SUPPLEMENTATION OPTIONS TO AID RECOVERY OF THE ENDANGERED ATLANTIC WHITEFISH (*COREGONUS HUNTSMANI*)

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by

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ABSTRACT

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Recent unauthorized introductions of non-native piscivorous fishes into endangered Atlantic whitefish (*Coregonus huntsmani*) habitat have elevated concern for the prospects for their survival and eventual recovery. Range extension could reduce dependency for species survival on the continued viability of the localized population that exists in the three small semi-natural lakes within the Petite Rivière that define the global distribution of Atlantic whitefish. The likelihood is low that range extension will occur from natural colonization of new habitat. Supplementation, or stocking, fish within the natural historic range of Atlantic whitefish may be required to increase the abundance of the naturally reproducing populations. There is presently minimal documentation, specific to Atlantic whitefish, available to support the development of supplementation activities, or to guide release strategies. This report reviews the challenges that the current status of Atlantic whitefish present to the design and implementation of supplementation activities enacted to aid either survival or recovery. A frame work is proposed to help select stocking methods, stocking locations, and the choice of the stocking target as either enhancement of the existing population, or development of anadromous populations and/or additional freshwater-resident populations. Supplementation actions designed to restore anadromy to the extant Petite Rivière population may currently offer the greatest conservation benefit to Atlantic whitefish.

RÉSUMÉ

Bradford, R.G. 2017. Options d'ensemencement pour aider au rétablissement du corégone de l'Atlantique (*Coregonus huntsmani*) Rapp. manus. can. sci. halieut. aquat. 3124: vi +29p.

De récentes introductions non autorisées de poissons piscivores non indigènes dans l'habitat du corégone de l’Atlantique (*Coregonus huntsmani*) en voie de disparition ont accentué les préoccupations concernant les perspectives pour sa survie et son éventuel rétablissement. L'élargissement de l'aire de répartition pourrait réduire la dépendance de la survie de l'espèce à la viabilité continue de la population localisée vivant dans les trois petits lacs semi-naturels de la Petite Rivière qui définissent l'aire de répartition mondiale du corégone de l'Atlantique. Il est peu probable que l'élargissement de l'aire de répartition se produira avec la colonisation naturelle d'un nouvel habitat. L'ensemencement ou l'empoissonnement dans l'aire de répartition historique naturelle du corégone de l'Atlantique peuvent être nécessaires pour accroître l'abondance des populations qui se reproduisent naturellement. Il y a actuellement peu de documentation propre au corégone de l'Atlantique disponible pour appuyer l'élaboration de stratégies d'ensemencement ou pour orienter les stratégies de remise à l'eau. Le présent rapport examine les défis que pose l'état actuel du corégone de l'Atlantique pour la conception et la mise en œuvre d'activités d'ensemencement adoptées afin d'aider à la survie ou au rétablissement de l'espèce. Un cadre est proposé afin d'aider à sélectionner les méthodes d'empoissonnement, les lieux d'empoissonnement et le choix de la cible d'empoissonnement, à titre de mise en valeur de la population existante ou de développement de populations anadromes ou d'autres populations d'eau douce. Les mesures d'ensemencement visant à rétablir l'anadromie de la population existante de la Petite Rivière peuvent offrir à l'heure actuelle le plus grand avantage en matière de conservation pour le corégone de l'Atlantique.

INTRODUCTION

Recent unauthorized introductions of non-native, piscivorous Smallmouth bass (*Micropterus dolomieu*) and Chain pickerel (*Esox niger*) into endangered Atlantic whitefish (*Coregonus huntsmani*) habitat (Themelis et al. 2014) have elevated concern that their conservation status is at risk of further decline. It is not clear whether Atlantic whitefish can remain viable within the three small (16 km^2 total surface area) semi-natural lakes that define their range in the wild or whether the impact of these species on Atlantic whitefish and their supporting habitat can be managed. Alternatives to reliance on the viability of the extant Atlantic whitefish populations for species survival are being evaluated.

Supplementation of natural production by stocking fish, either propagated by captive breeding or captured from a water body for translocation to another water body, is a common practice to increase fish production for conservation purposes. Both propagation and translocation have been proposed as aids to recovery of Atlantic whitefish (DFO 2009) and technical expertise has been developed for the captive breeding and rearing of Atlantic whitefish (Whitelaw et al. 2015). However, guidance on the application of propagation and translocation to aid Atlantic whitefish survival or recovery is lacking.

The objectives of this report are to:

1. Summarize the evolutionary, conservation, and demographic status of Atlantic whitefish and identify the specific elements of their biology and current status that require consideration while planning supplementation activities.
2. Summarize the scope of propagation and translocation activities that have been conducted elsewhere to supplement fish production for the purposes of survival or recovery, and as well the benefits and risks that are associated with each option.
3. In light of Objective 1, identify options for supplementation of Atlantic whitefish and the life-stage(s) when fish releases could occur.
4. Describe the attributes of supplementation activities that can help to improve effectiveness.
5. Rank the supplementation options available to improve the status of Atlantic whitefish.
6. Provide recommendations.

The intentional movement of animals into vacant habitat or areas of low population density is practiced globally to meet conservation goals for a diversity of taxa (IUCN/SSC 2013). In many cases the terms and definitions associated with animal introductions are generally similar both within and among taxa (see IUCN/SSC 2013). However, the suite of activities initiated during animal introductions can vary depending on the aims, options, scope, and tools available to fulfill specific conservation objectives. The following definitions are applied in this document to help describe and discuss the options available to enable range extension of Atlantic whitefish. These have been drawn from the literature associated with aquatic organisms.

Augmentation is the addition of either propagated or translocated fish to an existing population.

Introduction is the relocation of fish outside of their native range.

Propagation is the production of individuals from captive reared brood stock for the purpose of reintroduction to the wild.

Reintroduction is a release of either propagated or translocated fish to habitat lying within the historic range of a species where population(s) no longer exist.

Stocking is used generically in this report to describe a release of fish into the wild.

Supplementation is the stocking of fish within the natural historic range of a species in order to increase the abundance of naturally reproducing fish populations. Supplementation involves the intentional demographic integration of hatchery and natural production (Fraser 2008), with the goal of improving the status of an existing natural population (Waples et al. 2007). Supplementation includes activities where fish may be stocked into barren habitat (Cuenco et al. 1993).

Translocation is the movement of wild-caught fish, or the progeny produced from artificial spawning of wild-caught parents, from one place to another within their known range.

ATLANTIC WHITEFISH

STATUS

Atlantic whitefish (*Coregonus huntsmani* Scott, 1987) are the sole extant member of the Coregonus lineage that diverged from the remainder of the genus during the Miocene era, approximately 15MY BPE (Before Present Era) (Crête-Lafrenière et al. 2012). They are irreplaceable, endemic to Canada, and exist only within the Province of Nova Scotia (Scott 1987). Atlantic whitefish are considered to be anadromous by nature (Scott 1967). The existing population is land-locked and limited in distribution to Minamkeak, Milipsigate and Hebb lakes within the Petite Rivière catchment, Lunenburg County (Bradford et al. 2004; Fig. 1). The anadromous population of the Tusket and Annis river drainages, Yarmouth County (Edge 1987a; Edge et al. 1991) is considered extirpated (DFO 2006, 2009; COSEWIC 2010). Construction, and the commissioning in 2012 (DFO 2012), of a fishway around the formerly impassable dam across the outlet of Hebb Lake, the lower most lake in the chain of lakes defining their global range, offers potential to re-introduce anadromy into the life-history of the species.

