Fisheries and Oceans Canada Pêches et Océans Canada
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Research Document 2010/005 **Document de recherche 2010/005**

2009 Update Status Report for Atlantic Whitefish (*Coregonus huntsmani*)

Mise à jour du rapport de situation de 2009 sur le corégone de l'Atlantique (*Coregonus huntsmani*)

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

TABLE OF CONTENTS

Correct citation for this publication:

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

ABSTRACT

The Atlantic whitefish (*Coregonus huntsmani*), considered to be anadromous by nature, is endemic to Canada (Scott 1987), and found only in the Province of Nova Scotia. They presently exist as a land-locked population within three small semi-natural lakes in the Petite Rivière. The lakes can not be accessed from the sea. Atlantic whitefish are listed and protected as endangered under the Canada *Species at Risk Act* (*SARA*). Analyses of both mitochondrial and nuclear DNA support their putative status as an ancient and highly discrete lineage of whitefish. However, the remaining population exhibits extremely low genetic diversity, and no genetic variation among the three lake contingents. The land-locked population is probably resource limited, generally small-bodied, short-lived, and limited in reproductive capacity when compared to members of the same population introduced into captive rearing. These traits of the land-locked population do not appear to have changed greatly over the past several decades. Somatic growth realized by Atlantic whitefish in a captive rearing environment is virtually the same as that of the anadromous population that existed on the Tusket River prior to 1982. A re-construction of the prevalence, location, and date of construction of man-made dams in southwestern Nova Scotia rivers in 1926 indicates that river accessibility was probably impeded in the decades prior to the first description of Atlantic whitefish as a species in 1922. Removal of many of these dams, and a strengthened regulatory framework concerning fish passage around existing structures suggest that the level of threat to recovery arising from inadequate fish passage is likely lower today than it may have been prior to 1922. Therefore, and in light of the only limited information about the past distribution of Atlantic whitefish, any watershed within Nova Scotia could be considered a potential candidate for Atlantic whitefish introduction, particularly watersheds lying within the bounds of their known former range. Information about past abundance or productivity of Atlantic whitefish populations is not sufficient to form a basis for establishing watershed-specific abundance recovery targets or the number of populations required to ensure long-term viability. The minimum census population size required to maintain genetic diversity is estimated to be in the vicinity of 550 – 2,000 mature individuals. An interim watershed specific abundance target above the mid-point of this range (i.e., above 1,275 mature individuals) is proposed.

RÉSUMÉ

Le corégone de l'Atlantique (*Coregonus huntsmani*), considéré comme anadrome par sa nature, est une espèce endémique au Canada (Scott 1987) qui se trouve seulement dans la province de la Nouvelle-Écosse. Sa population est présentement confinée dans trois petits lacs semi-naturels de la Petite Rivière. Les lacs ne sont pas accessibles à partir de la mer. Le corégone de l'Atlantique est une espèce inscrite sur la liste des espèces menacées et est protégé en vertu de la *Loi sur les espèces en péril* (LEP) du Canada. Les analyses de son ADN mitochondrial et de son ADN nucléaire confirment sa filiation putative en tant qu'ancien représentant d'une lignée unique du grand corégone. Toutefois, sa population restante présente une diversité génétique extrêmement faible et il n'existe aucune variation génétique entre les populations des trois lacs. Les individus de cette population confinée ont probablement des ressources restreintes, sont généralement de petite taille, ont une vie courte et une capacité de reproduction limitée, comparativement aux membres de la même population que l'on a commencé à reproduire en captivité. Ces traits de la population confinée aux lacs ne semblent pas avoir évolué énormément au cours des dernières décennies. La croissance somatique enregistrée par le corégone de l'Atlantique élevé en captivité est virtuellement la même que celle de la population anadrome que l'on retrouvait dans la rivière Tusket avant 1982. Une reconstitution de la prévalence, de l'emplacement et de la date de construction des barrages érigés par l'homme sur les rivières du sud-ouest de la Nouvelle-Écosse en 1926 montre que l'accessibilité aux rivières était probablement déjà entravée des décennies avant la première description du corégone de l'Atlantique en tant qu'espèce, en 1922. L'élimination d'un grand nombre de ces barrages et un renforcement du cadre de réglementation concernant les obstacles au passage du poisson autour des structures existantes portent à croire que la menace au rétablissement attribuable à ces obstacles est sans doute moins grave de nos jours qu'elle a pu l'être avant 1922. Par conséquent, et vu que les renseignements sur la répartition passée du corégone de l'Atlantique sont limités, n'importe quel bassin hydrographique de la Nouvelle-Écosse pourrait être considéré comme un site candidat potentiel pour son introduction, en particulier les bassins situés à l'intérieur des limites de son aire de répartition passée connue. Les renseignements actuellement disponibles sur l'abondance et la productivité passées des populations de corégone de l'Atlantique ne sont pas suffisants pour servir de fondement à l'établissement de cibles d'abondance par bassins hydrographiques ou du nombre de populations requises pour assurer leur viabilité à long terme. La taille minimale de population recensée requise pour maintenir la diversité génétique est estimée comme se situant entre 550 et 2 000 exemplaires matures. Une cible d'abondance provisoire par bassins hydrographiques se situant au-dessus du point milieu de cette fourchette (p. ex. plus de 1 275 exemplaires matures) est proposée.

INTRODUCTION

First described by Huntsman (1922), the Atlantic whitefish (*Coregonus huntsmani*) is anadromous by nature (Scott and Scott 1988), endemic to Canada (Scott 1987), and found only in the Province of Nova Scotia (Edge 1984; Scott and Scott 1988)[1]. Atlantic whitefish were declared endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1984 and again in 2000, in light of evidence of a disjunctive, global distribution limited to the Tusket-Annis and Petite rivers (Figure 1) and pronounced decline in abundance in recent decades (Edge 1984; Edge and Gilhen 2001). The Tusket-Annis population, which was known to be anadromous, was likely extirpated by the 1980s (Bradford et al. 2004a). The Petite Rivière population is land-locked within three small semi-natural lakes (Figure 2) that can not be accessed from the sea (Bradford et al. 2004a). Threats were defined by COSEWIC in 2000 as habitat loss and degradation caused by acidification (acid rain), ineffective fish passage around dams, introductions of exotic species, and incidental fishing (Edge and Gilhen 2001).

Since 2004, the Atlantic whitefish has been listed and protected as endangered under the Canada *Species at Risk Act* (*SARA*). In compliance with Section 37 of *SARA,* a Recovery Strategy for the Atlantic whitefish (DFO 2006) has been developed, which has 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 recovery goal is to be met through the implementation of four inter-related strategic objectives (DFO 2006):

1. *Conserve, protect, and manage the species and its habitat;*
2. *Increase the number and range of viable populations;*
3. *Increase understanding of the species and its habitat, and;*
4. *Increase public involvement and acceptance.*

Knowledge of Atlantic whitefish status, biology, life-history, and habitat use is considered essential to the design, planning and execution of activities that may be undertaken to support the Recovery Strategy (DFO 2006). This information is also required to help identify actions or alternatives possible to address current threats to survival or recovery with particular reference to Section 73.3 of the Act (DFO 2007a,b). This section of the Act establishes that incidental harm authorizations may be issued only if the competent minister is of the opinion that:

(a) all reasonable alternatives to the activity that would reduce the impact on the species have been considered and the best solution has been adopted;
(b) all feasible measures will be taken to minimize the impact of the activity on the species or its critical habitat or the residences of its individuals; and
(c) the activity will not jeopardize the survival or recovery of the species.

The Atlantic whitefish has historically not received much attention from the scientific community. A baseline study aimed at establishing the taxonomic status of Atlantic whitefish (Edge et al. 1991), and basic biological information gathered during the course of that study (Edge 1984), have served as the principle bases for the biological understanding of the species until recently. In 1999, in anticipation of a formal listing of Atlantic whitefish as 'at risk' under pending federal endangered species legislation, the Department of Fisheries and Oceans (DFO), in

[1] References prior to Scott (1987) used either Sault whitefish or Acadian whitefish as common names, the respective scientific names were *C. labradoricus* and *C. canadensis* (see Piers 1927, Livingstone 1953).

collaboration with numerous academic, industry, and non-governmental organization (NGO) partners, initiated a series of meetings and investigations to improve our understanding of the fish, their habitat requirements and interactions with humans. The outcomes of investigations conducted to update knowledge of the areas of occurrence and occupancy of Atlantic whitefish, and the life-history tactic (freshwater-resident, anadromous) expressed by extant populations, were reported in Bradford et al. (2004a).

Threats and Recovery Potential: Historical Context

It is important to keep in mind the historical, multi-decadal scale context of the collapse of Atlantic whitefish. Extensive range contraction had likely already occurred by the time of its description as a species in 1922 (DFO 2004). Not all of the threats identified by COSEWIC would necessarily have contributed to the early decline. Negative interaction with invasive species would not have been a factor at that time. Smallmouth bass (*Micropterus dolomieu)* were not present in Nova Scotia until 1908 and not recorded as present in the Tusket-Annis and Petite Rivière drainages until 1989 and 1994, respectively (Bradford et al. 2004b). Chain pickerel (*Esox niger)* were not present in Nova Scotia until 1944 (NSDAF 2004) and were not present in the Tusket-Annis until 1976 (Bradford et al. 2004a).

Paleolimnological records (Ginn et al. 2007) and water quality data (Watt et al. 1983; Clair et al. 2004) indicate that many southwestern Nova Scotia rivers are naturally acidified. The rivers most sensitive to acidification did not exhibit a detectable response to the atmospheric deposition of acid (rain) until around 1940 (Ginn et al. 2007, 2008).

Documentation of directed and by-catch fishing for Atlantic whitefish preceded the period of pronounced decline (Gilhen 1977), although local knowledge suggested that the fisheries detected the decline of the Tusket-Annis River population (Gilhen 1977). Section 6 of the *Maritime Provinces Fishery Regulations* (MPFRs) subsequently came into effect to prohibit the retention or possession of Atlantic whitefish (Bradford et al. 2004b).

The state of fish passage around man-made dams located in Nova Scotia rivers prior to the early-mid-20th century has not been documented in detail. The extent to which the presence of dams may have altered Atlantic whitefish demographics, with specific reference to their rivers of occupancy before the early 20th century, is, therefore, not fully understood. A chronological record of fish passage around dams located on both the Tusket and Petite rivers was compiled by Bradford et al. (2004b) to help assess recovery feasibility and the scope for allowable harm (DFO 2004). Existing facilities and recently de-commissioned facilities were, therefore, the principle focus (Bradford et al. 2004b).

Few of the records retained at the Bedford Institute of Oceanography (BIO) concerning fish passage were generated prior to about 1950; whereas, the history of dam construction on the Petite Rivière and its lakes extends back to the 1700s (Bradford et al. 2004b). Information concerning the number, location and purpose of dams, and provisions in effect to facilitate fish passage around facilities that may have existed at earlier dates on the Tusket and Petite rivers and other southwestern Nova Scotia rivers, is lacking.

Biological Considerations

Atlantic whitefish spawning in the wild has never been observed. Historical data indicates that gravid anadromous Atlantic whitefish ascended the Tusket River from tidal waters during October-November (Edge and Gilhen 2001). Both wild-caught, captive-spawned Atlantic whitefish and their progeny raised to maturity in captivity at the DFO Mersey Biodiversity Facility

(MBF), Milton, Nova Scotia, spawned from late November to early January (DFO 2004a). The characteristics of suitable spawning habitat are not known, although it appears as though the Petite Rivière population spawns in the lakes, as is typical for both lake whitefish (*C. clupeaformis*) and cisco (*C. artedii;* Scott and Crossman 1973).

Estimates of the diameter of fertilized water-hardened eggs vary from 3 mm - 5 mm (mean = 3.5 mm (A.M. Cook, unpublished data) to mean 4.1 mm ± 0.89 mm (Hasselman et al. 2007) in culture conditions. Eggs are demersal and slightly adhesive (Hasselman et al. 2007). Larvae hatch after 260 ± 5.5 incubation degree days, which corresponds to an April-May hatch period in most natural environments (A.M. Cook, unpublished data). Estimated lengths at hatch vary from 12.4 mm ± 0.9 mm (Hasselman et al. 2007) to 14.2 ± 3.4 mm (A.M. Cook, unpublished data). Feeding under culture conditions may occur by the fourth day post hatch. Metamorphosis from larva to juvenile can occur around 30-days post hatch (Hasselman et al. 2007) and at total lengths varying between 31 mm and 49 mm (Hasselman et. al. 2007; A.M. Cook, unpublished data). Atlantic whitefish exhibit obvious and quantifiable differences from both lake whitefish and cisco in both morphology during embryogenesis/ontogeny and in the time to attain common development milestones (heterochrony; Hasselman et al. 2007). Several traits can be helpful with field identifications including egg size, myomere counts, and pigmentation patterns (Hasselman et al. 2007).

Post-juvenile stage Atlantic whitefish can be successfully discriminated from lake whitefish, a morphologically similar, wide-spread, and native Nova Scotia species (Bradford et al. 2004a; Murray 2005) using only external characters (Hasselman et al. 2009). Atlantic whitefish possess a significantly ($p<0.001$) greater number of lateral line scales[2] (range 90-102; mean = 93.8 ± 2.7) than lake whitefish (range 66-91; mean =77.2 ± 4.2), a significantly ($p<0.01$) shorter pectoral fin than lake whitefish (11% and 16% of fork length, respectively), and a significantly ($p<0.001$) more terminal mouth than lake whitefish (ratio of upper jaw to lower jaw =0.98 ± 0.07 and 0.82 ± 0.06, respectively; Hasselman et al. 2009).

The habitat preferences of immature Atlantic whitefish are not well understood, although recent research has provided insight into the role of water quality (temperature, salinity, pH) as a determining factor in survival (see Cook et al. 2010). No age 0^+ (years) individuals have been captured in either Milipsigate or Minamkeak Lake. Age 0^+ individuals have been sampled within Hebb Lake only as a single specimen intercepted with a beach seine deployed in the lake shallows during June 2000 (Hasselman et al. 2005).

