvenile (parr) stages. Based on long-term sampling (20 years) in Catamaran Brook, we have found evidence of density-dependent effects on young-of-the-year size and a declining trend in age and size of smolts (1990–2008). Our research has also suggested that beaver activity, together with low autumn streamflow, can affect distribution of juvenile salmon within a river system, and this relationship can subsequently limit the abundance of resident species such as slimy sculpin. Recent studies of extreme warming events in New Brunswick rivers has demonstrated evidence of physiological stress responses (including anaerobic metabolism) and thermoregulatory behavior such as aggregating at cool water refugia, and long distance (> 5 km) movements.

General discussion notes

Q: Are the life table summary results published and available?
A: Yes, see Cunjak and Therrien (1998). Inter-stage survival of wild juvenile Atlantic salmon, Salmo salar L. Fisheries Management and Ecology 5:209–223.

Q: When the fish move to temperature refugia, do they stay there?
A: Yes, fish move out of the warm temperature and stay there.
C: Need to have increased thermal monitoring of Lake Ontario tributaries including finding groundwater refugia to determine the extent of thermal habitat issue.

Q: Are the ground water seeps permanent and drought-resistant?
A: Yes.

Q: Does the Catamaran Brook watershed contain gravel moraine?
A: Yes.
C: The gravel moraine landscape makes the area very susceptible to drought.

Q: The lethal effects of temperature are dramatic; is there a sub-lethal growth effect?
A: Yes, the high temperature puts stress on the fish and reduces growth.

C: An increased temperature tolerance could be a heritable trait that could be selected over time.
C: Yes, but it happens too fast to allow for selectivity.

Are Our Stocking Locations and Associated Habitat Conditions and Expected Spawning Habitats Sufficient for Survival and Spawning Success, or Do We Know?

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Abstract

Phone conversations were had with district biologists (Aurora and Peterborough) as well as conservation authorities (Credit Valley and Toronto Region to document the methodology behind stocking site selection. It was indicated that the following methodology was used to select Atlantic salmon stocking sites:

1. Based on the 2003 update (Greig et al., 2003) to the Atlantic salmon restoration plan and the designation of the three best-bet streams and Stanfield's criteria of quality habitat (Figure 1).

2. Conservation authorities and district offices selected stream sites with the appropriate stream characteristics and Stanfield visually confirmed their suitability.

Furthermore, the changes that have been made to stocking locations since 2005 within the Credit, Duffins or Cobourg have been primarily based on survival of stocked Atlantic Salmon. The criteria that were used for the selection of stocking sites post-2003 were consistent with criteria outlined in the 2003 plan as well as habitat suitability determined by Stanfield and Jones (2003). These criteria were as follows:

- Abiotic characteristics (pebble/rocks, correct temperature, etc. from Stanfield and Jones, 2003)

- Biological (avoiding species interactions)

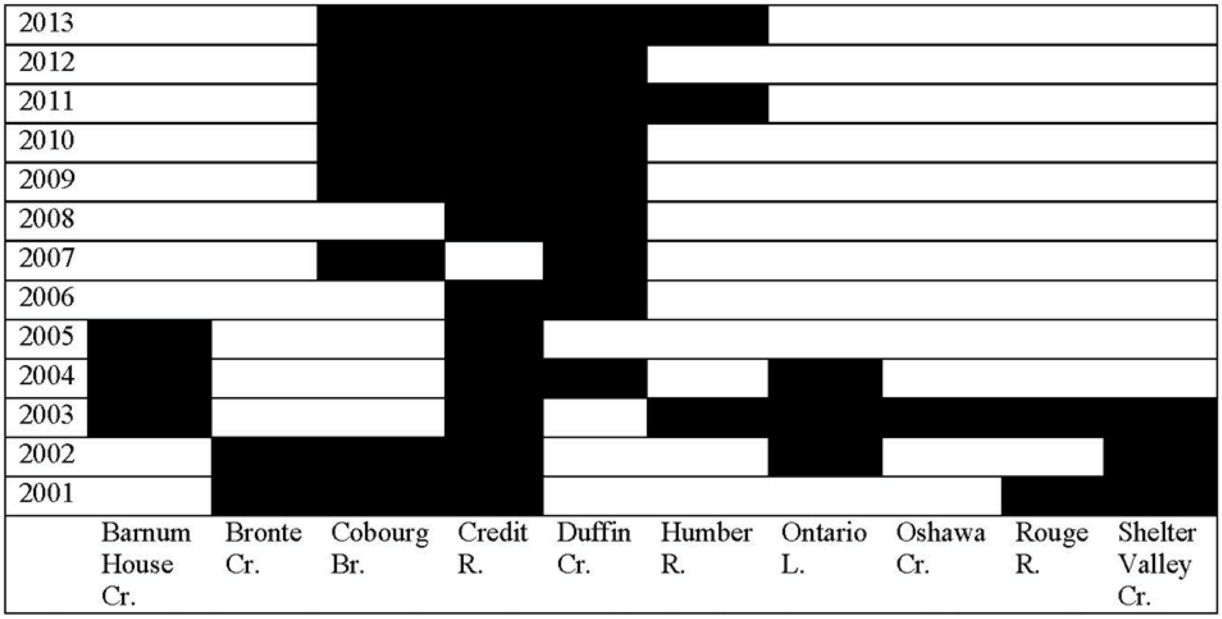

Figure 1: Tributaries stocked by year since 2001.

References

Greig, L., Ritchie, B., Carl, L., Lewis C.A., 2003. Potential and strategy for restoration of Atlantic Salmon. In. Lake Ontario: A workshop report. Prepared by ESSA Technologies Ltd., Toronto, ON. Ontario Ministry of Natural Resources and Forestry, Lake Ontario Management Unit. Peterborough, pp. 39.

Stanfield, L.W., Jones, M.L., 2003. Factors Influencing Rearing Success of Atlantic Salmon Stocked as Fry and Parr in Lake Ontario Tributaries. North American Journal of Fisheries Management. 23, 1175–1183.

General discussion notes

Q: Is there data in the binder outlining selection process?
A: In section 1, 1995 plan p.9, but not actual spreadsheets.

C: Let the fish tell you what good habitat is and assess what their performance is, instead of relying on expert opinion alone. Use data on the ground in terms of fish survival, density, growth.
C: Yes we expect adults to return to stocking sites. Literature says returning adults have a high affinity to their natal areas, which is not yet seen in all streams, though.

Q: What does "area" mean?

Q: Exactly what data was used, if any?
A: *Brief outline by CR of process.* We used LDI, slope, substrate, stream width, rainbow trout growth rates, and other factors such as barriers and social.

Q: Are we confident sites have appropriate thermal regimes?
A: Only on some areas on Credit which had actual temperature data available.

Q: Did we use this process for stocking sites for all life stages?
A: No, it was really only based for fry, then we used conservation areas and districts for local consultations about sites. So, not good information on fingerling fry and yearling stocking sites; could be revisited.

Q: Are we recording data needed per earlier question on habitat quality at stocking sites?
A: No.

C: The problem with stocking above barriers is we can't complete life cycle assessment based on habitat.
C: Could assess to smolt stage though.

Q: Are collecting data on mortality and growth at those sites, in the Credit River specifically? Where early growth is occurring?

Atlantic Salmon Spawning Habitat: What Do We Know About Spawning Substrate Requirements? (Question 4d)

John D. Fitzsimons, Fisheries and Oceans Canada, Burlington, Ontario, L7R 4A6

Abstract

There are several reviews in the literature on spawning habitat for Atlantic salmon (Armstrong et al. 2003). Briefly, Atlantic salmon reportedly spawn in water velocities of from 35–80 cm/s^{-1} (Beland et al., 1982) at water depths ranging from 17–76 cm (Beland et al., 1982) on substrate having a mean particle size of 100 mm (Heggberget, 1991), having from 2.3–8.0 % fines (< 1 mm; Moir et al., 1998). The depth of burial of eggs in the redd varies from 15–25 cm (Bardonnet and Bagliniere, 2000).

Fitzsimons et al. (2013) evaluated spawning habitat of wild and stocked Atlantic salmon in the Credit River using measures of egg survival. Several methods exist for determining the survival of eggs of fluvial spawners in situ, including Whitlock-Vibert boxes (Mackenzie and Moring, 1988), specially modified egg bags (Pauwels and Haines, 1994), or specially modified PVC tubes (Palm et al., 2007; Merz et al., 2004). In view of the limitations of existing egg incubation methods (Fitzsimons et al., 2013), a new method was developed (Figure 1). With this method, almost the entire egg incubator, herein termed a capsule, is permeable to water as well as infiltrating sediments and, by design, can be injected directly into redds. The capsule (Figure 1) consists of a polypropylene mesh tube (5 mm square mesh; 7 cm diameter, 20 cm length) having detachable porous (1000 µm) end caps which, if required, can be replaced with a collection device for collecting emergent fry (Figure 1). The inside of the capsule is lined with 1000 µm Nitex mesh to prevent the loss of hatched fry but allow the infiltration of fine sediment. An egg-and-gravel (1–2 cm) slurry consisting of 100 hatchery broodstock eggs per capsule is added to the capsule which is sealed and transported to the river. At the river, a capsule insertion device (Figure 1) is driven into the redd to the appropriate depth for naturally-spawned eggs, usually 15–20 cm (DeVries, 1997). The central rod used to drive the capsule insertion device into the substrate is then removed while the outer tube of the capsule insertion device is held in place, providing a void space in the substrate. An individual capsule is then placed into the void space in the outer tube, and a rod is used to hold the capsule in place while the outer tube is withdrawn from the substrate. Once complete, the capsule is not visible from the surface, confirming burial. Its position is marked by a coloured string attached to the capsule prior to insertion, allowing it to be readily found and removed at a later date. To assess the effects of holding eggs in the capsule and transportation effect on egg capsules, a subsample of loaded capsules is subjected to the same handling as buried capsules, incubated under hatchery conditions, and examined at the same time as capsules are removed from the river. At the time of withdrawal from the substrate, capsules are immediately frozen on dry ice. Survival is determined after the capsule contents are thawed and the quantity of fine sediment determined.

Using the above method, the suitability of redds constructed by hatchery Atlantic salmon in the Credit River and Rodgers Creek, Ontario, a small tributary of the Credit River, was evaluated. It was evident that incubation of hatchery eggs in natural redds resulted in reduced survival relative to controls reared in the hatchery (Figure 2). Moreover, the survival using known numbers of hatchery eggs reared in capsules resulted in a lower estimate of survival potential within an individual redd than survival based on naturally-deposited eggs (Figure 2). Although there appeared to be some difference in survival of hatchery eggs in capsules between redds of wild and hatchery spawners (Figure 3), both of these values likely overestimate true survival.

Many factors likely contributed to the decline in embryo survival in capsules in the wild relative to capsules held in the laboratory and may involve water flow (Silver et al., 1963), dissolved oxygen (Meyer et al., 2008), and the amount and duration of exposure to fine sediment (Louhi et al., 2008, 2011). It was not possible to explain variation in survival either to hatch or to the live fry stage at the time capsules were recovered based on the proportion of fine sediment alone (Figure 4), suggesting multiple factors need to be measured to account for variation in survival. Alternatively, it is not known when sediments were entrained into capsules, and variability in the period of entrainment and concurrent exposure of eggs may explain some of the variation in survival relative to sediment composition. Foremost among factors known to affect embryonic survival and fitness for fluvial spawners is substrate composition, particularly the amount of fine material present (Chapman, 1988). Recent work indicates that the finest material (< 125 μm) may be responsible for the greatest decline in survival and at a relatively small percentage of the sediment present (Louhi et al., 2008, 2011)

Fitzsimons et al. (2013) also used stable isotopes to differentiate the source of eggs (hatchery or wild) spawned in redds located in the Credit River. A total of 79 potential Atlantic salmon redds were identified in the reaches of the upper Credit River. These were associated with an unknown number of wild spawners and the 342 hatchery salmon stocked into the upper Credit River during 2009 (Fitzsimons et al., 2013). Of the 79 suspected redds, 34 were excavated and found to contain eggs, all of which were confirmed by genetic analysis to be those of Atlantic salmon. A much smaller number of wild salmon (18) were stocked into Rodgers Creek, consisting of 10 males and 8 females, having an average total length of 531 mm. On Rodgers Creek, a total of 23 potential redds were identified, although eggs could only be extracted from five of these redds, and all of these were confirmed as being those of Atlantic salmon.

Using the stable isotope data to assign putative redd parentage (e.g. wild or hatchery), the spawning habitat used on the upper Credit River by hatchery spawners was largely indistinguishable from that of wild spawners with two exceptions (Fitzsimons et al., 2013). These exceptions were the type of habitat Atlantic salmon spawned in and the proportion of riparian vegetation associated with the spawning area. The type of habitat used for spawning (e.g. riffle, pool-riffle, run) differed between wild and hatchery spawners; wild salmon appeared to prefer pool-riffle (60 %) over riffle (40 %) or run (0 %) habitat whereas hatchery-reared salmon preferred riffle (64 %) over pool-riffle (27 %) or run (9 %) habitat. Wild salmon spawned in areas with significantly-greater amounts of riparian vegetation (86 %) than hatchery-reared (59 %) salmon. The limited data available for wild redds on Rodgers Creek indicated that wild salmon selected similar habitat on this smaller system with the exception of stream width which was, as expected, less (4.0 m) than for the larger upper Credit River (14.8 m) and distance from the nearest shore (1.8 m), which was less than one half that of the Credit River (3.8 m).

Spawning fish, whether putative wild or hatchery in origin, selected spatial habitat in proportion significantly different from available habitat (Fitzsimons et al. 2013). The width of stream used by spawning Atlantic salmon was wider (14.8 m) than was available (11.6 m) with spawning occurring in shallower water depths (35.4 cm) than were available (50.7 cm) but at higher flows (0.6 m/s) than were available (0.4 m/s). The proportion of type of habitat used for spawning (e.g. riffle, pool-riffle, run, pool) did not differ from the proportions available.

Selection of spawning habitat that is inappropriate for reproduction can have profound fitness implications (Schjørring, 2002) and affect survival (Chapman, 1988). In their study, Fitzsimons et al. (2013) detected few measurable differences between the habitat used by hatchery and wild spawners. Of those differences, the apparent preference for riffle habitat over pool-riffle habitat by hatchery spawners may be because of the reduced upwelling flow in riffles, as opposed to pool-riffles which have the greatest potential to negatively affect embryonic survival, but more work would be required to confirm this. The wild spawners responsible for the wild redds identified in this study were likely the result of earlier stocking activities of hatchery-reared Atlantic salmon so are not representative of a wild remnant stock. These salmon, based on numbers and life stages of salmon stocked, were probably of an earlier developmental stage than adults because of the much higher stocking of yearling and younger stages that has occurred (M. Daniels, Ontario Ministry of Natural Resources and Forestry, personal communication). Nevertheless, despite the period of holding under hatchery conditions, the spawning habitat used by wild salmon in this study was similar to that given in reviews of the freshwater requirements of Atlantic salmon based on wild salmon (Gibson, 1993).

Based on the Credit River, the best-studied tributary of Lake Ontario which historically supported large runs of Atlantic salmon, wild Atlantic salmon are able to access high-quality spawning habitat high in the watershed, apparently in the face of several partial barriers. Although encouraging, the numbers of redds built by wild spawners on the Credit River continue to be quite low despite large stockings of multiple life stages over multiple years. Accordingly, factors limiting run size need to be evaluated, and this should include not only factors in the lake (e.g. feeding niche) and in the river (e.g. competition). Although there are several methods for evaluating the number of spawning redds and their suitability for rearing embryos to emergence, more work is required to relate these to measures of survival and numbers at successively older life stages relative to management targets.

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a) b).c)

Figure 1. Details of a) egg capsule injection device disassembled with a capsule, b) assembled egg capsule injection device, and c) egg capsule with emergence collection net attached and sample of substrate used.

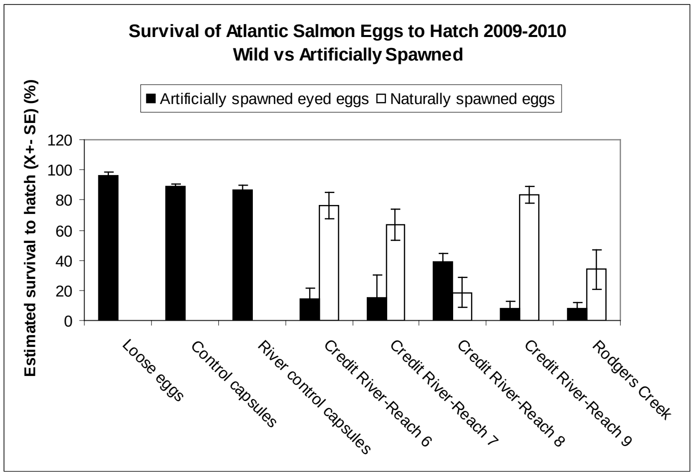

Figure 2. Comparison of survival of Atlantic salmon eggs in capsules in controls relative to eggs in capsules and eggs excavated from redds in the Credit River and Rodgers Creek.

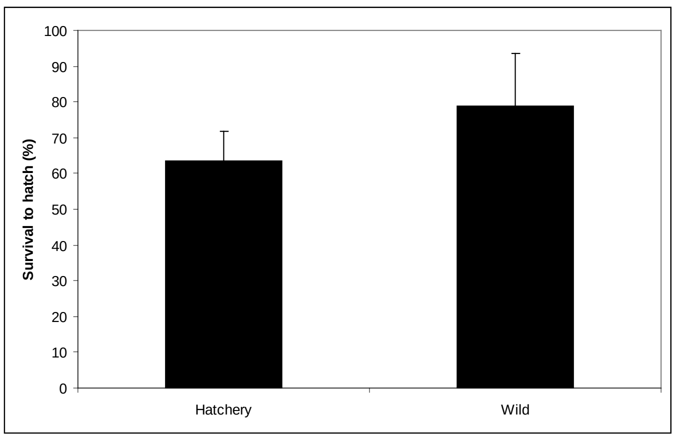

Figure 3. Mean survival to hatch of Atlantic salmon eggs in capsules injected into Atlantic salmon redds built by either hatchery or wild spawners.

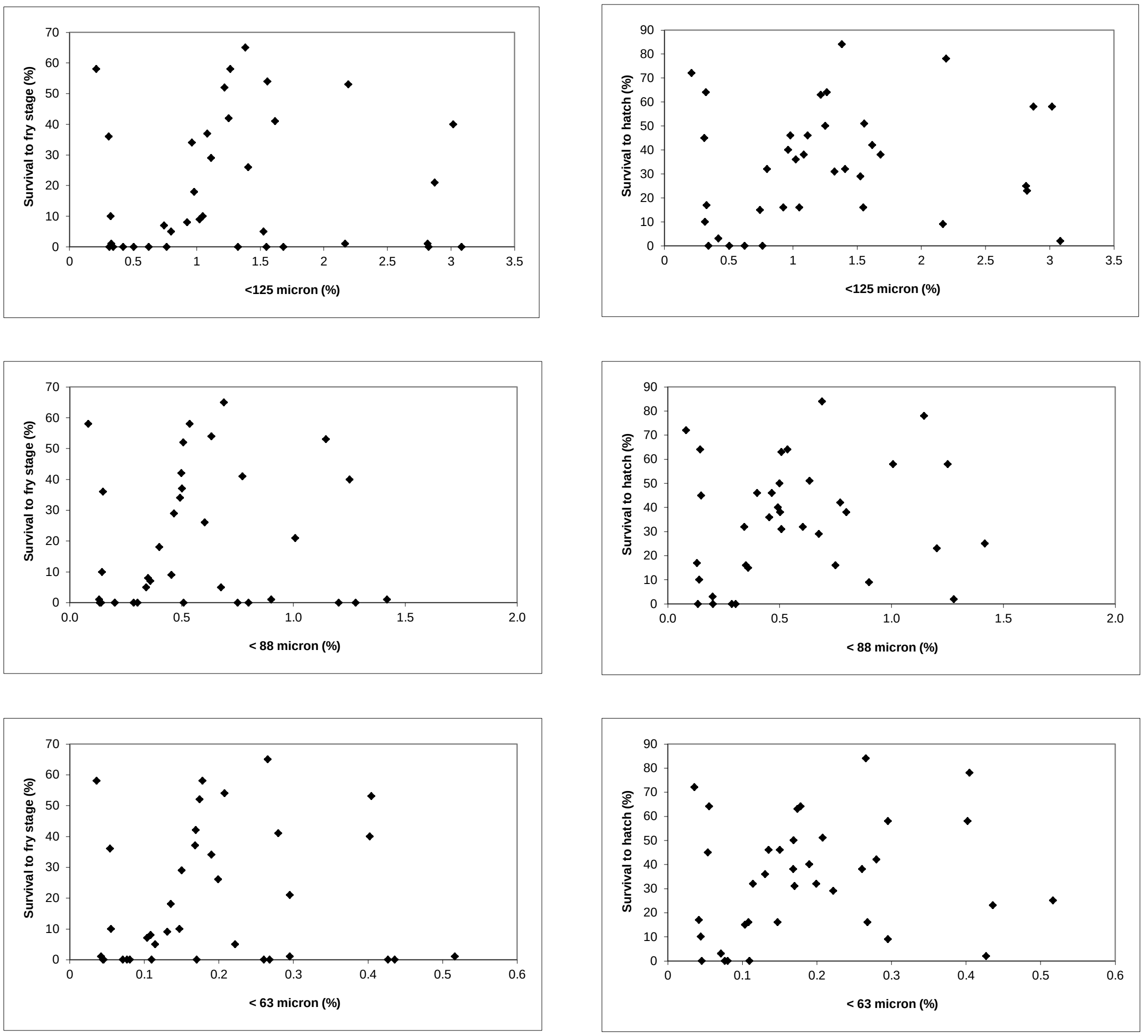

Figure 4. Comparison of Atlantic salmon egg survival in egg capsules to the fry or hatch stage relative to infiltration (%) by three successively smaller sizes (a) < 125, b) < 88 and c) < 63 micron of fine material.

General discussion notes

C: *Reference to Scotland/Ian Malcom's work on dissolved oxygen (DO) in redds*.
C: Saw some changes in DO. Couldn't relate them to changes in egg survival in particular redds. Need to take on a multivariate approach with DO, fines, etc.

Q: Is there any merit in doing randomized redd surveys, including a groundtruthing females/redds survey?
A: There are so few redds right now, we want to enumerate all of them rather than use subsets.
C: We have to verify each redd is really an Atlantic salmon redd.
C: Or a false red.

Q: We stocked hatchery adults in 2009; did we track fry?
A: No, just to March. We ran out of funds to go further.
Q: Wouldn't any surviving fry have shown up in genetic assessments?
A: Correct, they would show up as unmatched.

Q: In 2009, the number of wild redds: is that correct, 21 redds?
A: Yes, it probably represented about 59 actual females, based on correction factor (based on observed surplus hatchery fish ratio), confirmed with genetics as being non-hatchery fish. They went over Streetsville and Norval on their own.

Q: I agree that brown trout have similar spawning requirements to Atlantic salmon. Can we not assume then habitat quality for spawning is okay for Atlantics as there are a lot of browns in the Credit River, so it should be ok for Atlantics?
C: Paper by Zimmerman showed brown trout were further downstream.
C: Brown trout spawn up at forks too.
C: Only saw a couple of brown trout redds in these surveys.
C: Range in past went from 75–400 brown trout redds.

Q: Are brown trout resident or migratory in Upper Credit?
A: Resident.

C: Salmon River has lake-run brown trout that spawn in heavy concentrations but rarely show up as fry. Thiamine is okay in parents. Lots of redds, no progeny. A grad student tracked emergence in stream, but still no fry.
C: Could be things like water quality.
C: Brown trout could be putting redds in poor habitat; I hope Atlantic salmon don't do the same.
C: Brown trout have re-used Pacific salmon redds in other areas, Atlantic salmon could do same.
C: Redds are not deep though, and are vulnerable to scouring.

Considerations Related to Aquatic Connectivity in Habitat Suitability Assessments

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Abstract

Fragmentation of riverine habitats has been implicated as a primary driver of the extirpation of Atlantic salmon in Lake Ontario and their decline in many other parts of their range. While the effects of stream fragmentation on spawning migrations are widely recognized, other life stages (e.g. parr) also require access to a variety of habitats for feeding and refuge opportunities. Stream connectivity has traditionally been considered during restoration efforts of Atlantic salmon, but the paucity of metrics to measure and model connectivity have left managers with little choice but to include connectivity in a qualitative manner that does not account for cumulative effects of multiple barriers. More recently, metrics have been developed to quantify stream connectivity, but field validation of such approaches are largely lacking.

We assessed the relevance of a commonly-used approach (Dendritic Connectivity Index; Cote et al., 2009) to the fish species and community of Lake Ontario watersheds, using existing OMNRF fish community data as well as available GIS layers that identified fish barriers, landscape cover and stream site characteristics (e.g. stream width, elevation). Multivariate statistics that accounted for other confounding environmental factors indicated that connectivity influenced stream fish community structure ($P < 0.005$; Figure 1), but the strength of the relationships were secondary to other environmental factors such as land use and stream width. Species richness ($P = 0.022$; Figure 2) and the abundance of some species (e.g. rainbow trout; Figure 3) were also positively linked with the degree of connectivity. Due to poor representation, Atlantic salmon were not included in the analysis. As aquatic connectivity is an important factor in shaping Ontario fish communities, consideration should be given to incorporating it into performance assessments of release sites and during restoration initiatives.