Long-term survival of the Petite Rivière populations is considered to be at risk from a combination of factors: a small (~16 km^2) global distribution; a low level of exhibited productivity; and the presence of illegally introduced, non-native, piscivorous Smallmouth bass (*Micropterus dolomieu*) (Bradford et al. 2010). The recently confirmed presence of reproductively active Chain pickerel (*Esox niger*) (Themelis et al. 2014) in Milipsigate and Hebb lakes, a result of another unauthorized introduction, has elevated the concern that the viability of these populations, and therefore, the species, is at further risk.

Atlantic whitefish were designated 'Endangered' by the Committee on the Status of Endangered Wildlife in Canada in 1983 (COSEWIC 2010). They have been listed and protected as endangered on Schedule 1 of the Canada *Species at Risk Act* (*SARA*) since June 2003 (DFO 2006). The Atlantic whitefish Recovery Strategy (DFO 2006, 2016) recognizes the benefits of reducing reliance on the extant land-locked populations of the Petite Rivière for survival. The overall goal of the strategy is "*Achieve stability in the current population of Atlantic whitefish in Nova Scotia, reestablishment of the anadromous form, and expansion beyond its current range"* (DFO 2006, 2016). None of the elements of the recovery goal have been achieved to date. It is now uncertain whether the watershed specific abundance target of >1,275 mature individuals[1] that was established by DFO (2009) can be maintained in the presence of both Smallmouth bass and Chain pickerel. The likelihood that range extension will occur through natural colonization of new habitat is considered to be low (DFO 2008).

SUPPLEMENTATION FOR ATLANTIC WHITEFISH SURVIVAL OR RECOVERY

Translocation of wild fish and the release of propagated eggs or fish into locations outside of the current distribution of Atlantic whitefish are two types of supplementation activities that have been identified as potentially useful for range extension (DFO 2006). Neither activity has been attempted as a concerted action to establish new self-sustaining populations of Atlantic whitefish. Experimental releases of Atlantic whitefish spawned in captivity from wild-caught parents have, however, occurred in recent years: into the Petite Rivière below the (then) impassable Hebb Lake Dam during 2007 - 2009 (Whitelaw et al. 2015) and into Anderson Lake, Halifax County, NS (Fig. 2) from 2005-2012 (Bradford et al. 2015). The releases occurred to make the best use of fish that were surplus to research requirements and as such were not specifically designed to increase the likelihood that additional self-sustaining populations could develop. Neither release appears to have resulted in spawning success, although the search effort for evidence of successful spawning has not been comprehensive for either one of the trial release locations.

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[1] Atlantic Whitefish abundance in the lakes has never been quantitatively assessed. The abundance target was defined by DFO (2009) as the number of individuals that would be required to maintain genetic diversity given an estimated effective population size of 500 adults.

LIMITATIONS AND UNCERTAINTIES

Imprecise understanding of habitat suitability and use

Habitat requirements for completion of the Atlantic whitefish life-cycle are known only in general terms. Field observations and measurements associated with spawning, and the progression from egg to sub-adult in the wild, are few for the land-locked form and absent for the anadromous form. Identification of important habitat has therefore been precautionary; i.e., all parts of the lakes where populations are present are considered to be important in the absence of contrary evidence (DFO 2009).

Neither the extent, nor the areas, of occurrence of Atlantic whitefish prior to the settlement of Nova Scotia by Europeans are known (Bradford et al. 2004, 2010). The Tusket and Annis rivers, which share a common estuary in Yarmouth County, and the Petite Rivière, Lunenburg County, defined their known global distribution at the time of their recognition as a distinct species in 1922 (Huntsman 1922). These historical contingencies lend uncertainty to the identification of water bodies beyond the Petite Rivière that offer suitable habitat for Atlantic whitefish, the life-history achievement objective (land-locked versus anadromous) of supplementation, and as well to definition of stocking targets relative to habitat carrying capacity. Available empirical measures of habitat suitability are limited to water quality, namely water temperature and pH (Cook et al. 2010). Current science advice concerning locations to attempt range extension is accordingly general in scope and suggests that any watershed within mainland Nova Scotia could be considered a potential candidate for Atlantic whitefish introduction, particularly watersheds lying within the bounds of their known former range (DFO 2009).

Anadromous donor populations do not exist

Land-locked fish represent the sole source of donor stock to facilitate anadromy. The prospects for successful development of anadromous populations via supplementation must therefore be assessed on the basis of experimental salinity tolerance evaluations (Cook et al. 2010) of progeny from land-locked parents.

Rehabilitation of habitat within the Petite Rivière lakes is not certain

Propagation and translocation are usually discouraged as substitutes for addressing the factors that resulted in species declines in the wild (Snyder et al. 1996). Elimination of threats is considered to be preferable (Snyder et al. 1996). The recent restoration of connectivity between Hebb Lake and tidal waters via construction of a fishway around a formerly impassable dam is one example of a preferred action to mitigate threats. However, experiences with invasive fish species control elsewhere (Halfyard 2010) indicate that the likelihood is low that the emergent threats presented by the establishment of Smallmouth bass and Chain pickerel in the Petite Rivière, can be addressed via their eradication from the lakes, tributaries and connecting waterways without risk of serious harm to Atlantic whitefish. It is also not certain at this time that removal-based measures to control invasive species could be applied at a scale to maintain the function of the lakes as supporting habitat for Atlantic whitefish.

Quantitative assessment of extant populations not currently possible

Current abundance, relative to minimum viable population size, is not known for any of the three lake populations of Atlantic whitefish. The number of fish that can be safely removed from the donor populations to support supplementation activities is not known.

PROPAGATION AND TRANSLOCATION AS CONSERVATION TOOLS

USES, LIMITATIONS AND RISKS

Propagation and translocation have been practiced extensively over many decades to aid the survival and/or recovery of a wide variety of endangered species, including fish species (George et al. 2009). They are frequently applied when wild populations do not appear to be sustainable without action (George et al. 2009). Both propagation and translocation are supplementation activities.

Propagation has been applied to fish populations in order to:

- enhance the productivity of existing populations,
- repatriate species to habitat formerly used by the species, and
- establish new populations where supporting habitat is considered to be available.

Propagation can play a crucial role in recovery of some species for which effective alternatives are unavailable in the short term. However, experience has shown that it should not displace habitat and ecosystem protection, nor should it be invoked in the absence of comprehensive efforts to maintain or restore populations in wild habitats (Snyder et al. 1996).

Translocation has been used to:

- extend the range of species by establishing new populations,
- prevent extinction following the loss of donor populations, and
- create reserve populations from which individuals are stocked into the habitat of the donor stock following mitigation of threats.

Translocation offers the potential for natural recruitment within the introduced population and may reduce many problems associated with propagation facilities, such as transmission of disease, domestication or artificial selection (George et al. 2009) and the inability to successfully propagate fish in a captive rearing environment (Chilcott et al. 2013).

Both techniques have limitations and carry risks that should be thoroughly assessed before proceeding. For propagation, these include (Snyder et al. 1996):

1. captive populations may not be self-sustaining, removals from the population to support supplementation actions may carry risks to population viability,
2. poor success owing to a number of factors that result in low survival or failure to successfully reproduce,
3. high costs,
4. domestication,
5. pre-emption of other recovery techniques,
6. disease outbreaks, and
7. maintaining administrative continuity.

