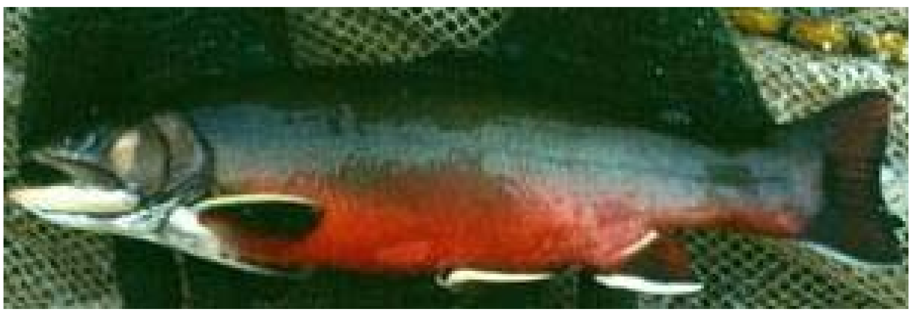
COSEWIC
Report on the Eligibility

for the

Aurora Trout
Salvelinus fontinalis timagamiensis

in Canada



Ineligible for Assessment
2011

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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Aurora Trout — supplied by the author.

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COSEWIC
Executive Summary

Aurora Trout
Salvelinus fontinalis timagamiensis

Wildlife Species Description and Significance

The Aurora Trout is a variant of the Brook Trout distinguishable from the latter in terms of skin colouration: (1) adult Aurora Trout lack the yellow spots and worm-like markings (vermiculations) that typically occur on the dorsal surface of other Brook Trout; and (2) the numerous red spots surrounded by blue halos characteristically found on the sides of Brook Trout are greatly reduced in number or are absent on Aurora Trout. The Aurora Trout has a high public profile as an endangered species, and as an icon for the biological damage caused by acid rain. It also serves as a positive example of habitat rehabilitation and biological restoration, because, despite its original extirpation in the wild, severe population bottleneck, and generations of captive breeding, it has been successfully re-established in both of the lakes to which it was native. Recent information from genetic and breeding studies, however, indicates that the Aurora Trout does not satisfy the discreteness and significance criteria that would justify its recognition as a designatable unit within Brook Trout.

Distribution

The native range of the Aurora Trout consists of two small lakes, Whirligig Lake and Whitepine Lake, located 110 km north of Sudbury, Ontario. Reproducing populations that were introduced and established during the 1990s in Southeast Campcot Lake and Northeast Campcot Lake near Terrace Bay, Ontario are now extirpated. Currently, ten other lakes in northern Ontario contain introduced Aurora Trout populations that are maintained by stocking of hatchery-raised juvenile fish. A captive brood stock is maintained in one provincial fish culture facility near Kirkland Lake, Ontario. Recently a few trout similar in appearance have been reported from two lakes (de la Bidière, 495ha and de la Hase, 10 ha) in the Laurentides region of Québec. To date (since 2005) only 10 specimens of this colour morph in Québec have been observed and the morph appears to live in sympatry with “typical”-looking Brook Trout. The population assessment and genetic work required to assess their status and similarity to Aurora Trout, however, have not yet been done. Consequently, fish in the Québec lakes are considered to be a parallel phenotype and within-population colour variant until more data are available.

Habitat

The two native Aurora Trout lakes are part of a chain of lakes situated on a ridge in Lady Evelyn Smoothwater Provincial Park in northeastern Ontario, which are some of the highest elevation lakes in Ontario. Whirligig Lake (11 ha surface area; maximum depth 9.1 m; Secchi depth 3.3-6.2 m in 1999; 435 m elevation) flows into Whitepine Lake (77 ha surface area; maximum depth 21.3 m; Secchi depth 3.5-6.0 m in 1999; 430 m elevation). The surrounding terrain is hilly and rough, topography typical of the Precambrian Shield. The lakes are 10 km from the nearest road and accessible only by canoe and trail or by aircraft. Their watersheds have low acid-neutralizing capacities and are vulnerable to acidification.

Biology

The thermal and ecological requirements of Aurora Trout are similar to other Brook Trout. Brook Trout generally inhabit water temperatures below 20˚C and when temperatures rise above that they seek cooler water by shifting their depth distribution or by inhabiting areas associated with groundwater springs. At spawning time female Aurora Trout, like other Brook Trout inhabiting lakes on the Canadian Shield, seek areas of groundwater upwelling on which to build their nests known as “redds”. A pH of at least 5.0 is required for successful reproduction and maintenance of self-sustaining populations. In captivity, Aurora Trout exhibit lower survival, reduced fecundity, and lower fitness for several life history traits than other Brook Trout. It is not yet known whether this reduced fitness reflects inbreeding depression or loss of fitness during the original population declines, founding of the captive population, and/or subsequent generations of captive breeding.

Population Sizes and Trends

The two native populations were extirpated by lake acidification during the 1960s. Since then the Aurora Trout has been maintained by artificial breeding that began in 1958 from a founding population of only nine individuals. The captive brood stock currently numbers 500-1,000 fish. During the 1990s, self-sustaining populations were re-established in the two native lakes following water quality improvements. The biomass of Aurora Trout in Whirligig Lake and Whitepine Lake quickly increased after stocking to levels comparable to that of Brook Trout populations in non-acidified lakes and growth rates of the fish are similar to those exhibited in pre-acidification times. Natural reproduction occurred in two non-native lakes (Southeast Campcot Lake, Northeast Campcot Lake) during the 1990s, but those populations are now extirpated. There is no evidence of successful reproduction in Alexander Lake, the lake where Aurora Trout were introduced and that serves as the egg source for hatchery brood stock, or in any of the nine lakes that are used for the limited recreational fishery.

Threats and Limiting Factors

The native lakes are located within the zone affected by acid deposition from Sudbury metal smelters. Extirpation of the Aurora Trout during the 1960s coincided with acidification of the lakes to below pH 5.0, the threshold for Brook Trout reproduction. Although water quality improvements have occurred in the two native lakes since 1989 as a result of whole-lake liming and reductions in atmospheric pollution levels, the lakes are poorly buffered and they remain threatened by acidification. The main source of acid is atmospheric deposition of pollutants, but historically deposited sulphur may also be stored in adjacent wetlands and could contribute to re-acidification following drought years when oxidized sulphur is released into the lake.

The spawning sites that have been identified to date are all on groundwater springs. The failure of stocked Aurora Trout to reproduce in all 10 non-native lakes may be due to the lack of suitable groundwater sites for spawning and/or lack of thermal refugia in these lakes. Reduced fitness as a result of historical bottlenecks and inbreeding depression has also been identified as a probable limiting factor and long-term threat.

Protection, Status, and Ranks

The Aurora Trout is currently listed as Endangered under the federal *Species at Risk Act* and Ontario's *Endangered Species Act*, which both afford legal protection to Aurora Trout and their habitats. Additional protection is provided by the federal *Fisheries Act*, which provides habitat protection provisions for all fish species. Aurora Trout is ranked as S1 (Ontario) and globally ranked as G5T1Q? (NatureServe) and Endangered by the American Fisheries Society.

TECHNICAL SUMMARY

Genus species *Salvelinus fontinalis timagamiensis*

English common name: Aurora Trout French common name: Omble de fontaine aurora

Range of occurrence in Canada (province/territory/ocean): Ontario

Demographic Information

Generation time	3+yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	No
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	n/a
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	n/a
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	n/a
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	n/a
Are the causes of the decline clearly reversible and understood and ceased?	No (lake pH, reversabile, but not ceased); uncertain (inbreeding)
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	< $500 km^2$
Index of area of occupancy (IAO) (naturally reproducing populations only)	$8 km^2$ (2x2 km^2 grid)
Is the total population severely fragmented?	No
Number of locations∗ (* potential occurrences in Quebec are not included due to current lack of data *)	Two breeding populations; 10 stocked lakes (no reproduction).
Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy?	No
Is there an [observed, inferred, or projected] continuing decline in number of populations?	No
Is there an [observed, inferred, or projected] continuing decline in number of locations*?	No
Is there an [observed, inferred, or projected] continuing decline in [area, extent and/or quality] of habitat?	Potentially (acidification of native lakes)
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?	No
Are there extreme fluctuations in index of area of occupancy?	No

∗ See definition of location in O&P manual

Number of Mature Individuals (in each population)

Population **	N Mature Individuals
Whirligig Lake	450 – 780
Whitepine Lake	1,565 - 2,845
Total	2,005-3,625
naturally reproducing populations only; captive broodstock and population maintained by stocking not included in total	

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not done

Threats (actual or imminent, to populations or habitats)

Actual

Reduced fitness from inbreeding depression associated with small population sizes.
Acidification through release of sulphur following drought events.

Potential

Competition from introduced species such as Yellow Perch, and loss and degradation of spawning habitat.

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Non existent as they are endemics	
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?	Possible from hatchery stocking; otherwise no.

