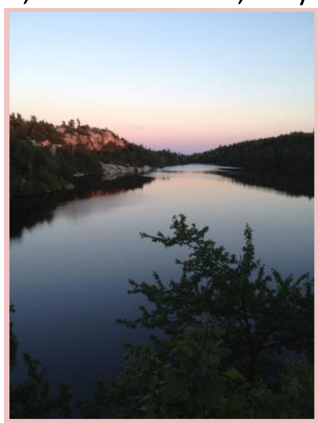
NEW YORK STATE
WATER RESOURCES INSTITUTE
Department of Earth and Atmospheric Sciences

1123 Bradfield Hall, Cornell University
Ithaca, NY 14853-1901
http://wri.eas.cornell.edu

Tel: (607) 255-3034
Fax: (607) 255-2016
Email: nyswri@cornell.edu

Using high frequency lake data and fish population analyses to inform management and outreach in the Sky Lakes, Shawangunk Ridge, eastern New York

*David C. Richardson**, PhD, Assistant Professor, Biology Dept., SUNY New Paltz
*richardsond@newpaltz.edu, 845-257-3805
John Thompson, Director of Conservation Science, Mohonk Preserve
Kathleen C. Weathers, PhD, Senior Scientist, Cary Institute of Ecosystem Studies



Abstract

Lake Minnewaska, located within Minnewaska State Park, southeastern New York, has historically been a clear, acidic and fishless lake. Recently, increases in pH and an introduction of a minnow species, Golden Shiner, have rapidly changed the ecosystem. Over the summer of 2014, we measured the fish population size and demographics with the addition of Largemouth Bass, a new species recently introduced to the lake. We found that predation resulted in the complete extirpation of the Golden Shiners. We also deployed a data logging sonde across three Sky Lakes for two weeks each measuring high frequency measurements of temperature, conductivity, pH, and chlorophyll to determine the effect of algal production on diel pH shifts. We found that the diel chlorophyll fluctuations were strongly correlated with diel cycles in pH. The research from this project is a result of strong collaboration with stakeholders, governmental agencies, and non-profits and will ultimately inform conservation and management efforts in three parks and preserves.

Three Summary Points of Interest

- **One species of introduced fish have effectively disappeared from Lake Minnewaska.**
- **Diel fluctuations in pH are linked to diel cycles in algal biomass resulting in up to 1 pH unit of change.**
- **Removal of remaining fish may restore ecosystem function but pH will remain neutral in Minnewaksa.**

Keywords: Environmental sensors, lake acidity, introduced species, fish, trophic cascades.

Introduction

Freshwater lakes are critically important resources and have been impaired by human activities, including pollution and land use change. Lakes within managed forests are largely protected from the impacts associated with human-dominated land uses, and thus present an opportunity to study the indirect impacts of humans on lake ecosystems. Indirect human drivers on lakes include climate change, atmospheric pollutants, and introduced species. The overarching research goal is to determine how environmental drivers affect in-lake biological populations, community structure, and ecosystem function in 5 local Sky Lakes on the Shawangunk Ridge, Hudson Valley, NY. The Shawangunk Ridge is located in the Hudson Valley, west of the Hudson River in Ulster County. Our three study lakes, Mohonk, Minnewaska, and Awosting are oligotrophic, clear, mountain lakes with unique watersheds, geology, and ecology. There are no perennial inflows to and minimal outflows from the lakes; the bedrock is solid with little groundwater exchange (Caine et al. 1991). The lakes reside within protected and managed lands (i.e. state parks or private preserves), are minimally influenced by humans and relatively isolated from the surrounding landscape, and are significant economic resources for the Hudson Valley region drawing in >250,000 tourists per year for outdoor recreation. However, the lakes have experience biological and physical change recently. For example, over the past 30 years, Minnewaska has had rising pH levels. Since the 1920s, Minnewaska has been fishless since the 1920s with little information from before that time period (Smiley and Huth 1983); however, in 2008/2009, *Notemigonus crysoleucas* (Golden Shiners, a small minnow, ~7-12cm) were introduced to the lake likely as discarded bait fish (NYS Office of Parks, Recreation, and Historic Preservation, pers. comm.). In 2012, Minnewaska suddenly had a small Large Mouth Bass population, also likely introduced by humans. The ecosystem level changes have been visually evident – we have talked with several park visitors who have been swimming in Minnewaska for >10 years and have noticed changes in the water clarity, water color, and biology of the lake (e.g., introduction of fish, increase in snakes, decreases in salamanders). The park managers and environmental monitors are concerned and would like to approach their management strategies from a scientific and long-term perspective.