The marine habitat preferences of the anadromous Tusket River population were never reported. Distant captures along the Nova Scotia coast of the Bay of Fundy (Edge and Gilhen 2001) indicate they probably acquired a tolerance to full sea water at some stage of their life.

Document Purpose and Scope

This document updates to the extent possible the general and phylogenetic status of Atlantic whitefish, their intraspecific genetic diversity, and their biological traits. Information concerning the number and location of dams installed in southwestern Nova Scotia rivers around and prior to 1922, when Atlantic whitefish were first described (Huntsman 1922), is also presented to lend context to the present state of fish passage relative to that available at the time of probable pronounced decline. It is anticipated that the information will help support recovery activities

[2] Lateral line scale number is positively correlated with myomere number, a trait established during ontogeny, and has a species specific value for Atlantic whitefish relative to both lake whitefish and cisco (Hasselman et al. 2007).

and, as well, fulfill at least some of the elements of the DFO Recovery Potential Assessment terms of reference (DFO 2007a,b), namely to:

1. Evaluate present species status for abundance, range and number of populations.
2. Evaluate recent species trajectory for abundance, range, and number of populations.
3. Estimate, to the extent that information allows, the current or recent life history parameters for the species (total mortality [Z], natural mortality[m], fecundity, maturity, recruitment, etc.) or reasonable surrogates, and associated uncertainties for all parameters.
4. Estimate expected population and distribution targets for recovery, according to DFO guidelines.

Specific information concerning the effects of water temperature, pH, and salinity on early life-stage Atlantic whitefish survival and, therefore, recovery potential is reported in Cook et al. (2010).

MATERIALS AND METHODS

Phylogenetic Status and Intraspecific Genetic Diversity

Microsatellite analyses are described in detail in Murray (2005); a brief description follows here. DNA was isolated from dried scales or ethanol-preserved fin tissue using a DNeasy Extraction Kit (Qiagen). Primers for 12 microsatellite loci (Table 1) were used to characterize genetic diversity in Atlantic whitefish, lake whitefish, and a single cisco (*Coregonus artedii*) population (Table 2). Microsatellite alleles were amplified using the polymerase chain reaction (PCR), resolved via electrophoresis on denaturing polyacrylamide gels, and visualized using an FMBIO II scanner (Hitachi).

A variety of measures of genetic diversity and differentiation were calculated, including expected heterozygosity (H_E), allelic richness, the number of alleles standardized to the lowest sample size (A_E; Kalinowski 2005), and F_{ST} . A neighbour-joining tree was constructed using Cavalli-Sforza and Edward's (1967) chord distance (D_{CE}) to determine branching order and the $(\delta\mu)^2$ distance (Goldstein et al. 1995) to fit branch lengths. Statistical confidence in the tree topology was assessed by bootstrapping over loci. Long-term effective population size was calculated based on the expected relationship between homozygosity, mutation rate, and effective population size for microsatellite loci (Xu and Fu 2004).

Mitochondrial cytochrome oxidase subunit 1 (mtDNA CO1) was sequenced using standard methods (Hubert et al. 2008). A neighbour-joining tree was constructed using Kimura 2-parameter estimates of sequence divergence.

Distribution and Abundance

There have not been any directed systematic surveys of the Tusket-Annis rivers, or the Petite Rivière outside of the three lakes that represent their known distribution, or of water bodies in any other Nova Scotia catchments, since Bradford et al. (2004a). Stewardship and public outreach activities have, however, raised awareness of the Atlantic whitefish among both the public and targeted interest groups throughout southwestern Nova Scotia. The reporting of suspected sightings is encouraged. A notice published in the Nova Scotia Anglers Handbook and Summary of Regulations every year since 2000 has invited the public to report any suspected occurrences of Atlantic whitefish to DFO, for example. Because this document is concerned with the status of wild Atlantic whitefish, only the potential sightings on the Petite

Rivière below Hebbville Dam before May 2006, are reported here. Experimental releases of cultured fish raised at the MBF have occurred since then.

Traditional Ecological Knowledge

The outcome of interviews conducted 13-16 August, 2002, with Acadia First Nation members from the Wildcat, Shelburne, and Yarmouth reserves were reported in Bradford et al. (2004a). No surveys to gather aboriginal traditional knowledge concerning Atlantic whitefish has been gathered since.

Tusket-Annis

There has been no directed monitoring since the 2004 assessment either of the fish ways leading to Lake Vaughn, or the downstream bypass facility located in the main dam at the head of tide, at times that Atlantic whitefish could be potentially present. Volunteered reports from the public, local fishers and industry are the sole potential source of information concerning presence of Atlantic whitefish.

Petite Rivière Lakes

Attempts since 1999 to monitor and assess the status of the populations that reside in Minamkeak, Milipsigate, and Hebb lakes[3] (Figure 2) have been hampered by limited capture success using gear types that were known to be effective sampling platforms for other coregonid species (Bradford et al. 2004a). As well, experience has shown that water temperatures above 16°C are stressful to the fish with the result that sampling usually has to cease by early June, and usually can not resume until waters cool around mid-September to October. Sampling protocols that can provide reliable estimates of abundance by life-stage from catch and effort are still under development. As a result, analysis of status as a time series beyond simple presence absence and inference concerning breadth of ages represented in the sample catch are not available. The distribution of the sample effort among water bodies, among years (1999 to 2008) and by type of gear deployed is summarized in Table 3.

Other Locations

A fish counting facility installed in the Morgan Falls fish way, LaHave River (Figure 2) has been operated by DFO every year since 1972, generally from May to mid-October. The front of the trap is constructed of 1.25 cm vertical rods on 3.8 cm centers to allow gaspereau to escape. However, any large-bodied Atlantic whitefish that may attempt to negotiate the fish way could be expected to be retained. Downstream (bypass) assessments have been conducted generally during May every year since 1996 at a facility installed in the Morgan Falls Powerhouse. The facility generally intercepts fish of approximately 10 cm fork length (FL) and larger.

Biological Traits

While efforts to monitor and quantitatively assess Atlantic whitefish status in the Petite Rivière have not been successful to date, the sampling effort since 1999 has enabled observations and limited sampling (i.e., length, removal of external body scales for ageing, collection of tissue samples to support genetic analyses) of approximately 180 lake-resident specimens (Table 4a).

[3] As reported in Bradford et al. (2004a) much of the monitoring since 2000, particularly at Milipsigate Dam, has been an integrated activity with the collection of broodstock to support captive rearing of Atlantic whitefish at the DFO Mersey Biodiversity Centre. Collections ceased in 2005.

Data concerning age, size at age (length, weight), age at maturity, and fecundity is available for up to 275 specimens held in captive conditions at the MBF (Table 4a). These samples represent a blend of live-captured individuals brought onto the site from the Petite Rivière to serve as brood stock for captive breeding and rearing experiments and first generation (F1) progeny from these experiments. Acquired experience has shown that the land-locked form of the Atlantic whitefish does not tolerate capture-transport-introduction into a captive environment very well. Wild fish transferred to the facility are, therefore, not always sampled before or immediately upon arrival at the facility in order to minimize mortality. Some of the fish are, therefore, often not sampled for the first time until after a period of somatic growth has occurred.

Change in Body Size with Time/Location

Fork lengths (mm) are available for some of the archived specimens collected from the now extirpated anadromous Tusket population (n =13 between the years 1940 to 1964) and from Milipsigate Lake, Petite Rivière (n =8) in 1923 and again in 1955. These data, which have been reported elsewhere (see Edge 1984, Edge and Gilhen 2001; Hasselman et al. 2009), are used here to help establish whether:

1. The wild, land-locked Atlantic whitefish population is potentially resource limited,
2. The body size frequency distribution of the land-locked population in the Petite Rivière lakes has changed with time,
3. Wild land-locked Atlantic whitefish, and their progeny spawned and reared in captive conditions, can attain body sizes reported for the anadromous Tusket River population, and,
4. Samples acquired via trap netting in Hebb Lake proper differs in body size composition from that of the interannually predictable May-June aggregation that appears below Milipsigate Lake dam (representing the most frequently sampled site).

Age and Growth

Individual ages (years) for wild fish were estimated via interpretation of the number of annuli recorded on external body scales (Appendix I.I) with the estimates arrived at independently by 2 readers accepted. Ages of Atlantic whitefish under culture at MBF were assigned by reference to their year of production. No attempt was made for the present assessment to estimate ages of the wild-caught fish used as broodstock at MBF because of uncertainties associated with establishing the specific date (season) and/or year that they would have been received into the facility. This is unfortunate because brood fish likely represent the oldest and largest living specimens of Atlantic whitefish available and, therefore, could yield insight into potential maximum age, size at age, and life span.

The von Bertalannfy growth parameters were estimated separately for wild and cultured Atlantic whitefish by pooling the available samples for both groups across years. Slope of the regression of L_{t+1} versus L_t , equivalent to e^{-k} was used to estimate the growth parameter k. Maximum theoretical length (L_{inf}) was estimated from the intercept of the regression with Y=X (Walford Plots after Ricker 1975).

Fecundity

Fecundity is defined here as the number of eggs extruded from spawning females under culture conditions. The number of extruded eggs was estimated from calibrated volumes. Estimation of fecundity at age for wild-caught whitefish is not presently possible for the reasons provided in the above section. Results are, therefore, presented relative to Fork Length (mm) for both the wild fish under culture and for F1 progeny.

Presence of Dams in 1926

Documents concerning a 1926 survey of "dams on the principle streams and rivers in the Maritime Provinces" (Anonymous 1926) were located in the National Archives, Ottawa (RG23, Volume 784, File 719-1-3). The aim of the survey was to establish "from a fisheries standpoint" (Found 1926a) the overall need for fish passage around existing dams and to help develop the "policy of the department in regard to the construction of fish ways" (Found 1926b). That is, who should bear the cost of installing fishways within existing dams. Briefly, the fisheries overseers of each sub-district were forwarded a standard questionnaire concerning fish passage (see Appendix I.II) that was to be completed for each dam, such "that all dams within the limits of your sub-district should be described, unless they occur on brooks too small to be of any importance" (Found 1926a). The timing of the survey (1926) is fortuitous in that it can help to re-construct the location of dams in southwestern Nova Scotia at around the time that Atlantic whitefish were first described (e.g., Huntsman 1922). However, it is important to bear in mind that the survey was only concerned with dams in use at that time.

RESULTS

Phylogenetic Status and Intraspecific Genetic Diversity

Neighbour joining analysis of the microsatellite data revealed three well-resolved groups: Atlantic whitefish, Lake Ontario cisco, and lake whitefish (Figure 3). Within the lake whitefish cluster, some sub-groups were evident. Most notably, the two populations belonging to the Mississippian glacial lineage, Lake Ontario and MacAlpine Lake (Nunavut), grouped separately from the remainder of the lake whitefish populations, which were all from Nova Scotia and New Brunswick, and presumably belonged to the Atlantic glacial lineage. The branch lengths on the dendrogram, which reflect mutational distance, revealed the extremely divergent nature of the Atlantic whitefish cluster relative to the other species and populations represented on the tree. Also evident was the absence of any genetic differentiation among the three extant populations of Atlantic whitefish (Figure 3). The F_{ST} estimated for the three populations, Minamkeak, Milipsigate, and Hebb lakes, was -0.014, effectively zero.

The neighbour joining tree based on mtDNA CO1 also supported the taxonomic distinctiveness of Atlantic whitefish relative to lake whitefish, cisco, and other coregonid species; in fact, *C. huntsmani* occupied a basal position in the tree relative to other members of the genus *Coregonus* (Figure 4).

The microsatellite data indicated that genetic diversity in the three Atlantic whitefish populations was low relative to that in all lake whitefish populations, and the one cisco population, that were assayed (Figure 5). Of 12 microsatellite loci that were examined in both Atlantic and lake whitefish, the proportions of loci that were polymorphic were 33% and 83%, respectively. Only 11 loci were amplified in cisco, but, of these, 82% were polymorphic. Average estimates of unbiased allelic richness and expected heterozygosity within populations were lower in Atlantic whitefish than in lake whitefish or cisco (A_E = 1.39, 2.51, 3.83; H_E = 0.14, 0.38, 0.56, respectively). In these comparisons, the two largest (and most genetically diverse) lake whitefish populations, Lake Ontario and MacAlpine Lake, were excluded to avoid upwardly biasing the lake whitefish estimates. Allele sizes for microsatellites in Atlantic whitefish were comparable to those seen for the same loci in lake whitefish and cisco, suggesting that the low genetic diversity in Atlantic whitefish was not an artefact of shorter (therefore less mutationally active) microsatellite repeat arrays (Figure 5).

Genetic diversity (A_E) in lake whitefish was positively correlated with log lake area, as was long-term effective population size (N_e[4]) calculated from the genetic diversity data (Figure 6). Genetic diversity in the one cisco population analyzed matched the general lake area – genetic diversity pattern seen with lake whitefish, whereas genetic diversity and N_e for Atlantic whitefish were both low relative to expected values for lake whitefish in the same size habitat (Figure 6).

Distribution

There have been no additional reports of possible occurrences of wild Atlantic whitefish beyond the Tusket-Annis and Petite Rivière drainages since those reported previously by Bradford et al. (2004a).

Tusket-Annis

There have been no reported suspected occurrences of Atlantic whitefish either by the public or by interest groups since the 2004 assessment.

Petite Rivière

Below Hebbville Dam

An Atlantic whitefish was reported as angled and released in June 2004 near Crousetown. A photograph returned with the report confirms the fish as an Atlantic whitefish.

Above Hebbville Dam

Presence of Atlantic whitefish in Minamkeak Lake (Figure 2) has not been assessed by directed sampling since 2004 (Table 3). A single Atlantic whitefish was angled for the purposes of broodstock collection in the pool below the dam across the outlet in 2005.

There has been no attempt to establish presence of Atlantic whitefish in Milipsigate Lake via directed sampling since the autumn of 2007 (Table 3). While no fish were physically sampled during the 2007 survey, several are known to have escaped over the top of the netting while the trapnet was being fished. A dead Atlantic whitefish was removed from the stomach of a brook char (*Salvelinus fontinalis*) angled during May 2007, from Birch Brook (P. Longue, Laconia, NS, personal communication), which flows into Milipsigate Lake. The specimen was returned to DFO and positively identified as an Atlantic whitefish.