Current Status

COSEWIC: Endangered (2000) re-examined and designated ineligible (May 2011)
SARA: Endangered, Schedule 1 (2003)
ESA 2007: Endangered (2008)
NatureServe: Ontario: S1, G5T1Q(?) globally

Additional Sources of Information:

Aurora Trout Recovery Team. 2006. Recovery Strategy for the Aurora trout (*Salvelinus fontinalis timagamiensis*) in Canada.

Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada. Ottawa 35 pp.

Status and Reasons for Designation

Status: *	**Alpha-numeric code:**
Reasons for designation: A change in status from Endangered is warranted because of new genetic and breeding data that indicate that the Aurora Trout is not a valid designatable unit within Brook Trout.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals):
Criterion B (Small Distribution Range and Decline or Fluctuation):
Criterion C (Small and Declining Number of Mature Individuals):
Criterion D (Very Small or Restricted Total Population):
Criterion E (Quantitative Analysis):

*Not applicable as the Aurora Trout is not a designatable unit and is ineligible for assessment

PREFACE

This report includes new information gathered since the last COSEWIC status report on Aurora Trout (Snucins and Gunn 2000). Specifically, the report provides ecological and demographic information on the re-established populations of Aurora Trout in their original native habitats, biological and life history data from captive rearing trials, a re-appraisal of the proper taxonomic status of Aurora Trout, and a summary of available phylogenetic and population genetic data for Aurora Trout. New information reports Brook Trout from two Québec lakes that resemble Aurora Trout, but until further information is available for these populations their status as either a colour variant distinct from Aurora Trout or additional populations of Aurora Trout remains uncertain. New inferences from genetic data and breeding studies were used to assess whether Aurora Trout constitute a designatable unit (DU) within Brook Trout (*Salvelinus fontinalis*). A critical summary of new genetic information strongly suggests that the Aurora Trout does not meet the combined “discrete” and “significance” criteria necessary for recognition as a designatable unit, and thus is ineligible as a wildlife species for assessment.

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
(2011)

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.

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

The scientific name for the Aurora Trout is *Salvelinus fontinalis timagamiensis* (Henn and Rinkenbach 1925). The French common name is Omble de fontaine aurora. The hierarchical formal taxonomic designation of Aurora Trout is as follows:

Phylum Chordata
- Subphylum Vertebrata
  - Superclass Gnathostomata
    - Grade Teleostomi
      - Class Actinopterygii
        - Subclass Neopterygii
          - Division Teleostei
            - Subdivision Euteleostei
              - Superorder Protacanthopterygii
                - Order Salmoniformes
                  - Family Salmonidae
                    - Subfamily Salmoninae
                      - Genus *Salvelinus*
                        - Subgenus *Baione*
                          - Species *Salvelinus fontinalis*

Salvelinus fontinalis timagamiensis is the only described subspecies of Brook Trout, and is considered endemic to northern Ontario. Aurora Trout was originally described as a distinct species (*Salvelinus timagamiensis*) by Henn and Rinkenbach (1925), who considered it to be a sister species to Arctic Char (*S. alpinus*) (Henn and Rinkenbach 1925). The many similarities of Aurora Trout to Brook Trout caused Martin (1939) to consider it a subspecies of Brook Trout, and Vladykov (1954) argued that it was better recognized as a Brook Trout colour variant. Subsequent arguments were made for subspecies designation (*S. fontinalis timagamiensis*) based upon morphometric and ecological studies that included the original populations in Whitepine and Whirligig lakes (Sale 1967; Qadri 1968; Behnke 1980). The differences that were identified between Aurora Trout and other Brook Trout included colouration and skeletal structure (numbers of trunk vertebrae, single neural spines, epineurals, and strongly bifid ribs (Sale 1967; Qadri 1968). Further, Aurora Trout were thought to have separate spawning behaviour, as implied by inferred reproductive isolation with little apparent hybridization between the sympatric populations of Aurora Trout and normal type Brook Trout in Whitepine Lake (Henn and Rinkenbach 1925).

At present, Aurora Trout are still listed as a subspecies by some authors (Parker and Brousseau 1988; Jelks et al. 2008), but are considered to be merely a colour variant of Brook Trout by others (Snucins et al. 1995). Genetic studies, based on allozyme, mitochondrial DNA and microsatellite DNA data, do not support the subspecific status (see below and Wilson and Mandrak, unpublished data).

Morphological Description

The basic colouration of Aurora Trout is similar to other Brook Trout (Sale 1967). Dorsal colouration is olive green to dark brown. Along the sides this fades to steel blue and silver and pales to a white abdomen that is often tinged with pink. Pectoral, pelvic and anal fins have a leading white edge backed by a black bar and orange or red posterior. During spawning season the colour of males intensifies, the sides and upper abdomen taking on a bright red colour, often edged by a band of black along the abdomen (Figure 1). The distinguishing aspects of Aurora Trout colouration are that adult Aurora Trout lack the yellow spots and vermiculations (“worm-like” markings on the back and fins) that typically occur on the dorsal surface of other Brook Trout, and the numerous red spots surrounded by blue halos characteristically found on the sides of Brook Trout are greatly reduced in number or are absent on Aurora Trout (Henn and Rinkenbach 1925; Sale 1967). Sale (1964) observed a tendency for the yellow markings to be present in young Aurora Trout. These markings are generally considered to be absent in adult Aurora Trout, although they can be observed in formalin-preserved adult specimens (Qadri 1968) and hatchery broodstock adults (R. Ward, OMNR, pers. comm. 2010). Sale (1967) further noted that the body colour of Aurora Trout exhibits a strong iridescence not apparent in other Brook Trout.

a) b)

Figure 1. a) Typical Brook Trout b) Male Aurora Trout during spawning season

Population Spatial Structure and Variability

All genetic studies which have been done to date have shown that Aurora Trout possess common, local Brook Trout variants at neutral allozyme, mitochondrial DNA, and microsatellite DNA loci. For all of these, Aurora Trout are solely notable for possessing extremely low diversity (little or no variation). For instance, allozyme data for Aurora Trout exhibit polymorphism at only one of 32 loci, with two alleles present (Ontario Ministry of Natural Resources [OMNR], unpubl. data, 2010). McGlade (1981) argued that Aurora Trout showed no unique variants for allozyme loci, and did not merit subspecific status. Studies of mitochondrial DNA based on restriction fragment length analysis also did not detect any differences between Aurora Trout and Brook Trout from northeastern Ontario (Grewe et al. 1990; Danzmann et al. 1998). These results were supported by more recent sequence-based analyses of mitochondrial DNA (Kyle and Wilson 2007; Wilson and Mandrak unpubl. data, 2010), which similarly failed to detect any evidence of divergence from the common regional Brook Trout haplotype (Danzmann et al. 1998). Sequencing of the nuclear ribosomal internal transcribed spacer (ITS-1), a nuclear region that is useful for identifying distinct taxonomic units, similarly failed to detect differences between Aurora Trout and Brook Trout (Wilson and Mandrak unpubl. data 2010).

Aurora Trout show a similar lack of evolutionary divergence from wild-type Brook Trout at neutral genetic loci. Among over 100 populations of Brook Trout that were surveyed across Ontario for variation at 43 allozyme loci, Aurora Trout showed the lowest diversity of all surveyed populations, with variation at only one locus (OMNR, unpublished data 2010). This lack of variation was confirmed by genetic monitoring data from hatchery production lots, broodstocks, and wild spawn collections between 1984-1998, with no additional polymorphisms or unique genetic characteristics observed (OMNR, unpublished data 2010). Analysis of microsatellite DNA yielded similar results: of 17 polymorphic loci that are routinely variable within and among populations of Brook Trout in Ontario, surveys of the re-established wild populations, hatchery broodstock, and sanctuary lake (Alexander Lake), 11 loci were monomorphic; 6 other loci exhibited two alleles each, with one of these loci being only weakly polymorphic (rare allele at a frequency < 0.05) (C. Wilson, unpubl. data, 2010). Despite extensive screening, no significant genetic variation has been detected among the re-established or stocked populations, or between historical samples (1970s) and the contemporary populations and broodstock (C. Wilson, unpubl. data, 2010). In each case, the observed alleles were not unique to Aurora Trout, but occur in other Brook Trout populations as well (C. Wilson, unpubl. data). Based on these genetic data, it appears likely that the unique characteristics of Aurora Trout evolved *in situ* from wild-type Brook Trout which colonized their native habitats at the end of the Pleistocene Epoch (Danzmann et al. 1998), and that the observed low levels of genetic diversity reflect both historical demographic limitations on genetic diversity due to limited habitat sizes and 20th century bottlenecks associated with habitat degradation and captive founder effects.

The Aurora Trout were first recognized in 1923 (Henn and Rinkenbach 1925). Recent paleolimnological evidence suggests that the native lakes began to acidify as early as the 1940s (Dixit et al. 1996). In 1951, the Ontario government began to monitor the native Aurora Trout populations and by the late 1950s the populations had noticeably declined. By 1967 the Aurora Trout had disappeared from its native range. The other fish species in the native lakes were also extirpated.

