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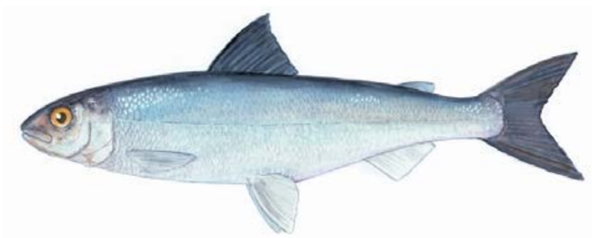
STRATEGIES FOR THE ESTABLISHMENT OF SELF-SUSTAINING ATLANTIC WHITEFISH POPULATION(S) AND DEVELOPMENT OF A FRAMEWORK FOR THE EVALUATION OF SUITABLE LAKE HABITAT



Atlantic Whitefish (Coregonus huntsmani) (Source: DFO 2009)

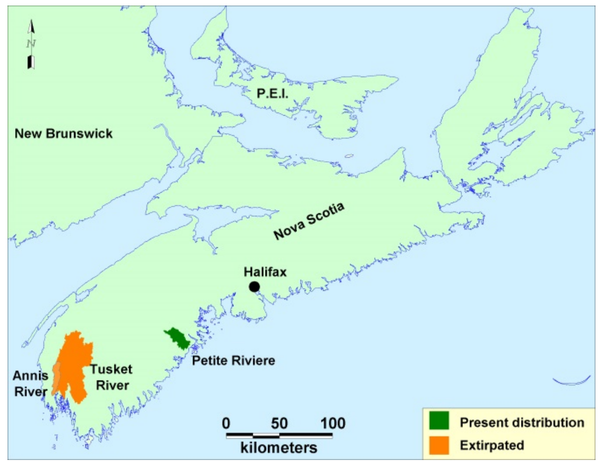


Figure 1. Global distribution of Atlantic Whitefish.

Context:

The Atlantic Whitefish (Coregonus huntsmani) is an endangered species that is at high risk for global extinction. The species global distribution has been restricted, for at least the past three decades, to three small interconnected lakes in the upper Petite Rivière watershed in southwest Nova Scotia. The continued survival of Atlantic Whitefish is now further threatened by illegally introduced invasive piscivorous fish species (Smallmouth Bass (pre-2003) and Chain Pickerel (2013)) within this remaining habitat.

Range expansion, the establishment of additional self-sustaining populations outside the currently occupied habitat in the Petite Rivière watershed, is identified as the distribution objective of the Atlantic Whitefish Recovery Strategy and could also prevent extinction. In spring 2017, three options in support of survival and recovery of Atlantic Whitefish were considered by Fisheries and Oceans Canada (DFO). Options included: simple translocation, translocation with temporary holding, and the establishment of a new propagation program at a DFO Biodiversity Facility with the option of translocation with temporary holding approved. This option would see Atlantic Whitefish, captured from the Petite Rivière Lakes, transported to a DFO Biodiversity Facility for short-term holding, before being released into new non-natal habitat. However, insufficient numbers of Atlantic Whitefish are available from the wild to provide a reasonable likelihood of success of this option at present. Propagation support could increase the likelihood that releases of Atlantic Whitefish result in the successful establishment of self-sustaining populations.

Opportunities to expand the species range to another system(s) within its assumed historic distribution, and adjacent areas outside of the Petite Rivière Lakes, are being considered. Undertaking release activities in habitats outside of the Petite Rivière Lakes requires Science advice on the recommended strategy to maximize the likelihood of successfully establishing self-sustaining Atlantic Whitefish population(s). Science advice is also required to develop a framework in which potential waterbodies *can be evaluated for their suitability to support Atlantic Whitefish.*

This science advisory report is from the November 1-2, 2017, meeting Stocking Strategy for the Establishment of Self-sustaining Atlantic Whitefish Population(s) and Development of a Framework for the Evaluation of Suitable Lake Habitat. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The Atlantic Whitefish is an endangered species that is at high risk for global extinction. The only remaining source stock is from the Petite Riviére Lakes (Minamkeak, Milipsigate, and Hebb).
- The introduction of invasive predatory species (Smallmouth Bass and Chain Pickerel) throughout the remaining critical habitat of Atlantic Whitefish remains a significant and emergent threat to their continued survival. Within Hebb Lake, Atlantic Whitefish have declined below detectable thresholds since the introduction of Chain Pickerel, further reducing the species global distribution by approximately one third.
- Atlantic Whitefish population abundance within the Petite Lakes has never been quantitatively assessed and therefore abundance, relative to minimum viable population size, is unknown. The number of Atlantic Whitefish that can be safely removed from the Petite Lakes to support recovery activities is unknown.
- Range expansion efforts, whether lake-resident or anadromous, will require propagation to secure sufficient numbers of Atlantic Whitefish to meet release targets that provide a reasonable likelihood of success for establishing a self-sustaining population(s).
- Conservation release programs of related Coregonid species have been successful at establishing self-sustaining populations. Comparable egg and larvae propagation targets for Atlantic Whitefish would require, approximately 220 – 320 mature adults exhibiting the traits (i.e. size, fecundity) of the lake-resident donor population or approximately 95 - 135 mature adults using wild-caught fish maintained in a captive environment.
- Propagated Atlantic Whitefish should be released into the wild at the earliest possible life stage to reduce risks associated with domestication selection. Post-yolk sac larvae are recommended as the preferred release life stage for Atlantic Whitefish recovery efforts.
- Releases should occur incrementally as fish are produced, and should be continued until the release targets have been achieved for a suitable number of years. It is unlikely that sufficient numbers will be available to permit more than a single population for the first several years of any newly developed propagation program.
- At a minimum, release site selection criteria for freshwater-resident populations should include systems that: are free of invasive species and/or possess a barrier to upstream fish passage, maintain a pH >5.0, and are of sufficient size and depth to provide a well oxygenated coldwater hypolimnion during summer conditions. For anadromous populations, the same criteria would be generally applicable; however, a system providing direct access to the sea would be necessary.
- It is highly unlikely that objectives to establish additional freshwater populations (for survival) and the establishment of anadromous populations (for recovery) can be achieved without significant and long-term human intervention.

BACKGROUND

The Atlantic Whitefish (*Coregonus huntsmani*) is classified as critically Endangered by the International Union for the Conservation of Nature (IUCN) and is at high risk for global extinction (Smith 2017). Atlantic Whitefish were first designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1984. The species' endangered status was re-examined and reconfirmed by COSEWIC in 2000 (COSEWIC 2000) and again in 2010 (COSEWIC 2010). The Atlantic Whitefish has been listed under the Canadian federal *Species at Risk Act* (SARA) since 2003 (DFO 2006). Under SARA, the responsibility to prevent the extinction of Atlantic Whitefish lies with the Department of Fisheries and Oceans Canada (DFO) (DFO 2016a). Fisheries and Oceans Canada has developed an Atlantic Whitefish Recovery Strategy (DFO 2006; 2016a), which continues to have the goal: "to achieve stability in the current population of Atlantic Whitefish in Nova Scotia, re-establishment of the anadromous form, and expansion beyond its current range".

The global distribution of Atlantic Whitefish has been restricted for at least the past 3 decades to the Petite Rivière watershed, within the approximately 16 km^2 combined area of Minamkeak, Milipsigate, and Hebb lakes (hereafter the Petite Lakes) (Bradford et al. 2015; Bradford 2017). The Petite Lakes serve as the water supply for the Town of Bridgewater, Nova Scotia, and were not accessible from the sea for several decades, until the provision of fish passage at Hebb Lake Dam in 2012 (Themelis et al. 2014). The Petite Lakes have been designated as Critical Habitat for Atlantic Whitefish, where critical habitat is defined as the habitat necessary for the survival or recovery of a listed wildlife species (DFO 2016b). At present, survival of the species is dependent upon its continued production within the Critical Habitat of the Petite Lakes.

Several factors have contributed to the declines in Atlantic Whitefish abundance (DFO 2016a); however, a significant and emergent threat facing survival and recovery is the establishment of illegally introduced, invasive, piscivorous, Smallmouth Bass (since before 2003) and Chain Pickerel (since 2013) within the Petite Lakes. The presence of predatory species throughout the Critical Habitat of Atlantic Whitefish threatens their survival and elevates the risk of extinction. Since the detection of Chain Pickerel in 2013, few Atlantic Whitefish have been observed during various types of monitoring within the Petite Lakes (see Appendix 1) (DFO 2009; Themelis et al. 2014; BCAF 2015; 2016). Under similar levels of monitoring effort, Atlantic Whitefish abundance has declined below detectable thresholds within Hebb Lake, resulting in further reduction of the species global distribution by approximately one third since the last species assessment by COSEWIC in 2010.