Limitations and risks associated with translocations include:

1. large numbers of individuals (e.g., adults) may need to be removed from the donor population to enable development of a self-sustaining population elsewhere,
2. success is potentially low when the suitability of the receiving habitat is not known with certainty (George et al. 2009).

In the particular case where reserve populations are established to generate progeny for use in rehabilitating the donor population, it should be recognized that the progeny may:

1. be at a survival disadvantage when introduced into the original site,
2. not retain the potential for breeding with the source population and
3. differ in both phenotype and genotype from the source population (Etheridge 2009).

Both propagation and translocation are generally discouraged as continuous activities and their duration should be constrained to the time required to establish self-sustaining populations. The attributes of a self-sustaining population are defined as spawning-age adults and younger age classes at appropriate densities over a prescribed area (USFWS 2000). A requirement to monitor beyond completion of either activity should be anticipated (USFWS 2000). The length of time required to achieve self-sustainability may be lengthy.

FISH SUPPLEMENTATION WITHIN A CANADIAN CONTEXT

In Canada, preventative approaches and early intervention are priority measures to fulfil the ultimate goals of conserving biodiversity and preventing species from becoming at risk (National Framework for Species at Risk Conservation). Propagation and translocation are seldom considered to be proactive measures to conserve Canadian aquatic biodiversity. DFO-Science advice, specific to the role of supplementation as an aid to conservation, is limited to live gene bank activities and recommends that it should not be applied as a stand-alone solution to conservation of biodiversity (DFO 2008). Threats to wild populations must be addressed effectively for the conservation of biodiversity to be achieved (DFO 2008). This perspective is similar to that held within the United States of America, where the first priority for the recovery of a species is to improve the status of wild populations in their natural habitat (USFWS 2000). Propagation and translocation are accordingly discouraged as substitutes for addressing the factors that resulted in the decline of the species in the wild (Snyder et al. 1996; George et al. 1999). They are undertaken only if other recovery options addressing these factors are not likely to be effective in the foreseeable future (USFWS 2000).

Whichever option is chosen, the intent should be to replicate natural patterns of diversity and to allow the natural environment to drive the adaptation and fitness of the target population (Stockwell et al. 1996). Loss of genetic variation, both in captive and translocated populations, should be minimized (Stockwell et al. 1996) to help maintain overall fitness viability of the fish released to the wild, and those that result from natural production within the receiving water body.

RATIONALE FOR SUPPLEMENTATION OF ATLANTIC WHITEFISH

Bradford et al. (2004) compared fish assemblages, extensively surveyed in 2000-2001, from lakes within the Tusket-Annis river systems with historical (1952-1999) lake survey data to assess changes following unauthorized introductions of Smallmouth bass and Chain pickerel. The results indicated that most soft-fin rayed native fish species declined below the levels of detection once Smallmouth bass and Chain pickerel became established (Bradford et al. 2004). These data, acquired from river drainages within the known historical range of Atlantic whitefish (Edge and Gilhen 2001), indicate that populations of Smallmouth bass and Chain pickerel, now present in Milipsigate and Hebb lakes, present a high level of risk to the continued viability of this endangered species, a soft-fin rayed fish. These lakes represent 2 of the 3 lakes that currently define the global distribution of extant Atlantic whitefish and eradication of invasive predators from these lakes may not be possible. Whether removal based methods can be developed to mitigate the effects of invasive species on the Atlantic whitefish populations of Milipsigate and Hebb lakes is not known at this time.

Risks associated with not proceeding with recovery actions in a timely fashion include:

1. further decline in demographic status and increased uncertainty that the watershed abundance target of >1,275 mature individuals is being met;

2. modest removals of fish from Milipsigate and Hebb lakes to support range extension activities may not be possible over time without threatening survival; and
3. all prospects for species survival, and all future measures to enable recovery, will depend upon the status of a single lake population, Minamkeak Lake, where Smallmouth bass are established (Bradford et al. 2010).

ATLANTIC WHITEFISH SUPPLEMENTATION OPTIONS

Knowledge of the specific habitat traits, and the population dynamics, of Atlantic whitefish that allow completion of their life-cycle within the Petite Rivière is limited. The global extent of occurrence of Atlantic whitefish prior to development of industry in Nova Scotia is not known. Uncertainties associated with the current status of Atlantic whitefish, and therefore the availability of donor stocks, impose limits on the kinds of supplementation activities that can be considered. These factors in turn limit the ability to identify locations where self-sustaining populations, either anadromous or freshwater-resident, could be developed. Nonetheless, documented reviews of supplementation activities, conducted to aid the conservation of other freshwater fishes, provides insight into the attributes of successful projects (George et al. 2009). Consideration of these attributes in the context of Atlantic whitefish recovery planning and priorities, and in light of current limitations, should provide some guidance on a framework for supplementation activities enacted to improve the conservation status of Atlantic whitefish.

Briefly, the need for supplementation has to be clear; and supplementation, if enacted, should not result in harm either to donor populations, or to the aquatic ecosystem of the recipient water body (George et al. 2009). Supplementation projects are more likely to meet with success through careful selection of the donor stock, the method of supplementation and the release strategy (George et al. 2009). The capacity to assess the effectiveness of supplementation, through adequate monitoring, is imperative to support an adaptive management approach (George et al. 2009). Public support is important (George et al. 2009). These guidelines, which were largely developed through reference to North American freshwater fish species, are consistent with those developed for application to all taxa (IUCN/SSC (2013). IUCN/SSC (2013) recommend planning, feasibility and design, risk assessment, release and implementation, monitoring and continuing management as the core elements for reintroduction and translocation activities.

ATLANTIC WHITEFISH DONOR STOCK AND PRODUCTION TARGETS

The census population size of wild Atlantic whitefish is not known. Evaluation of supplementation methods, and locations to enable either freshwater residence or anadromy, is therefore limited to considerations of relative risk and the potential to manage these risks. Irrespective of the activity selected for application, constraints on the number of fish, and the life-history stage of fish, available for removal will likely apply for the reasons associated with population viability discussed above and the logistics of collections.

Tolerance of early-life stage Atlantic whitefish to broad ranges of water salinity, temperature, and pH, and tolerance to full sea-water by juveniles and adults (Cook et al. 2010), indicates that both anadromous runs and lake resident populations could be established, potentially in a broad range of river drainages (DFO 2009).

Sub-adult and non-spawning Atlantic whitefish are the only life-stages that have been caught on a regular basis (Bradford et al. 2004, 2010), and only at a single site below Milipsigate Dam. Specific spawning locations have never been identified, and even if known, the lateness of the spawning season (December-January; Whitelaw et al. 2015) would present difficulties for brood stock collection due to ice cover development. These constraints currently eliminate the following as options:

- Collection of adults in spawning condition for diversion into captive rearing facilities or direct transplant into vacant habitat, and
- capture of mature adults that could be stripped of eggs and milt for use in stocking before being returned to the wild, as practiced with coregonids in Europe (Maitland 2004; Adams et al. 2014) and in North America (Harris 1992; Harris and Hulsman 1991; Lassenby et al. 2001; Johnson et al. 2017).