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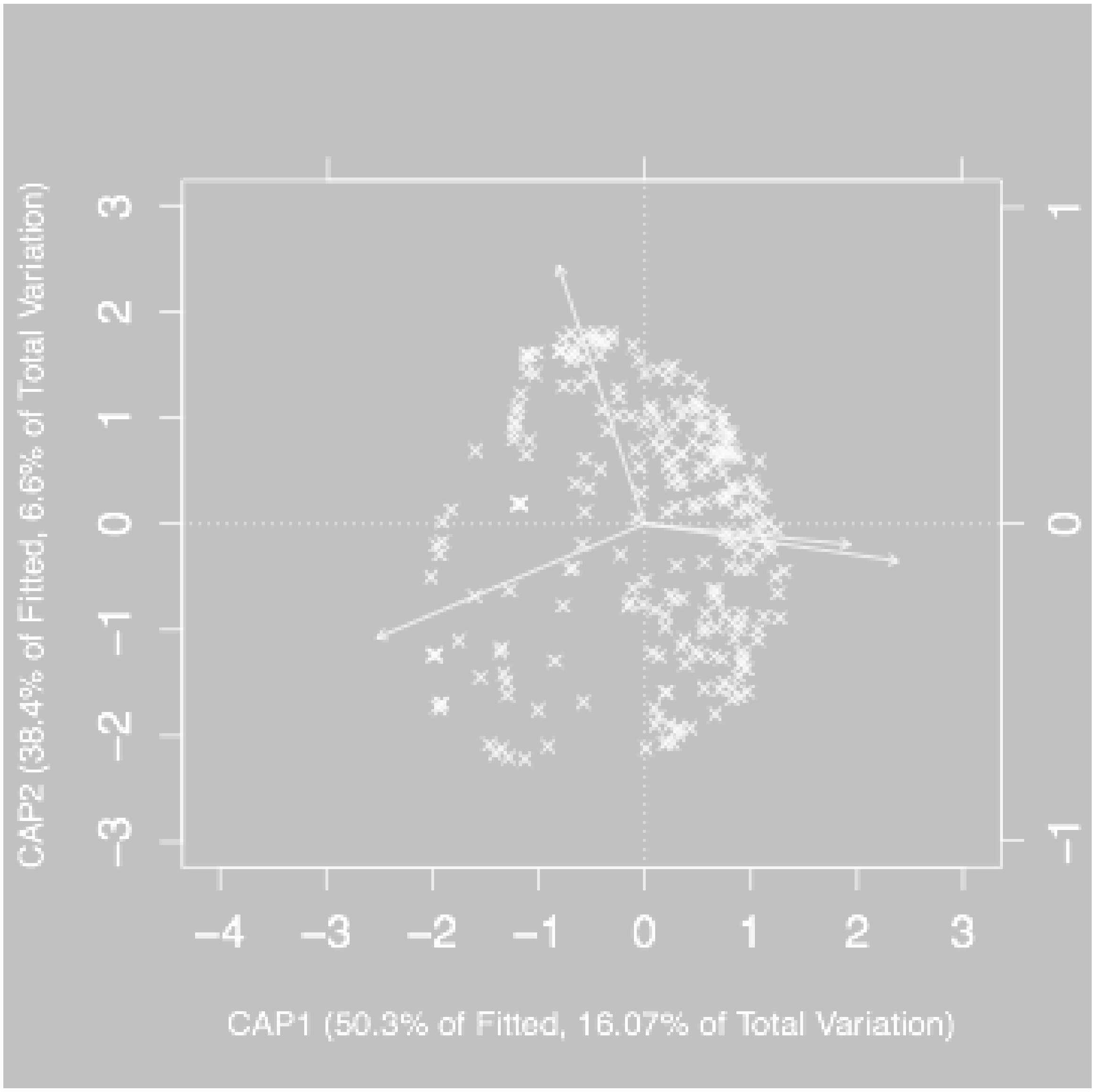

Figure 1. Distance-based redundancy analysis of Lake Ontario fish community structure Dendritic Connectivity Index (DCI) and environmental variables. Redrawn from Mahlum et al. (Canadian Journal of Fisheries and Aquatic Sciences, in review).

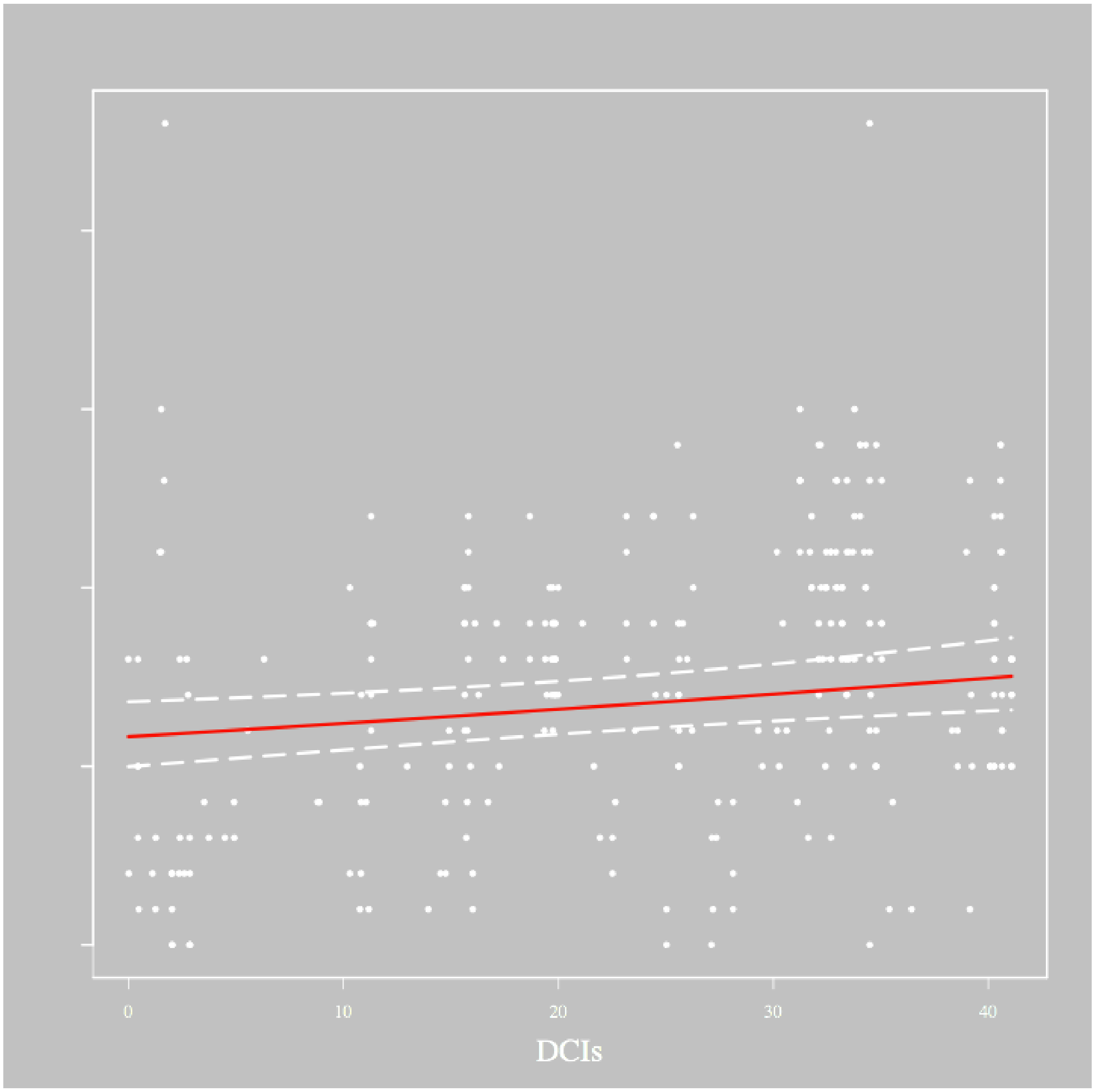

Figure 2. Relationship between Dendritic Connectivity Index (DCI) and fish species richness in Lake Ontario tributaries. Correlation was significant (P = 0.022). Redrawn from Mahlum et al. (Canadian Journal of Fisheries and Aquatic Sciences, in review).

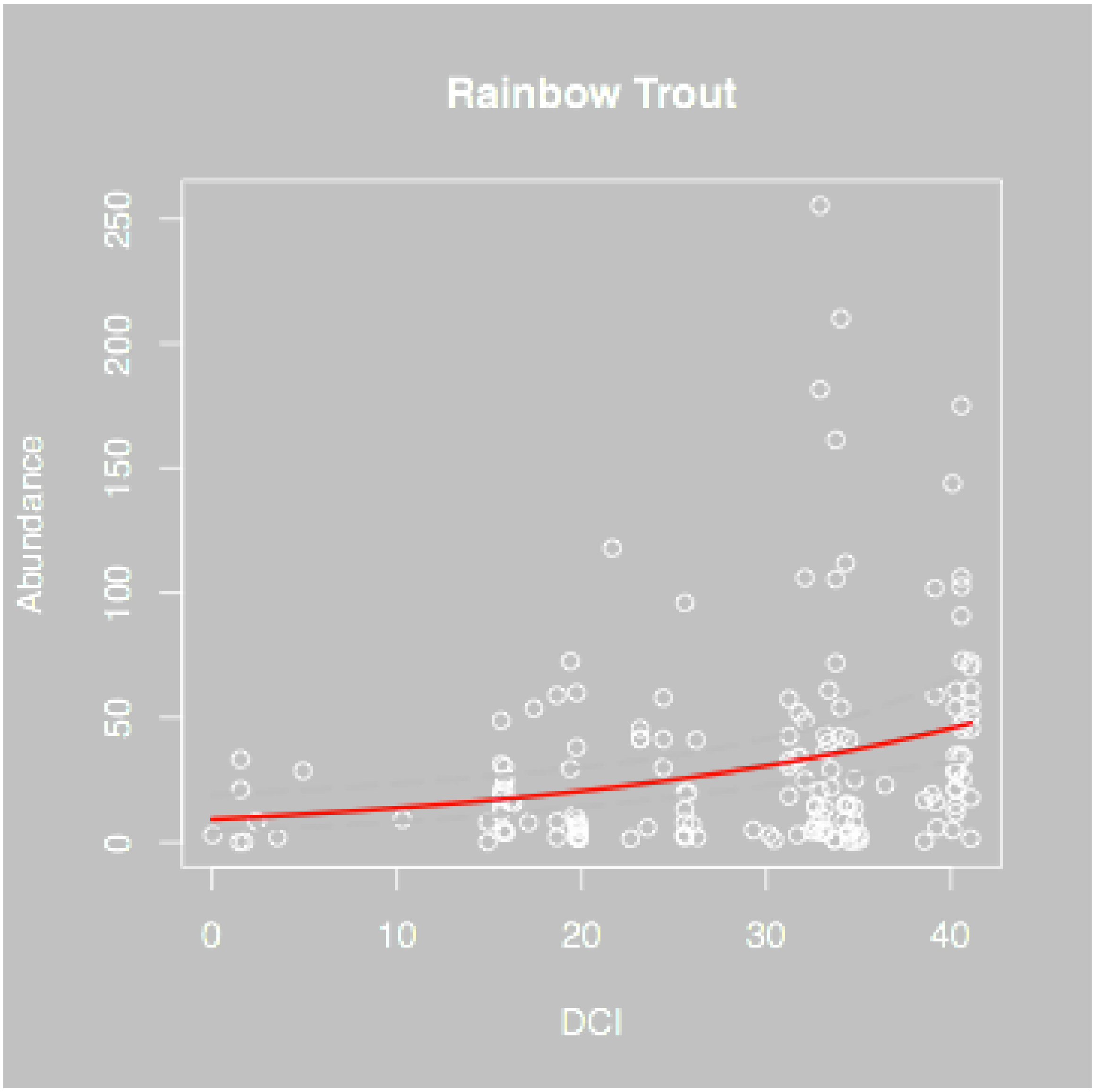

Figure 3. Relationship between Dendritic Connectivity Index (DCI) and rainbow trout abundance in Lake Ontario tributaries. Redrawn from Mahlum et al. (Canadian Journal of Fisheries and Aquatic Sciences, in review).

General discussion notes

Q: Are there times when it's healthy in a system to have partial or temporary natural blockages of tributaries? For example, beavers can lead to population complexity where adults can and can't get above a barrier, which increases growth and makes a more stable population overall. Ice jams can back up water and help systems.

A: Index is really just a structural property of the system; natural fragmentation such as a waterfall is not bad. The system adapts or evolves to deal with it.

Q: Are folks applying DCI to prioritize barriers? For example, using it to guide reconnecting systems?

A: Yes, to figure out optimal gains combined with cost factors to prioritize projects.

Q: Could you use other habitat values than stream length in DCI? More biologically meaningful in some cases? GIS applications will help.

A: Never ran analysis for Atlantic salmon as a single species, didn't have the numbers.

Landscape Factors Influencing Stocking Densities of Atlantic Salmon

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Abstract

Since 2006, Atlantic salmon have been stocked into reaches of several Lake Ontario tributaries following the site level criteria outlined in Stanfield and Jones (2003). These criteria do not consider the landscape criteria of catchment size, geology, slope or land-use that have been shown through several studies to be primary constraints to salmonid survival (Stanfield and Kilgour, 2006, 2012; Stanfield et al., 2006). In particular, these papers demonstrate a strong threshold effect to a metric of land use disturbance (LDI) whereby streams with values > 9.0 are deemed largely unsuitable for salmonids, < 9.0 and > 6.6 are suitable for rainbow trout, and < 6.6 are suitable for brook trout. This paper applies these surrogate thresholds to evaluate the suitability of stocked sites for rearing of Atlantic salmon and the degree to which densities of fall fingerlings are correlated with LDI values.

Stocking site locations obtained from FSIS were mapped onto stream segment LDI values based on an older (1995–1996) land cover layer that provided a minimum disturbance value for each stream segment (ALIS, 2002). As a first cut, most stocking sites that received spring fingerlings were located on segments with the lowest LDI values. However, some stocking events were carried out on segments with high values that would not be expected to result in survival (Figure 1). Several stocking locations on the west branch of Duffins Creek are into segments that exceed or are approaching the LDI threshold for salmonids. Note that most stocking sites on all the streams are upstream of the first permanent barrier to rainbow trout migration.

Atlantic salmon density data were compiled from three major sources and two collection methods that provided a total of 78 electrofishing sites to evaluate stocking success. Survey results were summarized as the mean density/100m^2 for all survey years and compared to both yearly stocking locations and LDI values. A limitation of the comparison is that Atlantic salmon spring fingerlings are stocked throughout a segment, with lengths presumably related to both availability of habitat and fish. The length of the stocking site is not recorded, so comparisons to electrofishing surveys cannot reliably be associated with stocking data. This analysis presumed that electrofishing data > 1 km from a stocking site were not reliable. Most of the stocking on the Humber River is to low LDI segments well-upstream of barriers, but only one electrofishing site's data are available as a comparison (Figure 1). This site exceeded the target densities for Atlantic salmon.

Credit River

Atlantic salmon densities exceeded the target density of 5 fish/100m^2 at all of the locations where data were available, and densities were greater than 100 fish/100m^2 at

many sites. However, there are many areas on the Credit River where fish are stocked and no assessment data are available. Further, there is a strong downstream tendency for LDI values to increase above the threshold as the river and its tributaries approach Mississauga. Clearly, both stocking and assessment have targeted the optimal habitats for Atlantic salmon in this watershed and a broader evaluation of suitability is warranted.

Duffins Creek

Electrofishing data for Duffins Creek provided a more thorough evaluation of the system, largely due to the availability of data from TRCA. Not surprisingly, there was much greater variability in stocking survival throughout the system. Similar to the Credit, one area on the East Duffins near Claremont routinely recorded densities > 30 fish/100m^2. However, sample sites on East Duffins and Ganatsekiagon Creek routinely captured few to no Atlantic salmon. Further, densities were typically below the target within a short distance below the prime habitat (West Duffins and Ganatsekiagon, Figure 3).

Cobourg Creek

Partly as a result of a master's project, Cobourg Creek has a comprehensive longitudinal assessment of Atlantic salmon survival from stocking (Figure 4). Highest densities are observed in the reaches upstream of Dale Road on the East Cobourg and Baltimore Creek tributaries. With the exception of one small section of East Cobourg, few Atlantic salmon are observed below the confluence of these two tributaries even though the LDI ratings remain suitable. Minimal stocking and no assessment has been carried out on the west branch of Cobourg where LDI values are deemed moderate.

Conclusions

To date, with a few minor exceptions, Atlantic salmon are being stocked into segments that meet the optimal landscape criteria that would be expected to be suitable for survival. The density data support this contention with many sites greatly exceeding the minimum density targets. However, a cursory assessment of the Lake Ontario tributaries indicates that such habitats are becoming increasingly rare and few systems maintain these LDI ratings from headwater to outlets. The decline in densities with distance downstream on Cobourg Creek is disconcerting and suggests that a more thorough investigation of the suitability of the target streams from a landscape perspective is warranted. The assessment should also consider the overall effect of fragmentation on stream suitability as the cumulative effects of this and land-use is of increasing concern (Cote et al., 2009; Stanfield 2013; Mahlum et al., in review). The need for such an assessment is especially justified given the fact that the existing landscape analysis is based on nearly 20-year-old data and that future planning scenarios call for populations in the Greater Toronto-Hamilton area to double again by 2020.

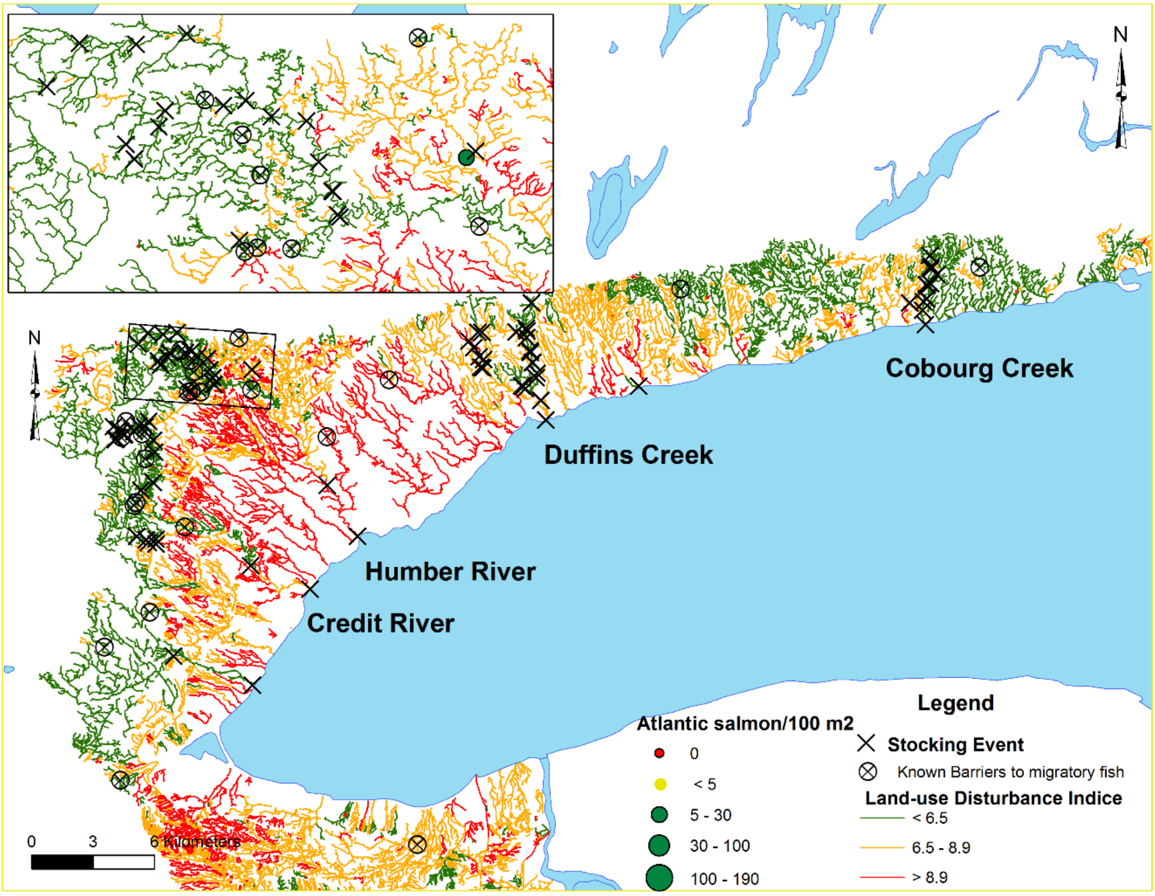

Figure 1. Atlantic salmon stocking locations in comparison to a land-use disturbance index prediction of stream suitability and location of the first upstream barrier to rainbow trout migration.

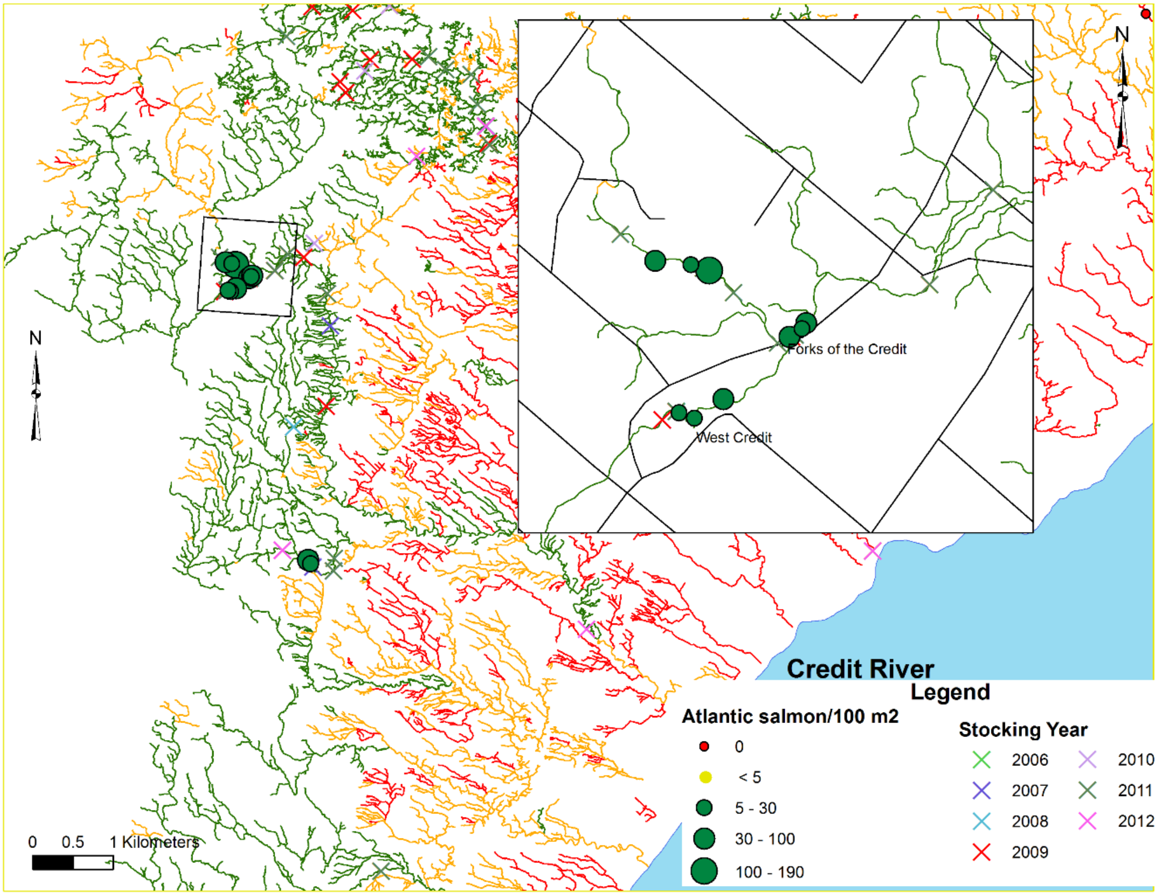

Figure 2. Mean density of Atlantic salmon/100m^2 for the Credit River in comparison to a land-use disturbance index prediction of stream suitability.

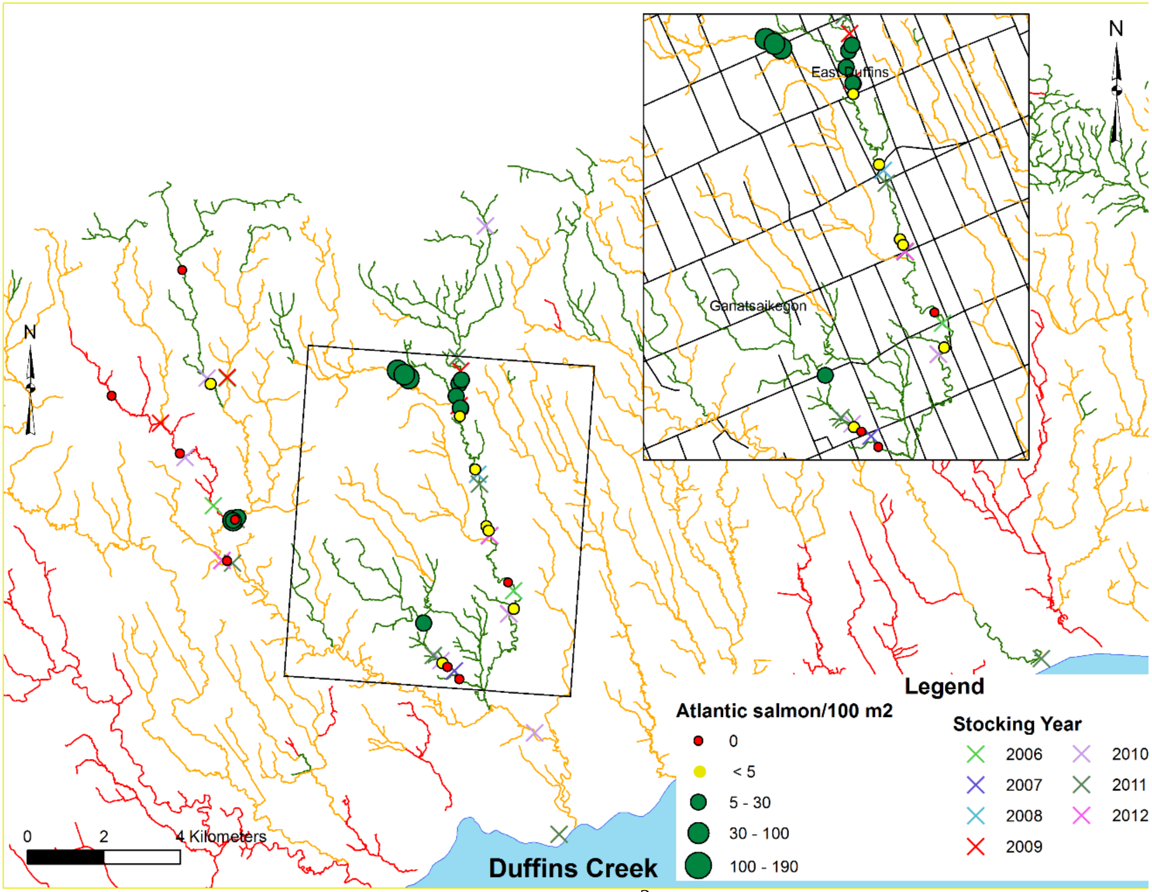

Figure 3. Mean density of Atlantic salmon/100m^2 for Duffins Creek in comparison to a land-use disturbance index prediction of stream suitability.