Ultimately, we had two research questions for this project. **First, why is pH changing variably across the Sky Lakes?** Acidification of freshwater ecosystems has historically been a problem in the northeastern United States with increased anthropogenic sources (e.g., burning of fossil fuels and agricultural activity) of sulfur, nitrogen, and acidity in rain water (Schindler et al. 1989, Driscoll et al. 2001). Acidification of lakes from acid rain results in changes in chemistry and losses of sensitive taxa including fish and macroinvertebrates (Schindler 1989). From 1998 to 2000, rain water in the Catskill region just west of the Sky Lakes, had a pH of 4.4 (Driscoll et al. 2001, 2003). Rain acidity, an external force, is decreasing in the Northeast due to the Clean Air Act amendment that has limited sulfur emissions since the 1990s (Greaver et al. 2012); pH of rain water has increased from 4.3 in 1985 to 4.9 in 2010 as measured at the nearby Catskill Mountains National Atmospheric Deposition Program site (http://nadp.isws.illinois.edu/). With underlying quartz conglomerate, the soils are shallow with little buffering of rain water. Mohonk has exposed shale lithology within the lake which buffers the lake pH; Mohonk is closer to neutral (pH = 6.5 to 7). All other lakes have had historically low pH (<5). In Awosting, the pH has increased from 4.2 in 1982 (Smiley and Huth 1983) to 4.75 in April 2012 (Richardson unpubl.). However, in Minnewaska, the pH has risen from acidic (~4.5) to near neutral over the past 35 years.

In Minnewaska, external and internal forces might be affecting lake water chemistry and changing lake pH. Acid rain, an external force, has been increasing and this should lead to changes in all the Sky Lakes except for Mohonk where exposed shale buffers rain acidity. In Minnewaska, the lake pH can also be controlled by internal processes. For example, fluctuations in elevated gross primary production during the day and respiration at night can cause large changes in the pH due to changing concentrations of CO_2 and the carbonate buffering system (Maberly 1996). Further, Minnewaska State Park has been applying locally mined shale on the two miles of carriage roads that surrounds the lake. At specific parts of the lake, some of the trails are <1 meter away from the edge of the lake. The carriageways often wash into the lake during heavy

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storms and snowmelt. This and leaching from rain or snow could contribute to the neutralizing of the lake water. Comparisons across the three lakes can address the external forces; however, high frequency measurements of pH will enable us to determine which of the internal drivers are facilitating pH change.

Second, we asked **what is the size and population growth of the *N. crysoleucas* population in Lake Minnewaska? Is the newly introduced *M. salmoides* (Largemouth Bass) stabilizing the *N. crysoleucas* population?** *N. crysoleucas* are small minnows (~6-10 cm max. in Minnewaska currently) that exhibit generalist feeding behavior, consuming zooplankton, insects, small fish, and algae (Hall et al. 1979). The rising pH in Minnewaska allowed the introduced *N. crysoleucas* to survive and procreate. The introduction of *N. crysoleucas* appears to indicate the beginning of a regime shift to an alternate ecosystem state (Holling 1973; Levin and Lubchenco 2008). Minnewaska appears to be the only Sky Lake undergoing this shift in contrast to the other Sky Lakes without fish (Awosting) and with fish (Mohonk). In temperate lakes, regime shifts are common; for example, clear water can shift to turbid water as a result of introduced species, watershed land use change, or elevated levels of nutrients (Folke et al. 2004; Carpenter et al. 2011). In some cases, these regime shifts might be irreversible (Folke et al. 2004).

Trophic cascades are often the cause of regime shifts, especially when initiated by fish successfully invading lakes (Zavaleta et al. 2001). Trophic cascades can result from the invading fish species' overconsumption of herbivorous species like zooplankton, releasing the primary producers from top-down control, yielding increased gross primary production (GPP), producer biomass, and decreased water clarity (Baxter et al. 2004, Ellis et al. 2011). In this case, the trophic cascade appeared to be rapid and affected water quality because Minnewaska has few trophic levels and *N. crysoleucas* represented a new trophic level, not just an additional species in an existing level. Additionally, *N. crysoleucas* could be directly contributing to increasing water column nutrients via direct excretion (Zimmer et al. 2006) after consuming plant and prey species that live on the bottom and edges of the lake. We recently found *M. salmoides* in the past 2 years representing the introduction of another upper trophic level. If the ecosystem has not been pushed too far to an alternate state, *N. crysoleucas* populations may be stabilized or reduced, reversing the effects of the trophic cascade and alleviating the need for drastic management strategies.

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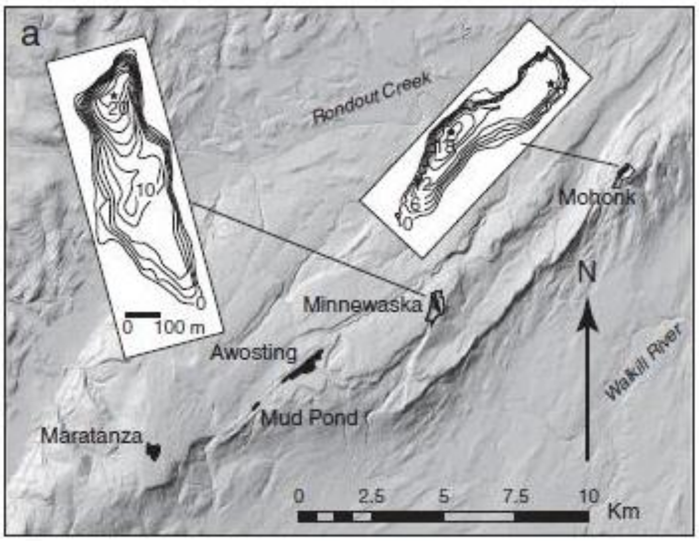
Site Description – Despite being separated by <20 km, our three focal lakes (Awosting, Minnewaska, and Mohonk, Fig.1) differ physically and ecologically. ***Minnewaska*** (Minnewaska State Park) has two ecological features that are unique. First, the lake is home to a rare mat of *Sphagnum trinitense* moss that grows over 10m deep in the lake and is the only place in New York where this underwater peat bog occurs (N. Miller pers. comm.). Second, because of the historical absence of fish predators, Minnewaska *E. bislineata* salamanders exhibit little parental care of egg clutches (Bahret 1996) a behavior that may be unique to this population. Minnewaska, a formerly clear water oligotrophic lake, is rapidly changing. Over the past 30 years, Minnewaska has had rising pH levels. Since the 1920s, Minnewaska has been fishless since the 1920s with little information from before that time period (Smiley and Huth 1983); however, in 2008/2009, *Notemigonus crysoleucas* (Golden Shiners, a small minnow, ~7-12cm) were introduced. ***Awosting*** (Minnewaska State Park) is about 5 km from Minnewaska and is the biggest of the Sky Lakes.