Annual capture rates of wild sub-adult and adult Atlantic whitefish with non-lethal sampling gear have tended to vary between 20-70 per annum with modest effort (e.g., 5-10 days; Bradford et al. 2010). These relatively low yields, together with uncertainty in their future availability, eliminate as an option the translocation of fish of reproductive age due to:

- the overall uncertainty in the survival potential of fish translocated into new habitat, scale loss during capture/transport is known to reduce survival of wild-caught fish for example (John Whitelaw, DFO, personal communication);
- the reproductive success of low numbers of translocated adults is uncertain, several years of translocation activities may be required to establish a viable number of spawners and to either realize a conservation benefit or to determine the outcome;
- the number of translocated adults required to enable a stocked population to build to a watershed abundance target of >1,275 mature individuals is not known but probably significantly exceeds the number of fish available in a given year;
- the natural mortality of Atlantic whitefish in the receiving habitat would increase the overall donor fish requirement, and

- the low availability of donor stock will likely limit translocation activities to a single site.

Larval and juvenile Atlantic whitefish have been difficult to capture in any abundance using gear types commonly used elsewhere to successfully collect coregonids (Bradford et al. 2004). Age 0^+ year old juveniles have been collected in recent years (2016 and 2017) with a Rotary Screw Trap deployed below Milipsigate Lake dam. Annual catches have been less than 100 juveniles and while low they may represent:

- opportunities to collect fish to support captive rearing.

Continued monitoring that targets juveniles at Milipsigate Lake dam in combination with directed sampling at other suitable locations may increase the total annual catch but at present their numbers:

- are not likely sufficient as the sole source to support translocation activities given that compensation for the high rate of natural mortality that is expected to operate on small, young fish would require considerably larger numbers of donor stock.

Activities patterned around live-gene banking practices for salmonids, namely distribution into, and collection of juveniles from, native habitat (see DFO 2008) may not be feasible at the present time due to the current overall low availability of donor stock. However, the principles applied to maintain genetic fitness in live-gene bank programs (DFO 2008) should be a consideration during the development of supplementation activities for Atlantic whitefish.

Captive Breeding

Efforts to establish additional populations of Atlantic whitefish, whether freshwater-resident or anadromous, will require some form of captive breeding in order to secure a source of fish to enable supplementation activities. There are currently no Atlantic whitefish being held in any captive rearing facility, therefore all brood stock requirements will need to be met through collection of wild-caught individuals. Translocation of first generation (F1) offspring spawned from wild-caught parents should be prioritized over stocking offspring from parents bred and reared in captivity, in order to reduce risks associated with domestication selection.

Beyond ensuring the availability of seed stock, the maintenance of a captive population of wild-caught brood stock offers the potential to increase the number of F1 fish for distribution. Members of the land-locked Milipsigate Lake and Hebb Lake populations are relatively small-bodied (Fig. 3a) and not highly fecund (Fig. 4b; Bradford et al. 2010). However, fish collected from these lakes and reared in captivity exhibited enhanced growth (Fig. 4a) and achieved body sizes comparable to the larger bodied, historical anadromous population from the Tusket-Annis rivers (Fig. 3b; Bradford et al. 2010). The larger body size realized when in captivity resulted in a ~four-fold increase in egg production per female (Fig. 4b; Bradford et al. 2010). Wild-caught Atlantic whitefish have remained reproductively viable for as long as eight years in captivity (DFO 2009).

Production Targets

Stocking coregonids for conservation purposes within the British Isles has succeeded, or is anticipated to succeed, in establishing additional populations following average annual distributions of 55,000 – 81,500 fertilized eggs, 12,500 – 15,150 larvae and in combination with relatively small numbers (25 – 85) of wild-caught adults (Table 1). Comparable egg and larvae targets for Atlantic whitefish would require, on average 125–175 mature adults exhibiting the traits (i.e. size, fecundity) of the land-locked donor populations and 50 – 75 using wild-caught fish maintained in a captive environment (Table 2). These estimates compare favourably with estimates of the effective population size (N_e) required to maintain existing levels of genetic diversity, e.g., N_e =18 (95% CI 14, 37) when calculated using a method that considers the effective number of parents contributing to the sample and assuming no immigration and N_e =38 (95% CI 14, 141) when calculated using estimates of genetic drift between successive generations (see Cook 2012, Chapter 2).

ATLANTIC WHITEFISH RELEASE STRATEGIES

Release strategies for freshwater-resident populations may differ from those for anadromous populations. Available information suggests that irrespective of the target population release strategies designed to help conserve Atlantic whitefish would release fish to the wild at the earliest possible life stage in order to help reduce costs for propagation at a facility and to reduce risk associated with domestication selection (Jones et al. 2006). Although survival in the wild is generally expected to be higher for older and larger individuals it is perhaps significant that the releases of predominantly age 1^+ year old and older fish into Anderson Lake did not result in demonstrable reproduction (Bradford et al. 2015) whereas supplementation using eggs and larvae has met with some success, when applied to coregonid species, in the British Isles (Table 1). Multi-life stage releases combined with adequate post-release monitoring may be required to help identify the most effective release strategy to adopt in subsequent years (George et al. 2009). Release strategies should be adaptive to benefit from information gathered during monitoring (Armstrong and Seddon 2008).

RANKING ATLANTIC WHITEFISH OPTIONS FOR SUPPLEMENTATION

LOCATIONS AND LIFE-HISTORY OPTIONS

Ranking of options for stocking Atlantic whitefish are organized relative to: their present distribution, the Petite Rivière; historic locations, the Tusket-Annis rivers; and the biogeographic area where locations may exist to support additional populations, the Southern Uplands (SU) of Nova Scotia. Within each of these envelopes the potential to establish land-locked and anadromous populations can be considered, yielding for consideration 6 options.

	Location Options		
Life-History Options	Petite Rivière	Tusket-Annis rivers	SU Nova Scotia
Freshwater			
Anadromous			

The outcomes of the rankings for the Petite Rivière and the Tusket-Annis rivers may be useful in helping to identify specific locations within the SU Nova Scotia region where supplementation could be attempted.

PROJECT ATTRIBUTES

The suitability of locations to establish freshwater or anadromous populations through supplementation are assigned relative ranks, the criteria for each will be discussed below, for each of the following attributes:

- alignment with recovery strategy,
- risk of loss,
- habitat suitability,
- public receptiveness,
- allowable harm,
- operational requirements, and
- conservation benefit.

Alignment with Recovery Strategy

The 3 core elements of the Recovery Strategy for Atlantic whitefish are survival, recovery, and range extension (DFO 2006). For the purposes of evaluating risk, a score of 1is assigned for each recovery objective that can be addressed for each combination of Location and Life-History options (Table 3).

Risk of loss

Risk to donor population

When possible, the threat of extinction without supplementation should be assessed and contrasted with the risk to the viability of the donor population from removal of individuals to support supplementation (George et al. 2009). The risk to extant populations of Atlantic whitefish resulting from removal of individuals cannot be quantitatively assessed. For the purposes of evaluating risk, supplementation is assumed to be successful, and a score of 0 to 2 is assigned to the level of risk (qualitatively) to the donor population, as follows:

0= Absolute loss of production to donor population

1 = Potential benefit to donor population

2= Benefit to donor population

Risk to receiving habitat

The risk of negative impacts on the native species assemblage of the introduction site, resulting from supplementation, needs to be considered. Experience with freshwater fishes has shown these risks can be minimized by restricting stocking activities to the historic range of the endangered species (George et al. 2009). This risk is assigned a score of 0 or 1, as follows:

0 = Not Certain

1 = No risk or low risk

Habitat suitability

Both the present and future suitability of the habitat within the historic range of the species requires consideration (George et al. 2009). Consideration of marine habitat is difficult given the imitations of the direct observations on Atlantic whitefish at sea to records of occurrence at the time that anadromous populations existed (see for example Edge and Gilhen (2001). Habitat suitability for anadromous populations is therefore limited to evaluation of the ability of freshwater environments to provide for the freshwater life stages, and availability of an open connection to tidal waters.