There was no directed sampling for Atlantic whitefish below Milipsigate Dam in 2008; however, they were observed present during May (R. Bradford, personal observation). Atlantic whitefish were collected below Milipsigate Dam whenever effort was directed to collection between the years 2000 and 2007 (Tables 3,4). Experimental fishing with a trapnet hung from a rigid floating frame successfully sampled Atlantic whitefish within the main body of Hebb Lake during both May and September-October, 2007 (Tables 3,4).

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[4] Ne - the number of mature individuals in an ideal population that would lose genetic variation due to drift or inbreeding at the same rate as the number of reproducing adults in the real population under consideration.

Other Locations

There were no recorded occurrences of Atlantic whitefish at either the upstream or downstream bypass monitoring facilities operated by DFO at Morgan Falls, LaHave River.

Biological Traits

Change in Body Size with Time/Location

Atlantic whitefish reared in captivity can attain lengths (FL) not realized by the land-locked resident population of the Petite Rivière (Figure 7a). The length frequency distributions of wild land-locked Atlantic whitefish sampled since 2000 (n =145, 228 mm ± 28 mm) and that of the archival collections (n =18, 234 mm ± 30 mm)(Figure 7b) are statistically the same (ANOVA: df =1, 162, F = 0.57, N.S.). Inspection of the length frequency distributions of cultured and the historical anadromous Tusket River run (Figure 7c) indicates that culture can replicate the upper limit of body size of the anadromous run – that is the spawning component of the population. Experimental fishing during 2007 in Hebb Lake with a trapnet hung from a rigid floating frame, while successful in capturing Atlantic whitefish appears to have not representatively sampled with respect to body size distribution (Figure 7d). The fish sampled from Hebb Lake (n = 24, 205 mm ± 21 mm) were smaller on average than the seasonal aggregations that occur below Milipsigate Lake (n =95, 237 mm ± 27 mm)(ANOVA: df =1, 118, F =28.97, P<0.01).

Age and Growth

Regressions of L_{t+1} (years) versus L_t (years) yielded slopes of 0.81 and 0.75 and corresponding estimates of k of 0.206 and 0.289 for cultured and wild Atlantic whitefish, respectively (Figure 8). Theoretical maximum length (l_∞) was estimated to be 400 mm and 300 mm (Figure 8), and t_0 was estimated to be -1.25 and -1.15 for cultured and wild Atlantic whitefish, respectively (Figure 8).

Wild land-locked Atlantic whitefish tend to be smaller than cultured Atlantic whitefish at age 3 years and older (Figure 9; upper panel). Fitted von Bertalanffy growth functions fitted to length at age data are shown for both cultured (middle panel) and wild (lower panel) Atlantic whitefish in Figure 9.

Total body weight (TW g) exhibits an allometric increase with increasing body length (FL mm) (ln(TW) = 3.01 x ln(FL) -11.49 (n = 284, r^2 = 0.98, Figure 10a).

Fecundity

Eggs (extruded) per female varied from about 1,500 at 250 mm FL to more than about 10,000 at 450 mm FL and increased with fish length as:

ln(Eggs) = 3.62 x ln(FL) – 12.97 (n =26, r^2 = 0.88).

There is no obvious difference in egg number between wild-captive and F1 adults (Figure 10b). With reference to the possible size frequency distribution of anadromous Atlantic whitefish (Figure 7) and their similarities in body size at maturity with cultured fish, egg production per female by anadromous fish would appear to be potentially greater by a factor of approximately 4 than for the wild land-locked population (maximum observed length of ~ 300 mm FL; Figures 7, 10).

Presence of Dams in 1926

Most of the “principle rivers and streams” of southwestern Nova Scotia were dammed to some extent in 1926. In total, 92 dams (Table 6) were recorded as present on 33 southwestern Nova Scotia drainages bounded by the Annapolis River to the north and the Sackville River to the east (Figure 11). The location of the first barrier (relative to tidal waters) was at the head of tide for 15 rivers, including the Petite Rivière (Table 6; Figure 11). A further four, including the Annis River, were first-barriered within 0.1km - 0.5 km above the head of tide. Ten rivers had at least 5 km of unbarriered river above the head of tide, including the Tusket River that was unbarriered for at least 15 km or more, depending upon the branch of the river considered (Table 6, Figure 11).

The average year of construction for 73 of the dams (Table 7) was 1882 (± 35.3 years), with the oldest being constructed in 1802 and the newest during the year of the survey (Figure 12). The construction date for most of the dams on the Petite and Tusket rivers pre-dated proclamation of the *Fisheries Act* in 1868; the lowermost dam on the Annis was constructed in 1869. Forestry and manufacture of wood products were the principle use of water power (Table 8).

DISCUSSION

Phylogenetic Status and Intraspecific Genetic Diversity

Microsatellites are not usually regarded as the markers of choice for interspecific phylogenies because rapid evolution and homoplasy (alleles that are identical in state, but not identical by descent) confound comparisons of populations that have diverged by more than tens of thousands of years. Nonetheless, microsatellites can confirm the divergent nature of lineages that have been reproductively isolated for long periods of time, and because of their multilocus, biparentally inherited nature, provide a sensitive marker for detecting any introgression that may have occurred between species.

The fact that the allele sizes are similar among the test species populations suggests that low genetic diversity in Atlantic whitefish microsatellites is not an artefact of collapsed microsatellite loci. The available data falls short of proof, though, because other types of mutations (substitutions) in the repeat array can act to inhibit the slippage mutations that cause microsatellite polymorphism. Still, the fact that lower levels of polymorphism was a general pattern across multiple loci in Atlantic whitefish lends support to an interpretation of low long-term N_e as the most likely explanation for the low diversity (Figure 3). The loci Chu6, BWF2, and Chu19 (Figure5) can probably be considered as diagnostic for Atlantic whitefish. The lake area versus genetic diversity/ N_e comparison across species (Figure7) carries the implicit assumption that carrying capacities relative to lake area are similar across the three species.

CO1 sequences are becoming a widely accepted measure of species distinctiveness for most vertebrate and invertebrate taxa (e.g., Hubert et al. 2008 and references therein). CO1 is one of the more slowly evolving protein genes on the mitochondrial genome and typically reveals little or no variation within species, occasionally even among recently diverged species. CO1 differences such as those seen for Atlantic whitefish versus lake whitefish are, therefore, a conservative indicator of inter-specific divergence. On the other hand, as a maternally inherited, non-recombining marker, mtDNA is not well suited (by itself) for detecting introgression between species.

The neighbour joining tree based on mtDNA CO1 (Figure 4) also supported the taxonomic distinctiveness of Atlantic whitefish relative to lake whitefish, cisco, and other coregonid species, with *C. huntsmani* occupying a basal position in the tree (Figure 4).

Distribution

There are no records of occurrence of anadromous Atlantic whitefish on the Tusket-Annis system more recent than October, 1982, although there has not been directed monitoring for this species since the time of the last assessment in 2004. Monitoring activities in the Petite Rivière indicate that Atlantic whitefish were present in Hebb Lake as recently as 2008, and they are likely present in Milipsigate Lake on the basis of 2007 reported occurrences. Minamkeak Lake has not been monitored for Atlantic whitefish presence since 2004. The single report of an angled Atlantic whitefish in June 2004, near Crousetown (Figure 2) likely represents a stray from the upper lakes, as was thought to be the case for reported past occurrences below Hebbville Dam (Bradford et al. 2004a).

Available information, therefore, indicates that the Petite Rivière remains the global distribution of wild Atlantic whitefish with reproducing individuals occurring in no more than the 16 km^2 combined area (Bradford et al. 2004a) of Minamkeak, Milipsigate, and Hebb lakes. The current status of the land-locked Petite Rivière population is ‘uncertain’. This represents a change in their designation as ‘secure’ within the three lakes at the time of the last assessment (DFO 2004).

The change in designation is considered warranted on the basis of: 1) an absence of information that new individuals are produced annually in Minamkeak Lake, and 2) collections in 2008 of immature age classes of smallmouth bass in Milipsigate Lake (Atlantic Whitefish Conservation and Recovery Team [AWRT] Meeting Minutes November 2008). The indication, therefore, is that piscivorous smallmouth bass have spread since the time of the 2004 assessment from Minamkeak Lake where they are thought to have been illegally introduced in the mid-1990s (NSDAF 2004).

At a minimum, future monitoring activities should aim to: 1) establish whether Atlantic whitefish continue to produce new individuals annually in Minamkeak Lake, 2) monitor the response of the Milipsigate Lake contingent to a likely increase in smallmouth bass abundance in the coming years, and 3) establish indices of current status within Hebb Lake in advance of colonization by smallmouth bass.

Biological Traits

Available information indicates that Atlantic whitefish are probably resource limited (small size at age as adults), short lived (maximum observed age of 4-5 years), and, therefore, of limited individual reproductive capacity within their present range. However, there is uncertainty in the accuracy of the ages of wild Atlantic whitefish interpreted from body scales (Appendix I.I). It is possible that the ages of wild Atlantic whitefish reported here are overestimated by one year due to inaccurate interpretation of the growth at the edge of the scale. Age validation is required.

Wild-caught Atlantic whitefish exhibit enhanced somatic growth, a physiological capacity to live as long as eight years, and an approximate four-fold increase in egg production when introduced into culture. Culture in turn appears to replicate the general body size traits of the now extirpated anadromous Tusket River population. Biological information of the fish under culture could help to establish prior references points against which to evaluate the outcome of experiments that would introduce the species into other freshwater habitat or that could offer Atlantic whitefish access to the sea.

The general features of somatic growth by the land-locked Petite Rivière population appear to have been relatively invariant over the past several decades, if the similarity of the length frequency distributions of the archival and recent specimens is considered to be an acceptable indicator (Figure 7). Another lake dwelling coregonid, Irish pollan (*C. autumnalis*), is also characteristically of small body size (<300 mm FL) and generally short-lived (3-4 years; Harrod and Griffiths 2004).

Presence of Dams in 1926

The history of river dams in southern Nova Scotia appears to have been extensive and lengthy, with 93 dams located within 33 drainages by 1926 and with some constructed as early as 1802. There is no certainty that dams with inadequate fish passage would have led to the collapse of any river-specific populations of Atlantic whitefish that may have existed prior to 1922, and prior to their construction. However, the fact that the only, and last, anadromous run of Atlantic whitefish occurred on one of the few drainages that by 1922 was free running for much of its lower portions is potentially significant.[5]

Many of these dams no longer exist, although other dams have been constructed since (e.g., the Tusket main dam). Most dams that exist today possess efficient fish passage facilities that are regulated under the *Fisheries Act*. Thus, the degree of potential threat from inadequate fish passage on many southwestern Nova Scotia rivers is likely lower today than it may have been prior to 1922. Some of these rivers may, therefore, warrant consideration as potential stocking sites to re-establish anadromous runs.

Other sources of information indicate that barriers to fish passage existed elsewhere on the rivers in earlier days. The following 1903 account provided by W.E. Rogers, Inspector of Fisheries for Nova Scotia, of a dam on the Clyde River (which in 1926 was potentially affected by only a single (driving) dam located 8 km above the head of tide) helps to illustrate this point: “a dam near the mouth of the Clyde river [sic], …had existed for about forty years, and as a result, the river had become almost entirely depleted of fish. No artificial planting had been done in the stream at any time, but several fruitless efforts had been made to overcome the obstruction by the building of so-called fish ways. All failed in their purpose, however, till a fishway was built … in the fall of 1879.” Rogers (1903) also stated that, “In the fall of 1892 the dam was broken and up to this time has not been repaired.”

Petite Riviére

The results of the 1926 survey indicate that fish passage along the Petite Rivière was probably more extensively impacted by damming than previously thought. For example, a wooden dam constructed during 1889 at Crousetown (Figure 2) was thought to be the first structure installed at this location (Bradford et al. 2004b). The survey, however, indicates that the river at Crousetown was dammed as early as 1802 (Table 7), well before any regulated requirement to provide fish passage came into effect under the authority of the *Fisheries Act* in 1868. Even then, there were questions concerning the efficacy of the passage offered. Concerns with fish passage around a dam constructed in 1809 at the head of tide were recorded in department correspondence as late as 1931. Marshall (1931) reported that the ‘fishway’ consisted of a run-

[5] The present hydroelectric facility located at the head of tide on the Tusket River was not constructed until 1929 (Bradford et al. (2004b).

around channel with no flow control structures in place and that access to the foot of the passage was obstructed by large boulders.

Concern over blockages from deposited debris and inadequate fish passage facilities around dams located further upstream were also common, as illustrated by the following account by the local fishery overseer: "The obstructions in the river consist of shoals composed of small rocks very close together, which, when the water is at all low picks up all of the debris that comes down stream and blocks the passage of the fish going up or coming down. Thus is the state of the river up to Conquerall Mills, the fish ways are fairly good until Mr. Frank Kaulback's dam is reached, which is about (1/4) a quarter of a mile below Conquerall or Fancy [sic] Lake …but the fish cannot get there on account of the fish way in Mr. Kaulback's dam at the foot of the lake which is impossible for any kind of fish, as it is simply a narrow perpendicular cutting in the rock, which passes under a mill, making it so dark that fish will not make any attempt to ascend, which it would be impossible for the fish to do if they tried." (Morris 1907)[6].

General inadequacies in passage along the Petite Rivière below Fancys Lake (Figure 2) also appear to have been the underlying reason for an authorized exemption for fish passage in the Hebbville Dam at the time the structure was converted to generate hydroelectricity in 1898. Upon receiving an instruction from the local fishery overseer to allow for fish passage around the facility, the owners replied in part to the Department that, "So far as we can learn, no fish have gone up as far as the point where the dam is built, during the past 25 years, and the dam that was in existence at the time we bought the property, had no fish way of any description" (Duff 1898). It was later agreed "that the fish-pass be allowed to remain closed for the present in view of the doubt as to its usefulness but that should experience show in the future the necessity for opening of the pass the Town authorities will have to submit to the ruling of the department." (Nolan 1903). In other words, the Department of Fisheries and the facility owners had agreed that impediments to fish passage further downstream needed to be addressed before the need for fish passage around Hebbville Dam could be re-considered.

