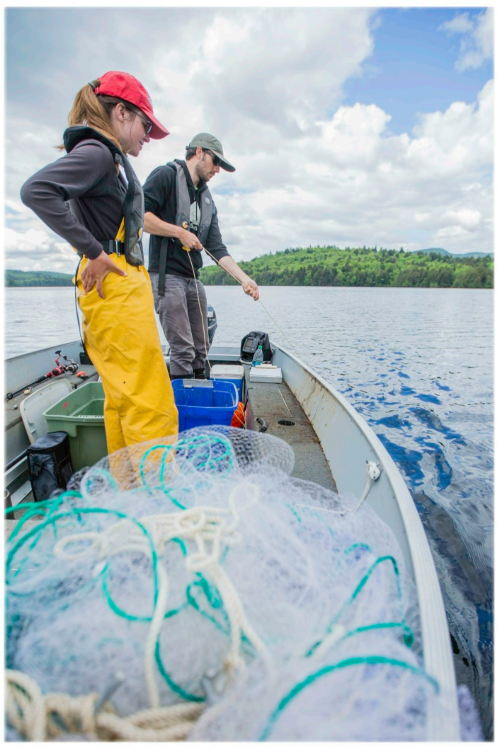
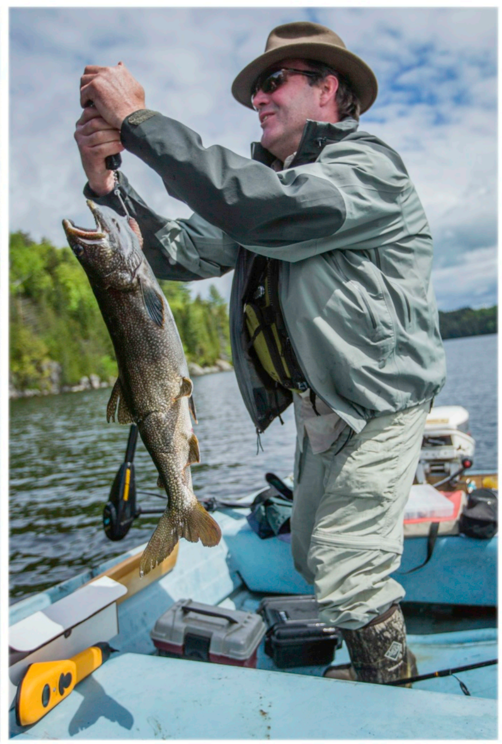
LAKE TROUT AND CLIMATE CHANGE IN THE ADIRONDACKS





2014

Status and long-term viability

A survey report for the Adirondack Chapter of The Nature Conservancy
By Mary Thill

The Nature Conservancy
Protecting nature. Preserving life.™
Adirondack Chapter

"In lake trout, we have something very unique and precious, maybe the most precious resource on the reserve."

—Bill Curtis, fisheries chairman
Adirondack Mountain Reserve

Illustration by Ellen Edmonson, New York Department of Conservation biological surveys, 1926–1939

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Executive summary: Lake Trout and Climate Change in the Adirondacks

The top native terrestrial predators of the Adirondacks, the wolf and mountain lion, were hunted to regional extinction in the 1890s. By then, the largest native freshwater predator, lake trout, had been fished out of an estimated 20 percent of its Adirondack range and concern was mounting about its future survival in the region.

New York State ultimately enacted regulations to protect the coldwater char from overharvest. But other factors increased the extirpation count to 75 lakes (42 percent of water bodies) over the 20th century. Today the Adirondacks appears to be experiencing a significant moment in lake trout recovery. Reintroductions are taking hold as the region rebounds from acid-rain damage, DDT and poor wastewater infrastructure. Lake trout are present in an estimated 102 cold, deep, rocky Adirondack lakes. Native populations are self-sustaining in half, while the species is supported or maintained by stocking in three dozen; a few populations are faltering, and their status is simply unknown in other waters.

Now climate change is expected to eliminate a significant amount of the region's coldwater fish habitat over the next century. Especially in smaller lakes and those with impaired water quality, lake trout and climate change are on a collision course. On the other hand, lake trout appear likely to persist in certain deep lakes, if action is taken to minimize stormwater inputs, introduced species, and other stresses.

Lake trout require the most demanding combination of temperature and oxygen of all of New York's freshwater game fish: water must be very cold (<55°F) and highly oxygenated (5+ milligrams per liter, or at least 50 percent saturated). The southern limit of lake trout range is (with exceptions) 43° latitude: the southern boundary of the Adirondack Park. Consequently, lake trout in the Adirondacks are confined to the coldest water at the bottom of the deepest (30+ feet) lakes in summer. The species name *namaycush* is believed to be an Algonquin term for "dweller of the deep."

The Adirondack Park's high elevation, remote waters and land-use protections present one of the best chances in the 48 contiguous United States to retain viable inland refuge for lake trout in a warmer and potentially stormier future. As the longest-lived (20+ years is not uncommon) member of the salmon family, lake trout can also serve as a long-range indicator of how well Adirondack deepwater habitat is meeting the needs of cisco, round whitefish and other species. Because large, deep Adirondack lakes tend to be places people seek out for drinking water, recreation and shoreline homes, lake trout can also tell us how our most valued waters are faring.

Purpose: Why frame questions around temperature?

Water quality changes and species introductions are serious and long-established threats to individual lake trout populations. This report recognizes those pressures and factors in the emerging challenge of climate change to help meet a need for temperature-related threat assessment and long-range planning for deepwater habitat. Mean annual air temperature in the eastern Adirondacks warmed by 2.1°F 1976–2005, according to U.S. Historical Climatology Network (USHCN) data. Based on this trend and Intergovernmental Panel on Climate Change (IPCC) model projections, the range of anticipated additional warming in this region over this century is 6–11°F under doubled CO^2 emissions (current path). Also according to USHCN, heavy rains (2+ inches over 48 hours) are occurring more frequently than in the early 1900s (Stager and Thill, 2010).

This report attempts to answer:

- What types of coldwater lakes are most resilient to climate change stress?
- What types of coldwater lakes are most vulnerable to climate change stress?
- How much lake trout/coldwater habitat is expected to be lost?
- How can stresses or losses be minimized?
- Should especially resilient or vulnerable lakes be managed differently?

Methods

This report synthesizes current research, scientific literature, state fisheries records, and the observations of landowners and natural-resource managers. It summarizes:

- What is known about lake trout in the Adirondacks
- Current and anticipated climate-change impacts to inland coldwater habitat

The report then examines how well lake trout might persist, as determined by:

- The dynamics of individual lakes
- Stewardship by anglers and watershed residents
- Actions and long-range planning of landowners and resource managers
- Adaptation potential of the species

Conclusions

All projections point to a decrease in Adirondack lake trout habitat. But some habitat appears likely to persist, if stresses can be minimized.

An increase in temperature and stormwater runoff is predicted to:

- Extend duration of spring-to-fall temperature stratification, deplete oxygen in the deeps of lake trout lakes, and shrink habitat—eliminating coldwater refuges entirely in the shallowest lakes currently inhabited by lake trout.
- Create anoxic dead zones in some deep lakes where fertilizers are washed from the watershed and interact with warmer surface waters to cause algae blooms that fall to the bottom and are decayed by oxygen-consuming bacteria; in other words, even if a deep lake retains cold water at depth, lake trout may not be able to persist if stormwater is not absorbed by vegetation on shore.
- Magnify the impact of introduced species. As young lake trout are forced out of de-oxygenated depths, they fall prey to introduced bass and pike; because lake

trout are slow to replace themselves, this can eliminate naturally sustaining populations from a lake.

- Throw into flux the timing of spawn, hatch, and food-emergence for fry.

There is little monitoring to help assess how new stresses are affecting deep Adirondack waters. And this report found no evidence that turnover timing has begun to change in the Adirondacks, but there are indications that some smaller local lakes may be experiencing oxygen/temperature-related population decline. In addition, outside the region, in Maine, a large lake, Lake Auburn, experienced a severe lake-trout kill in summer 2012; record early ice-out and prolonged temperature layering caused oxygen depletion in the deepwater zone to drive lake trout into warm waters.

How much deepwater habitat will be lost in the Adirondacks is not yet estimated. Scientists in Ontario and Minnesota, which are also on the retracting edge of lake trout range, project habitat losses of 30 to 40 percent.

A good next step in the Adirondacks would be to assess levels of vulnerability and resilience of individual lake-trout lakes based on depth, flush rate, land cover in the nearshore watershed, and other characteristics. The Nature Conservancy has begun to compile a database to help natural resource managers anticipate losses and identify potential refuges (Appendix A is an excerpt from the first draft).

Recommendations

How well coldwater fish endure increases in temperature and stormwater will be determined lake-by-lake and depend on physical and cultural influences, the care taken by people who use and live by the lakes, and the foresight of ecosystem managers.

The Adirondack Chapter of The Nature Conservancy commissioned this report in the hope that it will help identify gaps in knowledge and be useful to natural resource managers and partners across northern New York.

This project is about more than a single species: healthy lake trout numbers are an indication that overall water quality is high, and a decline can signal stress among lesser-known species. This report concludes with research and management options to be considered in maintaining viable coldwater habitat.

