Chemical and Biological Recovery from Acidic Deposition in the Honnedaga Lake Watershed

Abstract

Honnedaga Lake supports one of seven remaining heritage strains of brook trout designated by the State of New York. During the past century, long-term acidic deposition has altered water chemistry and fish populations within the Honnedaga Lake watershed. Brook trout were the only fish species known to inhabit Honnedaga Lake prior to European settlement. Stocking of hatchery reared fish in the late 1890s resulted in the establishment of reproducing populations of lake trout, round whitefish, creek chub, and white sucker, but all of these species – with the exception of brook trout – disappeared from the lake between 1930 and 1955. By 1980, surface waters were chronically acidified (pH <5) with inorganic monomeric aluminum at lethal levels (>150 ug/L) for brook trout. Yet during this period of chronic acidification brook trout were able to sustain populations in several small groundwater tributaries to Honnedaga Lake where pH remained >5. Amendments to the Clean Air Act in 1990 lead to decreased SO_4 (sulfate), increased pH (>5), and decreased inorganic monomeric aluminum (<50 ug/L) in lake surface waters with a coincident modest recovery of the brook trout population in the lake. The continued chronic acidification of numerous tributaries likely limits young-of-year survival and recruitment; and, therefore continues to limit adult brook trout abundance in Honnedaga Lake.

Male and female brook trout from Honnedaga Lake (Fall 2007)

Introduction

Honnedaga Lake is the largest (770 surface acres) and deepest (183 feet) water body on the ALC Preserve. Honnedaga Lake was historically called “Transparency Lake” owing to it’s high water clarity with visibility greater than 75 feet. At 2,300 feet above sea level, Honnedaga is one of the highest elevation lakes on the Preserve. Honnedaga Lake supports one of the seven remaining heritage or original genetic strains of brook trout designated by the State of New York.

Honnedaga Lake is classified as a thin-till drainage lake with poorly buffered soils and is highly susceptible to acid deposition from airborne pollutants. Due to it’s location in the southwestern Adirondacks, the watershed receives large amounts of acid-laden precipitation in the form of rain and snow (Figure 1). The combination of a poorly buffered watershed and large amounts of acidic deposition result in Honnedaga Lake being highly sensitive to the effects of acidic deposition.

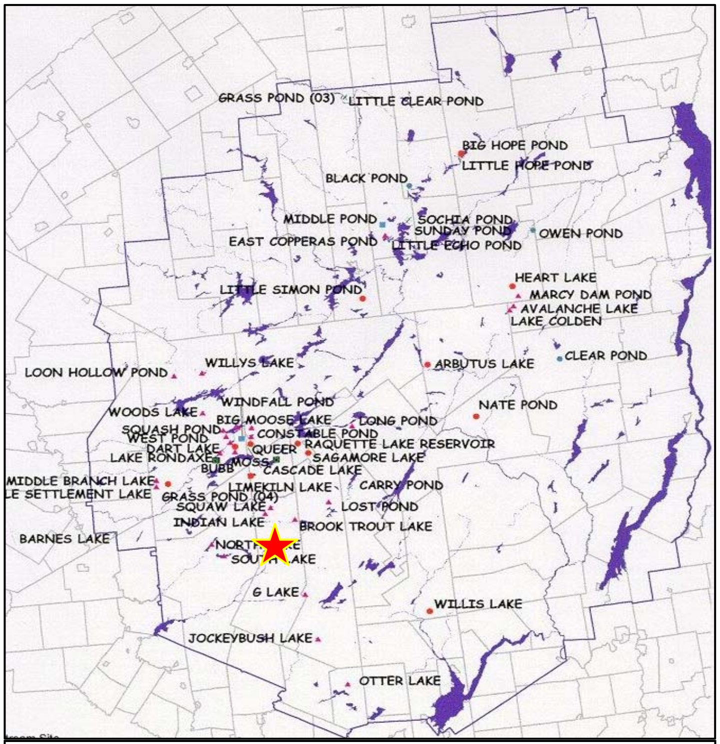
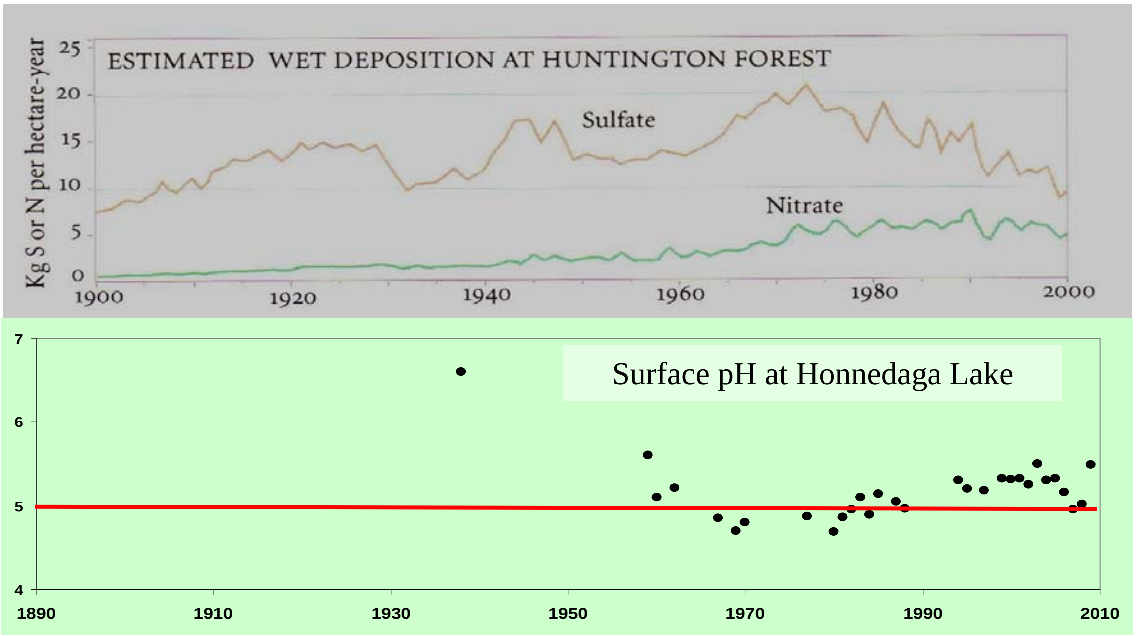