Adult Atlantic Whitefish were last observed in 2014 at a location immediately below the Milipsigate Lake Dam. Atlantic Whitefish larvae (young of the year) have been intercepted at the same location using a Rotary Screw Trap (RST) in 2015 (n=4), 2016 (n=52), and 2017 (n=37) (BCAF 2015; 2016; unpublished data). These larvae are considered to be lost from the population as lack of upstream fish passage prevents return movement to their lake of origin and they continue to be exposed to a substantial predator field as they move downstream. In spring 2017, 3 options for the provision of Atlantic Whitefish in support of population survival and recovery efforts were considered by DFO. Options included simple translocation (movement of Atlantic Whitefish from the Petite Lakes directly to a non-natal release site), translocation with temporary holding (movement of Atlantic Whitefish from the Petite Lakes to a DFO Biodiversity Facility prior to movement to a non-natal release site), and the establishment of a new propagation program housed at a DFO Biodiversity Facility (movement of Atlantic Whitefish from the Petite Lakes to a DFO Biodiversity Facility for long-term holding as broodstock with which to conduct captive rearing). Translocation with temporary holding was approved; however, at present, insufficient numbers of Atlantic Whitefish are available from the

Petite Lakes to provide a reasonable likelihood of success of establishing a population by translocation.

Propagation and translocation are approaches that have been previously proposed as aids to the survival and recovery of the Atlantic Whitefish (DFO 2009, Bradford 2017). Controlled propagation, augmentation, and reintroduction (hereafter PAR, see Appendix 2) of endangered animals have become priority actions for recovery and, in many cases, are actions of last resort to restore and/or maintain existing populations (McMurray and Roe 2017). In general, the design and implementation of recovery actions for Atlantic Whitefish have been hampered by a lack of information on the basic biology, physiology, life history, and habitat requirements of the species (Cook et al. 2010). Success of activities implemented to ensure both the survival of the existing population, and recovery of the species via range expansion and restoration of anadromy are dependent upon the adaptability of the remaining population to ongoing environmental and human-induced changes within the Petite Lakes (Bradford et al. 2004; DFO 2004a; DFO 2009) and the viability of releases into new freshwater and marine habitats (DFO 2004; 2009).

Recovery of the Atlantic Whitefish is considered to be both biologically and technically feasible (DFO 2006, DFO 2016a), and significant technical expertise was developed for the propagation of Atlantic Whitefish at the former Mersey Biodiversity Facility (Whitelaw et al. 2015). Recent monitoring effort in the Petite Lakes suggests that abundance of Atlantic Whitefish is critically low (Themelis et al. 2014; BCAF 2015; 2016) and, in combination with the failure of experimental stocking activities in Anderson Lake to achieve reproductive success (Bradford et al. 2015), highlight the importance of restoring a propagation program for Atlantic Whitefish. Propagation is necessary to leverage the limited number of Atlantic Whitefish that may be available for capture from the Petite Lakes, in order to provide sufficient numbers of source stock in support of survival and recovery objectives. It is, therefore, the objective of this report to review and provide guidance on the applicability of PAR activities, in light of the known limitations of our understanding of Atlantic Whitefish, that will best support recovery objectives to establish additional freshwater populations (for survival) and the establishment of anadromous populations (for recovery).

SPECIES BIOLOGY AND ECOLOGY

Atlantic Whitefish belong to the family Salmonidae and are part of the subfamily Coregoninae, which are freshwater whitefish species globally distributed across the northern temperate and sub-arctic zones (Cavender 1970). Atlantic Whitefish are both phylogenetically (Bradford et al. 2010) and phenotypically (Hasselman et al. 2009) distinct from all other Coregonid species and, therefore, represent a unique lineage within their genus. Atlantic Whitefish are endemic to Nova Scotia and are a unique and irreplaceable component of local, national and global biodiversity (DFO 2016a).

Atlantic Whitefish are suspected to have been widely distributed throughout Nova Scotia's Southern Uplands region prior to European colonization (Bradford et al. 2004; DFO 2009). However, by the mid-twentieth century, reported occurrences of Atlantic Whitefish were limited to the Tusket-Annis Rivers and Petite Rivière watersheds (Figure 1), as well as rare reports from coastal waters proximal to these 2 river systems (Scott and Scott 1988; DFO 2009). Although considered to be an anadromous species by nature, the wild population is found within 3 small, interconnected, semi-natural, freshwater lakes (16 km^2) in the upper Petite Rivière watershed; namely Minamkeak Lake, Milipsigate Lake, and Hebb Lake (Figure 2) (Bradford et al. 2004; DFO 2016a). Atlantic Whitefish have been shown to exhibit low overall genetic diversity, and genetic differentiation has not been detected between individuals within Minamkeak, Milipsigate, and Hebb lakes (Cook 2012).

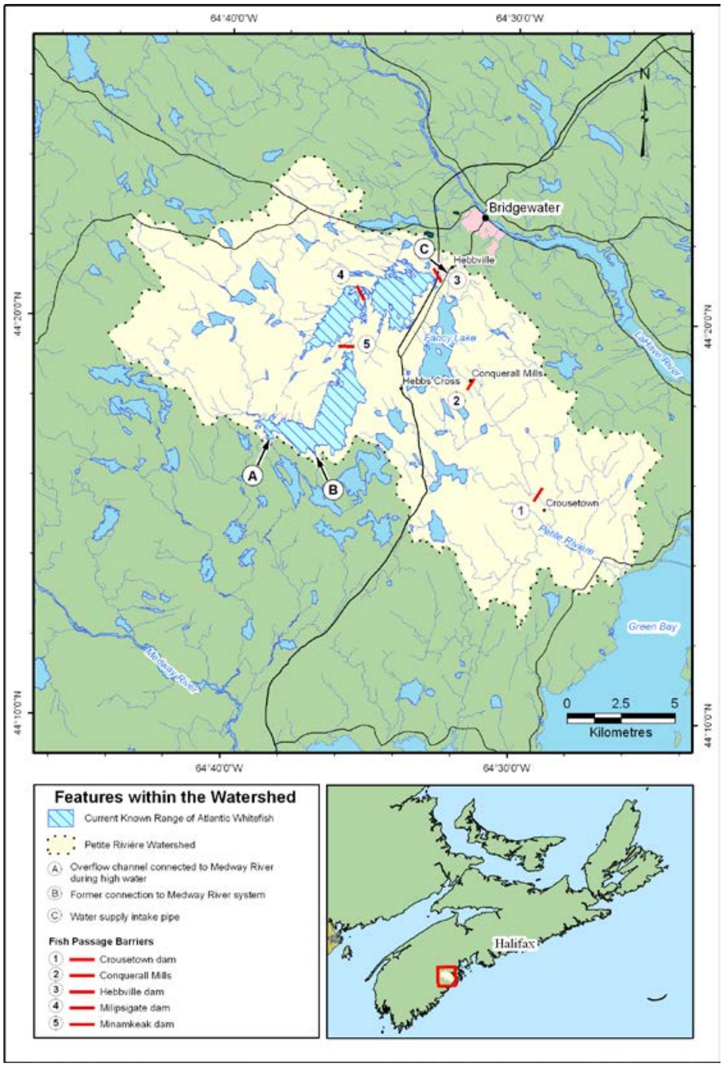


Figure 2. Map of the Petite Rivière watershed.

Anadromous adults, from the now extirpated Tusket-Annis River population, were typically larger (up to 50 cm in fork length [FL] and 3.6 kg in weight) than freshwater residents from the Petite Lakes (usually less than 30 cm in FL) (DFO 2009). Maturity of wild individuals from the Petite Lakes population occurs at approximately 20 cm FL and as early as Age 2+ years, with maximum age in the wild estimated to be 4-5 years (DFO 2009). While it is known that Atlantic Whitefish life cycle closure exists in the Petite Lakes, spawning has never been observed in the wild and spawning habitat requirements remain unknown (DFO 2009).

Historical data indicates that gravid anadromous Atlantic Whitefish ascended the Tusket River during late September to November (Edge and Gilhen 2001). Both wild-caught lake resident Atlantic Whitefish, and their progeny raised to maturity in captivity (under natural light and seasonal temperature profiles), spawn from late November to early January (Whitelaw et al. 2015). Fecundity of Atlantic Whitefish collected from the Petite Lakes and reared in captivity varied from approximately 1,000 extruded eggs per female at 25 cm FL to approximately 12,000 extruded eggs per female at 45 cm FL (DFO 2009; Whitelaw et al 2015). The attainable size of female Atlantic Whitefish in culture approximates that of reproductively mature females from the anadromous Tusket-Annis River population. Therefore, egg production per anadromous female is expected to be greater than per lake-resident female by a factor of approximately 4 (DFO 2009). Larvae emerge in April-May under typical Nova Scotia winter/spring incubation conditions, and metamorphosis to juveniles begins around 30-days post hatch (Hasselman et al. 2007; DFO 2009).

Habitat use of Atlantic Whitefish by life-history stage is poorly understood within the Petite Lakes. Sampling to date has shown that they have occurred throughout the lakes and the streams that connect the three lakes (e.g., eggs are demersal, juveniles were sampled in the shallows, adults and sub-adults are pelagic) (DFO 2009; Cook et al. 2014). Larval Atlantic Whitefish have been collected below the Milipsigate Lake Dam in each of the past three years (2015-2017) (BCAF 2015; 2016; A. Breen, pers. comm.); however, their lake of origin (i.e. Milipsigate and/or Minamkeak) has not been confirmed. Stomach analyses of Atlantic Whitefish from the Petite Lakes indicated a diet that included aquatic insects and small fish but not benthic organisms (Edge and Gilhen 2001).