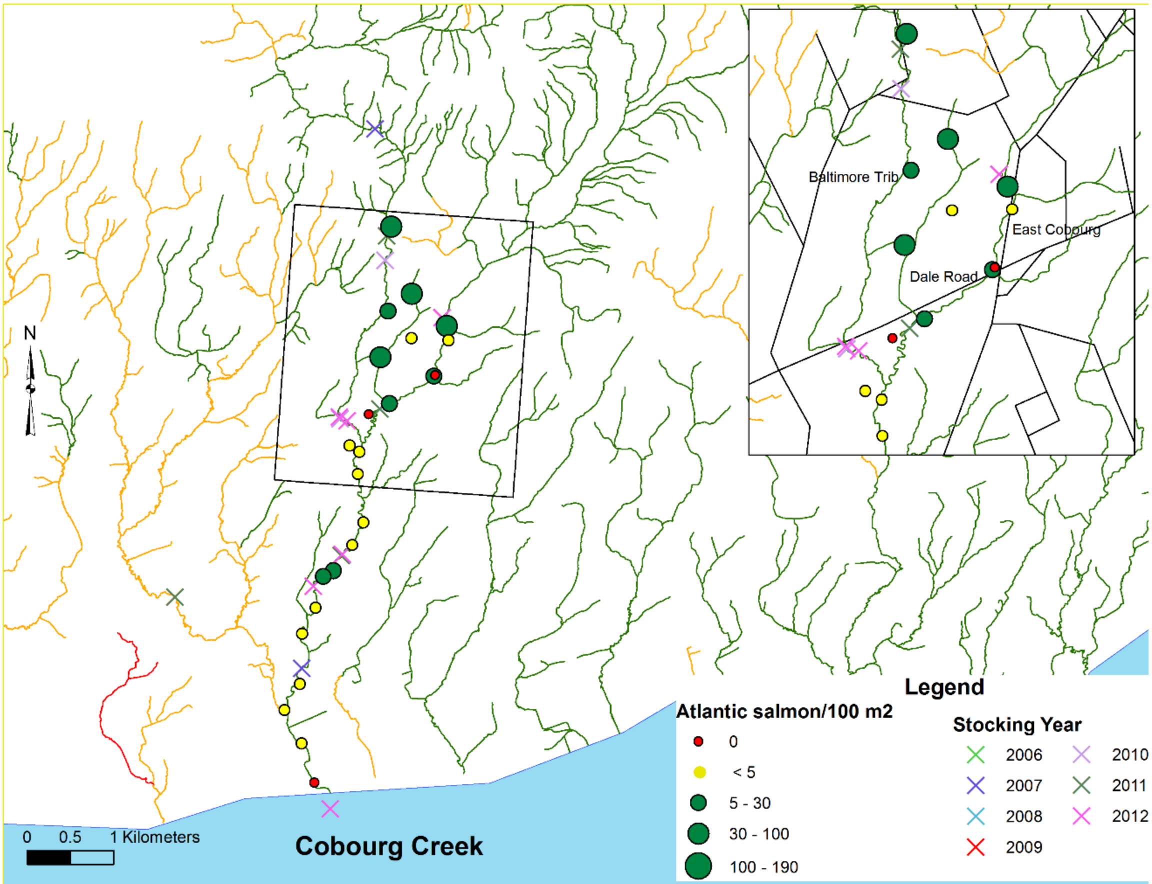

Figure 4. Mean density of Atlantic salmon/100m^2 for Cobourg Creek in comparison to a land-use disturbance index prediction of stream suitability.

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General discussion notes

Q: If we put stock into the LDI, what is best for Atlantic salmon?
A: To the east, or with municipalities willing to protect watersheds.

Q: This is only one benchmark, are other factors available?
A: Some are available on individual tributaries.

C: We can also use Atlantic salmon as a signature species to guide, restrict, and inform development and to use it to guide habitat restoration and priorities.
C: Credit River is an example of trying to provide guidance using metrics like the LDI and minimize impacts.

Q: Is there another iteration of modeling, updating information from early 2000s?
A: Not without resources.

C: Some of the good LDI is above the Escarpment on the Credit and western tributaries, so it is indirect help for Atlantic salmon and helps brook trout and is also protected by the Escarpment Act.
C: Yes, we need to groundtruth where green really is and if it's really good habitat.

Q: What are next steps connecting LDI with DCI?
A: We talked in past about the need for a decision support system to guide restoration, habitat restoration.
C: From a consulting perspective, you need defensible criteria that can be used to prevent death by small cuts.

Restoring Biodiversity and a Valuable Fishery: Atlantic Salmon Reintroduction into Lake Ontario

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Abstract

A proposal is being developed to partner with industry, government, and special interest groups to scientifically evaluate Atlantic salmon performance in Ontario streams and develop best practices for stock selection, hatchery rearing, and release timing and locations. The purpose of this talk is to make workshop participants aware of the work and to seek comments, support, and potential collaborators.

General discussion notes

Q: Can the experiment stock overlay on existing stocking sites?
A: To some extent. Not for e-DNA, but hydroacoustic experiments would work. We want to get into better sites but were sort of pushed out by production stocking in Phase 1, at least on the main tributaries. Duffins should have been okay. Off year for OMNRF stocking?

Q: Clarification: how much time from stocking to assessing parr?
A: Five months later. We were supposed to follow up further, but only at two sites on Duffins (with and without rainbow trout) a year after release; lower numbers than previous fall.

Q: How big were the stocked fry?
A: One gram in the middle of May.

C: Look at timing and handling before stocking. Aim for after black fly hatch, two to three weeks after hatch at the latest.
C: We were confident on handling, followed OMNRF protocol; ditto for the timing of stocking.

Facilitated Discussion II

Knowledge gaps

- Do we need to prioritise getting these “missing” natural heritage tools defined for these tributaries?

- Do we need to enhance monitoring / assessment to fill in gaps?

- Are there critical questions that need to be addressed now?

    - In general, most sites are good, but if you want to go to other streams or reaches you can use this tool, but might want to first evaluate other benchmarks so we have a more complete understanding of potential survival / returning adults. From an overall life history perspective, these sites might be good for stocking but other reaches are used by other life stages that are sub-optimal.

- We need to look at the entire watershed in terms of whether we are in the correct systems in terms of long-term rehabilitation of the species. Are there other watersheds which, as a whole, might be more effective at re-establishing ATS?

- Will these watersheds remain “best bets” given future human population growth?

    - Development, climate change, and similar factors are recommended to be considered as future scenarios, but this group seems to feel that is for managers to decide is this is a priority to consider.

- Better habitat data are needed at appropriate scales.

- We need to re-visit habitat analysis for the chosen sites, since it has been 20 years. Sites chosen only for early life stages never considered fall fingerlings and smolt. We need to consider fish community for these other life stages.

- We need to evaluate fall and overwinter habitat. We used to assume if fry survived to fall fingerling and yearling then habitat was okay. No evidence in Massachusetts shows that frazzle ice or jams are an issue for smolt.

- Michigan DNR does a biological assay of a sample of fishes for size (length & weight), dissection, and fin condition before they are stocked to have some idea of what shape they are in before they are released.

Management implications

- How do you "change" a land use disturbance index (LDI) on a stream to facilitate restoration?
  - We used to direct to where restoration work should occur, or to identify priority areas that should be avoided for development. Low LDI areas have no non-native salmonids, so these may be are areas to prioritise for stocking if other factors such as substrate and gradient are suitable.
- Is it appropriate to use other salmonid as predictor of ATS potential success? In other words, is there good production in these watersheds that contain "bad" LDI in lower reaches?
  - There is always potential for extreme events that might be problematic for multiple life stages. Analogous to risk assessment, we must consider the full suite of factors to decide which rivers are "best" for both current and future. The original process to select streams did not include landscape processes. We must consider multiple life stages in determining the streams with greatest potential for rehabilitation.
- We assume upper reaches are utilised by fry, middle reaches by fall fingerling, and lower reaches for yearlings, but has this been evaluated?
  - If we are stocking fall fingerling in sub-optimal habitat and that is why we have poorer survival, then maybe we have a flawed experimental design rather than assessing life stage in an unbiased way. The recurrent theme is that we need to consider all life stages before we draw conclusions about which life stage is surviving best and the quality of fish. For example, stocked yearlings show higher incidence of fungal infection, so are they predisposed not to survive as well?

Smolt Development in Anadromous and Landlocked Atlantic Salmon

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Abstract

Smolt development in anadromous Atlantic salmon has been the subject of extensive research over the last twenty years. The parr-smolt transformation includes changes in morphology, imprinting, physiology, and behavior. Environmental regulation of all of these appears to be similar with behavioral changes and imprinting having the added component of environmental cues such as temperature, flow, and turbidity that act as “releasing factors.” In general, juveniles with a fork length of 12 cm or greater in January will become smolts in spring. Photoperiod is the primary determinant of the overall timing of smolt development. Artificial lighting such as security lights can interfere with normal smolt development. Temperature can only slightly modify the timing of the increase in physiological smolt development but has a large impact on the loss of smolt characters which is related to degree-days (cumulative average daily temperature) experienced from the peak of smolt development. Downstream migratory behavior is strongly correlated to increased temperature; a temperature threshold of 10 °C has been proposed but may also be related to the degree-days experienced. Imprinting appears to take several days to two weeks to be fully developed which has implications for fish that are transferred from hatcheries into rivers when returning adults to the river (rather than just ocean or lake survival) is the goal.

There is much less information available on smolt development of landlocked Atlantic salmon. A “common garden” experiment of Connecticut River (anadromous) and Lake Sebago (landlocked) strains of Atlantic salmon indicates that increases in gill Na^+, K^+ -ATPase activity, salinity tolerance, and circulating levels of cortisol occur in both strains but to a lesser degree in the landlocked strain. Based on hatchery and field studies, the size threshold of smolting appears to be similar for the two strains, as is the timing of physiological and behavioral smolt development. Although increased gill Na^+, K^+ -ATPase activity and salinity tolerance are less important to landlocked salmon, the timing of smolt development and migration is likely to be critical to restoration and is deserving of increased research.

General discussion notes

C: Fish are not smolting; fish are the wrong size.

Q: Is there an ecological or evolutionary penalty of maintaining high level of -ATPase production for land locked populations?
A: Yes, if expression was not evolutionarily costly, it would remain.

Q: What is the window of smelting: is it distance-dependent between 1–100 km?
A: In 400 degree-days, smoltification is done from peak. Depends on speed of migration: how far can they move in 400 degree-days?

Q: Does size affect timing window with all else being equal?
A: No, but the smallest and largest smolts do poorly. 18–22 cm, the middle of the bell curve, do best. These data are for anadromous fish. Likely, predation effects the smallest fish while the largest smolts have a lower migration inclination.

Restoring River-runs of Landlocked Atlantic Salmon in Lake Champlain

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Abstract

Landlocked Atlantic salmon were extirpated from Lake Champlain in the early 1800s. Management actions, including sea lamprey control and stocking yearling smolts, provide for a popular salmon fishery in the lake. However, spawning runs of salmon to rivers (river-runs) have remained low. In 2010, we initiated a long-term adaptive management experiment focused on increasing river-runs of salmon to enhance in river fisheries and restore natural populations. Examples of ongoing experiments include:

1. Identifying indicators of smolting to optimize timing of stocking to periods when fish are likely to imprint on rivers.

2. Evaluating alternative hatchery rearing methods.

We identified gill Na^+, K^+ -ATPase activity during the spring as a potential indicator of smolting for landlocked salmon but activity levels were much lower than observed in anadromous populations. We also observed a large impact of alternative hatchery rearing on adult returns to a focal river in 2013. There was a fourfold increase in adult return rate of smolts reared in river water with an ambient temperature profile compared to smolts reared on well water with an increased temperature profile. Our results demonstrate potential for rapid increases in river-runs using hatchery smolts combined with targeted research and adaptive management.

General discussion notes

Q: You had lower returns of well-reared fish; was this a quick migration out before assessment?

A: We are working with fishers and returns of fin-clipped fish. We use this data to confirm or refute lab results.

Q: Would a viable option be to blend creek water with well water to encourage early smolting?

A: The results are too preliminary. Not sure if the extra work is worth it. A more natural system is preferable. It may be a good opportunity for an experiment.

C: As long as temperature manipulation doesn't compromise production of large enough fish to smolt in January.

A Perspective on Atlantic Salmon Culture and Stocking

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Abstract

Lake Superior State University (LSSU) in conjunction with Cloverland Electric Cooperative and the Michigan Department of Natural Resources (MDNR) Fisheries Division has been making great strides in introducing Atlantic salmon, one of the world's premier sportfish, into the St. Mary's River. As of now, it is the only successful stocking program in the Upper Great Lakes with a fishable return in northern Lake Huron and the St. Mary's River.

The LSSU Aquatic Research Laboratory (ARL) has been rearing and stocking Atlantic salmon into the St. Mary's River in Sault Ste. Marie (Chippewa County), Michigan since the mid-1980s. The first stocking was in 1987 with yearling smolts, and since then just over 767,000 Atlantic salmon have been stocked at an average of 30,700 per year, averaging 178 mm in length. Fall fingerlings were stocked for a few years in the mid-to-late 1990s but the returns were very poor.

The university's primary mission is not to stock fish, but rather to use the hatchery as a training tool for undergraduates. Students are trained in all aspects of hatchery work, from collecting returning adults from the St. Mary's River for egg-take, to stocking fish 18 months later, and everything in-between. Students handle all aspects that are required in rearing (yearling) production fish.

In the early years, the ARL had some difficult times, losing over 90 % of its eggs or fish because of a lack of knowledge or understanding of Atlantic salmon and how to rear them. It took us about 10 years to begin to understand the fish and still today the ARL staff will not lay claim to knowing it all on them; Atlantics still give staff problems from time to time in the hatchery.

From 2004–2013, ARL fish were a lot healthier at stock-out and the returns rates showed it. During this time, we stocked an average of just under 29,000 spring yearlings annually with average lengths of just over 192 mm. Atlantic salmon stocked by LSSU have consistently provided a better catch per number of fish stocked (return-to-creel) than any other salmonid stocked in Lake Huron (Johnson, 2012). After the alewife collapse in 2004 in Lake Huron, the return rates for Atlantic salmon averaged about 5.5 %, which is nearly 10 times the return-to-creel for steelhead during the same period (Johnson, 2012). The same increase is shown from our broodstock collection over the year (we use a gill net in the discharge of the hatchery in the St. Mary's River) as shown below. The fish are stocked in the first week of June if the river is at least 8 °C; if not, the fish are held until it is 8 °C.

Since 2003, the ARL has been self-supporting in its egg-take needs (and getting enough eggs for the MDNR, when needed) through harvesting eggs from returning fish in the St.

Mary's River. We feel the fish we collect each year are a land-locked strain from West Grand Lake in Maine, as this is the strain we have worked with the most. We did work with Penobscots from the USGS Tunison Lab in New York and Sebago from Maine, but we had very poor survival at that time and we stocked very few fish.

How are we successful? This is a question we hear a lot, and here is what we think:

- Fish are reared in the same water in which they are stocked.
- Fish are held until they are 1½-year-old smolts.
- We now have a better understanding of the fish–our biggest reason for success.
- St. Mary's River is a dynamic system that can accommodate a great variety of fish.
- The biggest reason why is time to work with the fish and to get to understand them.

General discussion notes

Q: Were the eggs treated eggs for thiamine deficiency?
A: Yes, 2 ppm thiamine treatment and some in ambient for comparison.

Q: A return rate at 1 %; can this be better assessed?
A: We only do limited amount of netting for aquaculture purposes, no total assessment. Fish can get by the hatchery, but upstream migration is limited by a fence.

Q: Is there a targeted fishery?
A: Yes, 3–4 guides, reported to have 19-fish days.

Q: Is there an index for the catch rate?
A: No, we do not monitor catch rates at the University, but it is reported in Johnson (2012) provided in the binder.

Size and Time of Release at Stocking (Question 3a)

Evan Hall, Lake Ontario Management Unit, Ontario Ministry of Natural Resources and Forestry

Abstract

Fish size and the timing of release are likely important factors that determine the survival and success of stocked fish. Stemming from presentations in this workshop as well as findings in grey literature, a hypothesis exists that either the size or timing (or a combination of the two) of Atlantic salmon being released may be a factor which is contributing to low adult returns.

A summary of the time of year (month) as well as the average weight in grams was provided as reference material in order to facilitate an informed discussion around the subject (Table 1). Furthermore, a question was posed to the out-of-province experts seeking input on the size and time of release in their respective jurisdictions. Although this question was not explicitly addressed by each expert, the general consensus that pervaded some facilitated discussions is that the later life stages are being stocked at insufficient condition (both in terms of size and in terms of health) and that the timing of their release is not conducive to successful development in the stream.

Life Stage	**Feb**	**Mar**	**Apr**	**May**	**June**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
fry			0.18	1.37	1.28					1.18
fingerling			2.26	1.72	1.43	7.38	9.18		1.69	
yearling	15.50	18.30	25.74	42.20	78.34		12.08	9.38	16.40	27.24
sub-adult							126.9			126.9

Table 1. Summary of average weight (g) of each life stage of Atlantic salmon Stocked over the last four years (2010–2013) and the timing (months) that stocking occurred.

Predicting the Number of Atlantic Salmon Smolts in the Credit River based on Stocking Size

Jim Bowlby, Lake Ontario Management Unit, Ontario Ministry of Natural Resources and Forestry

Abstract

The objectives of this presentation are:

1. To review data from OMNRF studies (Stanfield and Jones, 2000, 2003) that compare the effectiveness of stocking Atlantic salmon fry and spring fingerlings.

2. To use overwinter survival (Bowlby, 2014, this workshop) to predict the number of Atlantic salmon smolts stocked (in the Credit River) as fall fingerlings and spring yearlings and compare results with predicted spring fingerling smolts (Bowlby, 2014) and estimated smolts from smolt trap (Desjardins, 2014).

Stanfield and Jones (2000, 2003) found that Atlantic salmon stocked as spring fingerlings (post-feeding age->0 juveniles) in Lake Ontario tributaries were slightly larger and had more than twice the survival of fish stocked as fry (Table 1). Based on these results and fish culture issues with raising fry, OMNRF chose to proceed with spring fingerlings, rather than fry for Atlantic salmon restoration in Lake Ontario.

Parameter	Fry	Spring fingerling
Stocking weight (g)	0.2	0.7
Fall length (mm)	95	99
Fall weight (g)	9.4	9.7
Fall density (m^{-2})	0.07	0.16

Table 1. Comparison of growth and density in fall for Atlantic salmon stocked as fry and spring fingerlings in Lake Ontario tributaries (Stanfield and Jones, 2000, 2003).

I predicted the number of Atlantic salmon smolts in 2011 from fall fingerling and yearling stocking in the Credit River by applying the life history model and overwinter mortality presented in this workshop by Bowlby (2014). The sizes of stocked fall fingerlings and yearlings were available only as the mean weights, rather than size distribution. For fall fingerlings, I developed a relationship between expected percentage that would smolt at age-1 and the mean weight at stocking based on the size distributions of age-0 Atlantic salmon in the Credit River and tributaries (Bowlby, 2014). This relationship assumes fish $\geq$ 98 mm would smolt (% smolt = 0.4231 X ln[weight] – 0.6696). The predicted number of yearling smolts from fall stocking ranged 7–14% during 2005–2013 (Figure 1). The remaining survivors were assumed to smolt at age-2.

For yearlings stocked in spring, I developed a relationship between expected percentage that would smolt at age-1 and the mean weight at stocking based on pre-stocking

sampling in 1989 and 2007 (Bowlby, 2007). I assumed a minimum smolt size of 115 mm (17 g) based on observations from the Credit River (Desjardins, 2014) and Hutchings and Jones (1998). This relationship is % smolt = 0.5141 X ln(weight) - 1.1016. The predicted number of yearling smolts from spring yearling stocking ranged 40–70 % during 2005–2013 (Figure 2). The remaining survivors were assumed to smolt at age-2.

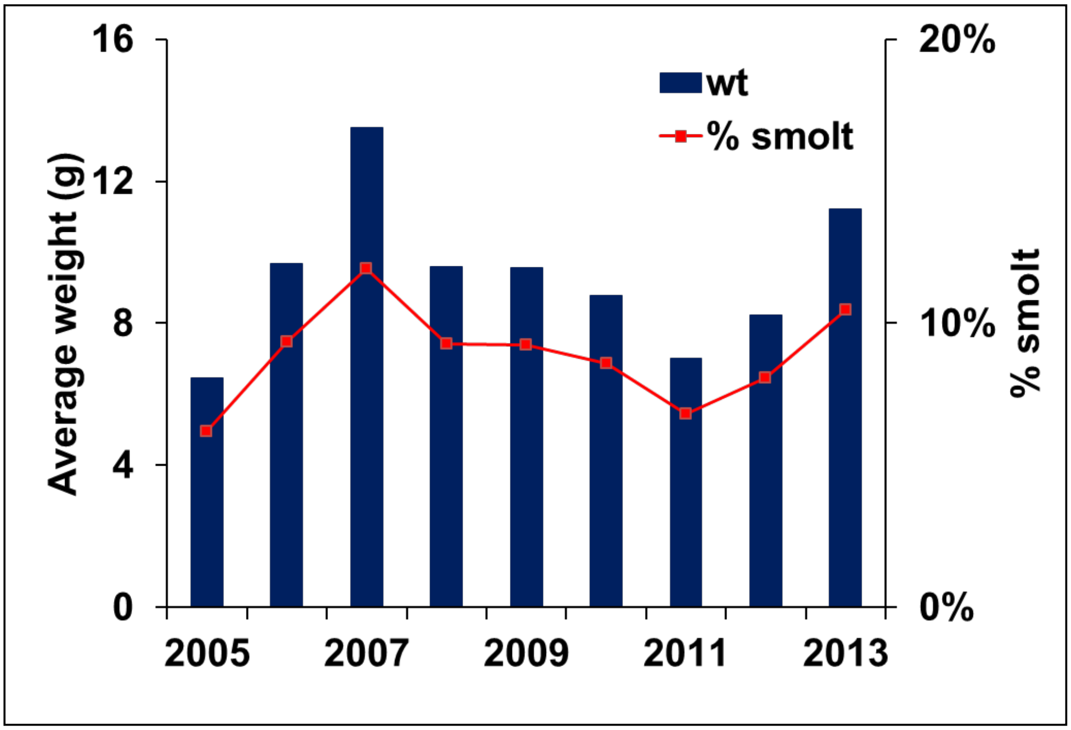

Figure 1. Trend in weight of Atlantic salmon fall fingerlings stocked in the Credit River and expected % age-1 smolts.

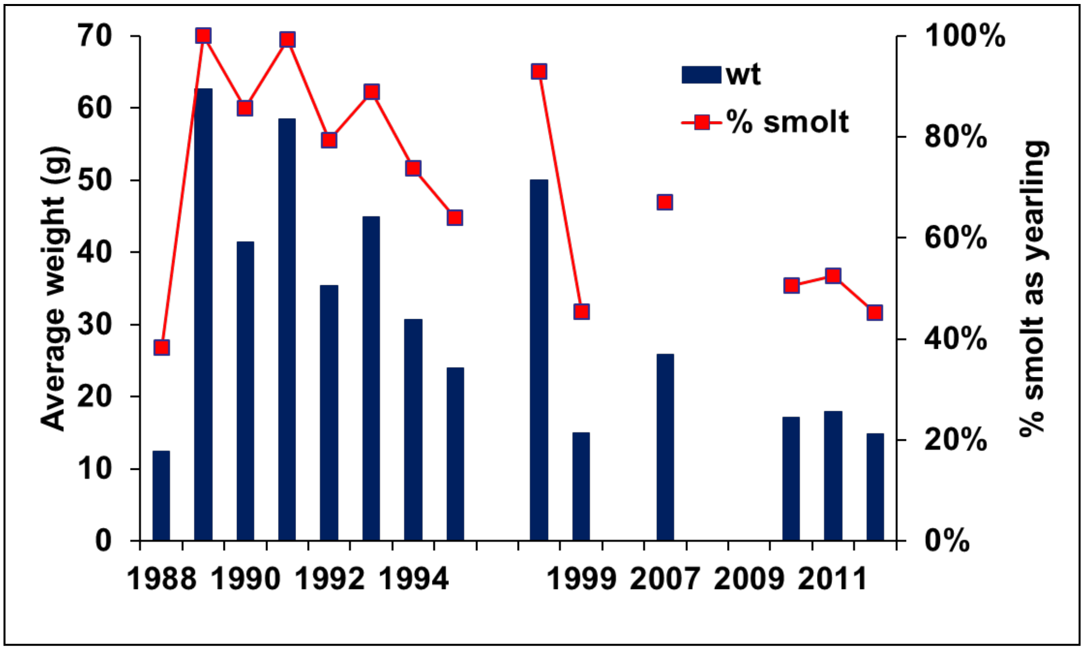

Figure 2. Trend in weight of Atlantic salmon yearlings stocked in the Credit River and expected % age-1 smolts.