Since 1958 the Aurora Trout has been maintained artificially in OMNR fish culture facilities. The lineage of all Aurora Trout in existence today can be traced back to a collection of mature adults in 1958. That year 3,644 eggs were collected from one Whitepine Lake female and two Whirligig Lake females (Patrick and Graf 1961). The eggs from each female were mixed with the sperm from two males. Thus, the founding population size was nine individuals (three females, six males) and may have been much fewer if all males did not contribute to fertilization. To minimize selection for captivity, Aurora Trout were stocked into a reclaimed, formerly acidified lake (Alexander Lake, located southeast of Timmins, Ontario) in 1970 (two generations after the original hatchery founding event) to maintain them in a natural environment, and the lake has subsequently been used for a wild egg source from 1973 to the present (OMNR 2005). Currently, in any one year 500-1,000 fish are kept as brood stock in the Hill's Lake Fish Culture Station, and this brood stock is maintained by biannual egg collections in Alexander Lake (25,000-40,000 eggs/year). The total number of eggs collected per year by the captive breeding program, including those from Alexander Lake, is 50,000-150,000.

Successful reproduction has occurred annually in Whirligig Lake since it was restocked with hatchery-reared Aurora Trout in 1990 and in Whitepine Lake since 1994 following stocking that was done in 1991 and 1994. The biomass of Aurora Trout in Whirligig Lake and Whitepine Lake quickly increased after stocking to levels comparable to that of Brook Trout populations in un-acidified lakes and growth rates of the fish are similar to pre-acidification (Snucins et al. 1995) (Table 1). Natural reproduction was also documented in Southeast Campcot Lake in 1991-1993 and in Northeast Campcot Lake in 1993-1994. The abundance of those populations appeared to decline during the late 1990s and by 2001 they were extirpated for unknown reasons. There is no evidence of successful reproduction in Alexander Lake, the egg source for hatchery brood stock, or in any of the nine lakes that are used for the limited recreational fishery.

Table 1. Estimated number (N) and biomass (B) of Aurora Trout in Whirligig Lake (age >1 year) and Whitepine Lake (> 320 mm fork length). Numbers in parentheses are lower and upper 95% confidence intervals.

Lake	Year	N	B (kg/ha)
Whirligig	1993	456 (337-639)	15.8 (11.2-23.1)
	2003	598 (457-781)	20.2 (15.4-26.4)
Whitepine	2003	2,086 (1,565-2,845)	15.7 (11.8-21.4)

Designatable Units

Currently, Aurora Trout are listed as a subspecies under the *Species at Risk Act*, which ensured their protection under previous guidelines for recognizing designatable units (DUs, Green 2005). The clarification of their taxonomic status and updated criteria for recognizing designatable units by COSEWIC (2009), however, necessitate a re-evaluation for their consideration as a DU within Brook Trout populations in Canada.

Recent studies indicate that the subspecific status of Aurora Trout is not supported by molecular genetic evidence, and no genetic data indicate that Aurora Trout have had a distinct evolutionary ancestry from other populations of Brook Trout in northeastern Ontario. Under the current DU 'discrete' criterion (COSEWIC 2009), Aurora Trout are distinct from other Brook Trout populations in terms of neutral genetic markers, but these differences are a result of the greatly reduced diversity at microsatellite DNA loci rather than by the presence of novel or diagnostic alleles in Aurora Trout. In fact, analyses at 17 loci clearly indicate that Aurora Trout are fixed for the most common, or one of the most common, alleles found in other Brook Trout (e.g., Figure 3). Their native populations are not isolated from other conspecific populations other than by natural limitations of local topography and direct freshwater connections. The re-established native populations are also not disjunct from other Brook Trout populations in northeastern Ontario at the aquatic ecoregion level (Mandrak and Crossman 1992a), and would have shared a common history of postglacial colonization with other Brook Trout populations in the area (Qadri 1968; Mandrak and Crossman 1992b; Danzmann et al. 1998; Karas 2002).

Morphological studies by Sale (1967) and Qadri (1968) identified minor morphometric differences between Aurora Trout and other Brook Trout, but none of the 25 morphological or eight meristic traits that were measured were significantly different (Sale 1967, Qadri 1968). Both studies agreed that Aurora Trout most likely arose *in situ* following postglacial recolonization, and had no taxonomic validity above a subspecific level.

The most visibly distinctive feature of Aurora Trout is their colouration, as described above, which likely led Henn and Rinkenbach (1925) to consider it as a distinct species. By contrast, Qadri (1968) stated that the colour differences between Aurora Trout and Brook Trout did not merit species-level separation, given the range of variation observed in Brook Trout populations and forms. Although plastic to some degree, as evidenced by hatchery fish and preserved specimens (Henn and Rinkenbach 1925, Qadri 1968), Aurora Trout consistently have fewer and less distinct vermiculations than typical Brook Trout, substantially reduced spotting (few or absent red spots with blue halos), and increased iridescence (Sale 1967). These differences are greatly reduced, but still evident in captivity (C. Wilson, unpublished data, 2010; R. Ward, OMNR, pers. comm. 2010, Figure 4). These differences are heritable, as evidenced by breeding crosses at the OMNR Codrington research hatchery (C. Wilson, unpublished data, 2010, Figure 4). Second-generation crosses are currently underway to resolve the number and timing of genes influencing the observed colour differences (C. Wilson, unpublished data, 2010).

The significance of the distinct colouration of Aurora Trout is, however, as yet unclear. Although originally considered by Henn and Rinkenbach (1925) to differ ecologically based on their lake-spawning behaviour, this behaviour has since been more widely recognized in lake-dwelling populations of Brook Trout elsewhere (Scott and Crossman 1973). When first discovered, it was also reported that Aurora Trout co-occurred with “true” Brook Trout in Whitepine Lake , but the two types did not interbreed there (Henn and Rinkenbach 1925; Karas 2002). There were, however, no actual data or evidence reported (such as comparative measurements in samples of each type, descriptions of differences in spawning times or places) in support of this idea (Henn and Rinkenback 1925). A similar suggestion has been made in the two Québec lakes where a colour morph similar to Aurora Trout also appears to co-occur at low frequencies with typical Brook Trout morphs. In the northeastern Ontario lakes where Aurora Trout and Brook Trout have been stocked, the two forms interbreed readily (Sale 1967), and captive breeding studies have shown that these intraspecific ‘hybrids’ are fertile and produce viable progeny (Fortier 2010). In addition, there are no known or suspected unique characteristics of either the physical or chemical composition of the lakes in which Aurora Trout are native that can reasonably be argued to select for the distinctive colouration of Aurora Trout (Sale 1967).

In summary, there is some evidence that the Aurora Trout is discrete from other Brook Trout in terms of molecular genetics and colouration. The molecular differences, however, are driven by the reduced variation within Aurora Trout and there are no novel or diagnostic alleles found in Aurora Trout. In addition, the colour differences are to a large degree environmentally plastic and the functional and adaptive significance of the genetic components of colour differences, if any, is unknown. For the reasons outlined above, the (re-established) native populations of Aurora Trout do not meet the criteria for recognition as a DU distinct from other *S. fontinalis* (COSEWIC 2009).

Special Significance

The Aurora Trout has a very high public profile as an aquatic endangered species, and has served as an important icon for the biological damage caused by acid rain. The naturally limited distribution of Aurora Trout (two native lakes in Lady Evelyn-Smoothwater Provincial Park) and its symbolic value in the continuing fight against acid rain and for the protection of wilderness lakes give it significant cultural significance for conservation of wilderness and aquatic ecosystems. The Aurora Trout also serves as a positive example of habitat rehabilitation and biological restoration, as despite its original extirpation in the wild, severe population bottlenecks, and generations of captive breeding, it has been successfully re-established in both of its native habitats.

DISTRIBUTION

Global Range

The global distribution of Aurora Trout is limited to two small lakes, Whirligig Lake (47˚ 22’ 32”, 12.1 ha surface area) and Whitepine Lake (47˚ 23’ 00”; 81.55 ha surface area), located 110 km north of Sudbury, Ontario, Canada, in Lady Evelyn Smoothwater Provincial Park (Figure 2).

