# 11

# Preservation of Biodiversity: Aurora Trout

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> . . . the worst thing that will probably happen . . . is not energy depletion, economic collapse, conventional war, or even the expansion of totalitarian governments. As terrible as these catastrophes would be for us, they can be repaired within a few generations. The one process now going on that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly our descendants are least likely to forgive us.
>
> *(Wilson 1984)*

The habitat alteration and destruction caused by Sudbury's metal extraction and smelting industries have contributed to the global depletion of biological resources (Box 11.1). Damage to local terrestrial vegetation and soils, described in Chapter 2, was striking. Less apparent but more widespread was the damage to aquatic ecosystems. Acidification of lakes from atmospheric deposition of smelter emissions occurred over an area of 17,000 km$^2$ and affected lakes as far as 120 km from the city (Neary et al. 1990). An estimated 134 gamefish populations, as well as many populations of less well-studied fish species were extirpated (Matuszek et al. 1992). The loss of these populations did not endanger entire species, but it did contribute to the loss of unique genetic strains. The losses are part of an alarming global trend to decreasing fish diversity. By region, the percentages of fish species classified as endangered, threatened, or in need of special protection are as follows: South Africa, 63%; Europe, 42%; Sri Lanka, 28%; North America, 31%; Australia, 26%; Iran, 22%; Latin America, 9% (Moyle and Leidy 1992). Within-species genetic diversity is also declining as fish are extirpated from individual lakes and rivers that comprise portions of their native range (Nehlson et al. 1991; Kaufman 1992).

Of the many populations threatened by acidification of lakes in the Sudbury area, only the aurora trout (see Plates 12 and 15, following page 182), a rare strain of brook trout (*Salvelinus fontinalis*), was the subject of extraordinary preservation efforts. It was extirpated from its native habitat and in 1987 was placed on Canada's endangered species list (Table 11.1). This chapter presents the story of the aurora trout restoration program, a combination of personal and agency commitment and perseverance, that saved the fish from extinction and ultimately restored it to its native habitat.

### *Box 11.1. Global Loss of Biological Diversity*

Biological extinction is not a new phenomenon. In fact, it is estimated that more than 90% of all the species that ever existed on earth are now extinct (Simpson 1952). The fossil record indicates that there have been five main periods of mass extinction during the past 600 million years. Although there is some debate over the causes of these extinctions, most authorities seem to agree that each was triggered by a natural catastrophic event in the environment, such as sudden climatic change, drop in sea level, or meteorite impact (Raup 1986).

Averaged over the entire span of life on earth, the rate of extinction amounts to about one species per year. But our current trend far exceeds this rate. Some scientists believe that, on average, several species are disappearing each day, and they estimate that if present trends continue, more than one-quarter of the earth's biodiversity, estimated to be between 3 and 30 million species (May 1990), will be lost in the next 20–30 years (McNeely et al. 1990). The current period of mass extinction is particularly worrisome in that it is caused largely by human activity. Habitat alteration and destruction, chemical pollution, overharvesting, and the introduction of exotic species that displace or eliminate native biota are among the factors contributing to the modern depletion of biodiversity.

The current accelerated loss of biological diversity should concern us. From an ethical standpoint, some people argue that every species has an inherent right to exist independent of its material benefit to humans. There are also many human-centered utilitarian reasons for preserving biodiversity, not the least of which is that our survival depends both directly and indirectly on diversity at all levels of biological organization. Ecosystems with their variety of habitats and communities provide

*Box 11.1. (continued).*

essential ecological services such as the maintenance of air and water quality, soil formation and protection, climate control, and nutrient cycling. The harvesting of natural resources supplies us with food, clothing, and shelter. Wild plants supply the genetic material for selective breeding of domestic crops to increase yields and enhance pest and disease resistance. Many pharmaceuticals, too, are derived from plants. Within-species genetic diversity provides the many varieties of a species that are each suited to different environmental conditions.