The life history model predicted well the number smolts in 2011 from spring fingerling stocking (Table 2; Bowlby 2014). The observed numbers of smolts in 2011 from fall fingerling stocking in 2009 and 2010 and from yearling stocking in 2010 and 2011 were orders of magnitude less than predicted by the life history model (Table 2). One aspect of these results is easily explainable: stocked yearling Atlantic salmon in the Credit River likely smolted prior to setting the smolt and were missed (Desjardins, 2014). However, the low number of observed age-1 and age-2 smolts stocked as fall fingerlings and age-2 smolts stocked as yearlings indicate higher mortality than with the smolts stocked as spring fingerlings. Low survival of fall fingerlings and spring yearlings could be due to either poor-quality habitat or fish community effects. Juvenile Atlantic salmon hide under rocks during daylight in winter. In the Credit River, the habitat contains fewer large rocks and higher fines in the locations where yearlings and fall fingerlings are stocked. As well, fall fingerlings are stocked where the brown trout population is high, and competition or predation from brown trout may be more intense than locations where spring fingerlings are stocked.

Year		Age-1 Smolts	Age-2 Smolts	Total smolts
Spring fingerlings	Stocked	293,524	209,189	
and fry	Model	3,219	807	4,026
	Smolt trap	2,757	1,260	4,017
Fall fingerlings	Stocked	91,814	150,216	
	Model	16,644	5,007	20,967
	Smolt trap	77	512	589
Yearlings	Stocked	45,907	43,140	
	Model	17,512	4,587	22,099
	Smolt trap	181	569	750

Table 2. Estimates of smolts from life history model vs estimated smolts from smolt trap in the Credit River in 2011.

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General discussion notes

Q: Are spring fingerlings and fall fingerlings going into the same stream?
A: Yes, but in different locations.

Q: For yearlings, the smolt trap estimated very few numbers (181) compared to the prediction from the model (17,000), why?
A: Smolt left early and were missed by the trap.

Q: What are we (the OMNRF) going to do?
A: Produce larger smolts that stay longer.

Q: How do you better understand poor winter habitat/survival?
A: Pit tagging studies.

Influence of Stocking Site Distance to River Mouth on Survival of Smolts (Question 4c)

Jerry Smitka[1] and Jack Imhof[2]

[1]Retired Biologist, Trout Unlimited Member
[2]Director of Conservation Ecology, Trout Unlimited Canada

Abstract

Juvenile Atlantic salmon undergo behavioural, morphological, and physiological changes as they undergo the transformation from parr to smolt and move from riverine juvenile habitats downstream to ocean/lake environments. The physiological transformation includes changes to several hormones and at least one enzyme, Na^+, K^+ -ATPase. The transformation appears to be triggered by a combination of photoperiod and the size of the fish by January 1 and controlled by stream temperature. Research on the gill enzyme Na^+, K^+ -ATPase suggests that the activity level of Na^+, K^+ -ATPase increases during the parr-smolt transformation coincident with the onset of downstream migration and the development of salt water tolerance. Based upon the influence of temperature, the research also suggests that fish have 100–200 degree-days (after the peak of gill enzyme activity) to complete the downstream migration before a significant loss of gill enzyme activity initiates a loss of smolt characteristics and behaviour. Loss of smolt characteristics will revert the smolt to pre-smolt levels of gill enzyme activity. The concern in southern Ontario is whether the Atlantic salmon smolt have sufficient time from the onset of smolting to complete the downstream migration given how quickly our streams warm in the spring (and amass degree-days).

Two actions are proposed. First, it is suggested that monitoring of gill enzyme activity be done in hatcheries prior to stocking so that we better understand the dynamics of the physiological changes in relation to size, temperature, and stocking time. Second, it is suggested that we conduct studies to determine if this conversion back to pre-smolt condition can be avoided by stocking smolting fish closer to river mouths during the peak of gill enzyme activity to allow for both imprinting and completion of the downstream migration within the window of physiological change. Perhaps the province should consider monitoring gill enzyme activity at ATS hatcheries so that we can understand the physiological state of the fish at stocking. The hope is to reduce loss and mortality of post-smolt in rivers and increase the potential for lake survival and returning adults.

General discussion notes

Q: What's the window for entering Lake Ontario, different from the smolting window?
A: Smolting window is the priority, then the lake condition window.

C: Design an experiment that includes a comparison of performance/returns of fish released in traditional locations, lower in the drainage area, and net pens. It may involve both batch marking or radio telemetry.
C: Fish that overwinter are going downstream in "2" zone, which is supposed to be too late. Fish seem to be telling us something different. Atlantic salmon are going downstream with rainbow trout.

C: Temperatures at the upper end of drainage are cooler and thus influence the total degree-days. These temperatures can't be extrapolated based on temperatures recorded lower in the drainage.

C: Paired studies were done historically. LaHave succeeded.

Q: Why use older life stages? Younger life stages seem to be better. Avoid trying to manage the smolt stage, then; just stick to stocking spring fingerlings.
A: Don't have enough data to pick spring fingerling stocking over spring yearlings. Not enough adult returns to properly evaluate. Need hundreds of fish returning before picking life stage.

Approaches to Enhancing the Post-stocking Survival and Homing Behaviour of Atlantic Salmon Through Manipulation of Hatchery Conditions

Ryan Zheng, Fish Culture Section, Ontario Ministry of Natural Resources and Forestry

Abstract

The principal goal of the Lake Ontario Atlantic Salmon Restoration Program is to establish a self-sustaining population of Atlantic salmon in Lake Ontario. Achieving this goal will depend upon the success of stocking program which, in turn, will depend upon the suitability of the strains being cultured; rearing practices; when, how, and at what size they are stocked; the suitability of the receiving streams; competition effects; and other factors. This paper summarizes the results of a literature review that sought to identify those things that can be manipulated in the hatchery environment over and above size and time at stocking that have the potential to influence the survival of fish following stocking, the degree to which those fish imprint on the streams in which they are stocked, and their subsequent rate of return to those streams as adults.

Several studies have examined the potential for improving the survival of fish following stocking by enhancing their physical and behavioural fitness at the time of stocking through manipulation of the culture conditions. For example, Pederson et al. (2008) noted reduced swimming performance in hatchery-reared Atlantic salmon and brown trout smolts compared to wild smolts when tested under laboratory conditions and speculated that the reduced physical fitness of hatchery-reared fish may contribute to reduced survival following stocking. Anttila et al. (2006) found that the swimming performance of Atlantic salmon smolts could be enhanced in the lab by exposing them to higher velocities than control fish. Similarly, Cramon-Taubadel et al. (2005) noted body shape differences between hatchery-reared Atlantic salmon smolts and wild smolts and argued that these differences could affect survival following stocking.

Other studies have investigated the role of enriched hatchery conditions on the behavioural fitness of hatchery-reared fish following stocking. Rodewald et al. (2011) were able to enhance the foraging performance of hatchery-reared Atlantic salmon parr on natural prey following stocking by providing variations in water depth, velocity, and direction in the hatchery. More recently, Hyvärinen and Rodewald (2013) produced a 100 % increase in survival two months after stocking of 2-year-old Atlantic salmon that had been reared under enriched conditions for two years prior to stocking. Enrichment was achieved by periodically changing water depth, velocity, and direction and the availability of cover and gravel substrate during the 2 years prior to stocking. Unfortunately, it was not possible to determine which enrichment factors contributed the most to the increase in survival, although the increased initial swimming speed of enriched fish following stocking suggests that the exercise component of the enrichment regime was beneficial. Although this study assessed the benefits of enrichment on Atlantic salmon stocked as 2-year-olds, the technique may also provide benefits to fish stocked at younger stages.

The ability of fish to imprint onto the unique odour of their natal streams (or the streams where they are stocked) is believed to be at its peak when they smolt. Several studies suggest that hatchery rearing conditions can be modified to enhance their behavioural and/or physiological readiness to imprint following stocking. This would be particularly important in hatcheries which receive water from sources other than the streams in which fish will be stocked. The benefits of doing so should be better returns of adult fish to the streams where they are stocked, and should be additional to the benefits of stocking at the optimal size and time.

Most of these studies have focused on the effects of modified rearing conditions prior to the normal smolting period. Duston and Saunders (1992) found that juvenile Atlantic salmon reared under a 12-month photoperiod smolted more effectively than fish grown under 6-month or 18-month photoperiods. McCormick et al. (2007) found differences in the hormonal response of Atlantic salmon parr and smolts to increasing day-length, opening the door to the possibility that photoperiod manipulation in the months prior to the normal smolting window may affect their readiness to smolt and the timing and duration of the smolt window. No effects were found with parr.

Temperature is also known to affect the onset of smolting. There is some evidence to suggest that periods of increasing water temperatures and/or extended periods with water temperatures above 10 °C will initiate smolting (Solomon, 1978). Recently, Zydlewski et al. (2005) concluded that the cumulative increase in water temperature may be a better way to describe how rearing temperature initiates smolting. They found that increasing rearing water temperatures to a suitable level and holding it at or slightly above that level for 650–700 degree-days resulted in effective and uniform smolting in yearling Atlantic salmon.

These findings suggest that manipulation of the hatchery environment may offer a means of enhancing the survival of Atlantic salmon following stocking and strengthening their ability to imprint, resulting in an increase in the number of fish that return as adults to spawn in the streams in which they were stocked. While most of these studies focussed on smolts and pre-smolts, the benefits observed may be applicable to earlier life stages. Going forward, our challenge will be to identify the best bets for implementation in a production-scale facility.

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General discussion notes

C: DFO hatchery Maquac has outdoor simulated streams at a hatchery. They have been having success with smolts increasing survival due to a more complex (naturalized) rearing habitat.

Q: When is it best to start exercising?
A: Don't start until 7 cm. They stay in the gravel until then.

C: We may be able to implement the conditioning fairly easy by dropping the standpipe periodically.

C: See the Peter Gray book about Atlantic Salmon rearing in the UK regarding water velocity. (Swimming Against the Tide-Restoring Salmon to the Tyne by Peter Gray and Michael Charleston, Medlar Press Limited, www.medlarpress.com)

C: Enriched environment is different for small (< 7 cm) fish. They may need cover at small sizes.

Facilitated Discussion III

Knowledge gaps

- Why aren't yearlings surviving?

- As a point of clarification on Bill Ardren's presentation on adult returns and origins, data should be shown scaled to the number of fish stocked at each stage, which might change the relationship. Tom and Chris W. will do so as a product for this report (Appendix D).

- What is the ideal smolt size? We need to know Lake Ontario specifics.

    - Steve presented info on the physiological smolt window, so his smolt minimum size relates to January (12 cm). Others are referring to the time of stocking (14 cm). Survival depends on size, with a median size doing better and smaller more vulnerable to predation. Larger smolt are in poorer shape at stocking. That size need overlays the smolt timing window.

- If fish miss their smolting window, do they stay or die?

    - It is possible that a smolt window never opened that year. If they revert, a window won't open again until next year. They will smolt normally then, but pay mortality price – not an energetic cost per se, just the cost of another year in river.

- What are we trying to do with yearlings? Are we looking for imprinted yearlings that can survive? What do those look like?

- What is best measure – length or weight?

    - This is complicated by condition factor, so one regression may not work. It depends on diet, too, to make better smolts. Lower condition factors may be better; around one or slightly below one gave better returns based on evidence (see Jack). It may depend on the release program, too; stocking early will give fish time to become more wild, which includes losing some condition.

    - Expert opinion is that we need both. Fish Culture will collect both and other info.

Management implications

- Are we looking for fish for people to take out the lake?
    - The general consensus was that we need it. Such a fishery would help with some public perception, and the survival of such fish is also a measure of success for overall restoration.
- The original plan is for restoration, but do we need to think of creating a fishery as a separate objective?
    - The management workshop just needs to know that options are available to do the latter that can mesh with restoration.
- Yearling stocking, based on experience and evidence, can be low-hanging fruit for assessment and adaptive management and increase short term returns. Small changes in hatchery practice can pay off in changes in returns. However, LOMU is currently doing net penning with CNS; catastrophes can happen.
- The current fishery is a one-fish limit in a lake with a size limit, but we are looking to open a C&R fishery in the tributaries next year. We need benchmarks for fish policy for C&R and an eventual harvest fishery.
- Regarding a lake fishery versus a tributary fishery, NY anglers' view is that Atlantic salmon are just another salmonid in open water. They are special to anglers in tributary though.
- The new regulations are for a river fishery. We didn't worry about imprinting for non-natives and they have established themselves, but that is an assumption that has to be tested.
- Some workshop participants are warming up to Bill Ardren's comments about doing a mix of fish for the fishery and for restoration through different methods.
- Some are also warming up to "sea ranching" off the river mouth, not necessarily with pen rearing. This will get fish returning at about same time as fish with stream residency but these will not run up river. Sea ranched fish are found near shore.
    - Sea ranching requires pens as per European methods. Alternatively, Oak Orchard Creek in NY uses direct stocking at the river mouth with a dam 10 mi upstream and a smaller sub-tributary 15 mi long. Fish run up both. They also stock other salmon and trout species. Atlantic salmon are found there through other runs; other species are not impeding them, apparently.

- Breeding success needs more than just fish swimming around; it also needs fit fish that will spawn. Norway sea ranching has shown that fish don't reproduce, but these are domestic fish.

- We need to make decisions for 2014 stocking: where and when. This involves getting the most recent data for rivers to mesh with spring stocking, including degree days for yearlings.

- We need to manage public explanations, dispel myths, and acknowledge challenges and successes in a communications plan.

- Initiating gill enzyme activity is recommended as soon as possible.

- What else should we track in the hatchery?

    - Independent hatchery assessment teams could be run by biologists to work with hatcheries

    - Following Lake Champlain's example, fish that go into net pens or the river mouth stocking could be marked and used for assessment and research.

- LSSU has stocked fish right at smolt size (minimum) and had poor returns. LSSU wouldn't do pens.

- This is a new era with gobies in system. In older days, 30 g fish and 40 g in poorer prey environments were needed.

Lake Effects on Survival of Lake Ontario Atlantic Salmon

Tom J. Stewart[1] and Tim Johnson[2]

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Abstract

Little is known about what influences survival of stocked Atlantic salmon between the time they leave the tributaries and return as spawning adults. Here, we assemble available observations and consider hypotheses describing potential influences on lake survival. The combined observations of relatively-good survival in tributaries but few returning adult spawners suggests that survival of stocked Atlantic salmon in Lake Ontario may be low. Using measured and estimated life stage survival (Jim Bowlby, Ontario Ministry of Natural Resources and Forestry, personal communication) and stocking numbers (average 2009–2012), we estimated the number smolts expected to outmigrate from the major stocked tributaries (Figure 1). Literature values (Roberston, 2005; Johnson, 2012) and OMNRF restoration plan survival targets for lake survival (Miller-Dodd and Orsatti, 1995) were applied to these outmigrating smolt numbers to estimate the expected number of returning adults by stocking tributary (Figure 2). Assessment programs to detect and enumerate returning adults are very limited, but catches at fishways and anecdotal observations of adults suggest only hundreds of fish per year in the Credit River and less than 100 per year in other stocked tributaries. It is likely that lake survival is well below restoration plan target of (2 %) and more likely similar to lower values (0.19 %) observed for wild populations in the Penobscot River, Maine (Figure 2). We examined limited data to evaluate whether apparent poor lake survival might be related to competition with other salmonids, exploitation, or nearshore predation. Concerns have been expressed that surviving Atlantic salmon may compete with other predators for limited prey fish and increase the risk of over-consumption of alewife. Stable isotope values of carbon and nitrogen from adult salmonids suggest that Atlantic salmon utilize resources common to all other salmonid species (Figure 3). However, their presumed lower relative abundance compared to other salmonids combined with a relatively-large isotopic niche suggests that Atlantic salmon do not contribute substantially to consumptive demands on alewife. With respect to exploitation effects on survival, we used the analysis provided in Murry et al. (2010) and estimated that chinook salmon exploitation rate is 5.2 % and postulate that Atlantic salmon exploitation rates are no greater and very likely less than this value as Atlantic salmon are primarily caught incidentally while targeting other trout and salmon species. Such a low level of exploitation cannot account for the apparent poor survival of Atlantic salmon in Lake Ontario. Our predation hypothesis was assessed using an index of nearshore predator density developed from salmonid angler catch and effort statistics for anglers fishing nearshore (water depth < 10 m) during April–June. The index suggests that nearshore predator densities are highest in April and May and decline substantially in June (Figure 4). We hypothesize that outmigrating smolts or stocked

yearlings inhabiting the nearshore during April and May could be subject to high levels of predation, resulting in reduced lake survival.

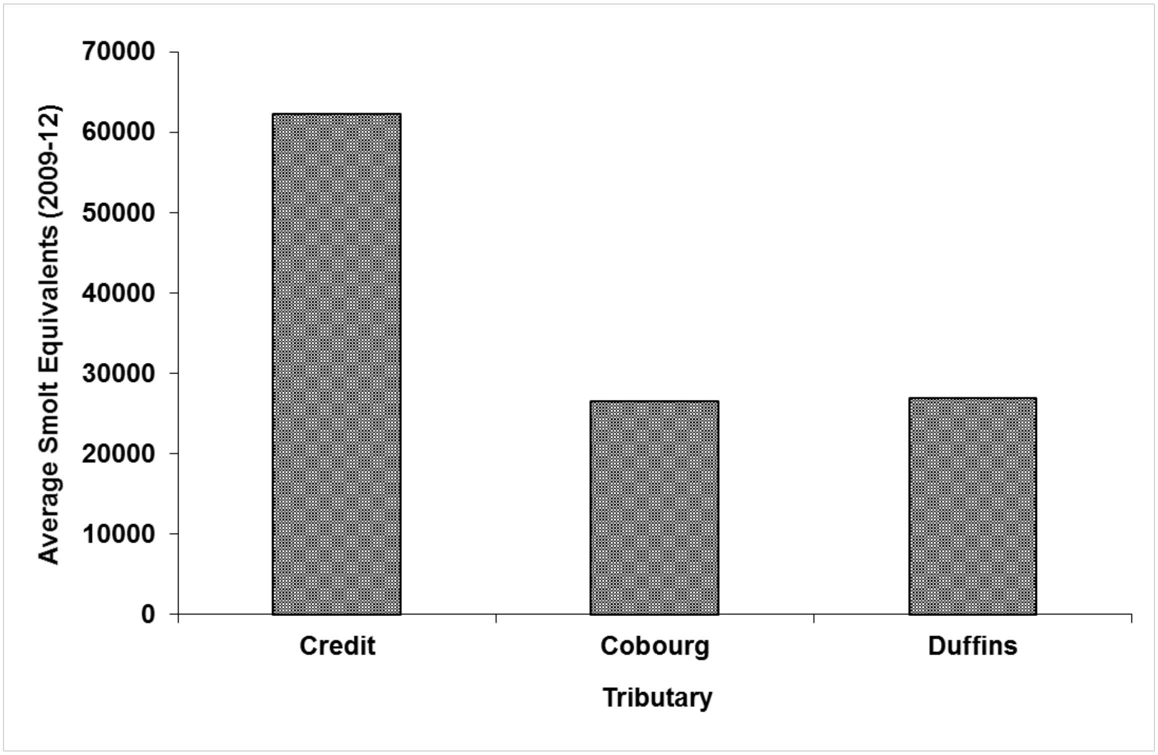

Figure 1. Estimated average number of outmigrating Atlantic salmon smolts for each of the major tributaries stocked with Atlantic salmon in Lake Ontario. Estimates were derived from average stocking levels and estimated tributary survival rates.

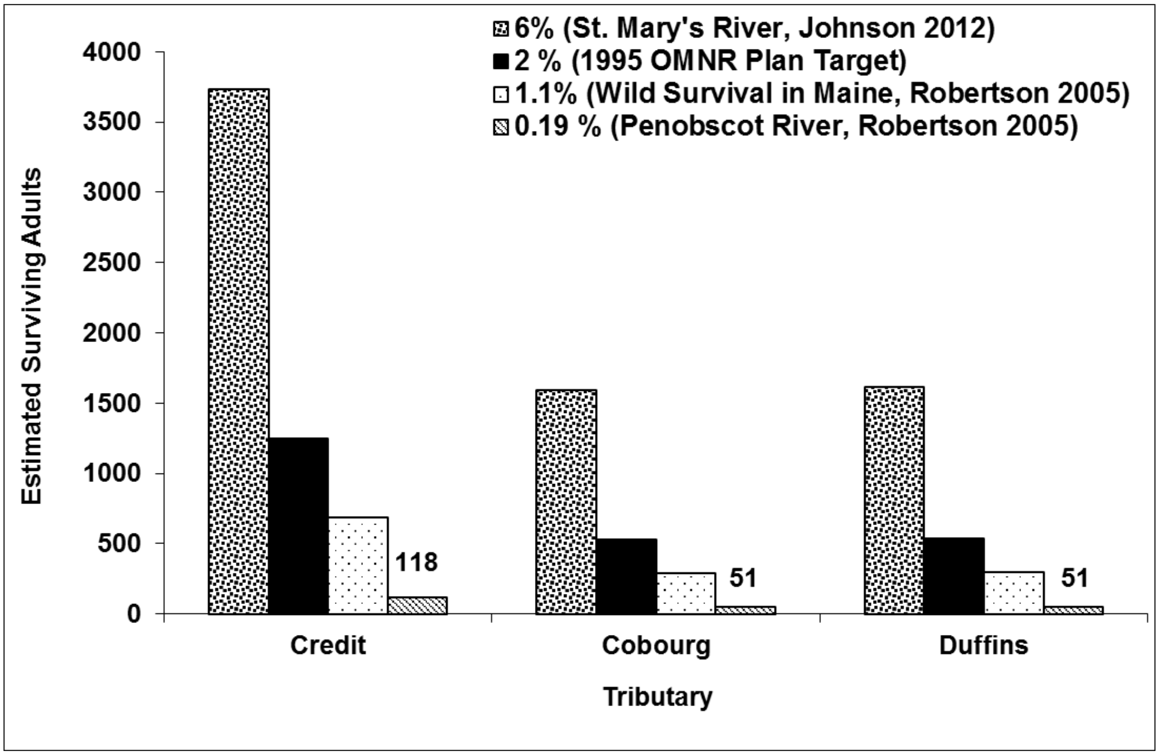

Figure 2. Estimated number of Atlantic salmon smolts returning as adults to each of the major tributaries stocked in Lake Ontario. Estimates were derived from smolt estimates (Figure 1) and literature survival rates.

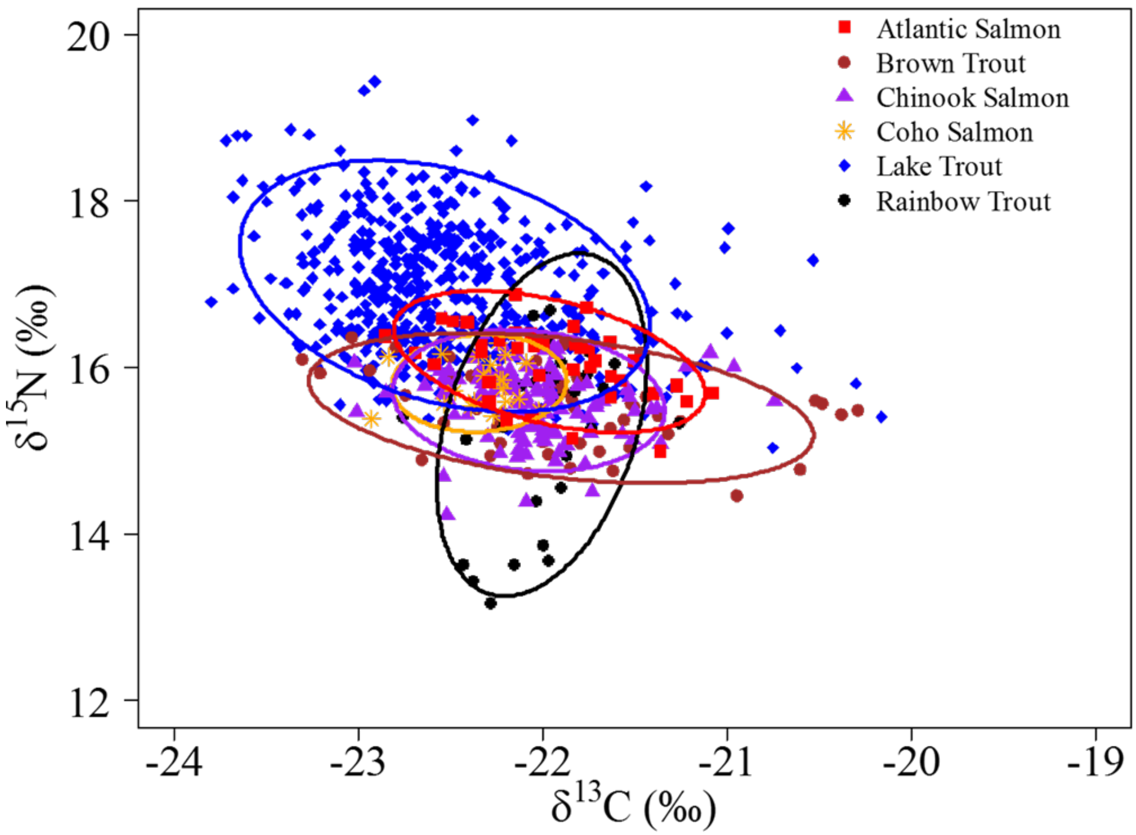

Figure 3. Carbon and nitrogen stable isotope values for Lake Ontario adult salmon and trout. Atlantic salmon samples were collected from 2004–2013 while the samples of other species were collected during 2012–2013.