Figure 2. Location of lakes in northeastern Ontario with Aurora Trout. The closed square indicates the location of the two lakes with self-sustaining native populations. The closed triangle indicates the two non-native lakes with reproducing populations that have since been extirpated. Open circles indicate the 10 lakes with introduced populations of Aurora Trout with no evidence of reproduction that are maintained by periodic hatchery stocking

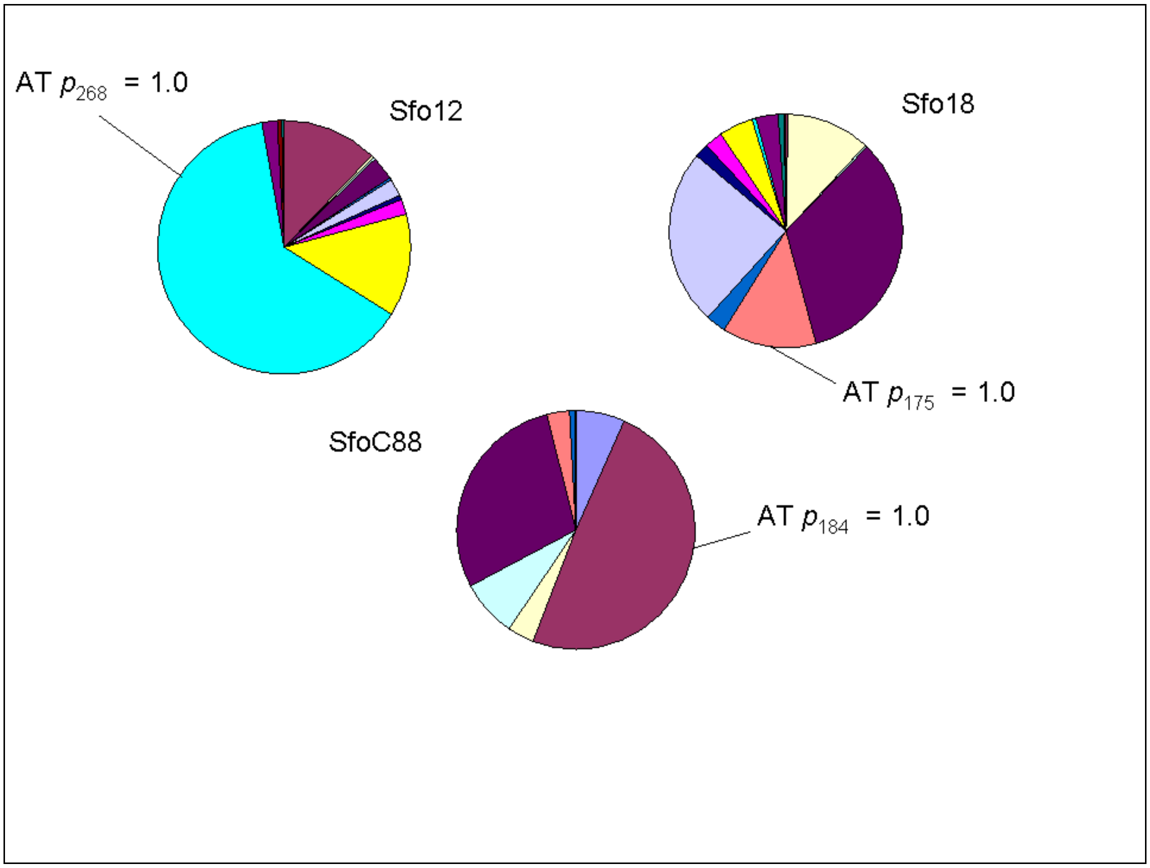

Figure 3. Mean frequencies (*p*) of alleles (different colours) at three microsatellite DNA loci in three populations of Aurora Trout (AT) and among 14 populations of Brook Trout.In each case (and at 11 other loci) the most common or fixed allele in Aurora Trout is the most common or one of the most common alleles in Brook Trout (C. Wilson, OMNR unpubl. data).

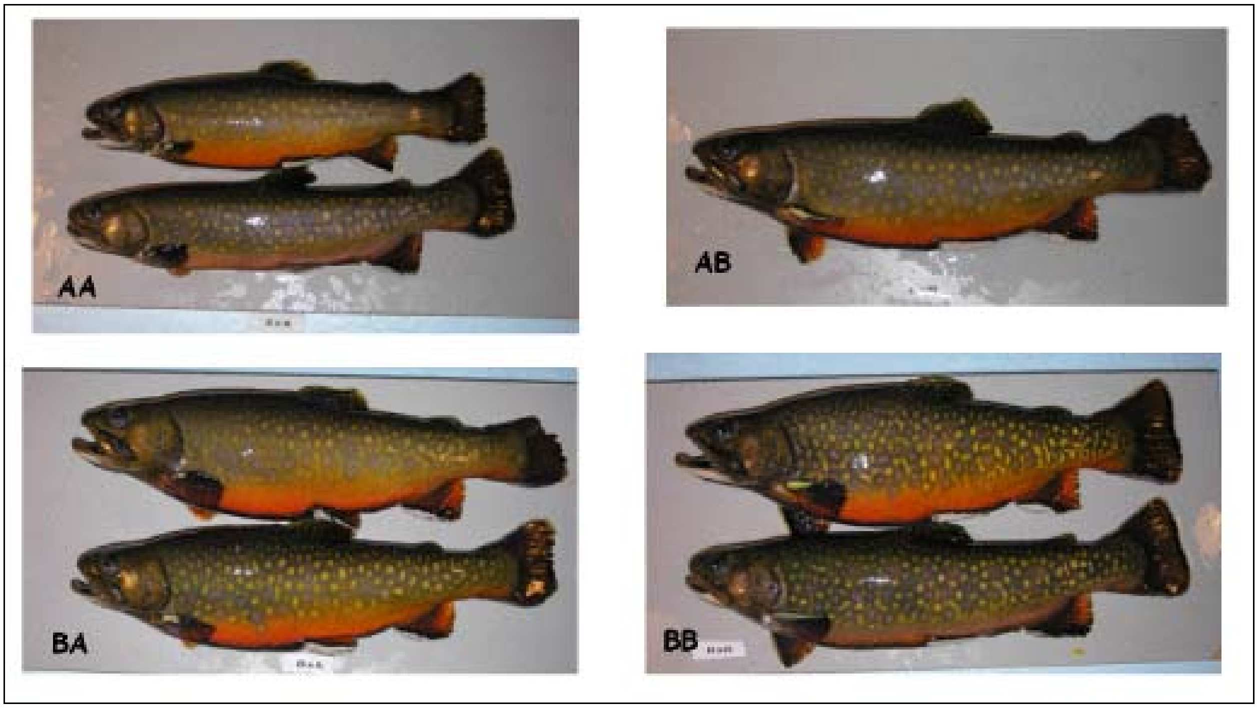

Figure 4. Images of Aurora Trout, Brook Trout, and first-generation (F1) crosses at five years of age (fish made from mating crosses in 2001 photographed in October 2006). Letters in each image indicate maternal x paternal ancestry: pure Aurora Trout (AA); Aurora Trout female x Brook Trout male (AB); Brook Trout female x Aurora Trout male (BA); pure Brook Trout (BB). Each photo shows male (upper) and female (lower), except for the AB cross (male only). Images were adjusted to show the relative sizes of the four crosses at a common scale. Phenotypic features to note are number, intensity, and location of red spots; size, colour, and intensity of surrounding halos; colour intensity of yellow vermiculations and general background colour; and extent of vermiculations. Note also that Aurora Trout exhibit some degree of yellow spotting / vermiculation under hatchery conditions; this was reported by Henn and Rinkenbach (1925) for preserved specimens as well, but is much less apparent in living wild fish (C. Wilson, OMNR, unpubl. data).

Canadian Range

Although Henn and Rinkenbach (1925) listed a number of other waterbodies other than Whirligig and Whitepine lakes with possible occurrences of Aurora Trout, no authenticated records of indigenous breeding populations exist for any other waterbodies including Aurora Lake and Wilderness Lake, both of which were listed as having indigenous populations by Parker and Brousseau (1988). The population in Wilderness Lake reported as native by Sale (1967) was in fact introduced in 1955 when a few adults were transferred across the portage from Whitepine Lake (C. Elsie and D. Butler, personal communication, 2009). The infrequent reports of Aurora Trout in Marina Lake likely represent individuals that emigrated downstream from Whitepine Lake, rather than members of a breeding population in Marina Lake (Sale 1964). The recent observation of an Aurora Trout like morph in two Québec lakes (Lac de la Bidiere and Lac de la Hase) also awaits further sampling. Sampling in the two Québec lakes in 2007 and 2009 captured only one fish of this type and it was subsequently released (Turcotte et al. 2010).

During the 1990s self-sustaining Aurora Trout populations were re-established in both Whirligig Lake and Whitepine Lake following water quality improvements brought about by whole-lake liming of Whirligig Lake. Hatchery-reared fish stocked in Southeast Campcot Lake and Northeast Campcot Lake near Terrace Bay also reproduced successfully, but those populations were subsequently extirpated. Currently, 10 other lakes in northern Ontario contain introduced Aurora Trout populations that are maintained by stocking of hatchery-reared juvenile fish (Figure 2): Liberty Lake, Carol Lake, Reed Lake, Pallet Lake, Nayowin Lake, Big Club Lake, Semple #54 Lake, Wynn Lake, Borealis Lake, and Alexander Lake. The Canadian Extent of Occurrence (EO, as defined by COSEWIC 2009) is the same as the global EO at ~ 500 km^2. The biological area of occupancy is less than 1km^2 (based on surface area of two lakes with naturally reproducing populations (total 93.6ha). The Index of the Area of Occurrence (IAO) using a 2 x 2 km grid (COSEWIC 2009) for the lakes that have naturally reproducing populations is 8 km^2. If the fish reported from Québec are confirmed as Aurora Trout, this would substantially increase the estimated extent of occurrence, but not increase the area of occupancy significantly.