Overall, the lack of availability of any anadromous fishes in the waters lying immediately below Hebbville Dam, and the implication that the Hebbville Dam did not contain fish passage prior to the sites redevelopment for hydroelectric generation indicates that Atlantic whitefish may have become land-locked prior to about 1850.

RECOVERY TARGETS

Recovery targets are used to assess progress towards the recovery goal. The current goal of the Atlantic whitefish Recovery Strategy is "*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*" (DFO 2006). For both anadromous and fresh water resident

[6] It was common in the day to regard the river only as a thoroughfare used by both alewife and Atlantic salmon while migrating to and from their spawning sites located in lakes possessing substrates of "sand, rock, and gravel" (Morris 1907). Expenditures authorized by the federal government to enable stream clearing activity were often requested and justified as having a benefit to both the fisheries and the lumber industry: removal of impediments to fish passage also removed impediments to the efficient delivery (driving) of logs to downstream mills. The following excerpt of a letter from A.K. MacLean, MP, to R. Prefontaine, Minister of Marine and Fisheries, helps to illustrate this point. "The Petite Riviere [between the points of Crousetown and Conquerall Mills, a distance of five miles] is rather important and it is desirable to have this cleaned out for the purpose of having a better passage way for fish and also it would be in the interests of those who use the stream for the purpose of driving logs." (MacLean 1905).

populations where there is an expectation that straying among water bodies is low, the recovery targets could be specified for a set of watersheds in which populations would be recovered, as well as an abundance target for each population. At present, information about past abundance or productivity of Atlantic whitefish populations is not sufficient to form a basis for establishing watershed-specific abundance targets or the number of populations required to ensure long-term viability, although there is information that can guide these decisions.

Watershed-Specific Abundance Targets

The minimum population size needed to maintain genetic diversity can be used as a coarse abundance target. This value can be estimated from the effective population size required to maintain genetic diversity and the ratio of the effective population size (N_e) to the census population size (N_{census}), neither of which is known for Atlantic whitefish. An effective population size of 500 mature individuals is thought to be sufficient to maintain genetic diversity in many vertebrate species and could be assumed as a proxy for Atlantic whitefish. A review of N_e /N_{census} ratios for salmonids showed this ratio to be typically in the vicinity of 0.26 to 0.88, and these values could be assumed to be a rough approximation of the range of this ratio for Atlantic whitefish. Taken together, these ratios would place the minimum census population size required to maintain genetic diversity in the vicinity of 550–2,000 mature individuals. Atlantic whitefish are thought to be at low abundance, exhibit evidence of undergoing or having undergone a genetic bottleneck (which would lower the N_e /N_{census} ratio), and are at-risk from catastrophic events and/or environmental variability.

For these reasons, an interim watershed specific abundance target above the mid-point of this range (i.e., above 1,275 mature individuals) is proposed. This target will need to be revisited as recovery actions are implemented.

Number of Watershed-Specific Populations Required for Recovery

With only limited information about the past distribution of Atlantic whitefish, any watershed within Nova Scotia could be considered a potential candidate for Atlantic whitefish introduction, particularly watersheds lying within the bounds of their known former range. There is uncertainty about the number, location, and size of populations required to ensure the long-term viability of the species.

Fish life history theory suggests numerous reasons why establishing several populations in diverse habitats (i.e., in several watersheds as a distribution target) will increase the probability of successful (self-sustaining) reintroductions. First, there is habitat variability (e.g., pH; stream gradient; presence, amount, and accessibility of lake habitat; thermal characteristics) within the former range of Atlantic whitefish. Establishing populations in watersheds that represent the full breadth of conditions that Atlantic whitefish can tolerate could potentially increase their biological diversity and, with time, increase genetic variation (through local adaptation), thereby, enhancing the capacity of the species to respond to future environmental change.

Second, increasing the number of populations being used to maintain local variations decreases the risk of extirpation as a result of catastrophic events. Replication of habitat conditions described under the first point is desirable.

Third, other things being equal, larger populations have lower extinction risks than smaller populations and these tend to occur in larger watersheds. Watershed size or some other proxy for habitat amount should be considered when selecting locations for establishing additional populations.

Fourth, at present, the importance of straying and mixing among populations for maintaining Atlantic whitefish populations is not known. However, metapopulation structure is an important consideration in the conservation of salmonids generally, and it acts to increase regional persistence particularly when straying “rescues” a local population from extirpation. As a result, the probability of long-term persistence of Atlantic whitefish would be expected to increase as the number of watersheds in which Atlantic whitefish are recovered is increased.

Finally, as was the case with the watershed-specific abundance target, the distribution target will need to be revisited once knowledge about the dynamics of the recovering species is obtained.

ACKNOWLEDGEMENTS

We thank the past and present members of the Atlantic Whitefish Recovery Team for their many contributions to, and support of, the underlying projects and activities that have contributed information to this document.

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TABLES

Table 1. Characteristics of 16 microsatellite loci used in this study. T_A=annealing temperature.

Locus ID	Primer Sequence (5'-3') F:Forward; R:Reverse	Repeat Sequence 5'-3'	T_A	Reference	Label	Source species
Chu6	F:TAGGGTGTGACATCCATCCA R:CCTGCCTGGAATAAACCTCA	$(CCAT)_6N_{32}(CCAT)_8$	58	personal research	Hex	C. huntsmani
Chu16	F:ACCTTCACTGTGGGGCTCTA R:ATTGAGAGCATGACCGAGTG	$(CAGA)_8(CGGA)_4$ $(CAGA)_8$	65	personal research	Hex	C. huntsmani
Chu19	F:CATACACATGGCCAAACAG R:TAGAGAAGGAGGGAGCCACA	$(CCAT)_{19}$	65	personal research	Hex	C. huntsmani
BWF1	F:GTACAGAGAAATACACACAACGCATCAA R:CAGAGGTTCCATTACTGAGCAC	$(GA)_{16}$ N_{95} $(TG)_{13}$	58	Patton et al. 1997	Fam	C. nasus
BWF2	F:CGGATACATCGGCAACCTCTG R:AGACAGTCCCCAATGAGAAAA	$(CA)_{25}$	58	Patton et al. 1997	Fam	C. nasus
Cisco90	F:CAGACATGCTCAGGAACTAG R:CTCAAGTATTGTAATTGGGTAC	$(AC)_{10}$ ATAT $(AC)_3$	55	Turgeon et al. 1999	Fam	C. artedi
Cisco200	F:GGTTAGGAGTTAGGGAAAATATG R:GTTGTGAGGTAGGCCTGG	$(GT)_{45}$	61	Turgeon et al. 1999	Hex	C. artedi
Cisco157	F:CTTAGATGATGGCTTGGCTCC R:GGTGCAATCACTCTTACAACACC	$(GT)_{17}$	63	Turgeon et al. 1999	Fam	C. artedi
Cocl23	F:GCTGTATGAGGATAGCATTC R:GCATTAGGTCGTTTTGTGT	$(GT)_8$	55	Bernatchez et al. 1996	Fam	C. clupeaformis
Cocl-Lav49	F:AGCCAGTTGGAGGCTATTTG R:AGGGCTGCTGTTGAAGTCAT	$(GT)_{17}$	55	Rogers et al. 2004	Hex	C. clupeaformis
Cocl-Lav68	F:GTGTGTTACAAGTGGCTATG R:GTGATGGCTTTCAGAGGC	$(CA)_{11}$	57	Rogers et al. 2004	Hex	C. clupeaformis

Table 2. Sample locations, area in hectares, and sample size (n) of Atlantic whitefish, lake whitefish, and cisco populations.

Province / Watershed / Waterbody	area	N
Atlantic whitefish		
Nova Scotia		
1 Petite Riviere		
Minamkeak Lake	785	12
Milipsigate Lake	361	17
Hebb Lake	507	87
Total		116
Lake whitefish		
Nova Scoita		
2 Mira River		
Mira River	3,553	32
3 Hardy-Gabarus		
MacIntyres Lake	72	64
MacLeods Lake	74	49
4 St. Mary's River		
Eden Lake	223	45
5 Little River		
Scots Lake	76	46
6 Musquodoboit		
Shaw Big Lake	82	32
Gibraltar Lake	85	70
7 Mushamush River		
Little Mushamush Lake	437	50
8 Medway River		
Little Ponhook Lake	81	58
Shingle Lake	470	36
9 Tusket River		
Kempt Back Lake	330	52
Mink Lake	141	23
New Brunswick		
10 Saint John River		
Saint John River	43,550	40
Ontario		
11 Lake Ontario	1,030,000	25
Nunavut		
12 MacAlpine Lake	44,700	40
Total		662
Cisco		
Ontario		
11 Lake Ontario	1,030,000	30

Table 3. Methods of sampling employed since 1999 to capture Atlantic whitefish by water body and by year. Blank cells indicate years of zero effort.

	Year								
Location	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Upper Petite Riviere									
Hebb Lake		Seine						Floating Trapnet	
Hebb Lake (Milipsigate Dam)		Seine, Angling	Trapnet, Angling	Angling		Angling	Seine, Angling	Seine, Angling	
Milipsigate Lake				Trapnet			Trapnet		
Minamkeak Lake					Gill Net				
Lower Petite Riviere									
Estuary	Framed Trapnet	Framed Trapnet							
Below Hebb Lake Dam									Framed Trapnet

Table 4. A) Number of Atlantic whitefish sampled since 1999 by source, location, and year. B) Number of samples available to support determination of age (years) by source, year, location, and year.

A	**Year**									
Location	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Totals**
Upper Petite Riviere										
Hebb Lake		1						24		**25**
Hebb Lake (Milipsigate Dam)		78	5	1		4	19	29		**136**
Milipsigate Lake				7			0			**7**
Minamkeak Lake					19					**19**
										0
Lower Petite Riviere										**0**
Estuary	0	0								**0**
Below Hebb Lake Dam									0	**0**
										0
Mersey Biodiversity Facility										**0**
Captive-Wild plus Cultured					6	32	34	141	62	**275**
Totals	**0**	**79**	**5**	**8**	**25**	**36**	**53**	**194**	**62**	**462**

B	**Year**									
Location	**1999**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Totals**
Upper Petite Riviere										
Hebb Lake		1						23		**24**
Hebb Lake (Milipsigate Dam)		33	4				15			**52**
Milipsigate Lake				7			0			**7**
Minamkeak Lake					12					**12**
										0
Lower Petite Riviere										**0**
Estuary	0	0								**0**
Below Hebb Lake Dam									0	**0**
										0
Mersey Biodiversity Facility										**0**
Captive-Wild plus Cultured						19	15	136	60	**230**
Totals	**0**	**34**	**4**	**7**	**12**	**19**	**30**	**159**	**60**	**325**

Table 5. Reported number of dams in 1926 on southern Nova Scotia rivers relative to the distance (km) upstream of the head of tide.

	Distance (km) from Head of Tide															
Drainage	**0**	**0.1**	**0.5**	**1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**45**	**55**	**65**	**80**	**Grand Total**
Annapolis					1											1
Annis		**1**				**1**	**1**	**1**	**2**							**6**
Argyle	1															1
Barrington		1		1												2
Bear	2		1	1			2									6
Broad	1															1
Clyde					1											1
East River Chester			1		1											2
Forchu Br.					1		1									2
Gold									1							1
Green Harbour						1										1
Herring Br.				2	1											3
Herring Cove Br.	1		1		1											3
Hubbards				1												1
Ingram				1												1
Jordan	1			1		1										3
Lahave	1		1			1		1	1		1	1				7
Lequille		1		1	1		1									4
Martins	1															1
Medway				1	1							2	3	1		8
Mersey	1			4					1						1	7
Middle					1											1
Milton	1															1
Mush-a-Mush	1		1													2
Nictaux									2	1						3
Nine Mile	1															1
Petite	**1**			**2**	**4**											**7**
Roseway	1			1	1				1							4
Sable						1										1
Sackville	1															1
Salmon						1										1
Sissiboo	1															1
Tusket							**1**	**2**	**2**			**1**				**6**
Grand Total	17	3	5	16	14	6	6	4	10	1	1	4	3	1	1	92

Table 6. Reported year of construction, and distance (km) upstream from the head of tide, of dams located on southern Nova Scotia rivers in 1926.

	Distance (km) from Head of Tide														
Drainage	**0**	**0.1**	**0.5**	**1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**45**	**55**	**65**	**80**
Annapolis					1919										
Annis		**1897**				**1857**	**1857**	**1869**	**1842**						
									1890						
Argyle	1882														
Barrington		1880		1919											
Bear	1900			1924			1890								
	Unknown						Unknown								
Broad	Unknown														
Clyde					1920										
East River Chester			1924		1925										
Forchu Br.					1827		1831								
Gold									1920						
Green Harbour						1924									
Herring Br.				1837	1900										
				1892											
Herring Cove Br.	Unknown		Unknown		Unknown										
Hubbards				Unknown											
Ingram				Unknown											
Jordan	1860			1860		1890									
Lahave	1827		1820			1864		1857	1888		1914	1914			
Lequille		1918		1902	1919		1900								
Martins	1913														
Medway				1917								1886	1806	1886	
												1926	1860		
													1886		
Mersey				Unknown											1907
				Unknown											
				Unknown											
				Unknown											
Middle					1860										
Milton	1852														
Mush-a-Mush	1862		1902												
Nictaux									1912	1924					
									1925						
Nine Mile	Unknown														
Petite	**1809**			**1852**	**1802**										
				1892	**1802**										
					1826										
					1910										
Roseway	1882			1900	1888				1874						
Sable						1923									
Sackville	Unknown														
Salmon						1900									
Sissiboo	Unknown														
Tusket							**1909**	**1824**	**1847**			**1857**			
								1897	**1913**						

Table 7. Reported use of water power generated by dams located on southern Nova Scotia rivers in 1926.