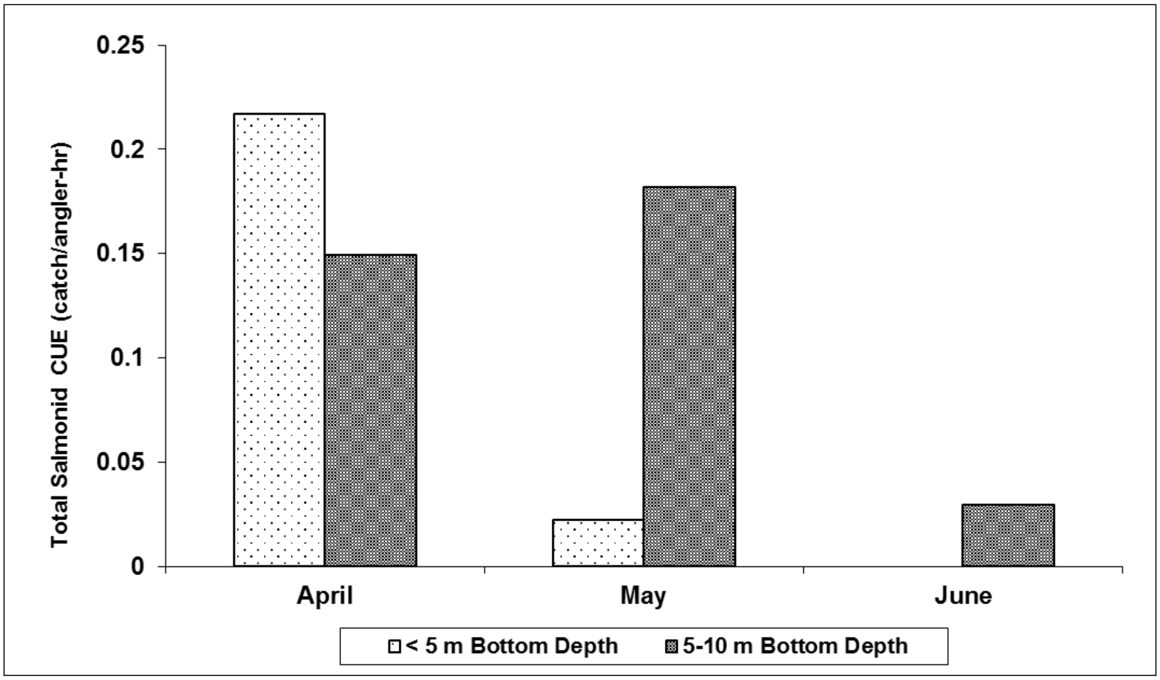

Figure 4. Catch-per-unit effort for anglers fishing for salmonids in nearshore waters of Lake Ontario during 1997–2005. Total number of angling trips was 346.

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A Risk Assessment on the Impacts of Salmonids on Atlantic Salmon in Lake Ontario Tributaries

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Abstract

Rationale

There currently exists some confusion on the potential impacts of salmonid interactions with Atlantic salmon, and we want to know if, when, and where salmonids (especially rainbow trout) could reduce survival/success of Atlantic salmon to a level that would substantially impede the restoration and long-term sustainability of Atlantic salmon in Lake Ontario.

Methods

The approach to determine the level of impact each of the four salmonid species have on Atlantic salmon is based on a literature review conducted by Houde et al. (2014). The review synthesized information on salmonid interactions from several reports, which included laboratory as well as field studies from both Eastern North America and tributaries of Lake Ontario.

The purpose of this report was to synthesize the level of competition documented in literature and translate potential competitive interactions into levels of “risk” they pose to impeding the restoration of Atlantic salmon. Interactions among salmonid species within the pelagic and nearshore waters of Lake Ontario are not well understood, and so the focus of this risk assessment was inclusive to the interactions between Atlantic salmon and other salmonids within streams. Each level of risk indicates the amount of juvenile salmon of any species that are likely to compete with and, in turn, affect the survival of Atlantic salmon juveniles (Table 1) and a risk-based “decision key” where the level of interaction with Atlantic salmon as well as any mitigating measures were factored in to the overall impact the presence of salmonids have on Atlantic salmon (Table 2; Figure 1).

Results

Based on existing literature, it was determined that both chinook and coho salmon juveniles pose a low risk to Atlantic salmon juveniles (Table 2; Figure 1). Rainbow trout juveniles pose a medium risk (rainbow trout are likely to reduce survival and growth of Atlantic salmon but there appear to be ways to mitigate these interactions), and brown trout juveniles pose a high risk to Atlantic salmon juveniles. Furthermore, in streams where multiple salmonid species are present, Atlantic salmon juvenile performance may be reduced more than predicted by simply adding two-species competitions together. This may be due to the variability in niche overlap between multiple species as well as

synergistic effects related to competition (Huisman and Weissing, 1999, 2001, 2002). However, it is unclear how this may impact survival of Atlantic salmon juveniles and further, if certain species account for more of this effect than others.

In closing, interactions that are identified as medium- or high-risk can be mitigated by ensuring Atlantic salmon juveniles are provided habitat that favours them (Table 2) and where exposure to brown trout juveniles is minimized. Further study into what habitat conditions favour Atlantic salmon juveniles over brown trout juveniles as well as the effects of multi-species competition on survival will be key pieces of information that may further increase the success of Atlantic salmon juvenile survival by informing management practices such as stocking site selection, timing, etc.

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Risk Level	Definition
High	Evidence that presence of other salmonid will impede growth, alter behavior and/or increase mortality of juvenile Atlantic salmon substantially.
Medium	Evidence that presence of other salmonid may impede growth, alter behavior and/or increase mortality of juvenile Atlantic salmon in streams but where measures exist to mitigate the impact to a much lower level.
Low	Little to no evidence that presence of other salmonid may impede growth, alter behavior and/or increase mortality of juvenile Atlantic salmon in streams.

Table 1. Definitions of risk posed to Atlantic salmon juveniles.

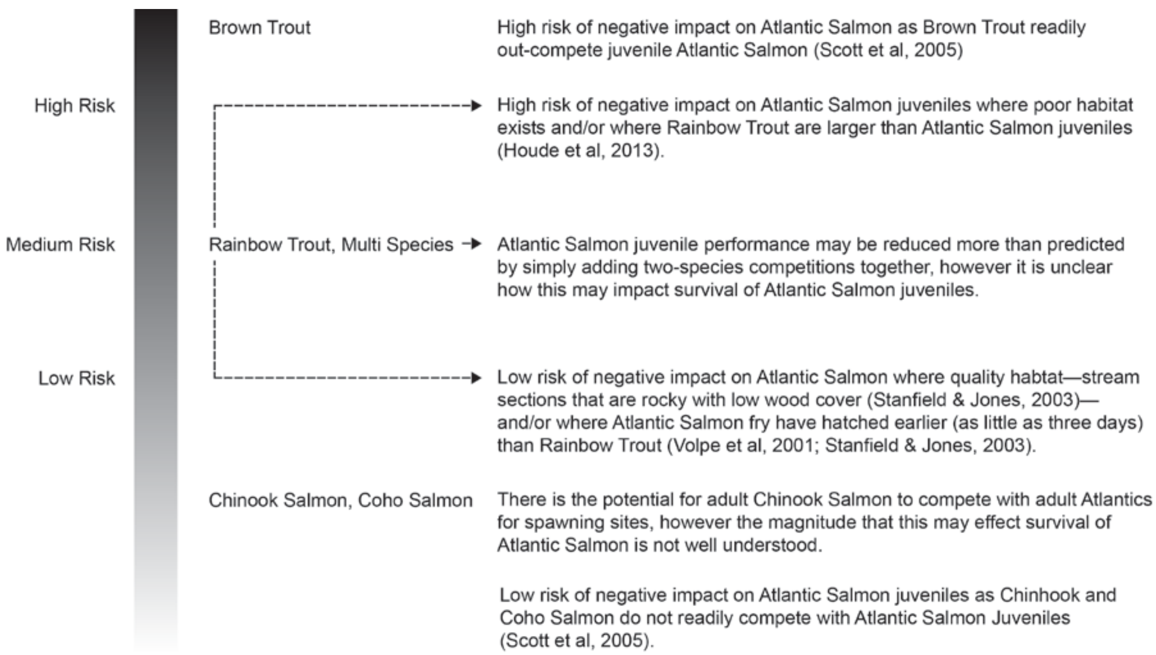

Figure 1. Risk key identifying which species interactions may present higher levels of risk to juvenile Atlantic salmon where other species are common.

Species	**Risk**	**Rationale**
Brown trout	High	Brown trout juveniles are able to outcompete Atlantic salmon juveniles at a level that results in high juvenile mortality in Atlantic salmon
Rainbow trout	Medium	Low risk where there is habitat favouring Atlantic salmon which are identified within Houde et al. (2014 and references within) as: rocky habitats with low wood cover, higher gradients, higher temperatures and lower pH or where Atlantic salmon juveniles have prior residency to rainbow trout juveniles High risk in habitats favouring rainbow trout and where rainbow trout juveniles are larger than Atlantic salmon juveniles
Chinook salmon	Low	Little competition exists between juvenile Atlantic salmon and chinook salmon in streams and are not likely to cause substantial mortality in Atlantic salmon juveniles There is the potential for adult chinook salmon to compete with adult Atlantic salmon for spawning sites, however the magnitude that this may effect survival of Atlantic salmon is not well understood
Coho salmon	Low	Little competition exists between juvenile Atlantic salmon and juvenile coho salmon and so are not likely to cause substantial mortality in Atlantic salmon juveniles
Multi-species	Medium	Atlantic salmon juvenile performance may be reduced more than predicted by simply adding two-species competitions together, however it is unclear how this may impact survival of Atlantic salmon juveniles

Table 2. Risk to Atlantic salmon juvenile survival where other species are common

General discussion notes

Q: What size or age does competitive crunch occur?
A: If it is larger than what occurs naturally (i.e. stocked), it should be ok.
Q: It seems to work in Credit River where spring fingerlings Atlantics are stocked with brown trout.

C: I am concerned where huge numbers of chinook salmon are stocked in May. Even if Atlantic salmon can compete, the numbers game wins out, especially if they are wild Atlantics.
C: The lab behavioural observations suggest they don't impact each other where the size of the fish and size and numbers the same.

Q: Chinook salmon may be larger at that time; but what if competing with smolts?
A: We would like to see how performance is impacted in field sites.

Q: What is the density threshold for problems with brown trout, rainbow trout, or Atlantic salmon?
A: Research isn't really there for consequences of abundance.

Q: How does the effect of stocking situation compare to field or lab situation?
A: It needs to be site based. It could vary from site to site and in field situations. Atlantic salmon can have advantages in fast water situations with large pectoral fins.
A: More field studies are needed on rainbow trout to define competition at a finer scale.

Q: What abundances were fish tested at in lab trials?
A: Within natural range; perhaps slightly higher density than wild situations but not stocked. The intention of the study was to look at baseline situations.

C: Data from 95–99 on brown trout could be worked up.

Q: How were streams selected with respect to competition?
A: Factored in, but it is hard to find places without at least one competitor. We tried to minimize it.
A: We assumed browns could have the pools, Atlantics would have the riffles.

Review of Thiamine for Atlantic Salmon Workshop 2014

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Abstract

This review is aimed at answering the question, “Is thiaminase an impediment to Lake Ontario (Atlantic salmon) restoration? (Question 5b).” It reviews the role of thiamine, the sources of thiamine and thiaminase in Great Lakes food chains, particularly as they relate to alewife, and provides an overview of thiamine dynamics and levels at multiple life stages of the food chain. To provide a perspective on the current thiamine status of Lake Ontario Atlantic salmon relative to diet, the review summarizes thiamine levels in populations where there appears to be no thiamine deficiency issues (East Coast) and compares levels between a population where alewife consumption has shown a dramatic increase following an alewife invasion (Lake Champlain) to a population where alewife consumption has likely undergone a dramatic decline following a crash in the alewife population (Lake Huron).

Role of thiamine

In the Great Lakes, the most obvious manifestation of a diet-related thiamine deficiency has been early mortality syndrome (EMS) in the larval stages of coho salmon, chinook salmon, Atlantic salmon, and lake trout (Fitzsimons et al., 1999; Marcquenski and Brown, 1997; Hornung et al., 1998; McDonald et al., 1998; Werner et al., 2006, 2011). Early mortality syndrome is a collection of behavioral and morphological signs observed in affected larvae that include loss of equilibrium, alternating hyperexcitability and lethargy, and reduced yolk sac utilization which eventually result in death. Symptoms resembling those of EMS have been observed in larval coho salmon since 1966 (Fitzsimons et al., 1999). Despite the early evidence of a thiamine deficiency in larval stages of coho salmon, there was no indication that adult parents of larvae developing EMS were suffering effects of a thiamine deficiency until 1996. At that time, Michigan Department of Natural Resources hatchery personnel observed unusual behavior in migratory adult coho salmon at a collection weir on the Platte River, a tributary to northeastern Lake Michigan. The behavior, termed “wiggling,” was clearly distinguishable from normal behavior and was characterized by a loss of equilibrium wherein affected fish had difficulty remaining upright, literally rolling onto their sides when changing direction during swimming.

Suspicion was raised as to the possible involvement of thiamine because of the similarity of signs with those of a thiamine deficiency affecting adult Baltic salmon in which affected fish showed wiggling and lack of coordination and, in severe cases, death (Amcoff et al., 1998). Accompanying these adult effects was a larval mortality syndrome similar to EMS, known as M74 (Amcoff et al., 1998, 1999). Samples collected from wiggling and distressed adult Lake Michigan coho salmon in 1999 confirmed that adults were indeed suffering from a severe thiamine deficiency when compared with normally-behaving fish from other locations (Brown et al., 2005a). This was also a year when over 90 % of Platte River coho salmon females had progeny that displayed EMS, which resulted in 100 % mortality (Wolgamood et al., 2005). Given the variety of clinical signs associated with the thiamine deficiency in adult coho salmon up until 2000, which varied from altered swimming behavior to mortality, the possibility existed that their ability to undertake an upstream spawning migration was likely adversely affected. Normally, spawning places a heavy requirement on body energy stores (Brett, 1995) that can vary with the velocity and amount of turbulence encountered during the in stream migration (Hinch and Rand, 1998). Utilization of body energy stores to support metabolism is highly regulated by thiamine. Thiamine is involved in generating ATP equivalents (NADH, NADPH) through three thiamine-dependent enzymes: transketolase (2.2.1.1; IUBMB, 1992) of the pentose phosphate shunt, pyruvate dehydrogenase (1.2.4.1) in the glycolytic pathway, and a-ketoglutarate dehydrogenase (1.2.4.2) in the citric acid cycle. All three enzymes are essential for cell metabolism and require thiamine in its phosphorylated form (i.e. thiamine pyrophosphate [TPP]) for their catalytic activity. Given how essential these enzymes are to cellular metabolism, it seems likely that a number of subcellular effects in thiamine-deficient fish may precede the manifestation of obvious clinical signs of a thiamine deficiency (e.g. behavior) and may significantly constrain energy mobilization for migration.

The nervous system is also vulnerable to the effects of a thiamine deficiency. The central nervous system derives most of its energy from the metabolism of glucose (Morito et al., 1986). With thiamine acting as an important co-enzyme in carbohydrate metabolism, utilization of glucose in fish could be reduced by as much as 50–60 % when in a thiamine-deficient state such as occurs in mammals, severely affecting neurological function (Guyton, 1981). Adult Baltic salmon displaying overt neurological signs of thiamine deficiency had altered serotonergic and dopaminergic activities (Amcoff et al., 2002).

Conditions of low energy and compromised neurological function resulting from a thiamine deficiency could potentially be further exacerbated by effects on the cardiovascular system. In mammalian species, thiamine deficiency reduces cardiac contractility, heart rate, and blood pressure (Cappelli et al., 1990; Onodera et al. 1991) thereby increasing susceptibility to cardiomegaly and congestive heart failure (Caster and Meadows, 1980).

Because of its wide range of effects on metabolism, nervous system, and cardiac function, a thiamine deficiency could exert a considerable impact on the upstream migration of Atlantic salmon, depending on the level of the deficiency. Effects could include an inability to migrate upstream especially through areas with obstructions or fast water, difficulty in initiating and completing spawning, or mortality occurring either en route to or at the spawning grounds. It is noteworthy here with regards to Atlantic salmon that despite increasing sport catch in Lake Ontario (J. Lantry, NYDEC, personal communication) suggesting increased abundance in the lake, runs of Atlantic salmon up the Credit River where the largest runs to date have occurred remain quite low, being less than 30 fish per year and without trend (M. Heaton, OMNRF, personal communication).

Sources of thiamine in the aquatic food chain

The lower food web supporting Great Lakes fishes shows considerable variability in thiamine content. There was significant among-site variation in thiamine evident for net plankton but not Mysis or Diporeia (unpublished data, John Fitzsimons; Table 1) for six locations sampled in Lake Michigan and one location sampled in Lake Superior during 2005. The pattern of spatial variation in mean thiamine concentration was not correlated with that for thiaminase activity either within or among groups. Mean site thiamine concentration was unrelated to either Mysis or Diporeia density. For thiamine, based on the three locations in Lake Michigan (Elk Rapids, Ludington, Saugatuck), there was evidence of variation among groups, with concentrations in net plankton (9.3 ± 1.4 nmol/g) higher than that for either Mysis (6.2 ± 1.2 nmol/g) or Diporeia (4.6 ± 1.5nmol/g), that did not differ from each other. For four locations in Lake Michigan (Elk Rapids, Ludington, Saugatuck, Manitowoc), there was no variation in thiamine concentrations between Mysis (5.5 ± 1.0 nmol/g) and Diporeia (4.2 ± 1.1 nmol/g).

Location	Net plankton	Mysis	Diporeia
Lake Superior			
Whitefish Bay	2.2b (0.8)	9.0a (0.9)	5.4a (1.3)
Lake Michigan			
Big Bay de Noc	12.2a (2.6)		
Baileys Harbour	14.2a (1.5)	7.6a (6.7)	
Manitowoc		3.5a (1.0)	3.3a (0.7)
Elk Rapids	13.6a (0.6)	5.0a (1.3)	3.3a (2.9)
Ludington	8.2a (2.1)	6.5a (2.4)	1.9a (1.1)
Saugatuck	6.2ab (1.7)	6.9a (3.1)	2.7a (0.4)

Table 1. Mean (± SE) thiamine (nmol/g) in net plankton, Mysis, and Diporeia collected from one location in Lake Superior and six locations in Lake Michigan during 2005. Means followed by the same letter are not significantly different from other means in the same column with the same letter.

Sources of thiaminase in the food chain

Thiaminase, the enzyme believed to be responsible for development of thiamine deficiency in several species of Great Lakes salmonines as a result of alewife consumption (Brown et al., 1998a; Fitzsimons et al., 1999; Fitzsimons and Brown, 1998; Honeyfield et al., 2005; Brown et al., 2005) occurs in lower trophic level organisms. As for thiamine, there is also considerable variability in the thiaminase content of lower trophic level organisms that support alewife as well as other biota. For six locations sampled in Lake Michigan and one location sampled in Lake Superior during 2005, significant among-site variation in thiaminase activity was detected for Mysis but not net plankton or Diporeia (Table 2; unpublished data, John Fitzsimons). Mean thiaminase activity for Mysis was correlated with Mysis density. Based on three locations in Lake Michigan (Elk Rapids, Ludington, Saugatuck), mean (± SE) thiaminase activity for Mysis (800.1 ± 305.5 pmol/g/min) was higher than for Diporeia (266.9 ± 176.3 pmol/g/min) by a factor of threefold but not for net plankton (750.5.1±402.3pmol/g/min). When comparisons were made between Mysis and Diporeia for four locations in Lake Michigan (Elk Rapids, Ludington, Saugatuck, Manitowoc), the difference between groups was even greater with mean concentrations for Mysis (1149.0 ± 440.5 pmol/g/min), over fivefold higher than for Diporeia (210.3 ± 129.5 pmol/g/min).

Location	**Net plankton**	**Mysis**	**Diporeia**
Lake Superior			
Whitefish Bay	178.0a (37.2)	169.0bc (93.6)	10.0a (0)
Lake Michigan			
Big Bay de Noc	124.7a (114.7)		
Baileys Harbour	67.7a (77.7)	120.9bc (11.9)	
Manitowoc		2195.9a (1555.3)	59.3a (39.3)
Elk Rapids	229.4a (72.7)	63.0b (32.2)	259.0a (249.0)
Ludington	102.7a (11.7)	1334.7a (516.5)	663.9a (653.9)
Saugatuck	1944.5a (939.2)	1002.2ac (644.4)	10.0a (0)

Table 2. Mean (± SE) thiaminase (pmol/g/min) in net plankton, Mysis, and Diporeia collected from one location in Lake Superior and six locations in Lake Michigan during 2005. Means followed by the same letter are not significantly different from other means in the same column with the same letter.

Of the preyfish species examined, thiaminase occurs at much higher concentrations in alewife than most other preyfish species (Tillitt et al., 2005). For Lake Michigan, thiaminase activity (pmol of thiamine destroyed per gram of tissue per minute or pmol/g/min) in whole alewife (4280) was found to be slightly greater than that for rainbow smelt (2640), and much higher than for deepwater sculpin (172), ninespine stickleback (85), bloater (35), round goby (18) or yellow perch (12). It was only for gizzard shad (31800) and spottail shiner (32700) thiaminase activity was greater higher than for alewife.

Thiaminase activities of different alewife populations show considerable variability that may be significant to the development of thiamine deficiency in their predators. In Lake Michigan, thiaminase activity of alewife was affected by year, season, and size (Tillitt et al., 2005) while Fitzsimons et al. (2005) reported that thiaminase activity of Finger Lakes alewife varied from lake to lake. Honeyfield et al. (2005) found that the egg thiamine concentration of lake trout fed mixtures of bloaters and alewife was inversely related to the total thiaminase activity of the diet. The thiaminase activity (pmol/g/min) of alewife in Canadice Lake (2545), where their lake trout predators are self-sustaining (Smith, 1998), was significantly lower than for Lake Ontario (4336), Lake Michigan (5064), Seneca Lake (4336), and Cayuga Lake (5346) where lake trout also feed heavily on alewife but do not maintain self-sustaining populations (Fitzsimons et al., 2005).

The source of thiaminase in alewife may involve bacteria in their gut as well as possible dietary sources. Tillitt et al. (2005) suggested the evidence for bacterial origin of thiaminase comes from the observations that:

1. Thiaminase has been identified and the gene has been cloned in Paenibacillus thiaminolyticus (Abe et al., 1987).

2. P. thiaminolyticus has been isolated and cultured from some but not all alewife digestive tracts (Honeyfield et al., 2002).

3. The distribution of thiaminase in tissues of alewife is consistent with tissues where bacteria are known to be present in fishes (e.g. spleen, intestine, kidney) (Zajicek et al., 2005).

4. The biochemical characteristics (e.g. pH and temperature optima) of the thiaminase activity observed in tissues of Lake Michigan alewife were consistent with a bacterial source (Zajicek et al., 2005).

Results of Richter et al. (2012), however, demonstrated that P. thiaminolyticus was not the primary source of thiaminase activity affecting Great Lakes salmonines and called into question the longstanding assumption that P. thiaminolyticus was the source of thiaminase in other wild and domestic animals. The activity of particular bacteria may be influenced by physiological conditions of alewife as well as external environmental factors such as temperature, oxygen, dietary factors such as prey type, and associated quantitative (e.g. density) and qualitative (e.g. lipid content) attributes of this prey.

As a dietary source potentially influencing alewife thiaminase activity, attention has recently focused on cyanobacteria (Arsan, 1970; Arsan and Malyarevskaya, 1974), some of which are known to produce thiaminase (Fujita, 1954). Cyanobacteria have increased in the Great Lakes following invasion by dreissenids (Vanderploeg et al., 2001), and this increase has been coincident with increases in EMS, a mortality syndrome associated with high dietary intake of thiaminase, in coho salmon, although a cause-effect linkage has not been identified (Makarewicz et al., 1999; Brown et al., 2005). Dreissenids that invaded the Great Lakes in the mid-1980s are known to preferentially excrete cyanobacteria in their pseudofaeces and contain very high levels of thiaminase (Vanderploeg et al., 2001; Tillitt et al., 2009).

As thiaminase activity of Finger Lakes alewife was highly correlated with their lipid content (Fitzsimons et al., 2005), variation in diet may be involved. The lipid content of fish appears to be controlled by feeding activity and lipid content of their diet (Madenjian et al., 2000). If, in fact, diet is important in controlling alewife thiaminase activity, its importance could vary considerably because of qualitative variation in the diet of alewife, which is related to feeding mode and habitat of alewife prey. Alternatively, lipid may simply be a covariant that reflects the feeding status of the alewife but does not actually interact with thiaminase activity. Feeding habitats of alewife appear to differ among the Great Lakes, controlled in part by its ability to particulate or filter feed (Janssen, 1976). The proportion of Mysis and Diporeia in the diet of alewife in Lake Michigan (25–45 %;

Hewett and Stewart, 1989; Hondorp et al., 2005), was much higher than for Lake Ontario (5–15 %) with the majority of the diet in Lake Ontario comprised of microcrustacean zooplankton but influenced by season, location, and size (Mills et al 1992). Since the invasion of dreissenids in the 1980s, there have been dramatic declines as well as disappearances of the amphipod Diporeia throughout the Great Lakes (Nalepa et al., 1998) such that the relative importance of Diporeia in the diet of alewife likely declined as well. In Lake Michigan and Lake Superior, greatest thiaminase activity was found in Mysis and net plankton, with relatively little in Diporeia (unpublished data, John Fitzsimons). In the New York Finger Lakes, there was evidence of lake-to-lake and year-to-year variation in the thiaminase activity of net plankton (unpublished data, John Fitzsimons). In Lake Ontario, where thiaminase activity in net plankton showed considerable temporal and spatial variability, during one year it was correlated with biomass of cyanobacteria. There was no evidence that the thiaminase activity and thiamine content of any of the groups was correlated.

Owing to the predominance of alewife in the diets of many Great Lakes salmonines, high thiaminase activity of alewife (Tillitt et al., 2005) and their ability to induce thiamine deficiency in lake trout (Honeyfield et al., 2005), alewife are thought to be responsible for thiamine deficiency in salmonine predators throughout the Great Lakes (Fitzsimons and Brown, 1998; Fitzsimons et al., 1999, 2007; Marcquenski and Brown, 1997) with severe consequences to recruitment (Fitzsimons et al., 2003; Brown et al., 2005a). In contrast, another clupeid Atlantic herring which is also known to contain high thiaminase activity and cause thiamine deficiency effects in Atlantic salmon (Saunders and Henderson, 1974) has not been associated with population effects in its native coastal habitat of North America. This is likely because the diets of coastal Atlantic salmon depend on a much more diverse prey community such that the influence of a high thiaminase-containing Atlantic herring diet is reduced considerably (A. Locke, DFO, St. John, NB, personal communication).