Search Effort

No other Aurora Trout populations were discovered during the survey of over 10,000 lakes by the Ministry of Natural Resources in the 1970s and 1980s or during extensive survey studies in the Greater Sudbury area in recent decades (Matuszek et al. 1992, Mandrak and Crossman 1992a).

Sampling of wild Brook Trout populations in Québec has identified a possible allopatric population of Brook Trout with a similar phenotype, although whether these are Aurora Trout has yet to be determined (Caroline Turcotte, biologist, Ministère des Ressources naturelles et de la Faune du Québec, pers. comm. 2010). According to information from local anglers, there has been a special colour morph of brook trout occurring at a low frequency in these lakes for a long time. A concentrated netting effort in Lac de la Bidiere and Lac de la Hase in 2007 and 2009 captured only one fish with an Aurora Trout – like appearance in six days of netting (50-80 net lifts) on each lake (Turcotte et al. 2010). Working with anglers, Québec biologists have collected six fish resembling the Aurora Trout phenotype from the two lakes in since 2007 (Caroline Turcotte, Québec, pers. comm. 2010). It is worth noting that normal-appearance Brook Trout are abundant within both lakes, and that the fish resembling Aurora Trout in these lakes occur in sympatry with normal Brook Trout (Turcotte et al. 2010).

HABITAT

Habitat Requirements

The two native Aurora Trout lakes are part of a chain of lakes situated on a ridge in Lady Evelyn Smoothwater Provincial Park. Whirligig Lake (11 ha surface area; maximum depth 9.1 m; Secchi depth 3.3-6.2 m in 1999; 435 m elevation) flows into Whitepine Lake (77 ha surface area; maximum depth 21.3 m; Secchi depth 3.5-6.0 m in 1999; 430 m elevation) and are among the highest elevation lakes in Ontario. The surrounding terrain is hilly and rough, topography typical of the Precambrian Shield. The lakes are 10 km from the nearest road and accessible only by canoe and trail or by aircraft. Their watersheds have low acid-neutralizing capacities and are vulnerable to acidification.

The native lakes are located within the zone affected by acid deposition from Sudbury metal smelters (Neary et al. 1990). Extirpation of the Aurora Trout during the 1960s coincided with acidification of the lakes to below pH 5.0 (Keller 1978), the threshold for successful Brook Trout reproduction (Beggs and Gunn 1986). By 1976 the pH of Whitepine Lake was 4.7. During the 1980s water quality remained unsuitable for Aurora Trout survival in their native lakes (Snucins et al. 1988). Following liming in 1989 the pH of Whirligig Lake increased from 4.8 to about 6.5. The pH has subsequently declined and additional liming was necessary in 1993 and 1995 to increase the pH. However, between 1997 and 1999 the pH remained relatively steady at 5.3-5.6 (Figure 5). This is close to the natural pH of the lake, as estimated by paleolimnological analysis of sediment cores (Dixit et al. 1996), and is suitable for Aurora Trout reproduction. Whitepine Lake also exhibited some water quality improvement. Its pH increased from 4.9 in the late 1980s to 5.2 by 1993 and 5.3-5.4 by 1999. The pre-industrial pH of Whitepine Lake was 5.4-5.7 (Dixit et al. 1996). The improvement may be due to input of limed water from Whirligig Lake or atmospheric pollution reductions or both.

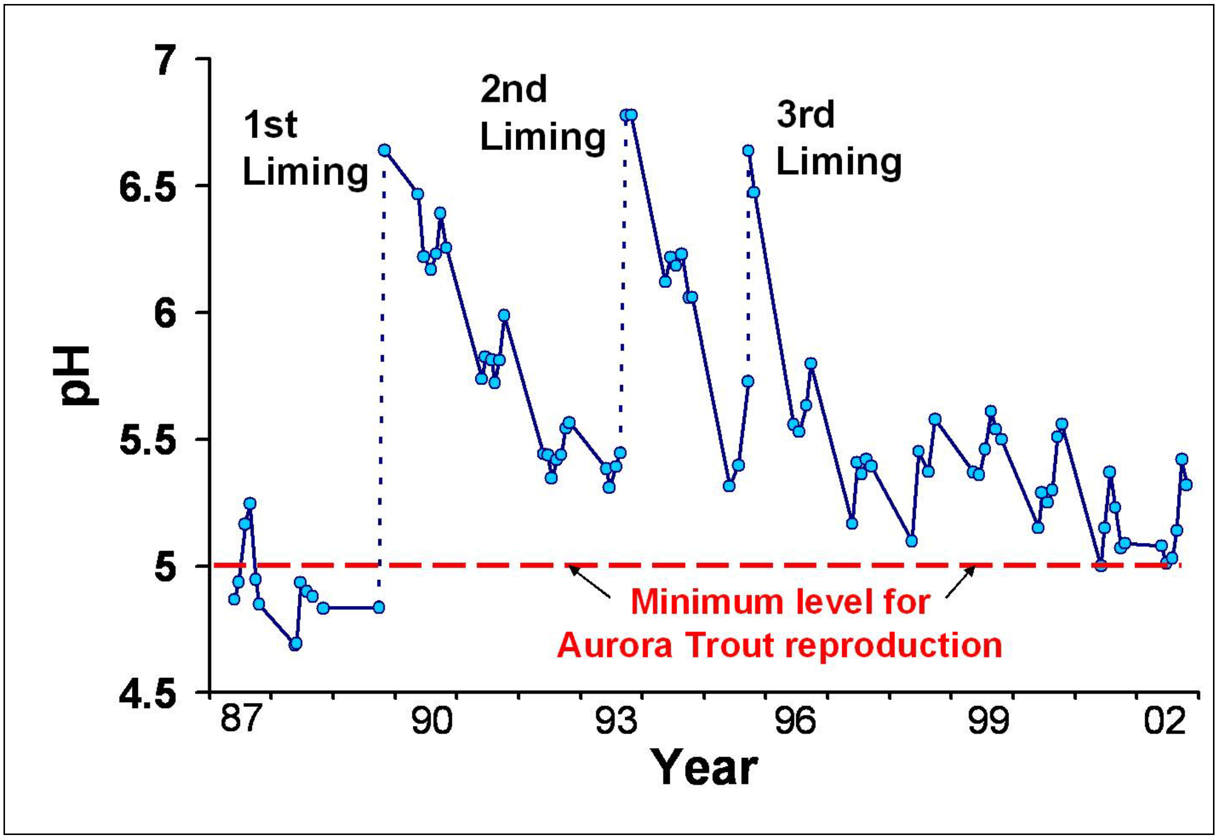

Figure 5. The pH of Whirligig Lake from 1987 to 2002, showing acidification and liming events (data from Keller et al. 2008).

The other two lakes that had reproducing populations during the 1990s, Southeast Campcot Lake (35.6 ha, 43 m maximum depth, 6.8 m Secchi depth) and Northeast Campcot Lake (20.8 ha, 28 m maximum depth, 8.3 m Secchi depth), are located in well-buffered watersheds and are not threatened by acidification.

Spawning by Aurora Trout in Whirligig Lake occurs on groundwater seepages over sand, gravel and rock substrate in water 1.2-4.1 m deep at distances of 2-45 m from shore. The spawning sites in the other lakes have not yet been identified. This use of groundwater upwelling areas for spawning habitat is considered typical for lake-dwelling populations of Brook Trout (Scott and Crossman 1973) and is observed elsewhere in Ontario (Noakes and Curry 1995; Blanchfield and Ridgway 1997).

Habitat Trends

The most pronounced trends in the habitat quality of the native lakes with Aurora Trout were the severe decrease in pH from industrial pollutants. Following major reductions in smelter emissions in the 1970s, the water quality of many lakes in the Sudbury area began to recover, with most improvements occurring in the early 1980s (Keller and Pitblado 1986; Keller et al. 1992, Figure 5). Unfortunately, only small improvements occurred in the lakes of native Aurora Trout, where water quality remained unsuitable for Aurora Trout reproduction (pH < 5.0; Al > 130 µ/L; Snucins et al. 1988). The limited chemical response of the Aurora Trout lakes to reductions in acid deposition and the lack of success in establishing reproducing populations in non-native lakes left fishery managers faced with the prospect of continued long-term artificial propagation of the stock. It was felt that if the acidification problem could be eliminated, the best chance for reestablishing a self-sustaining population in the wild was in the native lakes. During October 1989, whole-lake liming, a proven method of reducing acidity and increasing Brook Trout survival and reproduction(Gloss et al. 1989), was carried out in both Whirligig Lake (pre-treatment pH 4.8) and its headwater, Little Whitepine Lake (19 ha surface area; pre-treatment pH 5.6). The lakes were treated with 21 tonnes of powdered calcite ($CaCO_3$), which increased the pH of both lakes (Figure 5).