Habitat suitability factors to consider include:

Water quantity

Geomorphological assessments indicate that the Nova Scotia catchments that support, or were known to have supported, Atlantic whitefish possess similar attributes (Cook 2012). It is therefore assumed that any SU Nova Scotia lake-river-estuary systems that share the traits of the Petite Rivière and Tusket-Annis rivers could support land-locked and anadromous populations of Atlantic whitefish. This risk is assigned a score from 0 to 3, as follows:

0 = No direct data support

1 = May exist within specific water bodies based upon available but incomplete information

2 = Availability supported or historical presence of Atlantic whitefish but verification that the attribute persists is required

3 = Available

Water quality

pH: Many of the rivers in Nova Scotia that are thought to have supported Atlantic whitefish populations at one time were naturally acidic to some degree. Paleolimnological records, and ongoing water quality monitoring, indicate that the three Petite Rivière lakes still possessing Atlantic whitefish have consistently maintained a mean annual pH greater than 5.6. Controlled experiments have shown that a pH of less than 5.0 can decrease the survival of Atlantic whitefish eggs, whereas a pH of less than 4.5 decreased survival of larvae and juveniles (DFO 2009).

Temperature: Atlantic whitefish can grow at temperatures between 11.7ºC and 24.0ºC, with optimum growth at 16.5ºC (DFO 2009).

Scores are assigned as for *Water Quality* above.

Spawning and early-life history

Salinity tolerance: Fertilized eggs are not salt tolerant, and Atlantic whitefish are therefore considered to be obligate freshwater spawners (DFO 2009). The characteristics of suitable spawning habitat are not known, although it appears as though Atlantic whitefish in the Petite Rivière spawn in the lakes, as is common for both lake whitefish and cisco (DFO 2009). Similarly, the habitat requirements for larval survival are not known but can be assumed to exist in lakes that share the characteristics of those that support Atlantic whitefish in the Petite Rivière. Scores are assigned as for *Water Quality* above.

Juvenile nursery habitat

The habitat preferences of immature Atlantic whitefish are not well understood. A single immature Atlantic whitefish was intercepted with a beach seine within the shallows of Hebb Lake during June 2000, and several immature whitefish were captured in a 15 m deep floating trap net installed in Hebb Lake in 2007 (DFO 2009). These limited data do not support an extended definition of habitat for juveniles other than that they use lake habitat. The recent captures of Age 0^+ year old juveniles in the flow from Milipsigate Lake are consistent with this broad description but leave open the question of whether or not the habitat contained within the connecting waterways between the lakes offer support for life functions other than migration. Scores are assigned as for *Water Quality* above.

Food supply

Adult-sized Atlantic whitefish feed on a wide variety of aquatic organisms. Stomach analyses of fish from the Petite Rivière lakes indicated a diet of aquatic insects and small fish, but not benthic organisms (DFO 2009). There is no information concerning the diet of young juveniles. Scores are assigned as for *Water Quality* above.

Non-Native Species

Presence of Smallmouth bass and Chain pickerel has the potential to severely reduce the likelihood that Atlantic whitefish can sustain a level of productivity to allow persistence. Water bodies where Smallmouth bass and Chain pickerel are present should be considered not suitable for stocking if the objective is to establish land-locked populations.

Populations of anadromous Atlantic whitefish may be less susceptible to pronounced negative impacts of these invasive predators, as returning adults are anticipated to be larger bodied, and therefore less susceptible to direct predation. Their larger size also results in a higher fecundity, and therefore they are potentially more capable of sustaining a higher level of productivity. As well, their time of residency within the lakes (autumn-winter) coincides with a period of lower metabolic demand for the freshwater-resident invasive species, which means the annual predation rate on anadromous adults is potentially low, relative to land-locked adults.

Although the life-stage for outmigration to sea water for Atlantic whitefish is not known with certainty, there is an expectation that lake residence time for anadromous-oriented juveniles will be less than the 2-3 years required for sexual maturation within lake resident populations. Salinity tolerance of Atlantic whitefish increases with ontogenetic development, such that survival at hatch (100% in freshwater) decreases to 93% and 91% in 15 and 30 parts per thousand (ppt) salt water respectively, whereas both juveniles and adults tolerate 30 ppt (DFO 2009).

This risk is assigned a score of from 0 to 2, as follows:

0 = Invasive species are present

1 = Compensation for presence of invasive species is potentially feasible

2 = Invasive species are not present

Public receptiveness

Atlantic whitefish were first designated endangered by COSEWIC in 1984 (Edge 1987b) and as such were automatically placed on Schedule 1 following formal proclamation of SARA. As such, no public consultation concerning the potential listing of Atlantic whitefish under SARA occurred. However, public outreach and client consultations have been core elements of Atlantic whitefish recovery planning, which requires range extension, including potentially into waterbodies either where they once existed or where demographic factors have suggested that they may have existed at one time. The waterbodies that received the captive-bred Atlantic whitefish that were stocked from the Mersey Biodiversity Facility from 2005 to 2008 (Whitelaw et al. 2015; Bradford et al. 2015) were selected in part on the basis that public interest groups were receptive. Rating of public receptiveness is accordingly scaled from 1 to 3 based on perceived willingness to have Atlantic whitefish introduced into a local watershed as follows:

1 = Records of concerns expressed by stakeholders or industry not resolved in support of stocking

2 = Potentially receptive

3 = Prior experience has demonstrated receptiveness

Allowable Harm

Potential for harm to Atlantic whitefish varies from direct interaction that results in some mortality, as could be the case at hydroelectric utilities or capture in commercial, recreational and aboriginal fisheries directed at other species, to habitat alterations that may result in in-direct harm through loss of productivity, shoreline developments for example. Sources of direct harm are presently few owing to the highly restricted range of the species but range extension carries the risk of exposing the species to a broader spectrum of human activities. The ranking of potential harm is therefore by necessity coarse at this time and limited to assigning scores that reflect scope for direct mortality versus scope for in-direct mortality versus some allowable harm is authorized given the perceived effect of a human activity on the extant population of Atlantic whitefish. The rankings, from 1 to 3 are as follows:

1 = Activities that result in direct mortality occur

2 = Activities that may result in direct or in-direct harm occur

3 = Prior determination of scope for allowable harm

Operational Requirements

Supplementation activities that extend beyond those of a captive rearing facility will benefit from availability of infrastructure to support 1) fish husbandry and fish distribution, 2) security/protection of fish and facilities, 3) monitoring, and 4) collection of brood fish that may result from supplementation.

Infrastructure to support husbandry and distribution

Risk associated with availability of infrastructure that allows for on-site husbandry of fish and for the distribution of fish from holding facilities is assigned a score of from 0 to 2, as follows:

0 = Does not exist, poor prospects for development

1 = Facilities at the stocking site can be modified to support operations

2 = Suitable facilities exist

Site Security

Risk is assigned as for Infrastructure to support husbandry and distribution.