Perhaps the greatest long-term benefit of biodiversity is the supply of the raw materials that enable humans and nature to respond to changing environments and stresses. Our welfare will largely be determined by how we respond to the current period of accelerated biodiversity loss in which this storehouse of potential solutions to current and future problems is quickly becoming depleted.

## Description of the Aurora Trout

The aurora trout and its mother species, the brook trout, are both multihued and spectacularly beautiful, although different in the details of their coloration. Brook trout have a dorsal background color of olive green to dark brown, which is mottled by yellow spots and vermiculations (Fig. 11.1). Along the sides, this coloration pales to a snow-white abdomen that is often tinged with pink. Many red spots surrounded by pale blue halos speckle the sides. Pectoral, pelvic, and anal fins have a leading white edge backed by a black bar and orange or red posterior.

In contrast, the aurora trout's dorsal coloration fades along the sides to iridescent steel blue and silver, colors mimicking the shimmering brilliance of the fish's namesake, the aurora borealis, or northern lights. Adult aurora trout do not possess the yellow spots and vermiculations of the brook trout, and there are few, if any, red spots (Figs. 11.2 and 11.3). The coloration of the males intensifies during spawning. The sides and upper abdomen take on a vivid red color, often accented with a band of midnight black along the abdomen.

## History of the Aurora Trout

The native range of the aurora trout consists of two small waterbodies: Whirligig Lake (11-ha surface area) and Whitepine Lake (77-ha surface area), located 110 km north of Sudbury (Fig. 11.4). Each is part of a chain of lakes situated on a ridge in an isolated part of Lady Evelyn Smoothwater Wilderness Park. The surrounding terrain is hilly and rough, topography typical of the Precambrian Shield, and access is gained by canoe or aircraft only. Historically, Whitepine Lake also contained a population of brook trout, and both lakes supported white sucker (*Catastomus commersoni*) populations.

The aurora trout likely evolved from a population of brook trout isolated some time after continental glaciers receded, about 10,000 years ago. The brook trout were probably trapped as water levels dropped and the land slowly rebounded upward after being freed of the weight of the glaciers. This strain of fish subsequently evolved in isolation and diverged sufficiently to become distinct from other brook trout.

In 1923, a party of anglers from the United States visiting Whitepine Lake caught some of these fish and took one back to the Carnegie Museum in Pittsburgh. The following year, more specimens were collected, and in 1925, a description of the fish was published in the scientific literature. Subsequently, the lakes were often visited by anglers willing to undertake the 4-day journey by canoe and trail to catch this trophy sportfish renowned for its spectacular coloration and superior fighting ability.

**TABLE 11.1.** 1993 Canadian Species at Risk

Mammals

*Extinct*
- Dawson Caribou
- Sea Mink

*Extirpated*
- Atlantic Walrus (*N.W. Atlantic Pop.*)
- Black-footed Ferret
- Gray Whale (*Atlantic Pop.*)
- Grizzly Bear (*Plains Pop.*)
- Swift Fox

*Endangered*
- Beluga Whale (*S.E. Baffin Is. Pop., St. Lawrence R. Pop., and Ungava Bay Pop.*)
- Bowhead Whale
- Eastern Cougar
- Peary Caribou (*High Arctic Pop. and Banks Is. Pop.*)
- Right Whale
- Sea Otter
- Vancouver Is. Marmot
- Wolverine (*Eastern Pop. Quebec/Labrador*)

*Threatened*
- Beluga Whale (*Eastern Hudson Bay Pop.*)
- Harbour Porpoise (*Western Atlantic Pop.*)
- Humpback Whale (*North Pacific Pop.*)
- Peary Caribou (*Low Arctic Pops.*)
- Pine Marten (*Nfld. Pop.*)
- Wood Bison
- Woodland Caribou (*Maritime Pop.*)

Birds

*Extinct*
- Great Auk
- Labrador Duck
- Passenger Pigeon

*Extirpated*
- Greater Prairie-Chicken

*Endangered*
- Eskimo Curlew
- Harlequin Duck (*Eastern Pop.*)
- Henslow's Sparrow
- Kirtland's Warbler
- Loggerhead Shrike (*Eastern Pop.*)
- Mountain Plover
- Peregrine Falcon (subspecies anatum)
- Piping Plover
- Sage Thrasher
- Spotted Owl
- Whooping Crane