Figure 1. Location of Honnedaga Lake (*red star*) in relation to 52 Long-Term Monitoring lakes monitored by agency scientists to assess the impacts of acid deposition in the Adirondacks

Historical changes in the fish community provide insight into the effects of acidic deposition on Honnedaga Lake’s chemistry and biota. Brook trout is the only fish native to the lake. In the early 1890s, lake trout, round whitefish, white sucker, and creek chub were introduced to Honnedaga Lake and established self-sustaining populations. A lake trout sport fishery thrived between 1890 and 1930, with typical fish averaging around three pounds and at times reaching ten pounds. Round whitefish, white sucker, and creek chub had disappeared from the lake by 1930, and lake trout were no longer present by 1955. Only brook trout are now found in the lake, and hindsight suggests that the disappearance of various fishes – including the near loss of brook trout from this lake in the 1970s – can now be attributed to the acidification of Honnedaga Lake by airborne pollutants.

Water chemistry data from Honnedaga Lake is scarce for the years prior to the late 1950s. However, estimates of sulfate (sulfuric acid) and nitrate (nitric acid) wet deposition for the Adirondacks are available from the SUNY-ESF Huntington Research Forest near Newcomb (Figure 2a). Creek chub, white sucker, and round whitefish were no longer found in Honnedaga Lake by 1930, by which time sulfate and nitrate wet deposition had increased substantially. Sulfate and nitrate levels continued to increase by 1955, at which time the first pH measurement was taken from Honnedaga Lake that indicated that pH was unusually low at a level of less than 5.5 (the lethal limit for lake trout). During the peak of sulfate and nitrate deposition in the 1970s and 1980s, brook trout were not observed within the main body of the lake and were relegated to a few small groundwater-fed tributaries where pH remained >5. Brook trout require groundwater to spawn and often move back and forth from tributaries to large lakes and rivers, therefore these fish were able to utilize small tributaries as refuges during the period of chronic lake acidification during the 1970s and 1980s (Figure 2b). Improvements in surface water chemistry (increased pH, decreased sulfate, and decreased monomeric aluminum concentrations) in Honnedaga and other Adirondack lakes resulted from amendments to the Clean Air Act in 1990, which ultimately contributed to making conditions suitable for brook trout survival in Honnedaga Lake.