	Water Power Used for the Purpose of									
Drainage	**Driving**	**Electricity**	**Not Stated**	**Pulp**	**Shoe factory**	**Storage**	**Wood Products**	**Wood, Grains**	**Wood, Woolens**	**Grand Total**
Annapolis		1								1
Annis							**6**			**6**
Argyle							1			1
Barrington		1							1	2
Bear			3			2	1			6
Broad			1							1
Clyde	1									1
East River Chester		2								2
Forchu Br.					1		1			2
Gold							1			1
Green Harbour		1								1
Herring Br.							3			3
Herring Cove Br.			3							3
Hubbards			1							1
Ingram			1							1
Jordan	3									3
Lahave						1	6			7
Lequille		1				1	2			4
Martins							1			1
Medway			1	1		3	3			8
Mersey			6				1			7
Middle							1			1
Milton						1				1
Mush-a-Mush		1					1			2
Nictaux		1				1	1			3
Nine Mile			1							1
Petite			**1**				**4**	**2**		**7**
Roseway		1					3			4
Sable	1									1
Sackville			1							1
Salmon							1			1
Sissiboo			1							1
Tusket		**1**				**1**	**4**			**6**
Grand Total	5	10	20	1	1	10	42	2	1	92

FIGURES

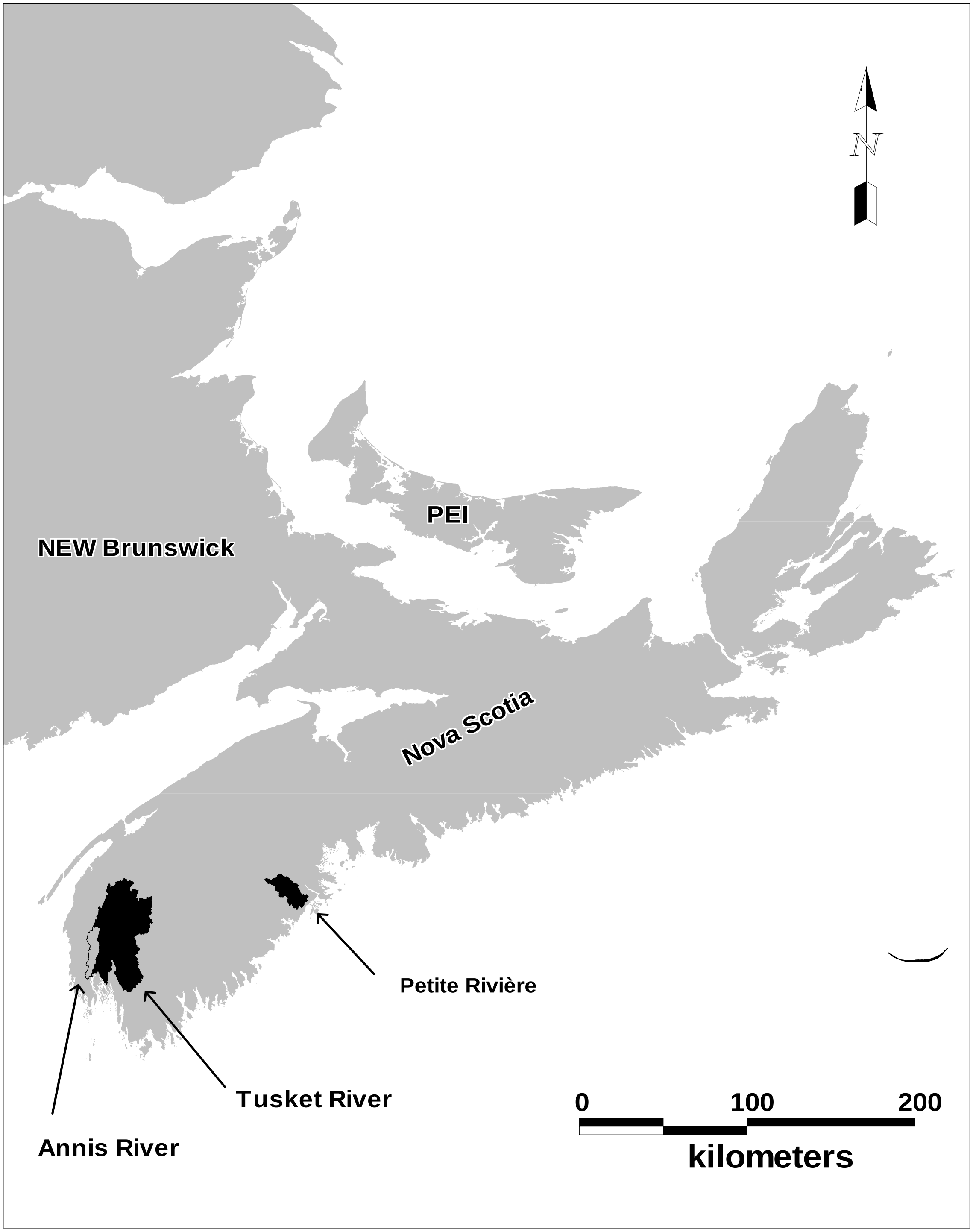


Figure 1. Location of the Petite Rivière and the Tusket-Annis rivers, Nova Scotia.

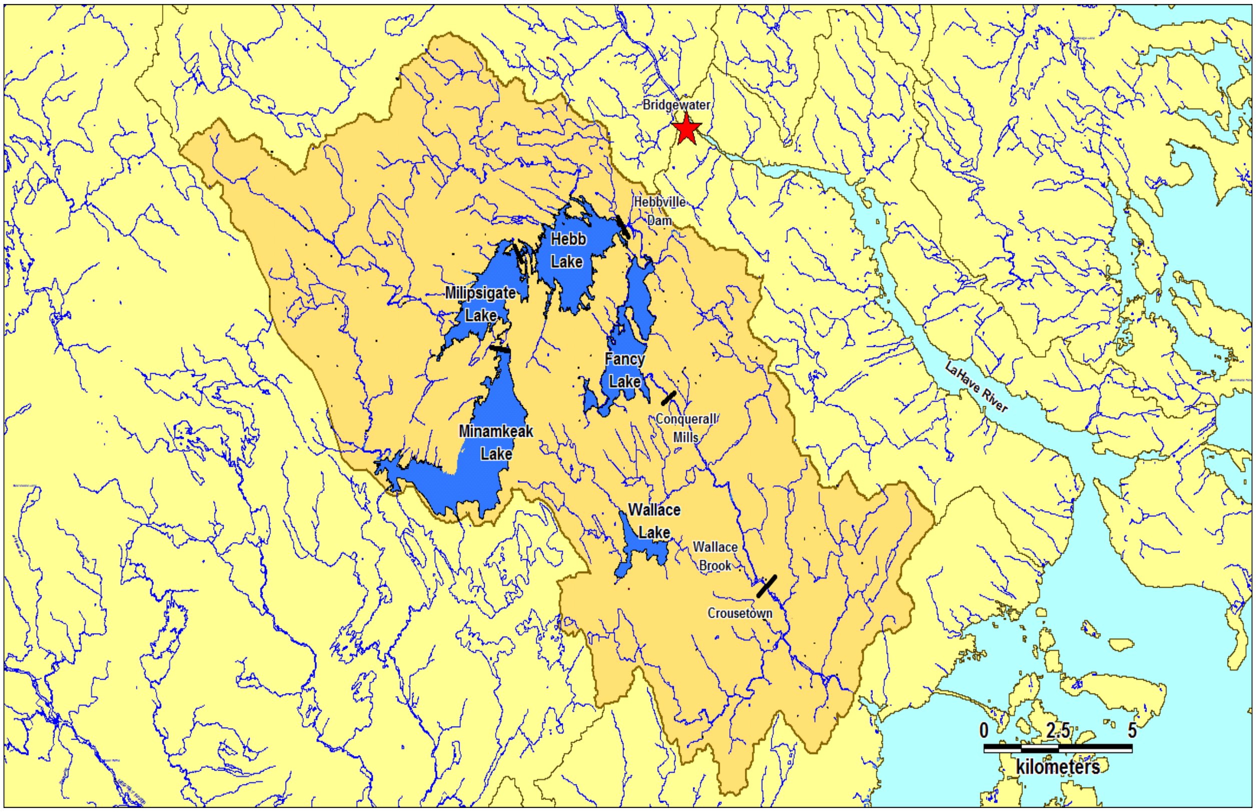


Figure 2. Map of the Petite Rivière showing location of sites referred to in the text. Dams are presently located at Crousetown, Conqueral Mills, and Hebbville.

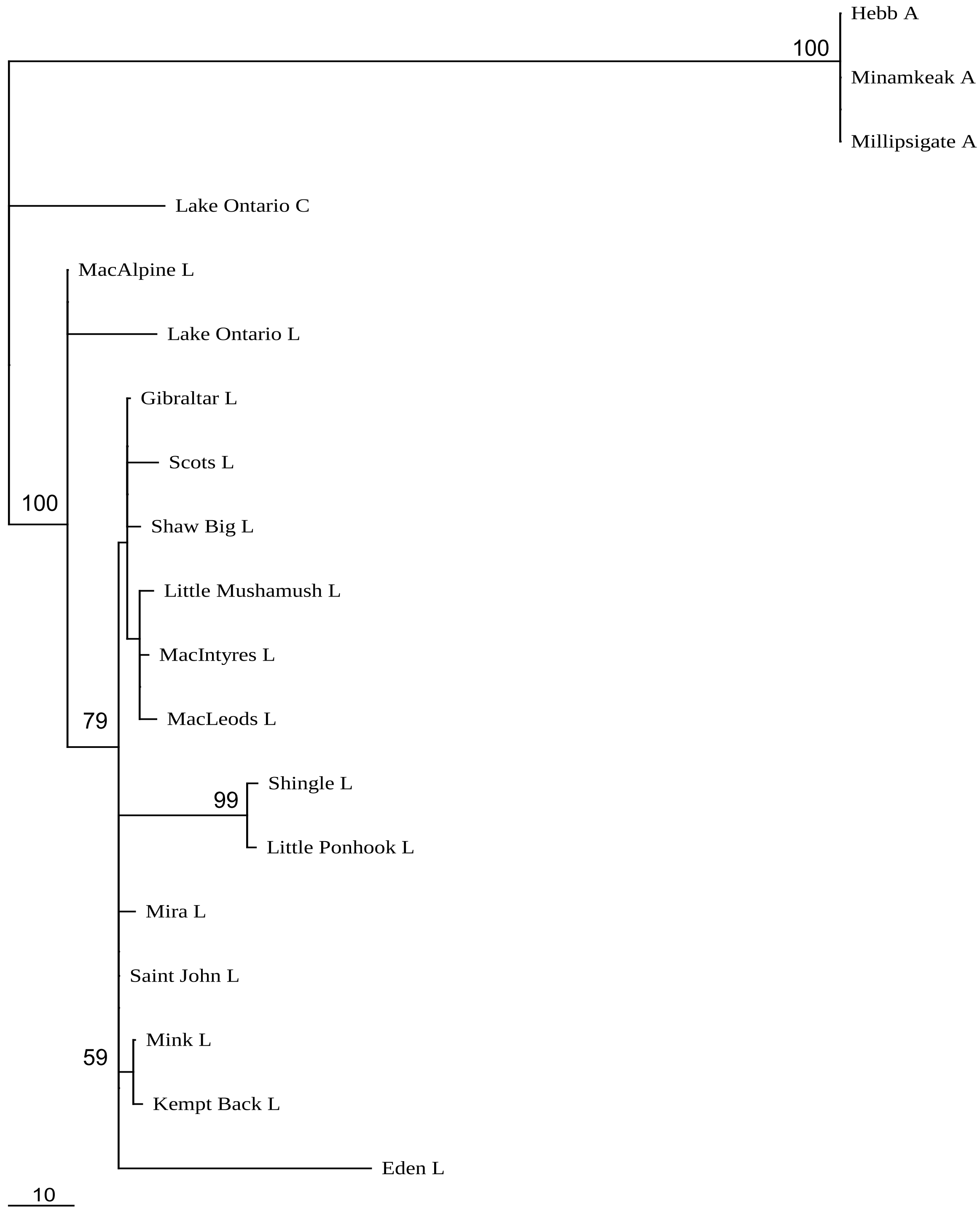


Figure 3. Population dendrogram based on D_{CE} topology and $(\delta\mu)^2$ branch length illustrating the relationship among three populations of Atlantic whitefish (A), 15 populations of lake whitefish (L), and one population of cisco (C).

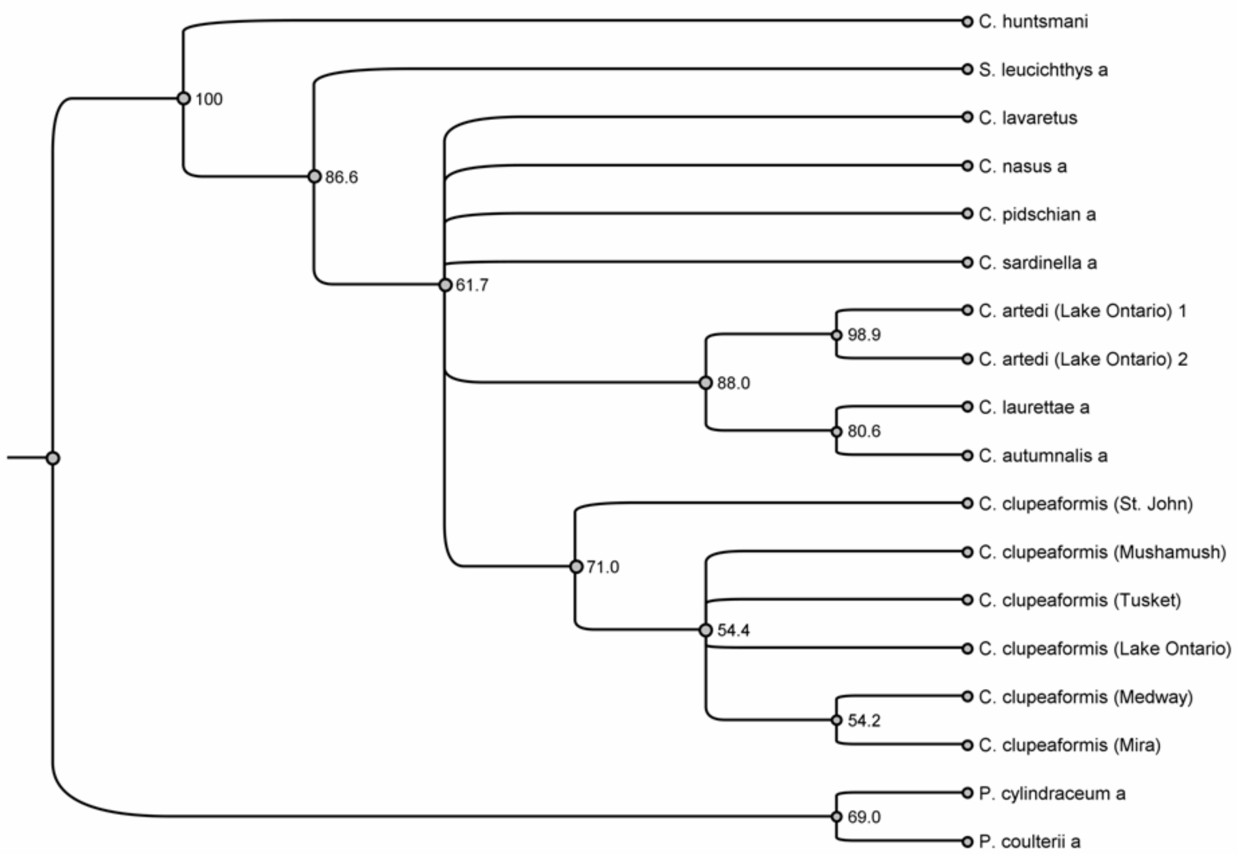


Figure 4. Consensus neighbour joining tree of CO1 sequences for Coregonus species. Node labels represent percent bootstrap support. Stenodus leucichthys was chosen as an outgroup to root the tree.