Capacity to Monitoring

Monitoring of a reintroduced, or augmented, population is critical for evaluating success and to manage adaptively (George et al. 2009). Monitoring considerations include, but are not limited to: detection probability, development of recruitment indices, area of occupancy, and response of the aquatic community (Shute et al. 2005). Sites where monitoring facilities that could support quantitative assessments either already exist or where the option exists for these to be installed would have greater value than sites that would support only qualitative assessments (e.g., presence/absence) or where logistic challenges to monitoring exist. This risk is assigned a score of from 0 to 3 as follows:

0 = Monitoring is likely to be difficult from a logistic perspective

1 = Potential for qualitative assessments

2 = Quantitative assessment is potentially feasible

3 = Quantitative assessment is possible with existing facilities (e.g., fish ways)

Collection of Incipient Brood Stock

Adult fish that result from supplementation and that can be captured when sexually mature could potentially be used to either supplement, or replace, the use of wild-caught adults from the original donor population as brood stock for continuing stocking activities. This risk is assigned a score of from 0 to 3 as follows:

0 = Facilities amenable to brood stock collections do not exist, poor prospects for development

1 = Facilities at the stocking site can be modified to support operations

2 = Suitable facilities exist

Conservation Benefit

Yield per Fish

Atlantic whitefish appear to exhibit enhanced growth, the capacity to live as long as eight years, and a four-fold increase in egg production when introduced into culture. Culture in turn appears able to replicate the general body size traits of the anadromous population that once existed in the Tusket River. This suggests that there are demonstrable benefits to productivity and survivorship by re-establishing anadromous populations. The observed tolerance of early-life stage Atlantic whitefish to a broad range of water salinity, temperature, and pH indicates that establishing both anadromous runs and lake resident populations is biologically feasible, and potentially feasible in a broad range of river drainages (DFO 2009). This risk is assigned a score of from 1 to 2, as follows:

1 = No change in reproductive potential is anticipated

2 = Higher reproductive potential is anticipated

RANKING OUTCOME

Supplementation with the objective of developing anadromy among the Petite Rivière population presently ranks the highest of the six location and life-history targets under consideration, both on the basis of overall assigned score and rank relative to each individual stocking activity attribute (Table 4). Supplementation to enhance production of an existing population within the Petite Rivière received the second highest rank on the basis of total score largely due to the greater certainty that supporting habitat exists within the lakes, existing public receptiveness and scope for allowable harm. However this target ranks low relative to the attributes of alignment with the Recovery Strategy and conservation benefit and operational requirements (on-site infrastructure) to support conservation stocking activities (Table 4). Supplementation to establish anadromous populations is consistently ranked the highest for all three of the location options considered (Table 4).

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TABLES

Table 1. Summary of supplementation activities enacted to extend for conservation purposes the range of Coregonid populations by, year releases occurred, country of activity, donor and recipient water body, number of males, females, and families used to generate progeny for distribution, number of fish released by life history stage and the reported outcomes of the stocking activity.

	Years			Waterbody		Donor Number			Releases						
Species	**Year**	**n**	**Country**	**Donor**	**Recipient**	**Males**	**Females**	**Families**	**Eggs**	**Larvae**	**Juveniles**	**Adults**	**Outcome**	**Reference**	**Comments**
C. lavaretus		3	Wales	Llyn Tegid	Llyn Arenig	366	50		81,300				Adults	Thomas et al. 2013	
		3	Scotland	Loch Lomond	Loch Sloy			22		12,227		85	Population	Thomas et al. 2013	
		3			Carron Valley			22		13,123			Population	Thomas et al. 2013	
						Average/year			**81,300**	**12,675**	**0**	**85**			
C. albula		1	England	Bassenwaithe	Doune North Pond								Failed	Winfield et al. 2008	Lake acidification
		1		Bassenwaithe	Loch Earn								Failed	Winfield et al. 2008	Lake acidification
	1996	1		Bassenwaithe	Loch Skeen		21	35		17,500			Population	Winfield et al. 2008	Eggs and larvae
	1999	1		Bassenwaithe	Loch Skeen				47,500						
	1997	1		Derwentwater	Daer Reservoir		6	6		12,800			Uncertain	Adams et al. 2014	
	2005	1		Derwentwater	Sprinkling Tarn	38	82	14	134,480			25		Adams et al. 2014	
					Daer Reservoir				28,700					Adams et al. 2014	
	2008			Derwentwater	Daer Reservoir				3,600					Adams et al. 2014	
	2011	1		Derwentwater	Loch Valley			33	70,000				Unknown	Adams et al. 2014	
						Average/year			**56,856**	**15,150**	**0**	**25**			
C. huntsmani	2005		Canada	Petite Rivière	Anderson Lake						1,500		Failed	Bradford et al. 2015	
	2006			Petite Rivière	Anderson Lake					5,000	1,515		Failed	Bradford et al. 2015	
	2007			Petite Rivière	Anderson Lake					2,000	1,506		Failed	Bradford et al. 2015	
	2008			Petite Rivière	Anderson Lake							296	Unknown		
	2012			Petite Rivière	Anderson Lake							80	Unknown		
						Average/year			**0**	**3,500**	**1,507**	**188**			

Table 2. Estimates of the numbers of Atlantic whitefish required to produce the average annual number of eggs and larvae stocked in the British Isles to establish populations of indigenous Coregonid populations (see Table 1). The source populations of Atlantic whitefish are those possessing the traits of populations in the wild and those of wild fish reared in captivity (from Bradford et al. 2010). Estimates are generated for each source using mean body size and mean fecundity (eggs/female) and for body size and fecundity ± 1 Standard Deviation.

				Females Required for				**Captive Population of Wild-Caught Fish**			
				Eggs		**Larvae**		**Total Females**		**Adults @ 50:50**	
Source	**Body Size**	Fork **Length (cm)**	Eggs/ **Female**	**55,000**	**81,500**	**12,500**	**15,150**	**Min**	**Max**	**Min**	**Max**
Wild	**X-1SD**	247	1061	52	77	24	29	75	105	151	211
	X	260	1278	43	64	20	24	63	87	125	175
	X+1SD	273	1525	36	53	16	20	52	73	105	147
In Culture	**X-1SD**	266	1390	40	59	18	22	58	80	115	161
	X	329	2999	18	27	8	10	27	37	53	75
	X+1SD	392	5653	10	14	4	5	14	20	28	40

Table 3. Score and rank assigned to each attribute of Atlantic whitefish stocking activity by location (Petite Rivière, Tusket-Annis rivers, Southern Uplands Nova Scotia) and by life-history target population (Freshwater, Anadromous)(EL-H = Early Life-History).

Location		**Petite Rivière**		**Tusket River**		**Southern Uplands NS**	
Population Objective		**Freshwater**	**Anadromous**	**Freshwater**	**Anadromous**	**Freshwater**	**Anadromous**
Attribute	**Variable**						
Alignment with RS	Survival	1	1				
	Recovery		1	1	1	1	1
	Range Extension		1	1	1	1	1
Score		**1**	**3**	**2**	**2**	**2**	**2**
Rank		**6**	**1**	**2**	**2**	**2**	**2**
Risk of Loss	Donour Population	2	2	0	0	0	0
	Receiving Habitat	1	1	1	1	0	0
Score		**3**	**3**	**1**	**1**	**0**	**0**
Rank		**1**	**1**	**3**	**3**	**5**	**5**
Habitat Suitability	Water Quantity	3	3	2	2	1	1
	Water Quality	3	3	2	2	2	2
	Spawning and EL-H	3	3	2	2	1	1
	Juvenile Nursery Habitat	2	2	1	1	2	2
	Food Supply	3	3	3	3	3	3
	Non-Native Species	0	1	0	1	2	2
Score		**14**	**15**	**10**	**11**	**11**	**11**
Rank		**2**	**1**	**6**	**3**	**3**	**3**
Public Receptiveness		**3**	**3**	**1**	**1**	**2**	**2**
Rank		**1**	**1**	**5**	**5**	**3**	**3**
Allowable Harm		**3**	**3**	**2**	**1**	**2**	**2**
Rank		**1**	**1**	**3**	**6**	**3**	**3**
Operational Requirements	Infrastructure	1	1	1	1	1	1
	Site Security	2	2	1	1	1	1
	Capacity to Monitor	1	3	1	3	1	2
	Collection of Incipient Broodstock	1	2	1	2	0	0
Score		**5**	**8**	**4**	**7**	**3**	**4**
Rank		**3**	**1**	**4**	**2**	**6**	**4**
Conservation Benefit	Yield per Fish	**1**	**2**	**1**	**2**	**1**	**2**
Rank		**4**	**1**	**4**	**1**	**4**	**1**
		30	**37**	**21**	**25**	**21**	**23**
		2	**1**	**5**	**3**	**5**	**4**

Table 4. Summary of stocking options for each location and life-history target. The upper panel shows the score assigned by attribute and the overall total score. The lower panel shows the rank score by attribute, rank of the total score and the mean rank of the ranks for each attribute (rounded to nearest whole number).

