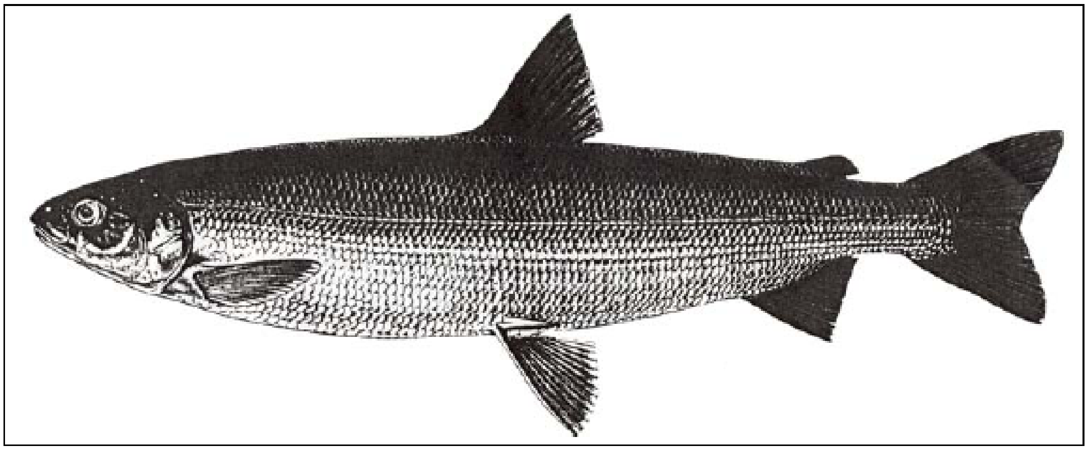
COSEWIC
Assessment and Status Report

on the

Atlantic Whitefish
Coregonus huntsmani

in Canada



ENDANGERED
2010

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Edge, T., and J. Gilhen. 2000. Update COSEWIC status report on the Atlantic Whitefish *Coregonus huntsmani* in Canada *in* COSEWIC assessment and update status report on the Atlantic Whitefish *Coregonus huntsmani* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-35 pp.

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COSEWIC acknowledges Tim P. Birt for writing the provisional status report on the Atlantic Whitefish, *Coregonus huntsmani*, prepared under contract with Environment Canada. The contractor's involvement with the writing of the status report ended with the acceptance of the provisional report. Any modifications to the status report during the subsequent preparation of the 6-month interim status report were overseen by Dr. John Post, COSEWIC Freshwater Fishes Specialist Subcommittee Co-chair.

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Atlantic Whitefish — Drawn by P. Drucker Bramwell, 1984.

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COSEWIC
Assessment Summary

Assessment Summary – November 2010

Common name
Atlantic Whitefish

Scientific name
Coregonus huntsmani

Status
Endangered

Reason for designation
This species, a unique Canadian endemic present in only a single location, is restricted to three interconnected lakes in Nova Scotia. Its viability is threatened by illegal introduction of exotic fishes.

Occurrence
Nova Scotia

Status history
Designated Endangered in April 1984. Status re-examined and confirmed in November 2000 and November 2010.

COSEWIC
Executive Summary

Atlantic Whitefish
Coregonus huntsmani

Species information

The Atlantic Whitefish (subfamily Coregoninae) has silvery sides, a white belly and a black, dark green or blue back. Wild fish in the existing population attain a maximum fork length of approximately 300 mm. The Atlantic Whitefish is morphologically and meristically differentiated from Lake Whitefish by its more terminal mouth, shorter pectoral fins, and greater lateral line scale (>90) and vertebrae (>64) counts. Mitochondrial DNA (COI) sequence data confirm that the Atlantic Whitefish is a distinct species that is strongly differentiated from other whitefishes.

Distribution

The Atlantic Whitefish is a Canadian endemic that is restricted to three lakes (Hebb, Milipsigate and Minamkeak) in the Petite Rivière watershed, near Bridgewater, Nova Scotia. Therefore there is a single designatable unit for Atlantic Whitefish. In recent years a few specimens have also been caught in lower sections of the Petite Rivière; these were probably strays from the three upper lakes. Historically, the species was commonly caught in the Petite Rivière estuary. A second population of Atlantic Whitefish has been introduced to Anderson Lake, Dartmouth, Nova Scotia, on an experimental basis. Life cycle closure has not been confirmed at this new location. The population that occurred historically in the Tusket-Annis watershed, Yarmouth County, Nova Scotia, has probably been extirpated.

Habitat

The Atlantic Whitefish, particularly the Tusket River population, was historically anadromous. Adults were reported from estuarine and sea waters during the summer and migrated into fresh water during the autumn months. After spawning, at least some Atlantic Whitefish were known to spend the winter in fresh water before descending into tidal waters the following spring.

Atlantic Whitefish in the Petite Rivière lakes are land-locked and complete their life cycle in these lakes and connecting streams. Atlantic Whitefish are occasionally reported in the Petite Rivière system below the three lakes. There is no evidence to suggest that these individuals are remnants of an anadromous population; more likely these are fish from the land-locked population that have washed over the dam at Hebb Lake. Capture records and gut analyses indicate that unlike Lake Whitefish, which is predominantly a benthic species, Atlantic Whitefish occurs throughout the water column.

Biology

Much of the basic biology of Atlantic Whitefish is unknown. Spawning occurs in December/January; adhesive, negatively buoyant eggs settle on lake substrates although specific spawning sites have not been identified. Young-of-the-year have occasionally been observed in littoral areas of the Petite Rivière lakes, but rearing habitat for young fish is not well characterized. Growth rates and age distributions are not known because of uncertainty associated with age determination. Movement patterns within the lakes are not known. Limited gut content analysis indicates a diet consisting largely of zooplankton, insects and some forage fish. Some evidence suggests the wild population is resource-limited; fish are small-bodied, short-lived and have limited reproductive potential. This may be related to freshwater residency as individuals in historically anadromous populations grew considerably larger.

Population genetic analyses have revealed no differentiation among Atlantic Whitefish in the three Petite Rivière lakes and low levels of microsatellite and mitochondrial DNA variation.

Population sizes and trends

No quantitative estimates of abundance are available. Qualitative information indicates that the population has declined in recent decades and that abundance in the Petite Rivière watershed is low. Based on the presumption that Atlantic Whitefish has been extirpated from the Tusket-Annis system, the area occupied by the species has decreased by 50% over the past 30 years (note that extirpation from the Tusket system occurred prior to the 2000 COSEWIC status assessment). Long-term genetically effective population size has been estimated at 140 individuals, an order of magnitude smaller than estimates for Lake Whitefish populations in Nova Scotian lakes of similar size. Since the previous COSEWIC assessment the extent of occurrence has remained unchanged, and comprises an area of approximately 16 km^2 defined by the three Petite Rivière lakes and connecting waters.

Limiting factors and threats

Contemporary limiting factors and threats affecting the Petite Rivière population include barriers to fish passage, introduction of Smallmouth Bass and urbanization impacts such as pollution caused by leaching of domestic waste. Lower risk sources of direct or indirect mortality/injury include bycatch in recreational and commercial fisheries, entrainment of fish in irrigation and municipal water supply intakes, water quality degradation resulting from agriculture, forestry and mining activities, acid toxicity due to acid precipitation and losses resulting from research, assessment and recovery activities. An unknown level of risk is posed by fish introductions resulting from recreational fishery enhancement.

Special significance of the species

Genetic information indicates that the Atlantic Whitefish is an evolutionarily distinct and ancient member of the whitefish group, not closely related to other species. Its lineage is clearly *not* a recent (i.e., post-Pleistocene) offshoot of any modern whitefish line. It should therefore be considered a globally significant component of Canada's biodiversity.

Existing protection

The Atlantic Whitefish is currently listed by COSEWIC as *Endangered* and is protected under the *Fisheries Act* and supporting regulations. It is also listed as *Endangered* under the *Species at Risk Act* and is protected under provincial legislation, namely the *Environment Act* and the *Endangered Species Act*. As mandated by the *Species at Risk Act*, a Recovery Strategy has been prepared by Fisheries and Oceans Canada.

TECHNICAL SUMMARY

Coregonus huntsmani
Atlantic Whitefish — Corégone de l'Atlantique
Range of occurrence in Canada:Nova Scotia

Demographic Information

Generation time estimate; see Life cycle and reproduction	3-4 yrs
Is there a continuing decline in number of mature individuals? See Limiting Factors and Threats	Uncertain
Estimated percent of continuing decline in total number of mature individuals	Unknown
Percent reduction in total number of mature individuals over the last 3 generations.	Unknown
Projected percent reduction in total number of mature individuals over the next 3 generations.	Unknown
Estimated percent reduction in total number of mature individuals over any 3 generations period, both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased?	N/A
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence EO represents the summed surface area of the three lakes and interconnecting waterways that support remaining wild population. EO estimated using minimum convex polygon method = 39 km^2	16 km^2
Index of area of occupancy (IAO) 2x2 grid value: 76 km^2	76 km^2
Is the total population severely fragmented?	No
Number of "locations∗"	1
Is there a continuing decline in extent of occurrence?	No
Is there a continuing decline in index of area of occupancy?	No
Is there a continuing decline in number of populations? Only 1 population known.	No
Is there a continuing decline in number of locations?	No
Is there a continuing decline in quality of habitat? Smallmouth Bass introduction; eutrophication from urban development; barriers to fish passage.	Probably
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations∗?	No
Are there extreme fluctuations in extent of occurrence? Stable over last 3 generations	No
Are there extreme fluctuations in index of area of occupancy? Stable over last 3 generations	No

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Petite Rivière Lakes	Unknown
Total	Unknown

∗ See definition of location.

Quantitative Analysis

Probability of extinction in the wild	Unknown

Threats (actual or imminent, to populations or habitats)

- Barriers to fish passage reduce Atlantic Whitefish productivity. Fish that fall over Hebbville Dam are lost from the breeding population. Barriers also prevent anadromy.
- Introduced Smallmouth Bass are predatory and have potential to alter trophic and competitive regimes of habitat.
- Acidification played a role in extirpating Atlantic Whitefish from Tusket-Annis drainage and will be a consideration in identifying watersheds for establishing additional populations (i.e., effecting range extension).