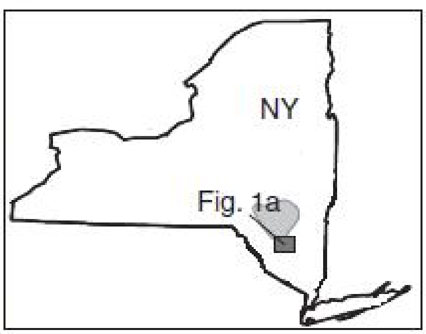


Figure 1. Location of lakes on the Shawangunk Ridge (left) within New York State (above). The bathymetry maps for Minnewaska

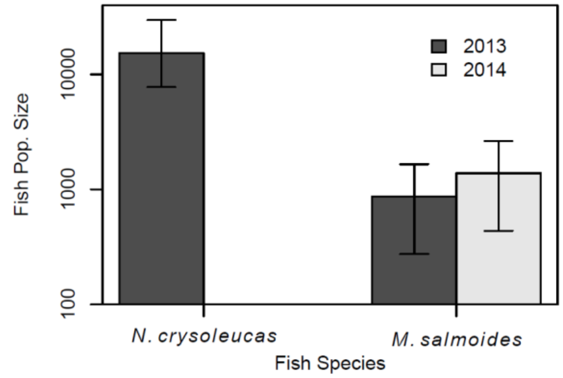


Figure 2. Population size estimates of *N. crysoleucas* (Golden Shiner) and *M. salmoides* (Largemouth Bass) in Lake Minnewaska. No *N. crysoleucas* individuals were found in 2014.

Awosting is an oligotrophic, clear-water lake with no fish observed in >100 years (Smiley and Huth 1983). ***Mohonk*** is a clear, oligotrophic lake, is buffered by exposed shale in the lake, and has had fish in the lake for years, including trout and other species stocked for visitors to the Mohonk Mountain House which sits on the northwest edge of lake and has been operating since 1869.

Results & Discussion

History of fish in Minnewaska prior to 2008 – Minnewaska and all of the other Sky Lakes are glacial in origin with waterfalls in their outlet streams which probably restrict fish migration. Loggers or stonecutters could have stocked Minnewaska with several species of fish that could be used as a food source at the logging camps prior to the 20th century. This would be similar to procedures done in northeastern forests in northern New York and New England where logging companies would send teams a decade in advance of logging a watershed to stock lakes with fish species that are easy to catch for food at the camps (Brokaw and Lucas 2008). This hypothesis is supported by the presence of two or three species of popular game fish, including *Esox* spp. L. (pickerel) and *Perca flavescens* Mitchill (Yellow Perch) in the Shawangunk Sky Lakes by the 19th century. Ultimately, the date of the last fish recorded in Minnewaska was in 1922 when 300 Yellow Perch were retrieved following the dynamiting of the lake to retrieve a drowning victim (Smiley and Huth 1983).

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Following that time, Minnewaska and other Sky Lakes, were too acidic to support the survival of fish. For example, in 1957, 1,500 trout from various species were stocked in nearby Lake Awosting with similar acidity to Minnewaska; within 4 or 5 days, most of the trout were dead (Smiley and Huth 1983).

