Annual Silver Lake Report 2013

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Executive Summary

Data collected from Silver Lake since the initiation of the joint gill net/hydroacoustic surveys in 2008 have allowed for the description of long term trends in the Silver Lake ecosystem. These data give us a better understanding of the dynamics of the alewife (*Alosa pseudoharengus*) population in Silver Lake and its effect on the ecosystem.

The observations in Silver Lake suggest a trophic cascade between alewife and large zooplankton in Silver Lake, PA. The alewife population is variable and may be highly influenced by winter duration. However, trout stocking has not yet caused a decline in the alewife population. To better understand over-winter mortality of alewife, we plan on adding one sampling event in the late spring of 2014, as the winter of 2014 has been relatively cold to date and we expect a long period of ice cover. A spring survey will allow us to evaluate the importance of alewife winter mortality in Silver Lake. Without a spring survey, we cannot know if a potential population decline in 2014 is due to trout stocking or winter mortality. We also like to continue with the fall survey in 2014 and the limnological sampling throughout the open water season.

Summary of the results from the 2013 research program:

-Alewife density was 5172 fish/hectare (ha) in 2013. This is the second highest alewife population observed since 2008.

-Alewife produced a new year class each year between 2008 to 2013.

-Alewife growth rate and condition was low in 2013.

-In 2011, we observed a cold winter with few surviving age-1 fish. -The *Daphnia* population was low throughout the open water season.

-Water clarity was less than 4 meters (m) most of the summer. Both low *Daphnia* density and high summer precipitation may have contributed to poor water clarity in 2013.

-Water column profiles of temperature and oxygen indicate that sufficient trout habitat is present from 5-10 m at the peak heat of summer and 0-10 m into the fall when deepwater habitats become anoxic.

-600 brown trout (*Salmo trutta*) were stocked in 2013 to add to the 600 rainbow trout (*Oncorhynchus mykiss*) stocked in 2012.

-Two large brown trout from earlier stocking events were caught in the fall survey. These fish do consume alewife. The female was ripe, but reproduction of brown trout depends on the presence of suitable spawning streams.

These results are consistent with the presence of a large alewife population that depresses the population of the larger zooplankton grazers (*Daphnia sp.*). Water clarity is likely affected both by the low *Daphnia* abundance and the high precipitation in 2013, which would result in increased runoff into Silver Lake. Trout stocking seems to have had little effect on the alewife population to date. Sufficient numbers of adult alewives have survived to produce new year classes each year since 2008. However, the winter of 2014 could lead to high alewife mortality, potentially pushing the alewife population to levels low enough to be controlled by the resident trout. Even so, we cannot recommend additional trout stocking as an alewife control measure until we evaluate the spring 2014 alewife population.

Introduction

The E. L. Rose Conservancy and the Actus Foundation have supported environmental conservation with a philosophy of stewardship and a desire for contemporary knowledge of the area's natural resources. This desire has led to the cooperative relationship between these groups and Cornell University in an effort to understand, improve, and protect the water quality, fisheries and aquatic ecosystem associated with Silver Lake. The 2013 field season marked the tenth year of this cooperative relationship to monitor and manage the aquatic resources of Silver Lake. The initial focus of Cornell researchers was to review available historical information on the aquatic resources of Silver Lake and assess the biological integrity and the fish community of Silver Lake through a variety of field sampling efforts. Efforts and attention since 2008 have concentrated on investigating impacts from introduced alewife and evaluating trout stocking as a means to control these impacts.

The alewife (*Alosa pseudoharengus*) is a non-native fish species believed to have been introduced to Silver Lake sometime after 1992. The presence of alewife has subsequently caused a decrease in water clarity as a result of alewife feeding on large zooplankton, which in turn reduced consumption of algae. With support from the E.L. Rose Conservancy and the Silver Lake Association, a trout-stocking program, using both rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), was implemented in the fall of 2006 with the goal of reducing alewife abundance through predation by trout and subsequently increasing water clarity. Stocking of trout occurred in each fall in 2007, 2008, and 2009 (300 fish per year), and again in the fall of 2012 and 2013 (600 fish per year). No trout were stocked in 2010 or 2011.

In 2013, the primary focus of Cornell researchers has been developing annual estimates of alewife abundance in Silver Lake. We also increased the number of sampling events throughout the year with the collaboration of Russ Cole. Information gathered through these surveys is the primary way to assess the effectiveness of trout stocking as a means of controlling alewife numbers and to understand how alewife abundance is influencing the physical and biological components of the Silver Lake ecosystem.

Research activities conducted in 2013 included the following:

-Hydroacoustic sampling of the open water portion of the lake was conducted on the night of October 24, 2013 to develop estimates of the density and biomass of alewife in Silver Lake.

-Gill-net surveys were conducted concurrently with the hydroacoustics to sample the fish community in open-water portions of the lake. These samples provide supporting data for the hydroacoustic analysis and yielded specimens of alewife for evaluating the overall condition and age structure of the population.