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? No other populations are known	
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	N/A
Is there sufficient habitat for immigrants in Canada?	N/A
Is rescue from outside populations likely?	**No**

Current Status

COSEWIC: Endangered 2010 - SARA: Endangered, Schedule 1 - IUCN Red List: Vulnerable D2

Status and Reasons for Designation

Status:	**Alpha-numeric code:**
Endangered	B1ab(iii)+2ab(iii)

Reasons for designation:
This species, a unique Canadian endemic present in only a single location, is restricted to three interconnected lakes in Nova Scotia. Its viability is threatened by illegal introduction of exotic fishes.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals):
Not applicable. No information on number of mature individuals.

Criterion B (Small Distribution Range and Decline or Fluctuation):
Meets Endangered under B1ab(iii)+2ab(iii) as both the EO (16 km²) and IAO (76 km²) values are lower than the thresholds for Endangered, the species is known to exist in <5 locations, and there is continuing decline in quality of habitat b(iii).

Criterion C (Small and Declining Number of Mature Individuals):
Not applicable. No information on number of mature individuals.

Criterion D (Very Small or Restricted Total Population):
Not applicable. No information on number of mature individuals.

Criterion E (Quantitative Analysis):
Not done

PREFACE

Our knowledge of Atlantic Whitefish has expanded considerably since the last Status Update. The Recovery Potential Assessment (RPA) for Atlantic Whitefish indicates that the species' survival depends upon its continued reproduction within the Minamkeak, Milipsigate, and Hebb lakes (DFO 2009) and that this information may form the basis for an identification for critical habitat. An analysis of microsatellite variation found no genetic differentiation among Atlantic Whitefish from the three lakes. Overall genetic variation of Atlantic Whitefish was found to be low relative to that of Lake Whitefish populations from other lakes in Nova Scotia. Mitochondrial DNA sequences have revealed that Atlantic Whitefish represent an ancient phylogenetic lineage that is strongly differentiated from other whitefishes. Protocols have been developed for culturing Atlantic Whitefish. The availability of cultured fish has facilitated studies of early development and physiological tolerances. Atlantic Whitefish develop salinity tolerance at a young age and are quite tolerant of acidic conditions. Cultured fish have also been released on an experimental basis in Anderson Lake, Nova Scotia. Survival and growth have been demonstrated in the introduced fish over a period of five years. Monitoring of the Petite Rivière lakes population has been hampered by the inability to make quantitative estimates of abundance. Since publication of the last Status Update, improvements have been made in methods of nonlethal sampling and in age determination using scales. These developments are expected to be helpful in future attempts to estimate the size of the remaining wild population. New information is also available about Atlantic Whitefish habitat. Sediment cores have revealed that the Petite Rivière lakes have been relatively stable in terms of pH and nutrient levels since pre-industrial times. The cores suggest a warming trend in the lakes over this period.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2010)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

on the

Atlantic Whitefish
Coregonus huntsmani

in Canada

2010

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WILDLIFE SPECIES INFORMATION

Name and classification

The Atlantic Whitefish, *Coregonus huntsmani*, is a member of the whitefish subfamily Coregoninae, family Salmonidae. While originally described by Scott (1967) as *Coregonus canadensis*, the species was known to exist at least 40 years earlier (Huntsman 1922). Scott (1987) subsequently renamed the species *C. huntsmani* in honour of A.G. Huntsman when the original specific epithet was shown to be unavailable. Other invalid scientific names appearing in published accounts include *C. quadrilateralis* (Huntsman 1922) and *C. labradoricus* (Piers 1927). Previously used common names include Acadian Whitefish, Sault Whitefish, Round Whitefish and Common Whitefish. The French name for Atlantic Whitefish is corégone de l'Atlantique.

One reason for the delayed recognition of the Atlantic Whitefish as a good species is its morphological similarity to the more widespread Lake Whitefish, *Coregonus clupeaformis*. Edge *et al.* (1991) and Hasselman *et al*. (2009) conducted comprehensive anatomical comparisons of the two species and reported several consistent meristic and morphological differences. Analysis of variation in isozymes, mitochondrial DNA and microsatellites demonstrated that Atlantic Whitefish is strongly differentiated genetically from Lake Whitefish and Lake Cisco, *C. artedi* (Bernatchez *et al*. 1991; Murray 2005; Hubert *et al*. 2008; Bradford *et al*. 2010).

Morphological description

The Atlantic Whitefish is similar morphologically to the Lake Whitefish; it is a silvery fish with a white belly and a black, blue-black or dark green back (Fig. 1). Atlantic Whitefish in all size classes have well developed teeth on the premaxillaries, vomer, and palatines in contrast with Lake Whitefish, which lack such teeth (Scott 1987). Edge *et al*. (1991) reported that the Atlantic Whitefish could be reliably distinguished from the Lake Whitefish sampled in the Maritime Provinces and the State of Maine by its more terminal mouth and a greater number of vertebrae (64-67, mean 65.3 versus 58-64, mean 60.6). The number of lateral line scales also distinguished the species in 93 percent of the specimens examined (88-100, mean 93.8 versus 63-95, mean 76.6 in Atlantic Whitefish and Lake Whitefish respectively). Hasselman *et al*. (2009) found that Atlantic Whitefish could be discriminated (>95%) from Lake Whitefish on the basis of three external characters used together, namely proportional pectoral fin length, lateral line scale count and mouth position.

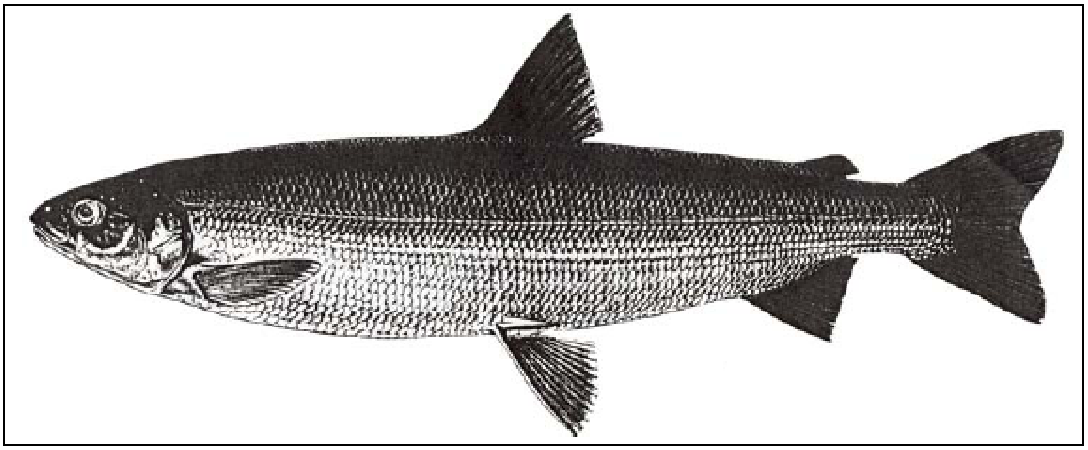

Figure 1. The Atlantic Whitefish, *Coregonus huntsmani* (by permission of Don McAllister). Drawn by P. Drucker Bramwell, 1984.

Spatial population structure and variability

Bernatchez *et al*. (1991) reported fixed differences separating Atlantic Whitefish from Lake Whitefish in two of five isozyme loci. Similarly, these authors reported that restriction analysis of mitochondrial DNA revealed a single haplotype was found in three Atlantic Whitefish specimens that is strongly differentiated from haplotypes found in Lake Whitefish (mean pairwise sequence divergence of 3.77 percent). The large sequence divergence estimate indicates that the Atlantic Whitefish lineage is ancient, i.e., the lineage predates the Pleistocene Epoch. More recently, sequence analysis of the mitochondrial COI gene in Atlantic Whitefish, Lake Whitefish and Lake Cisco populations confirmed the strong differentiation of Atlantic Whitefish from its presumed closest relatives and supports distinct species status for Atlantic Whitefish (Hubert *et al*. 2008; Bradford *et al*., 2010).

Strong genetic differentiation between Atlantic Whitefish and other whitefishes was also reported by Murray (2005), who assayed variation at 15 microsatellite loci in Atlantic Whitefish, Lake Whitefish and Lake Cisco. F_{ST} estimates were very high: 0.77 and 0.71 for Atlantic Whitefish versus Lake Whitefish and Atlantic Whitefish versus Lake Cisco, respectively. Within Atlantic Whitefish from the Petite Rivière, no genetic differentiation was observed among fish from the three lakes (F_{ST} = -0.014) indicating the presence of a single population. Furthermore, microsatellite variation was found to be very low. Only 33% of loci were variable in Atlantic Whitefish compared with >80% in Lake Whitefish and Lake Cisco. The average number of alleles per locus was also lower in Atlantic Whitefish (1.6) than in Lake Whitefish (4.2) and Lake Cisco (7.3). Estimates of microsatellite diversity were much lower in Atlantic Whitefish after correcting for lake size (a correlate of population size).

Designatable units

No subspecies of Atlantic Whitefish is recognized. The lack of genetic structure in the Petite Rivière lakes indicates a single population within the watershed. As this is the only known wild population the species is comprised of a single designatable unit.

Special significance

The Atlantic Whitefish is a uniquely Canadian species whose entire wild distribution is restricted to a single Nova Scotia watershed. The taxonomic distinctiveness of Atlantic Whitefish was unrecognized until quite recently due to its morphological similarity to Lake Whitefish. Genetic information has revealed the species to be strongly differentiated from other whitefishes and indicates an ancient phylogenetic split from a common ancestor. In other words, the Atlantic Whitefish is the sole representative of a highly significant lineage that predates the Pleistocene epoch. The genetic uniqueness of Atlantic Whitefish, as revealed by allozyme, microsatellite, and mitochondrial DNA variation (Bernatchez *et al*. 1991; Murray 2005; Hubert *et al*. 2008; Bradford *et al.* 2010), is consistent with ecological features that are unique to the species, e.g., strong salinity tolerance/preference early in development (Cook *et al*. 2010). Additional study of the Atlantic Whitefish will enhance understanding of the biology and evolution of the economically important coregonine fishes. Extinction of the Atlantic Whitefish would be a significant loss of Canadian biodiversity.