The reason why alewife in the Great Lakes contain high thiaminase activity unlike most other preyfish occupying the same food chain (Fitzsimons et al., 2005; Tillitt et al., 2005) remains unclear, although it is not unique to Great Lakes stocks and appears to be characteristic of clupeids in general. Like Great Lakes stocks, high thiaminase activity was also noted for alewife from the Gulf of St. Lawrence (Fitzsimons et al., 2005). Similarly, other clupeids including gizzard shad, threadfin shad, Baltic herring, and sprat all contain elevated thiaminase activity (Tillitt et al., 2005; Wistbacka et al., 2002; Honeyfield et al., 2007).

In spite of alewife having some of the highest thiaminase activity which varies from lake to lake, by season, and by location within a lake, the reasons for this variation are not well understood. The variation observed in thiaminase activity of alewife may involve variation in external (e.g. diet) as well as internal (e.g. intestinal bacteria sources; Tillit et al., 2005; Fitzsimons et al., 2005) factors. In the New York Finger Lakes, alewife thiaminase activity was found to be negatively correlated with lipid content, suggesting that feeding or other factors may have some influence on thiaminase activity (Madenjian et al., 2000; Fitzsimons et al., 2005). Tillitt et al. (2005) reported that thiaminase activity was highest in the spring with lower levels in the summer and fall. This finding is consistent with an inverse relationship between lipid and alewife thiaminase activity; alewife exhibit lowest lipid levels in the spring with higher but similar levels during the summer and fall (Flath and Diana, 1985). Collectively, these findings suggest that thiaminase activity might be inversely related to feeding activity since highest growth and, hence, feeding activity of alewife, occurs in the summer and fall (Flath and Diana, 1985). Moreover, lipid levels in fish are related to feeding rate as well as the lipid content of their prey (Flath and Diana, 1985; Madenjian et al., 2000).

Diet composition may also be an important influence on thiaminase activity of alewife. An inverse relationship between thiaminase activity of freshwater fish and their thiamine contents was associated with exposure to toxic cyanobacteria (Arsan, 1970; Arsan and Malyarevskaya, 1974). This could be at least partially food chain-mediated because Birger and Malyarevskaya (1977) reported inverse relationships between the thiaminase activity and thiamine concentration of the gammarid, the zebra mussel, and the chironomid exposed to algal toxin. Gut flora may also contribute to alewife thiaminase activity. Honeyfield et al. (2002) reported the presence of thiaminase-producing bacteria Bacillus thiaminolyticus in alewife, but in only 25 % of the fish examined was its presence confirmed. Bacteria other than Bacillus thiaminolyticus may have also been present and may have had thiaminase activity, but until conditions for their culture and identification are established, it will not be possible to know to what extent bacteria influence alewife thiaminase activity.

Understanding the factors responsible for the variation in alewife thiaminase activity is potentially useful to managers in understanding variation in EMS and managing the consequences of alewife diet-induced thiaminase deficiency. Honeyfield et al. (2005) noted that when alewife from Cayuga Lake having an average thiaminase activity of ~9,400 pmol/g/min were fed to lake trout, it resulted in lower lake trout egg thiamine concentrations (2.29 nmol/g) than eggs (3.61 nmol/g) of lake trout fed Lake Michigan alewife that had twofold lower thiaminase activity (~4,800 pmol/g/min). While only representing a relatively small difference in egg thiamine concentration (1.32 nmol/g), based on the dose response relationship between EMS and egg thiamine concentration for lake trout (Fitzsimons et al., 2007), this could represent the difference between having some EMS and no EMS, although a thiaminase activity of ~4,800 pmol/g/min could result in egg thiamine concentrations causing reduced growth or foraging that could lead to increased mortality (Fitzsimons et al., 2009). Lake trout reproduce successfully in Keuka Lake on a diet of alewife, having a thiaminase activity of ~4,000 pmol/g/min or in Canadice Lake where the thiaminase activity of alewife is ~2,500 pmol/g/min, but not Cayuga Lake where alewife thiaminase activity is ~5,300 pmol/g/min (Fitzsimons et al., 2005; Brown et al., 2005a).

Variation in alewife thiaminase activity may be responsible for long-term variation in EMS in salmonines in the Great Lakes (Fitzsimons et al., 1999; Brown et al., 2005a). Coho salmon in Lake Michigan feed almost exclusively on alewife (Stewart et al., 1981; Jude et al., 1987; Stewart and Ibarra, 1991; Madenjian et al., 1998). As Honeyfield et al. (2005) found that egg thiamine concentration, and, hence, EMS were proportionate to the amount of thiaminase activity in the diet. It follows that variation in EMS in coho salmon may indicate variation in the thiaminase activity of its alewife diet and, possibly, factors affecting that thiaminase activity. For example, Honeyfield et al. (1998) reported a marked increase in EMS in Lake Michigan coho salmon in the mid-1990s, suggesting an increase in the thiaminase activity of its alewife diet. Since this increase was coincident with colonization of the lake by dreissenids (Ricciardi and MacIsaac, 2000), they may have directly or indirectly affected alewife. Affecting their thiaminase activity as diet is a major source of thiaminase for alewife. This could be the result of cyanobacteria blooms (Vanderploeg et al., 2001) or a change in diet (Madenjian et al., 2003) that historically contained up to 80 % Diporeia, depending on alewife size and season (Hondorp et al., 2005).

Thiamine deficiency in Great Lakes fishes

Salmonines: eggs

Egg thiamine concentrations are the most commonly-used method of assessing thiamine status of salmonines within the Great Lakes and, in turn, effects on egg viability as measured by the occurrence of early mortality syndrome or EMS. To assess the possible effects of thiamine deficiency on salmonine reproduction, Fitzsimons et al. (2007) measured egg thiamine concentrations for five species of Lake Ontario salmonines. From this, they estimated the proportion of families susceptible to EMS based on whether they were below the ED20, the egg thiamine concentration associated with 20% mortality due to EMS. The ED20s were 1.52, 2.63, and 2.99 nmol/g egg for chinook salmon, lake trout, and coho salmon, respectively. Based on the proportion of fish having egg thiamine concentrations falling below the ED20, the risk of developing EMS in Lake Ontario was highest for lake trout, followed by coho salmon and chinook salmon, and the least risk for rainbow trout. For lake trout from western Lake Ontario, mean egg thiamine concentration showed significant annual variability during 1994 to 2003, when the proportion of lake trout at risk of developing EMS based on ED20 ranged between 77–100 %.

Lake trout fed mixtures of alewife and bloater showed declines in egg thiamine relative to the net thiaminase content of the diet, and these declines were exponential and nonlinear (Figure 1; Honeyfield et al., 2005). This indicates that an alewife diet may have a higher-than-expected effect in lowering egg thiamine levels of predators relative to the proportion of alewife in the diet (Figure 1).

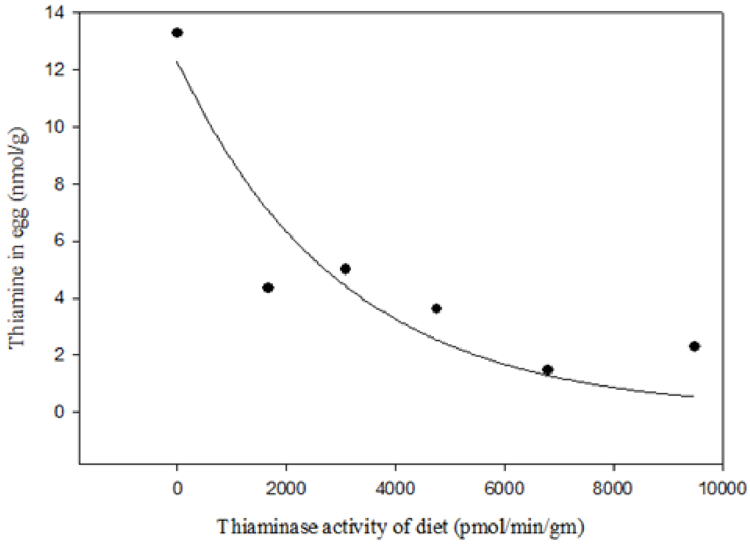

Figure 1.

Salmonines: muscle – lake trout

The diets of Lake Ontario lake trout collected 2005–2006 showed a continuous size-related increase in the proportion of alewife, based on stomach contents whereas, using the stable isotope values of prey and lake trout in mixing models, alewife appeared much less important for most size classes (Figure 2; unpublished data, J. Fitzsimons). Instead, round gobies were the dominant prey based on mixing model predictions. The high importance of round gobies in lake trout diets was confirmed in 2008 (Rush et al., 2012; Figure 2).

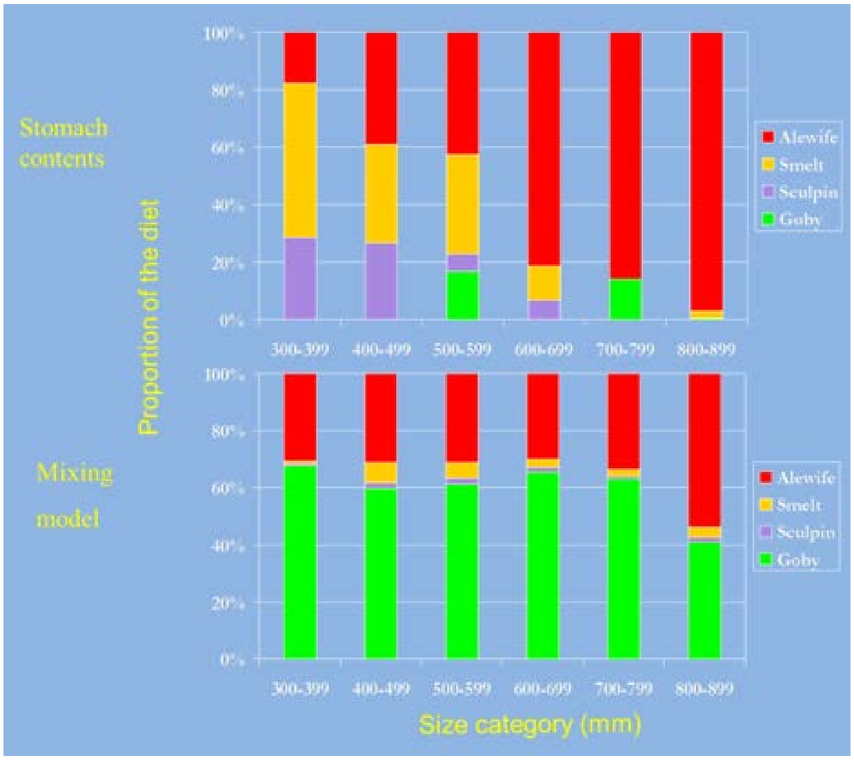

Figure 2.

The muscle thiamine of Lake Ontario lake trout collected in 2005–2006 was related to estimated proportion of alewife in the diet based on stable isotope and mixing models. This was similar to the relationship derived from data in Honeyfield et al. (2005) between egg thiamine and the thiaminase content of mixed bloater-alewife diets and suggestive of a greater-than-expected effect on thiamine of the proportional abundance of alewife in the diet by an exponential relationship. From this relationship and the relationship between egg thiamine and muscle thiamine (Figure 3), it is estimated that a diet containing less than 10 % alewife would be required for there to be sufficient thiamine in the muscle to deposit sufficient thiamine in the eggs to avoid the lethal and sublethal effects of thiamine deficiency in embryos (Figure 4).

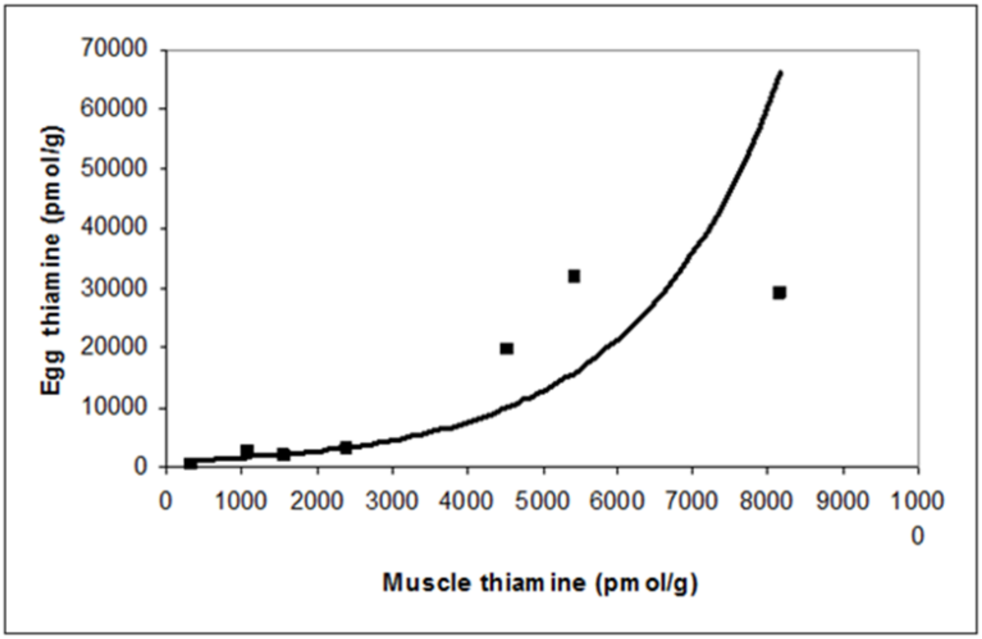

Figure 3.

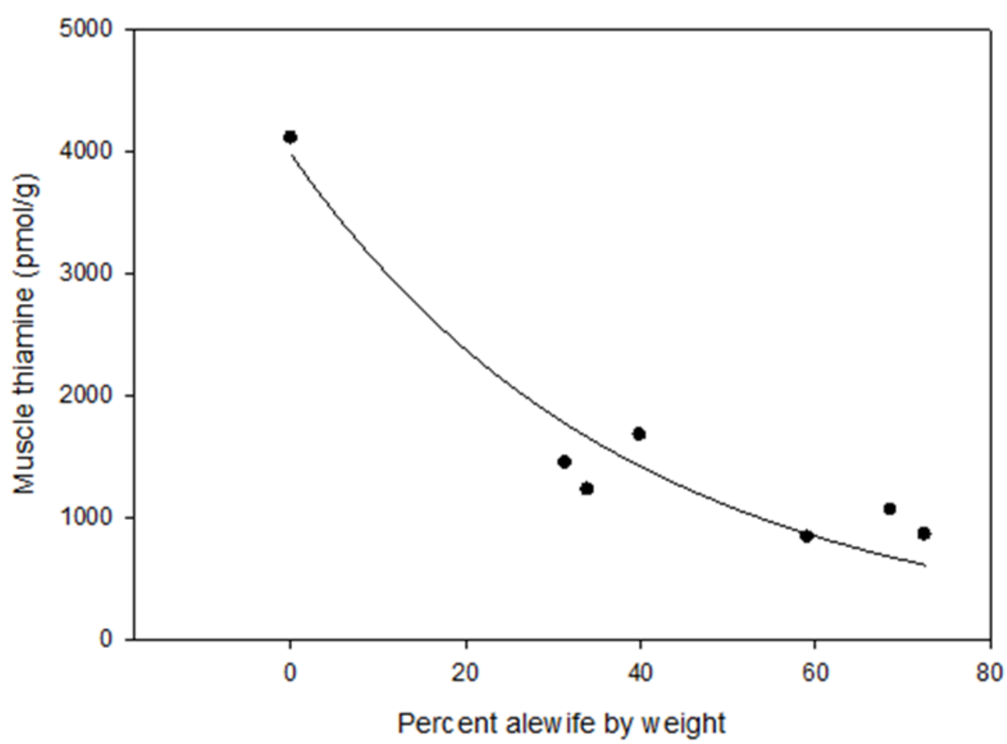

Figure 4.

Salmonines: muscle – chinook salmon

Compared to a more generalist predator like lake trout, chinook salmon make almost exclusive use of alewife in their diet in Lake Ontario based on collections made in 2005–2006 (unpublished data, John Fitzsimons; Figure 5a). With this high, early, and continuing alewife consumption, there is a concomitant dramatic decline in muscle thiamine concentration (Figure 5).

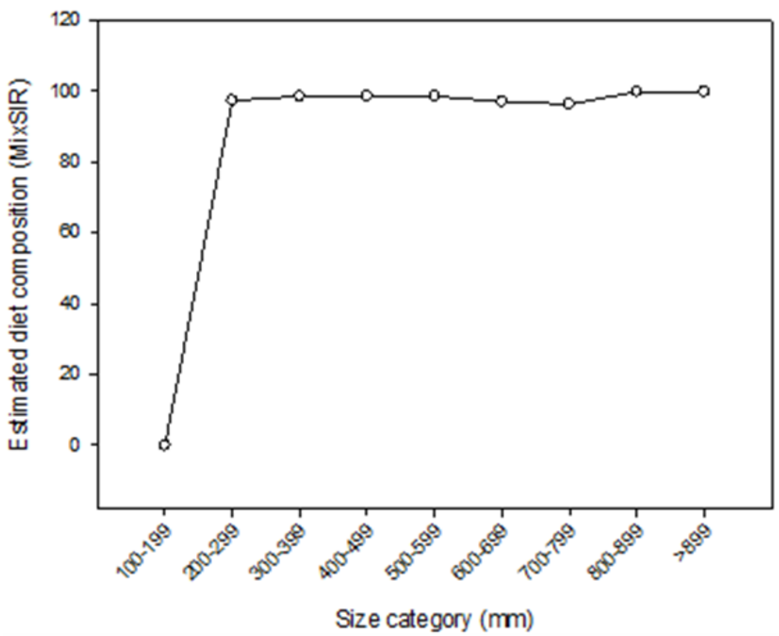

Figure 5.

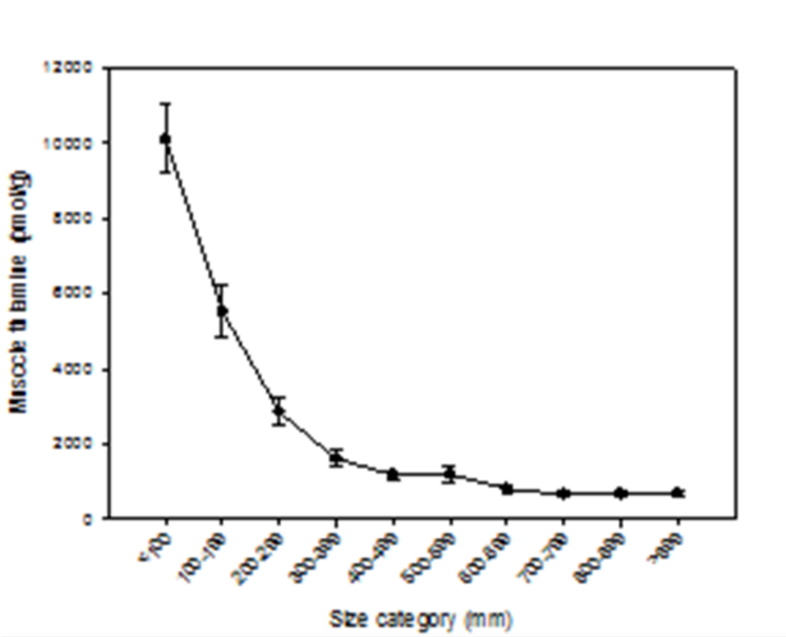

Figure 5a.

Walleye

Walleye is a top predator in Lake Erie's eastern basin that consumes primarily rainbow smelt. The effects of a diet of rainbow smelt that also contains high levels of thiaminase (Tillitt et al., 2005) on thiamine-deficiency mediated reproductive success as rainbow smelt also have elevated thiaminase, are less clear compared to the salmonines lake trout and rainbow trout. In 2004, 12 walleye were sampled from the Grand River (Ontario) in Lake Erie's eastern basin, and mean egg-thiamine concentration (3.70 ± 0.36 nmol•g^{-1} [mean ± SE]) was less than one-third the average for 24 walleye sampled during 2004 from southern Lake Winnipeg (13.31 ± 0.37 nmol•g^{-1}) where rainbow smelt were absent (Fitzsimons et al., 2009). Johnson et al. (2005), however, were unable to relate variation in early-life stage survival of Bay of Quinte (Lake Ontario) walleye to egg-thiamine concentration that averaged 4.58 ± 2.08 nmol•g^{-1} (range 2.17–12.25 nmol•g^{-1}). Similarly, Honeyfield et al. (2007) were unable to find a link between the reproductive status of walleye stocks in three southern U.S reservoirs and their mean egg thiamine concentrations that ranged from 2.13–3.14 nmol•g^{-1}. Although the thiamine concentration of Lake Erie walleye appears to be affected by its rainbow smelt-dominated diet, reproductive effects seem unlikely.

American eel

The Lake Ontario Upper St. Lawrence River (LOUSL) population of American eels (hereafter "eels") was once one of the most important groups of the species but is now in a state of serious decline. Given that thiamine deficiency has been observed in almost all of the top predators in Lake Ontario, there was a strong potential that a diet-induced thiamine deficiency associated with consumption of alewife could affect eels as well, although contemporary eel diets had not been determined. Muscle thiamine was measured in eels from throughout the LOUSL corridor and was compared with putative threshold effect levels established from the literature. Mirex concentrations were used to separate Lake Ontario-resident eels from non-Lake Ontario-resident eels (Fitzsimons et al., 2013). Stable isotope analyses of eel muscle samples and potential prey, including alewife, were combined with mixing model software to infer the diets consumed by Lake Ontario eels. Although residence in Lake Ontario was associated with a significant decline in muscle thiamine concentration, estimated alewife consumption by eels was unexpectedly low. Instead, mixing model results indicated that crayfish and round goby were the major prey. Both taxa are known to contain thiaminase so may have the potential to cause thiamine deficiency, but there are no reports of thiamine deficiency associated with round goby consumption, thus implicating crayfish. There was no recovery in eel thiamine levels prior to the initiation of oceanic migration. As a result, thiamine levels of Lake Ontario-resident eels prior to migration were only slightly above putative threshold effect levels for pathological and behavioral effects in Japanese eels, but this would require confirmation with American eels. Since thiamine levels are expected to decline further during migration, additional effects on eel behavior, reproduction, and survival seem probable. Because of panmixia, such effects—when combined with the relatively high reproductive potential of Lake Ontario-resident eels—may have consequences for the entire species.

Lake whitefish

Lake whitefish are known to prey heavily on dreissenids which are known to contain some of the highest thiaminase levels among Great Lakes biota (Tillit et al., 2009) and higher than alewife. To determine whether lake whitefish were affected by thiamine deficiency Riley et al. (2011) measured thiamine levels of lake whitefish eggs collected from Lake Huron and Lake Michigan and compared them with eggs from lake whitefish from Lake Superior where dreissenids are largely absent. Mean thiamine concentrations in lake whitefish eggs were highest in Lake Huron, intermediate in Lake Superior, and lowest in Lake Michigan, although thiamine concentrations in Lake Superior were not different from the other lakes. Relatively few fish had thiamine concentrations below putative thresholds for lethal or sublethal effects in salmonines, and the proportion of fish with thiamine concentrations below these thresholds was similar across the three lakes.

Effect of thiamine deficiency by life stage

Embryos

Alevins and fry of Atlantic salmon with a thiamine deficiency have high mortality (Fisher et al., 1995; Fitzsimons et al. 1995) but, based on lake trout thiamine deficiency, appear to have no effect on earlier developmental stages including egg fertilization rate, eye-up, or hatching (Fitzsimons et al., 2012). In addition, for Atlantic salmon alevins and fry can have light body colouration, yolk opacities, lesions, and abnormal swimming behaviour (Fisher et al., 1996; Ketola et al., 2000; Koski et al., 2002). Lake trout that were made thiamine deficient using the thiamine antagonist oxythiamine administered at water hardening showed reduced yolk sac absorption and growth at the sac-fry stage

(Fitzsimons et al., 2012). Once yolk sac absorption is complete, naturally thiamine-deficient lake trout alevins had reduced growth, foraging efficiency, and predator avoidance (Fitzsimons et al., 2009).

Based on sensitivity the thiamine antagonist oxythiamine (Figure 6), Atlantic salmon appear to be at least as sensitive to the effects of thiamine deficiency as lake trout and perhaps even more sensitive. The oxythiamine concentration associated with Cayuga Syndrome mortality in Atlantic salmon (4.39 nmol/g) was one-half that for lake trout (8.2 nmol/g; Fitzsimons et al., 2001a, 2001b)

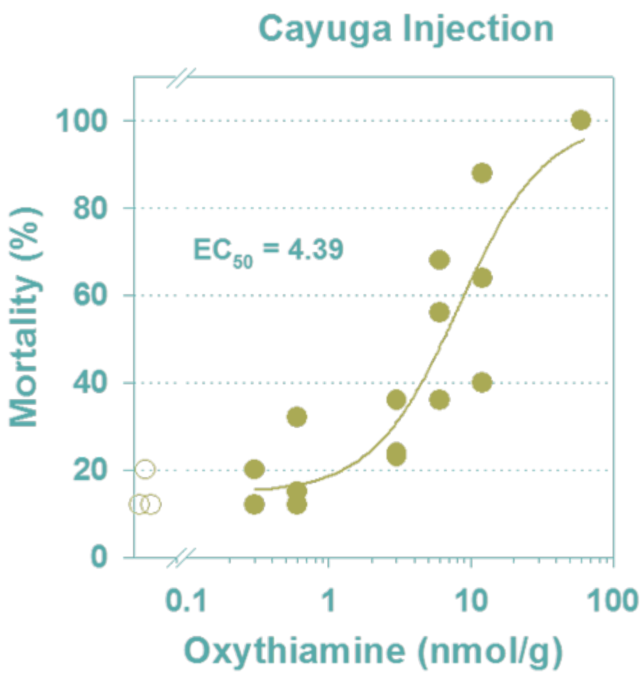

Figure 6.