Whirligig Lake gradually re-acidified after the 1989 liming treatment, and by 1992 its pH had declined to 5.4. During September 1992, in an attempt to reverse the deterioration in water quality, a wetland that contributed acid drainage (pH 4.5) into Whirligig was treated with 32 tonnes of agricultural limestone. This wetland treatment did not immediately improve the water quality of the lake, so during September 1993 the lake itself was treated with 6 tonnes of powdered calcite. This second whole lake treatment succeeded in raising the lake pH to 6.8.

Since the most recent liming of Whirligig Lake in 1995, the pH of the Aurora Trout Lakes has remained slightly above 5.0, the threshold necessary for successful Brook Trout reproduction (Figure 5). Overall the invertebrate communities are abundant in all study lakes, although species composition reflects the generally low pH of the lakes. Both phytoplankton and zooplankton communities have experienced a shift from dominance by acid tolerant taxa to include more acid-sensitive species in recent years (Keller et al. 2008).

BIOLOGY

Life cycle and Reproduction

Aurora Trout spawn in late October and early November when lake water temperatures are below 8˚C. Sexual maturity is reached at age 2+ to 4+ years. The maximum known lifespan is 9 years. Spawning is thought to occur annually after sexual maturity is reached (Aurora Trout Recovery Team 2006). Although the number of eggs produced by mature female Brook Trout is dependent on size, Aurora Trout females appear to have reduced fecundity compared to wild-type Brook Trout. Ripe females in the native lakes ranged in size from 335 mm to 458 mm fork length. Brook Trout of that size typically produce 1,000 (325 mm fork length) to 3,000 (470 mm fork length) eggs (Vladykov 1956). Wild egg collections from Alexander Lake typically range from 1,400 to 1,600 eggs per female (OMNR 2005), and captive broodstock females typically yield 400 to 1,000 eggs per female (ages 4 to 7) (R. Ward, OMNR Hills Lake Fish Culture Station, pers. comm. 2009). In addition, comparative life history trials in a shared hatchery environment showed Aurora Trout females to mature one year later than wild-type Nipigon strain Brook Trout (Fortier 2010).

Physiology and Adaptability

A pH of at least 5.0 is required for successful reproduction and maintenance of self-sustaining populations (Beggs and Gunn 1986). Aurora Trout stocked into Whirligig Lake during the late 1980s when it was still quite acidic (pH 4.8) survived in small numbers, but they were physiologically stressed, could not reproduce, and had a shortened lifespan.

The spawning sites that have been identified to date are all on groundwater springs which is typical of Brook Trout on the Canadian Shield (Noakes and Curry 1995; Blanchfield and Ridgway 1997). The failure of stocked Aurora Trout to reproduce in most non-native lakes is probably due to the unavailability of suitable groundwater sites for spawning in those lakes.

Aurora Trout appear to have similar thermal physiology to other populations of Brook Trout (Sale 1962). Using thermal performance as a means of assessing the taxonomic affinity of Aurora Trout, Sale (1962) repeated earlier temperature trials that had been carried out on separate geographic populations of Brook Trout (McCauley 1958), and found Aurora Trout to have the same thermal tolerance and limits as Brook Trout, contrasting sharply with Arctic Char that were used for comparison.

In captivity, Aurora Trout exhibit lower activity levels and higher susceptibility to stress and disease than other captive Brook Trout populations (C. Wilson, pers. obs.). This has been corroborated by observation of production fish for stocking (R. Ward, OMNR, pers. comm. 2009), although the causal mechanism is unknown.

Dispersal and Migration

Aurora Trout are limited to their native and introduced lakes. Migration between populations is not possible, except for downstream movement from Whirligig Lake to Whitepine Lake. It is possible that reports of Aurora Trout in Marina Lake resulted from downstream emigration from Whitepine Lake (Sale 1964). Brook Trout generally inhabit water temperatures below 20˚C and when temperatures rise above that they seek cooler water by shifting their depth distribution or by inhabiting groundwater springs (Scott and Crossman 1973; Power 1980). At spawning time Aurora Trout will seek areas of groundwater upwelling on which to excavate redds.

Interspecific Interactions

Very little information is available on interactions between Aurora Trout and other species. There are no other fish species known to be present in the native Aurora Trout lakes. Similarly to other forms of Brook Trout, Ontario stocking guidelines (OMNR 2002) recommend against stocking Aurora Trout into lakes with introduced salmonids, particularly Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*). None of the ten stocked lakes where Aurora Trout have been introduced contain any sport fish species or known competitors or predators (Aurora Trout Recovery Team 2006).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

The re-established populations of Aurora Trout in their native habitats were assessed from 1992 to 1995 and in 2003 and 2004 (Keller et al. 2008). Population size and biomass were estimated using the Schnabel mark-recapture method (Ricker 1975). To obtain estimates, fish were captured daily during the last two weeks of October using trap nets, fyke nets, and short-duration gillnets. In 2003 and 2004 angling was also used. Fish were anaesthetized and measured for fork length, total length, and weight. Fin rays were used to age fish. To identify subsequent recaptures, each fish was marked with a hole punch in the caudal fin. In 2003 and 2004, the fin tissue samples provided by the hole punch from the first 100 fish in each lake were preserved in 95% ethanol for genetic analysis at the MNR genetics laboratory at Trent University in Peterborough, Ontario.

Abundance

Successful spawning occurred each year in Whirligig Lake following reintroduction of the fish. The 1993 mark-recapture population estimate (N = 456; 95% confidence interval 337-639, Table 1) indicated that three year classes (1990-1992) of naturally produced fish inhabited the lake and that 66% (N = 300; 95% confidence interval 229-403) of the fish in the population (older than age one) were natural recruits. In Whitepine Lake, abundance was estimated as N = 2,086 (95% CI = 1565-2845, Table 1). These estimates suggest that both in Whirligig and Whitepine lakes populations had expanded to levels typical of healthy Brook Trout populations (Keller et al. 2008).

Fluctuations and Trends

Relative to the population data collected in the mid-1990s, the Whirligig Lake population has similar size distribution, abundance and biomass (Keller et al. 2008). The Whitepine Lake population appears to have followed the same pattern but less frequent sampling is available for this lake. On the whole, these data suggest that the transient pH depressions in 2001 and 2002 did not measurably damage the Aurora Trout populations in the native lakes.

Rescue Effect

Although there may be some downstream movement from Whirligig Lake to Whitepine Lake there is limited opportunity of natural rescue of one population by another. The difference in elevation prevents unassisted movement upstream from Whitepine Lake to Whirligig Lake. As the Aurora Trout in the ten introduced, non-native habitats are not connected to the native populations and do not show evidence of natural recruitment, unassisted colonization from these hatchery-maintained populations is highly unlikely.

THREATS AND LIMITING FACTORS

Whirligig and Whitepine lakes are still threatened by acidification. The main source of acid is atmospheric deposition of pollutants, but historically deposited sulphur may also be stored in adjacent wetlands and could contribute to re-acidification following drought years (Schindler 1998).

When Aurora Trout, normal (‘wild-type’) Brook Trout and their reciprocal hybrids provided are raised under common laboratory conditions, there is strong evidence that Aurora Trout have substantially reduced performance in traits related to fitness, including multiple reproductive and life history traits (Wang et al. 2002; Ryan et al. 2003; Frankham et al. 2005; Fortier 2010). Differences in survivorship were most pronounced for early life stages, with observed levels of egg mortality (34%) comparable to those originally reported (32%) by Patrick and Graf (1961). Aurora Trout also exhibited significantly higher mortality for the first four months post-hatch in comparison with pure wild-type Brook Trout and their reciprocal hybrids (Fortier 2010). Overall, Aurora Trout showed markedly lower fitness for multiple life history traits: in addition to significantly higher egg and juvenile mortality, pure Aurora Trout families exhibited smaller size-at-age, delayed maturity, reduced fecundity, reduced gamete quality, and lower reproductive success (Fortier 2010).

Although the evidence of markedly lower fitness (Fortier 2010) has not been conclusively shown to result from inbreeding depression, given the evidence of a historical decline in both native populations of Aurora Trout and their subsequent history of captive breeding based on nine founding individuals, it seems likely that Aurora Trout experience at least some degree of inbreeding (Wang et al. 2002; C. Wilson, unpubl. data 2010). Estimation of effective population size (N_e) and inbreeding (F) for the post-founding population (initial founders and all subsequent generations) based on breeding records (OMNR 2005) gives an average demographic N_e estimate of 44 and minimum population-level inbreeding estimate of F = 0.168 (C. Wilson, unpubl. data 2010).