The species was almost certainly more widespread before European colonization. While never considered to be a food or sport fish of major importance, the Atlantic Whitefish has been described as an excellent table fish and a gamey fighter. In future, the species, particularly the larger anadromous form, could conceivably become the subject of a sport fishery following successful range expansion to rivers offering unimpeded access to the sea.

DISTRIBUTION

Global range

The only records of Atlantic Whitefish from freshwater sites, i.e., spawning populations, are from the Tusket River and the Petite Rivière in southwest Nova Scotia (Figure 2).

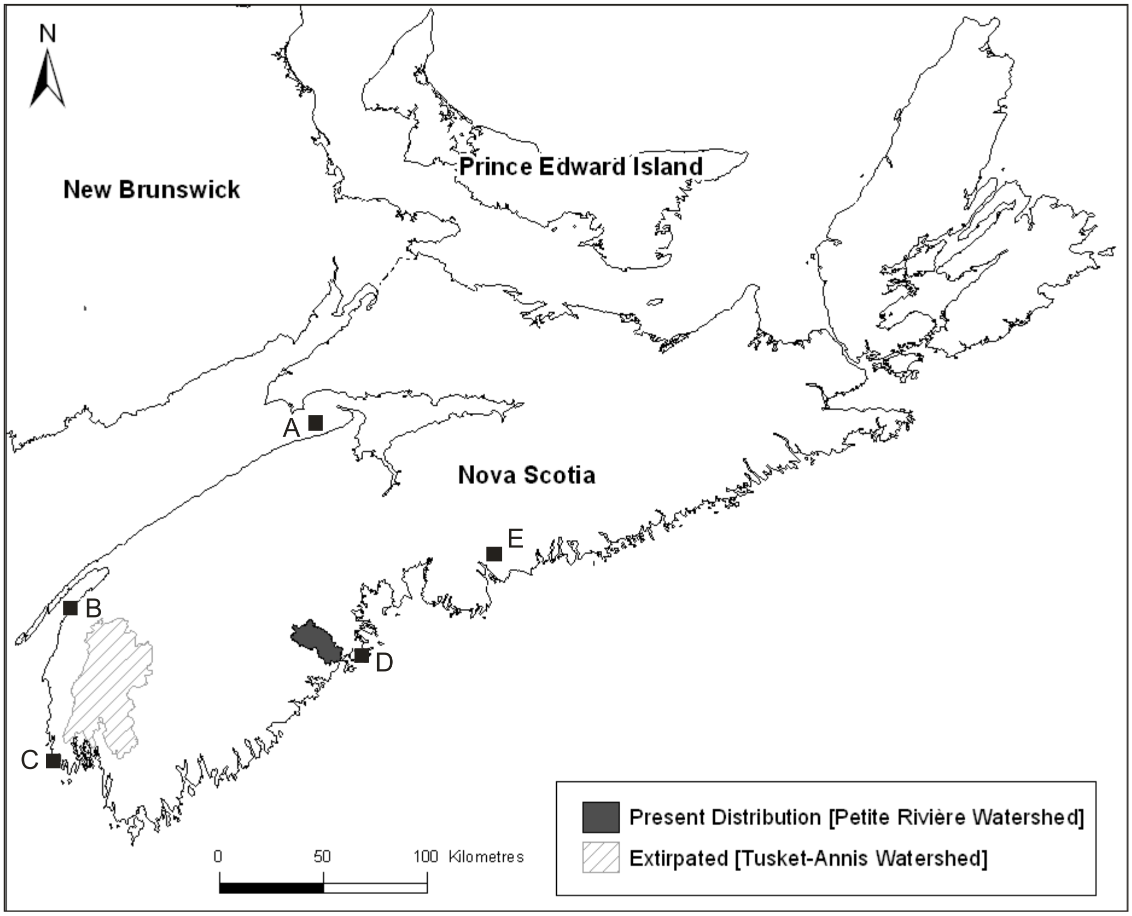

Figure 2. Locations of the Petite Rivière and Tusket-Annis rivers in Nova Scotia. Locations of historical capture records of Atlantic Whitefish outside the Tusket-Annis and Petite Rivière watersheds are indicated: A, Hall's Harbour; B, Sissiboo River; C, Yarmouth Harbour; D, Lehave River estuary. The location of the experimental population in Anderson Lake is also indicated: E.

Canadian range

The Atlantic Whitefish is an endemic Canadian species known only from southwestern Nova Scotia. Field studies conducted in 1982, 1983 and 1985 found the Atlantic Whitefish restricted to two disjunct watersheds: the Tusket-Annis watershed, Yarmouth County, and the Petite Rivière watershed, Lunenburg County (Edge 1987; Figure 2). The Tusket-Annis population is now considered extirpated because no records are known since 1982 (Bradford *et al*. 2004a). In the Petite Rivière, most of the Atlantic Whitefish records are from three interconnected lakes (Minamkeak, Milipsigate and Hebb) with a combined area of 16 km^2 (Figure 3). As these lakes are inaccessible to upstream migrants due to the lack of fish passage facilities at Hebbville Dam, this population is freshwater resident. A few records of Atlantic Whitefish are known from the Petite Rivière outside of these three lakes including Birch Brook, the mainstem of the river (Bradford *et al.* 2010), and Fancy Lake. They are also known to occur in small numbers in the Petite Rivière estuary.

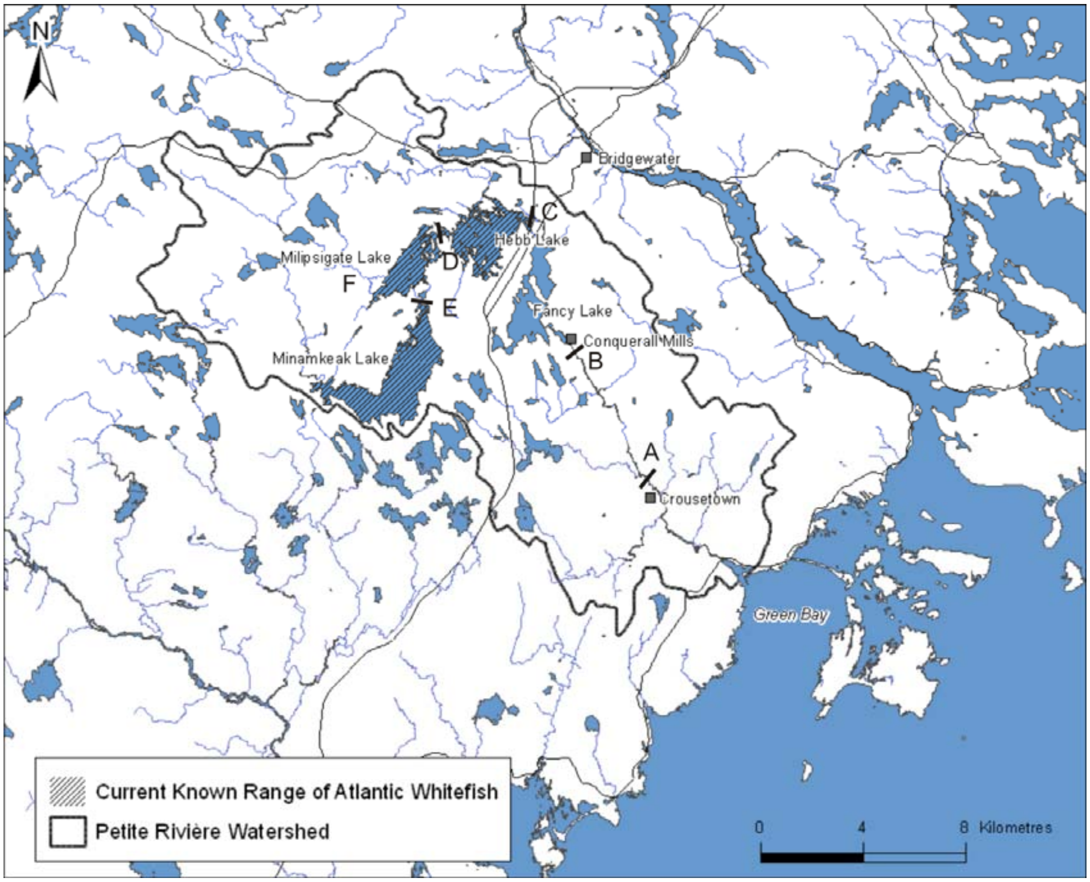

Figure 3. The Petite Rivière watershed showing lakes that contain land-locked Atlantic Whitefish and other sites noted in report. Also indicated are locations of dams currently in place at Crousetown (A); Conquerall Mills (B); Hebbville (C); Milipsigate Lake outlet (D); and Minamkeak Lake outlet (E). The location of Birch Brook is also shown (F). The Medway watershed borders the Petite Rivière watershed to the south.

Atlantic Whitefish populations have not been reported in fresh waters outside the Tusket-Annis and Petite Rivière watersheds despite long-standing and extensive commercial and recreational fisheries in fresh and coastal waters throughout Nova Scotia and surrounding jurisdictions. Furthermore, extensive province-wide fish surveys have failed to identify additional Atlantic Whitefish populations. For example, fish populations were surveyed in 744 lakes throughout Nova Scotia between 1964 and 1981 by Fisheries and Oceans Canada (DFO), the Canadian Wildlife Service, and the Nova Scotia Department of Lands and Forests (Alexander *et al*. 1986). Atlantic Whitefish were not recorded in any of these waters while Lake Whitefish were identified in 14 lakes. Although these surveys were not designed specifically to find Atlantic Whitefish, and therefore the apparent absence of the species must be interpreted cautiously, the results are consistent with the general view that the species is not widespread in occurrence. Similarly, surveys conducted for the Atlantic Whitefish throughout Nova Scotia in 1982 and 1983 found four lakes containing Lake Whitefish, but Atlantic Whitefish were not found outside of the Annis and Petite Rivière watersheds (Edge 1987).