2a

2b

Figure 2. Wet deposition of sulfate and nitrate at Huntington Forest from 1900-2000 (*2a*) and surface water pH in Honnedaga Lake (*2b*) from 1900-2009. Red line on lower panel indicates pH 5.

Honnedaga Lake provides an opportunity to evaluate changes in brook trout populations and habitats that support various life stages of these fish in response to improving water chemistry conditions, as well as explore questions about growth, survival and reproduction of this species in this unusually large lake. Our primary management and research goals are to maintain the heritage population through natural reproduction and restore a recreational brook trout fishery in Honnedaga Lake. The remainder of this section summarizes what we have learned during the past decade of evaluations of the water chemistry and brook trout population in the Honnedaga Lake watershed.

Methods and Results

Lake Water Chemistry

Water samples have been collected sporadically from Honnedaga Lake since the late 1950s. More comprehensive seasonal (May through September) evaluations of water chemistry in the lake and tributaries were initiated in 2001 to more accurately describe the water chemistry within the entire Honnedaga Lake watershed. Sampling initially focused on measurements of pH, acid neutralizing capacity (ANC), and temperature in the lake and tributary sites; then expanded to include a broader range of water chemistry measures. Peter Grose (Honnedaga Lake member) organized the current volunteer water sampling program in 2006, allowing for detailed weekly measurements of lake surface water and selected tributary chemistry from May through September.

Very little pH and other chemical data are available from Honnedaga Lake prior to the late 1950s. The only known pH measurement prior to the 1950s was reported as a value of pH 6.6 in 1938, but the analytical method is unknown. Reliable pH data collected since 1960 show a sustained period of summer surface pH <5 from 1960 through 1990, after which summer surface pH has consistently been >5 and sulfate levels have declined (Figure 3).

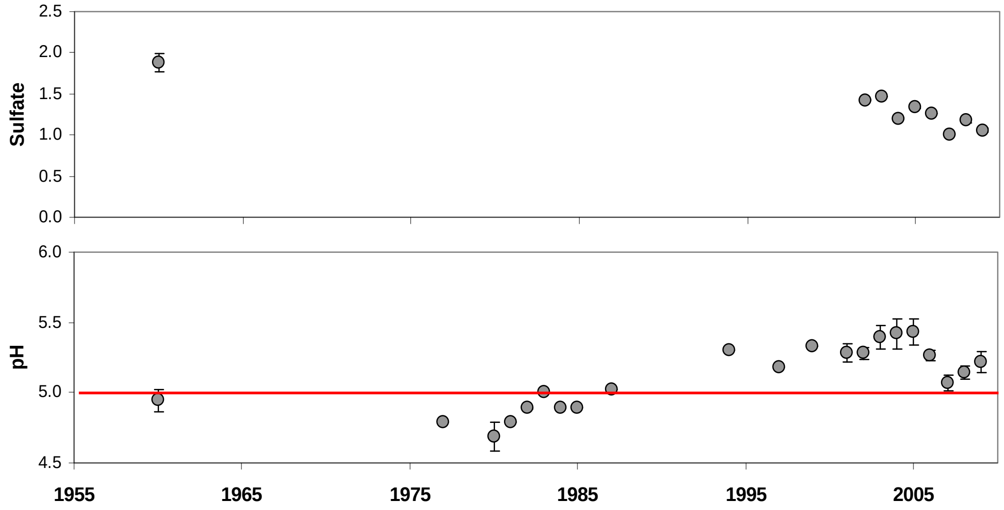


Figure 3. Surface water sulfate (mgS/L) and pH measurements from Honnedaga Lake (1955-2010) Red line indicates pH= 5 below which toxic levels of aluminum occur in Honnedaga Lake.

The relationship between brook trout presence/absence and pH is linked to the relationship between pH and inorganic monomeric aluminum, a chemical constituent toxic to fish at levels associated with low pH. Brook trout mortality ranges from 60% to 100% when inorganic monomeric aluminum concentrations exceed 150 ug/L. Measurements of inorganic monomeric aluminum from Honnedaga Lake water samples show that lethal levels occurred in the early 1980s and decreased to non-lethal levels in the 2000s (Figure 4). Caged brook trout bioassays in 1983 and 1984 resulted in 100% mortality within 48 hours of exposure to Honnedaga Lake water. Fortunately, increases in lake pH have led to declines in inorganic monomeric aluminum over the past 25 years, which have been the most important factor leading to improved survival of brook trout.