Laboratory experiments have shown that Atlantic Whitefish can grow at temperatures between 11.7ºC and 24.0ºC, with optimum growth at 16.5ºC (Cook et al. 2010). Egg survival is decreased at a pH less than 5.0, whereas a pH of less than 4.5 decreased survival of both larvae and juvenile life stages (Cook et al. 2010). Salinity tolerance increases with ontogenetic development. Survival at the time of larval hatch decreases from 100% in freshwater to 93 and 91% in 15 and 30 ppt, whereas both juveniles and adults tolerate 30 ppt (Cook et al. 2010). Fertilized eggs are not salt tolerant and Atlantic Whitefish are, therefore, considered to be obligate freshwater spawners (Cook et al. 2010).

The marine habitat preferences of anadromous Atlantic Whitefish are not known, although their presence has been documented in estuaries and bays adjacent to the Tusket River and Petite Rivière (DFO 2016a). Occurrence of Atlantic Whitefish in locations as distant as Hall's Harbour, Nova Scotia (Scott and Scott 1988) indicates that the species was not wholly resident within estuaries (DFO 2009). Atlantic Whitefish captured in the marine environment were predating on shrimp, amphipods, fish and marine worms (Edge 1987; DFO 2009).

RECOVERY TARGETS

Atlantic Whitefish abundance within the Petite Lakes has never been quantitatively assessed, but available information suggests that absolute abundance is very low and declining (DFO 2009; COSEWIC 2010; DFO 2016a). Declines in other native species (i.e. White Sucker, White Perch, etc.) have occurred concurrently since the introduction of non-native invasive predators, particularly since the discovery of Chain Pickerel in 2013 (BCAF 2015; 2016*)*.

Available information regarding the past or present abundance or productivity of Atlantic Whitefish populations is not sufficient to form a basis for establishing watershed-specific abundance recovery targets, nor for determining the number of populations required to ensure the species long-term viability (DFO 2009; Bradford 2017). A minimum census population size required to maintain genetic diversity was previously estimated to be in the range of 550 – 2,000 mature individuals and an interim watershed specific abundance target above the mid-point of this range (> 1,275 mature individuals) was proposed (DFO 2009) and adopted as the Recovery Strategy population objective (DFO 2016a).

While generally considered to be much lower than census population size (i.e., abundance), estimates of genetic Effective Population Size (N_e) represent a theoretical long-term estimate of the number of individuals contributing to a generation (Frankham 1995). Estimates of N_e for Atlantic Whitefish were found to range between 18 and 38 individuals (Cook 2012). No evidence was found to indicate that the species had recently experienced a population bottleneck, but the Petite Lakes population has been at a low effective population size for most of its recent history (i.e. 100 years; Cook 2012). Estimates of N_e reported by Cook (2012) are among the smallest reported for a single population of fish. In the absence of quantitative population assessment data, these estimates provide further evidence to validate the critically low population size and low genetic diversity of Atlantic Whitefish within the Petite Lakes (Cook 2012).

ATLANTIC WHITEFISH PROPAGATION AND RELEASE EXPERIENCE

From 2000 to 2012, a DFO propagation program for Atlantic Whitefish was successful in moving wild fish into a facility and subsequently to release sites (DFO 2016a). Atlantic Whitefish were successfully bred in captivity for the first time at the DFO Mersey Biodiversity Facility (MBF), Milton, Nova Scotia, in December 2000 using wild adults captured from the Petite Lakes (Whitelaw et al. 2015). The principal aim of the early propagation trials was to provide small numbers of eggs, larvae, and juveniles for research purposes (Hasselman et al. 2007; Cook 2012; Bradford et al. 2015).

Advances by MBF staff in increasing egg fertilization success and reducing mortality of Age 0+ Atlantic Whitefish resulted in significant and accumulating, surpluses of F1 fish (first generation resulting from wild parents bred in captivity) relative to research needs (Bradford et al. 2015). Trial releases of the surplus F1 Atlantic Whitefish into non-native habitat was chosen as an acceptable ethical and scientific use of the fish (Bradford et al. 2015). It was recognized that releases over time could potentially result in range expansion of the species and the possible establishment of a backup population (Bradford et al. 2015; DFO 2016a). However, it was equally recognized that releases of surplus fish should not be equated with a stocking strategy designed to maximize the likelihood that self-sustaining populations could result from the activity (Bradford et al. 2015).

Two locations were selected to receive F1 Atlantic Whitefish: the portion of the Petite Rivière below the (then) impassable Hebb Lake Dam, and Anderson Lake, Halifax County, NS (Bradford et al. 2015). The lower Petite Rivière site offered the potential to evaluate the response of the F1s to open access to tidal waters, whereas Anderson Lake represented vacant lake habitat where the outcomes of the stocking would be wholly dependent upon the response of the stocked fish to the lake habitat (Bradford et al. 2015).

Monitoring of Atlantic Whitefish in Anderson Lake (2006-2010, and 2012) showed that some cultured fish were able to survive, grow, and reach sexually maturity (Bradford et al. 2015). However, there was no indication of reproductive success, and the establishment of a self-sustaining population did not occur (Bradford et al. 2015). Monitoring conducted by DFO Science in 2016 and 2017 failed to find evidence to suggest that Atlantic Whitefish continue to persist in Anderson Lake. While releases from this program did not result in the establishment of a self-sustaining population, the program was successful in developing the expertise and techniques to spawn and rear Atlantic Whitefish in abundance in captivity, including the ability to recondition wild-caught fish to spawn frequently over consecutive years (Bradford et al. 2015; DFO 2016a). Further, it was confirmed that the species is tolerant of transport and subsequent release into areas outside of its current range and that lakes of suitable size can be used as temporary holding facilities to expose propagated fish to wild conditions, prior to recollection.

EUROPEAN COREGONID RELEASE EXPERIENCE

Conservation release programs of related Coregonid species have been successful in establishing self-sustaining populations. The transfer and release of Coregonids has been practiced for centuries and has considerably extended their distribution throughout Europe (EIFAC 1994). In recent decades, releases of *Coregonus lavaretus* and *Coregonus albula*, with the objective of establishing refuge populations, have been conducted in United Kingdom (UK) with success or with a high expectation of success (see Winfield et al. 2012, Thomas et al. 2013, and Adams et al. 2014; summarized in Bradford et al. 2015; Bradford 2017). These initiatives included release of propagated eggs and/or larvae, and occasional transplants of wild-caught adults. Notably, no F1 juveniles were released in these programs. In contrast, Atlantic Whitefish of adult age released into Anderson Lake up to 2008 were F1s bred and reared in captivity and no eggs were distributed (Bradford et al. 2015). With respect to the release of Coregonid larvae, it is notable that the surface area of Anderson Lake lies within the range of those stocked with larvae in the UK (Bradford et al. 2015). While lake area does not directly equate to the availability of suitable habitat, it is still of interest to note that the total number of Atlantic Whitefish larvae released in Anderson Lake was comparatively low on a per unit area (ha) basis (Bradford et al. 2015; Bradford 2017).

ATLANTIC WHITEFISH RELEASE STRATEGY CONSIDERATIONS

Propagation, augmentation, and re-introduction (PAR) activities can play an important role in the recovery of species, particularly in situations for which effective recovery and/or threat mitigation actions are unavailable or ineffective in the short term (McMurray and Roe 2017). The primary objective of PAR efforts is to establish reproductively viable, free-ranging, self-sustaining populations (IUCN/SSC 2013; McMurray and Roe 2017). Actions to undertake PAR efforts are advisable when the population is considered to be at: 1) significant risk of extirpation, 2) is extirpated and appears unlikely to recolonize formerly occupied areas by natural processes, 3) is unable to naturally recolonize, and/or 4) when the population represents a significant portion of the total population or genetic diversity of that species (McMurray and Roe 2017). All of these criteria are applicable to the Atlantic Whitefish (Bradford 2017).

Propagation, augmentation, and re-introduction activities are discouraged as substitutes for addressing the factors resulting in the decline of the species in the wild (Cowx 1994; Snyder et al. 1996; DFO 2008; George et al. 2009; IUCN/SSC 2013; McMurray and Roe 2017). However, if other recovery options addressing these factors are not likely to be effective in the foreseeable future, PAR activities can be actions of last resort (USFWS 2000; McMurray and Roe 2017). The presence of invasive Smallmouth Bass and Chain Pickerel within the Petite Lakes pose a threat to the survival of Atlantic Whitefish. Although removal-based invasive control measures can be effective at reducing the impact of these predators, the timeframe required to elicit a measurable benefit to the Atlantic Whitefish population, or to maintain the function of the Petite Lakes as supporting habitat for Atlantic Whitefish, remains unknown (Bradford 2017). It is highly unlikely that survival and recovery objectives for Atlantic Whitefish can be achieved without significant and long-term human intervention.