*Threatened*
- Baird's Sparrow
- Burrowing Owl
- Ferruginous Hawk
- Loggerhead Shrike (*Western Pop.*)
- Marbled Murrelet
- Roseate Tern
- White-headed Woodpecker

Fish

*Extinct*
- Blue Walleye
- Deepwater Cisco
- Longjaw Cisco
- Longnose Dace (*Banff Pop.*)

*Extirpated*
- Gravel Chub
- Paddlefish

*Endangered*
- Acadian Whitefish
- Aurora Trout
- Salish Sucker

*Threatened*
- Black Redhorse
- Blackfin Cisco
- Channel Darter
- Copper Redhorse
- Deepwater Sculpin (*Great Lakes Pop.*)
- Enos Lake Stickleback
- Lake Whitefish (*Lk. Simcoe Pop.*)
- Margined Madtom
- Shorthead Sculpin
- Shortjaw Cisco
- Shortnose Cisco

Reptiles & Amphibians

*Extirpated*
- Pygmy Short-horned Lizard

*Endangered*
- Blanchard's Cricket Frog
- Blue Racer
- Lake Erie Watersnake
- Leatherback Turtle

*Threatened*
- Blanding's Turtle (*Nova Scotia Pop.*)
- Eastern Massasauga
- Spiny Softshell Turtle (*Eastern Pop.*)

Plants

*Extirpated*
- Blue-eyed Mary
- Illinois Tick Trefoil

*Endangered*
- Cucumber Tree
- Engelmann's Quillwort
- Furbish's Lousewort
- Gattinger's Agalinis
- Heart-leaved Plantain
- Hoary Mountain Mint
- Large Whorled Pogonia
- Mountain Avens (*Eastern Pop.*)
- Pink Coreopsis
- Pink Milkwort
- Prickly Pear Cactus (*Eastern Pop.*)
- Skinner's Agalinis
- Slender Bush Clover
- Slender Mouse-ear Cress
- Small White Lady's Slipper
- Small Whorled Pogonia
- Southern Maidenhair Fern
- Spotted Wintergreen
- Thread-leaved Sundew
- Water-pennywort
- Western Prairie Fringed Orchid
- White Prairie Gentian
- Wood Poppy

*Threatened*
- American Chestnut
- American Ginseng
- American Water-willow
- Anticosti Aster
- Athabasca Thrift
- Bird's Foot Violet
- Blue Ash
- Bluehearts
- Colicroot
- Giant Helleborine
- Golden Crest
- Golden Seal
- Kentucky Coffee Tree
- Mosquito Fern
- Nodding Pogonia
- Pitcher's Thistle
- Plymouth Gentian
- Purple Twayblade
- Red Mulbery
- Sand Verbena
- Small-flowered Lipocarpha
- Sweet Pepperbush
- Tyrell's Willow
- Western Blue Flag
- Western Spiderwort

Species: Any indigenous species, subspecies, or geographically separate population.
Extinct: A species indigenous to Canada that is no longer known to exist anywhere.
Extirpated: A species no longer existing in the wild in Canada but occurring elsewhere.
Endangered: A species threatened with imminent extirpation or extinction throughout all or a significant part of its Canadian range.
Threatened: A species likely to become endangered in Canada if the factors affecting its vulnerability are not reversed.
Status determinations included in this list are determined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