I. Introduction

The top native predators in upland Adirondack waters have historically been brook trout (*Salvelinus fontinalis*) and lake trout (*Salvelinus namaycush*). Both are members of a genus of the salmon family known as char, identified by red or light spots over a darker body. As a 10,000-year era of relative climate stability comes to an end, both are signaling different transitions in the region's water quality.

Brook trout inhabit Adirondack streams, ponds and a variety of lakes. Over the past decade increased surface-water temperatures have diminished brook trout growth, reproduction and ability to survive in Rock Lake (maximum depth 18 feet) in the southwest Adirondacks (Robinson et al., 2010; Warren et al., 2012). There are indications that similar changes may be under way in other lakes.

Brook trout have come to symbolize cool clear Adirondack streams. Lake trout are less familiar though they are the keystone species of the region's deep cold lakes. The species name *namaycush* is believed to be an Algonquin term for "dweller of the deep." They are found only in highly oxygenated depths of 30 feet or more in summer. "Lake trout undoubtedly have one of the most demanding combinations of environmental requirements (cold temperature—abundant oxygen) of New York's freshwater game fish," reported a New York State Department of Environmental Conservation (DEC) statewide assessment of the species, published in 1977.

Brook trout range extends down the spine of the Appalachian Mountains, but the southern limit of lake trout is (with the exceptions of the extremely deep Finger Lakes and Great Lakes) 43° latitude, the southern boundary of the Canadian Shield.

Lake trout and their habitat are not as well studied as brook trout in this region. But with closer monitoring lake trout could serve as an indicator of how much cold, oxygen-rich habitat the Adirondacks might sustain in a warmer future.

Mean annual air temperature in the eastern Adirondacks warmed by 2.1°F between 1976 and 2005, according to U.S. Historical Climatology Network (USHCN) data. Based on the trend of these records and Intergovernmental Panel on Climate Change (IPCC) model projections, the range of anticipated additional warming in this region over this century is 6–11°F under a scenario of doubled CO^2 emissions, the current path. Also according to USHCN data, since 1970 bouts of heavy rain are occurring more frequently than they did in the early 1900s (Stager and Thill, 2010).

Increase in air temperature and stormwater runoff could:

- Extend the duration of summer temperature stratification, depleting oxygen in the cold bottom water of smaller, shallower lakes—and eliminating coldwater refuges entirely in the shallowest lakes currently inhabited by lake trout.

- Create dead zones in deep lakes where nutrients such as phosphorus are washed into the watershed and interact with warmer surface waters to cause algae blooms that fall to the bottom and are decayed by oxygen-consuming bacteria; so, even if a deep lake retains cold water at depth, lake trout may not be able to persist if stormwater inputs are heavy.

- Magnify the impact of introduced species. As young lake trout are forced out of de-oxygenated bottom water into the middle temperature zone, they fall prey to introduced bass and pike; because lake trout are slow to replace themselves, this can eliminate the species from a lake entirely.

- Throw into flux the timing of spawn, hatch, and food-emergence for fry.

A site of recent lake trout population decline in the Adirondacks is Upper Ausable Lake, a relatively small (153-acre, 49-foot-deep) stratified lake surrounded by protected forest. Since 2009 scientists have observed critically low adult lake trout numbers, a paucity of younger fish, and low oxygen in the lake trout's cold temperature niche (Josephson and Field, 2012). Nutrient pollution and introduced species have been ruled out as factors. A lack of monitoring of other lakes is a barrier to broader insight.

The 2011 *Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State* categorizes lake trout as "highly vulnerable" by the following criteria:

- *adapted to cold or high-elevation conditions*
- *near the southern boundary of their range*
- *narrow range of temperature tolerance*
- *specialized habitat requirements*
- *susceptible to new competitors*

Restricted habitat, slow growth, late maturity and slow replacement rate have historically made lake trout vulnerable to overfishing, competition from introduced species, and pollution—stressors that are magnified by increased temperature. It's unclear how much Adirondack range has been lost since settlement; records are unreliable, but by one estimate it has decreased 19 percent (George, 1981). Today, lake trout—stocked and naturally replenishing—live in approximately 100 Adirondack lakes.

Healthy lake trout numbers can indicate that overall water quality is high, and a decline can signal stress among less-studied fish such as cisco, round whitefish, and other species that rely on cold water.

II. Lake trout in the Adirondacks: What we know

Fossil records suggest that lake trout (*Salvelinus namaycush*) and brook trout (*Salvelinus fontinalis*) followed closely the retreat of the glaciers 11,700 years ago (Wilson & Mandrak, 2004). These freshwater char were among the first fishes to colonize the Adirondacks. Because temperature is the primary limiting factor for lake trout, when surface waters warm in late spring and summer, lake trout retreat to deeper water. Over time they became isolated to Adirondack lakes typically with a depth of 30 feet or greater, where they can find summer refuge in temperatures of 55°F or colder. As a result, lake trout occur in fewer and generally larger Adirondack lakes than brook trout, which occupy a higher temperature range of 52–61°F but tolerate up to 68°F.

Life history

Adirondack lake trout depend on lake turnover to replenish the oxygen supply in deeper waters. All lake-trout lakes here are dimictic: water mixes from top to bottom twice yearly, in spring and fall. During winter and spring, and again in autumn, when surface water temperatures cool, lake trout are often found near shore. They are most abundant in lakes with large volumes of deep water with deep basins where temperatures remain 55°F or lower in summer, and where levels of dissolved oxygen exceed 6 milligrams per liter.

Food: Lake trout is the dominant member of the native Adirondack aquatic food web and remains a top predator, though today it often shares the role with introduced bass, pike and salmon. Lake trout are opportunistic carnivores, feeding on what's available. Native forage include round whitefish, cisco, white sucker, longnose sucker (Smith, 1985) and young lake trout. Introduced forage include smelt, perch and rock bass. Young feed on zooplankton, then larger invertebrates and insects, and small fish.

Although introduced basses live mostly near shore, they can reduce the number of forage fish available for species in deeper water. When minnows and small fish are few, lake trout shift to zooplankton, invertebrates and other small prey, and grow more slowly (Lepak et al., 2006). Vander Zanden et al. (2004) found that lake trout growth was reduced 25 to 30 percent in an Ontario lake following bass establishment. In **Little Moose Lake** in the southwest Adirondacks, the catch rate of round whitefish increased after 90 percent of smallmouth bass were removed over six years (Weidel et al., 2007). In **First Bisby Lake** electrofishing removal of smallmouth bass since 2003 appears to be playing a role in lake trout recovery (Josephson et al., 2014). Rock bass and yellow perch are the main predators of lake trout fry in Lake Champlain (Riley and Marsden, 2009).

Spawn: Adirondack lake trout spawn over pebbly or rocky shoals in three to eight feet of water where currents sweep the cobbles free of silt. Spawning appears to be triggered by temperature and takes place around the time of autumn turnover, when surface water falls below 55°F (52° and 53° often correspond with peak spawn on **Raquette**

Lake, according to 50 years of DEC records). Lake trout have been recorded spawning in water as warm as 57°F in Raquette Lake, but timing of peak spawn there has remained consistent since 1964; October 17 is the most common date.

Hatch: Eggs hatch in late winter or early spring. Consistent water levels are important to the egg survival. If dam-controlled reservoirs are lowered after spawn, eggs can freeze, be scraped by ice, or dry out in the five to six months of incubation.

Growth: Lake trout are the longest-lived member of the salmon family (salmon, trout, char, freshwater whitefish), sometimes living 25 years and longer. They are slow-growing and late to mature. In **Raquette Lake** maturity is reached at five years for males and eight years for females, according to Preall. Unstocked, unexploited and slower-growing populations can reach maturity later in life. Growth varies from place to place depending on diet and water temperature. Smith (1985) estimates length at maturity usually at 14 to 17 inches. Long-term juvenile surveys in Raquette Lake find that six-year-old trout are considered slow-growing at 18 inches, healthy at 19 inches, and fast-growing at 20 inches. Lake trout in Raquette Lake under 16 inches are generally considered juvenile. Stocked yearling trout are around 6 inches long (Preall, 1991).

In lakes where there are no prey fish, plankton-feeding lake trout can weigh 1 to 2 pounds as adults, while lake trout that feed upon fish can grow in excess of 3 feet and 30 pounds (Kraft et al., 2006). In the Adirondacks, there are examples of populations that consume primarily zooplankton and macro-invertebrates where forage fish are scarce (Josephson, personal communication). **Lake Placid**, **Brandreth Lake**, and **Little Simon Pond** present a split scenario: According to Preall, minnows in those lakes are scarce, so young adult lakers depend on invertebrates and are slow growing for many years. Then, when a trout reaches a length of 15 inches or so, it begins to feed on smaller lake trout, rock bass, perch and suckers, and it grows at a faster rate. As a result, Lake Placid contains adult lake trout less than 15 inches long but also yields trophy fish.

In 1973, DEC increased minimum harvest size from 18 to 21 inches in Raquette Lake. This helped stabilize the population by protecting adults in the first two years of spawning (Preall, personal communication). In 1977, 21 inches became the statewide minimum harvest size on most lakes.