Immediate action is required to ensure that the continued survival and eventual recovery of Atlantic Whitefish can be achieved. Efforts to establish additional populations, whether freshwater-resident or anadromous, will require propagation support to secure sufficient numbers of Atlantic Whitefish to support release activities. Release strategy considerations for Atlantic Whitefish are described below and are presented in light of the uncertainty that surrounds our limited understanding of the species current population abundance, life-history, and habitat requirements.

RANKING ATLANTIC WHITEFISH SUPPLEMENTATION OPTIONS

A ranking of release options for Atlantic Whitefish was presented by Bradford (2017) building upon selection criteria outlined in the Decision Support Tool (DST) for Stocking Atlantic Whitefish (DFO 2004b), which were based on the National Code on Introductions and Transfers of Aquatic Organisms (DFO 2003). Release options for Atlantic Whitefish were evaluated and ranked relative to their present distribution, the Petite Lakes; historic locations, the Tusket-Annis Rivers; and the biogeographic area where locations may exist to support additional populations, the Southern Uplands of Nova Scotia (Bradford 2017). Within each of these categories, the potential to establish lake-resident and anadromous populations was considered for a total of six options. Ranking criteria are fully described in Bradford (2017).

Supplementation to develop anadromy among the Petite Lakes population was ranked highest of the six location and life-history targets considered, on the basis of overall assigned score and rank relative to each individual release activity attribute (Bradford 2017). Supplementation to enhance production of the Petite Lakes population received the second highest rank on the basis of total score largely due to the greater certainty that supporting habitat exists within the lakes, an existing level of public receptiveness, and the scope for allowable harm has already been defined and addressed by management action (Bradford 2017). However, this target ranked low relative to the attributes of alignment with DFO's Recovery Strategy, conservation benefit, and operational requirements (on-site infrastructure) to support conservation stocking activities (Bradford 2017). Supplementation to establish anadromous populations was consistently ranked the highest for all three of the location options considered (Table 3 in Bradford 2017).

SOURCE STOCK

The former DFO propagation program for Atlantic Whitefish concluded in the spring of 2012 with the closure of the former DFO Mersey Biodiversity Facility and is, therefore, no longer a potential stock source (Whitelaw et al. 2015). Experimental releases in Anderson Lake were unsuccessful in establishing a self-sustaining population of Atlantic Whitefish (Bradford et al. 2015) and, as a result, Anderson Lake is not a stock source. The former Tusket-Annis population is considered to be extirpated (DFO 2004). There are no captive holdings of Atlantic Whitefish (Bradford 2017). The only source stock of Atlantic Whitefish available to support PAR activities is from the Petite Lakes. Further, it is unlikely that Atlantic Whitefish continue to persist in Hebb Lake as they have been below detectable levels for several years under similar levels of monitoring effort (Themelis et al. 2014; BCAF 2015; 2016). Therefore, Milipsigate and Minamkeak lakes are considered the only locations from which Atlantic Whitefish can potentially be sourced.

Larval stage Atlantic Whitefish have been collected in each of the past three years (2015 (n=4), 2016 (n=52), and 2017 (n=37)) using an RST situated in the outflow below the Milipsigate Lake Dam (BCAF 2015; 2016; unpublished data). It is unknown if these larvae originate from Milipsigate and/or Minamkeak lake. These larvae are considered to be lost from the lake of origin as upstream fish passage does not exist at either Minamkeak or Milipsigate Lake dams, and any downstream movement exposes the larvae to a substantial predator field where the cumulative risk of mortality is very high. The risk associated with removing lost larvae from the Petite Lakes population is considered to be negligible, whereas the collection of adult fish to serve as broodstock is considered to pose a much higher relative risk to the population as abundance of adults are unknown but considered to be declining. Numbers of larvae collected to date indicate that collections over several years will likely be necessary to produce sufficient numbers of broodstock. These larvae are considered to be representative of the phenotypic and genetic variation in the available population. Collection of multiple year classes as source stock will help to maximize the genetic diversity available from the Petite Lakes population. Efforts to collect and transfer Atlantic Whitefish larvae to a secure facility to form the basis of a propagation program are considered to be of the highest priority for the species survival and recovery.

RELEASE LIFE STAGE

Supplementation using eggs and larvae has met with some success when applied to Coregonid species in the United Kingdom (reviewed in Bradford 2017). Available information suggests that irrespective of the population objective, propagated fish should be released into the wild at the earliest possible life stage to reduce risks associated with domestication selection (Jones et al. 2006). To further reduce the potential risks of domestication selection, the release of F1 offspring spawned from wild-caught parents should be prioritized over releasing offspring from parents bred and reared in captivity (summarized in Bradford 2017).

Spawning locations and requirements for Atlantic Whitefish are unknown. The direct release of fertilized eggs onto a substrate of unknown suitability is not recommended as very poor survival would be expected. Therefore, post-yolk sac larvae are recommended as the preferred release life stage for Atlantic Whitefish PAR efforts. Husbandry practices can significantly increase overall fertilization success and survival during development from egg to the larval stage that would not be possible in the wild and, therefore, can assist in maximizing the limited productivity of any Atlantic Whitefish sourced from the Petite Lakes. Survival of released larvae may be further enhanced through small modifications of developmental temperatures during culture. These modifications can potentially result in delaying hatching until later in the season permitting the release timing of post-yolk sac larvae to better coincide with the emergence of planktonic prey items and thereby ensuring that a sufficient food source is available in the receiving habitat (Luczynski 1984). The life stage/timing of outmigration for anadromous Atlantic Whitefish is unknown. Propagated Atlantic Whitefish destined for release where an anadromous life-history strategy is the objective would be expected to benefit from longer duration stay in the receiving waters in order to maximize imprinting potential to the release system.

RELEASE TARGET AND DURATION

Information derived from conservation release activities of closely related Coregonid species has highlighted that the number of individuals released into Anderson Lake were an order of magnitude below other Coregonid release programs (Bradford 2017). Coregonid releases in the United Kingdom for conservation purposes have succeeded, or are anticipated to succeed, in establishing self-sustaining 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 (Bradford et al. 2015; Bradford 2017). Comparable egg and larvae propagation targets for Atlantic Whitefish would require approximately 220 – 320 mature adults exhibiting the traits (i.e. size, fecundity) of the lake-resident donor populations or approximately 95 - 135 mature adults using wild-caught fish maintained in a captive environment (Table 1, Bradford 2017).

Release programs that commit to providing introductions over multiple seasons have been most effective (EIFAC 1994). As Atlantic Whitefish propagation program development occurs, releases should occur incrementally as fish are produced and be continued until the release targets have been achieved for a suitable number of years. The success of a release program is monitored and determined by the establishment of a self-sustaining population. Until release targets have been met for a suitable number of consecutive years, the establishment of a self-sustaining population cannot be determined and the success of the program decided. An adaptive approach, based on informed feedback from monitoring activities, is expected for determining release duration requirements.

Table 1. Estimates of the numbers of Atlantic Whitefish required to produce the average annual number of eggs and larvae stocked in the United Kingdom to establish Coregonid populations. The source populations of Atlantic Whitefish are those possessing the traits of reproductively mature wild fish and those of wild fish reared to reproductive maturity in captivity (as reported in 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 (SD). Calculations assume egg survival of 0.5 and larval survival of 0.8 (Cook 2012; Whitelaw et al. 2015). (Modified from Bradford 2017)

				Females Required for				Captive Population of Wild-Caught Fish			
				Eggs		Larvae		Total Females		Adults at 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	104	154	29	36	133	190	266	380
	X	260	1278	86	128	24	30	110	158	220	316
	X + 1SD	273	1525	72	107	20	25	92	132	184	264
In Culture	X - 1SD	266	1390	79	117	22	27	101	144	202	288
	X	329	2999	37	54	10	13	47	67	94	134
	X + 1SD	392	5653	19	29	6	7	25	36	50	72

RELEASE LOCATION(S) AND HABITAT SUITABILITY CONSIDERATIONS

Throughout their distribution, self-sustaining Coregonid populations require oligotrophic and mesotrophic, cool and well-oxygenated waters (EIFAC 1994). Like most other Salmonids, temperature, dissolved oxygen, and pH are important water quality parameters and, together with the presence of suitable spawning substrates, largely define the locations of self-sustaining Coregonid stocks (EIFAC 1994).

The response of Atlantic Whitefish to water quality varies with life stage (Cook et al. 2010). Simulations have shown that freshwater resident Atlantic Whitefish populations can potentially survive in all watersheds of Nova Scotia’s Southern Uplands Region. River-specific median survival probabilities ranged from 0.20 to 0.96, with reduced survival occurring in the most acidified systems (Cook 2012). The inclusion of anadromous migrations in the simulations resulted in 30% increases in the survival probability for Atlantic Whitefish in the most acidified rivers, irrespective of the life stage at which the migration occurred (Cook 2012).