-With the assistance of resident Russ Cole, limnological sampling was conducted on seven occasions from May 30 to October 24, 2013. This included water clarity measures using a Secchi disk and vertical net tows for zooplankton. In addition, Cornell measured the vertical profile of temperature, oxygen and chlorophyll (using fluorometry) in July and October. Phosphorus samples were also taken but 2013 data are unavailable as of publication of this report. 2012 data are reported, however.

Section 1: The State of Silver Lake in 2013

With the help of Russ Cole, we monitored the limnology of Silver Lake in 2013 through the season from May 30 through October 24, 2013. On October 24, 2013 we surveyed the alewife population in the lake using hydroacoustics and vertical gillnets. The seasonal limnological information adds value to this data set and helps us understand the impact of alewife and other factors affecting the lake. In this section, we address five key questions:

1) Has the alewife population declined?

2) Is water clarity improving?

3) Were large-bodied zooplankton such as Daphnia present in 2013?

4) Were conditions in the lake during 2013 suitable for cold-water species, such as rainbow trout and brown trout that are our primary tool for alewife management?

5) Has the lake maintained its historical low-mid productivity trophic state or is it showing signs of increased nutrient loading?

Answering these questions is essential to further our understanding of the lake and assessing the success of the alewife management project.

1) Has the alewife population declined?

The alewife population in Silver Lake was estimated using both hydroacoustic and gill net data. The density of alewives in Silver Lake was estimated to be 5172 fish/hectare (ha) in October 2013. This represents the second highest density of alewife recorded since we started these surveys in 2008 and represents an increase in alewife abundance compared to 2012 (3738 fish/ha). Of the years surveyed, only 2010 had a higher observed density of alewife (6165 fish/ha). High alewife abundance is consistent with the low alewife growth rates and condition observed in Silver Lake. Therefore, the answer to question one is no; our data indicate that alewives have not declined in Silver Lake between 2012 and 2013. Please see appendix 1 for a complete description of the alewife survey.

2) Is water clarity improving?

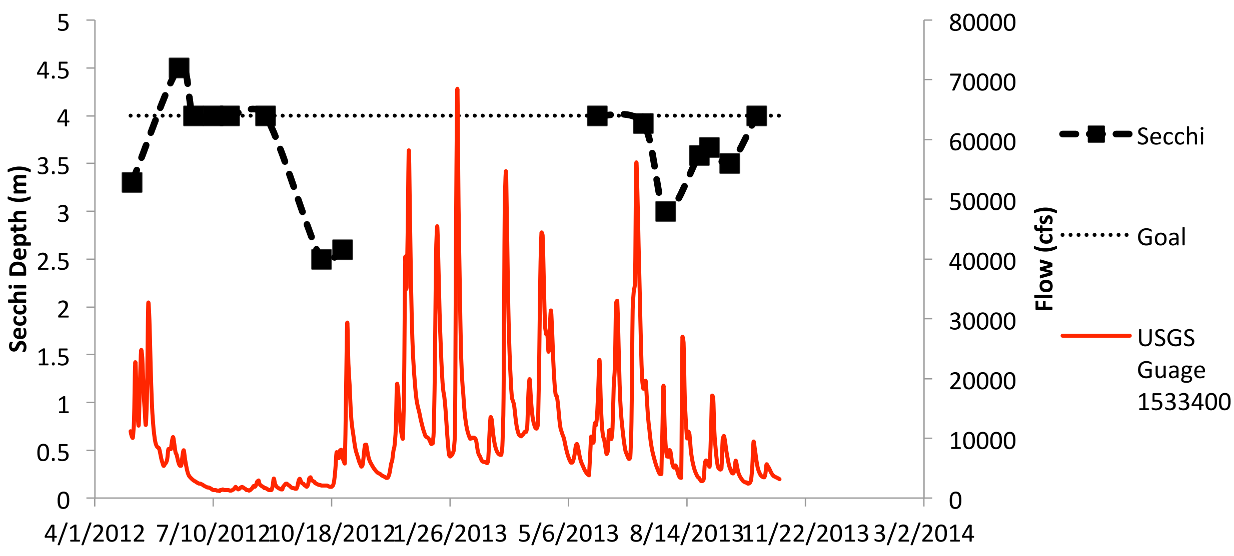
Water clarity in Silver Lake was measured with a Secchi disk, a weighted, 8-inch diameter disk with four alternately colored black-and-white sections. The depth to which the disk can be viewed provides a standardized measure of water clarity, roughly the depth at which 18% of the surface light penetrates. With the help of resident Russ Cole, we were able to track water clarity over the entire summer of 2013.

Water clarity did not meet the goal of 4 meters (m) for Secchi disk readings from 7/8/2013 to 9/19/2013 (Figure 1). Readings taken in the spring and fall had greater Secchi depth than those taken during the summer. Summer readings show a substantial decrease in water clarity during the month of July. August and September readings show a fairly consistent Secchi depth of about 3.5 m which increases to 4 m in the fall. Mean Secchi depth in 2013 was 3.6 m, which was similar to the mean Secchi depth in 2012 (3.7 m). However, the seasonal pattern of water clarity differs between the two years. In 2012 water clarity was greater during the summer whereas in 2013 the water clarity was greater in the spring and fall.