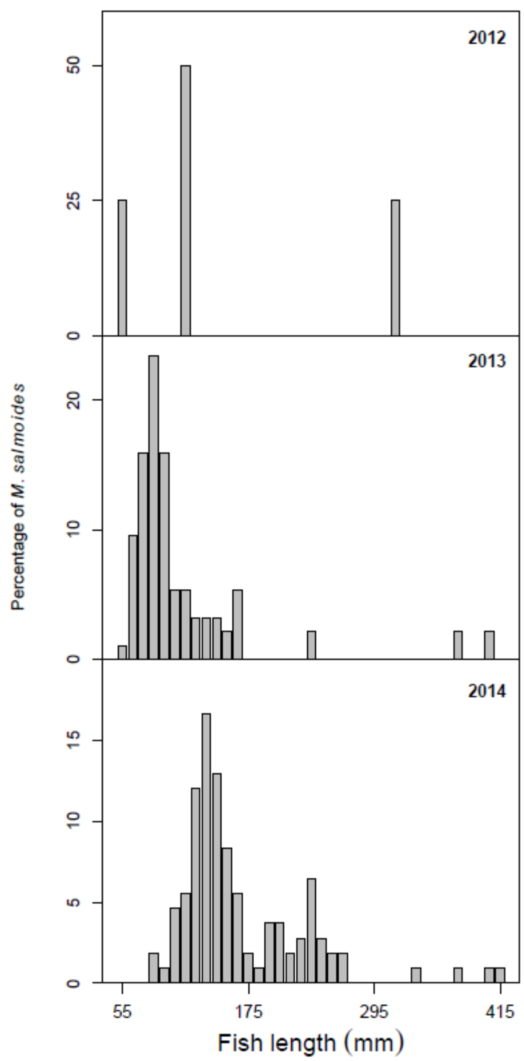

Figure 3. Histograms of *M. salmoides* (Largemouth Bass) length in 2012 (n=4), 2013 (n=94), and 2014 (n=108). Mean length in 2012 was 149.8±57 mm, mean length in 2013 was 113.1±7.0 mm, mean length in 2014 was 168.8±5.9 mm (all mean±SE).

Reintroduction of fish in 2008 **–** In 2008, individual Golden Shiner were first spotted in Minnewaska and the population increased rapidly over the next few years until schools of Golden Shiner were visible to all visitors to the lake. In 2012, there were clear populations of Golden Shiner that were easy to catch via beach seining and could be seen in the shallows around the entire lake. In 2013, we estimated the Golden Shiner population size at 15,320±5,300 (mean±SE); however, in 2014, no Golden Shiner individuals were found. This represents a statistically significant decrease ($t=3.35$, $p<0.001$, $df=327$, Fig. 2). We first observed Largemouth Bass in 2012; the population increased from 869±471 (mean±SE) individuals in 2013 to 1,380±770 in 2014. Although the population increased by 60%, this difference was not significant ($t=0.54$, $p=0.59$, $df=157$, Fig. 2) due to a large degree of error from few individuals recaptured.

Mean Golden Shiner size in 2012 was 82±2.1 mm (mean±SE) and 90±0.7 mm (mean±SE) in 2013, a significant increase in mean fish size ($t=-3.3$, $df=104$, $p=0.001$). Golden Shiner length was positively and linearly related to fish age (Age (years) = 0.022[Fish length (mm)] – 0.25, $F_{1,67}=47$, $p < 0.001$, $r^2 = 0.41$). Using the length-age regression gives average ages of 1.5 years in 2012 and 1.7 years in 2013. Mean Largemouth Bass size was 149.8±57 mm, 113.1±7.0 mm, 168.8±5.9 (mean±SE) in 2012, 2013, and 2014 respectively (Fig. 3). There was a significant size main effect (one-way ANOVA: $F_{2,203}=39$, $p<0.001$) with posthoc means comparisons indicating that mean size significantly increased from 2013 to 2014 but neither 2013 nor 2014 were different from 2012 likely due to small sample size (n=4 Largemouth Bass caught). There was a significant positive linear relationship between fish length and age in Largemouth Bass (Age (years) = 0.012[length (mm)], $F_{1,40} = 138$, $p < 0.001$, $r^2 = 0.78$). Largemouth Bass average age were calculated to be 2.0 years in 2012, 1.6 years in 2013, and 2.3 years in 2014.

Sonde deployments – We deployed the sonde for ~6 weeks with 2 weeks at each lake moving from most oligotrophic (Awosting) to transitioning (Minnewaska) to mesotrophic (Mohonk). The sonde recorded temperature, conductivity, pH, and chlorophyll *a* concentrations (Figs. 4-6). Across all lakes, the temperature in the epilimnion exhibited typical diel cycles of cooling and warming with changing temperature depending warm/cool days and climate

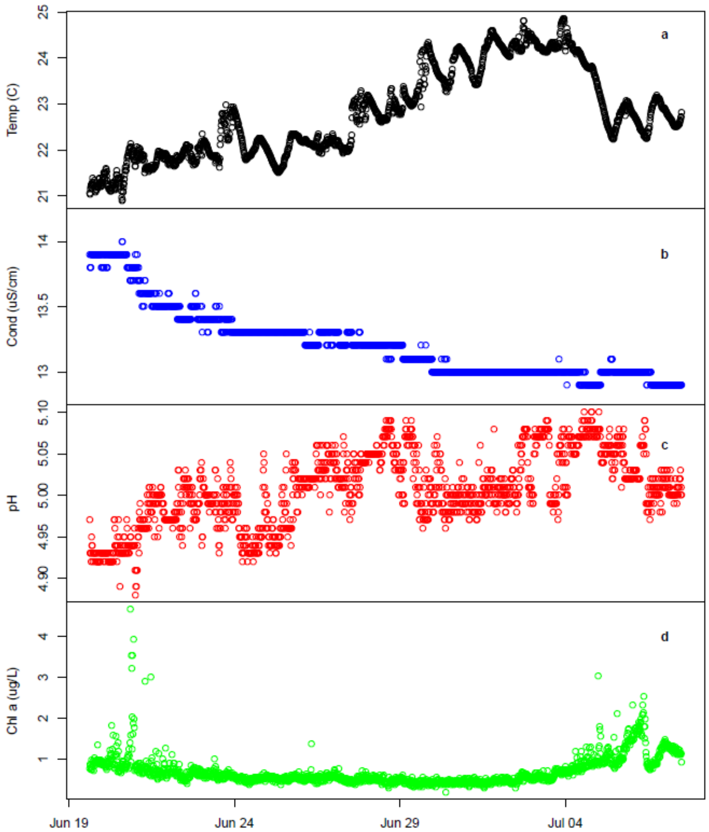

Figure 4. High frequency sonde data for Lake Awosting between 19 Jun 2014 and 07 Jul 2014 at the deepest location in the lake. Temperature (a), specific conductivity (b), pH (c), and chlorophyll *a* concentrations (d) were measured at 2m deep at 15 minute time increments.