Atlantic Whitefish are suspected to have been more widely distributed throughout Nova Scotia's Southern Uplands Region prior to European colonization (Bradford et al. 2004; DFO 2009). Suitable sites for introduction releases could be identified leading to the potential for establishment of several populations in diverse habitats, i.e., in several watersheds as a distribution target. This approach has been suggested to potentially increase the probability that Atlantic Whitefish releases will be self-sustaining in the long term (DFO 2009; Bradford 2017). Any attempt to establish multiple populations will be dependent upon the availability of propagated fish in sufficient numbers and over a suitable number of years. It is unlikely that sufficient numbers will be available to permit more than a single population for the first several years of any newly developed propagation program.

Both the present and future suitability of release habitat should be considered (George et al. 2009). Specifically, for potential anadromous populations, consideration of marine habitat is difficult given the limited number of direct observations of Atlantic Whitefish at sea at the time that anadromous populations existed (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 (Bradford 2017).

PHYSICAL FEATURES

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 Southern Upland Nova Scotia lake-river-estuary systems that share the traits of the Petite Rivière and Tusket-Annis rivers could potentially support lake-resident and/or anadromous populations of Atlantic Whitefish (Cook 2012). Within the southern, more temperate portions of their range Coregonid species prefer deep lakes (EIFAC 1994). Minamkeak, Milipsigate, and Hebb lakes are relatively shallow (13 to 16 m; Table 2). Acoustic telemetry studies conducted in Hebb and Anderson Lakes have shown that Atlantic Whitefish exhibit preference for deeper water habitat throughout much of the year but show evidence of seasonal shifts toward shoal habitat in late fall, which was assumed to represent movements to spawning areas (Cook et al. 2014). As spawning has never been observed, it is not possible to characterize the spawning substrate preferred by Atlantic Whitefish.

Table 2. Physical characteristics of lakes within the upper Petite Rivière watershed known to provide supporting habitat for Atlantic Whitefish and Anderson Lake where Atlantic Whitefish introductions have occurred. (Source: Bradford et al. 2015; NS Lake Survey Program)

Lake	Surface Area (ha)	Volume (m^3)	Mean Depth (m)	Max Depth (m)	Smallmouth Bass	Chain Pickerel
Hebb	431.0	1.2×10^7	3.0	15	Yes	Yes
Milipsigate	335.8	1.5×10^7	4.5	16	Yes	Yes
Minamkeak	788.6	3.8×10^7	4.8	16	Yes	No
Anderson*	61.7	6.0×10^6	9.8	24	No	No

***** - Non-natal habitat, Atlantic Whitefish introduced.

A minimum lake size has not been identified, but lakes of at least 60 ha (i.e. Anderson Lake) have supported growth and sexual maturation of introduced Atlantic Whitefish (Bradford et al.

2015). Cook (2012) showed that genetic diversity and long-term effective population size were positively correlated with lake area for Lake Whitefish (*Coregonus clupeaformis*) populations. A logistical consideration, however, is that monitoring complexity and resource requirements are also likely to scale with increasing lake size. Lake morphometry and habitat classification/quantification are factors that have not been fully investigated to evaluate potential habitat suitability for Atlantic Whitefish. Investigation of these metrics is recommended, as they have been suggested as being beneficial in classifying available habitat (Coyle and Adams 2011) and in determining niche partitioning between species and potential interactions between predators/prey (Dolson et al. 2009; Sandlund et al. 2011).

WATER QUALITY

Water quality parameters considered most pertinent to Atlantic Whitefish, including temperature, pH, and salinity were selected for laboratory testing and reported by Cook et al. (2010) and Cook (2012).

Temperature and Dissolved Oxygen

Laboratory experiments were used to determine an optimum growth temperature of 16.5 ºC, and maximum growth temperature (i.e. high temperature representing zero growth) of 24.6 ºC (Cook et al. 2010). Atlantic Whitefish were found to possess an intermediate optimum temperature of 16.4 ºC, similar to that of Sockeye Salmon (*Oncorhynchus nerka)*. However, Atlantic Whitefish are more similar in thermal physiology to Atlantic Salmon (*Salmo salar*) both of which possessed the highest levels of maximum growth temperature, scope for growth, and thermal resistance (Cook 2012).

The Petite Lakes can thermally stratify during the summer, but a cold water hypolimnion is not generally present in Hebb Lake (Edge 1987; COSEWIC 2010). Consequently, extensive volumes of cooler water may not always be available in Hebb Lake during summer. It is possible that the Petite Lakes only provide limited suitable habitat for Atlantic Whitefish, which in part, may explain the species limited overall productivity in the Petite Lakes. In general, dissolved oxygen levels for Coregonids should not fall below 4 mg/L within the hypolimnion, and oxygen saturation on spawning grounds should not fall below 70% (EIFAC 1994).

Quantification of available oxy-thermal habitat is advised in evaluating candidate waterbodies for Atlantic Whitefish releases and in ongoing investigations of the Petite Lakes. The availability of oxy-thermal habitat has been identified as an important metric in predicting the population dynamics of the related species, Cisco (*Coregonus artedi*) (Jacobson et al. 2010; Lyons et al. 2017), and has been used in modeling population responses to future climate change scenarios (Fang et al. 2012; 2016).

pH

Many of the rivers in Nova Scotia that may have historically supported Atlantic Whitefish populations were naturally acidic to some degree (Bradford 2017). Reported pH has varied among the three Petite Lakes from 6.0 and 4.5 and is considered to be generally high compared with other watersheds along the south shore of Nova Scotia (Cook 2012). Paleolimnological records and more recent water quality monitoring indicate that the three Petite Rivière lakes have consistently maintained a mean annual pH greater than 5.6 (Ginn et al. 2008; DFO 2009).

In laboratory studies, reduced pH decreased the survival of Atlantic Whitefish for all life-history stages (Cook et al. 2010). Controlled experiments have shown that a pH of less than 5.0 can decrease the survival of Atlantic whitefish eggs, whereas pH of less than 4.5 decreased survival of larvae and juveniles (Cook et al. 2010). Cook et al. (2010) defined the most-to-least sensitive life stages of Atlantic Whitefish as:

Egg>Hatch>Larvae=Early Juveniles>Juveniles.

Salinity

Salinity tolerance of Atlantic Whitefish was found to be life stage dependent (Cook et al. 2010). Larval survival decreased moderately from 100% in freshwater to 94% and 92% at 15 ppt and 30 ppt, respectively. Juveniles and adults were found to be tolerant of full salinity seawater (Cook 2012). The ontogenetic increase in salinity tolerance was mirrored by the preference for marine salinity levels in juveniles (Cook et al. 2010). Experimental results show that regardless of acclimation salinity, juveniles almost exclusively preferred full strength seawater (30 ppt) (Cook et al. 2010). Fertilized eggs are not salt tolerant and Atlantic Whitefish are, therefore, considered to be obligate freshwater spawners (DFO 2009).

OTHER BIOLOGICAL CONSIDERATIONS

Disease Transfer

The National Code on Introductions and Transfers of Aquatic Organisms provides federal, territorial, and provincial governments with a consistent process for assessing potential impacts of moving aquatic organisms from one water body, or facility, to another (DFO 2003). The Introductions and Transfer (I&T) permitting process enables each jurisdiction to work with applicants to minimize the risks of unintentionally spreading diseases or pests, altering the genetic makeup of native species, or otherwise negatively impacting surrounding ecosystems (DFO 2003). A mandatory fish health screening for bacteriology and virology is required as part of the I&T permit application process to ensure that the receiving environment is free of disease, and that disease will not be introduced as a result of Atlantic Whitefish releases (DFO 2003).

Interspecific Interactions

Interspecific interactions between fish species are complex and can change across different life stages. These interactions can be in the form of competition for resources or predation. Predatory species of Atlantic Whitefish within the Petite Lakes are known to include the invasive Smallmouth Bass and Chain Pickerel. Presence of predatory invasive species has the potential to greatly reduce the likelihood that Atlantic Whitefish can sustain a level of productivity to allow persistence (Bradford 2017). Water bodies where Smallmouth Bass and Chain Pickerel are present should not be considered as suitable release locations, particularly if the objective is to establish lake-resident populations (Bradford 2017).

Populations of anadromous Atlantic Whitefish may be less susceptible to pronounced negative impacts of invasive predators, as returning adults are anticipated to be larger bodied and, therefore, less susceptible to direct predation (Bradford 2017). The larger size also results in a higher fecundity and, therefore, anadromous adults are potentially capable of sustaining a higher level of productivity (DFO 2009; Bradford 2017). As well, their time of residency within the lakes (autumn-winter) would coincide with a period of lower metabolic demand for the freshwater-resident invasive species, meaning the annual predation rate on anadromous adults is potentially lower, relative to lake-resident adults (Bradford 2017). Although the life-stage for outmigration for Atlantic Whitefish is not known with certainty, there is an expectation that lake residence time for anadromous-oriented juveniles will be far less than the 2-3 years required for sexual maturation within lake resident populations and, therefore, reducing the overall risk of mortality due to predation by invasive species (Bradford 2017).

