Restoration of the Aurora Trout to Its Acid-Damaged Native Habitat

E. J. SNUCINS,* J. M. GUNN,* AND W. KELLER†

*Ontario Ministry of Natural Resources, Aquatic Ecosystems Research Section, Cooperative Freshwater Ecology Unit, Department of Biology, Laurentian University, Sudbury, Ontario, Canada P3E 2C6
†Ontario Ministry of the Environment and Energy, Cooperative Freshwater Ecology Unit, 199 Larch Street, Sudbury, Ontario, Canada P3E 5P9

Introduction

Acidification has led to the extirpation of many fish populations from lakes in Europe and North America (Sevaldrud et al. 1980; Kelso et al. 1990; Berquist 1991). Numerous lakes around Sudbury, Ontario, Canada, have been acidified by the atmospheric deposition of vast quantities of sulphur dioxide produced by the metal smelting industry in Sudbury (Keller et al. 1980; Neary et al. 1990). Widespread fish losses around Sudbury first became noticeable during the 1950s and 1960s (Beamish & Harvey 1972; Beamish et al. 1975; Kelso & Gunn 1984).

The estimated losses in the Sudbury area include 94 populations of lake trout (*Salvelinus namaycush*), 18 populations of smallmouth bass (*Micropterus dolomieui*), 14 populations of brook trout (*Salvelinus fontinalis*), and 7 populations of walleye (*Stizostedion vitreum*) (Matuszek et al. 1992), as well as numerous populations of less well-studied species. Included in these losses was the aurora trout, a unique genetic stock of brook trout that was named for the similarity of its coloration to the shimmering lights of the aurora borealis. We describe how the aurora trout was saved from extinction and subsequently restored to its native habitat.

Distribution and Taxonomy

The native range of the aurora trout consisted of two small lakes, Whirligig Lake (47°22′40″N, 80°38′15″W) and Whitepine Lake (47°23′00″N, 80°38′00″W), located 110 km north of Sudbury, Ontario, on a ridge in an isolated part of Lady Evelyn Smoothwater Provincial Park (Fig. 1). Whirligig Lake (11 ha surface area; 435 m elevation) flows into Whitepine Lake (77 ha surface area; 430 m elevation). The outlet stream from Whitepine Lake drops 36 m before emptying into Marina Lake. Detailed physicochemical and morphometric data for the lakes are given by Sale (1967) and Keller (1978). The other native fish species were white sucker (*Catastomus commersoni*) in both Whirligig and Whitepine lakes and brook trout in Whitepine Lake. The aurora trout population in nearby Wilderness Lake reported by Sale (1967) as native 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). Currently, nine lakes in northern Ontario other than the native lakes contain introduced aurora trout populations that are maintained by stocking juvenile fish.

The aurora trout was originally classified by Henn and Rickenbach (1925) as a distinct species (*Salvelinus timagamiensis*), but a closer affiliation with the brook trout has subsequently been favored. Martin (1939) classified it as a subspecies, and Vladykov (1954) referred to it as a brook-trout color variant. Ecological and skeletal differences have been cited as evidence for subspecies status (Sale 1967; Qadri 1968; Behnke 1980), but that has not been corroborated by recent genetic analyses (McGlade 1981; Grewe et al. 1990), and the aurora trout is now considered a unique genetic stock rather than a subspecies of the brook trout.

The most striking difference between the aurora trout and other brook trout is its coloration (Sale 1967). Brook trout have a dorsal background color of olive green to dark brown, mottled by yellow spots and worm-shaped markings, which fades to a white abdomen. Numerous red spots surrounded by blue halos speckle the sides. In contrast, adult aurora trout lack the yellow markings, and the olive dorsal coloration fades along the sides to a uniform iridescent steel blue and silver. Some aurora

Paper submitted May 31, 1994; revised manuscript accepted November 18, 1994.

Figure 1. Map of Ontario, Canada, showing location of lakes of native aurora trout.

trout have a small number of red spots, usually one or two per side, which may or may not be surrounded by blue halos (Henn & Rickenbach 1925; Patrick & Graf 1961; Sale 1967).

The aurora trout likely evolved from a population of brook trout that was isolated in Whitepine Lake and Whirligig Lake some time after the continental glaciers receded about 10,000 years ago. Sale (1967) suggested that a second invasion of Whitepine Lake by brook trout accounted for the coexistence of brook trout and aurora trout in that lake. Alternatively, the aurora trout may have evolved in Whirligig Lake and subsequently emigrated to Whitepine Lake. Little interbreeding occurred between the coexisting aurora trout and brook trout stocks in Whitepine Lake, possibly due to differences in spawning habitat (Sale 1967).

Management and Restoration

Located in watersheds with low acid-neutralizing capacities and in the path of prevailing winds from the Sudbury metal smelters, the native aurora trout lakes were vulnerable to acidification from deposition of atmospheric pollutants. Extirpation of the aurora trout during the 1960s coincided with acidification of the lakes to about pH 5.0 (Keller 1978), the threshold for brook trout survival (Beggs & Gunn 1986). The other native fish species were also extirpated. By 1976 the pH of Whitepine Lake was 4.7.