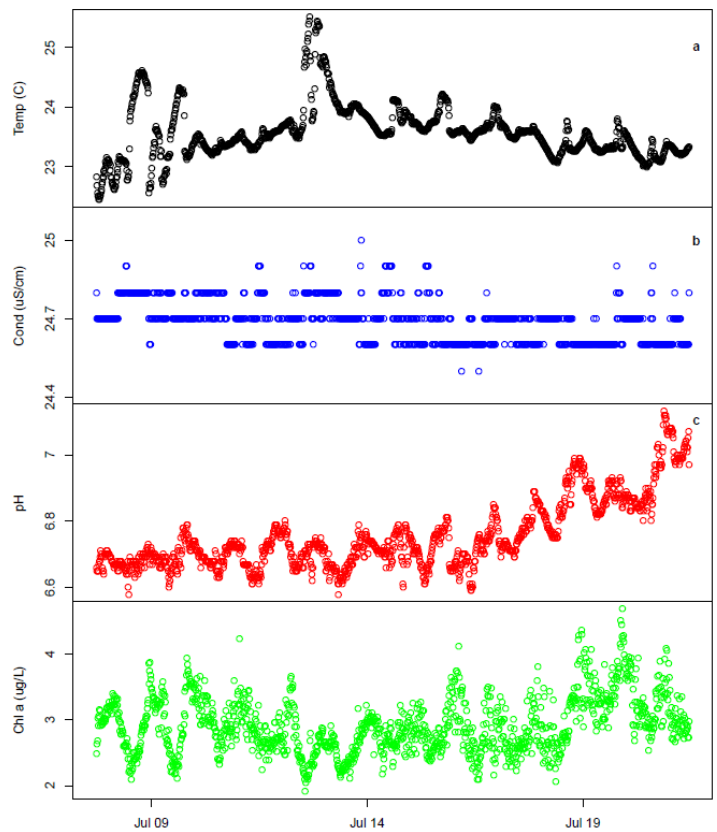

Figure 5. High frequency sonde data for Lake Minnewaska between 07 Jul 2014 and 21 Jul 2014 at the deepest location in the lake. Temperature (a), specific conductivity (b), pH (c), and chlorophyll *a* concentrations (d) were measured at 2m deep at 15 minute time increments.

systems (Figs. 4a, 5a, 6a). Awosting has the lowest conductivity (13 µS/cm), followed by Minnewaska (24 µS/cm), and Mohonk (86 µS/cm) but there were really no major diel or weekly fluctuations across each deployment period (Figs. 4b, 5b, 6b). pH was acidic in Awosting with a small range and little diel fluctuations (4.95-5.05, Fig. 4c). Similarly, the chlorophyll was low with little diel fluctuations (Fig. 4d) as would be expected in an oligotrophic lake. However, in Minnewaska and Mohonk, the pH was much more neutral with diel swings of up to 0.6 pH units (Figs. 5c, 6c). This match diel swings of chlorophyll *a* concentrations (Figs. 5d, 6d). In fact, the diel patterns of chlorophyll a and pH are strongly correlated after zooming and overlaying the variables for a 48-hour period in Minnewaska (Fig. 7).

Discussion – No Golden Shiner were found in Minnewaska in summer 2014 during electrofishing and diving surveys; this apparent extirpation likely occurred as a result of Largemouth Bass predation. However, the winter between 2013/2014 was long and cold with the lake ice longer than is typically seen (J. Thompson, Mohonk Preserve, New Paltz, New York, unpubl. data). Major winter fish kills were not observed but dead fish could have washed out the outflow during the spring melt. Largemouth Bass increased in length by 56 mm between 2013 and 2014 resulting in larger fish with bigger gape sizes; following this, Largemouth Bass were able to consume larger Golden Shiners. Without the zooplanktivorous minnows, the lake will be trophically structured by piscivores like nearby Lake Mohonk. Largemouth Bass are known to cannibalize smaller