The largest lake trout on record in New York is 41 pounds, taken from Lake Erie in 2003. **Follensby Pond** in the Adirondacks long held the record, for a 31-pound fish taken in 1922. That record stood until 1985, when a 32-pounder was caught in **Lake Placid**.

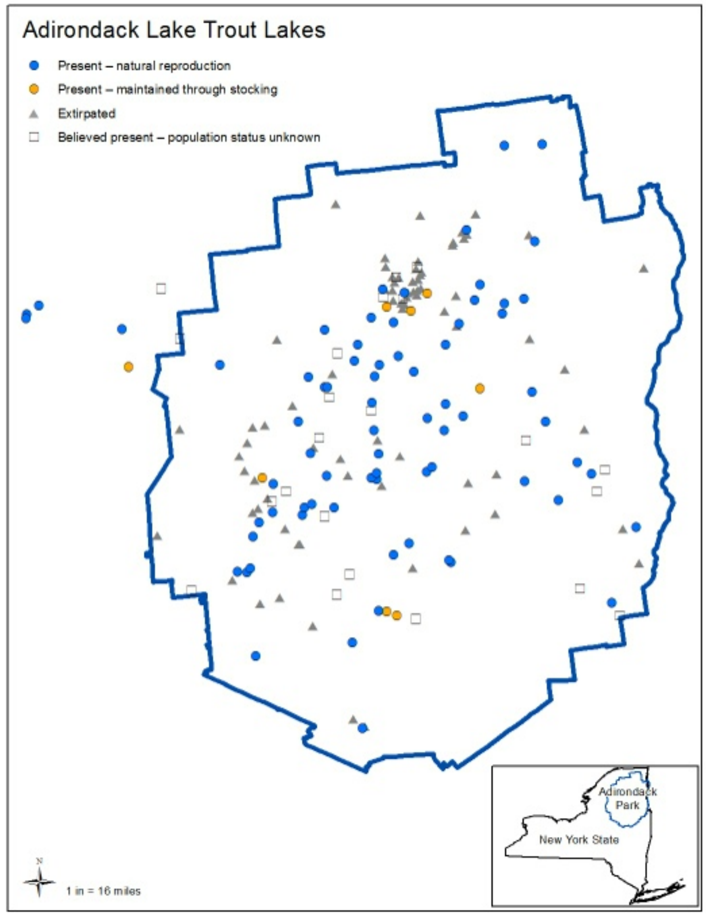
Adirondack range and decline

Excluding Lake Champlain, there are 102 lakes (mean surface area 923 acres) with confirmed or recent records of lake trout in the 12 Adirondack counties. (Figure 1; Appendix A).

Figure 1: Northern New York lake trout lakes

Lake trout are currently found in an estimated 102 inland North Country lakes. They have been extirpated from an estimated 75 lakes (42 percent of former water bodies).

Only Maine is comparable in the 48 contiguous states for number of lake trout waters (approximately 111) spread across a large landscape.



Historical data on the abundance of lake trout in New York are unreliable, according to Daniel S. Plosila, a now-retired DEC associate aquatic biologist, who published the last statewide assessment of lake trout populations, in 1977. Plosila's report estimated that lake trout were then present in 100 Adirondack lakes with a mean surface area of 914 acres.

State fisheries officials first expressed concern over shrinking lake trout populations due to unregulated fishing as early as the 1860s. Around 1870, the New York State Commissioners of Fisheries reported that lake trout was important as a sport and food fish, but its failure to remain abundant justified stocking of "some other equally valuable and more productive species." Smallmouth bass and yellow perch were then introduced widely in the Adirondack interior, and northern pike were moved into new ponds.

In 1977 Plosila listed 34 North Country lakes from which lake trout had disappeared. He identified habitat degradation as the chief cause of decline: stormwater runoff, inadequate wastewater-treatment infrastructure, and other sources of fertilizer that feed algae and deplete oxygen in summer deep-water basins. He also cited overfishing, insecticides and acid rain as factors in the decline/extirpation of individual populations.

By 1981 the species had been extirpated from an estimated 19 percent of its Adirondack habitat because of displacement by introduced species, early overfishing, DDT, acid rain, and pollution caused by deforestation, faulty wastewater disposal and other shoreline activities, according to a report for DEC on Adirondack fishes by Carl George, a biologist with Union College. In the 1980s, the Adirondack Lakes Survey Corporation (ALSC) surveyed smaller ponds (.5 to 700 acres). ALSC estimated 9 to 21 percent of lake trout losses in its sample might have been related to acidification (Gallagher and Baker, 1990). According to DEC, lake trout have been eliminated from approximately 25 Adirondack ponds by reclamation intended to eliminate yellow perch and other introduced fish in the interest of restoring brook trout. At the same time, DEC has restored or established lake trout in approximately 10 waters where the species had been listed as extirpated by Plosila, or where conditions seemed favorable.

A review of records for this report finds that lake trout are no longer detected in approximately 75 Adirondack waters where they were once reported (Figure 1). According to this estimate, lake trout have so far been extirpated from 42 percent of former Adirondack water bodies (total volume of habitat not calculated).

Plosila estimated that two-thirds of Adirondack lake trout waters were open to public fishing; the rest were on private preserves. The current estimate is that 80 percent of lake trout lakes have public access. (Note that some publicly accessible lakes on Forest Preserve are not served by boat launch or reachable by road.)

Lake trout are native to the Canadian Shield and generally do not occur below the 43rd parallel. Lake Erie and the Finger Lakes are southern outliers, able to support lake trout because of extreme volume, depth (up to 600 feet) and glacial history. Lake Erie's and Lake Champlain's native lake trout are believed extirpated; stocked fish grow to large size in those waters, and they spawn, but fry apparently do not survive to mature and replace the population.

Stocking and recovery

In 1977, lake trout populations in 30 Adirondack lakes were maintained or supplemented by stocking, while the rest (~70 percent) were sustained by natural reproduction, according to Plosila. Currently the ratio appears to be about the same; DEC stocks 37 northern New York lakes to create or supplement lake trout fisheries (28 in Region 5, 9 in Region 6).

Early in the 20th century, Finger Lakes lake trout were stocked in Adirondack and peripheral waters but evidently did not interbreed with endemic trout because breeding habitat did not overlap; nor did they survive on their own (Plosila, 1977). Finger Lakes fish have been genetically linked to both Atlantic and Mississippi refugia, habitats physically separated by ice sheets at the periphery of the last glacier (Wilson and Mandrak, 2004). Finger Lakes fish spawn in much deeper waters than Adirondack lake trout and are silvery in color. Adirondack lake trout have been genetically traced solely to the Atlantic refugium. They are darker—similar to the brown or greenish tint of the lakes they inhabit—with yellowish-white bean-shaped spots. It isn't known whether lake trout isolated in individual Adirondack ponds for millennia have evolved genetically unique "heritage" strains as brook trout have, mostly because no one has looked.

According to DEC senior aquatic biologist for Region 5 Richard Preall, the effectiveness of Adirondack stocking techniques and survival of stocked fish have improved over recent decades. All fish stocked in the Adirondacks are raised from **Raquette Lake** broodstock and so are of native heritage. Raquette Lake trout have been genetically tested and linked to the Atlantic refugium (Wilson and Mandrak, 2004). In the 1980s, 60 percent of lake trout DEC surveyed in Raquette Lake had been stocked, 40 percent were wild-born. Since the mid 1990s the ratio has reversed to 60 percent wild, 40 percent stocked. Also, Preall says fewer fish are now stocked because survival rates of hatchery-raised fish increased as size at time of stocking increased.

DEC has harvested eggs from Raquette Lake almost every October since 1933. They are hatched and raised to yearling size (±6 inches) at DEC's Chateaugay Fish Hatchery. DEC has conducted a survey of juvenile lake trout in Raquette Lake every five years since 1980. Its data on wild and stocked Raquette Lake trout are extensive and thorough.

Lake trout were fished out of Lake Champlain in the late 1800s. After a century of stocking and study, lake trout still fail to replace themselves in Lake Champlain for reasons that are not clear (Riley and Marsden, 2009). However, there are examples of successful re-establishment of self-sustaining populations in the upland Adirondacks. DEC cites **Lake George** as a notable recovery. Fry there were failing to survive because of DDT spraying for insect control in the mid 20th century. DEC prohibited use of DDT in the Adirondacks in 1962, and subsequent stocking helped lake trout re-establish. The population was reproducing on its own again by the 1970s. Today Lake George supports a thriving lake trout fishery (Preall, personal communication).

Naturally sustaining populations have also improved in **Seventh Lake of the Fulton Chain, Woodhull Lake, Piseco Lake** and **Schroon Lake**; DEC still stocks those waters (Woodhull excepted), but at a reduced rate, according to Preall. As noted in the "Adirondack range" section above, DEC is now stocking some promising waters where Plosila noted they had been extirpated; these include **Rollins Pond, South Pond, Lake Kushaqua, Polliwog Pond** and **Bug Lake**. Because it takes lake trout up to eight years to reach maturity, the success of reproduction in those waters is not yet known (Preall).