Fortunately, before the aurora trout were lost a captive breeding program was started. The lineage of all of the aurora trout in existence today can be traced back to a 1958 spawn collection. That year 3644 eggs were collected from one Whitepine Lake female and two Whirligig Lake females (Patrick & Graf 1961). The eggs from each female were mixed with the sperm from two males. Thus, the founding population size was nine individuals and may have been as few as six if all males did not contribute to fertilization.

The aurora trout is currently the most genetically uniform brook trout stock of the 99 that have been studied in Ontario (P. Ihssen, Ontario Ministry of Natural Resources, Maple, Ontario, personal communication). It is not known if the low genetic diversity is natural, a consequence of the small founding population, or the result of hatchery practices.

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 & Pitblado 1986; Keller et al. 1992). Unfortunately, only small improvements occurred in the lakes of native aurora trout, where water quality remained unsuitable for aurora trout survival (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 nonnative 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 (Gloss et al. 1989), was carried out in both Whirligig Lake (pretreatment pH 4.8) and its headwater, Little Whitepine Lake (19 ha surface area; pretreatment pH 5.6). The lakes were treated with 21 tonnes of powdered calcite ($CaCO_3$), which increased the pH of both lakes to about 6.5. The following year, in May 1990, 950 hatchery-reared aurora trout of various ages (700 age two, 150 age three, 100 age five) were introduced into Whirligig Lake. An additional 285 hatchery-reared fish (age four) were stocked in May 1991. Each age class was uniquely marked through fin clipping.

The population size and biomass of the aurora trout were estimated each year during the last two weeks of October using the Schnabel mark-recapture method (Ricker 1975). To obtain the estimates, fish were live-captured using trapnets, fyke nets, and short-duration gillnet sets. Observations of spawning activity were made concomitant with the mark-recapture estimates.

Although all of the 100 age-five fish that were stocked in May 1990 were sexually mature, no spawning was observed in the fall of 1990. Researchers suspected that this was due to an absence of high-quality groundwater upwelling sites, the typical spawning habitat of brook trout, so two artificial upwelling boxes (Webster 1962) were installed in the lake prior to the 1991 spawning season. Also, 11 adults were captured in late October and injected with salmon pituitary extract to induce maturation. Despite these efforts, no spawning was observed in 1991.

Although we were unable to observe spawning in Whirligig Lake, evidence of successful reproduction by aurora trout introduced into Southeast Campcot Lake was found in 1991, indicating that the aurora trout was still capable of reproducing on its own. We suggest that the failure of numerous attempts since the late 1950s to establish reproducing populations in other nonnative lakes has been due to unavailability of suitable spawning sites in those waters. In the summer of 1992, evidence of natural reproduction in Whirligig Lake was finally obtained when a diver snorkeling along the shoreline observed two young-of-the-year aurora trout.

Successful spawning had in fact occurred each year in Whirligig Lake following reintroduction of the fish. The 1993 mark-recapture population estimate ($n = 456$; 95% confidence interval 337-639) 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.

Most spawning occurred in water 3-4 m deep, hidden from surface observation by the brown-colored water until detected by a diver in 1993. Spawning took place in late October and early November at water temperatures below 8°C. The redds were constructed on sand, gravel, and rock substrate with groundwater seepage, in water 1.2-4.1 meters deep at distances of 2-45 from shore.

The growth rate of the stocked hatchery fish was good, and the maximum size of fish we measured (1500 g;

45 cm fork length) was similar to the maximum size attained by aurora trout in the lake prior to acidification (Ontario Ministry of Natural Resources, unpublished data). The biomass of the introduced hatchery fish increased rapidly after stocking and reached 17.2 kg/ha (95% confidence interval 9.7–26.0) by the fall of 1991. In 1993, when natural recruits older than age one were included in the population estimate, the population biomass was 15.8 kg/ha (95% confidence interval 11.2–23.1). These standing crops are comparable to those of healthy brook-trout populations in other lakes (Fraser 1981; Gowing 1986; Schofield et al. 1991).

Whirligig Lake gradually reacidified after the 1989 liming treatment, and by 1992 its pH had declined to 5.4. During September 1992, in an attempt to reverse this deterioration in water quality, a wetland-contributing acidic drainage (pH 4.5) into Whirligig Lake 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.

Conclusions

The long-term viability of the aurora-trout population in Whirligig Lake remains uncertain. The small founding population, several generations of domestication, and possible inadvertent selection of maladaptive traits through hatchery rearing practices may have reduced the stock's ability to persist in the wild. But the initial good growth and reproduction suggests that, at least in the short term, the reintroduction to Whirligig Lake has been successful.