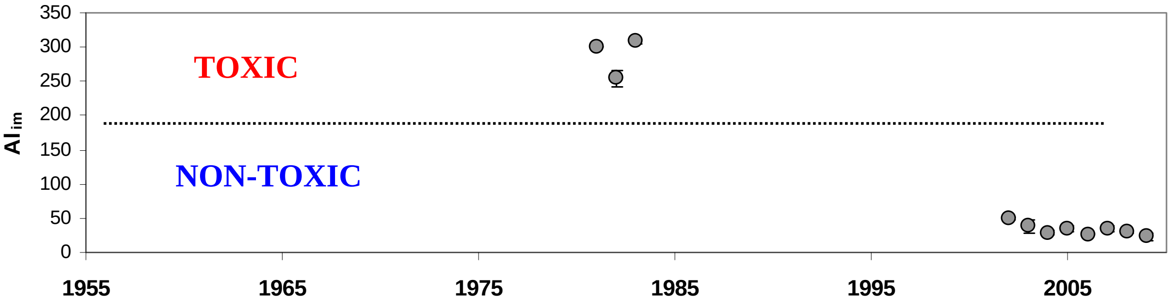


Figure 4. Surface water inorganic monomeric aluminum (ug/L) in Honnedaga Lake inorganic monomeric aluminum >150 ug/L is lethal to brook trout (dotted line).

Trends in SO_4 (sulfate), pH, and inorganic monomeric aluminum concentrations in Honnedaga Lake are similar to a nearby lake on State land, Brook Trout Lake (Figure 5), which is one of 52 Adirondack Lakes Survey Long-Term Monitoring lakes from which longer time series of water chemistry data are available. Changes in water chemistry in both lakes reflect the effectiveness of 1990 amendments to the Clean Air Act to reduce sulfate emissions.

During the same time period other changes have occurred in lake water quality. Water clarity (Secchi disc depth) in Honnedaga Lake has progressively declined from 22-24 meters (72-79 feet) in the 1980s to 17-18 meters (56-59 feet) in the1990s and more recently to 11-12 meters (36-39 feet) in the late 2000s (Figure 6a). As water clarity has declined, the concentration of chlorophyll *a* (a measure of algae abundance in lake water) has increased (Figure 6b). Similar changes in clarity and chlorophyll a have been observed in many other Adirondack lakes since 1990.