As western Adirondack lakes recover from acid rain damage, they are returning to a pH that can sustain more plant plankton, indicated by levels of chlorophyll A, and more dissolved organics and color (Momen et al., 2006); suspended and dissolved particles in the water column can block sunlight and maintain a larger layer of cold near bottom (NYSFOLA). Also, improvements in wastewater infrastructure have begun to restore water quality on settled lakes; as a result of cleaner water, DEC resumed lake trout stocking in **Sacandaga Lake** and **Lake Pleasant** in 2009.

Reintroductions are taking hold as the region continues to rebound from acid rain and DDT, and to improve wastewater infrastructure. However, threats remain to individual lakes—among them introduced species, lake-level fluctuation in dam-controlled reservoirs, heavy sportfishing pressure on small waterbodies, and oxygen depletion.

Sportfishing and economic impact

Lake trout ranks fifth in sportfishing popularity in New York State, according to a 2007 angler survey by Cornell University (bass were first; brook, rainbow and brown trout were collectively ranked second; walleye third; yellow perch fourth).

Lake trout ranks fourth in popularity in DEC Region 5, which encompasses most of its Adirondack habitat. Anglers spent an estimated $8.2 million in one Region 5 county, Franklin, pursuing all species in 2007 (Connelly & Brown, 2007).

Slow maturity and slow replacement rate make lake trout vulnerable to overharvest and slow to recover following population decline. Current sportfishing regulations are designed to protect populations by ensuring that lake trout surpass spawning size before they can be harvested: In 1977, DEC instituted a default statewide daily creel limit of three fish of at least 21 inches.

The New York State season for lake trout is April 1 through October 15. Lakers may be caught through the ice on designated New York lakes in winter. It’s possible to catch lake trout in inshore waters in early spring or fall, even on a fly, but they retreat to deep water from mid June to early October. Summer deepwater trolling with weighted line is a common way to pursue lake trout, so waters that are accessible by motorboats are subject to the highest fishing pressure (Plosila, 1977). However, a small lake can also be “figured out” and fished hard because its coldwater basin is compact; an example in the High Peaks Wilderness is **Big Pine Pond**, a 40-acre, 65-foot-deep pond where summer holes are predictable and vulnerable to anglers in small boats.

At **First Bisby Lake** in the southwest Adirondacks, Cornell University's Adirondack Fishery Research partnership implemented a catch-and-release policy on lake trout in 1998, after catches in trap-net surveys had dropped to historic low levels. The rationale behind a moratorium on creeling was to protect the remaining adult population and to allow juveniles to reach sexual maturity. Fifteen years later, fall trap-net catches of lake trout show a significant increase from the early 2000s (< 0.25 fish / trap net night) to the early 2010s (2.0 fish / trap net night). The majority of lake trout caught from 2011 to 2013 are juvenile fish from 4 to 10 inches, indicating a population increase among younger fish (Josephson, personal communication).

One approach to angling management

Follensby Pond has been privately owned by the Adirondack Chapter of The Nature Conservancy since 2007. As McGill University scientists study the lake's deepwater fish population structure, the Conservancy prohibits lake trout fishing in summer, when high surface temperature can decrease a released fish's chance of survival. TNC also applies the following rules to minimize stress and mortality from hooking, handling, decompression and temperature change:

- Artificial lures only
- Single, barbless hooks (or barb pinched back)
- No targeting lake trout in July and August
- No lead-core/steel or fast-sinking lines
- Release fish at boat. If a net is necessary, use rubber or knotless mesh
- Keep fish in water while releasing

New York State's calibration of a minimum-size limit appears to have been effective and farsighted in halting the population decline caused by turn-of-the-20th-century overfishing, and in maintaining reproduction during recovery from subsequent environmental stresses. However, anticipated increase in surface-water temperature and decrease in deepwater oxygen appears to have potential to limit lake trout management goals, perhaps even where catch-and-release is implemented. In one study, 87 percent of lake trout caught and released in a Colorado lake during a critical late-summer period with low oxygen (3 mg/L) died (Lee and Bergersen, 1996). (Eighty-eight percent of fish released when the thermal refuge still contained adequate oxygen survived.) Wisconsin's Coldwater Fish and Fisheries Working Group has recommended restricting fishing at times of year when warm temperatures are stressful to stream trout (Mitro et al., 2010). The combination of hooking, low oxygen and temperature shock can kill juveniles and young adults inadvertently hooked. In order to ensure continued naturally sustaining populations, resource managers could monitor deepwater oxygen levels and turnover timing on key lakes, and consider management approaches that go beyond minimum size limits.

Lake trout decline could have an economic impact on Adirondack communities that depend on tourism associated with a North Woods image and trout fishing, especially as warming reduces fishing opportunities for coolwater species such as brook trout.

Increases in non-native warmwater fish such as bass and walleye could offset angler demand. But what makes the Adirondacks a unique and specialized fishing destination in the United States is its Canadian Shield assemblage of native brook and lake trout; only Maine is comparable in the 48 contiguous states for number of lake trout waters (approximately 111) spread across a large landscape (Johnson, 2001).

III. Climate change impacts on Adirondack coldwater habitat

Water temperature: Mean annual air temperature in the eastern Adirondacks warmed by 2.1°F between 1976 and 2005, with the most significant warming during summer and autumn, according to U.S. Historical Climatology Network (USHCN) data analyzed by Curt Stager, paleoecologist and professor of natural sciences at Paul Smith's College.

Based on historical patterns and Intergovernmental Panel on Climate Change (IPCC) model projections, the range of anticipated additional warming in this region over this century is 6–11°F under a scenario of doubled CO^2 emissions, the current path (Stager and Thill, 2010). In simulations, summer surface water temperature increases at a rate directly tied to air temperature, at a proportion of 60 to 80 percent. For example, an air temperature increase of 9˚F would result in a surface-water temperature increase of 5–7˚F (NYSERDA—Shaw, 2011). In actual measurement, the rate can differ from lake to lake. Summer surface-water temperatures are increasing more rapidly than air temperatures in some lakes, including Lake Superior (Austin and Coleman, 2007).

As discussed, lake trout avoid contact with summer surface water; in temperate regions they take refuge in the cold bottom layer of lakes that are deep enough to stratify by temperature (Figure 2). A review of scientific literature revealed little data on temperature change in bottom water to date. Nor has the New York State Federation of Lake Associations identified a clear trend in water temperature in the 110 lakes monitored through the Citizens Statewide Lake Assessment Program (N. Mueller, personal communication). "Most climate change research has not been conducted at a sufficiently detailed scale to evaluate how it affects the small lakes and ponds in New York State," according to the New York State Federation of Lake Associations (2009).

Likewise, there are few projections for bottom-water temperature, although De Stasio et al. (1996), applying several model scenarios to four small northern Wisconsin lakes, supposed: "Maximum temperatures of bottom waters consistently increased for all [current-path CO^2 emissions scenarios] simulations on all lakes." A model applied to a stratified, dimictic lake in Germany predicted that the lake would gradually lose its winter ice cover, would blend only once a year (in winter), and bottom temperatures would increase during summer (Kirillin, 2010). There are so many possible variables that the models are not yet useful for describing a future Adirondack temperature scenario; actual monitoring of deep Adirondack lakes would provide the most useful indicators.

The New York State Energy Research and Development Authority (NYSERDA) 2011 report *Responding to Climate Change in New York State* and the National Wildlife Federation report *Assessing the Vulnerability of Key Habitats in New York: A Foundation for Climate Change Planning* (2013) recommends increased monitoring of stratified lakes for temperature and turnover timing.

Ice cover: While information on bottom-water temperature is scarce and incomplete, the ice-cover record is clear. On Adirondack lakes, ice generally sets up later and melts earlier than it did a century ago; **Mirror Lake**, which contains lake trout, is covered by ice, on average, two fewer weeks than it was a century ago (Stager et al., 2009).

Oxygen and mixing: Oxygen depletion is predicted to be the main driver of climate-related lake trout habitat loss in the Adirondacks.

In fall, surface waters cool and become denser. They descend, displacing deep waters. Autumn turnover mixes oxygen-poor water in the deeper areas with surface water containing more dissolved oxygen. This prevents anoxia, or complete oxygen depletion, of the lower levels of deep lakes.

Researchers project that the seasonal layering of warm surface water and cooler bottom water will set up earlier in spring and endure longer into fall. Oxygen in lake trout habitat will be taxed as the period lengthens. This report was unable to turn up any field data on alteration of turnover timing in temperate stratified lakes. However, a change in pattern has been observed in Lake Tahoe, in California. Tahoe is much deeper than Adirondack lakes and mixes only once per year, but the length of time that upper waters remain stratified has increased by almost 20 days per year since 1965 (UC Davis, 2012).

The Ontario Ministry of Natural Resources requires a dissolved oxygen minimum of 7 mg/L for an inland lake to be designated a "lake trout lake" and thus subject to special management (2006). Plosila in New York and Johnson in Maine recommended that any water considered for lake trout stocking have mid-summer oxygen values of 5 mg/L or greater near bottom. (Milligrams per liter are roughly equivalent to parts per million. Dissolved oxygen content can also be expressed in percentage of saturation; for example, 50°F water containing 6 mg/L of dissolved oxygen is 53 percent saturated.)