Although there is no information on the timing of thiamine deposition into ova of Atlantic salmon, for lake trout, most of the deposition of thiamine into the egg, based on the amount of thiamine present, appeared to occur during a relatively short period some three to four months prior to spawning based on a thiamine replete stock (Opeongo Lake; unpublished data, John Fitzsimons; Figure 7)

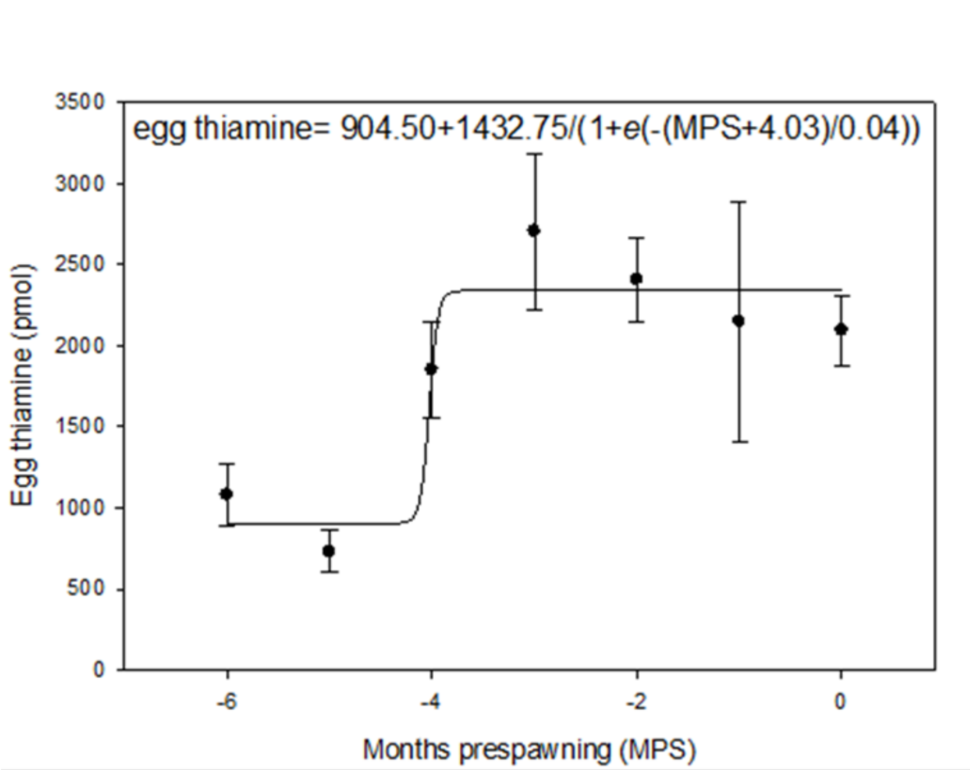

Figure 7.

Juveniles

While several studies have examined the effects of thiamine deficiency in adult salmonids, effects have rarely been examined in younger salmonids that are starting to consume thiaminase-containing preyfish in the lakes. Younger (smaller) salmonids appear to be more sensitive to the effects of thiamine deficiency than older (larger) salmonids, possibly because older salmonids are better able to conserve thiamine in tissues (Morito et al., 1986; Ketola et al., 2008).

Adults

Thiamine deficiencies in adults have been associated with reduced individual fitness in fishes. Fishes with thiamine deficiencies have lethargy, "wiggling" behaviour, loss of equilibrium, cessation of feeding, and higher mortality (Morito et al., 1986; Amcoff et al., 1998). These effects have also been observed in natural populations of coho salmon during spawning migrations into Lake Michigan tributaries (Brown et al., 2005; Fitzsimons et al., 2005). Vigorous activity and increased temperature could put additional demands on thiamine reserves because of increased metabolism (Fitzsimons et al., 2012). The lethargy may be due to increased plasma lactate concentrations and reduced ATP production (Fitzsimons et al., 2012). The changes in behaviour have been related to increased serotonergic and dopaminergic activity in the brain (Amcoff et al., 2002).

Female salmonids with thiamine deficiencies may transfer the deficiency onto her offspring (Fisher et al., 1995; Fitzsimons et al., 1995; see Early life stage salmonids below). While the effects of thiamine deficiency on female salmonid reproductive traits are well known, not much is known about the effects of a thiamine deficiency on male salmonid reproductive traits. Males with a thiamine deficiency may have higher offspring mortality, possibly because of a reduction in sperm quality, and transfer of thiamine to offspring (Koski et al., 2002, but see Fisher et al., 1995). The reduction in sperm quality may be related lower sperm density; spermatogenesis requires thiamine in humans (Gangolf et al., 2010).

Thiamine levels of in the eggs of Atlantic salmon populations

East Coast

Atlantic salmon eggs collected from adults returning to rivers in Nova Scotia (Mabou, St. Francis Harbour, and Pictou Rivers, River Phillips) and New Brunswick (Miramichi, Sevogle, Clearwater, Burnthill, Juniper, Dungarron, and Cairns Miramichi Rivers, Rocky Brook) showed considerable variation in egg thiamine levels but unrelated to river. Cluster analysis revealed five different clusters whose mean thiamine concentration ranged from 5,096–21,495 pmol/g (Figure 8). The reason for the variation is unknown but since thiamine is an essential vitamin may reflect in part, variation in the thiamine levels of prey items consumed in the North Atlantic Ocean. Atlantic salmon do not feed in spawning rivers (Kadri et al., 1995). Whether or not thiamine concentrations in any of the clusters particularly cluster 1 were influenced by the occurrence of a thiaminolytic prey organism in the diet is not known.

Cluster	Mean Thiamine (pmol/g)	SE	Probable Diet
1	5096	184	mixed
2	7808	234	mixed
3	11690	326	mixed
4	16800	1916	mixed
5	21495		

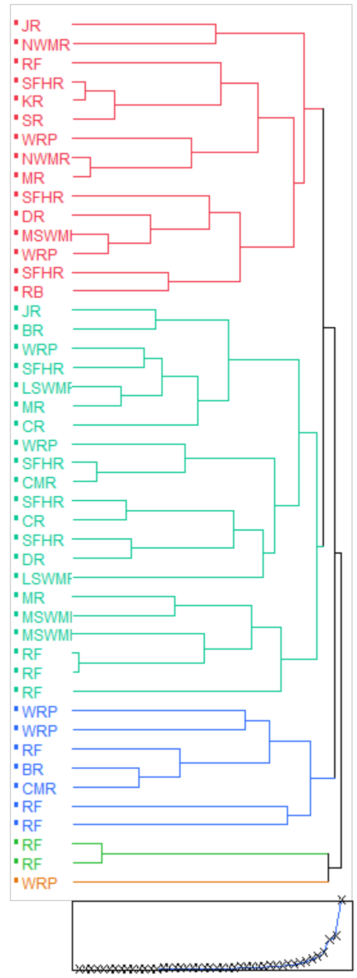

Figure 8.

Finger Lakes

Reproductive impairment has been identified in Atlantic salmon populations inhabiting the Finger Lakes of New York State. This reproductive problem manifests as a lethal syndrome in sac-fry larvae or first feeding fry, is referred to as the Cayuga syndrome, and occurs when egg thiamine levels fall below 1 nmol/g. The Cayuga syndrome has been observed in progeny from every Cayuga Lake Atlantic salmon female examined since 1974 with mortality usually reaching 100 %, yet lake trout, rainbow trout, and brown trout appear unaffected (Fisher et al., 1995b, 1998).

Baltic Sea

A yolk-sac fry mortality syndrome of Baltic salmon associated with low thiamine concentrations was first described in 1974 in Swedish compensatory hatcheries (Norrgren et al., 1993). Thereafter, the syndrome has been designated as the M74 syndrome. M74 has been observed in the yolk-sac fry of feral Baltic salmon in several rivers of Sweden and Finland but not in Latvian or Polish rivers (Karlsson et al., 1999). The incidence of the M74 syndrome is variable. Analysis of long-term mortality records from two Swedish Baltic salmon hatchery stocks in the years 1928–1998 indicated low or no occurrence of M74 before 1974. In the 1990s, 25–80 % of Baltic salmon females which ascended rivers to spawn produced yolk-sac fry suffering from the syndrome. In the years 2003–2005, only a small percentage of the salmon fry suffered from the syndrome, but a current analysis monitoring the level of M74 in 2006 suggests there is a higher incidence than in previous years. Whereas most of the observations of the syndrome have been made in offspring that originate from artificially fertilized eggs intended for stocking, there are strong indications from electrofishing and parr abundance estimations from Swedish rivers that M74 has also affected naturally-spawning populations during the periods of high occurrence (Karlstrom, 1999). M74 is maternally transmitted and affects the yolk-sac stage of the fry. Within an affected family group the fry mortality is often 100 %, although groups of partial mortality have also been described (Amcoff et al., 1999). M74-affected fry have several typical neurological, cardiovascular, morphological, and other symptoms: They show a disturbed swimming pattern, impaired coordination, a lack of phototaxis, and a decreased heartrate (Lundstrom et al., 1998, 1999). The absorption of yolk is slowed down. The M74 fry are also characterized by a small, pale spleen and show blood congestion, a reduced number of circulating erythrocytes, abnormal hemorrhages/blood coagulation, exopthalmia, glycogen depletion, and an increased number of necrotic cells in the brain. Dying yolk-sac fry are lethargic and have convulsions and bradycardia. M74-producing broodfish may show wiggling behavior that is most likely caused by alterations in dopaminergic and serotonergic activity in the brain (Amcoff et al., 2002). M74 is associated with low thiamine content in the broodfish and eggs. The symptoms of M74 can be treated with thiamine and induced with thiamine antagonists. Consequently, it has been suggested that a decrease in the thiamine content of food or an increase in its thiaminase activity could be the cause of the syndrome

Lake Huron

Historically, Atlantic salmon in Lake Huron were believed to consume primarily alewife (Werner et al., 2006). Atlantic salmon were probably forced to switch to other more numerous prey in Lake Huron when alewife populations crashed in 2003 (Riley et al., 2011). Cluster analysis of Atlantic salmon egg thiamine levels at the time of the crash in 2003 and six years later in 2009 revealed three different clusters which are assumed to reflect thiamine levels and amount of thiaminase in prey (Figure 9). The cluster with the lowest thiamine concentration involving mostly 2003 samples was probably associated with an alewife diet. There was a single sample collected in 2009 that fell into this cluster. Another cluster involving 2003 samples corresponded to a higher mean thiamine concentration and probably reflected a diet of rainbow smelt that contains some thiaminase. The mean thiamine concentration was still well below that of the five clusters identified among East Coast Atlantic salmon. In contrast to these two clusters, a third cluster associated with 2009 samples likely involved a diet having some combination of invertebrates or a fish such as round goby having low thiaminase. Stable isotopes and mixing models are being used to determine the probable diet composition of 2009 samples.

Cluster	Mean Thiamine (pmol/g)	SE	Probable Diet
1	1372	60	alewife
2	2946	217	smelt
3	5417	88	invertebrates

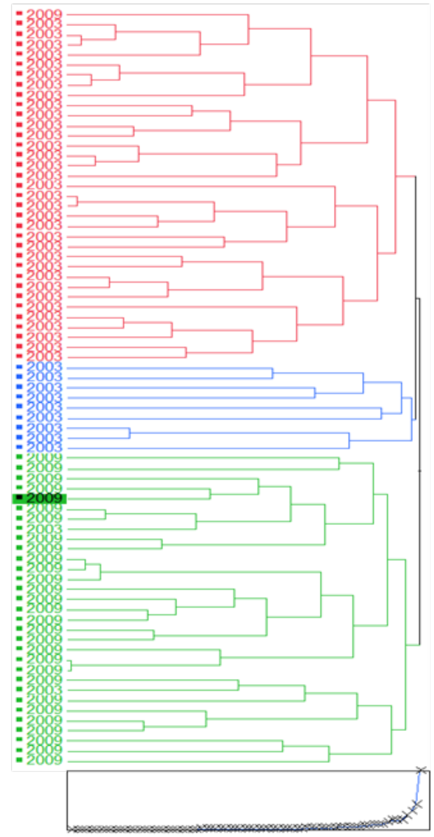

Figure 9.

Lake Champlain

Historically, Atlantic salmon in Lake Champlain were believed to consume primarily rainbow smelt (Ladago et al., in review). Alewife spread into Lake Champlain after gaining entry through Lake George and their abundance has since increased dramatically (L. Rudstam, personal communication). Given the consumption of alewife by Atlantic salmon in the Finger Lakes there was a strong possibility that Atlantic salmon in Lake Champlain would include alewife in their diet and although this has not been documented an effect on egg thiamine status of Lake Champlain Atlantic salmon been clearly established (Ladago et al., in review). Cluster analysis of Lake Champlain Atlantic salmon egg thiamine levels from 2004 before the alewife invasion and 2009 after the invasion had occurred indicated four clusters (Ladago et al., in review; Figure 10). The two clusters identified for exclusively 2004 samples having the highest egg thiamine concentrations probably correspond to a rainbow smelt diet and a diet containing some combination of invertebrates or a fish having low thiaminase. Thiamine concentrations associated with these two clusters are similar to cluster 3 and 4 for East Coast Atlantic salmon. The third cluster corresponding to mostly 2004 samples but with one 2009 sample, as well, had a lower mean egg thiamine concentration than the previous two clusters, and this may have corresponded to a mixed diet of rainbow smelt and other fish species or invertebrates but likely not alewife as 2004 predates their invasion of Lake Champlain. The fourth cluster, having the lowest mean egg thiamine concentration and comprised almost exclusively of 2009 samples, probably corresponded to an alewife diet, although levels were still over two-fold higher than for Lake Huron Atlantic salmon at the time of the alewife crash when Atlantic salmon were still likely to have had a high proportion of alewife in their diet.

Cluster	Mean Thiamine (pmol/g)	SE	Probable Diet
1	2751	212	smelt/alewife
2	5854	198	smelt
3	10150	313	other
4	14552	487	other

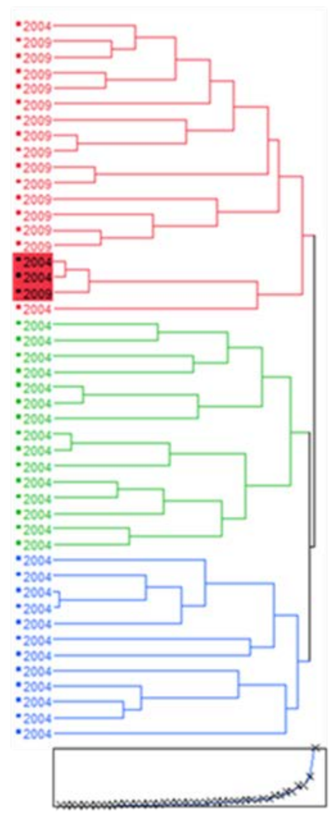

Figure 10.

Egg thiamine: comparison of hatchery and wild Atlantic salmon thiamine status

For the upper Credit River, when stable isotope data were used to assign putative redd identity (e.g. wild or hatchery), egg thiamine status of eggs excavated from redds varied ($F = 13.2$; $df = 4, 28$; $P < 0.001$) depending on the source of eggs (redd versus female) but not whether redds were of wild or hatchery origin (Table 3; Fitzsimons et al., 2013b). Overall, the highest egg thiamine concentration occurred in eggs from putative hatchery redds (14,865 pmol/g), but they were not different from eggs of known hatchery fish (14,200 pmol/g). Similarly, there was no difference in thiamine levels among the eggs of known wild spawners (3,692 pmol/g) and eggs from redds of known wild spawners (6,511 pmol/g) on Rodgers Creek, a tributary of the Credit River, and eggs from redds of putative wild spawners on the Credit River (8,474 pmol/g). Thiamine levels of eggs from putative hatchery redds, were significantly higher ($P < 0.05$) than eggs of known wild spawners (3,692 pmol/g) but not eggs from redds of putative wild spawners (8,474 pmol/g). The thiamine concentration of eggs from known wild redds on Rodgers Creek (6,511 pmol/g) differed ($P < 0.05$) from that of eggs from putative hatchery redds on the Credit River. In contrast, the eggs of putative wild redds (8,474 pmol/g) on the Credit River did not differ from that of putative hatchery redds ($P > 0.05$). The difference among groups did not appear related to the size of spawner since the thiamine concentration of eggs removed from known wild spawners was unrelated ($r = 0.37$, $df = 5$, $P > 0.05$) to the size of spawner.

Source of eggs	Type of female or redd	Location	N (pmol/g)	Thiamine mean (SE)
Females	Wild, known	Credit River	6	3,692 (783) y
Redds	Wild, putative	Credit River	14	8,474 (840) zy
Redds	Hatchery, putative	Credit River	6	14,865 (1,050) z
Redds	Wild, known	Rodgers Creek	5	6,511 (1,931) y
Females	Hatchery, known	Hatchery	5	14,200 (1,167) z

Table 3. Summary of egg thiamine for wild and hatchery Atlantic salmon eggs removed from females or redds on the Credit River and Rodgers Creek in 2009. Means followed by the same lowercase letter in the same column are not significantly different ($P > 0.05$).

Adult muscle thiamine

Thiamine levels in the muscle of Atlantic salmon collected in 2010 were generally above a threshold of 500 pmol/g associated with mortality and 1300 pmol/g associated with altered behaviour in other adult salmonines showed no obvious trend with fish size (unpublished data, John Fitzsimons; Figure 11; Brown et al., 2005). Some fish were below a concentration associated with altered behaviour in juvenile salmonines which appear to be more sensitive to the effects of thiamine deficiency than adults (Morito et al., 1996; Ketola et al., 2010; Figure 11)

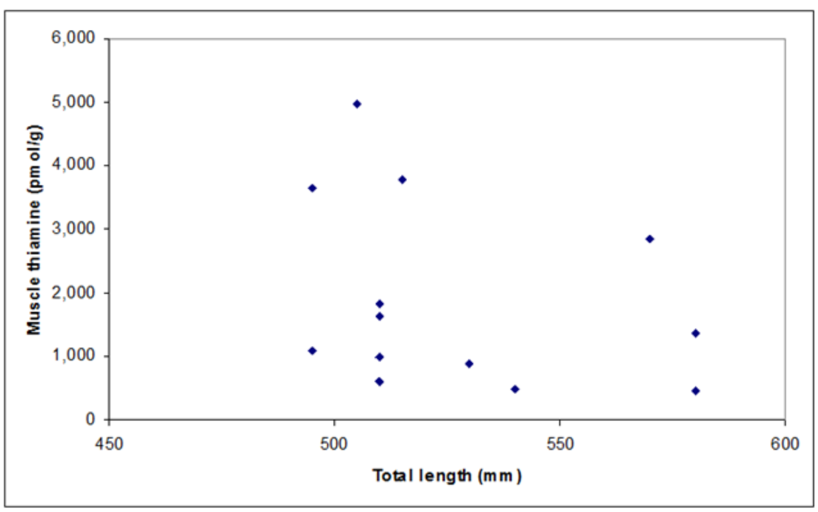

Figure 11.

Relationship of muscle thiamine to diet

Based on four years of data, albeit with relatively small sample sizes, estimates of diet composition using stable isotopes in Atlantic salmon and their potential prey showed that alewife comprised a relatively low percentage of the diet of Lake Ontario Atlantic salmon (unpublished data, John Fitzsimons; Figure 12). It was estimated that round goby made up the bulk of the diet in three of four years with emerald shiners being dominant in the fourth year.

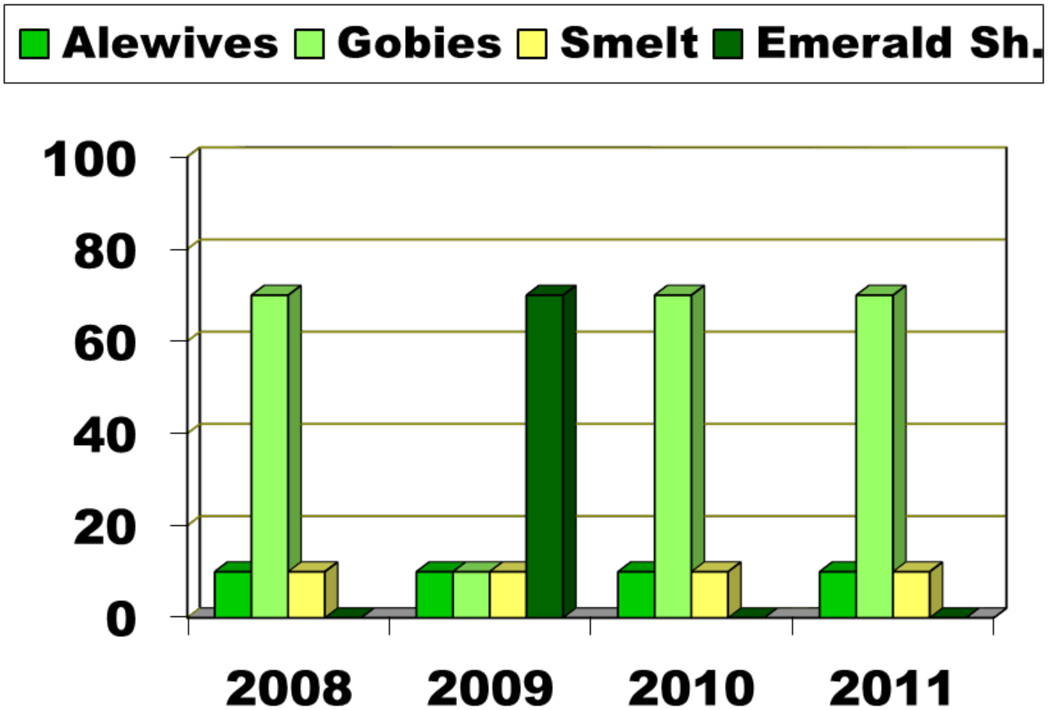

Figure 12.

Evidence for population specific variation in sensitivity to thiamine deficiency

There is no evidence for inter-population variation in sensitivity to thiamine deficiency for Atlantic salmon, although there is for lake trout based on differences in thiamine clearance by embryos between the time of fertilization and the sac-fry stage (unpublished data, John Fitzsimons). Of five populations evaluated—one with no alewife in the diet (Lake Manitou) and four (Seneca Lake, Lake Ontario, Charleston Lake, and Cayuga Lake) where alewife are the major prey—there was a significant decline in thiamine levels between fertilization and the sac-fry stage among all populations (Table 4; Figure 13). The rate of decline for Seneca Lake lake trout was less than that for the other populations (Table 5). The rate of decline for Cayuga Lake which was the highest overall, was greater than for all other stocks with the exception of Lake Ontario. The reasons for the variation in thiamine clearance rate among populations are not known.

Population	Intercept (SE)	Slope (SE)	Test statistic (slope not equal to 0)
Seneca	0.3617 (0.0892)	-0.4895 (0.1057)	4.632*
Ontario	0.8410 (0.1665)	-1.3921 (0.1543)	9.023*
Charleston	0.0081 (0.1224)	-1.1681 (0.1729)	6.757*
Manitou	2.8540 (0.0970)	-1.1369 (0.1340)	8.487*
Cayuga	1.8195 (0.1357)	-1.7194 (0.1945)	8.842*

Table 4. Results of ANCOVA to assess the effect of population on thiamine clearance rate. * significantly different from 0.

Population	Seneca	Ontario	Charleston	Manitou	Cayuga
Seneca	0.000				
Ontario	4.827*	0.000			
Charleston	3.349*	-0.967	0.000		
Manitou	3.794*	-1.249	-0.143	0.000	
Cayuga	5.557*	1.319	2.119*	-2.246*	0.000

Table 5. Comparison of the slopes of the relationship between log thiamine (nmol/g) and time (degree-days) for five lake trout populations. Cells at the interception for two populations with * are significantly different.

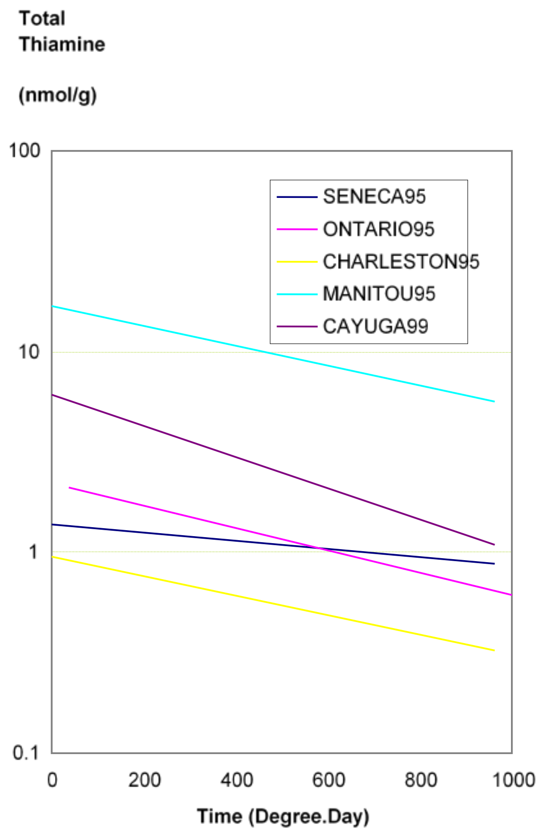

Figure 13. Relationship between average thiamine concentration and time (degree-days) for five lake trout populations based on parameters from ANCOVA.

Management implications

Based on the Finger Lakes and the work of Jeffery Fisher and colleagues, Atlantic salmon can be extremely sensitive to the effects of an alewife diet when prey lacking thiaminase are either absent or present at low abundance. However, as demonstrated for Lake Ontario lake trout, even a relatively small proportion of alewife in the diet of Atlantic salmon could dramatically lower thiamine levels in muscle and as a result levels in eggs with negative consequences for embryo survival. At present, Lake Ontario Atlantic salmon appear to be relying mostly on round gobies but are in competition with several other species including lake trout, brown trout, rainbow trout and smallmouth bass that also consume round goby and should round goby abundance decline, Atlantic salmon use of alewife may increase.