At one time, the Atlantic Whitefish may have occurred in the Medway River watershed. Minamkeak Lake, the uppermost lake containing Atlantic Whitefish in the Petite Rivière watershed, previously flowed into the Medway River. Dynamite was used to create an outflow from Minamkeak Lake into Milipsigate Lake around 1905, and the original outflow of Minamkeak Lake into the Medway system was blocked. Whether Atlantic Whitefish occurred in Minamkeak Lake prior to this diversion or the species arrived by upstream dispersal from Milipisgate Lake afterward is not known; however, circumstantial evidence argues against the former scenario. No records are known of Atlantic Whitefish in Minamkeak Lake prior to the diversion. In addition, fish surveys of several lakes in the Medway drainage conducted during the years 2001-2004 did not find Atlantic Whitefish (Bradford *et al*. 2004a).

Atlantic Whitefish specimens have been caught on at least five occasions in coastal waters outside the Tusket and Petite Rivière watersheds (Figure 2). A specimen was caught on June 12, 1940, in Yarmouth Harbour, Yarmouth County, and another on May 31, 1958, in a herring weir at Hall's Harbour, Kings County. Two specimens are also reported to have been caught in full seawater at the mouth of the Sissiboo River, Digby County on September 8, 1919 (Scott and Scott 1988). More recently, an Atlantic Whitefish specimen was caught in the smelt fishery in the Lehave River estuary, Lunenburg County, in February 1995 (D.R. Bell pers. comm. 1997) and another one was caught there on May 24, 1997 (A. Hebda pers. comm. 1998). The Lehave River watershed is adjacent to the Petite Rivière watershed. The isolated nature of all these captures suggests these specimens were likely from the Tusket and Petite Rivière watersheds.

An experimental release of captive-reared Atlantic Whitefish was attempted in Anderson Lake, Dartmouth, Nova Scotia, in 2005 and 2006 (DFO 2006). Survival and growth over a period of at least one year was achieved (DFO 2009).

The extent of occurrence estimate, made using the minimum convex polygon method, is 39 km^2. The polygon was constructed as the minimum area containing Hebb, Milipsigate and Minamkeak lakes. Despite records of Atlantic Whitefish from below Hebbville Dam, including the Petite Rivière estuary, these areas are not included in the calculation because such fish are considered to be strays. While 39 km^2 is a small area, it is an overestimate. As an aquatic organism, the Atlantic Whitefish does not move outside of the space defined by the lake boundaries. A more realistic estimate of extent of occurrence is simply the combined area of the three lakes, i.e., 16 km^2. The index of area of occupancy, calculated as the number of 1-km^2 grids that contain any part of the three lakes when overlaid on a map, is estimated to be 48 km^2. Using 2 X 2 km grids resulted in an estimate of 76 km^2. The biological area of occupancy, normally considered to be a portion of the extent of occurrence, is considered to be the same as the extent of occurrence for this species (16 km^2) because the Atlantic Whitefish is a pelagic fish that makes use of both inshore and offshore habitats, i.e., they occupy all areas within the lakes.

HABITAT

Habitat requirements

Habitat requirements for Atlantic Whitefish are not well defined and much remains to be learned about habitat use throughout the species' life history. Anadromous populations, by definition, use both fresh water and estuarine/marine habitats at certain life history stages. The recently extirpated population in the Tusket-Annis system was certainly anadromous and this watershed provides extensive estuarine habitat. The extent of penetration into fresh water in this system was never studied. Atlantic Whitefish have been captured in winter through ice in Lake Vaughn just above the Tusket River dam (Patrick Patten pers. comm. 2000). They are known to venture into full-strength seawater and specimens have been caught off Wedgeport, Yarmouth County, in water with a salinity of 31 ppt (Scott and Scott 1988).

The Petite Rivière population was probably anadromous historically. This is not known with certainty because the capture records from the Petite Rivière estuary and the nearby Lehave River estuary are from spring months only, i.e., there are no records of mature Atlantic Whitefish in the Petite Rivière estuary during the autumn months (Bradford *et al.* 2004a). As with other salmonids, Atlantic Whitefish are not obligately anadromous; the population above Hebbville Dam has been freshwater resident since at least 1898 when a pre-existing mill dam was converted for hydroelectricity generation with no allowance for fish passage (Bradford *et al*. 2010).

The Petite Rivière watershed drains an area of about 233 km^2. Farms and a few small towns are situated within the watershed, although forested areas predominate, particularly surrounding the lakes containing Atlantic Whitefish. A characteristic of the watershed is the abundance of bogs which impart a tea colour to the water. Bathymetric surveys of Minamkeak, Milipsigate and Hebb lakes indicated maximum depths in 1983 of 13 m, 16 m and 14 m respectively, although much of the area of these lakes is shallower. The lake bottoms are silt in the deeper areas, whereas shoals and shoreline areas are rocky. A study of the temperature profile in Hebb Lake in 1983 indicated the warmwater nature of this lake. While the lake did stratify to a degree during the summer, a typical coldwater hypolimnion was not present. The temperature at the bottom of the lake in May was 14°C, and it rose to almost 20°C by late August.

Experimental gillnet capture data reveal that Atlantic Whitefish are present throughout the water column in the Petite Rivière lakes (Edge 1987). Based upon catch-per-unit effort, the great majority of Atlantic Whitefish caught were in surface and midwater horizons. Those caught at the surface and at midwater depths comprised 27% and 20%, respectively, of the catch of all fishes whereas those captured in bottom sets comprised only 2% of the catch. Those Atlantic Whitefish caught near the bottom were almost invariably caught in the deeper parts of the lakes. Only 7% of the bottom catches of Atlantic Whitefish were made in gillnets set on the bottom at depths of less than 8 m.

Habitat requirements in the lower reaches of the Petite Rivière are poorly known. Whether Atlantic Whitefish in this area are a remnant anadromous population or strays that have passed downstream over the Hebbville Dam is unknown. While Atlantic Whitefish have been regularly caught over many years in the brackish waters of the Petite Rivière estuary, Gaspereau (*Alosa pseudoharengus*) fishers from this area have not heard of captures in fresh water in the lower Petite Rivière or in nearby seawaters (D.R. Bell pers. comm. 1997).

Habitat trends

Atlantic Whitefish freshwater habitat has been altered extensively over the last 400 years. The species was probably more widespread historically, at least in southern Nova Scotia. Given that the taxonomic distinctness of Atlantic Whitefish has been recognized only recently, early records of whitefish from this area may refer to this species because Lake Whitefish are also present in Nova Scotia waters. The habitat changes that have eliminated the species from all but one watershed relate to several habitat issues, the most important ones being barriers to fish migration, acidification and introduction of exotic species. Reports dealing with habitat trends have not considered tidal waters.

Bradford *et al*. (2010) describe the extent to which rivers in southwestern Nova Scotia were dammed during the early years of the 19th century based on results of a survey of dams conducted in 1926 by fisheries overseers in the Maritime Provinces. In 33 watersheds located within the area bounded by the Annapolis River in the north and the Sackville River in the east, 92 dams were reported. Dams at the head of tide were documented in 15 rivers. Only ten rivers ran freely for at least 5 km above the head of tide. The 92 dams were constructed between 1802 and 1926. Most were in place before the *Fisheries Act* was proclaimed in 1868, hence were not subject to rules pertaining to fish passage contained in the *Act.* Fish passage was not usually considered in the early dam designs and many structures completely cut off large portions of watersheds to upstream migrating fishes. Diadromous species, including Atlantic Whitefish, would almost certainly have been affected by these barriers. Both the Tusket River and Petite Rivière had several dams in place at the time of the survey; the Petite Rivière had a dam at the head of tide while the first dam in the Tusket River was 15 km upstream of the head of tide (the first dam on the Annis River was situated 0.1 km above the head of tide). An account of the chronology of hydroelectric development on the Tusket and Petite Rivière systems was provided by Bradford *et al.* (2004b).

The survey of dams represents a snapshot of the state of fish passage around the year 1926. Dams removed prior to the survey were not reported; some barriers reported in the survey are no longer in place and new dams have been constructed since 1926. Due to provisions in the *Fisheries Act,* most dams currently in place provide for fish passage (although passage is not provided at Hebbville Dam). River barriers may therefore represent less of a problem than they did previously and many rivers in southwestern Nova Scotia may now be suitable for Atlantic Whitefish introductions (Bradford *et al.* 2010).

Acid deposition and associated pH reduction have affected the Tusket River in particular and the Petite Rivière to a lesser extent. While historical data are not available regarding precise pH levels, many watersheds in southern Nova Scotia have low buffering capacity and have been affected significantly by this trend. Portions of the Tusket River are presently quite acidic compared to many other rivers in Nova Scotia (Farmer *et al*. 1980; Watt *et al*. 1983). Farmer *et al*. (1980) surveyed the Tusket River at Gavelton in 1979-80 and found pH values from 4.55 to 4.85. They considered the Tusket River to be one of seven mainland Nova Scotian rivers unsuitable for the successful reproduction of Atlantic Salmon, *Salmo salar*, and suggested that the small surviving salmon population in this river was restricted to the Carleton tributary where water quality had remained acceptable. Watt *et al*. (1983) reported the mean pH of the Tusket River to be 4.8 in 1980-81 (4.6 in the East Branch).