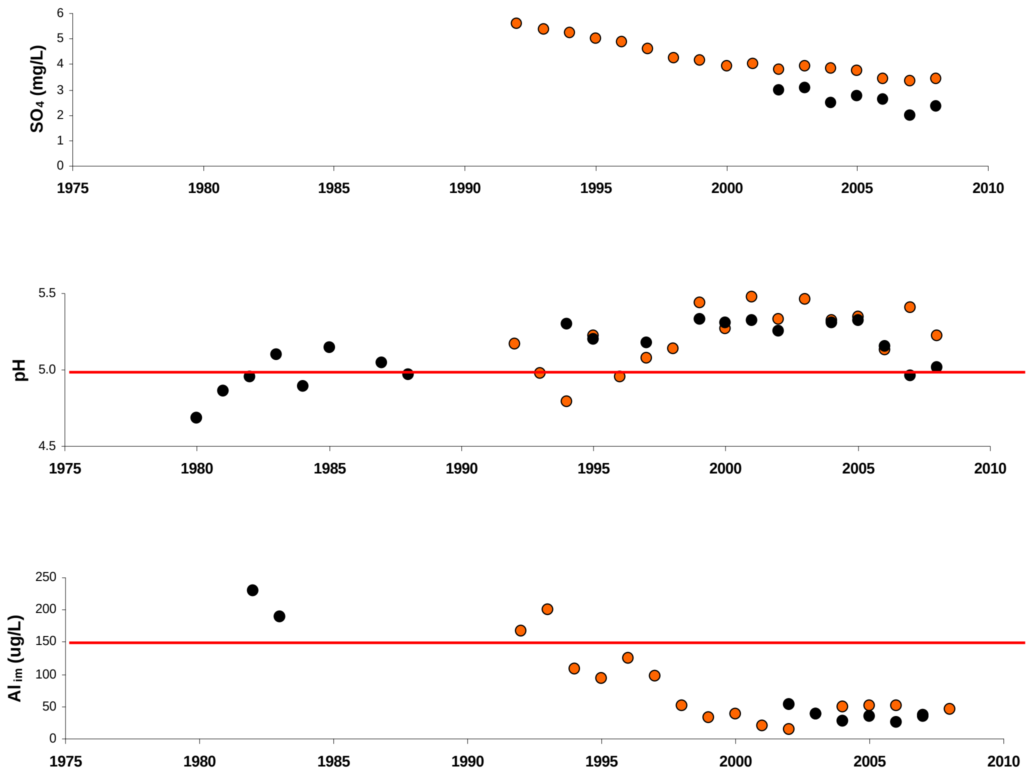


Figure 5. Surface water sulfate (mgS/L), pH, and inorganic monomeric aluminum (ug/L) in Honnedaga Lake (black circle) and Brook Trout Lake (orange circle) (1975-2010).

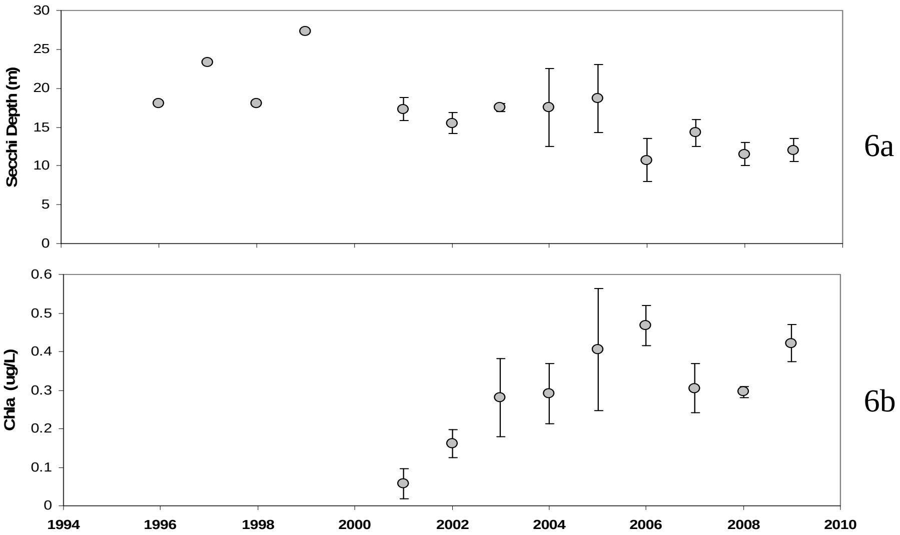


Figure 6. Secchi depth (m) and chlorophyll *a* (ug/L) concentrations in Honnedaga Lake (1995-2009)

Tributary Water Chemistry

We used a topographic index (TI) model to map and predict the intensity of groundwater inputs to Honnedaga Lake from tributaries and shoreline seeps (Figure 7). The TI map aided us in the identification of 24 tributaries in the Honnedaga Lake watershed. Water samples have been collected monthly (and in some cases weekly) since 2001 to characterize the chemistry of Honnedaga Lake tributaries.

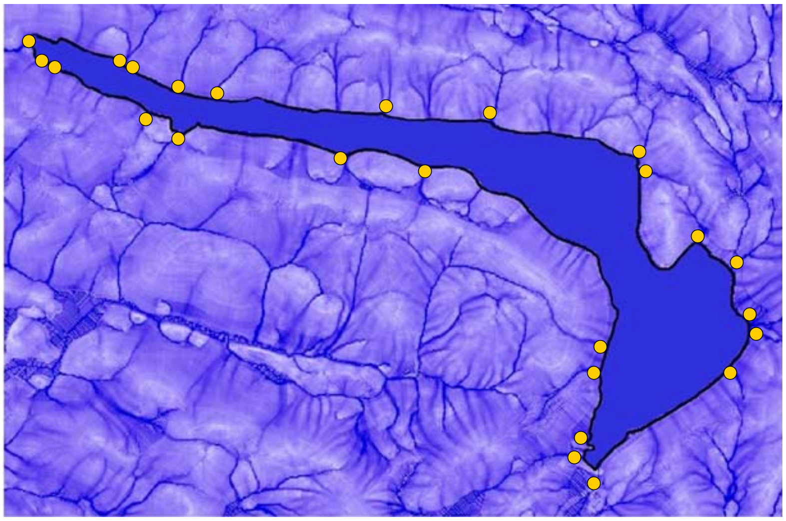


Figure 7. Honnedaga Lake tributaries (yellow circles) identified using a topographic index model.