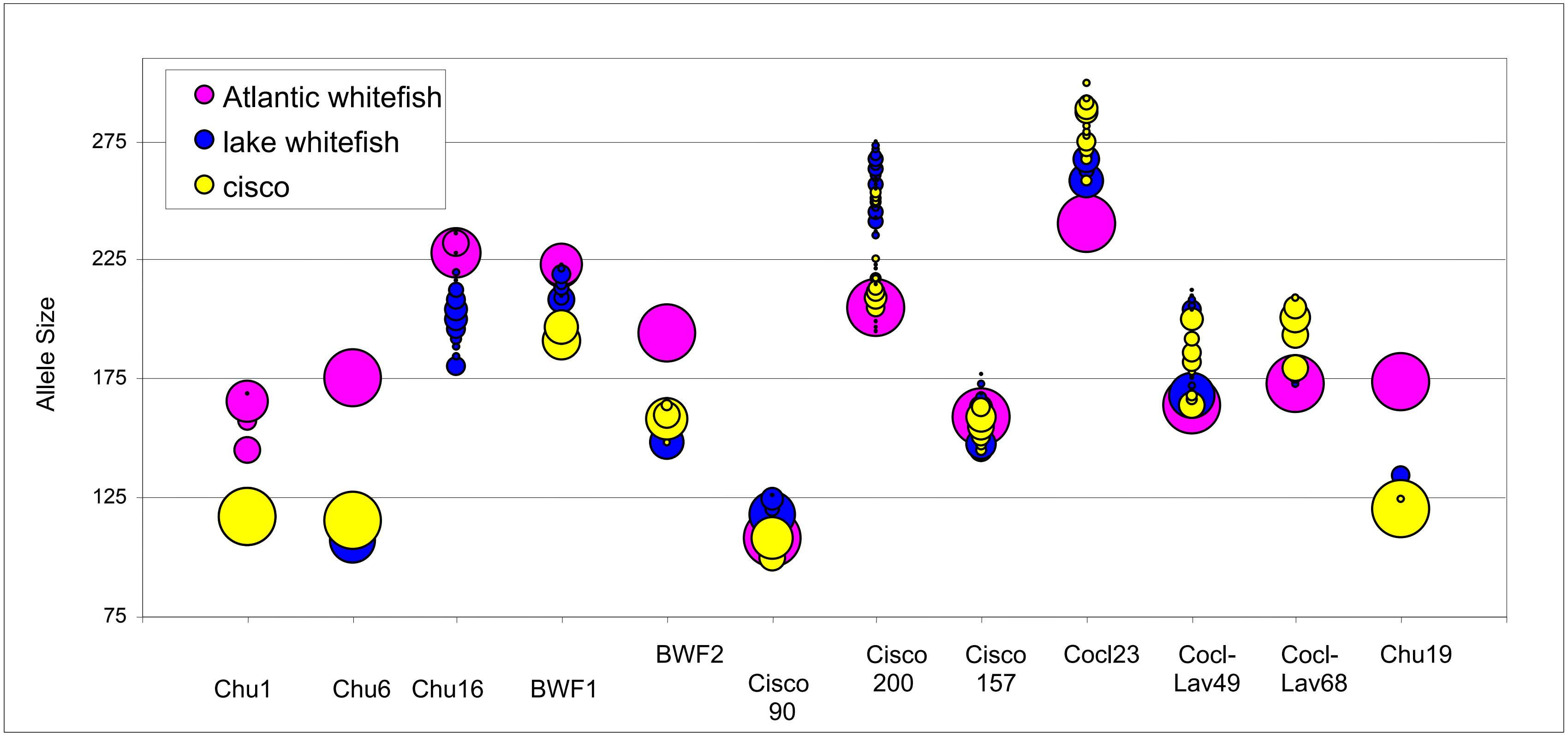
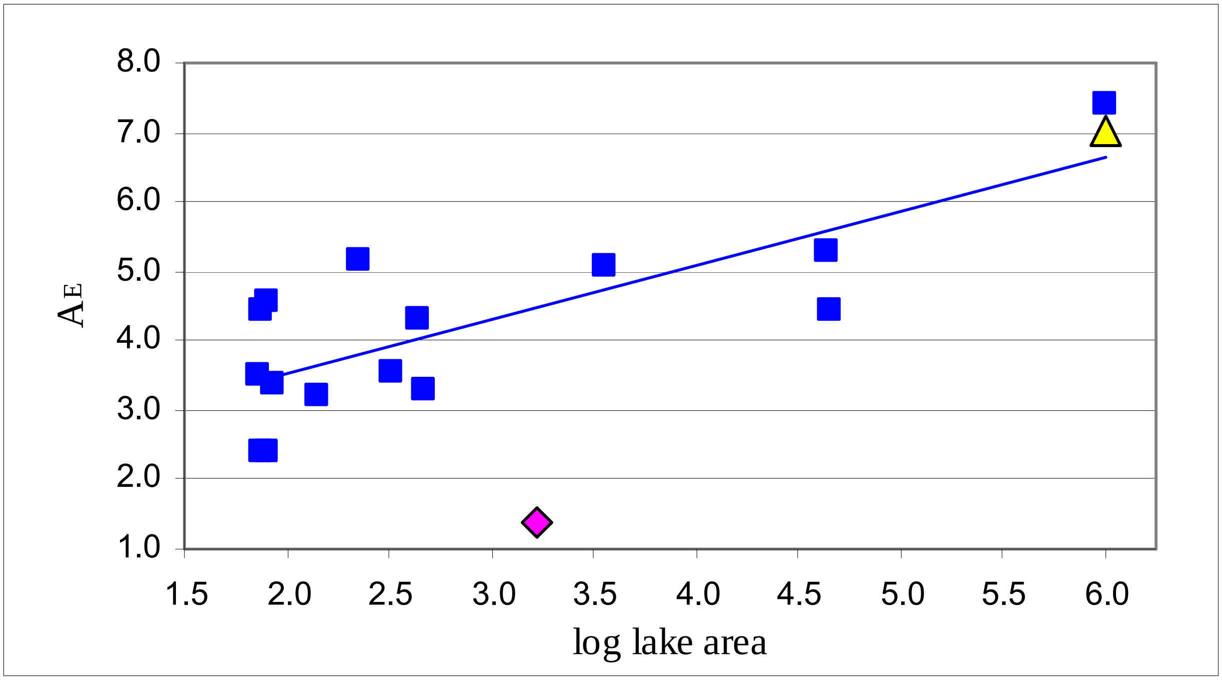


Figure 5. Frequency and size of alleles in base pairs for loci that cross amplify in Atlantic whitefish, lake whitefish, and lake cisco. No alleles are reported for cisco at locus Chu16 due to weak amplification.



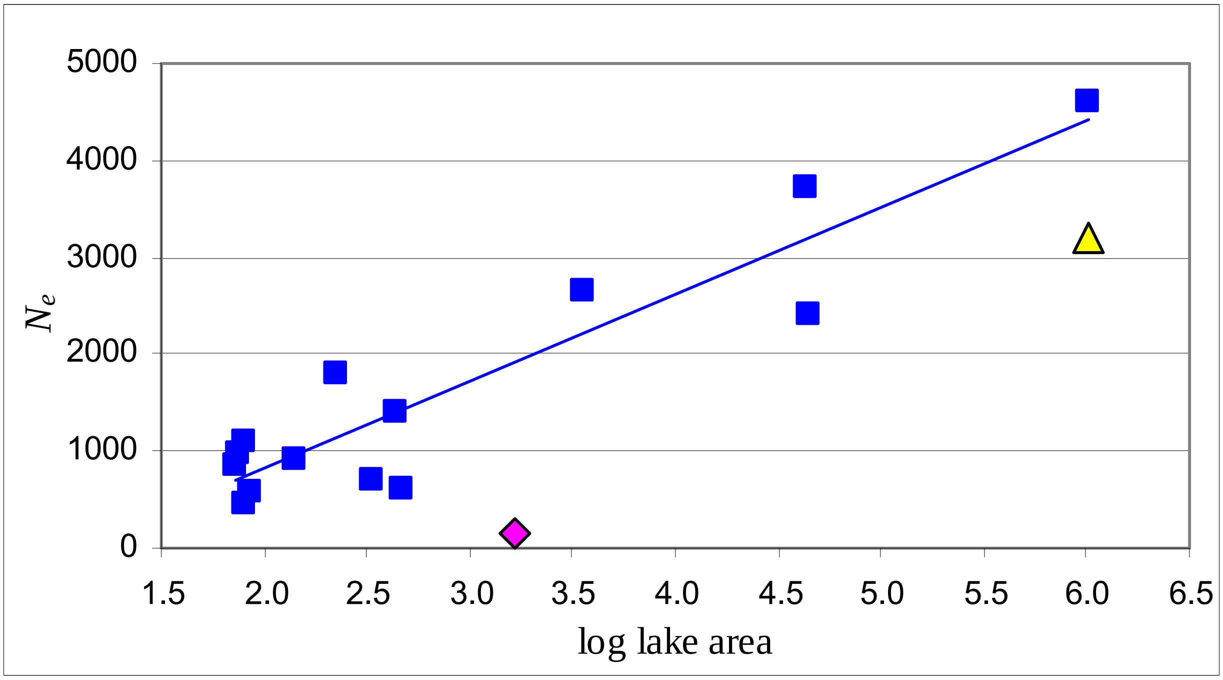


Figure 6. Scatterplots of log lake area per population against genetic diversity measures and the effective population size for all sampled lake whitefish, Atlantic whitefish, and cisco. a.Unbiased allelic richness (A_E) calculated with HP-RARE (Kalinowski 2005) b. Effective population size (N_e) calculated with ThetaF (Xu and Fu 2004).

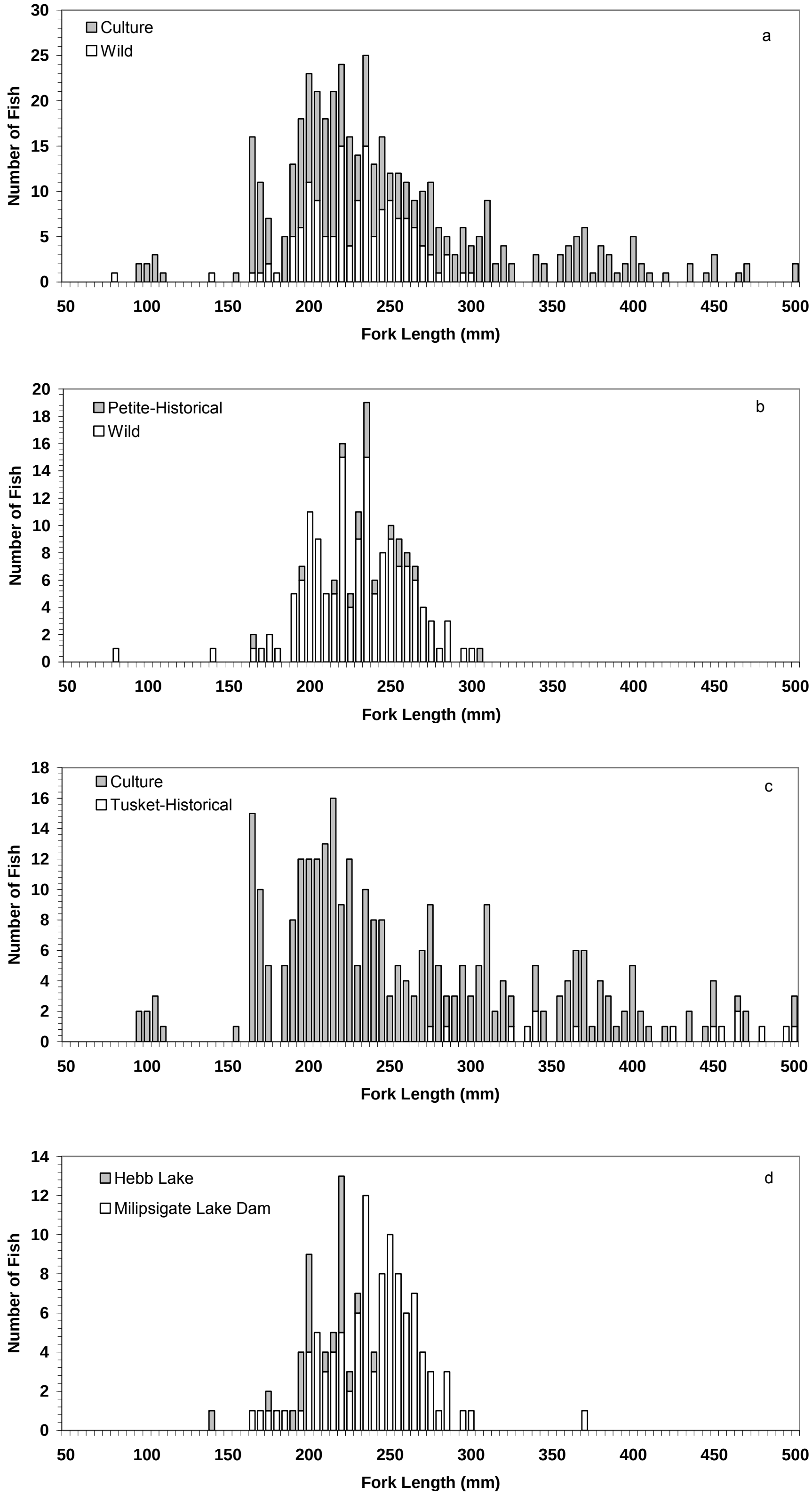


Figure 7. Atlantic whitefish fork length (mm) frequency distributions of a) cultured versus wild (lake resident) samples, b) historical versus contemporary samples from the Petite Rivière, c) cultured versus historical anadromous samples from the Tusket River, and d) Hebb Lake versus Millipsigate Lake Dam samples.