The survival of the aurora trout in Whirligig Lake depends on maintenance of pH levels above 5.0. Rapid reacidification after liming, as occurred in Whirligig Lake, and has been observed in other lake liming studies (Driscoll et al. 1989), indicates that liming is a temporary measure and that control at the source is the only long-term solution to anthropogenic acidification. Legislated emission cutbacks that took effect in January 1994 will substantially reduce acid deposition originating from the Sudbury metal smelters and may help delay or prevent reacidification of the native lakes.

The initial success of the aurora-trout restoration illustrates that it is possible to reestablish natural reproduction in a fish stock that has been archived in captivity. The expense and effort involved, however, mean that few gene pools can receive this intensive care and that the best means of preservation is to prevent their extirpation from the wild.

Acknowledgments

The aurora-trout restoration program is financed and conducted by the Ontario Ministry of Natural Resources, with technical support and field assistance from the Ontario Ministry of Environment and Energy, Sudbury. Additional financial support during the period 1992–1994 was provided by the Endangered Species Recovery Fund, cosponsored by World Wildlife Fund, Canada, and the Canadian Wildlife Service of Environment Canada. We thank the Aurora Trout Management Committee and the many individuals that have participated in the restoration effort, especially Jim Carbone, Peggy Gale, Vic Liimatainen, Rob Kirk, Rod Sein, and Albertina VanOgtrop. We also thank Leon Carl and Peter Ihssen for providing comments on an earlier draft of this manuscript. This is contribution number 94-08 of the Aquatic Ecosystems Research Section, Ontario Ministry of Natural Resources.

Literature Cited

Beamish, R. J., and H. H. Harvey. 1972. Acidification of the La Cloche Mountain Lakes, Ontario, and resulting fish mortalities. Journal of the Fisheries Research Board of Canada 29:1131–1143.

Beamish, R., W. Lockhart, J. Van Loon, and H. Harvey. 1975. Long-term acidification of a lake and resulting effects on fish. Ambio 4:98–102.

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.

Berquist, B. C. 1991. Extinction and natural recolonization of fish in acidified and limed lakes. Nordic Journal of Freshwater Research 66:50–62.

Driscoll, C. T., W. A. Ayling, G. F. Fordham, and L. M. Oliver. 1989. Chemical response of lakes treated with $CaCO_3$ to reacidification. Canadian Journal of Fisheries and Aquatic Sciences 46:258–267.

Fraser, J. M. 1981. Estimates of the standing stocks of fishes in four precambrian shield lakes. The Canadian Field-Naturalist 95:137–143.

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. Canadian Journal of Fisheries and Aquatic Sciences 46:277–286.

Gowing, H. 1986. Survival and growth of matched plantings of Assinica strain brook trout and hybrid brook trout (Assinica male × domestic female) in six small Michigan lakes. North American Journal of Fisheries Management 6:242–251.

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. Rickenbach. 1925. Description of the aurora trout (*Salvelinus timagamiensis*), a new species from Ontario. Annals of the Carnegie Museum 16:131–141.

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 Pollution 29:285–296.

Keller, W., J. Gunn, and N. Conroy. 1980. Acidification impacts on lakes in the Sudbury, Ontario, Canada area. Pages 228-229 in D. Drablos and A. Tollan, editors. Proceedings of the international conference on the ecological impact of acid precipitation. Acid precipitation—effects on forest and fish project. Aas, Norway.

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. Canadian Journal of Fisheries and Aquatic Sciences **49**(Suppl 1):25-32.

Kelso, J. R. M., and J. M. Gunn. 1984. Responses of fish communities to acidic waters in Ontario. Pages 105-115 in G. R. Hendrey, editor. Early biotic responses to advancing lake acidification. Butterworth Publishers, Toronto.

Kelso, J. R. M., M. A. Shaw, C. K. Minns, and K. H. Mills. 1990. An evaluation of the effects of atmospheric deposition on fish and the fishery resource of Canada. Canadian Journal of Fisheries and Aquatic Sciences **47**:644-655.

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

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. Canadian Journal of Fisheries and Aquatic Sciences **49**(Suppl 1):87-94.

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.

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.

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.

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

Schofield, C. L., C. Keleher, and H. K. Vanoffelin. 1991. Population dynamics of brook trout (*Salvelinus fontinalis*) during maintenance liming of an acidic lake. Water, Air, and Soil Pollution **59**:41-53.

Sevaldrud, I. H., I. P. Muniz, and S. Kalvenes. 1980. Loss of fish populations in Southern Norway. Dynamics and magnitude of the problem. Pages 350-351 in D. Drablos and A. Tollan, editors. Proceedings of the international conference on the ecological impact of acid precipitation. Acid precipitation—effects on forest and fish project. Aas, Norway.

Snucins, E. J., V. A. Liimatainen, and P. A. Gale. 1983. 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.

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.

Webster, D. A. 1962. Artificial spawning facilities for brook trout, *Salvelinus fontinalis*. Transactions of the American Fisheries Society **91**:168-174.