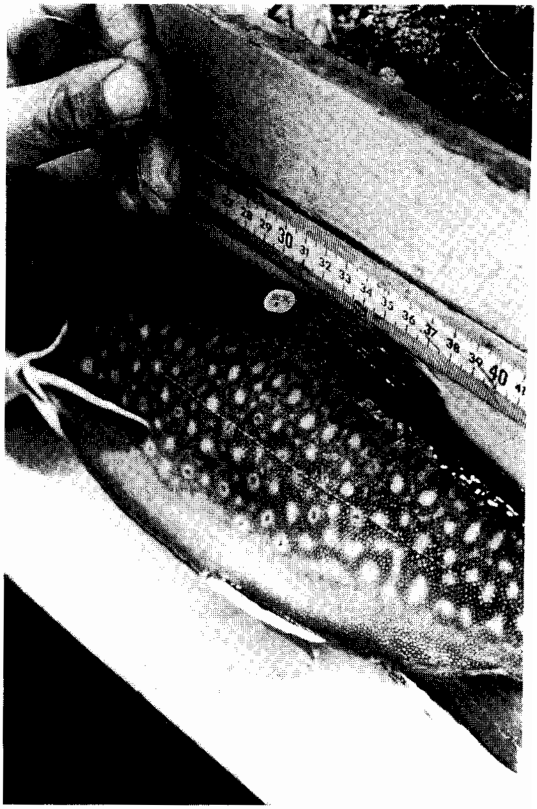


**Figure 11.1.** Male brook trout. The differences in coloration between the male brook trout (spotted sides) and the male aurora trout (Fig. 11.2) prompted early classification of the aurora trout as a separate species. It is now believed to be a rare strain or race of brook trout. (Photo by V. Liimatainen.)

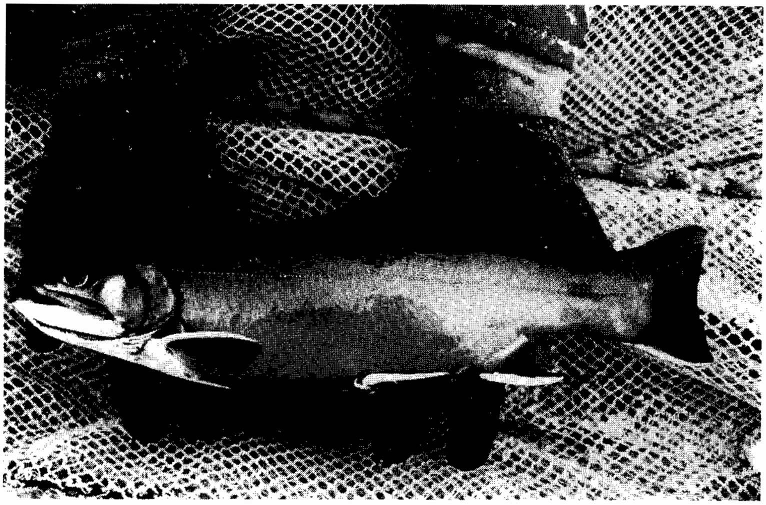


**Figure 11.2.** Male aurora trout. (Photo by E. Snucins.)

The classification of the aurora trout has been a source of controversy. It was originally classified as a distinct species (*Salvelinus timagamiensis*) (Henn and Rinkenbach 1925) until a closer affiliation with the brook trout subsequently found favor. On the basis of differences in behavior, coloration, and other characteristics, a subspecies classification was proposed (Sale 1967; Qadri 1968; Parker and Brousseau 1988). Recent work suggests that the genetic differences are not sufficient to justify subspecies status and that the aurora

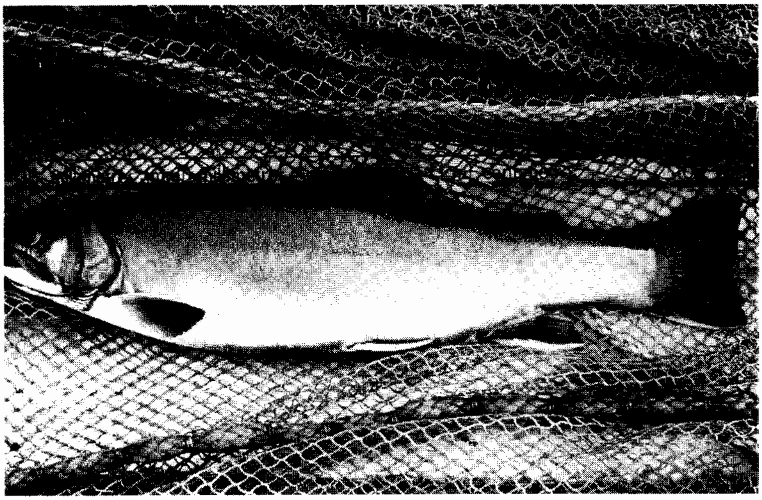


**FIGURE 11.3.** Female aurora trout. (Photo by E. Snucins.)

trout is simply a unique strain or race of brook trout (McGlade 1981; Grewe et al. 1990).