Chemical analysis of tributaries during the summer months has revealed that 17 tributaries have a pH <5, while only 7 tributaries had pH >5 (Figure 8). Most of the higher pH tributaries occur in the eastern basin, near the outlet end of this glacial lake. The catchments with higher pH tributaries are characterized by deeper sediments with more buffering capacity due to the presence of neutralizing chemical constituents in the underlying sand and gravel.

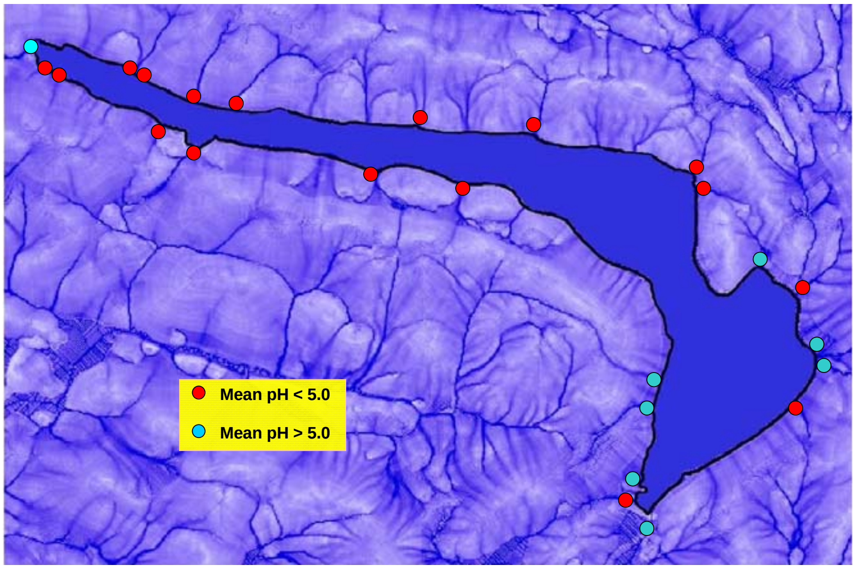


Figure 8. Tributaries with pH <5 (red circles) and pH >5 (blue circles) during summer months in Honnedaga Lake

Adult Brook Trout Population

Oneida-style trap nets have been used to sample brook trout in Honnedaga Lake since the 1950s. These nets are particularly effective at capturing adult brook trout during the fall spawning season – and as such the nets have typically been set in late October to mid-November. Although trap net surveys have not been conducted every year for the past 50 years, trap net surveys provide us with the most consistent historic assessment of the brook trout population in Honnedaga Lake.

Trap net catch per unit effort ranged from 40-140 fish/night in the early 1960s and was heavily influenced by the large numbers of fish stocked during that period (Figure 9). The stocking of unmarked fish in the 1950s and 1960s likely masked the actual decline of the wild brook trout population, which was clearly evident in trap net surveys in the 1970s when only a few wild fish were caught, indicating a dramatically reduced population (Figure 9). Trap net catches increased nearly 8-fold in the 2000s, reflecting improved pH and reduced inorganic monomeric aluminum levels in the lake. Estimates of the brook trout population size in the fall of 2007 and 2008 ranged from 286 to 1215 brook trout > 200 mm (8 inches); which corresponds to a fish density of less than ½ to1½ fish per acre.