	Petite Rivière		Tusket River		Southern Uplands NS		Maximum
Attribute	**Freshwater**	**Anadromous**	**Freshwater**	**Anadromous**	**Freshwater**	**Anadromous**	**Possible**
Score							
Alignment with RS	1	3	2	2	2	2	**3**
Risk of Loss	3	3	1	1	0	0	**3**
Habitat Suitability	14	15	10	11	11	11	**17**
Public Receptiveness	3	3	1	1	2	2	**3**
Allowable Harm	3	3	2	1	2	2	**6**
Operational Requirements	5	8	4	7	3	4	**9**
Conservation Benefit	1	2	1	2	1	2	**2**
Total	**30**	**37**	**21**	**25**	**21**	**23**	**43**
Percent of Maximum	**70**	**86**	**49**	**58**	**49**	**53**	**100**
Rank							
Alignment with RS	6	1	2	2	2	2	**NA**
Risk of Loss	1	1	3	3	5	5	**NA**
Habitat Suitability	2	1	6	3	3	3	**NA**
Public Receptiveness	1	1	5	5	3	3	**NA**
Allowable Harm	1	1	3	6	3	3	**NA**
Operational Requirements	3	1	4	2	6	4	**NA**
Conservation Benefit	4	1	4	1	4	1	**NA**
Overall from Total Score	**2**	**1**	**5**	**3**	**5**	**4**	
Mean Rank	**3**	**1**	**4**	**3**	**4**	**3**	

FIGURES

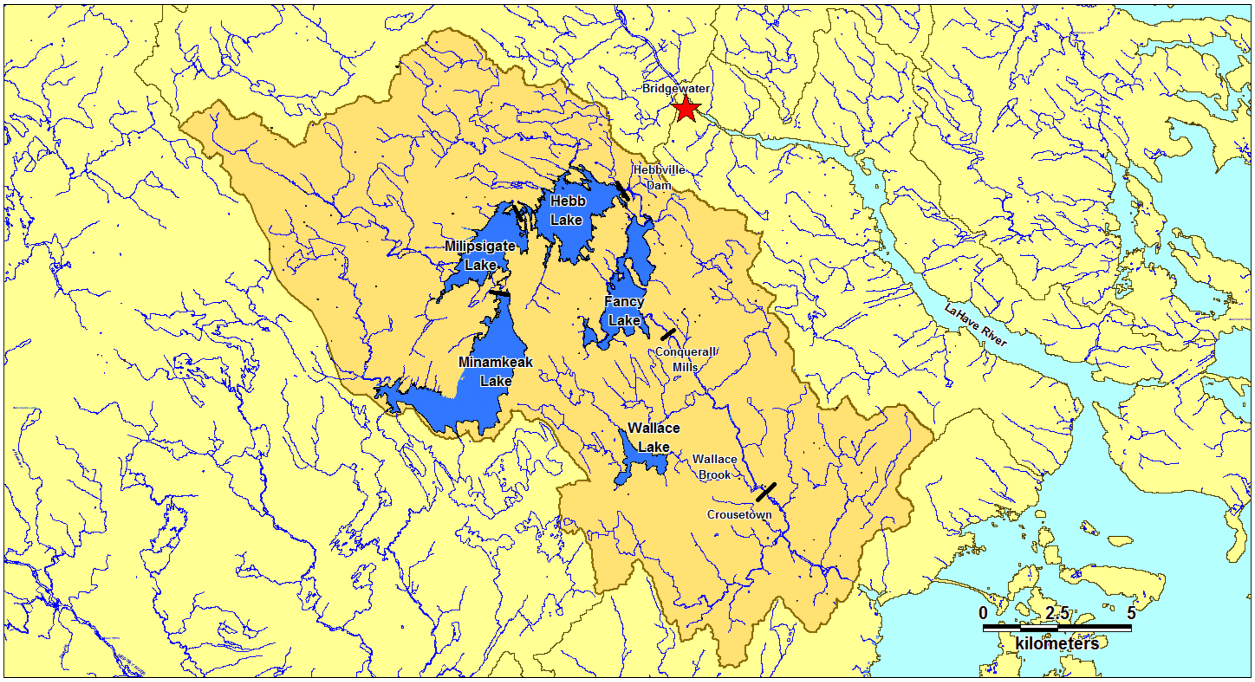


Figure 1. Map of the Petite Rivière showing location of sites referred to in the text.

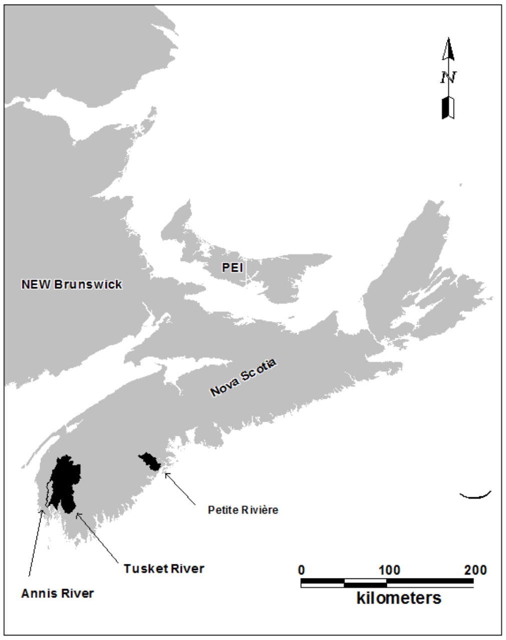
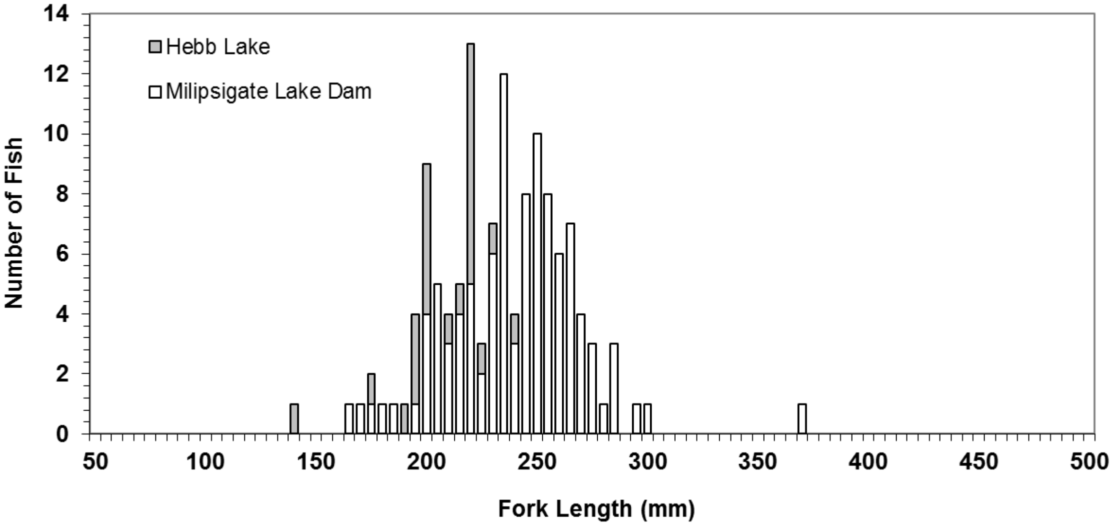


Figure 2. Location of the Petite Rivière and the Tusket-Annis rivers, Nova Scotia.