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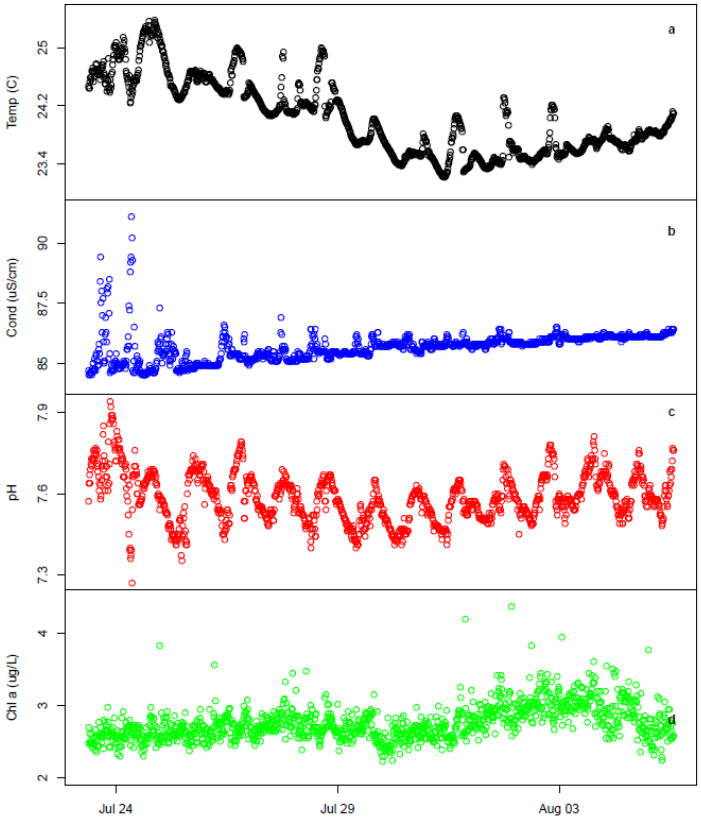

Figure 6. High frequency sonde data for Lake Mohonk between 23 Jul 2014 and 05 Aug 2014 at the wharf where samples are regularly taken. Temperature (a), specific conductivity (b), pH (c), and chlorophyll *a* concentrations (d) were measured at 2m deep at 15 minute time increments.

conspecifics, generally this will suppress the influence of zooplanktivorous young-of-the-year bass. However, increased prevalence of zooplanktivory may occur cyclically as the older cohorts die, thus allowing young Largemouth Bass to survive due to decreased cannibalism during these demographic turnovers (Persson et al. 2003).

The remaining fishless Sky Lakes are too acidic for most fish species. During summer 2014, the pH of Awosting was ~5.0 (Fig 4c). Some fish that are acid-tolerant have been found in lakes with similar pH, at least one Adirondack lake with a pH of ~4.5 contained Golden Shiner in the 1980's (Kretser et al. 1989), although it might have been a non-breeding relict population. As the fishless Sky Lakes slowly recover from acidification, it may be possible for them to support fish. The pH of Lake Awosting has been slowly recovering over the past 22 years. If recovery in Awosting continues linearly, the average pH will be 5.5 by ~2060, a pH suitable for fish survival. Fish will not be able to disperse into the lake without human aid due to geographic barriers. Unintentional introduction of fish by humans is also unlikely because of relative

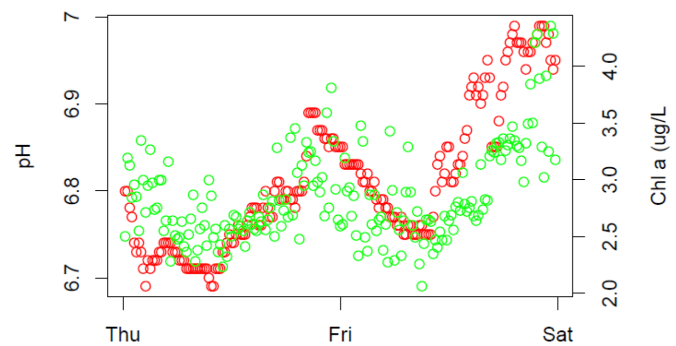

Figure 7. High frequency sonde data for Lake Minnewaska between 17 Jul 2014 and 19 Jul 2014 with pH (red circles and left axis) and chlorophyll *a* concentrations (green circles and right axis) over a 2 day period.

inaccessibility of Awosting compared to Minnewaska. Minnewaska is <100 m from a parking lot, while Awosting is a 4 km hike or bicycle ride from the nearest parking lot.

The presence and absence of fish in Lake Minnewaska is likely to be fully anthropogenic. It is unlikely that fish could disperse naturally into the lake and the species present during the 19th century were known to be used by logging camps as a food source in nearby regions (Brokaw and Lucas 2008). These fish were extirpated by acid deposition decreasing the pH below the physiological tolerance of fish. The reintroduction of fish to Lake Minnewaska can be viewed from multiple conservation perspectives. The lake is clearly on the road to recovery from anthropogenic acidification due to both recovery from acid rain and application of shale on the surrounding hiking trails. Increased algal production appears to account for up to 1 pH unit of recovery (Figs. 5c, 7). The reintroduction of fish has led to decreased abundance and extirpation of rare and uncommon species that were only able to take hold within the lake in the absence of fish. The once crystal-clear waters of the former oligotrophic lake have become green and opaque, much to the dismay of visitors to Minnewaska State Park Preserve. Little information is known about the state of the lake prior to acidification; however, a

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New York Times article indicated that the water was so clear that a white object may be seen 30 feet below the surface of Minnewaska during the 1870's (NYT 1876). If fish were present, perhaps native species like *Brook Trout* inhabited the lake. Management goals for Lake Minnewaska must be established in the context of what is known about its history and ecology. Therefore, it may be possible to track the Largemouth Bass population over the course of several years and remove them when there are only a few large-sized individuals present. Removal of fish may, to an extent, restore the rare community and ecosystem characteristics that existed historically, but future fish reintroductions will remain a possibility due to increased pH.