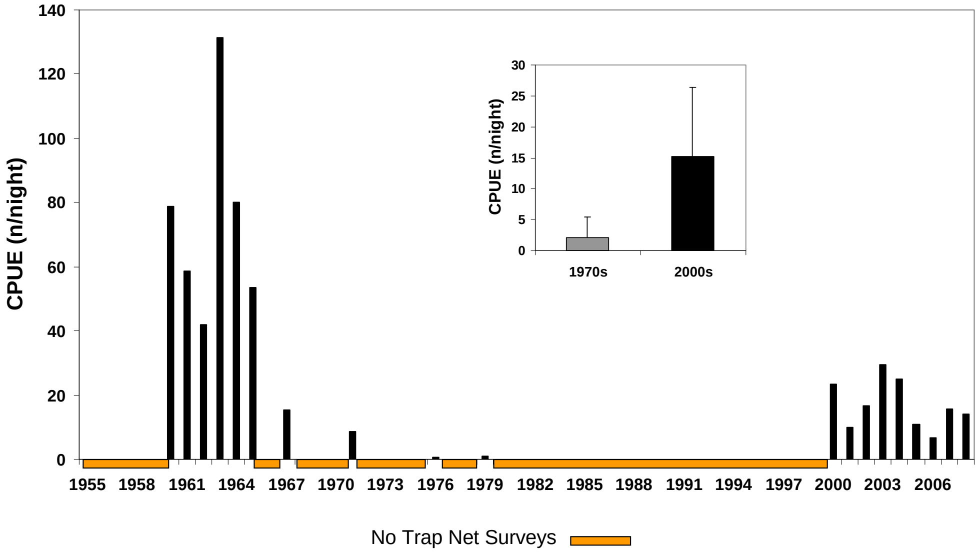


Figure 9. Fall trap net catch per unit effort (number / night) of brook trout in Honnedaga Lake (1955-2009).

Brook Trout Spawning

Annual surveys have been conducted to document the location and number of brook trout redds along the Honnedaga Lake shoreline and tributaries since fall 2001. The entire lake perimeter has been surveyed from a boat during each spawning season to look for in-lake spawning on shoals, and tributaries have been surveyed by walking and counting redds and spawning fish. In addition, ANC and pH in groundwater associated with selected redds were measured using piezometers in November 2006.

Redd counts have varied from year to year, ranging from 10 to 110 per year from 2001 to 2009. Several spawning sites on shoals and in tributaries have been consistently identified in the Honnedaga Lake watershed since 2000 (Figure 10), and all spawning sites are associated with tributaries and seeps with pH >5. Spawning within tributaries, associated shoals, and the lake outlet occurs primarily in the eastern basin of the lake where the deepest glacial till is found. pH in all sampled redds was >6.0, with the exception of one redd at East Shore shoal (pH = 5.8), indicating suitable conditions for egg and sac-fry survival.

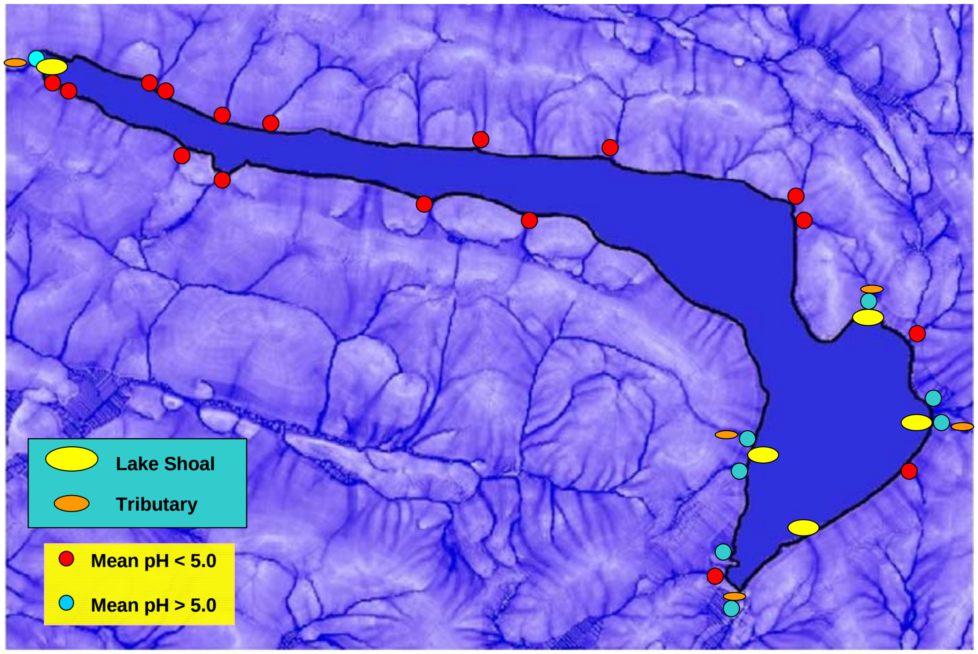


Figure 10. Location of brook trout spawning sites documented in Honnedaga Lake (2000-2009)

Young-of-Year Brook Trout Population

Small groundwater-fed tributaries and seeps provide critical habitat for young-of-year brook trout during the summer months. The abundance of young-of-year brook trout has been surveyed in Honnedaga Lake tributaries with backpack electro-fishing units since summer 2001. For these surveys the upstream and downstream boundaries of 15-20 m sections, beginning at the mouths of tributaries, are first blocked with nets. One to three passes with an electro-fishing unit are then used to collect brook trout within each sampling section. Various habitat measurements (pH, ANC, water temperature, and stream morphometry) were recorded. Inorganic monomeric aluminum was also measured in all tributaries in summer 2009.