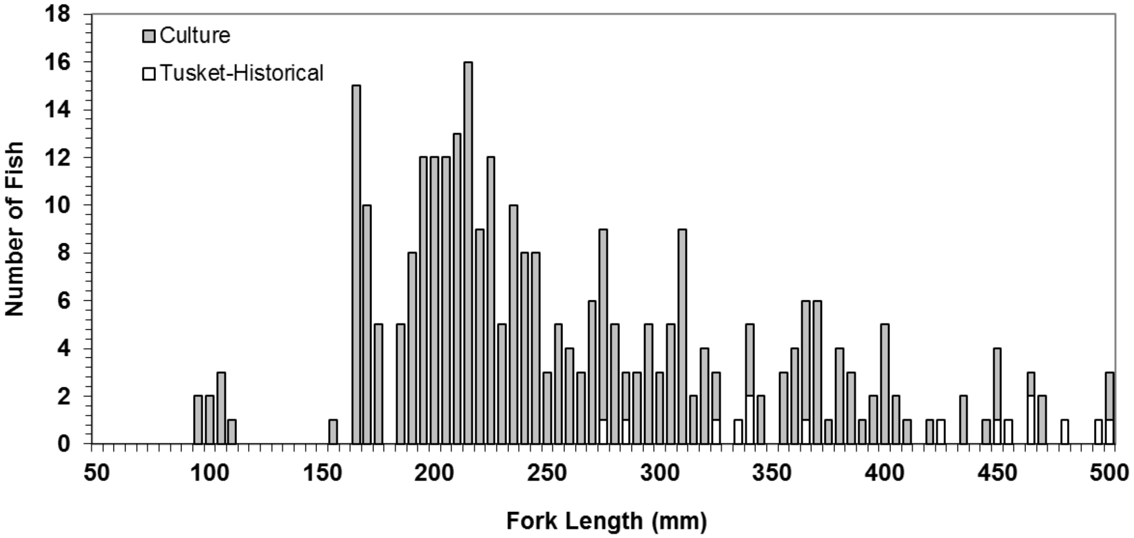


Figure 3. Atlantic whitefish fork length (mm) frequency distributions for wild fish sampled from (Upper Panel) Hebb Lake (grey bars) and from the base of Milipsigate Dam (white bars) and (Lower Panel) cultured (greay bars) versus historical anadromous samples from the Tusket River (white bars).

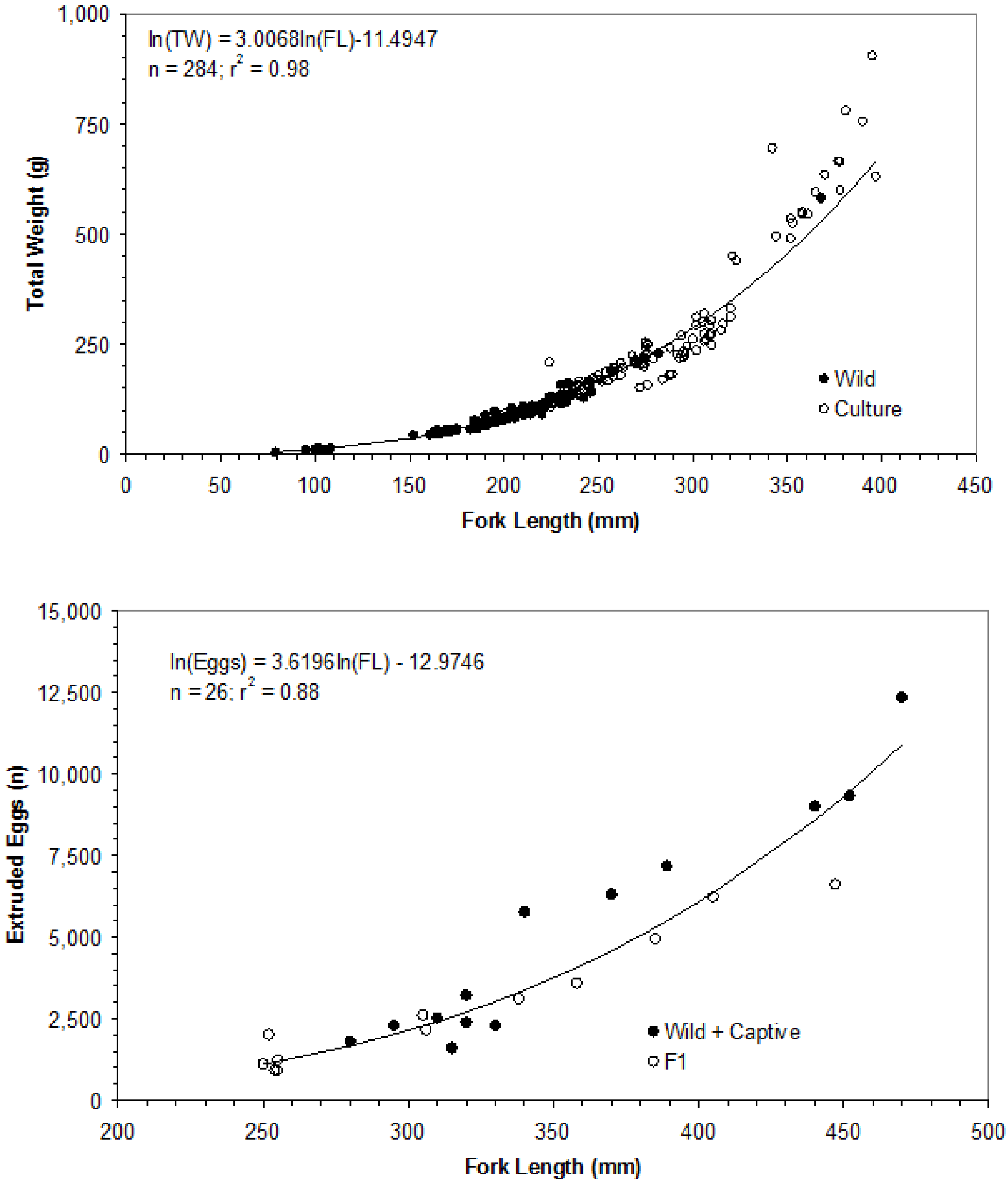


Figure 4. (upper panel) Total weight (g) – Fork Length (mm) relationship for combined samples of wild (closed circles) and cultured (open circles) Atlantic whitefish. (lower panel) Number of extruded eggs per female versus Fork Length (mm).