Brook Trout *(Salvelinus fontinalis)*, White Perch *(Morone americana)*, Yellow Perch (*Perca flavescens),* and Rainbow Smelt *(Osmerus mordax)* are native species that have co-existed with, but may also predate on eggs and/or early life stages of, Atlantic Whitefish. Within the Petite Lakes, Atlantic Whitefish have been noted to predate on White Sucker (*Catostomus commersonii*) eggs (BCAF 2015). In Europe, introduced Coregonids have been found to negatively impact Arctic Charr (*Salvelinus alpinus)* populations through direct competition (Sandlund et al. 2011), a potential consideration for release sites with existing Brook Trout populations.

The potential risk of Atlantic Whitefish interbreeding with Lake Whitefish *(Coregonus clupeaformis),*is expected to be low (Bradford 2017). Bradford and Mahaney (2004) documented the distribution of natural and historical introductions of Lake Whitefish. Lake Whitefish and Atlantic Whitefish may have historically co-existed in the Tusket River. The potential co-occurrence of these two species is of low risk and should not exclude a water body containing Lake Whitefish from consideration as a release site.

Intraspecific Interactions

Competition within and between cohorts of Coregonids have been noted at high densities, and cannibalism has been observed in some species (EIFAC 1994). The potential for intraspecific competition and predation is unknown for Atlantic Whitefish.

MONITORING APPROACH AND PERFORMANCE INDICATORS

The ultimate long-term performance indicator of any release program should be the establishment of a self-sustaining population(s). The attributes of a self-sustaining population are defined as spawning-age adults and a stable age structure of multiple year classes over a prescribed area (USFWS 2000). Propagation, augmentation, and reintroduction (PAR) actions are generally discouraged as continuous activities, and their duration should be constrained to the time required to establish self-sustaining populations (IUCN/SSC 2013; McMurray and Roe 2017). The time required to achieve self-sustainability is expected to be lengthy, and multiyear releases in combination with adequate post-release monitoring should be expected to help further refine the release strategy throughout its development (George et al. 2009).

Using wild-caught Atlantic Whitefish maintained in a captive environment, propagation targets of 12,500 – 15,150 larvae/year is expected to require a maintained population of approximately 95 - 135 adult broodstock. Short-term performance indicators of a new propagation program should aim to meet or exceed survival targets achieved by the DFO Mersey Biodiversity Facility propagation program, where egg survival to the eyed stage was approximately 0.5, and survival of larvae was approximately 0.8 (Cook 2012; Whitelaw et al. 2015).

A post-release monitoring approach should incorporate a combination of techniques to permit assessment of all Atlantic Whitefish life stages. The ability to evaluate presence/survival, growth, age structure, and sexual maturity is necessary. The monitoring approach will need to be adaptive to account for the characteristics of the receiving water body(ies), the specific recovery strategy objective, the life-history strategy goal applied (i.e. lake-resident vs. anadromous), and the facilities available to enable/support monitoring at that location. The adaptive approach will allow feedback gathered during post-release monitoring to be utilized most effectively (Armstrong and Seddon 2008). Monitoring techniques should be standardized so that they can be applied across multiple locations and permit comparisons both within and between release sites.

Uncertainty exists regarding which techniques to implement for Atlantic Whitefish monitoring. The species conservation status constrains techniques to those that are non-invasive and do not cause long-term harm to captured individuals. Past monitoring efforts have trialed a variety of techniques but have most consistently implemented floating trapnets, which are a non-selective passive collection technique. Floating trapnets have been successful in collecting adults when present at moderate abundances, but they have had limited effectiveness under conditions of reduced abundance. An evaluation of the capture efficiency of floating trapnets has not been possible. Floating trapnets are not designed for retention of juvenile life stages. In recent years, collection of larval/juvenile life stages has occurred following the addition of an RST to the monitoring program.

Development and refinement of monitoring techniques will be an important component of Atlantic Whitefish program advancement. Active techniques, such as hydroacoustics and optical surveys, have been implemented as primary components of monitoring programs for Coregonid species in the United Kingdom (Bean 2003; Winfield et al. 2010), and they should be evaluated for application to Atlantic Whitefish. Development of techniques to survey and quantify habitat could help inform knowledge gaps related to spawning habitat requirements for Atlantic Whitefish and to examine niche overlap between Atlantic Whitefish and invasive species. Further, Atlantic Whitefish population abundance within the Petite Lakes has never been quantitatively assessed. If successful, the development of techniques to support quantitative population estimates would reduce uncertainty with respect to the current status of Atlantic Whitefish within the Petite Lakes.

Sources of Uncertainty

Imprecise Understanding of Habitat Suitability and Use

Habitat requirements for completion of the Atlantic Whitefish lifecycle 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 lake-resident form and absent for the anadromous form (Bradford 2017). Identification of Critical Habitat has been precautionary and all parts of the Petite Lakes 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 with certainty (Bradford et al. 2004; 2015). 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 (lake-resident versus anadromous) of release, and as well to the definition of release targets relative to habitat carrying capacity (Bradford 2017).

Available measures of habitat suitability are limited to water quality, namely water temperature and pH (Cook et al. 2010; Cook 2012). Science advice concerning locations to attempt range expansion 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). The continuing natural and illegal spread of invasive species throughout Nova Scotia's Southern

Uplands may impose challenges on selecting candidate release locations both now and in future.

Anadromous Donor Populations do not Exist

Lake-resident Atlantic Whitefish represent the sole source of donor stock to facilitate all recovery activities including the re-establishment of anadromy. The prospects for successful development of anadromous populations via supplementation are, therefore, considered on the basis of experimental salinity tolerance evaluations of progeny from lake-resident parents (Cook et al. 2010).

Rehabilitation of Habitat within the Petite Lakes

Experiences with invasive fish species control (Halfyard 2010; DFO 2013; Biron 2015) indicate that the emergent threat presented by invasive predatory Smallmouth Bass and Chain Pickerel in the Petite Lakes is unlikely to be addressed through their eradication from the lakes, tributaries, and connecting waterways without risk of harm to Atlantic Whitefish (Bradford 2017). Removal-based invasive species control measures can be effective at reducing the impact of predatory Smallmouth Bass and Chain Pickerel; however, the timeframe required to elicit a measurable benefit to the Atlantic Whitefish population, or to maintain the function of the Petite Lakes as supporting habitat for Atlantic Whitefish, remains unknown (Bradford 2017).

Quantitative Assessment of Extant Populations not Currently Possible

Atlantic Whitefish population abundance within the Petite Lakes has never been quantitatively assessed and therefore abundance, relative to minimum viable population size, is unknown. The number of Atlantic Whitefish, of any life stage, that can be safely removed from the Petite Lakes to support propagation activities is unknown.

Continued Availability of Lost Larvae

Atlantic Whitefish larvae have been intercepted below the Milipsigate Lake Dam using an RST in 2015, 2016, and 2017 (BCAF 2015; 2016; A. Breen, pers. comm.). While the recurrent nature of these collections is promising, without knowledge of the contributing adult spawning stock, the ongoing availability and quantity of these larval collections remain uncertain. Should larval stage Atlantic Whitefish fail to occur in future years, contingencies will need to be available to collect other life stages.

Monitoring Programs Require Development

At present, the abundance of Atlantic Whitefish has declined below the detection thresholds of previously deployed monitoring equipment. Development and refinement of new techniques is required to permit both non-lethal direct sampling and indirect surveying of all Atlantic Whitefish life stages.

CONCLUSIONS AND ADVICE

Atlantic Whitefish are at high risk of global extinction. The species global distribution has been restricted to approximately 16 km^2 of critical habitat of the Petite Lakes for at least the past 3 decades and has further declined by one-third following the establishment of illegally introduced invasive species.

The introduction of invasive predatory species (Smallmouth Bass and Chain Pickerel) throughout the remaining critical habitat of Atlantic Whitefish remains a substantial and emergent threat to their continued survival. Smallmouth Bass and Chain Pickerel are not presently controlled, and their population sizes are not known. The predatory impact on any remaining Atlantic Whitefish by these invasive species, although not quantified, is expected to be high. Removal-based control measures can be effective at reducing the impact of predatory species on the Atlantic Whitefish population; however, the timeframe required to elicit a measurable benefit or to maintain the function of the Petite Lakes as supporting habitat is unknown. Immediate actions to establish self-sustaining populations of Atlantic Whitefish in invasive-free habitat could prevent extinction.

Current population numbers do not allow simple translocation (*i.e.* transfer of fish directly from the Petite Lakes into an invasive-free watershed) to be a viable approach to support successful range expansion. Range expansion efforts, whether freshwater-resident or anadromous, will require propagation to secure sufficient numbers of Atlantic Whitefish to meet release targets that provide a reasonable likelihood of success for establishing a self-sustaining population. Larval stage Atlantic Whitefish have been collected in each of the past three years using an RST located below the Milipsigate Lake Dam. These larvae are considered to be lost from the population as lack of upstream fish passage prevents return movement to their lake of origin, and further downstream movement increases exposure to a substantial predator field where the risk of mortality is high. Removal of these larvae is considered to be of low risk to the existing Petite Lakes population and provides a stock source to support broodstock development with which to begin a propagation program.