The aurora trout lakes lie within the area affected by acid deposition from the Sudbury metal smelters. By the middle of the century, acidification of these lakes was occurring, although it was not recognized at the time. In 1951, the Ontario government began to monitor the aurora trout populations. Angling was no longer permitted on the lakes, but by the late 1950s, the populations had noticeably declined, and by 1967, the aurora trout had disappeared from its home range. The demise of these populations coincided with the acidification of the lakes to near pH 5.0 (Keller 1978), the threshold for brook trout survival (Beggs and Gunn 1986).

Fortunately, before the aurora trout completely disappeared, fertilized eggs were collected from both native lakes, and a hatchery brood stock was established (Fig. 11.5). The work of Paul Graf and colleagues at Hills Lake Provincial Hatchery, their efforts at spawn collection, and the discovery in 1958 of a successful artificial rearing method saved the aurora trout from extinction. The lineage of all aurora

**FIGURE 11.4.** Aerial view showing the rugged Precambrian Shield terrain surrounding the home range of the aurora trout. This rare strain of brook trout likely developed when Whirligig and Whitepine lakes were isolated from surrounding waterbodies after the last continental glaciers retreated. (Photo by E. Snucins.)

**FIGURE 11.5.** When it was recognized that the aurora trout populations were declining, fisheries managers collected spawn to establish and maintain a hatchery stock. The aurora trout was subsequently extirpated from its home range until water quality improvements made it possible to re-introduce the fish to Whirligig and Whitepine lakes. (Photo by Ontario Ministry of Natural Resources.)

trout in existence today can be traced to the 1958 spawn collection, when 3644 eggs were collected from one Whitepine Lake and two Whirligig Lake females. The eggs from each female were mixed with the sperm from two males. Thus, the founding population size was only nine individuals and may have been as few as six if all males did not contribute to fertilization. The stock has been artificially maintained in the hatchery ever since.

By the late 1980s, the prospects of maintaining the captive aurora trout population in the hatchery became worrisome. Concern arose over the potentially deleterious effects of generations of domestication on the fitness of the stock (Franklin 1980; Hynes et al. 1981; Lacy 1992). Because selection pressures in the hatchery differ from those in the wild, the acquisition of characteristics that promote success in the hatchery can occur at the expense of other characteristics that are required for survival and reproductive success in the wild. The small founding population size of six to nine individuals may have limited the assortment of genes within the captive population, and genetic diversity could have been further reduced after a few generations in the hatchery. Also, genetic drift caused by nonrepresentative sampling within a small gene pool can alter gene frequencies, and in some species, inbreeding can result in lower viability and reduced fecundity.

## Rehabilitation of the Native Lakes

Given the failure of the many attempts made since the 1950s to establish reproducing populations of aurora trout in non-native lakes, fisheries managers in Ontario decided that the best chance of success would be to return these fish to their native lakes. However, the water quality in the native lakes was still too acidic to allow for the survival of the aurora trout. Therefore, both Whirligig Lake (pH 4.8) and its headwater Little Whitepine Lake (pH 5.6) were treated with 21 tonnes of powdered limestone in October 1989; this increased the pH of both lakes to 6.5 (Fig. 11.6). In May 1990, 950 aurora trout hatchery brood stock (aged 2–5 years) were introduced into Whirligig Lake.

During late October of the same year, biologists assessed spawning behavior of introduced fish in the limed lake. A group of about 40 fish was observed congregated at a near-shore groundwater upwelling site. The fish were sexually mature and in good condition, having experienced a threefold increase in weight during the 5 months that they had resided in the lake. However, no spawning was observed and a search for young fish during the spring of 1991 was unsuccessful. It seemed no reproduction had occurred.