Methods

Fish Population Estimate and Growth – In 2013 and 2014, fish population sizes in Minnewaska were estimated using catch-mark-recapture. Only two fish species have been found in the lake in the past 6 years: *Micropterus salmoides* Lacépède (Largemouth Bass) and *Notemigonus crysoleucas* Mitchill (Golden Shiner). Both Golden Shiner and Largemouth Bass were marked by clipping the dorsal portion of the caudal fin. Fish swimming ability was not obviously affected by fin clips and the mark was clearly noticeable for 1.5 months under laboratory conditions. During summer 2013, fish were initially caught by seining multiple times at several locations. Fish were recaptured by electrofishing. In summer 2014 electrofishing was used for both the capture and recapture phases. For electrofishing, fish were collected beginning at sunset using a Smith-Root 16 foot electrofishing boat with two bow scappers during each collection run. The electrofishing boat was operated at 1000V, 120 pps DC drawing 5A for all samples, with the exception of the 17 June 2014 sample when the boat was inadvertently operated in AC mode. Operating in AC may be less efficient, resulting in a decreased catch/effort, but, since this was the marking run of a mark/recapture sample effort this did not affect the final estimations of fish populations. All samples began roughly at sunset, and consisted of a minimum of one lap of the shoreline of Lake Minnewaska. Since the habitat for Largemouth Bass and Golden Shiner is better along the southern shore, another pass up this shore was often made in an attempt to collect more fish. However, each time this was done the habitat-specific catch rate for both species appeared to decline from the earlier pass. Additionally, on 30 June 2014, one linear run was made up the middle of the lake and back with the objective of sampling any pelagic Golden Shiner which may have been present. In the case of all samples, electrofishing was completed by 23:00. Population size estimates were calculated using Peterson's method (Krebs 1998). Confidence intervals (95%) were constructed using the Poisson distribution due to a small number (<10%) of recaptures relative to originally marked fish (Krebs 1998). All statistical analyses were conducted using the R statistical package (R Core Team 2013).

Age estimation from scales - Scale samples were taken from behind one of the pectoral fins of all Largemouth Bass collected for later age estimation, and a scale sample was taken between the dorsal fin and the lateral line of five Golden Shiners per centimeter length group. Scale samples were heat pressed into acetate plastic, and were inspected under magnification utilizing a microfiche reader. Ages were estimated by counting what were estimated to be annular marks on the individual scales, following the general methods described by Jearld (1983).

Largemouth Bass age estimates were assigned with reasonable confidence. However, Golden Shiner are not typically aged by the DEC in this region, so experience aging this species is very limited. Apparent check marks were noted in the pattern of circuli on some of these samples which did not exhibit the spacing expected from true annuli, so the age estimates of Golden Shiner should be used with some caution.

High frequency measurements of lake water chemistry: We measured two weeks of high frequency (15 minute) data in each lake to help elucidate if internal controls (e.g., photosynthesis and respiration) are causing the change in pH. We had one data sonde (YSI EXO1) with temperature, conductivity, pH, and chlorophyll *a* logging sensors for examination of diel swings of lake water chemistry. For each lake, we attached the sonde at 2 m deep on a temporary buoy for successive 2 week periods throughout the summer. The sensor was installed in each lake as follows: Awosting: 19 Jun 2014 15:00 to 07 Jul 2014 12:00; Minnewaska: 07 Jul 2014 17:30 to 21 Jul 2014 11:00; and Mohonk: 23 Jul 2014

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9:15 to 05 Aug 2014 14:00. The chlorophyll *a* concentrations from the sonde measurements were scaled based off grab samples during the time period processed via standard spectrophotometric methods.

Outreach Comments

This research project is a collaborative effort between governmental and non-governmental organizations including SUNY New Paltz, the Cary Institute of Ecosystem Studies, and the Mohonk Preserve (all three represented by co-authors on this report). Additionally, we have strong ties to the Minnewaska State Park, the managers of two of the Sky Lakes, The Nature Conservancy, The NY Department of Environmental Conservation (heavily involved with fish sampling), and the NY Environmental Management Bureau.

*We hold annual meetings each spring to assess what we learned and how the research can inform management of the Sky Lakes.

*One manuscript was submitted over the summer which included some of the pH analysis from the summer. This manuscript details the changing pH in multiple Sky Lakes and the implications for those changes on fish introductions, particularly in Lake Minnewaska. The manuscript, titled "*Fish introduction, facilitated by unexpected recovery from acidification, causes a trophic cascade in a lake ecosystem"* was submitted to the journal Ecosphere and is currently in peer review. Richardson (co-author here) is the lead author and Erich Stern, the intern from this project, is a co-author.

*A former undergraduate student (Charifson) and Richardson have lead a project looking at history of fish in Lake Minnewaska based on this work. The manuscript is titled "*Fish Disappearance Due to Acid Rain and Unintentional Reintroduction to Lake Minnewaska on the Shawangunk Ridge, Southeastern NY."* Currently, the manuscript is in peer-review at the journal Northeastern Naturalist (submitted Jan 2015).

*Additionally, Richardson gave a public seminar at SUNY New Paltz about this research in 2014 and will give one in February 2015 for the Shawangunk Ridge Biodiversity Program lecture series.