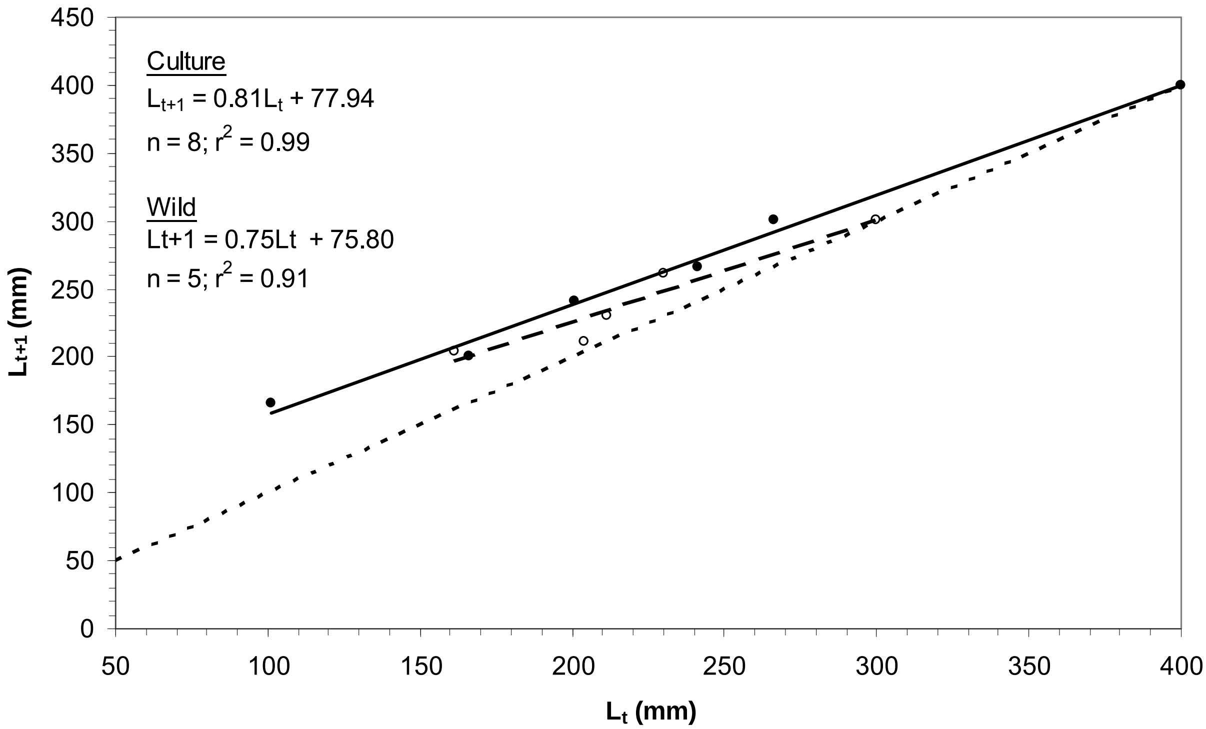


Figure 8. Walford plots for cultured (closed circles) and wild (open circles) Atlantic whitefish.

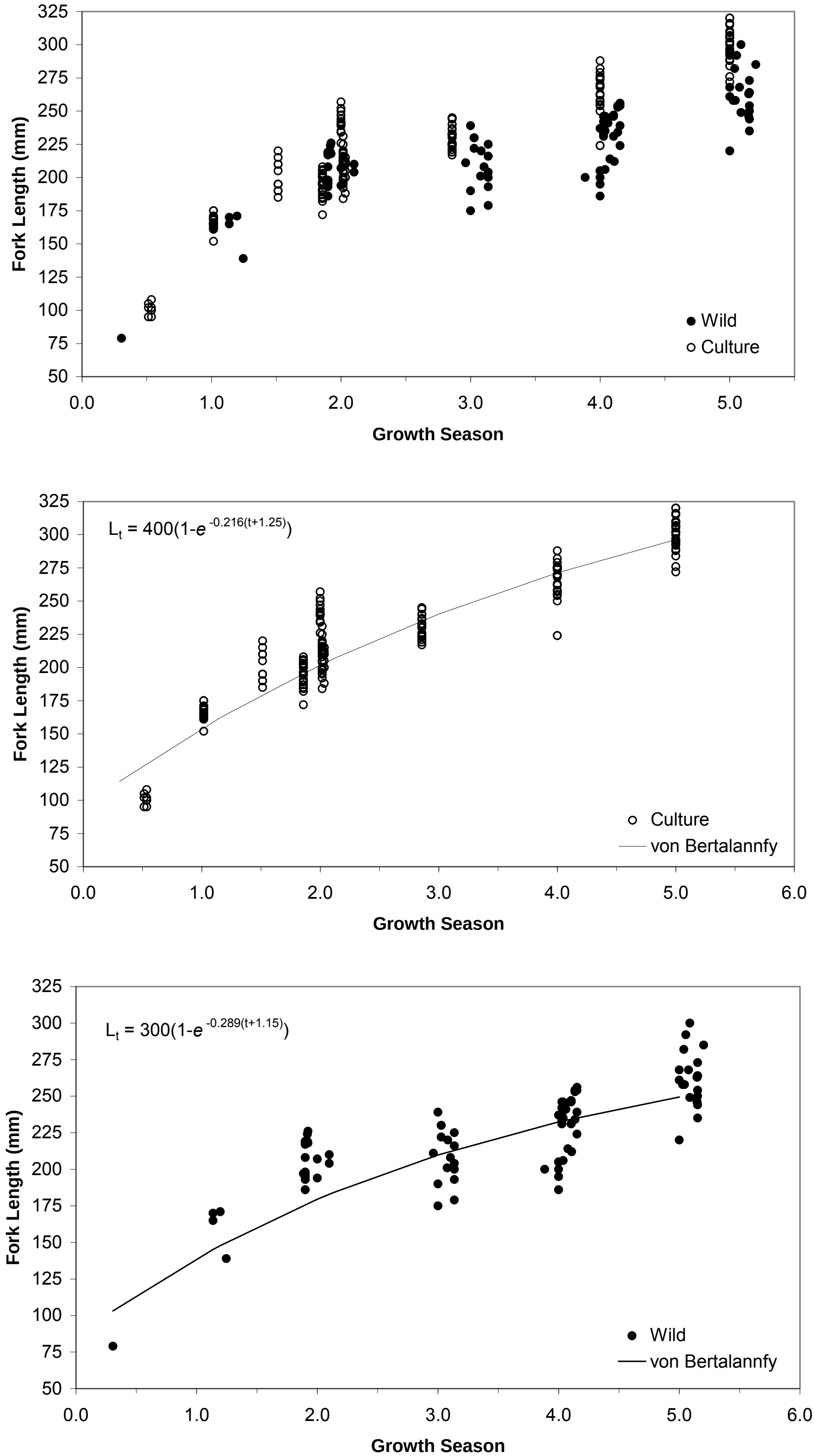
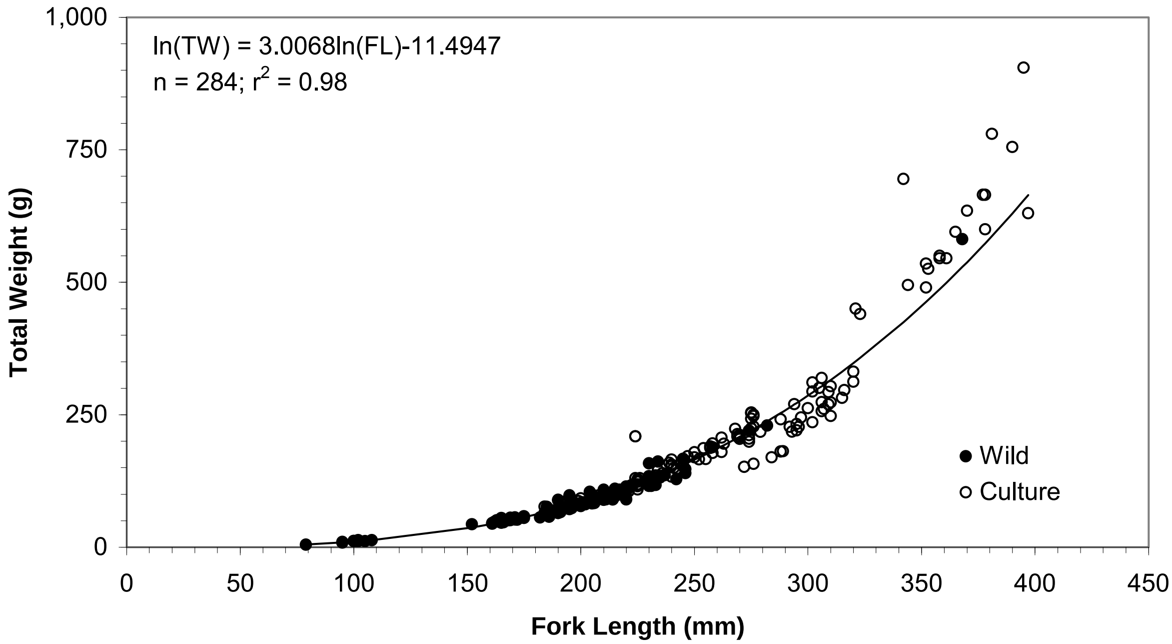


Figure 9. Fork Length (mm) versus age (years) for (upper panel) cultured (open circle) and wild (closed circle) Atlantic whitefish, and associated von Bertalannfy growth plots for (middle panel) cultured and (lower panel) wild Atlantic whitefish.



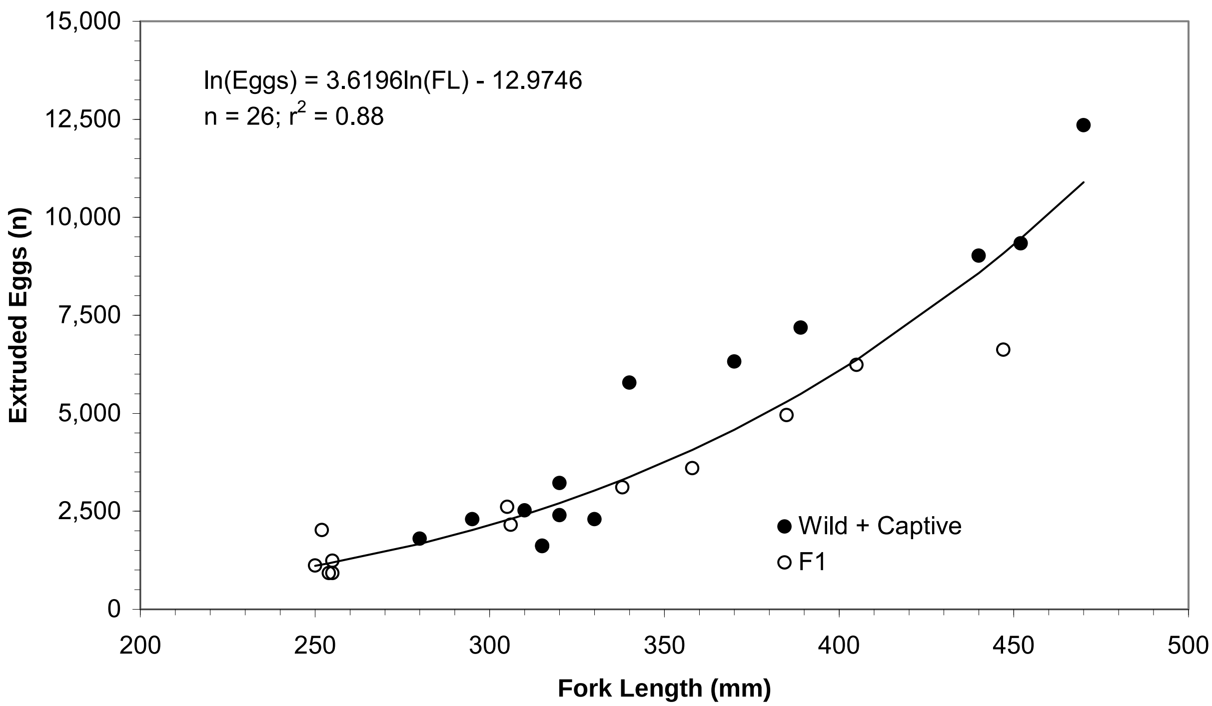


Figure 10. (a) Total weight (g) – Fork Length (mm) relationship for combined samples of wild (closed circles) and cultured (open circles) Atlantic whitefish. (b) Number of extruded eggs per female Atlantic whitefish versus Fork Length (mm).