**FIGURE 11.6.** Ontario government helicopter slings powdered limestone into a northeastern Ontario lake. Lime treatment was used to raise the pH levels of lakes in the home range of the aurora trout so that the extirpated aurora trout population could be re-established in the wild. (Photo by E. Snucins.)

Biologists believed that the failure to spawn may have been due to a low water table in 1990 and the consequent absence of high-quality groundwater upwelling sites, the typical spawning area of brook trout. Therefore, in 1991, two artificial upwellings were constructed at the location where the fish had congregated the previous October. Water from a small inlet stream was piped to two wooden boxes, each filled with limestone and granitic gravel, and lined with perforated pipe along the bottom. Water percolated up through the gravel, simulating a groundwater upwelling. During October, 11 adults were captured and injected with salmon pituitary extract to induce maturation. Again, despite these extraordinary efforts, no spawning was observed.

The results were disappointing to those working on the restoration project, and doubts arose over the reproductive ability of the introduced fish. Perhaps after many generations in the hatchery, the aurora trout was no longer able to reproduce in the wild. Much time, effort, and money had been spent, possibly to no avail. But worries quickly vanished the following year when two young aurora trout were observed by a diver swimming along the shoreline (Fig. 11.7).

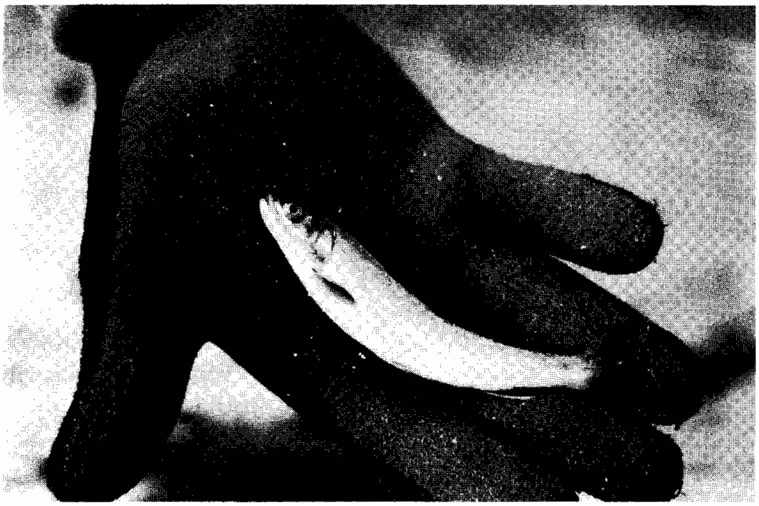
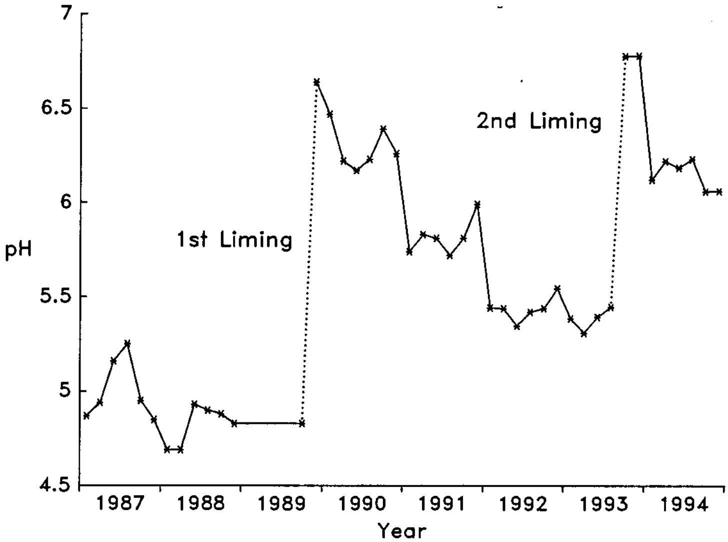


**FIGURE 11.7.** After nearly 2 years of searching, biologists discovered the offspring of aurora trout in Whirligig Lake in 1992, positive proof that the re-introduced species can reproduce in the wild. (Photo by E. Snucins.)