Water samples from the Tusket River area in 1983 and 1984 were analyzed (Edge 1987). These water samples were obtained from the Annis River and the Tusket River (at the Lake Vaughn Reservoir) just above the influence of tidal waters in September 1983 and January 1984. In September 1983, when Atlantic Whitefish would begin migrating into fresh water, the pH of the Tusket River at Lake Vaughn was 5.23 and the pH of the Annis River was 6.05. In January 1984, the pH at Lake Vaughn was 4.59 and the pH of the Annis River was 5.02. Data from the Tusket River were collected around 1980 in the Carleton tributary and in 1995-96 in the main Tusket branch (Wilsons Bridge; data from ENVIRODAT, Atlantic Database Water Chemistry Data). These data indicate the average annual pH in the Carleton River based upon 11 monthly samples was 5.65 in 1980. The average annual pH in the main Tusket branch based upon 12 monthly samples was 4.68 in 1995 and 4.64 based upon seven monthly samples in 1996. Low pH values like those in the Tusket River east main branch are detrimental to the survival of Atlantic Salmon (Lacroix and Townsend 1987) and probably had an adverse impact on the ability of Atlantic Whitefish to reproduce in the Tusket River.

The Petite Rivière has been less affected by acidification than the Tusket River. Watt *et al.* (1983) indicated the river had a mean pH of 5.6 between 1980 and 1981. Watt (1986) characterized the Petite Rivière as a river where Atlantic Salmon stocks had not yet been affected by acidification and where there is no sign of an impact of acidification on angling returns.

Water chemistry data were collected from the Petite Rivière watershed in 1983-84 (Edge 1987). The Petite Rivière showed a trend in seasonal pH variation similar to other rivers in Nova Scotia, i.e., pH was relatively high over the spring and summer and then fell quickly in the fall to a midwinter minimum. Wide variation in pH was noted throughout the watershed; while it was usually above 5.5 in the lower Petite Rivière at Conqueral, pH was rarely above 4.5 in Still Brook, a darkly coloured brook draining a bog area. The lakes within the Petite Rivière watershed usually had a pH above 5.0. During February 1985, however, pH values were recorded from Hebb and Minamkeak lakes as low as 4.5 and 4.8 respectively, indicating pH fluctuations that could adversely affect aquatic life. Data from the lower Petite Rivière, available from ENVIRODAT (Atlantic Database Water Chemistry Data), indicate the average annual pH in the Petite Rivière, based upon 11 monthly samples, was 5.62 in 1985.

Alkalinity values, indicative of the buffering capacity of water, also varied considerably throughout the watershed. Alkalinity was usually detectable in the Petite Rivière at Conqueral whereas Still Brook lacked measurable alkalinity throughout the year. The Petite Rivière lakes had low alkalinity values (usually below 1.0 mg $CaCO_3$/L), particularly over the winter, and alkalinity was not measurable in Minamkeak and Hebb lakes in February 1985.

Due to the lack of long-term monitoring, there is no direct information regarding historical trends in pH values or other environmental indicators. However, recent palaeolimnological data indicate that the Petite Rivière watershed has not been subject to either significant acidification or eutrophication since pre-industrial times (Ginn *et al.* 2008). Sediment cores from Minamkeak, Milipsigate and Hebb lakes show consistent dominance of diatom assemblages indicative of present day pH and nutrient conditions. On the other hand, Ginn *et al*. (2008) did note a change over time in other diatom species. Specifically, a shift in dominance from *Aulacoseira distans* to *Cyclotella stelligera* indicates that a warming trend has occurred in the lakes. The potential impact on water chemistry of the diversion of Minamkeak Lake into the Petite Rivière is not known.

Despite conservation efforts, the range of Atlantic Whitefish has contracted in recent years. The species has not been reported in the Tusket-Annis system since 1982 in spite of a systematic survey of the system in 2001/2002 and the population is considered extirpated (DFO 2009). This represents a range reduction of some 50 percent over a period of approximately 30 years. Since the extirpation of the Tusket population, the range of Atlantic Whitefish has probably remained unchanged and limited to the three Petite Rivière lakes.

Habitat protection/ownership

Atlantic Whitefish do not occur on Federal Lands. The habitat in the Petite Rivière lakes is protected to some degree by provincial legislation. The town of Bridgewater (population approximately 8000 in 2006) has received its water supply from Hebb Lake since the turn of the century and maintenance of water quality in the watershed has been a concern. The area surrounding Hebb Lake and Milipsigate Lake was designated a Protected Water Area under provisions of *The Water Act* in 1964. The area around Minamkeak Lake was similarly designated in 1975. The Minamkeak Lake and Milipsigate-Hebb lakes protected water areas encompass approximately one half of the watershed and protect against lakeshore development, recreational activities, and disposal of sewage, biocides or garbage near the lakes. In addition, the Petite Rivière Watershed Advisory Group has expressed concern about ensuring the protection of the Atlantic Whitefish in the watershed (Peter Oickle pers. comm. 1985). This group was created in 1977 by the Nova Scotia Department of Environment. It provides advice to the Province of Nova Scotia, the Town of Bridgewater and the Municipality of the District of Lunenburg about problems and solutions relating to water quality, levels and flows in the watershed of Minimkeak Lake, Milipsigate Lake, Hebb Lake, Fancy Lake, and the Petite Rivière system.

The Species at Risk Act (SARA) was passed by the Canadian Parliament in 2003. Under SARA the Atlantic Whitefish was listed as Endangered under Schedule 1, which provides legal protection to the species' critical habitat once identified in a final recovery strategy or action plan. The Recovery Potential Assessment (RPA) for Atlantic Whitefish indicates that the species' survival depends upon its continued reproduction within Minamkeak, Milipsigate, and Hebb lakes and that this habitat is considered necessary for its survival and subsequent recovery (DFO 2009). This information may form the basis for an identification for critical habitat for Atlantic Whitefish and once formally identified, protection measures for the identified critical habitat will be triggered.

BIOLOGY

Life cycle and reproduction

Atlantic Whitefish in the Petite Rivière system complete their entire life history in fresh water, although anadromy was probably a common (perhaps dominant) life history tactic before construction of barriers to fish passage. Spawning has not been observed in the wild but both captive wild-caught and captive-reared fish spawn from late November to early January (DFO 2009). The locations of spawning sites are not known. Eggs from fish spawned in captivity are demersal, slightly adhesive, amber in colour and have a mean diameter of 4.01 mm after water hardening (Hasselman *et al.* 2007). Fecundity estimates range from 1,500 eggs produced by females at 25 cm fork length to 10,000 eggs produced by females at 45 cm fork length (DFO 2009). In culture, eggs hatch following an incubation period of 195-235 degree-days and metamorphosis occurs between 3.1 and 4.9 cm total length (Hasselman *et al.* 2007).

In the only published observation of wild young-of-the-year Atlantic Whitefish, Hasselman *et al.* (2005) reported a small school of approximately 20-30 individuals swimming in the littoral area of Hebb Lake in June, 2000; little more is known about habitat use by young-of-the-year. Likewise, growth patterns and population age structure of Atlantic Whitefish are poorly known. Sexual maturity is achieved at a size of approximately 20 cm fork length at a minimum age of 2+ years (DFO 2009). Hasselman *et al*. (2007) reported that mature fish from the Petite Rivière system range between 18 and 32 cm total length. In an earlier report, Piers (1927) stated that Atlantic Whitefish angled from the Petite Rivière lakes were usually 17.5 to 40 cm in length although rare individuals as large as 45 cm have been caught. Mature fish from the anadromous Tusket River population grew larger than the land-locked fish from the Petite Rivière watershed. Scott and Scott (1988) indicated that Atlantic Whitefish were reported by a fishery officer to have been as large as 3.63 kg in the Tusket River. One specimen caught in an eel pot in the Annis River in the fall of 1981 weighed about 2.5 kg (Limon Earl pers. comm. 1982). Atlantic Whitefish in the lower Petite Rivière appeared to grow larger than the lake specimens. A Gaspereau fisher caught a specimen that was about 50 cm in length and 1.82 kg in mass in the estuary in May 1966 (D.R. Bell pers. comm. 1997). The largest specimens studied by Edge (1987) from the Tusket and Petite Rivière watersheds were 50.7 cm and 31.7 cm in total length, respectively. Growth rates and longevity in the above-noted fish could not be determined because of uncertainty associated with age determination.

The exact spawning period and spawning locations for Atlantic Whitefish are not known. Fish in the Tusket River probably spawned in the late fall or early winter. A female specimen caught in the Annis River on October 12, 1982, when water temperature was 12°C, had well developed ovaries but was not yet ready to spawn. A specimen caught at the Tusket River dam on November 4, 1967, also had well developed gonads but was not ready to spawn. Adults caught in the Tusket River on May 24, 1940, and June 24, 1966, had poorly developed gonads suggesting spawning had occurred. Spawning in the Petite Rivière probably also occurs in late fall/early winter. Despite having well developed gonads as late as November 13, 1982, when water temperature was 10°C, Atlantic Whitefish in Hebb Lake were not yet ready to spawn (COSEWIC 2000).

Generation time can only be estimated crudely because of uncertainty associated with age determination. Cultured fish can reach reproductive size (approximately 20 cm) at two years of age. Early in life, growth in wild fish appears to be similar to that in cultured fish; young-of-the-year trap-netted in the autumn measure approximately 10 cm in length (R.G. Bradford *et al*., 2010). Maximum age of wild Atlantic Whitefish appears to be 4-5 years (DFO 2009). Average age of wild spawners is therefore estimated to be approximately 3-4 years. This estimate can be refined only when age determination techniques are validated.

Predation

Little is known about natural mortality due to predation but it is reasonable to assume that some of the fish species that occupy the Petite Rivière watershed are capable of consuming small Atlantic Whitefish (e.g., White Perch (*Morone americana*), Yellow Perch (*Perca flavescens*), Brook Trout (*Salvelinus fontinalis*) and Brown Bullhead (*Ameiurus nebulosus*)). Hatchery-reared Brook Trout are released into the mainstem of the Petite Rivière and have been stocked in Fancy, Wallace and Andrew lakes. Spread of Brook Trout likely represents a threat to Atlantic Whitefish and their regular introduction to Fancy Lake likely contributes to the apparently sporadic presence of Atlantic Whitefish in this lake. An Atlantic Whitefish was found in the stomach of a Brook Trout angled in Birch Brook, a tributary of Milipsigate Lake (Bradford *et al*. 2010). This record confirms the presence of Brook Trout above Hebbville Dam and strongly suggests the species has access to lakes Hebb, Milipsigate and Minamkeak although gill net catches from these lakes in 1982-83 did not include Brook Trout (COSEWIC 2000).