It is unlikely that the historical or current hatchery programs for Aurora Trout pose a threat to their recovery. The first two generations of captive breeding used sufficient numbers of mated pairs (72 and 46 pairs, respectively) to avoid bottlenecks and minimize genetic drift within the hatchery, and the introduction of Aurora Trout to Alexander Lake in 1970 and subsequent wild egg collections have maximized the retention of genetic diversity while minimizing adaptation to hatchery conditions (OMNR 2005). The OMNR hatchery program has been a key element of the survival and rehabilitation of Aurora Trout, and remains an integral part of their recovery strategy (Aurora Trout Recovery Team 2006). With the re-established native populations exhibiting sufficient natural recruitment to be self-sustaining (Keller et al. 2008), hatchery practices pose no threat to their sustainability or future viability.

The use of groundwater springs for spawning and thermal refugia also leave Aurora Trout vulnerable to land use practices and climatic changes that affect the quantity and quality of groundwater seepage. In addition, Brook Trout are vulnerable to competition from other species such as Yellow Perch (*Perca flavescens*, Fraser 1978) if they ever were introduced (e.g., from bait buckets). Fortunately, angling is prohibited in the lakes with reproducing populations and there is a ban on use of live baitfish in all other lakes with Aurora Trout. Despite this ban on fishing, one instance of illegal harvesting did occur in 1994 on Northeast Campcot Lake (OMNR unpublished data).

PROTECTION, STATUS, AND RANKS

Legal Protection and Status

In 1987 the Aurora Trout was assigned an "Endangered" designation by COSEWIC, and is afforded protection as Endangered under the federal *Species at Risk Act* and Ontario's *Endangered Species Act*. All lakes that supported reproducing Aurora Trout populations during the 1990s are designated as fish sanctuaries. Angling is not permitted at any time on those four lakes (Whirligig, Whitepine, Southeast Campcot Lake and Northeast Campcot Lake), nor on Alexander Lake which is used as a source of eggs for the hatchery brood stock. Limited angling is allowed in the nine other non-native lakes containing stocked hatchery-reared fish, under Provincial regulation 242/08 for the *Endangered Species Act* (http://www.e laws.gov.on.ca/html/statutes/English /elaws_statutes_07e06_e.htm). Those lakes are opened to angling once every three years from August 1 to October 15. The catch and possession limits are one Aurora Trout per licenced angler or zero for anglers with a conservation licence (50% of normal daily limit). To prevent the accidental introduction of other species, the use of live baitfish is prohibited in these angling lakes. In May 2011 COSEWIC re-examined the status and designated this species ineligible.

Non-Legal Status and Ranks

Since 1983 the Aurora Trout Management Committee, composed of OMNR biologists, technicians and hatchery staff, has overseen the management of Aurora Trout. The current management objectives are: (1) to maintain the Aurora Trout gene pool and restore self-sustaining populations to their native habitat; and (2) to introduce Aurora Trout into a limited number of non-native lakes to maintain a brood stock, establish one reproducing satellite population and provide limited angling opportunities. The Conservation Data Centre rating is G5T, ON-S1 and Ontario recognizes the form as Endangered, but it is not regulated under the Ontario *Endangered Species Act*. NatureServe ranks the Aurora Trout as G5T1Q? and the Aurora Trout is classified as Endangered by the American Fisheries Society (Jelks et al. 2008).

Habitat Protection and Ownership

The habitat of the Aurora Trout is protected under the federal *Fisheries Act*, which provides protection to fish habitat in general and has specific provisions to regulate flow needs for fish, maintain fish passage, prevent the killing of fish by means other than angling, prevent the pollution of fish bearing waters, and prevent harm to fish habitat. The watersheds of Whiligig and Whitepine lakes are also protected from industrial activities (e.g., logging, mining) by virtue of their location in a wilderness park.

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

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List of Authorities Contacted for information regarding the Aurora Trout (Email Dec. 17, 2010):

1. Raymond Tyhuis, Member of Aurora Trout Recovery Team 2006
2. Karen Stokes, Member of Aurora Trout Recovery Team 2006
3. Chuck McCrudden, Member of Aurora Trout Recovery Team 2006
4. Larry Ferguson, Member of Aurora Trout Recovery Team 2006
5. Ron Ward, Member of Aurora Trout Recovery Team 2006
6. Thom Heiman, Member of Aurora Trout Recovery Team 2006
7. Alan Dextrase, Member of Aurora Trout Recovery Team 2006
8. Jeff Brinsmead, Member of Aurora Trout Recovery Team 2006
9. Kevin Pinkerton, Member of Aurora Trout Recovery Team 2006
10. Greg Deyne, Previous Member
11. Rodger Leith, Previous Member
12. Mike Mazzetti, Previous Member
13. Bill McCord, Previous Member
14. Ed Snucins, Previous Member
15. Angela McConnell, Required by COSEWIC
16. Ken Tuininga, Required by COSEWIC
17. Lynn Gillespie, Required by COSEWIC
18. Jennifer Doubt, Required by COSEWIC
19. Simon Nadeau, Required by COSEWIC
20. Christie Whelan, Required by COSEWIC
21. Gilles Seutin, Required by COSEWIC
22. Patrick Nantel, Required by COSEWIC
23. Michael Oldham, Required by COSEWIC

List of Authorities contacted for information regarding Traditional Knowledge (Emailed Dec. 17, 2009 and again Feb. 25, 2010):

1. Chuck McCrudden, Member of Aurora Trout Recovery Team 2006
2. John Salo, MNR Manager, Suggested by Ed. Morris, Parks Canada
3. Norm Dokis, MNR NorthBay, Suggested by Ed. Morris, Parks Canada
4. Neil Jones, Required by COSEWIC
5. Sonia Schnobb, Required by COSEWIC

Received two contact suggestions from Norm Dokis March 11, 2010. Emailed request for info March 11, 2010 to:

1. Doug Friday, Resource Technician, Daki Menan Lands and Resources Corp., Temagami First Nation
2. Rodney Wincikaby, Matachewan First Nation

Received response from Doug Friday March 15, 2010. He is going to inquire and report back.

Also contacted:

1. T. Heiman, DFO, pers. comm
2. Caroline Turcotte, Biologist, Ministère des Ressources naturelles et de la Faune (Quebec), pers. comm.

INFORMATION SOURCES

Aurora Trout Recovery Team. 2006. Recovery Strategy for the Aurora trout (*Salvelinus fontinalis timagamiensis*) in Canada. Ottawa, 2006. 46p. Available online at http://dsp-psd.pwgsc.gc.ca/Collection/En3-4-3-2006E.pdf (accessed March 15, 2010).

Beggs, G.L.,and J.M. Gunn. 1986. Response of Lake Trout (*Salvelinus namaycush*) and Brook Trout (*S. fontinalis*) to surface water acidification in Ontario. Water, Air, and Soil Pollution 30: 711-718.

Behnke, R.J. 1980. A systematic review of the genus Salvelinus. Pages 441-479 in E.K. Balon, editor. Charrs: Salmonid fishes of the genus *Salvelinus*. Dr. W. Junk, The Hague, The Netherlands.

Blanchfield, P.J. and M.S. Ridgway. 1997. Reproductive timing and use of redd sites by lake spawning brook trout (*Salvelinus fontinalis*). Canadian Journal of Fisheries and Aquatic Sciences 54: 747-756.

COSEWIC. 2009. Operations and Procedures Manual. Environment Canada, Ottawa.

Danzmann, R. G., R. P. Morgan, II, M. W. Jones, L. Bernatchez, and P. E. Ihssen. 1998. A major sextet of mitochondrial DNA phylogenetic assemblages extant in eastern North American Brook Trout (*Salvelinus fontinalis*): distribution and postglacial dispersal patterns. Canadian Journal of Zoology 76: 1300–1318.

Dixit, A.S., S.S. Dixit, and J.P. Smol.1996. Long-term trends in limnological characteristics in the Aurora Trout lakes, Sudbury, Canada. Hydrobiologia 335: 171-181.

Fortier, J. 2010. Inbreeding depression and genetic rescue in the endangered Aurora trout (*Salvelinus fontinalis timagamiensis*): assessment and conservation. M.Sc. thesis, Trent University. 95 pp..

Frankham, R., J.D. Ballou, and D.A. Briscoe. Introduction to Conservation Genetics. Cambridge University Press, Cambridge, UK.

Fraser, J.M. 1978. The effect of competition with yellow perch on the survival and growth of planted Brook Trout, splake and rainbow trout in a small Ontario lake. Transactions of the American Fisheries Society 107: 505-517.

Gloss,S.P., C.L. Schofield, R.L. Spateholts, and B.A. Plonski. 1989. Survival, growth, reproduction, and diet of Brook Trout (*Salvelinus fontinalis*) stocked into lakes after liming to mitigate acidity. Can. J. Fish. Aquat. Sci. 46:277-286.