**Figure 11.8.** Changes in the pH of Whirligig Lake before and after treatment with limestone.



Two near-shore nests, or redds, were found in 1992, but it was not until 1993 that the primary spawning sites were discovered. Most redds were constructed at depths of 3–4 m, and the lake's tea-colored water had hidden this deep spawning habitat from surface observation. The age distribution of juvenile fish in the population indicated that successful spawning had occurred every year since the fish were re-introduced.

The discovery that the aurora trout was still capable of reproducing in the wild was very encouraging, but the realization that the lake was re-acidifying and would soon be too acidic for fish survival was soon to follow. During 1992, the pH of Whirligig Lake fell to 5.4 (Fig. 11.8). Much of the acidic input seemed to be coming from a nearby wetland. During September 1992, 32 tonnes of agricultural limestone was applied to the wetland in an attempt to improve the lake's water quality, but this treatment was not immediately effective and it was necessary to lime the lake itself in September 1993. This succeeded in raising the lake pH to 6.8.

Because Whitepine Lake, the second native lake of the aurora trout, receives the runoff from Whirligig Lake, its water may also have benefited from the liming. The pH of Whitepine Lake rose from 4.9 in 1990 to 5.1 in 1993. In response to these improved conditions, aurora trout were re-introduced to Whitepine Lake in the spring of 1994 as the next step in the restoration plan.

## Summary

Our observations of good reproduction indicate that the return of the aurora trout to its native waters has, at least initially, been successful, but the long-term viability of the reintroduced population remains unknown. It is possible that the fitness of the stock for life in the wild has been reduced through inadvertent selection in the hatchery or because genes critical for survival were lost during the genetic bottleneck. However, if the original genetic material was not critically altered, the prospects for long-term persistence of the population in Whirligig Lake are probably good.

The continued survival of the aurora trout in Whirligig Lake depends on maintaining good water quality. Metal smelter emission reductions that began in 1994 will help reduce acid loading and may prolong the time to re-acidification. Water quality monitoring will need to continue, and if current pollution controls are not sufficient to prevent re-acidification, the lake will need to be relimed.

The genetic diversity represented by individual fish stocks uniquely adapted to local condi-

### *Box 11.2. Convention on Biological Diversity*

The Convention on Biological Diversity was signed at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil (June 3–14, 1992). Under the convention, steps will be taken to protect endangered species and their habitats. All signatory nations agreed to adopt regulations to conserve biological resources, including establishing a system of protected areas. Most of the world's biological diversity exists in the tropical developing countries. To promote conservation in these economically impoverished areas, the developed countries will help supply the required financial resources and technical expertise. Also, to more equitably distribute the financial benefits of genetic resources and thus encourage their preservation, the convention promotes biological diversity as a financial asset that can generate income for the country of origin, in particular the local indigenous peoples.

tions is an important resource for environmental restoration and management. The initial success of the aurora trout restoration program demonstrates that it may be possible to preserve at least some locally adapted gene pools despite alteration of their natural habitat. However, such efforts are costly and not every endangered stock or species can receive such intensive care. Although some success was achieved in saving the aurora trout, the main lesson learned was that habitat protection pays far greater dividends than single-species restoration efforts. The preservation of natural ecosystems with all their species is by far the most effective means of conserving biodiversity (Box 11.2), and it would be dangerous to focus on preserving individual stocks or species without addressing the root causes (habitat alteration by smelter emissions in the case of the aurora trout) that threaten their existence.