An additional threat is posed by introductions of non-indigenous species into the Petite Rivière and other Nova Scotia watersheds. Smallmouth Bass (*Micropterus dolomieu*) was illegally introduced in Wallace Lake around 1994 (A. Hebda pers. comm. 1999) and have spread within the watershed. They appear to be reproducing in Minamkeak and Milipsigate lakes (DFO 2009) and will almost certainly do so in Hebb Lake in the near future (R.G. Bradford pers. comm. 2009). The implications for Atlantic Whitefish remain to be determined but the potential for negative impact is evident from the history of Smallmouth Bass introductions to other watersheds (Jackson 2002; Bradford *et al*. 2004b).

The introduction of Chain Pickerel (*Esox niger*) in the Tusket-Annis system may have played a role in the extirpation of Atlantic Whitefish in this system and its presence will be a consideration in any repatriation initiative to this river. First noted in the Annis River in 1976, the species has spread throughout this system and is present in the Tusket River. Its expansion has coincided with the collapse of other soft-rayed fish populations including Lake Whitefish (Bradford *et al.* 2004b). While not present within the Petite Rivière system, its introduction there would have serious implications for the survival and recovery prospects of Atlantic Whitefish.

Physiology

Available physiological information on Atlantic Whitefish relates to evaluation of tolerance to various environmental conditions. As in many salmonids, salinity tolerance is low at the egg stage but, unlike many other salmonids, increases very rapidly post-hatch. Salinity tolerance develops to a high level early in development; both juvenile and adult Atlantic Whitefish are tolerant of salinities approaching full strength seawater (Cook *et al*. 2010.). Salinity tolerance does not appear to be associated with the suite of physiological alterations associated with the parr-smolt transformation observed in Atlantic Salmon and some other anadromous species.

In addition to having highly developed salinity tolerance soon after hatching, experiments by Cook *et al*. (2010) revealed that juvenile Atlantic Whitefish also prefer high salinity conditions. Given the option to choose among different salinities, juveniles strongly preferred a level of 30 ppt., i.e., a salinity approaching that of seawater. This observation, along with the results of the salinity challenge experiment, suggest that Atlantic Whitefish retain the basic physiological and behavioural capacity required for anadromy, i.e., the ability to regulate internal salt and water balance under marine conditions and preference for those conditions. This capacity has been retained in the Petite Rivière population since it was rendered land-locked more than a century ago by installation of the Hebbville Dam. The early development of hypo-osmoregulatory competence also suggests that seaward migration in anadromous fish occurred at a very young age. Enabling anadromy in the Petite Rivière Atlantic Whitefish and in populations that may be established elsewhere in future remains a possibility.

The temperature range supporting growth in Atlantic Whitefish has been established in recent investigations (DFO 2009; Cook *et al*. 2010). Growth can occur at temperatures between ~3-4°C and 24.0°C; the optimal temperature for growth is 16.5°C, an approximately average value among salmoniform fishes. The warmwater nature of Hebb Lake is illustrated by a 1983 survey that showed only slight thermal stratification and a bottom temperature of almost 20°C in August. The land-locked population appears to spend a considerable portion of the year in thermal conditions above the physiological optimum. This could be one factor contributing to the generally small size attained by land-locked Atlantic Whitefish in the Petite Rivière lakes.

Some physiological information related to pH tolerance has also become available recently. Atlantic Whitefish eggs are more sensitive to low pH than larvae and juveniles. Egg survival can be diminished at pH levels below 5.0 while survival of larvae and juveniles appears to drop at pH levels below 4.5 (DFO 2009). These data suggest that current conditions in the Petite Rivière system are acceptable to Atlantic Whitefish while the Tusket River has been acidified to a degree that could potentially affect repatriation efforts.

Laboratory experiments show a strong interaction between pH and temperature in regulation of growth in juvenile Atlantic Whitefish (Cook *et al*. 2010). Under strongly acidic conditions (pH < 4.75) the maximum temperature permitting growth and growth rate decreased. These same conditions did not alter optimal growth temperature. Reduced growth rates observed under acidic conditions were related to depressed food intake and probably also to increased energetic requirements for internal ionic regulation (Cook *et al.* 2010).

Dispersal/migration

The lack of specific information regarding spawning areas within the Petite Rivière watershed limits discussion of postnatal dispersal. Atlantic Whitefish are pelagic, highly mobile fish and presumably move freely throughout the Petite Rivière lakes. The only published account of an observation of young-of-the-year Atlantic Whitefish (Hasselman *et al.* 2005) suggests that movement within the lakes begins at an early age. The presence of an impassable barrier at the outlet of Hebb Lake and only partially negotiable barriers at the outlets of Minamkeak Lake and Milipsigate Lake constrains upstream interlake dispersal; most movement between lakes is probably unidirectional.

Historically, anadromy was an important component of dispersal in Atlantic Whitefish, particularly in the Tusket River population and likely in the Petite Rivière population as well. Downstream migration occurred in the spring although reports describing such movement do not differentiate between post-spawning adults and young fish entering the sea for the first time. The age of Atlantic Whitefish first entering the sea is not known although the early development of salinity tolerance suggests this movement could have occurred in very young fish. Like so many other aspects of the Atlantic Whitefish life history, information about dispersal within the ocean is fragmentary. The few catch records available, especially those from Hall’s Harbour and the Sissiboo River mouth, indicate that some proportion of seagoing whitefish travelled long distances. Whether the general pattern of marine migration in Atlantic Whitefish was more similar to that of Atlantic Salmon (i.e., relatively long distances travelled beyond the home river estuary over extended time periods) or that of Brook Trout (i.e., relatively short periods spent within the home river estuary) is not known.

Although records of dispersal between rivers are completely lacking, there is no reason to believe that such movement did not occur historically when the species was more widespread. The most likely mechanism would have been straying into rivers other than their natal river following the marine phase. This form of dispersal represents a potential source of gene flow among populations and a potential opportunity for population rescue (especially for small populations). Such metapopulation dynamics have been a long-recognized phenomenon in anadromous salmonid fishes. Unfortunately, unassisted population rescue is presently impossible for Atlantic Whitefish whose range is now limited to a single watershed in which anadromy has been virtually eliminated. The species will need to be established in additional rivers if potential for population rescue via this mechanism is to be restored.

Interspecific interactions

No reports of interspecific symbiotic or host/parasite relationships have been described for Atlantic Whitefish. Perhaps the most significant interspecific interactions are those with predatory fishes recently introduced into the Tusket and Petite Rivière systems (described above). Atlantic Whitefish could be affected directly by these introductions through predation and/or territorial behaviour, or indirectly through altered trophic structure of the lake communities. Research is in progress to explore these issues (R.G. Bradford pers. comm. 2009).

Atlantic Whitefish do not presently co-occur with the morphologically similar Lake Whitefish, i.e., the latter species is not known to occur in the Petite Rivière. Because Lake Whitefish are present in the Tusket-Annis system, the two species were potential competitors prior to the extirpation of Atlantic Whitefish from this system. Several lines of evidence suggest that interspecific competition may not have been strong between the two species. First, Lake Whitefish are known from lakes relatively high up in the Carleton Branch of the Tusket watershed (Bradford *et al*. 2004a). Due to uncertainty about the distance Atlantic Whitefish penetrated this system and the lack of evidence for freshwater resident populations it is possible that individuals of the two species encountered each other infrequently. Second, Atlantic Whitefish in the Tusket-Annis system were anadromous while Lake Whitefish tend to be freshwater resident. The different life history tactics would reduce competition between the species, especially if Atlantic Whitefish descended into tidal waters soon after hatching. Third, gill net capture data show that Atlantic Whitefish occur throughout the water column (Edge 1987) while Lake Whitefish are generally benthic fish. This is supported by dietary analysis, which showed that Atlantic Whitefish consume mostly zooplankton, insects and small fishes, in contrast to Lake Whitefish which consume mostly benthic organisms such as molluscs and amphipods (Edge 1987).

Adaptability

Adaptability is an important issue for the recovery of Atlantic Whitefish. The goal of the Atlantic Whitefish Recovery Strategy is to "*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). If the surviving population lacked the adaptive flexibility to survive and reproduce in habitats outside of the current range, then the recovery goal could not be achieved because range expansion would be impossible. Fortunately, there is evidence for adaptability in Atlantic Whitefish. Anadromy was probably an important component of the life history of the species prior to the widespread installation of barriers to fish passage in southwest Nova Scotian rivers. A benefit realized by anadromous fishes is the potential to attain larger body size than freshwater residents, and hence, greater fecundity (Dadswell *et al.* 1987). The demonstration by Bradford *et al.* (2010) of the positive relationship between body size and fecundity in Atlantic Whitefish suggests the survival potential of the Petite Rivière population might benefit if anadromy were an option. The latter is contingent upon provision of fish passage facilities.

Anadromy demands physiological and behavioural versatility because animals must be capable both of functioning in very different environments and of making successful transitions between such environments. Previously discussed collaborative research has demonstrated physiological tolerance of Atlantic Whitefish to variable regimes of salinity, pH and temperature (Cook *et al*. 2010). The observation of strong salinity tolerance (and preference) early in development in fish derived from the only extant wild population is notable because this population has been freshwater resident for more than a century. Despite many generations of freshwater residency, the population appears to have retained the physiological capacity for anadromy.

Expanding the range of Atlantic Whitefish into watersheds not currently occupied by the species will depend on the species' ability to tolerate local conditions. Observations of Cook *et al*. (2010) regarding pH and temperature tolerances indicate a degree of adaptability that permits consideration of many drainages in southwestern Nova Scotia as candidate sites for establishment of new populations.