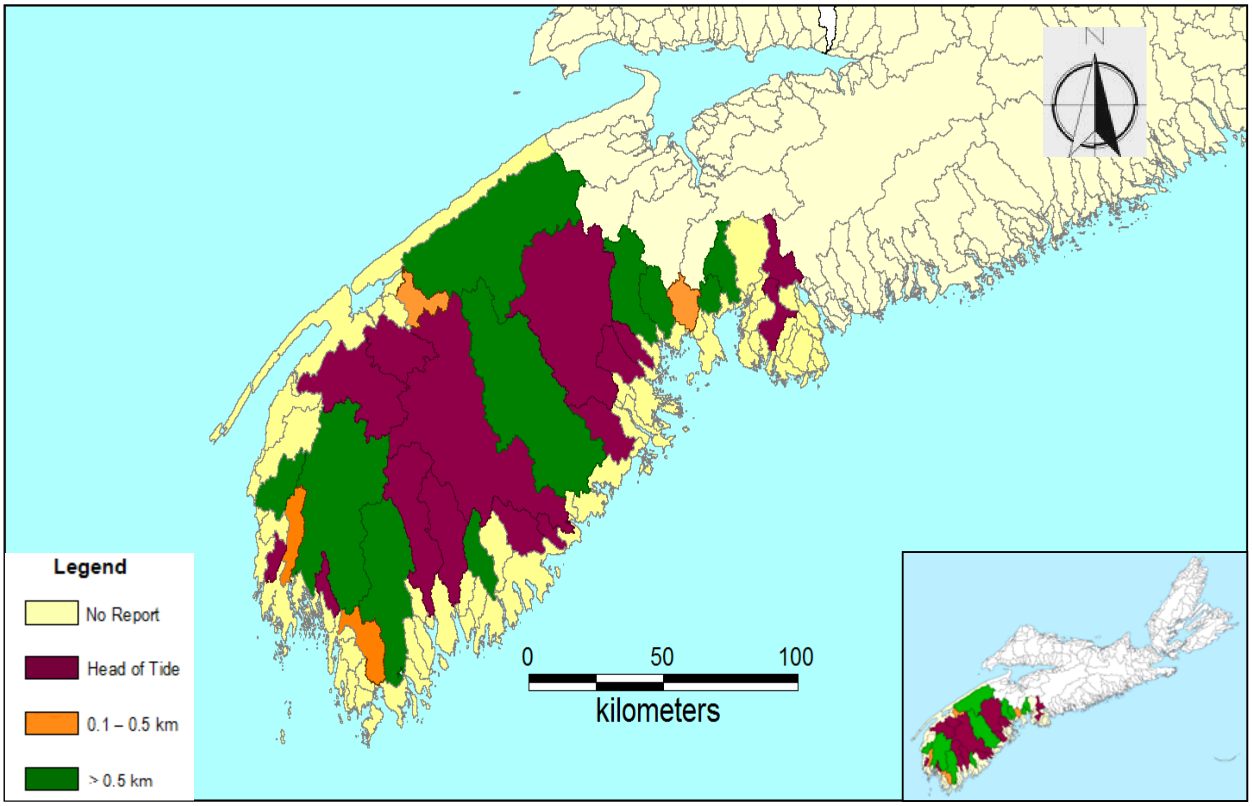


Figure 11. Southern Nova Scotia rivers with dams in 1926 grouped by the distance of the first dam from the head of tide.

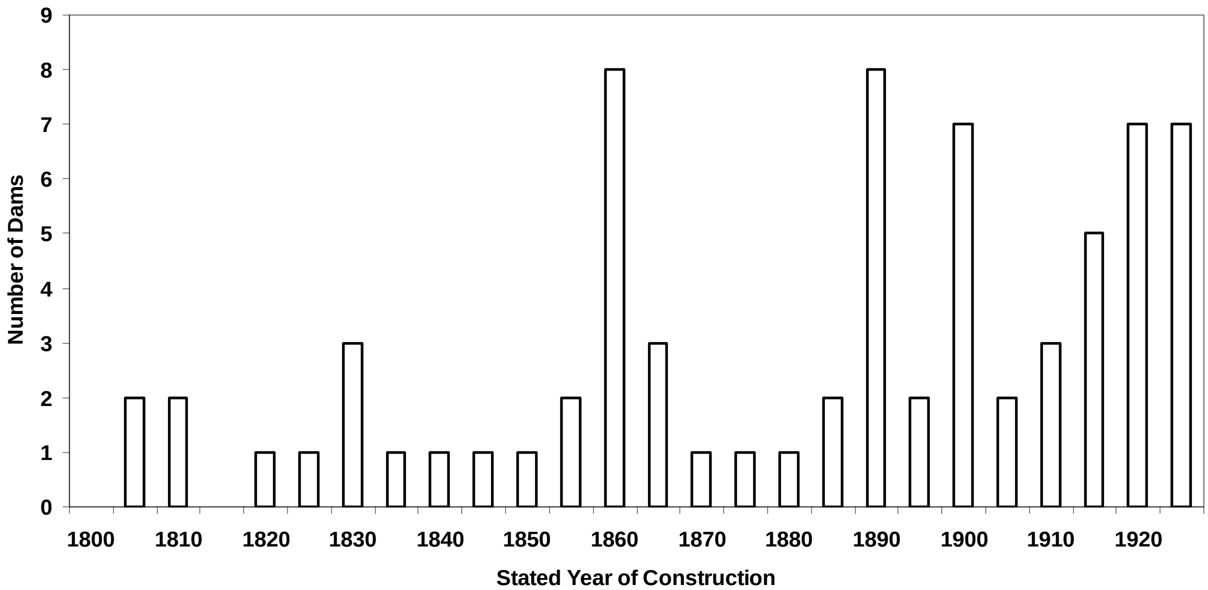
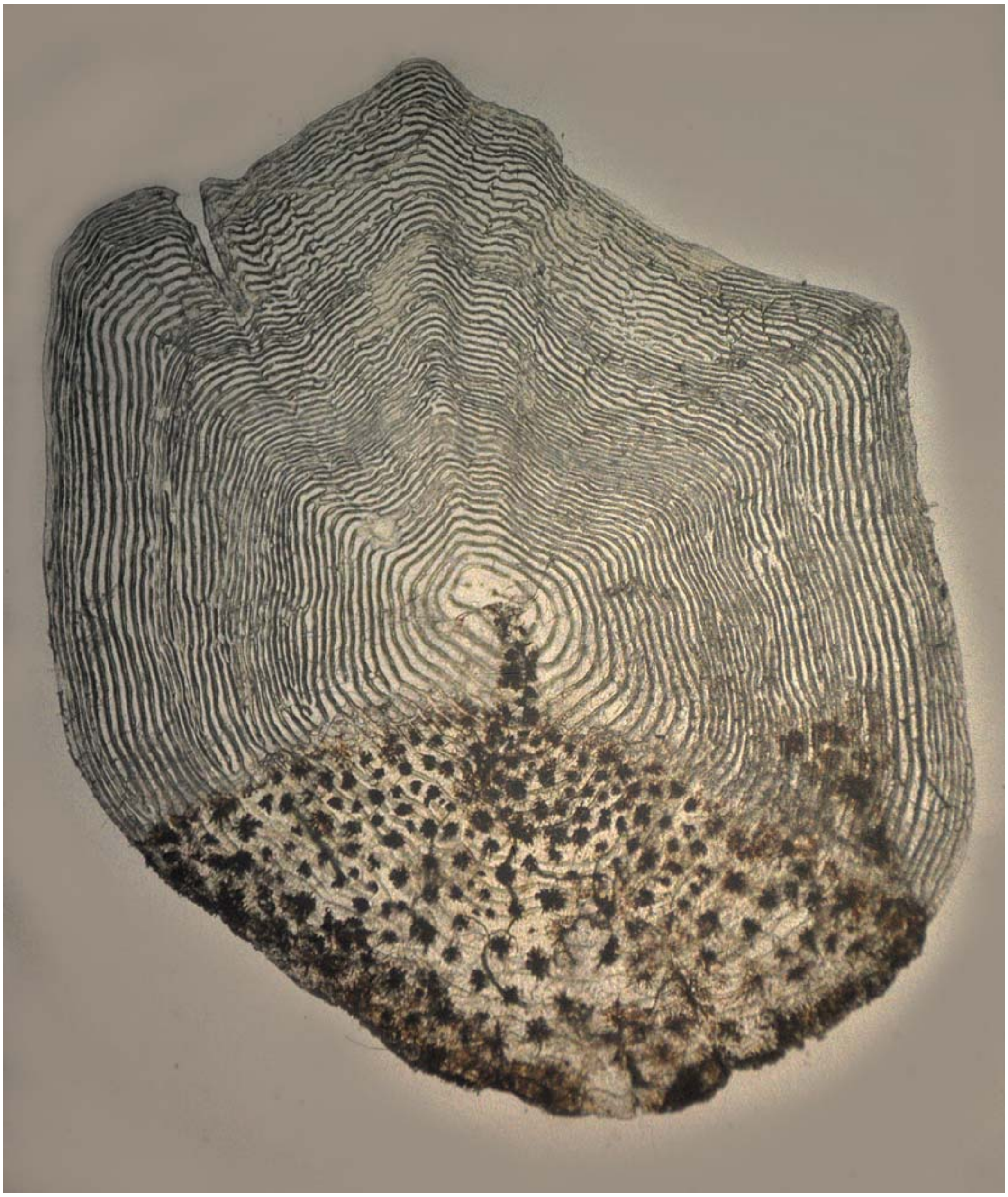


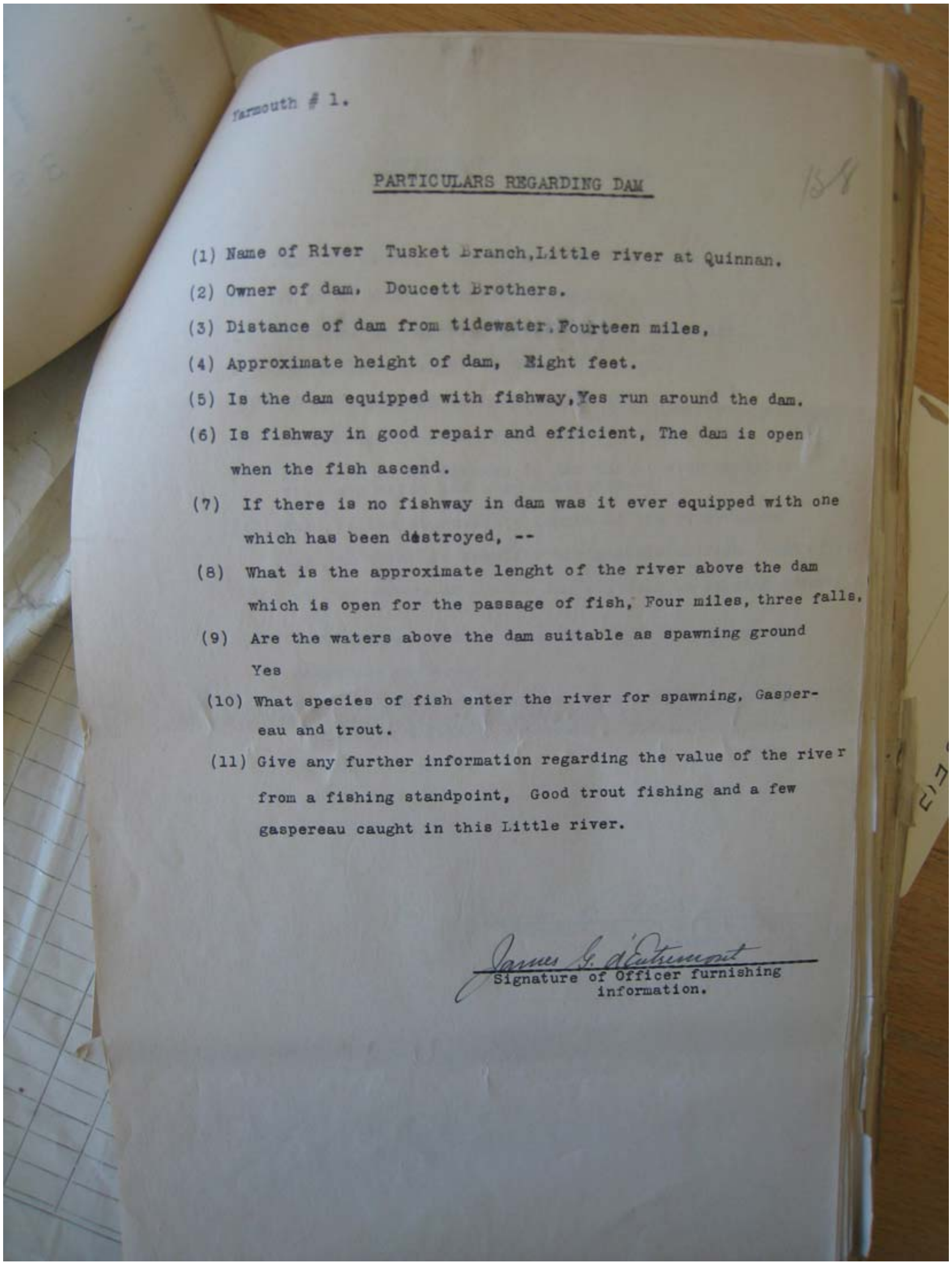
Figure 12. Reported age of construction for 73 of the 93 dams located on southern Nova Scotia rivers during 1926.

APPENDICES

Appendix I.I. Image of an external body scale sampled from a wild Atlantic whitefish in May and estimated to be 4^+ years of age.



Appendix I.II. Questionnaire distributed to fishery overseers.



Yarmouth # 1.

PARTICULARS REGARDING DAM

(1) Name of River Tusket Branch,Little river at Quinnan.

(2) Owner of dam, Doucett Brothers.

(3) Distance of dam from tidewater.Fourteen miles,

(4) Approximate height of dam, Eight feet.

(5) Is the dam equipped with fishway,Yes run around the dam.

(6) Is fishway in good repair and efficient, The dam is open when the fish ascend.

(7) If there is no fishway in dam was it ever equipped with one which has been destroyed, --

(8) What is the approximate lenght of the river above the dam which is open for the passage of fish, Four miles, three falls,

(9) Are the waters above the dam suitable as spawning ground Yes

(10) What species of fish enter the river for spawning, Gaspereau and trout.

(11) Give any further information regarding the value of the river from a fishing standpoint, Good trout fishing and a few gaspereau caught in this Little river.

James G. d'Entremont
Signature of Officer furnishing information.