*Acknowledgments.* Many individuals are responsible for the success of the aurora trout restoration program. The stock was saved from certain extinction by the foresight and initiative of the Hills Lake Hatchery staff and their associates in the Department of Lands and Forests. Since 1983, a management committee, composed of Ministry of Natural Resources biologists and hatchery personnel, has directed rehabilitation efforts. The restoration work is financed and conducted by the Ontario Ministry of Natural Resources. Between 1992 and 1994, additional funding was obtained from the Endangered Species Recovery Fund, cosponsored by World Wildlife Fund, Canada and the Canadian Wildlife Service of Environment Canada. Water quality assessments, field support, and additional funding are provided by the Ontario Ministry of the Environment and Energy, Sudbury.

## References

Beggs, G.L., and J.M. Gunn. 1986. Response of lake trout (*Salvelinus namaycush*) and brook trout (*Salvelinus fontinalis*) to surface water acidification in Ontario. Water Air Soil Pollut. 30:711–718.

Franklin, I.R. 1980. Evolutionary change in small populations, pp. 135–149. *In* M.E. Soule and B.A. Wilcox (eds.). Conservation Biology: An Evolutionary-Ecological Perspective. Sinauer Associates, Sunderland, MA.

Grewe, P.M., N. Billington, and P.D.N. Hebert. 1990. Phylogenetic relationships among members of *Salvelinus* inferred from mitochondrial DNA divergence. Can. J. Fish. Aquat. Sci. 47:984–991.

Henn, A.W., and W.H. Rinkenbach. 1925. Description of the aurora trout (*Salvelinus timagamiensis*), a new species from Ontario. Ann. Carnegie Museum 16:131–141.

Hynes, J.D., E.H. Brown, Jr., J.H. Helle, N. Ryman, and D.A. Webster. 1981. Guidelines for the culture of fish stocks for resource management. Can. J. Fish. Aquat. Sci. 38:1867–1876.

Kaufman, L. 1992. Catastrophic change in species-rich freshwater ecosystems. The lessons of Lake Victoria. Bioscience 42:846–858.

Keller, W. 1978. Limnological Observations on the Aurora Trout Lakes. Technical Report. Ontario Ministry of the Environment, Sudbury.

Lacy, R.C. 1992. The effects of inbreeding on isolated populations: are minimum viable population sizes predictable? pp. 277–296. *In* P.L. Fiedler and S.K. Jain (eds.). Conservation

Biology: The Theory and Practice of Nature Conservation, Preservation, and Management. Chapman and Hall, New York.

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(Suppl. 1):87–94.

May, R.M. 1990. How many species? Phil. Trans. R. Soc. Lond. 330b:293–304.

McGlade, J.M. 1981. Genotypic and phenotypic variation in the brook trout, *Salvelinus fontinalis* (Mitchell). Doctoral thesis, University of Guelph, Guelph, Canada.

McNeely, J.A., K.R. Miller, M.V. Reid, R.A. Mittermeier, and T.B. Werner. 1990. Conserving the World's Biological Diversity. IUCN, Gland, Switzerland; WRI,CI,WWF-US, and the World Bank, Washington, DC.

Moyle, P.B., and R.A. Leidy. 1992. Loss of biodiversity in aquatic ecosystems: evidence from fish faunas, pp. 127–169. *In* P.L. Fiedler and S.K. Jain (eds.). Conservation Biology: The Theory and Practice of Nature Conservation, Preservation, and Management. Chapman and Hall, New York.

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, Dorset, Ontario.

Nehlson, W., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4–21.

Parker, B.J., and C. Brousseau. 1988. Status of the aurora trout, *Salvelinus fontinalis timagamiensis*, a distinct stock endemic to Canada. Can. Field-Nat. 102 (1):87–91.

Qadri, S.U. 1968. Morphology and taxonomy of the aurora char, *Salvelinus fontinalis timagamiensis*. Natl. Museums Can. Contrib. Zool. 5:1–18.

Raup, D.M. 1986. Biological extinction in earth history. Science 231:1528–1533.

Sale, P.F. 1967. A re-examination of the taxonomic position of the aurora trout. Can. J. Zool. 45:215–225.

Simpson, G.G. 1952. How many species? Evolution 6:342.

Wilson, E.O. 1984. Biophilia. Harvard University Press, Cambridge, MA.