Whitefishes, particularly Lake Whitefish, are well known to display marked developmental plasticity, i.e., phenotypic variation resulting from environmentally induced changes in ontogenetic development (Lindsey 1981). For example, the commonly observed phenomenon of sympatric lacustrine populations of limnetic and benthic morphs of Lake Whitefish can be interpreted as an example of adaptive intraspecific variation that likely derives from developmental recombination (reorganization of ancestral phenotypes; West-Eberhard 2005). Anadromy versus freshwater residency is an expression of developmental plasticity in Atlantic Whitefish. While the existence of freshwater residency prior to the era of dam construction cannot be assumed, there is a strong probability that this life history tactic existed before that time, especially because both watersheds known to contain Atlantic Whitefish in modern times have numerous lakes. The presence of both anadromous and freshwater resident forms within the same watershed has been reported in other salmonid fishes (e.g., Foote and Larkin 1988; Birt *et al.* 1991). Ultimately, this life history variability can be interpreted as evidence for adaptability in the species.

Atlantic Whitefish have been brought into captivity and are being cultured successfully at the Mersey Biodiversity Facility. Hatchery-reared fish have been released on an experimental basis into Anderson Lake, Dartmouth, Nova Scotia in 2005 and 2006 (DFO 2006) and the lower Petite Rivière. Survival of hatchery fish in Anderson Lake has been confirmed in subsequent years (see below). The success of this introduction to this point is further evidence that the species retains some degree of adaptability to novel conditions.

POPULATION SIZES AND TRENDS

Search effort

Bradford *et al.* (2004a) describe sampling efforts undertaken from 1999 until 2002 in the Tusket-Annis system. This involved surveys of 20 lakes employing 30 m gillnets of variable mesh sizes set in deep (10 m) and shallow (2-3 m) water. Typically, two nets were set at each depth and fished overnight. In addition, upstream and downstream fish movement was monitored using traps set in the fish ladders of the Powerhouse and Lake Vaughn dams in the summer and autumn months. That no Atlantic Whitefish was observed in any of these surveys supports the view that the species has been extirpated from this watershed. Directed monitoring at fish passage facilities at these dams has not been done since the 2004 assessment and no report from the public of Atlantic Whitefish in the Tusket-Annis system has been received (Bradford *et al*. 2010).

Sampling in the Petite Rivière watershed since 2000 has employed various methods including angling, trapnetting, gillnetting and seining in Minamkeak, Milipsigate and Hebb lakes (Bradford *et al*. 2004a; DFO 2009). Unsuccessful attempts were made to survey juveniles using gear types reported in the literature as effective for capturing young whitefishes in European and North American waters (R.G. Bradford pers. comm. 2009). Gillnet surveys, as described for the Tusket system, were also made between 2001 and 2004 in six lakes above and six lakes below Hebbville Dam. Monitoring in the Petite Rivière estuary using trapnets and in the adjacent Medway and Lahave watersheds using gillnets, trapnets and fish counting facilities (upstream and downstream) has also been conducted. No Atlantic Whitefish was caught in any of the surveys conducted outside the Petite Rivière watershed. Within the Petite Rivière watershed, Atlantic Whitefish were caught only in Minamkeak, Milipsigate and Hebb lakes. Search efforts since the 2004 assessment are described by Bradford *et al*. (2010). One Atlantic Whitefish was angled from the Lower Petite Rivière near Crousetown in 2004. In 2007, several Atlantic Whitefish were observed during sampling operations in Milipsigate Lake and one specimen was recovered from the stomach of a Brook Trout angled in Birch Brook. Atlantic Whitefish were collected in Hebb Lake in 2005, 2006 and 2007. No collections were attempted in Hebb Lake during 2008 although Atlantic Whitefish were observed by R.G. Bradford in May below Milipsigate Dam. In 2009, Atlantic Whitefish were captured using floating trap nets in lakes Minamkeak and Milipsigate (R.G. Bradford pers. comm. 2009).

Angler surveys conducted since 2000 have sought public input regarding suspected reports of Atlantic Whitefish in Nova Scotia (Bradford *et al*. 2004a). Among 39 respondents, eight reported recent observations within the Petite Rivière watershed, seven of which were from below Hebbville Dam. Of these seven, three were from lakes situated on secondary tributaries. These reports should be viewed cautiously because the fish identities were not confirmed.

Abundance

There are no quantitative estimates of Atlantic Whitefish abundance due to uncertainty in relating catch to effort, hence census population size cannot be reported. The lack of any recent reports from the Tusket-Annis watershed and the negative results of the surveys described above support the view that Atlantic Whitefish have been extirpated from this system. In the Petite Rivière system, the species is present and largely confined to three lakes, but all that can be said about abundance is that it is low (DFO 2009). Genetically effective population size (N_e) has been estimated using microsatellite variation by applying traditional (moment-based) approaches (Murray 2005). The estimate of 140 individuals is more than 13 times lower than estimates for Lake Whitefish from lakes of comparable size. It must be stressed that this value of N_e represents a long-term theoretical estimate and should not be interpreted as a reflection of the contemporary situation. Furthermore, estimates of N_e are not equivalent to estimates of census population size, i.e., abundance (Frankham 1995).

Fluctuations and trends

Since the previous status update (COSEWIC 2000), the number of wild populations has not changed. Furthermore, recent studies reveal that the length frequency distribution of the Petite Rivière lakes population has remained stable for several decades (Bradford *et al.* 2010). Unfortunately, trends in abundance cannot be described quantitatively for the same reason that present-day abundance cannot be estimated quantitatively. Nonetheless, limited information permits a qualitative description of historic fluctuations and trends.

The abundance and distribution of the species prior to the arrival of Europeans is unknown, although it was almost certainly present in many rivers that do not contain Atlantic Whitefish today. An intensive period of dam construction occurred soon after arrival of European settlers and the species likely disappeared from many rivers over a short time as access to spawning areas was eliminated. Confirmed records of Atlantic Whitefish in modern times are known from only two rivers, the Tusket and the Petite.

Atlantic Whitefish was once abundant in the Tusket River watershed (Gilhen 1977; Scott and Scott 1988). Large numbers of anadromous fish were known to migrate up the river in the months of October and November, and anglers on the river and in Wedgeport and Yarmouth harbours considered them abundant. Prior to 1940, it was not uncommon to catch 200 specimens in a Gaspereau net on the Tusket River (Gilhen 1977). Similarly, large numbers were caught in Gaspereau nets in the Annis River. Scott and Scott (1988) indicated that an Atlantic Salmon trap located on the Tusket River in 1954 caught 86 upstream migrating Atlantic Whitefish between 18 October and 7 November.

The hydro dam constructed in 1929 at Tusket Falls appears to have had a significant impact on Atlantic Whitefish abundance. No facility was incorporated into the structure to deter fish from entering the sluices, probably resulting in mortality due to contact with turbine blades. Studies in 1960 and 1961 indicated that young salmon and Gaspereau descending through the turbines suffered mortality rates of 16.5% and >50% respectively (Smith 1960; 1961). While Atlantic Whitefish was not considered in these studies, it is reasonable to conclude that some level of mortality was sustained by migrating fish. Fish ladders constructed later may have reduced mortality in downstream migrants. Some fish ladders were ineffective for upstream migration and some that were effective were not secure and permitted poaching of large numbers of adults from the holding pools (Scott and Scott 1988; DFO 2006).

The population in the Tusket River appears to have declined most rapidly during the 1940s and 1950s. Gilhen (1977) suggested that abundance dropped noticeably in the 1940s due to the installation of more turbines in the Tusket River hydroelectric dam, the lack of screens to prevent fish entry into dam sluices, and some ineffective fish ladders. Scott and Scott (1988) suggested that after extensive poaching from fish ladders in the 1950s the Tusket River population never recovered to former levels of abundance. During these years, Atlantic Whitefish (and other species) were also challenged by reduced pH levels caused by increased acid deposition.

By the 1970s it was unusual to catch Atlantic Whitefish in the Tusket River (Gilhen 1977). The field survey conducted in the fall of 1982 failed to find any Atlantic Whitefish despite the operation of a DFO fish trap on the fish ladder at the Tusket River hydro-electric dam from 5 October to 20 November (Edge 1984). This fish ladder would have been the only means for entry to fresh water because the other fish ladder at the Tusket River holding dam had insufficient water flow.

In the Petite Rivière watershed a small recreational fishery has been pursued around Milipsigate and Hebb lakes since at least the 1870s. Although anglers have not considered Atlantic Whitefish to be plentiful in these lakes, these fish are known to congregate in schools below the Milipsigate Lake dam outlet in the spring, where they were vulnerable to capture. Reports from the 1920s indicate that significant numbers of whitefish were caught at this site by anglers and others using different methods. Atlantic Whitefish were not observed at this site between 9 May and 15 May 1983 when water temperature was 14°C. However, a small gillnet set overnight on 17 February 1985 caught five specimens at this site. Approximately 25-30 Atlantic Whitefish were observed near the Milipsigate Dam outlet in the spring of 1999 (Bradford *et al.* 2004a). The following spring there was an estimated 200-250 individuals observed at this location.

A field survey in the fall of 1982 found Atlantic Whitefish surviving in Hebb, Milipsigate and Minamkeak lakes within the Petite Rivière watershed (Edge 1984). This survey suggested populations were small based on average catches of 0.75, 1.25 and 2.0 whitefish per 75 m gillnet set for 18 hours in Milipsigate, Minamkeak and Hebb lakes respectively. A variety of gear types (minnow traps, seines, trapnets, and gill nets) was employed during the summer of 1983 to study fish populations in Hebb Lake (Edge 1987). Atlantic Whitefish were caught only with gillnets and represented just 4.9% of the catch, indicating that the population was small. Sampling was also conducted in most years between 2000 and 2008 in the Petite Rivière lakes, resulting in small numbers of Atlantic Whitefish being caught (DFO 2009).