Using wild-caught Atlantic Whitefish maintained in a captive environment, propagation targets of 12,500 – 15,150 larvae/year is expected to require a maintained population of approximately 95 - 135 adult broodstock. Multiple years of collection from the Petite Lakes are expected to develop these necessary broodstock targets. Short-term indicators of propagation program performance should include both egg and larval survival based upon previous Atlantic Whitefish husbandry experience. This is expected be a long-term project, with the long-term metric of success being the establishment of self-sustaining populations, at multiple locations, that exhibit a stable age structure. Development and refinement of new monitoring techniques should be considered in order to permit both non-lethal direct sampling and indirect surveying of all Atlantic Whitefish life stages.

Suitable release site criteria for freshwater-resident populations should include systems that: are free of invasive species and/or possesses a barrier to upstream fish passage, maintain a pH >5.0, and are of sufficient size and depth to provide a well oxygenated coldwater hypolimnion during summer conditions. For anadromous populations, the same criteria would be generally applicable; however, a system providing direct access to the sea would be necessary. Efforts to expand the species range to another system(s) within its assumed historic distribution may be precluded by water quality requirements and the expanding distribution of invasive species. As such, watersheds of the Southern Uplands region lying outside of the assumed historic distribution of Atlantic Whitefish should not be precluded from consideration as release sites.

It is highly unlikely that objectives to establish additional freshwater populations (for survival) and the establishment of anadromous populations (for recovery) can be achieved without significant and long-term human intervention.

SOURCES OF INFORMATION

This science advisory report is from the November 1-2, 2017, meeting Stocking Strategy for the Establishment of Self-sustaining Atlantic Whitefish Population(s) and Development of a Framework for the Evaluation of Suitable Lake Habitat. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Adams, C.E., Lyle, A.A., Dodd, J.A., Bean, C.W., Winfield, I.J., Gowans, A.R.D., Stephen, A., and Maitland, P.S. 2014. Translocation as a Conservation Tool: Case Studies from Rare Freshwater Fishes in Scotland. The Glasgow Naturalist 26: 17-24.

Armstrong, D.P., and Seddon, P.J. 2008. Directions in Reintroduction Biology. Trends Ecol. Evol. 23: 20-25.

Biron, M. 2015. Summary of the Control and Monitoring Activities for Smallmouth Bass (*Micopterus dolomieu*) in Miramichi Lake, NB, in 2013 and 2014. Can. Data Rep. Fish. Aquat. Sci. No. 1257.

Bluenose Coastal Action Foundation (BCAF). 2015. Atlantic Whitefish Recovery Project 2015 Report. Atlantic Whitefish Recovery Project Report on 2015 Field Activities. Retrieved May 2018

BCAF. 2016. Atlantic Whitefish Recovery Project 2016 Report. Atlantic Whitefish Recovery Project Report on 2015 Field Activities. Retrieved May 2018

Bean, C. 2003. A Standardized Survey and Monitoring Protocol for the Assessment of Whitefish, *Coregonus albula* (l.) and *Coregonus lavaretus* (L.), Population in the UK. Scottish Natural Heritage Commissioned Report 43 p.

Bradford, R.G. 2017. Supplementation Options to Aid Recovery of the Endangered Atlantic Whitefish (*Coregonus huntsmani*). Can. Manu. Rep. Fish. Aquat. Sci. 3124.

Bradford, R.G., and Mahaney, C.M.B.. 2004. Distributions of Lake Whitefish (*Coregonus clupeaformis*) Fry from the Lower Great Lakes Federal Hatcheries to Elsewhere in Canada and Beyond (Years 1878-1 91 4). Can. Data Rep. Fish. Aquat. Sci. 1149.

Bradford, R.G., Longard, D.L., and Longue, P. 2004. Status, Trend, and Recovery Considerations in Support of an Allowable Harm Assessment for Atlantic Whitefish *(Coregonus huntsmani)*, Dartmouth, Nova Scotia: Fisheries and Oceans Canada. Can. Sci. Advis. Sec. Res. Doc. 2004/109.

Bradford R.G., Bentzen, P., Campbell, D.M., Cook, A.M., Gibson, A.J.F, and Whitelaw, J. 2010. 2009 Update Status Report for Atlantic Whitefish (*Coregonus huntsmani*). DFO Can. Sci. Advis. Sec. Res. Doc. 2010/005. 39 p.

Bradford, R.G., Themelis, D., LeBlanc, P., Campbell, D.M., O'Neil, S.F., and Whitelaw, J. 2015. Atlantic Whitefish (*Coregonus huntsmani*) Stocking in Anderson Lake, Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 3142: vi + 45 p.

Cavender, T.M. 1970. A Comparison of Coregonines and other Salmonids with the Earliest Known Teleostean Fishes; pp. 1-32. In:C.C. Lindsey and C.S. Woods (eds.) Biology of Coregonid Fishes. University of Manitoba Press, Winnipeg, Manitoba.

Cook, A.M. 2012. Addressing Key Conservation Priorities in a Data Poor Species. Ph.D. Thesis Dalhousie University. 214 p.

Cook, A.M., Bradford, R.G., and P. Bentzen. 2014. Hydroacoustic Tracking of the Endangered Atlantic Whitefish (*Coregonus huntsmani*); Comparative Analysis from Wild and Hatchery Reared Populations. Environ. Biol. Fish. 97: 955-964.

Cook, A.M., Bradford, R.G., Hubley, B., and Bentzen,P. 2010. Effects of pH, Temperature and Salinity on Age 0+ Atlantic Whitefish (*Coregonus huntsmani*) with Implications for Recovery Potential. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/055.

COSEWIC. 2000. Update COSEWIC Status Report on the Atlantic Whitefish *Coregonus huntsman* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 35 pp.

COSEWIC. 2010. COSEWIC Assessment and Update Status Report on the Atlantic Whitefish Coregonus huntsmani in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

Cowx, I.G. 1994. Stocking Strategies. Fish. Manag. Ecol. 1:15-30.

Coyle, S., and Adams, C.E. 2011. Development of a Methodology for the Assessment of the Quality of Vendace Spawning Substrates and its Application to Sites in Scotland and northern England. Scottish Natural Heritage Commissioned Report No. 308: 33 p.

DFO. 2003. National Code on Introductions and Transfers of Aquatic Organisms. Fisheries and Oceans Canada, Ottawa. 60 pp.

DFO. 2004a. Allowable Harm Assessment for Atlantic Whitefish. DFO Can. Sci. Advis. Sec. Stock Status Rep. 2004/052.

DFO, 2004b. Proceedings of a Workshop on a Decision Support Tool for Stocking for Atlantic Whitefish. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2004/044.

DFO. 2006. Recovery Strategy for the Atlantic Whitefish (*Coregonus huntsmani*) in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa.

DFO. 2008. Evaluation of Captive Breeding Facilities in the Context of their Contribution to Conservation of Biodiversity. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/027.

DFO. 2009. Recovery Potential Assessment for Atlantic Whitefish (*Coregonus huntsmani*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/051.

DFO. 2013. Review of Control and Eradication Activites in 2010 to 2012 Targeting Smallmouth Bass in Miramichi Lake, New Brunswick. DFO Can. Sci. Advis. Sec. Sci. Resp. 2013/012.

DFO. 2016a. Amended Recovery Strategy for the Atlantic Whitefish (*Coregonus huntsmani*) in Canada [Proposed]. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa.

DFO. 2016b. Action Plan for the Atlantic Whitefish (*Coregonus huntsmani*) in Canada [Proposed]. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa.

Dolson, R., McCann, K., Rooney, N., and Ridgeway, M. 2009. Lake Morphology Predicts the Degree of Habitat Coupling by a Mobile Predator. Oikos. 118: 1230-1238.

Edge, T.A. 1987. The Systematics, Distribution, Ecology and Zoogeography of the Endangered Acadian Whitefish, *Coregonus canadensis* Scott, 1967, in Nova Scotia, Canada. M.Sc. University of Ottawa.

Edge, T.A., and Gilhen, J. 2001. Updated Status Report on the Endangered Atlantic Whitefish, *Coregonus huntsmani*. Can. Field-Nat. 115: 635-651.

European Inland Fisheries Advisory Commission (EIFAC). 1994. Guidelines for Stocking Coregonids. EIFAC Occasional Paper. No. 31. Rome, FAO. 18p.

Fang, X., Jiang, L., Jacobson, P.C., Stefan, H.G., Alam, S.R., and Pereira, D.L. 2012. Identifying Cisco Refuge Lakes in Minnesota Under Future Climate Scenarios. Trans. Am. Fish. Soc. 141(6): 1608-1621.