Green, D. M. 2005. Designatable units for status assessment of endangered species.*Conservation Biology, 19*(6), 1813-1820.

Grewe, P.M., N. Billington, and P.D.N. Hebert. 1990. Phylogenetic relationships among members of *Salvelinus* inferred from mitochondrial DNA divergence. Canadian Journal of Fisheries and Aquatic Sciences 47: 984-991.

Henn, A.W., and W.H. Rinkenbach. 1925. Description of the Aurora Trout (*Salvelinus timagamiensis*), a new species from Ontario. Annals of the Carnegie Museum 16: 131-141.

Jelks, H.L., SJ. Walsh, NM. Burkhead, S. Contreras-Balderas, E. Díaz-Pardo, DA. Hendrickson, J. Lyons, N.E. Mandrak, F. McCormick, J.S. Nelson, S.P. Platania, B.A. Porter, C.B. Renaud, J.J. Schmitter-Soto, E.B. Taylor, and M.L. Warren. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33: 372-407.

Karas, N. 2002. Brook Trout (revised edition). Lyons Press, Guilford, Connecticut.

Keller, W. 1978. Limnological observations on the Aurora Trout lakes. Technical report. Ontario Ministry of the Environment, Sudbury, Ontario, Canada.

Keller, W. and J. R. Pitblado. 1986. Water quality changes in Sudbury area lakes: a comparison of synoptic surveys in 1974-1976 and 1981-1983. Water, Air and Soil Pollut. 29:285-296.

Keller, W., J.R. Pitblado, and J. Carbone. 1992. Chemical responses of acidic lakes in the Sudbury, Ontario, area to reduced smelter emissions, 1981-1989. Can. J. Fish. Aquat. Sci. 49:25-32.

Keller, W., J. Heneberry, S. MacPhee, E. Snucins, and J. Gunn. 2008. Aurora trout lakes ecosystem data report:1976-2006. Ontario Ministry of the Environment, Cooperative Freshwater Ecology Unit Report, 127pp.

Kyle, C.J. and C.C. Wilson. 2007. Mitochondrial DNA identification of game and harvested fish species. Forensic Science International 166: 68-76**.**

Mandrak, N.E. and E.J. Crossman. 1992a. A checklist of Ontario freshwater fishes. Royal Ontario Museum, Toronto. 176pp.

Mandrak, N.E. and E.J. Crossman. 1992b. Postglacial dispersal of freshwater fishes into Ontario. Canadian Journal of Zoology 70: 2247 - 2259.

Martin, W. 1939. The Arctic char of North America. M.A. thesis. University of Toronto, Toronto, Canada.

Matuszek, J.E., D.L. Wales, and J.M. Gunn. 1992. Estimated impacts of SO_2 emissions from Sudbury smelters on Ontario's sportfish populations. Can J. Fish. Aquat. Sci. 49:87-94.

McCauley, R.W. 1958. Thermal relations o fgeographic races of Salvelinus. Canadian Journal of Zoology 36: 655-662.

McGlade, J.M. 1981. Genotypic and phenotypic variation in the Brook Trout, *Salvelinus fontinalis* (Mitchell) Ph. D. thesis. University of Guelph, Guelph, Canada.

Neary, B.P., P.J. Dillon, J.R. Munro, and B.J. Clark. 1990. The acidification of Ontario lakes: an assessment of their sensitivity and current status with respect to biological damage. Technical report. Ontario Ministry of the Environment, Toronto.

Noakes, D.L.G., and R.A. Curry. 1995. Lessons to be learned from attempts to restore *Salvelinus* species other than *S. namaycush*: a review of reproductive behaviour. Journal of Great Lakes Research 21 (Supplement 1): 54-64.

Ontario Ministry of Natural Resources (OMNR). 2002. Guidelines for Stocking Fish in Inland Waters of Ontario. Fisheries Section, Fish and Wildlife Branch, Ontario Ministry of Natural Resources. Available online at http://www.mnr.gov.on.ca/226921.pdf (accessed March 15, 2010).

Ontario Ministry of Natural Resources (OMNR). 2005. Fish Stocks Catalogue (2005 update). Fish Culture Section, Ontario Ministry of Natural Resources.

Parker, B.J., and C. Brousseau. 1988. Status of the Aurora Trout, *Salvelinus fontinalis timagamiensis*, a distinct stock endemic to Canada. Canadian Field-Naturalist 102: 87-91.

Patrick, N.D., and P. Graf. 1961. The effect of temperature on the artificial culture of Aurora Trout. The Canadian Fish Culturist 30: 49-55.

Power, G. 1980. The Brook charr, *Salvelinus fontinalis*. Pages 141-203 in E.K. Balon, editor. Charrs: Salmonid fishes of the genus *Salvelinus*. Dr. W. Junk, The Hague, The Netherlands.

Qadri, S.U. 1968. Morphology and taxonomy of the Aurora char, *Salvelinus fontinalis timagamiensis*. National Museums of Canada Contributions to Zoology 5: 1-18.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Fisheries Research Board, Canada.

Ryan, K. K., R. C. Lacy, and S. W. Margulis. 2003. Impacts of inbreeding on components of reproductive success, p. 82–96. In: Reproductive Science and Integrated Conservation. J. C. Rodger and D. E. Wildt (eds.). Cambridge University Press, Cambridge, U.K.

Sale, P.F. 1962. A note on the lethal temperature of the Aurora trout, *Salvelinus timagamiensis*. Canadian Journal of Zoology 40: 367-369.

Sale, P.F. 1964. Ecology and taxonomy of the Aurora Trout. M.A. thesis. University of Toronto, Toronto, Canada.

Sale, P.F. 1967. A re-examination of the taxonomic position of the Aurora Trout. Canadian Journal of Zoology 45: 215-225.

Schindler, D.W. 1998. A dim future for boreal waters and landscapes. Bioscience 48: 157-164.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184: 1-966.

Snucins, E.J., V.A. Liimatainen, and P.A. Gale. 1988. Effect of acidic lake water on survival of Aurora Trout (*Salvelinus fontinalis*) embryos and alevins. Ontario Fisheries Acidification Report Series no. 88-15. Ontario Ministry of Natural Resources, Toronto.

Snucins, E.J., J.M. Gunn, and W. Keller. 1995. Restoration of the Aurora Trout to its acid-damaged native habitat. Conservation Biology 9: 1307-1311.

Snucins, E.J., and J.M. Gunn. 2000. Status of the Aurora Trout, *Salvelinus fontinalis*, in Canada. COSEWIC Report.

Turcotte, C., Y. Bourque, C. Genest, A. Raymond and C. St.Georges. 2010. Belan des travaux 2007à 2010 sur l'omble de fontaine aurora (*Salvelinus fontinalis timagamiensis*) des Laurentides. En Project, préliminaire, Ministère des Ressources Naturelles et de la Faune, Juin 2010.

Vladykov, V.D. 1954. Taxonomic characters of the eastern North American chars (*Salvelinus* and *Cristivomer*). Journal of the Fisheries Research Board of Canada 11: 904-932.

Vladykov, V.D. 1956. Fecundity of wild speckled Trout (*Salvelinus fontinalis*) in Quebec lakes. Journal of the Fisheries Research Board of Canada 13: 799-841.

Wang, S., J.J. Hard, and F. Utter. 2002. Salmonid inbreeding: a review. Reviews in Fish Biology and Fisheries 11: 301–319.

Wilson, C.C. Historical population decline or extreme bottleneck: resolving causative factors for extremely low genetic diversity in Aurora trout (*Salvelinus fontinalis timagamiensis*). (in prep).

Wilson, C.C. and N.E. Mandrak. Genetic assessment and re-evaluation of the taxonomic status of the Aurora trout, *Salvelinus fontinalis timagamiensis*. (in prep).

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John Gunn is a Canada Research Chair in Stressed Aquatic Ecosystems at Laurentian University and founder of the Cooperative Freshwater Ecology Unit. The Co-op Unit mandate is to conduct research in the area of restoration ecology of industrially damaged ecosystems. The unit also has an environmental science training role and extensive public education programs. John's academic training is as a fisheries biologist and aquatic ecologist with degrees from Mt. Allison (B.Sc. 1973), Ottawa (M.Sc. 1976) and Guelph (Ph.D. 1987). He and colleagues at Laurentian's Cooperative Freshwater Ecology Unit have led the Aurora Trout recovery program for more than 20 years (Snucins et al. 1995, 2003; Snucins and Gunn 2000; Keller et al. 2008).

Chris Wilson is an OMNR research scientist at Trent University, and has led the OMNR Aquatic Biodiversity and Conservation research unit since 1998. He is a member of the COSEWIC Freshwater Fishes Specialist Subcommittee, as well as the Aurora Trout Recovery Team. His research on Aurora Trout has assessed the genetic evidence for their subspecific status, levels of genetic diversity within historical and contemporary populations, as well as their comparative life history and fitness.