In Adirondack lake-trout waters, warm and cold layers usually establish between May and mid June and last into October. Early stratification in Lake Auburn in 2012 appears to have set conditions for a late-summer fish kill (Courtemanch et al., 2013). Early stratification also affects growth. Lake trout feed intensely in spring throughout the water column. Earlier warming forces earlier migration of lake trout to deeper waters, curtailing feeding (King et al., 1999). A delay of mixing in autumn may deplete oxygen in bottom water by as much as 8 mg/L (DeStasio et al., 1996).

How will Adirondack lake trout populations respond to climate change?

Response to warmer temperatures will vary lake to lake, depending on elevation, latitude, depth, flush rate and shape (physical factors). Also influential will be introduced species (biotic factors) as well as nutrients that are washed into a lake from lawns, clearings and inadequate wastewater systems (cultural factors).

In general, warming is projected to cause:

- Oxygen depletion in summer and fall bottom waters (prolonged stratification)
- Smaller coldwater habitats, especially in basins containing extensive shallows
- Lake trout population decline driven by size of coldwater/high-oxygen habitat
- Increased predation by introduced warm-tolerant fish, such as bass and pike
- Change in timing of spawn, hatch and availability of zooplankton food for fry
- Possible increase in lake trout metabolism, resulting in higher food demands and smaller, less-vigorous fish.

Figure 2: Lake trout life events and potential climate change impacts by season

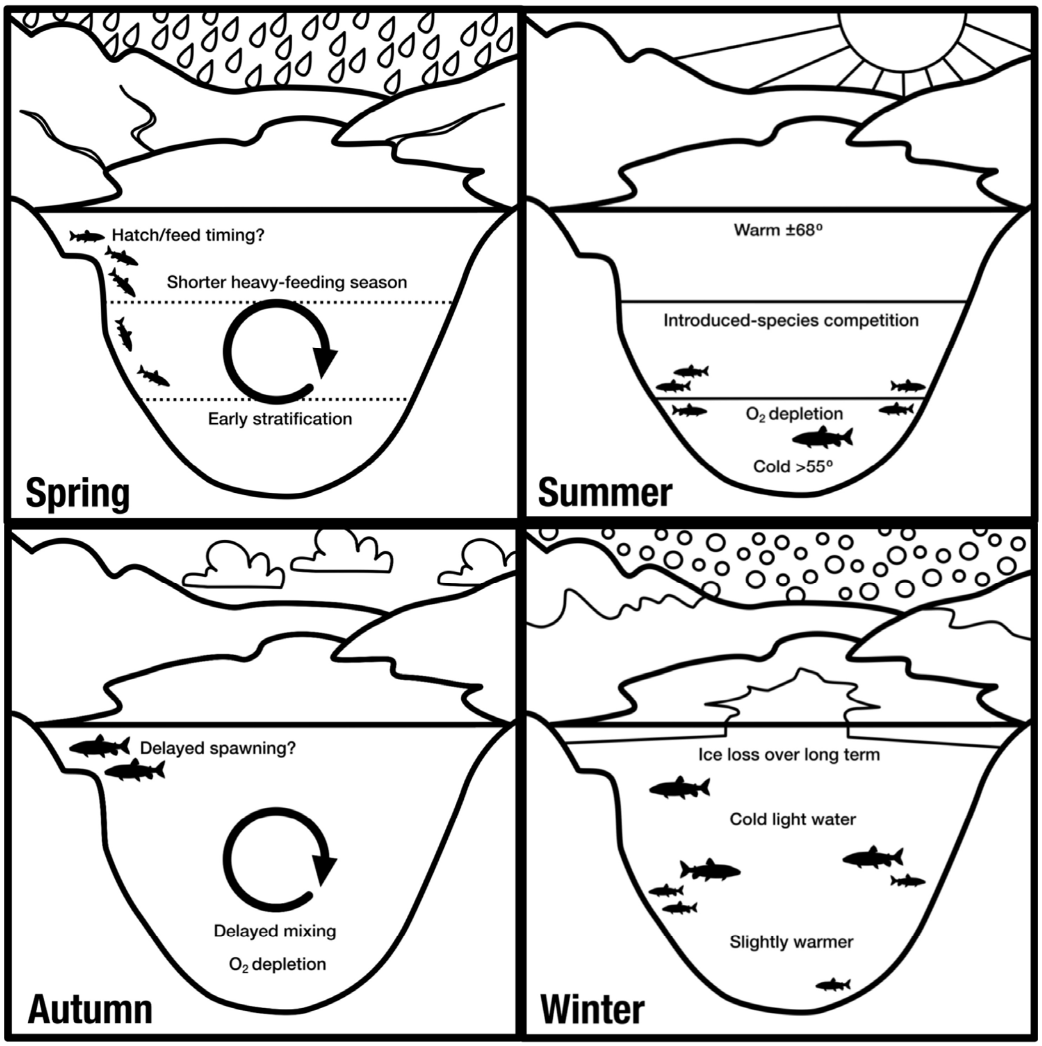


Illustration by Matt Paul

A wide variety of researchers anticipate a range shift. "We would expect cold water species such as lake trout and cisco to be restricted to lakes that are either farther north or at higher elevations than those in which these species now occur," summarizes the Center for Limnology at the University of Wisconsin (DeStasio et al., 1996).

Since the Adirondacks are at the southern limit of lake trout range, habitat is expected to retract here: How much is unclear. The answer will lie partly in the characteristics of individual lakes and their dynamics of change, and partly in management.

Indicators that change may be under way: Since 2010, **Upper Ausable Lake**, a small (153-acre, 49-foot-deep) stratified lake, has had critically low adult lake trout numbers and a paucity of younger fish (Josephson and Field, 2012). Measurements show increased temperature near surface and at thermocline, and low oxygen at depth. No evident preferred habitat was available from mid summer through autumn turnover, 2009–2013. The watershed is small and steep but forested. Scientists monitoring Upper Ausable have ruled out potential factors such as species introduction, siltation or fertilizers. The private owner, Adirondack Mountain Reserve, recently instituted a catch-and-release policy to reduce fishing pressure. Another small stratified Adirondack lake, **Ampersand**, is experiencing similar limited summer oxygen (see page 18). A larger lake (2,300 acres, 118 feet deep), Lake Auburn, in Maine, had a severe lake-trout die-off in summer 2012 following early stratification caused by record warm early-spring temperatures (Courtemanch et al., 2013).

Climate change will occur as a steady progression, but along the way there will be abrupt departures, such as the record-warm spring of 2012. Those departures could be too drastic for a species like lake trout to persist in lakes that already have limited coldwater habitat or declining quality (Courtemanch, personal communication).

Early warning from brook trout

There is little field data on how Adirondack lake trout are responding to climate change in the wild. But long-term monitoring by Cornell University's Adirondack Fishery Research Program has provided information on summerkill of Adirondack brook trout, caused by a combination of warmer water and decreased oxygen.

In **Rock Lake,** a shallow (maximum depth 18 feet) private lake in the southwest Adirondacks, most one-year and older brook trout died in 2005 and 2012, when water temperatures rose above 68°F for a sustained period – and exceeded 77°F at the bottom for at least one day. Young-of-year brook trout survived, probably taking refuge near a groundwater spring in a shallow area of the lake not frequented by adult fish in summer. Two consecutive years of sustained high water temperatures could eliminate brook trout from Rock Lake (Robinson et al., 2010).

Another study found that an increase of 1.8°F in summer mean maximum daily air temperature correlates with a one-week delay in peak spawning by brook trout in Rock Lake (Warren et al., 2012).

Temperature tolerance: In the Adirondacks, lake trout are not found in shallow lakes such as Rock Lake. How lake trout here persist is expected to depend less on direct contact with temperature itself than on how higher temperatures influence oxygen content, volume of habitat, and the dynamics of individual lakes.

Most literature suggests that 51–54°F is an optimal range for adult lake trout reproduction and growth, though fish are sometimes found outside these temperatures in the wild. Lake trout feed throughout the water column all winter, when Adirondack lake temperature is around 39°F. Summer forays into warmer water are rare and brief; temperatures greater than 59°F are unsuitable. Fry and fingerlings seem to fare best at lab temperatures of 48 to 51°F (Minns et al., 2009; Snucins & Gunn, 1995; USGS 1984).

The size of a lake trout population is strongly tied to the volume of habitat available in its preferred range; the more water at suitable temperature and oxygen, the more lake trout (Christie and Regier, 1988).

In Ontario researchers have identified four temperature classes of lake trout, indicating that lake-specific populations may be locally adapted. The four temperature classes include a "warm-adapted" class found in small lakes at temperatures of 53.6–57.2°F (Minns et al., 2009). There is no information on whether Adirondack lake trout have different temperature preferences in different lakes. But the concept raises questions about adaptation potential. Would cold-adapted (42.8–46.4°F) fish have a wider margin for adaptation, or narrower because colder habitat is expected to shrink more quickly (Minns et al., 2009)? Should warm-adapted fish be favored in stocking?