Student Training

Erich Stern, Biology 2014, SUNY New Paltz, Undergraduate

References

Bahret, R. 1996. Ecology of lake dwelling Eurycea bislineata in the Shawangunk Mountains, New York. Journal of Herpetology **30**:399-401.

Baxter, C. V., K. D. Fausch, M. Murakami, and P. L. Chapman. 2004. Fish invasion restructures stream and forest food webs by interrupting reciprocal prey subsidies. Ecology **85**:2656-2663.

Brokaw, R.K. and J. Lucas. 2008. Chain Pickerel Assessment. Maine Department of Inland Fisheries and Wildlife (DIFW). Available online at http://www.maine.gov/ifw/fishing/species/management_plans/pickerel.pdf. Accessed 22 November 2014.

Caine, J. S., D. R. Coates, N. P. Timoffeef, and W. D. Davis. 1991. Hydrogeology of the Northern Shawangunk Mountains. New York State Geological Survey Open File Report #1g806.

Carpenter, S. R., J. J. Cole, M. L. Pace, R. Batt, W. A. Brock, T. Cline, J. Coloso, J. R. Hodgson, J. F. Kitchell, and D. A. Seekell. 2011. Early warnings of regime shifts: A whole-ecosystem experiment. Science **332**:1079-1082.

Driscoll, C. T., G. B. Lawrence, A. J. Bulger, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard, and K. C. Weathers. 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. BioScience **51**:180-198.

Driscoll, C. T., D. Whitall, J. Aber, E. Boyer, M. Castro, C. Cronan, C. L. Goodale, P. Groffman, C. Hopkinson, K. Lambert, G. Lawrence, and S. Ollinger. 2003. Nitrogen pollution in the northeastern United States: Sources, effects, and management options. BioScience **53**:357-374.

Ellis, B. K., J. A. Stanford, D. Goodman, C. P. Stafford, D. L. Gustafson, D. A. Beauchamp, D. W. Chess, J. A. Craft, M. A. Deleray, and B. S. Hansen. 2011. Long-term effects of a trophic cascade in a large lake ecosystem. Proceedings of the National Academy of Sciences **108**:1070-1075.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C. S. Holling. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics **35**:557-581.

Greaver, T. L., T. J. Sullivan, J. D. Herrick, M. C. Barber, J. S. Baron, B. J. Cosby, M. E. Deerhake, R. L. Dennis, J.-J. B. Dubois, C. L. Goodale, A. T. Herlihy, G. B. Lawrence, L. Liu, J. A. Lynch, and K. J. Novak. 2012. Ecological effects of nitrogen and sulfur air pollution in the US: what do we know? Frontiers in Ecology … **10**:365-372.

Hall, D. J., E. E. Werner, J. F. Gilliam, G. G. Mittelbach, D. Howard, C. G. Doner, J. A. Dickerman, and A. J. Stewart. 1979. Diel foraging behavior and prey selection in the golden shiner (Notemigonus crysoleucas). Journal of the Fisheries Board of Canada **36**:1029-1039.

Holling, C. S. 1973. Resilience and stability of ecological systems. Annual review of ecology and systematics **4**:1-23.

Jearld, A. Jr. 1989. Age determination. Pp. 301–324 *in* L.A. Nielsen and D.L. Johnson (Eds.). Fisheries Techniques. American Fisheries Society, Bethesda, Maryland. 468 pp.

Krebs, C. J. 1998. Ecological Methodology. 2ND edition. Benjamin Cummings, New York, NY.

Kretser, W., J. Gallagher, and J. Nicolette. 1989. Adirondack Lakes Study 1984-1987: An evaluation of fish communities and water chemistry. Adirondacks Lakes Survey Corporation, Ray Brook, NY.

Levin, S. A., and J. Lubchenco. 2008. Resilience, robustness, and marine ecosystem-based management. BioScience **58**:27--32.

Maberly, S. C. 1996. Diel, episodic and seasonal changes in pH and concentrations of inorganic carbon in a productive lake. Freshwater Biology **35**:579-598.

New York Times. 1876. Pedestrianism. The Shawangunk Mountains from end to end. New York Times, December 24, 1876, p. 4.

Persson, L., A. M. De Roos, D. Claessen, P. Bystrom, J. Lovgren, S. Sjogren, R. Svanback, E. Wahlstrom, and E. Westman. 2003. Gigantic cannibals driving a whole-lake trophic cascade. Proc Natl Acad Sci U S A **100**:4035-4039.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. URL: http://www.r-project.org/.

Schindler, D. W., S. E. Kasian, and R. H. Hesslein. 1989. Biological impoverishment in lakes of the midwestern and northeastern United States from acid rain. Environmental science & … **23**:573-580.

Smiley, D., and P. C. Huth. 1983. Fish Disappearance in the Northern Shawangunks between 1862 and 1982. Mohonk Preserve, Inc., New Paltz, NY.

Zavaleta, E. S., R. J. Hobbs, and H. A. Mooney. 2001. Viewing invasive species removal in a whole-ecosystem context. Trends Ecol Evol **16**:454-459.

Zimmer, K. D., B. R. Herwig, and L. M. Laurich. 2006. Nutrient excretion by fish in wetland ecosystems and its potential to support algal production. Limnology and Oceanography **51**:197-207.

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