A total of 24 tributaries and the outlet were sampled by backpack electro-fishing in August 2009. All tributaries were small streams, typically less than 2 meters in width. Summer water temperatures in most streams range from 54-62 ^{o}F, reflecting that deep groundwater sources supply water to these streams under base-flow summer conditions. Chronic acidification is consistently evident in many of the tributaries with pH levels <5 and inorganic monomeric aluminum levels >150 ug/L, which are conditions toxic to brook trout.

The relationship between young-of-year brook trout and inorganic monomeric aluminum level was examined in 2009 for all Honnedaga Lake tributaries. A comprehensive statistical evaluation revealed that the level of inorganic monomeric aluminum explained a significant amount of the variation in the presence or absence of brook trout in lake tributaries. Young-of-year brook trout were absent from tributaries in which inorganic monomeric aluminum exceeded 150 ug/L, and density of young-of-year brook trout was generally higher in tributaries with inorganic monomeric aluminum <50 ug/L and water temperatures 54-62 ^{o}F. Young-of-year brook trout were only found in 11 of the 24 Honnedaga Lake tributaries; and thus only occupy 46% of the potential tributaries available for young-of-year brook trout. It appears that young-of-year recruitment is limited by the acid-impaired state of numerous tributaries within the Honnedaga Lake watershed. This low level of recruitment likely also limits the abundance of catchable adult brook trout in this lake.

Conclusions

The brook trout population in Honnedaga Lake is a valuable resource for a number of reasons, including its designation as a New York State heritage strain and its capacity to maintain a brook trout population in an acid-impaired watershed. Honnedaga Lake provides an excellent opportunity to study the response of a wild brook trout population to changes in water chemistry resulting from improvements in atmospheric acid deposition. This lake provides a natural laboratory for identifying biological and physical factors that may limit or control the abundance and growth of brook trout as levels of acid deposition are further reduced. Our continued comprehensive sampling program will allow for the detection of changes in water chemistry and brook trout population characteristics (survival, growth, reproduction) that may provide insight into ways to protect and enhance the self-sustaining heritage brook population in Honnedaga Lake and other brook trout populations in the Adirondack region.

The work that we are able to pursue in Honnedaga Lake is enhanced by work conducted by other managers and researchers working elsewhere in the Adirondacks, as well as in acid rain-impacted lakes throughout the world. We have observed a modest improvement in lake water chemistry (increased pH and decreased levels of inorganic monomeric aluminum), along with a brook trout population recovery within the Honnedaga Lake watershed, since amendments to the Clean Air Act in 1990 resulted in reduced sulfate emissions. Similar improvements in water chemistry have been documented for numerous lakes in the Adirondack region and European lakes where similar reductions in atmospheric emissions have occurred, but documented recoveries of self-sustaining fish populations in these lakes are rare. In addition, the heritage designation for the Honnedaga Lake brook trout population is unique for a restored or recovering fish population. Fortunately, a small number of tributaries within the Honnedaga Lake watershed are influenced by deep groundwater sources and have continued to serve as spawning, young-of-year, and even adult brook trout refuges from acidification. Nevertheless, the majority of tributaries within the Honnedaga Lake watershed remain chronically acidified (pH <5), and these tributaries will not recover from acidification in the foreseeable future under current levels of acidic deposition. Chronically and episodically acidified tributaries likely limit young-of-year survival and recruitment and consequently adult brook trout abundance in Honnedaga Lake.

In the coming months, we will be developing a tributary and watershed liming mitigation plan to restore water chemistry suitable for brook trout survival in selected acidified tributaries of Honnedaga Lake. The management goal will be to increase young-of-year recruitment and ultimately the abundance of the adult brook trout population in Honnedaga Lake