Isolated trout populations may evolve unique characteristics or behavioral traits to adapt to their local habitats. Because these fish have solved a variety of problems, many argue they are worth preserving—especially if specialized adaptations become important in the face of rapid environmental change.

In any case, since populations are restricted to a single body of water, the quantity and quality of cold, oxygen-rich habitat will determine persistence to a greater degree than adaptation strategies of separate populations (Courtemanch, personal communication).

Spawn timing: Spawn timing could change if surface water remains warm longer in fall, which could also alter hatch timing. The emergence of zooplankton that fry eat to survive could also change. The decoupling of predator from prey is potentially one of the most severe consequences of warming in temperate lakes (Peeters et al., 2007).

On Raquette Lake, spawn occurs in mid October when surface waters cool to 50–55°F. DEC records dating back to 1964 show no significant change in timing of peak spawn; nor do they show a trend in surface-water temperature during spawn. There is no apparent correlation between the occasional warmer-water peak spawn (57°F) and egg viability (NYSDEC records and Preall personal communication).

Lake trout eggs are found at depths of 100–200 feet in the Finger Lakes (Smith, 1985). This raises another adaptation question: whether lake trout in Adirondack lakes could move to deeper water to spawn, if autumn surface-water temperatures are disrupted.

Young of year: Lake trout younger than one year old have little energy reserve, so they are particularly sensitive to changes in temperature and food supply. Long-term data from an unstratified Arctic lake (McDonald et al., 1996) may provide insight into how temperature could affect them. Contact with warmer water puts direct stress on coldwater fish. When temperature rises, their metabolic rate increases: they must eat more to compensate. McDonald et al. used simulation models to predict that first-year trout in Toolik Lake, Alaska, would need to consume at least eight times as much food to achieve the same size as historically surviving fish if water temperature increased 5.4°F. In New York State, newly hatched lake trout remain on spawning beds for about four weeks before moving to deeper water, around May (Smith, 1985). As mentioned, delayed hatching could throw off synchrony with emergence of zooplankton that fry prey on to survive. Young-of-year lake trout can be hard to find but they have been observed during snorkel surveys in the summer in Woodhull Lake near the lake bottom at thermocline, the division between warm surface water and cold deeper water (Josephson, personal communication).

Fry and immature lake trout face increased competition and predation in that transition zone between warm and cold water. Northern pike and non-native bass are warm- and coolwater species, but as they grow larger they also frequent cold water in the 50–55°F range to regulate metabolism and to forage. If small-to-midsize trout don't have deeper, well-oxygenated 45°F-or-lower water to retreat to, they fall victim to predation in the middle threshold, narrowing the chance of young generations reaching maturity and replenishing their population (Preall, personal communication).

Intensity of precipitation: Data from the Lake Placid weather station show that the number of storms depositing more than 2 inches of precipitation within 48 hours doubled from a mean of 0.8 events per year in the early and mid-1900s to 1.5 per year after total annual precipitation increased in the early 1970s. The annual increase is probably not due to an increase in storm frequency but rather to an increase in average amount of precipitation per storm, pushing more storms above the 2-inch threshold (Stager and Thill, 2010). According to the 2014 National Climate Assessment, the Northeast has experienced a greater recent increase in extreme precipitation than any other region in the United States.

Floods and downpours wash fertilizer and silt into waterways and can overwhelm sewage systems. Warm surface-water temperatures catalyze fertilizers into algal blooms, especially in developed watersheds that are loaded with phosphorus and nitrogen. "It may not be coincidental that increasing occurrences of harmful algal blooms and toxic algae in recent years has been coincident with . . . warming trends," the New York State Federation of Lake Associations (NYSFOLA) stated in 2009.

When blooms fade, dead cells fall to the bottom and are decomposed by bacteria, which consume a considerable amount of oxygen in the process. Basins that de-oxygenate every summer are anoxic, or “dead zones.” Basins that fall below 7 milligrams of oxygen per liter are considered unsuitable for lake trout by Ontario provincial standards. Plosila in 1977 recommended that lake trout not be stocked in New York waters with less than 5 mg/L of dissolved oxygen. Literature on laboratory conditions reports that salmon and trout die when dissolved oxygen drops below 3 mg/L for a prolonged period. Lake trout caught and released into a Colorado lake with <3 mg/L of dissolved oxygen during late summer experienced a high rate of mortality (87.5 percent) (Lee & Bergersen, 1996). DEC has netted lake trout in waters with dissolved oxygen as low as 2–4 mg/L in Upper Saranac Lake, though it is not known if those fish dwelled there or were passing through on feeding forays (Preall, personal communication).

Actions to reduce runoff could have more influence on a lake’s long-term resilience than temperature itself. Methods to keep sediment and nutrients out of waterways include: maintaining natural buffers of shoreline trees and plants, limiting deforestation (clearcutting for building as well as logging), minimizing fertilizer use, and improving wastewater and runoff-catchment systems.

Lakes with a high flush rate (water is replaced more than once every two years in big lakes, more than once a year in lakes of less than 500 acres), and deep high-volume lakes have natural buffers that hinder nutrient accumulation.

Groundwater: Regardless of management and cultural factors, lake trout living in shallower lakes where coldwater zones are narrow are simply at the edge of viability.

Occasionally lakes are not deep enough to provide a stable layer of cold at the bottom in summer. Snucins and Gunn (1995) reported that lake trout in a shallow Ontario lake used a cold groundwater seep to avoid warm temperatures. Groundwater is more commonly associated with brook trout near shore, but two Adirondack landowners describe lake trout congregating around what they believe to be seeps at depths of 30 feet or greater (personal communications).

Groundwater is equal in temperature to mean air temperature. It is expected to warm at a more gradual rate than air, as determined by a formula based on depth and surrounding mass. This puts an indefinite time limit on the suitability of lakes whose coldwater refuges are provided by springs. Mean annual air temperature in the Adirondacks currently ranges between 40 and 45°F (NOAA). If current emissions projections are realized, the mean annual Adirondack air temperature could range 46–51° to 51– 56°F by the year 2100. If upper-end temperatures are realized, lake trout that are dependent on groundwater for summer refuge would reach the threshold of viability. Models cannot project temperatures beyond 2100 because of the unknowns of future greenhouse gas emissions. However, temperature is expected to plateau for centuries before CO^2 can be re-absorbed, no matter how much fossil fuel is burned (Inman, 2008).

Case Studies

Some lakes are vulnerable while others show potential to serve as lifeboats in a warmer, stormier future. Following is a look at the future of three lakes.

1. Upper Saranac Lake: vulnerable primarily because of cultural factors

Upper Saranac Lake, in southern Franklin County is a large (5,200 acres), deep (maximum depth 95 feet), historical lake trout fishery at an elevation of 1,572 feet. Upper Saranac once served as a broodstock for other Adirondack waters but is now an illustration of what could happen to slow-flushing Adirondack lakes in developed landscapes under warmer and stormier conditions.

Since the late 1980s Upper Saranac's deepwater refuges have been compromised by excess phosphorus and nitrogen, and water quality approached eutrophic 1989–1992. The north basin has de-oxygenated entirely, and south basin oxygen has fallen below 4 mg/L in September (Upper Saranac Lake Citizen Advisory Committee, 1998). Introduced warm- and coolwater predators such as smallmouth bass and northern pike have been established since at least 1929.

Lake trout now fail to replace themselves in Upper Saranac, and numbers are maintained by stocking. It's a put-and-take fishery, but a popular one. DEC biologist Rich Preall hypothesizes that lake trout probably do reproduce, but as smaller lake trout are forced out of deoxygenated bottom water in late summer they fall prey to introduced fish—larger bass and pike that frequent the 50°F zone. A high ratio of shallows also favors species that tolerate warmer water.

Residential development and infrastructure (lawns, septic systems, a NYSDEC fish hatchery, campgrounds, a golf course, roads), have all contributed nutrients (Upper Saranac Lake CAC, 1998). A flushing rate of once every 1.2 years abets accumulation of years of sediments. This internal source of phosphorus is continually released, even as leaky septic systems, fish-hatchery effluent and other inputs have been reduced. According to independent limnologist Michael Martin, who studied and helped manage Upper Saranac Lake in the 1990s, even without factoring warmer temperatures and more inputs, it can take a hundred years or longer for a lake to recover from a significant decline in water quality.

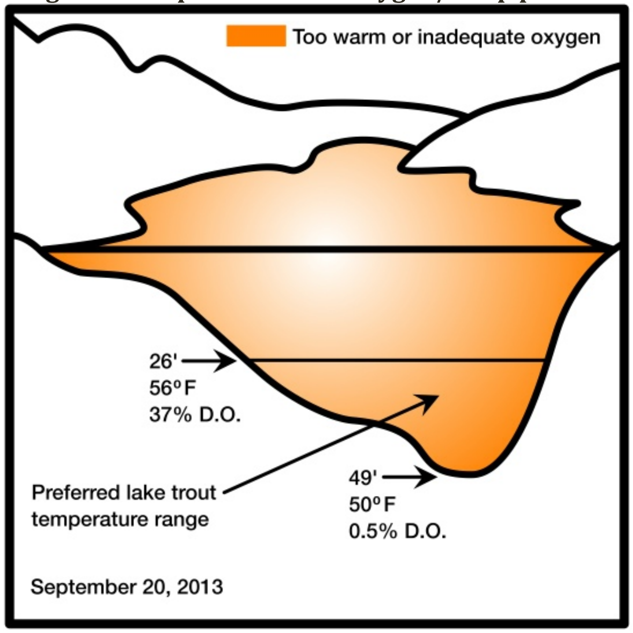
Two public boat launches and a private marina provide fishing access. DEC continues to monitor lake trout size and age classes in Upper Saranac.