Fang, X., Stefan, H.G., Jian, L., Jacobson, P.C., and Pereira, D.L. 2016. Projected Impacts of Climatic Changes on Cisco Oxythermal Habitat in Minnesota Lakes and Management Strategies; pp. 659-722. In: W.Y. Chen, T. Suzuki, and M. Lackner (eds.) Handbook of Climate Change Mitigation and Adaptation. Springer International Publishing, Cham, Switzerland.

Frankham, R. 1995. Effective Population Size/Adult Population Size Ratios in Wildlife: a Review. Genet. Res. 66: 95–107.

George, A.L., Kuhajda, B.R., Williams, J.D., Cantrell, M.A., Rakes, P.L., and Shute, J.R. 2009. Guidelines for Propagation and Translocation for Freshwater Fish Conservation. Fisheries 34: 529–545.

Ginn, B.K., Grace, L.C., Cumming, B.F., and Smol, J.P. 2008. Tracking Anthropogenic- and Climatic-related Environmental Changes in the Remaining Habitat Lakes of the Endangered Atlantic Whitefish (*Coregonus huntsmani*) Using Palaeolimnological Techniques. Aquat. Conserv.: Mar. Freshwat. Ecosyst. 18: 1217-1226.

Halfyard, E.A. 2010. A Review of Options for the Containment, Control, and Eradication of Illegally Introduced Smallmouth Bass (*Micropterus dolomieu*). Can. Tech. Rep. Fish. Aquat. Sci. 2865.

Hasselman, D.J., Whitelaw, J., and Bradford, R.G. 2007. Ontogenetic Development of the Endangered Atlantic Whitefish (*Coregonus huntsmani* Scott, 1987) Eggs, Embryos, Larvae, and Juveniles. Can. J. Zool. 85: 1157-1168.

Hasselman, D.J., Edge, T.A., and Bradford, R.G. 2009. Discrimination of the Endangered Atlantic Whitefish from Lake Whitefish by Use of External Characters. North Am. J. Fish. Manage. 29: 1046-1057.

Huntsman, A.G. 1922. The Fishes of the Bay of Fundy. Contrib. Can. Biol. 3:49-72.

IUCN/SSC. 2013. Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission.

Jacobson, P.C., Stefan, H.G., and Pereira, D.L. 2010. Coldwater Fish Oxythermal Habitat in Minnesota Lakes: Influence of Total Phosphorus, July Air Temperature, and Relative Depth. Can. J. Fish. Aquat. Sci. 67(12): 2002-2013.

Jones, J. W., Hallerman, A.M., and Neves, R.J. 2006. Genetic Management Guidelines for Captive Propagation of Freshwater Mussels (Unionoidea). J. Shellfish Res. 25: 527-535.

Lucynski, M. 1984. A Technique for Delaying Embryogenesis of Vendace *(Coregonus albula* L.) Eggs in Order to Synchronize Mass Hatching with Optimal Conditions for Lake Stocking. Aquaculture 41: 113-117.

Lyons, J., Parks, T.P., Minahan, K.L., and Ruesch, A.S. 2017. Evaluation of Oxythermal Metrics and Benchmarks for the Protection of Cisco (*Coregonus artedi*) Habitat Quality and Quantity in Wisconsin Lakes. Can. J. Fish. Aquat. Sci. 00: 1–9 (0000). Retrieved September 2017

McMurray, S.E., and K.J. Roe. 2017. Perspectives on the Controlled Propagation, Augmentation, and Reintroduction of Freshwater Mussels (Mollusca: Bivalvia: Unionoida). Freshwater Mollusk Biology and Conservation 20: 1-12.

Sandlund, O.T., Hesthagen, T., and Brabrand, A. 2011. Coregonid Introductions in Norway: Well-intended and Successful, but Destructive. Advance. Limnol. 64: 345-362.

Scott, W.B., and Scott, M.G. 1988. Atlantic Fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219.

Smith, K. 2017. *Coregonus huntsmani*. The IUCN Red List of Threatened Species 2017. Retrieved May 2018

Snyder, N.F.R., Derrickson, S.C., Beissinger, S.R., Wiley, J.W., Smith, T.B., Toone, W.D., and Miller, B. 1996. Limitations of Captive Breeding in Endangered Species Recovery. Conserv. Biol. 10:338–348.

Themelis, D.E., Bradford, R.G., LeBlanc, P.H., O'Neil, S.F., Breen, A.P., Longue, P, and Nodding, S.B. 2014. Monitoring Activities in Support of Endangered Atlantic Whitefish (*Coregonus huntsmani*) Recovery Efforts in the Petite Rivière Lakes in 2013. Can. Manuscr. Rep. Fish. Aquat. Sci. 3031.

Thomas, R., J.M. Fletcher, B. James, I.J. Winfield. 2013. Assessment and Conservation of Gwyniad (*Coregonus lavaretus* (L.)) in Llyn Tegid, U.K.: Persistence in the Face of Eutrophication, Water Level Fluctuations and Ruffe (*Gymnocephalus cernuus* (L.)) Introduction. Advanc. Limnol. 64: 363–376.

USFWS (United States Fish and Wildlife Service) 2000. USFWS-NMFS Policy Regarding Controlled Propagation of Species Listed Under ESA. Federal Register 65: 56916-56922.

Whitelaw, J., Manríquez-Hernández, J., Duston, J., O'Neil, S.F. and Bradford, R.G. 2015. Atlantic Whitefish (*Coregonus huntsmani*) Culture Handbook. Can. Manuscr. Rep. Fish. Aquat. Sci. 3074: vii + 55 p.

Winfield, I.J., Fletcher, J.M., and James, B.J. 2010. Monitoring the Fish Populations of Bassenthwaite Lake and Derwent Water, 2009. Report to Environment Agency, North Wales Region. LA/C03461/5. 54p.

Winfield, I.J., Adams, C.E. Bean, C.W., Durie, N.C., Fletcher, J.M., Gowans, A.R., Harrod, C., James, J.B., Lyle, A.A., Maitland, P.S., Thompson, C., and Verspoor, E. 2012. Conservation of the Vendace (*Coregonus albula*), the U.K.'s Rarest Freshwater Fish. Advanc. Limnol. 63: 547–559.

APPENDICES

Appendix 1. Number of Atlantic Whitefish sampled since 2000 by location, year and sampling method (A = Angling, F = Fishway, G = Gillnet, S = Seine, T = Trapnet, R = Rotary Screw Trap). Modified and updated from DFO 2009. Note: Table does not include anecdotal reports or casual observations, such as a fish angled below the Hebb Dam in 2004, or fish observed below Milipsigate Dam in 2008 and 2014. (= larval/juvenile capture; NE = no effort; NA = not available for capture as Atlantic Whitefish were not released into Anderson Lake until November 2005).*

Location	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**16**	**17**
Petite Riviére Estuary	0 (T)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Below Hebb Dam	NE	NE	NE	NE	NE	NE	NE	NE	0 (T)	NE	NE	NE	19 (F,R)	0 (F,T,R)	0 (F)	0 (F)	NA (F)
Hebb Lake	1* (S)	NE	NE	NE	NE	NE	NE	24 (T)	NE	NE	NE	NE	NE	NE	NE	0 (T)	NE
Below Milipsigate Dam	78 (A,S)	5 (A,T)	NE	1 (A)	NE	4 (A)	19 (S,A)	29 (S,A)	NE	NE	NE	NE	0 (T)	0 (T, S)	4* (R)	53* (R)	37* (R)
Milipsigate Lake	NE	NE	NE	7 (T)	NE	NE	0 (T)	NE	NE	NE	NE	NE	NE	NE	NE	NE	0 (T)
Minamkeak Lake	NE	NE	NE	NE	19 (G)	NE	NE	NE	NE	2 (T)	NE	NE	NE	0 (T)	1 (G)	NE	NE
Totals	**79**	**5**	NE	**8**	**19**	**4**	**19**	**53**	**0**	**2**	NE	NE	**19**	**0**	**5**	**53**	**37**
Anderson Lake	NA	NA	NA	NA	NA	NE	10 (T)	20 (T)	32 (T)	44 (T)	41 (T)	NE	2 (T)	NE	NE	0 (T)	0 (A)

Appendix 2. Definition of terms applied in this document to help describe and discuss the options available to enable range expansion of Atlantic Whitefish. These terms have been drawn from the literature associated with aquatic organisms (Snyder et al. 1996, Jones et al. 2006; George et al. 2009; IUCN/SSC, 2013; McMurray and Roe 2017) (modified from Bradford 2017).

Terms	Definition
Augmentation	The addition of either propagated or translocated fish to an existing population.
Introduction	The relocation of fish outside of their native range.
Propagation	The production of individuals from captive broodstock for the purposes of reintroduction to the wild.
Reintroduction	The release of either propagated or translocated fish to habitat lying within the historic range of a species where populations no longer exist.
Relocation	The movement of individuals from one location to another often conducted under the premise of rescuing animals from an imminent anthropogenic threat.
Release	The generic term to describe a distribution of fish into the wild.
Supplementation	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 propagation and natural production.
Translocation	The movement of wild-caught fish, or the progeny produced from the artificial spawning of wild-caught parents, into a non-natal location within the species known historical range.

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