The effects of thiamine deficiency in adult Atlantic salmon in Lake Ontario may only become apparent in the presence of other stressors that increase the metabolic demand for thiamine. On the Salmon River, a tributary of Lake Ontario, Everitt (2006) observed higher-than-expected prespawning mortality of migrating adult Lake Ontario chinook salmon during 2004–2005 which he attributed to the combined effects of high angling pressure, temperature stress, and thiamine deficiency but was unable to partition the individual effects of each. Mortality of prespawning adults during 2005 of 44 % (Everitt, 2006), was similar to the proportion (50 %) of spawning size Lake Ontario chinook salmon (> 800 mm) collected in 2005–2006 with muscle thiamine concentrations < 500 pmol/g (unpublished data, John Fitzsimons). The stress of angling and elevated temperature would be expected to increase the production of lactic acid which is metabolized to pyruvate. Since thiamine deficiency results in increased plasma concentrations of pyruvate and lactate due to inhibition of thiamine pyrophosphate-dependent pyruvate dehydrogenase (Combs, 1992; Molina et al., 1994), it would be expected that a pre-existing thiamine deficiency would exacerbate the effects of angling and elevated temperature and such effects may be progressive during the spawning run. Thiamine-deficient coho salmon on their spawning migration underwent a 50 % decline in muscle thiamine concentration from when they first entered the spawning river from the lake to the time they reached a collection weir 15 km upstream, and exhibited increased mortality even in the apparent absence of high angling or elevated temperature stress (Fitzsimons et al., 2005).

Atlantic salmon can enter spawning rivers as early as June when they cease feeding. In the absence or spatial restriction of coldwater habitat, they may experience much greater effects from high water temperatures on thiamine reserves than species like chinook salmon that ascend spawning streams near coincident with spawning and much later in the summer or fall when water temperature is declining. If it was concluded that Atlantic salmon were failing to ascend rivers to spawn because of a lack of thiamine or dying en route, it may be possible to capture them and administer sufficient thiamine for them to complete migration and deposit sufficient thiamine in the eggs for good survival. Using thiamine injection (50 mg thiamine/kg body weight) of ascending adult female coho salmon on the Platte River, Michigan, Fitzsimons et al. (2005) investigated the effects of thiamine supplementation on migration, adult survival, and thiamine status. The thiamine concentrations of eggs, muscle (red and white), spleen, kidney (head and trunk), and liver and the transketolase activity of the liver, head kidney, and trunk kidney of fish injected with thiamine dissolved in physiological saline (PST) or physiological saline only (PS) were compared with those of uninjected fish. The thiamine injection did not affect the number of fish making the 15 km upstream migration to a collection weir but did increase survival once fish reached the upstream weir, where survival of PST-injected fish was almost twice that of controls. The egg and liver thiamine concentrations in PS fish sampled after their upstream migration were significantly lower than those of non-injected fish collected at the downstream weir, but the white muscle thiamine concentration did not differ between the two groups. At the upper weir, thiamine levels in the liver, spleen, head kidney, and trunk kidney of PS fish were indistinguishable from those of non-injected fish (called “wigglers”) suffering from a severe deficiency and exhibiting reduced equilibrium, a stage that precedes total loss of equilibrium and death. For PST fish collected at the upstream weir, total thiamine levels in all tissues were significantly elevated over those of PS fish. Based on the limited number of tissues examined, thiamine status was indicated better by tissue thiamine concentration than by transketolase activity. The adult injection method used appeared to be a more effective means of increasing egg thiamine levels than immersion of eggs in a thiamine solution. In another study where Atlantic salmon were injected at a thiamine concentration that was one-seventh (7 mg/kg) of that used by Fitzsimons et al (2005), there was only a 1.5-fold increase in total egg thiamine concentration after two to three weeks (Ketola et al., 2000) whereas Fitzsimons et al. (2005) reported a 29-fold increase. The difference likely reflected the higher dose Fitzsimons et al. (2005) used as a 20-fold increase was noted by Börjeson et al. (1999) for Atlantic salmon eggs when adults were injected with 100 mg/kg of thiamine. However, the dose administered by Börjeson et al. (1999) was twice what Fitzsimons et al. (2005) used, which suggests that coho salmon may respond differently from Atlantic salmon in their deposition of thiamine Moreover, the increases observed by Fitzsimons et al. (2005) after 4 weeks may not fully represent final tissue concentrations as far fewer significant correlations were evident between thiamine concentrations in individual tissues for PST fish than for PS fish, suggesting that tissue thiamine concentrations in PST fish had not yet equilibrated with the injected thiamine.

Injection of broodfish, if done sufficiently before the time of ovulation, appears to be far more effective and practical than egg immersion in increasing egg thiamine concentrations in the wild and avoiding EMS. Thiamine prophylaxis developed to counteract the thiamine deficiency in the hatchery has become an important means of maintaining salmonine based sport fisheries in the Great Lakes but is inappropriate if natural reproduction is the management goal (Brown et al., 2005b). Close to 100 % early mortality syndrome (EMS) has been observed in some years for Lake Michigan coho salmon (Fitzsimons et al., 1999, Brown et al. 1998, 2005a). During these years, it was only possible to maintain hatchery production by bathing affected fry in thiamine (M. Wolgamood, MDNR, Wolf Lake hatchery, personal communication). Recruitment of coho salmon in Lake Michigan is almost totally dependent on hatchery production although some natural reproduction occurs (Carl, 1982, 1983). Similarly, in Lake Ontario, EMS is believed to be a major bottleneck to restoring lake trout populations in this lake (Fitzsimons et al., 2003; Brown et al., 2005a). Reproduction by coho salmon in Lake Ontario is very limited (J. Bowlby, OMNRF, Picton, ON, personal communication) and recent attempts to establish runs appear to have failed (M. Daniels, OMNRF, Peterborough, ON, personal communication). Hornung et al. (1998) using a thiamine immersion bath containing 960 mg/L was only able to increase coho salmon egg thiamine concentrations to 2 nmol/g, an increase of approximately twofold over controls. This level is just slightly above the approximately 1 nmol/g threshold for EMS noted by these authors. Based on investigations into the sublethal effects of a thiamine deficiency on larval lake trout, egg thiamine concentrations above 4 nmol/g or twice that associated with 50 % mortality from EMS would need to be reached to overcome the effects of thiamine deficiency on larval growth (Fitzsimons et al., 2009). The average egg thiamine concentration that Fitzsimons et al. (2005) achieved (22 nmol/g) for coho salmon was well in excess of the EMS threshold and probably exceeded thresholds for most other sublethal effects as well.

Although much of what is known about the effects of an alewife-induced thiamine deficiency on salmonine reproduction in the Great Lakes and is presented in this review pertains to salmonines other than Atlantic salmon, many of the same processes likely apply, and where they differ, these have been highlighted. As indicated, the proportion of alewife in the diet is likely the most important factor in determining thiamine status, although this effect may be much greater than expected for a given proportion of alewife in the diet. Thiamine levels appear adequate for reproduction for some Lake Ontario

Atlantic salmon given spawning of eggs with thiamine levels above thresholds in the upper reaches of the Credit River, but this is based on relatively small sample sizes. Small sample sizes have been a problem that has plagued, and may continue to plague advancements in the appraisal of the thiamine status of Lake Ontario Atlantic salmon and the extent to which thiamine deficiency may represent an impediment to restoration of self-sustaining Atlantic salmon populations in Lake Ontario. Small run sizes in spite of apparent increases in adults in Lake Ontario is a major impediment to the Atlantic Salmon Restoration Program, although it is uncertain to what extent thiamine deficiency may be involved. In future, studies need to take advantage of the large strides that have been made in biotelemetry and that have allowed the tracking of movements of adult salmonines over large areas of the lake and use of spawning habitat. Such work, if undertaken on Lake Ontario, would be highly complementary with river specific telemetry that could look at such factors as run timing and relationship with environmental factors as well as interactions with other species. Given the availability of effective methodologies for increasing thiamine levels in adult salmonines, the marriage of this work with biotelemetry seems an effective means for understanding the effects of current thiamine levels in influencing run size, timing and effectiveness.

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General discussion notes

Q: What is the effect of seasonal variation in in prey thiaminase levels?
A: Mixing models reflect some of that variation.

C: Gobies looks very prominent in the diet.

Q: Three-spine sticklebacks seen in Lake Ontario fish, is there a problem?
A: Should be in the model but it doesn't stick out.

Facilitated Discussion IV

Knowledge gaps

- Increased monitoring of hatchery products is needed, particularly for gill enzyme, condition factors, and temperatures.

- Natural enrichment experiments in hatcheries testing various treatments for increased fitness and survival are needed, such as mimicking ambient photoperiod, temperature and natural conditions. This could also include differences in flow, depth, cover, etc.

- How do we emulate ecological conditions in rivers in the hatchery to potentially improve fitness?

    - Increase the monitoring and research of yearling smolt behaviour and ecology.

- What does increased monitoring of tributary conditions entail?

    - Weather-related events should be included as well as monitoring temperatures for each of the systems 365 days a year.

    - Examples of additional info would be ice development, overwinter conditions, ice breakup timing, extent and scour potential and results.

    - We need to verify data available for Cobourg Creek, including temperature, flows, etc.

    - An additional info summary of real-time flow data and turbidity would aid in understanding migration of both smolt and adults.

    - Pulse flows in relation to movement of fish should be monitored, which could also include turbidity, sediment flow, and temperature.

    - Stocking requires site-specific monitoring and measurements.

- We need a better understanding of conditions in Lake Ontario. This includes

    - Smolt – BDA and adults; BDA

    - Events, weather conditions, and food

- We need to improve adult monitoring in rivers, especially in late spring and early summer. This includes increased surveillance for evidence for natural reproduction.

- Experiments on effects of stocking locations should be done in respect to distance, barriers, and timing. These experiments can provide data such as the relationship of dams and barriers to migration. This allows us to improve geographical locations in relation to temperatures, distance to the lake, barriers, etc.

- We need to improve our knowledge of the success rate for each of the strains and each of the stages stocked. This could include reviewing our methodologies, verifying them, and adding new methods for additional info such as telemetry, radio tracking, PIT tags, enzyme analyses, weir efficiencies, and more weirs. We would then be able to track the fish out of the river and look at experimental designs that exist such as genetic tagging to determine more that could be added to help answer additional questions that have come up.

- Fishway efficiencies and barrier impact should be reviewed.

- We should engage anglers and other interested people to help us collect data and monitor movement of adults and possibly smolt.

- Current available structures for evaluating migration of smolts and adults should be reviewed to determine whether our fishways and barrier dams are set up to efficiently monitor movements in and out of the river.

- We should increase resolution on factors influencing tributary survival and behaviour, outmigration, condition, time of returns and conditions by using new designs, PIT tags, and telemetry.

- Better information should be explored on the life history characteristics of other species in relation to their habitat use, life history pattern and potential impact on Atlantic salmon. This may help inform our understanding of species interactions in relation to Atlantic salmon. Some examples of locations for this type of work could include Wilmot Creek and Ganaraska in relation to stocking and timing.

- Chinook salmon and Atlantic salmon migration interference should be examined, particularly in the lower Credit River. We should also collect anecdotal info from other jurisdictions as in the St. Mary’s example from Roger.

- We should consider removing experiments of other species to determine if there is a positive impact on Atlantic salmon.

- Bryan Neff’s proposal in his short presentation shows research on factors that might be impeding juvenile life stages.

- We should consider thiamine-monitoring in the adult fish prior to wild production to determine if we have a problem. With this initiative we can continue monitoring the food web and trophic structure of Atlantic salmon in comparison to other salmonids, both from lakes and weir-caught fish. We can also monitor the potential prey.

- We also want info on growth, age, etc.

Management implications

- Consider reducing efforts to only one stream in order to increase staffing and capability for experimenting with the animals for the intent for restoration. This could improve the ability to better understand challenges and opportunities to optimize returns and restoration. Working on a smaller system also may have to be considered in order to get good results in a timely fashion with fewer problems.

- What are the risks and opportunities when re-considering the potential to establish a Lake Ontario broodstock based on returning adults?

    - New York is moving in this direction.

    - It takes at least 5 years to create this type of stock, so any interest should be addressed now.

    - There are still holding facilities at Ringwood.

    - Fitness of existing stocks and strains must be assessed for fitness over time.

    - The out-breeding depression that could be created by crossing strains should be explored. Is this a potential risk? Aimee suggests we might not see this until the second generation. Therefore, crossing strains may create an artificial impression of increased vigor, but this is likely an illusion and will fall apart.

- A re-evaluation of candidate tributaries in relation to landscape conditions and to consider present and future conditions would help to improve the restoration outcomes. This would examine potential impacts of climate change and changes in land use, stormwater, development, etc.

- The risks, benefits, and feasibility of species-removal experiments should be considered.

- Calculating the wild smolt production capacity of our streams would properly determine or modify reasonable expectations for restoration, especially when discussing them with the public. This can be considered a part of the landscape considerations.

- Are we truly applying an adaptive management approach in this program and in each of the streams?

- We need to improve data and information management.

Appendix A: Lake Ontario Atlantic Salmon Restoration Science Workshop Agenda

February 18–20, 2014
Chair: Tom Stewart
Steering Committee: Jack Imhof, Kevin Loftus, Chris Robinson, Chris Wilson, Evan Hall

Tuesday		
17:30–18:30		Dinner
18:30–19:30	Tom Stewart and Evan Hall	Introduction to Workshop
20:00–?		Social/Meet and Greet
Wednesday		
8:00–8:15	Evan Hall and Tom Stewart	Introductory Remarks
8:15–8:40	Jim Johnson USGS	Lake Ontario NY restoration overview
8:40–9:05	Bill Ardren	Lake Champlain restoration overview
9:05–9:9:15	Tom Stewart	Introduction of Lake Ontario Atlantic salmon plan survival benchmarks (Question 1)
9:15–9:30	Chris Wilson	Genetic methodology review
9:30–9:50	Jim Bowlby	Atlantic salmon parr performance (Question 2)
9:50–10:10	Marc Desjardins	Atlantic salmon smolt performance (Question 2)
10:10–10:30		Break
10:30–10:50	Chris Wilson	Atlantic salmon adult performance (Question 2)
10:50–11:10	Les Stanfield	Understanding factors that influence Atlantic salmon survival from stocking strategies
11:10–12:15	Facilitated Discussion	Discussion: Knowledge gaps, hypotheses,

		management implications
12:15–1:30		Lunch
1:30– 2:00	Facilitated Discussion (cont.)	Discussion: Knowledge gaps, hypotheses, management implications
2:00–2:30	Rick Cunjak	Seasonal drivers of juvenile survival
2:30–2:45	Evan Hall and Colin Lake	Where did we stock fish? (Question 4b)
2:45–3:00	John Fitzsimons	What do we know about spawning substrate requirements? (Question 4d)
3:00–3:20		Break
3:20–3:40	Dave Cote	Considerations related to aquatic connectivity in habitat suitability assessments
3:40–4:00	Les Stanfield, Colin Lake, and Jim Bowlby	A landscape perspective: Linking survivor densities with landscape model predictions? (Question 4e)
4:00–5:30	Facilitated Discussion	Discussion: Knowledge gaps, hypotheses, management implications
6:00–7:30		Dinner
7:30–?		Social
Thursday		
8:00–8:30	Steve McCormick	Drivers of smolt development
8:30–8:45	Bill Ardren	Lake Champlain Experimental Stocking Results
8:45–9:05	Roger Greil	A perspective on Atlantic salmon culture and stocking

9:05–9:15	Evan Hall	Influence of time of release and size on survival from the literature (Question 3a)
9:15–9:25	Jim Bowlby	Influence of stocking size of Atlantic salmon on expected survival to smolt in the Credit River (Question 3b)
9:25–9:45	Jack Imhof, Steve McCormick, and Jerry Smitka	Influence of stocking site distance to river mouth on survival to smolt (Question 4c)
9:45–10:05	Ryan Zheng	Can we produce fish with the right characteristics for survival (Question 3c)
10:05–10:30		Break
10:30–11:30	Facilitated Discussion	Discussion: Knowledge gaps, hypotheses, management implications
11:30–11:50	Tom Stewart and Tim Johnson	Lake effects on survival (Question 5a)
11:50–12:10	John Fitzsimons and Aimee Houde	Is thiaminase an impediment to Lake Ontario restoration? (Question 5b)
12:10–12:30	Aimee Houde and Evan Hall	Interspecific competition in tributaries (Question 5c)
12:30–13:30		Lunch
13:30–14:00	Facilitated Discussion	Discussion: Knowledge gaps, hypotheses, management implications
14:00–14:30	Tom Stewart	Wrap-up and adjourn workshop

Appendix B: Questions Posed to Investigators by Theme

Theme	Question
1.0 Are we meeting our survival benchmarks?	**la)** In the three initially-stocked tributaries (Credit River, Duffins Creek, Cobourg Creek) have restoration plan benchmarks for fingerling density (5–50/100m^2), survival from fingerling to smolt (at least 20%), and spawning adult density (2–20 adults/ha) been met and, if not, what are the likely mechanisms preventing attainment of the benchmark values?
2.0 What have we learned from the Lake Ontario stocking of different strains and life stages?	**2a)** What is the Lake Ontario performance (fall stocking density, estimated smolt equivalents; based on survival or measured, growth/size, adult return) of the different strains of Atlantic Salmon stocked?
	2b) What is the Lake Ontario performance (fall stocking density, estimated smolt equivalents; based on survival or measured, growth/size, adult return) of the different life stages Atlantic Salmon stocked?
	2c) What is the ratio of the number of fish stocked by life stage and their performance indicator (fall stocking density, estimated number of smolt equivalents [calculated from survival estimates] observed [not total] adult return)?
3.0 What is the influence of culture practices on the survival of stocked fish?	**3a)** What are the effects of size and time at release of fish stocked in Lake Ontario (for each life stage) on survival to smolt or other measures of survival (spawning returns, weir returns, angling returns) following stocking?

	3b) What are the effects of size, temperature, time at release of fish stocked, imprinting or other related factors observed in other systems (for each life stage) on survival to smolt, or other measures of survival (spawning returns, weir returns, angling returns) following stocking?
	3c) Do we know how to produce fish that have the target characteristics (length, weight, condition, developmental stage, physiology, fitness, imprinting ability) that will increase their survival following stocking including survival to spawning adult?
4.0 What habitat or biotic conditions in Lake Ontario and its watershed are influencing ATS restoration outcomes?	**4a)** What are the habitat requirements for each stocked life stage that will maximize survival to fall fingerling or yearling?
	4b) Are our stocking locations and associated habitat conditions and expected spawning habitats sufficient for survival and spawning success, or do we know?
	4c) Is there evidence that the distance from stocking location to the river mouth will influence the survival to smolt or imprinting of Atlantic salmon? If so is it related to temperature, distance, and/or physiological timing? (General question to all scientists presenting) Given the stocking history of Atlantic salmon in Lake Ontario, how likely is it that this factor has reduced survival to smolt?
	4d) What are the characteristics of spawning redd substrate and conditions that will increase hatching or emergence rates?

	4e) What do existing landscape analyses of watershed and predicted tributary conditions (e.g. Stanfield et al., 2004) tell us about the prognosis for Atlantic salmon tributary survival in Lake Ontario? How do the predictions of habitat suitability and inferred levels of survival from existing landscape analysis of stocked sites in the restoration tributaries (Credit, Duffins, and Cobourg) compare with measured survival of stocked Atlantic Salmon. Are the models right?
5.0 Are there species interactions that could significantly impede the restoration of ATS?	**5a)** What do we know about open lake species interactions? What does new diet or isotope data tell us about the potential for open lake competition. Review Lake Ontario Committee's approach to maintaining predator-prey balance in the open lake in the context of Atlantic Salmon restoration. How likely is it that open-lake harvest is causing excessive exploitation mor1ality?
	5b) Is there evidence that thiaminase in the diet of adult Lake Ontario Atlantic salmon poses a major impediment to their spawning success?
	5c) Summarize existing knowledge on inter-specific competition between Atlantic salmon and other salmonids in the tributaries from known historical Lake Ontario studies (Jones and Stanfield, 2003; Stanfiekt and Jones, 1993; Deitrich et al., 2004) and the literature. Evaluate the extent that competition with other salmonids, especially Rainbow Trout, could reduce the survival of stocked Atlantic salmon to a level that would significantly impede the restoration of Atlantic salmon in Lake Ontario?

Appendix C: List of Participants

Last Name	First Name	Affiliation
Ardren	Bill	U.S. Fish and Wildlife Service
Bowlby	Jim	Ontario Ministry of Natural Resources and Forestry
Clayton	Jon	Credit Valley Conservation Authority
Cote	Dave	Memorial University
Cunjak	Rick	University of New Brunswick
Damelio	Sylvia	Trout Unlimited
Desjardins	Marc	Ontario Ministry of Natural Resources and Forestry
Dietrich	Jay	AMEC Earth & Infrastructure
Durant	Gord	Ontario Ministry of Natural Resources and Forestry (retired)
Fitzsimons	John	Department of Fisheries and Oceans (retired)
Greil	Roger	Lake Superior State University
Hall	Evan	Ontario Ministry of Natural Resources and Forestry
Heaton	Mark	Ontario Ministry of Natural Resources and Forestry
Houde	Aimee	University of Western
Imhof	Jack	Trout Unlimited
Jakobi	Nina	Ontario Ministry of Natural Resources and Forestry
Johnson	Tim	Ontario Ministry of Natural Resources and Forestry
Johnson	Jim	U.S. Fish and Wildlife Service
Kidd	Anne	Ontario Ministry of Natural Resources and Forestry
Lake	Colin	Ontario Ministry of Natural Resources and Forestry
Loftus	Kevin	Ontario Ministry of Natural Resources and Forestry
Lunn	Greg	Ontario Ministry of Natural Resources and Forestry
Morrison	Brian	Ganaraska Region Conservation Authority
Neff	Bryan	University of Western
Portis	Rick	Toronto and Region Conservation Authority
Quinney	Terry	Ontario Federation of Anglers and Hunters
Rance	Tim	Toronto and Region Conservation Authority
Robinson	Chris	Ontario Federation of Anglers and Hunters
Rosborough	Dave	Ontario Ministry of Natural Resources and Forestry
Rosborough	Brian	Ontario Ministry of Natural Resources and Forestry
Simpson	Holly	Ontario Ministry of Natural Resources and Forestry
Smitka	Jerry	Trout Unlimited
Stanfield	Les	Ontario Ministry of Natural Resources and Forestry
Stewart	Tom	Ontario Ministry of Natural Resources and Forestry
Todd	Andy	Ontario Ministry of Natural Resources and Forestry
Tu	Christine	Toronto and Region Conservation Authority
Wilson	Chris	Ontario Ministry of Natural Resources and Forestry
Zheng	Ryan	Ontario Ministry of Natural Resources and Forestry

Appendix D: Stocked Life stage Performance Indicators

Tom Stewart, Evan Hall, and Colin Lake, Lake Ontario Management Unit, Picton, Ontario

At the workshop, data on life stage origin of observed adults returning were presented but were unable to assess performance by comparing returns relative to the number stocked. Following the workshop, data for the number of adults observed and the average (2009–2012) numbers stocked by life stage for the Credit River were applied to further evaluate life stage performance. A total of 84 returning adult Atlantic salmon were observed in the Credit River (Table 1). Genetic parentage analysis indicate that the majority of those were stocked as spring fingerlings (Table 1). The average number stocked by life stage was highest for spring fingerlings with much lower numbers for fall fingerlings and spring yearlings (Table 2). Based on these data, three performance indicators were calculated. The simplest is the number of observed adults per 1 million stocked which was highest (268) for spring fingerlings and lowest (36) for fall fingerlings (Table 3). The equivalent number of fish stocked to achieve the number of adults observed as spring fingerlings indicated that it would necessary to stock 7.5 times the number of fall-fingerlings as spring fingerlings, requiring that average stocking levels increase by a factor of 17.3. To achieve the same number of observed adults using spring yearling stocking would require 2.3 times as many spring yearlings and an increase in stocking levels by a factor of 13.8.(Table 3).

	Life-stage origin of observed adults				
Year	Spring Fingerling	Fall Finglerling	Spring Yearling	Unresolved	No Parents
2010	4	1	0	0	0
2011	37	1	4	0	2
2012	16	2	1	1	1
2013	12	0	0	2	0
Sum	69	4	5	3	3

Table 1. Number of adults Atlantic salmon observed in the Credit River from all sources by life stage and year. Life stage at stocking was determine by parentage analysis using genetic markers.

	Number stocked		
Year	Spring Fingerling	Fall Finglerling	Spring Yearling
2009	223325	150216	31886
2010	321558	91814	43140
2011	235632	113156	45907
2012	250232	90203	49606
Average	257687	111347	42635
Standard Deviation	43978	27944	7640

Table 2. Numbers of Atlantic salmon stocked by life stage and by year (2009–2012) in the Credit River. Database was edited and numbers updated (August 2014) after the workshop.

Life-stage	Stocked (1000s)	Observed	Number adults observed/ million stocked	Equivalents to achieve Spring Fingerling performance	Proportional increase in stocking to get the same number of adults returning as Spring Fingerlings
Spring Fingerling	258	69	268	1.0	1.0
Fall Finglerling	111	4	36	7.5	17.3
Spring Yearling	43	5	117	2.3	13.8

Table 3. Performance measure by life stage for returning Atlantic salmon adults observed in the Credit River relative to average (2009–2012; Table 2) stocking numbers.

Appendix E: Glossary of Latin Names Used

alewife: *Alosa pseudoharengus*

American eel: *Anguilla rostrate*

Atlantic (or Baltic) herring: *Clupea harengus*

Atlantic (or Baltic) salmon: *Salmo salar*

bloater: *Coregonus hoyi*

brown trout: *Salmo trutta*

chinook salmon: *Oncorhynchus tshawytscha*

chironomid: *Chironomus plumosus*

coho salmon: *Oncorhynchus kisutch*

deepwater sculpin: *Myoxocephalus thompsonii*

gammarid: *Rivulogammarus lacustris*

gizzard shad: *Dorosoma cepedianum*

Japanese eel: *Anguilla japonica*

lake trout: *Salvelinus namaycush*

lake whitefish: *Coregonus clupeaformis*

ninespine stickleback: *Pungitis pungitius*

rainbow smelt: *Osmerus mordax*

rainbow trout (steelhead): *Oncorhynchus mykiss*

round goby: *Neogobius malanostomus*

sea lamprey: *Petromyzon marinus*

slimy sculpin: *Cottus cognatus*

spottail shiner: *Notropis hudsonius*

sprat: *Sprattus sprattus*

threadfin shad: *Dorosoma petenense*

yellow perch: *Perca flavescens*

zebra mussel: *Dreissena polymorph*