Captain D.R. Bell, Petite Rivière, Lunenburg County, has provided insights on the history of Atlantic Whitefish that suggest a decline in population size over the last several decades (pers. comm. 1987). Captain Bell indicated that Atlantic Whitefish have occurred in the Petite Rivière estuary since at least the 1930s and that they were caught in drift nets in the harbour for use as lobster bait. Thirty to fifty Atlantic Whitefish could be caught in ten nets over one night's fishing. Prior to the late 1940s it was relatively common to catch them in the Gaspereau fishery from mid-April to June. Only one Gaspereau fisher remained on the Petite Rivière in 2000 and he caught and released only two or three Atlantic Whitefish on average over an entire season. He caught and released three Atlantic Whitefish in the spring of 1999. While abundance appears to have declined since the 1930s, Captain Bell indicated it is still not uncommon at times to see Atlantic Whitefish jumping, much like salmon on a rising tide, in the Petite Rivière estuary. These fish could conceivably be part of a remnant anadromous population living in accessible portions of the river but more likely they are strays from the freshwater resident population in the lakes.

Although quantitative estimation of fluctuation and trends in abundance is not possible given the information at hand, a long-term decline has occurred, probably beginning soon after European settlement. Assuming that the Tusket River population has been extirpated, the area of occupancy has declined by at least 50% since 1982. The remaining range of naturally occurring Atlantic Whitefish now appears to be restricted to an area of approximately 16 km^2 comprising the combined area of Minamkeak, Milipsigate and Hebb lakes (DFO 2009).

Rescue effect

The lack of populations outside Canada precludes the possibility of rescue via trans-border dispersal. Similarly, because all remaining wild Atlantic Whitefish are restricted to a single land-locked population residing in three lakes above Hebbville Dam on the Petite Rivière, the notion of population rescue via natural dispersal is largely meaningless. However, some potential for population rescue exists by virtue of current management activities. The development of protocols for the culture of Atlantic Whitefish at the Mersey Biodiversity Centre and the maintenance of a captive group provides options in support of recovery efforts, as well as specimens that can be used for research purposes (e.g., Cook *et al*. 2010). One such option, i.e., establishment of backup populations in water bodies outside the Petite Rivière drainage, has been attempted on an experimental basis in Anderson Lake. In 2005/2006 approximately 3000 captive-reared Atlantic Whitefish were released into Anderson Lake (DFO 2006). Although the experiment is not yet completed, preliminary observations (R.D. Bradford pers. comm. 2010) confirm survival and growth of released fish. Samples examined in 2007 and 2008 revealed that the introduced Atlantic Whitefish fish fell into two categories with regard to general condition; either they displayed good condition or rather poor condition with few fish in between. Few individuals in poor condition were observed in 2009. Furthermore a ripe and running female was observed in 2009. Sampling in 2010 and beyond is required to determine if Atlantic Whitefish in Anderson Lake have reproduced successfully.

A lake in Lunenburg County has been selected as a site to receive wild Atlantic Whitefish transferred from the Petite Rivière lakes in the event of a threat to the survival of that population (R.G. Bradford pers. comm. 2009). Efforts to achieve further range expansion will involve introductions to additional suitable watersheds, a number of which exist in southwestern Nova Scotia (DFO 2009).

LIMITING FACTORS AND THREATS

Bradford *et al*. (2004b) and DFO (2009) examined factors threatening the survival and recovery of Atlantic Whitefish and rated the relative importance of each threat. In the context of the sole remaining population in the Petite Rivière, several factors with the potential to cause direct and indirect mortality are associated with dams, including hydroelectric generation and municipal/agricultural water storage, extraction and drawdown. While hydroelectric generation no longer takes place on the Petite Rivière, dams constructed at Conquerall Mills and the Hebb Lake outlet were previously used for this purpose. Dams at the outlets of Minamkeak and Milipsigate lakes managed water flow to turbines at the Hebbville dam. The Conquerall Mills dam was opened in 1977, although it is uncertain whether unimpeded upstream movement is possible at the site throughout the year. Dams at the outlets of Minamkeak, Milipsigate and Hebb lakes remain in place; the latter completely bars upstream movement and therefore eliminates reproductive value from fish that fall over the dam. A wooden dam on the mainstem of the Petite Rivière at Crousetown (Fig. 3) was built in 1889 to power a mill. A run-around at this dam permits upstream passage for Gaspereau and Atlantic Salmon. However the efficiency of the run-around is not known for any fish species including Atlantic Whitefish.

While dams on the Petite Rivière played a role in the decline of Atlantic Whitefish by causing mortality of animals passing through turbines, they are probably not a direct cause of mortality today. The lack of fish passage around Hebbville Dam represents a loss of productivity as Atlantic Whitefish falling over the dam are unable to return to the lakes and are lost from the population. Lack of fish passage also precludes any increase in productivity that might arise from anadromy. Anadromous fish grow much larger than freshwater residents, hence they have much greater reproductive potential, particularly females.

A second imminent threat is the introduction of non-indigenous fishes (DFO 2009). Smallmouth Bass were first reported in the Petite Rivière watershed in 1994 and have since spread widely through the system, including Minamkeak, Milipsigate and Hebb lakes. Although the ultimate impact of this introduction on Atlantic Whitefish is uncertain, it needs to be viewed seriously due to the documented negative impact that introduced Smallmouth Bass have had on lake communities in other areas. Effects of Smallmouth Bass in the Petite Rivière system could take the form of direct predation on Atlantic Whitefish, habitat displacement and trophic disruption (Jackson 2002).

Introduction of exotic predators could limit recovery efforts on behalf of Atlantic Whitefish in other watersheds. Noteworthy is the introduction of Chain Pickerel into the Annis River. Similarly, Smallmouth Bass have been introduced to the Tusket River. Since the appearance of Chain Pickerel, lakes in the Annis River have experienced a decimation of soft-rayed fishes including Lake Whitefish (Bradford *et al*. 2004b). The presence of Smallmouth Bass and Chain Pickerel will need to be a consideration during selection of candidate rivers for introductions of anadromous runs, including the Tusket-Annis system.

A third factor limiting Atlantic Whitefish recovery is habitat acidification. Many rivers in southwest Nova Scotia have become acidified to the point that Atlantic Salmon can no longer reproduce and their native populations are considered extinct (Watt *et al.* 1983; Watt 1986; 1989). Watt (1986) categorized the Tusket as a river where only remnant salmon populations persist in one or two less acidified branches. Whereas the Annis River and the Carleton Branch of the Tusket are better buffered than the remainder of the Tusket, the pH in the latter can drop quite low at times; pH readings sufficiently low to induce mortality in eggs, larvae and early juvenile Atlantic Whitefish occur regularly in this part of the system. Although this factor will need to be considered in deliberations about repatriating the species to the Tusket River, certain aspects of the biology of Atlantic Whitefish suggest acidification may be less of a problem than it is for other species. Atlantic Whitefish are more acid-tolerant than Atlantic Salmon and preference for elevated salinity early in life (Cook *et al.* 2010) suggests shorter freshwater residence time prior to outward migration in anadromous fish. In contrast to the Tusket-Annis rivers, the buffering capacity of the Petite Rivière is greater and consequently the pH levels are generally higher. Acidification does not appear to be a limiting factor in the Petite Rivière.

A number of additional, though less imminent threats and limits to recovery have been identified (Bradford *et al*. 2004b). These include incidental catch by anglers and commercial fishers, fluctuating water levels, entrainment of fish into water intakes, removal/mortality associated with scientific sampling, siltation, eutrophication and habitat degradation by shoreline alteration. These factors are generally considered to have relatively low threat potential.

ABORIGINAL TRADITIONAL KNOWLEDGE

Results from interviews, conducted in August 2002, of 16 Acadia First Nation individuals, representing the Shelburne, Yarmouth and Wildcat Reserves, were reported by Bradford *et al*. (2004a). Nine individuals (eight from Yarmouth, one from Wildcat) were aware of Atlantic Whitefish. One reported catching an Atlantic Whitefish in the Kemptville area in the 1950s and a second reported catching an Atlantic Whitefish in the Medway River in the 1940s. ATK surveys have not been conducted since 2002 (Bradford *et al*. 2010).

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Atlantic Whitefish management and protection falls under the Canadian *Fisheries Act* and its supporting regulations, which contain provisions that can be applied to regulate flow needs for fish, fish passage, killing of fish by means other than fishing, the pollution of fish-bearing waters, and harm to fish habitat. Under section 6 of the Maritime Provinces Fishery Regulations, retention or possession of Atlantic Whitefish is prohibited. A variation order under the Fishery (General) Regulations prohibits all angling in Minamkeak, Milipsigate and Hebb lakes and connecting waters between the dates of 1 April and 30 June, annually. As of 2005, anglers may use only unbaited lures and artificial flies between the dates of 1 July and 30 September. Furthermore, gillnet fishing for Gaspereau in the Petite Rivière estuary is not permitted.

The Atlantic Whitefish was assessed as *Endangered* by COSEWIC in 1984. *Endangered* status was upheld in the 2000 and 2010 COSEWIC status assessment. The species was subsequently listed as *Endangered* under Schedule 1 of the Canadian *Species at Risk Act* upon its enactment in 2003. Protection provided by provisions of the *Species at Risk Act* applies to the introduced Anderson Lake population as well as to the population in the Petite Rivière lakes. The 2000 IUCN Red List of Threatened Species designated Atlantic Whitefish as *Vulnerable D2* which signifies a high risk of extinction in the wild in the medium-term future. Under the NatureServe (2010) ranking system, the Atlantic Whitefish has a global designation of G1 (critically imperiled). Atlantic Whitefish are also protected under provincial legislation, including the Nova Scotia *Environment Act* (1994-95), and the Nova Scotia *Endangered Species Act* (1998). Minamkeak, Milipsigate and Hebb lakes provide the municipal water supply for Bridgewater, hence they fall under regulations of the *Environment Act* which addresses activities within the watershed that could affect water quality such as forestry, agriculture and mining practices.

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