2. Ampersand Lake: vulnerable because of physical factors

Ampersand Lake, also in southern Franklin County, is on the shallower end of the spectrum of Adirondack lake trout lakes at 46 feet deep. The surface area is 338 acres, and elevation is among the highest lakes in the Adirondacks, at 1,877 feet.

The lake is privately owned and buffered by forest, and has long been protected from fishing pressure and introduced species, despite unsuccessful attempts to stock rainbow trout and Canadian-strain brook trout in the early 1970s. Ampersand appears to support a primeval fish assemblage: the top predators are brook and lake trout and no known alien species are present.

Figure 3. Ampersand Lake oxygen/temp profile



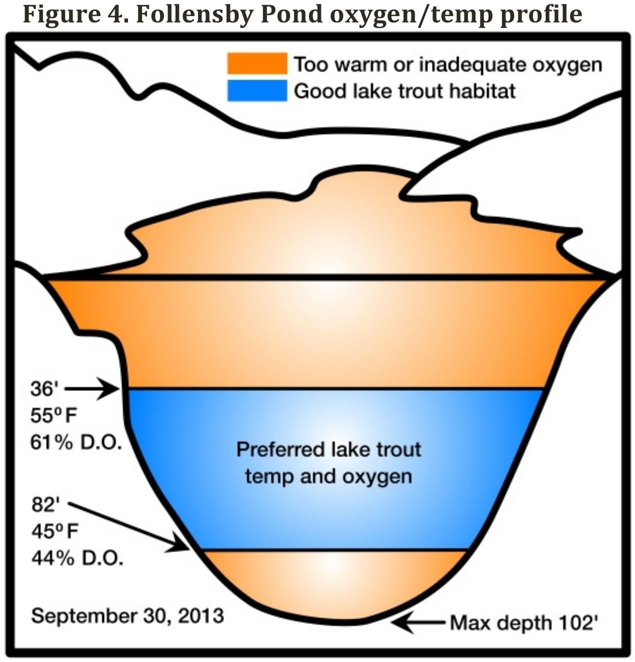
The owners describe lake trout fishery as healthy. They also say summer lake trout locations may be influenced by groundwater seeps (personal communication).

Although outside stresses are minimized and the lake is under optimal management, readings taken in September 2013 show inadequate deepwater oxygen: where lake trout temperatures were optimal, oxygen was below 3 milligrams per liter. Surface waters had adequate oxygen but unsuitably high temperatures for lake trout.

Ampersand is among the vulnerable lakes because of physical characteristics: a small coldwater refuge and lack of depth. A similar but more severe (advanced) scenario may exist for the declining lake trout population in Upper Ausable Lake.

3. Follensby Pond: potentially resilient because of physical and cultural factors

Figure 4. Follensby Pond oxygen/temp profile



Also in southern Franklin County, Follensby Pond, at an elevation of 1,545 feet, meets several criteria for resilient habitat. It is deep—maximum 102 feet—and bathtub-shaped: deeps are extensive while shallows are limited.

Dissolved oxygen content is high throughout: an oxygen/temperature profile from September 2013 shows sufficient oxygen at optimal temperatures, at 36–82 feet.

The 1,000-acre lake is privately owned and fishing pressure has been limited, historically as well as presently. There is minimal shoreline disturbance and the watershed is forested and protected from development. Introduced species such as smallmouth bass, perch and northern pike are well established, likely since the late 1800s. They are blamed for eliminating a native brook trout population, but their impact on deepwater fish is limited by minimal shallows. Lake trout appear to be abundant; the size of trout typically caught is six pounds (Tom Lake, personal communication).

The current owner, the Adirondack Chapter of The Nature Conservancy, has begun to monitor the lake's chemistry and evaluate the abundance and age structure of lake trout and cisco populations.

A New York State Conservation Department 1933 biological survey of the Raquette watershed indicates a long history of advantages:

> *In attempting to determine what elements have had a part in maintaining the [Follensby] fish population at such a high level over many years, consideration has been given to the fact that the lake is privately owned and not open to public fishing. It is obvious that this factor alone is not responsible, for many privately owned waters are so restricted but provide indifferent fishing.*
>
> *A partial explanation is to be found in the character of the water itself for it is clear and white and contains more dissolved oxygen at the bottom than many lakes at the surface. The [bathtub] contour of the lake basin and the almost total absence of weed beds may account in part for the relative scarceness of the yellow perch for the lake has few real shallows and bass and pike can forage to the shoreline.*

Climate impacts summary

Lake trout are an apex predator: their loss would signal a restructuring of an Adirondack lake's food chain.

By 2011 NYSERDA criteria, lake trout are "highly vulnerable" to a warming region:

- adapted to cold or high-elevation conditions
- near the southern boundary of their range
- a narrow range of temperature tolerance
- specialized habitat requirements
- susceptible to new competitors

Yet, properly managed, a number of Adirondack lakes show potential for resilience. Despite the unpredictability of many aspects of climate change, these waters are "best bets"—places most likely to sustain coldwater fish into the next century.

Which Adirondack lakes will no longer support lake trout?

- Shallower lakes where deep-water refuges are already small are vulnerable to oxygen depletion and habitat retraction as temperatures warm.
- Lakes that have been heavily disrupted by introduced species such as smallmouth bass, or whose oxygen is depleted by human activities in the watershed, are expected to experience magnified stress.
- Lakes in settled or deforested watersheds are vulnerable to more intense precipitation, erosion, nutrient-loading and subsequent oxygen loss at depth.

Which Adirondack lakes are likely to continue to provide resilient lake trout habitat?

- Larger, deeper, fast-flushing (at least once every two years for big lakes or at least once a year for smaller lakes) highly oxygenated, stratified lakes in forested watersheds may provide refuge even as air temperatures warm—if invasive species and other stressors are limited.

How much Adirondack lake trout habitat will be lost?

In **Ontario**, the Ministry of Natural Resources developed a forecast method that projects a decline in lake trout habitat of **30 to 40 percent** for the province as a whole by year 2100 (Minns et al., 2009). Stefan et al. (1996) projected that northern **Minnesota** could sustain a **41 percent** reduction in coldwater habitat by 2100.

Since New York State is the southern limit of lake trout range, decline is anticipated, driven by shrinking habitat. NYSERDA concluded that the dynamics in New York require further study "to determine how many lakes may develop serious oxygen deficiencies in the zones favorable to coldwater fish."

As a next step, the Adirondack Chapter of The Nature Conservancy, with input from DEC and Cornell, has begun to evaluate the long-range viability of the 102 known Adirondack lake trout waters. The Conservancy is beginning to rank potential resilience by physical characteristics, such as depth and volume, as well as by cultural and land-use variables, such as shoreline vegetation. A spreadsheet containing this information is available to researchers and lake managers for more-detailed analysis (see Appendix A for excerpt).

IV. Research and management

There is a clear and widespread need for more monitoring and field data. The information synthesized in this report may also have management implications for public and private waters. Reduction of coldwater habitat is inevitable but does not necessarily imply extinction from the region, if other stresses can be minimized. Actions that resource managers, policymakers and landowners take now appear likely to influence how many lake-trout lakes will persist in the Adirondacks.

Research and planning

- Increase monitoring of stratified lakes for temperature, oxygen, water quality, species assemblages, chemical composition and water level.
- Monitor the timing of spring stratification and autumn mixing on a set of lake trout lakes.
- Monitor the timing of spawn and hatch on more Adirondack lakes (currently only Raquette Lake has a set of long-term spawn/turnover information).
- Rank or classify lakes by vulnerability or potential resilience to warming and related stresses.

Note: A full suite of native deepwater species, including forage fish such as cisco, should be considered in assessments of viability of shared habitat.

Management

- Minimize impervious surfaces, shoreline lawns, and land uses that speed the input of stormwater and fertilizer into lakes. Encourage shoreline buffers of trees and plants that help absorb and filter precipitation and mitigate flooding.
- Prevent introduction of invasive species. In the absence of warm- and cool-tolerant competitors such as smallmouth bass, lake trout populations are more resilient as young are forced out of de-oxygenated basins. Other warmwater-shallows species reduce lake trout numbers at the egg and fry stage as well.
- Avoid collateral damage to potentially heritage lake trout populations when reclaiming waters for heritage brook trout.
- Consider angling-management alternatives for populations that appear especially vulnerable or exceptional. This report does not suggest a specific course of action; however, The Nature Conservancy's Adirondack Chapter is in the midst of working with McGill University scientists to model several management scenarios at Follensby Pond that could inform management decisions there and on similar lakes. There is so much unpredictability with climate change, and some fisheries are changing so rapidly, that the places that

are most likely to serve as lifeboats into the future may merit conservative management.

- Lake levels may become more variable as precipitation patterns change. To protect eggs from freezing or drying, lake trout lakes should not be subject to dam-controlled water drawdowns between spawn and hatch.

- Limited management resources should focus on waters where there is a chance of re-establishing naturally reproducing populations over the long term. For example, deep Adirondack lakes that are recovering from acid precipitation are likely candidates for stocking with lake trout.

- On the other hand, when considering how to allocate resources, there is reason to conduct cost-benefit analyses of stocking lakes where conditions prevent populations from replacing themselves.

- Avoid stocking lake trout in “heritage” lake trout waters that have likely never been stocked. These glacial-remnant populations have unique genetic material and are increasingly a rarity. “The luxury of having native populations with no stocking history is becoming scarce. . . . For the dwindling number of native lake trout populations on the [Canadian] Shield, [stocking] carries considerable genetic risks, particularly in small lakes where the native population may have been progressively fine-tuned to local conditions over literally hundreds or thousands of generations” (Wilson and Mandrak, 2004).

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As writer, editor and desk researcher, I hope I've helped others tell their lake trout story.

	LAKE #	Max Depth (ft)	Abundance (1977)	Abundance (current)	Current pop. source	2013 Stocking	Elev (ft)	Surface area (a)	County	Motor launch
1	020367	200	H	H	Natural		321	28160	Warren	Y
2	060277	180	H	H	Natural		1878	885	Hamilton	N
3	020254	164	H	H	Natural		1900	2801	Essex	Y
4	050374	152	M	M	Both	6600	807	4128	Essex	Y
5	040088	143	M	M	Natural			314	St. Law.	Y
6	070717	140	L	M	Both	2600	1550	554	Fulton	Y
7	040808	129	H	H	Natural		1787	671	Herkimer	N
8	050234	129	M	H	Both	3500	1660	2848	Hamilton	Y
9	050421	106	M	H	Both	330	1081	166.7	Essex	N
10	060182	105		H	Natural		1788	142	Franklin	N
11	020414	104	U	U	Natural if present		1462	101	Washington	N
12	060186	102	H	H	Natural		1545	934	Franklin	N
13	040977	101	M	M	Natural		2028	151	Herkimer	N
14	060307	100	H	M	Both	1000	1789	1261	Hamilton	Y
15	060165	100	U	M	Natural			205	St. Law.	N
16	040787B	100	M	M	Stocking			851	Hamilton	Y
17	060293	96	H	H	Both	5000		5274	Hamilton	Y
18	020227	95	M	M	Both	1700	138	856	Clinton	Y
19	020114	95	M	M	Stocking	10500	1573	5056	Franklin	Y
20	060112	90	M	H	Natural		1732	302	Franklin	N
21	040982	90	M	H	Natural		1875	1158	Herkimer	N
22	050412	90	H	H	Natural			421	Essex	N
23	040056	89	M	M	Both	650		128	Jefferson	Y
24	040552	89	M	M	Natural		1804	325.3	Hamilton	N
25	020055	88	L	M	Both	1300	1670	376.9	Franklin	Y
26	040958	85	U	M	Natural		1422	229	Oneida	N
27	040790	81	H	H	Both	1100	1791	302.8	Hamilton	Y
28	050458	80	U	H	Natural		1913	83	Essex	N
29	020161	80	M	H	Both	900	1617	448.8	Franklin	Y
30	050597	80	M	M	Stocking	6400	1649	4365	Hamilton	Y
31	040782D	80	H	M	Both	5800	1831	2171	Herkimer	Y
32	050694	80	H	H	Natural		1736	506	Essex	N
33	040009	80	M	M	Both	900	328	166	Jefferson	Y
34	060109	80	L	M	Both	10000		3782	Franklin	Y
35	040789	80	E	M	Both		2015	80	Hamilton	N
36	050292	79	M	L	Natural		2119	96.6	Warren	N
37	040746	79	U	L	Natural			102	Herkimer	N
38	020234	78	M	M	Natural		1815	22	Essex	N
39	030006B	78	M	L	Stocking	9000	1309	2594	Clinton	Y
40	020168	77	E	M	Stocking	1000		436	Franklin	Y

	POND #	Max Depth (ft)	Abundance (1977)	Abundance (current)	Current pop. source	2013 Stocking	Elev (ft)	S. area (A)	County	Motor lau
41	060087	76	H	H	Natural		1558	289.7	Franklin	N
42	060097	76	U	M	Natural		1696	896	Franklin	N
43	070836	76	L	L	Natural		1376	48.7	Herkimer	N
44	060313	75	U	H	Natural		1902	168	Hamilton	N
45	020436	75	U	U	U		836	123.5	Washington	
46	050395	75	H	H	Natural		1556	77	Essex	N
47	040024	75	E	L	Stocking	1800	768	1248	Lewis	Y
48	020120	74	E	L	Stocking (Both?)	700		208	Franklin	N
49	020020	72	M	L	Both	1500	1541	1807	Clinton	Y
50	050715	72	R in 1932	L	Stocking	830	1808	252	Essex	N
51	050313	72	E	U	Stocking	2100		1504	Hamilton	Y
52	060083	70	U	H	Natural		1659	141	St. Law.	N
53	040752	70	L	M	Natural		1825	1286	Herkimer	Y
54	020088	70	M	M	Natural		1660	256	Essex	N
55	040055	70	M	M	Natural		300	499	Jefferson	Y
56	060329	70	M	L	Natural			154	Hamilton	N
57	020379	70	L	L	Natural			237	Warren	Y
58	030369	70	H	H	Natural		1512	416	St. Law.	N
59	020083	70	M	M	Natural		1548	140	Essex	Y
60	050654	69	H	L	Natural		1870	26	Hamilton	N
61	050442	69	H	U	Natural if present		1237	77	Essex	N
62	030253	68	M	M	Natural		1637	45.2	Franklin	N
63	060257	68	L	M	Natural		1761	127.9	Hamilton	
64	050626A	66	M	L	Natural			275	Hamilton	N
65	040782C	66	H	L or E	Natural	450	1707	239	Herkimer	Y
66	050541	65	U	H	Natural		1176	1414	Hamilton	N
67	040281	65	M	M	Both	300 -new		237	St. Law.	N
68	020098	65	M	L	Both	180	1560	45.9	Franklin	N
69	020181	64	H	M	Both	300	1607	116.1	Franklin	N
70	050314	62	E	L	Stocking	2800		620	Hamilton	Y
71	040976	62	M	H	Natural		2028	000116	Herkimer	N
72	070908	62	L	U prob E	Natural if present			179	Hamilton	N
73	050247	62	H	H	Natural		1699	288.7	Hamilton	N
74	050625	62	H	M	Natural		1597	50.1	Hamilton	N
75	050432	61	M	H	Both	1550	817	934.5	Essex	Y
76	020250	60	M	M	Both	450	1855	128	Essex	N
77	030293	60	L	L	Both?	1200		365	St. Law.	
78	060146	60	H	M	Natural			371	St. Law.	
79	050682	59	P	M	Natural			376	Essex	N
80	060312	58	U	H	Natural		2020	117.6	Hamilton	N

	POND #	Max Depth (ft)	Abundance (1977)	Abundance (current)	Current pop. source	2013 Stocking	Elev. (ft)	S. area (a)	County	Motor lau
81	020198	57	E	M	Stocking	Stocked surplus	1611	998	Franklin	N
82	050597A	54	L	L	Stocking	(Indian Lake)	1650	356	Hamilton	Y
83	060221	54	M	M	Natural			173	Essex	N
84	030128A	53	M	U	Natural if present		1699	12.4	Franklin	N
85	060255	52	M to H	U	Natural if present		1745	250	Hamilton	N
86	050281	51	L	U	Natural if present		1673	49.9	Hamilton	
87	060145	50	H	L or E	Natural if present		1650	51	St. Lawrence	N
88	040120	50	M	M	Natural			51	St. Lawrence	N
89	060248	50	M	M	Both	2500	1723	563	Hamilton	Y
90	020277	47	M	L	Natural			134	Essex	N
91	060202	46	H	H	Natural		1875	352	Franklin	N
92	060245	43	L	M	Stocking	1400		425	Hamilton	N
93	060142	42	U	L	Natural		1909	101.8	Hamilton	N
94	050685	41	M	M	Natural		1598	679	Essex/Hamil.	N
95	050457	40	M	U	Natural if present		1830	63.7	Essex	N
96	050293	40	H	H	Natural			26	Warren	N
97	070936	40	L	L	Natural		2456	115	Hamilton	N
98	020173	38		M	Natural		1588	63	Franklin	N
99	060208	38	L	M	Natural		1650	6.7	Franklin	N
100	040584	35		L	Stocking	2000		144	Herkimer	Y
101	060306	31	L	L	Both (emigrants)		1788	162.5	Hamilton	Y
102	030147	30	U	L	Natural if present		1594	24	Franklin	N

Lake names are omitted in consideration of landowners who contributed information about private lakes, and in hopes of not influencing fishing pressure on any waters.

More data is available upon request to researchers and lake managers. Please contact:

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