Decreases in Secchi depth in early July are correlated with heavy rains across Eastern Pennsylvania in late June and early July 2013. Data from the USGS river gauges 01533400 (Susquehanna River at Meshopen, PA) and 01536500 (Susquehanna River at Wilkes Barre, PA) were obtained from the USGS WaterWatch website (U.S. Geological Survey 2014). Analysis of these data revealed a high flow for the Susquehanna peaking at 55600 cubic feet per second (cfs) on July 2, 2013 at Meshopen, PA and 57900 cfs on July 3, 2013 at Wilkes Barre, PA (Figure 1). The decrease in water clarity observed in July of 2013 is likely associated with this rain event and the subsequent increased runoff. In comparison, the summer of 2012 was relatively dry with a consistently low flow recorded on the Susquehanna River. Similarly, Silver Lake had relatively high water clarity for this time period. Thus, we have to consider the effects of high surface water runoff in addition to *Daphnia* grazing when evaluating water clarity in Silver Lake.

Considering the above, our answer to our second question is no; water clarity did not improve in 2013 compared to previous years.

Figure 1. Seasonal changes of Secchi depth (m) in Silver Lake from 5/2/2012 to 10/12/2013. The dashed line represents Secchi depth measurements and the dotted line represents the goal of 4 m Secchi depth. The solid red line shows flow measurements taken by USGS gauge 01533400 on the Susquehanna River near Meshopen, PA from 2012-2013 (U.S. Geological Survey 2014). Note the large difference in flow between 2012 and 2013.



3) Were large-bodied zooplankton such as <u>Daphnia</u> present in 2013?

The Silver Lake zooplankton community in 2013 was dominated by small cladocerans and cyclopoid copepods. Calanoid copepods and large bodied *Daphnia* were rare in 2013. Alewives preferentially consume large zooplankton that graze on phytoplankton. When large-bodied zooplankton, particularly *Daphnia* species (a genus of Cladoceran that is a highly effective consumer of phytoplankton), are reduced or eliminated by heavy predation, the density of phytoplankton in the water column increases, and water clarity decreases (Carpenter and Kitchell 1984). To measure zooplankton densities in 2013, samples were collected near mid-lake using a Wisconsin-style plankton net (153 micron (um) mesh) that is lowered to a depth of 20 m (~66 feet (ft)) and slowly lifted vertically to the surface.

With the help of resident Russ Cole, we were able to follow the development of the zooplankton community through the entire summer of 2013. Two replicate samples were taken on eight dates between May 30, 2013 and October 24, 2013. *Daphnia* densities were low throughout the field season of 2013. The lowest abundance occurred in May and populations slowly but consistently increased until peaking at 1.4 individuals/liter (#/L) on October 12, 2013 (Figure 2). Density on October 24, 2013 was significantly lower at 0.5 #/L. The only *Daphnia* species that was consistently present throughout the spring, summer and fall was *Daphnia parvula*. *Daphnia ambigua* was only observed in the samples collected on October, 2013. Both these *Daphnia* species are small and indicative of high fish predation. The maximum length of the *Daphnia* in 2013 was 1.2 millimeters (mm) (mean 0.7 mm). Both these species have been present in Silver Lake since 2008 and were more abundant in 2012 than in 2013. We note the absence of larger *Daphnia* species like *Daphnia mendotae* and *Daphnia pulicaria*, species that are present in lakes with lower fish planktivory (Mills and Forney 1988, Wang et al. 2010). The zooplankton dominating in 2013 were small cladocerans of the genus *Bosmina* and cyclopoid copepods (Figure 3). This is a zooplankton community structure that is typical of lakes with high alewife abundance (Brooks and Dodson 1965, Wang et al. 2010).

Daphnia sp. densities were significantly lower in 2013 than in 2012. Mean density in 2012 was 4.6 #/L and in 2013 it was 0.5 #/L. Additionally, seasonal variation in these densities also displayed a different pattern. In 2012, the highest *Daphnia sp.* densities were observed in the summer (on June 23, 2012 at 12.8 #/L) and decreased substantially in the fall. In 2013, *Daphnia* peaked at 1.4 #/L on October 12, 2013. Declines in *Daphnia* in the fall may indicate a high number of age-0 alewife in 2012. These small fish feed on *Daphnia* later in the summer when they have grown larger (Wang et al. 2010).

Our third question is about large *Daphnia* – are they increasing? The answer is again no. *Daphnia* actually decreased between 2012 to 2013 and densities in 2013 were low. This is consistent with the high alewife abundance measured in the lake in 2013.

Figure 2. Density (#/L) of all *Daphnia* species in Silver Lake during summers of 2012 and 2013. Average densities are based on duplicate tows for each date (error bars represent high and low densities from replicate samples for each date; error bars in 2013 are small).

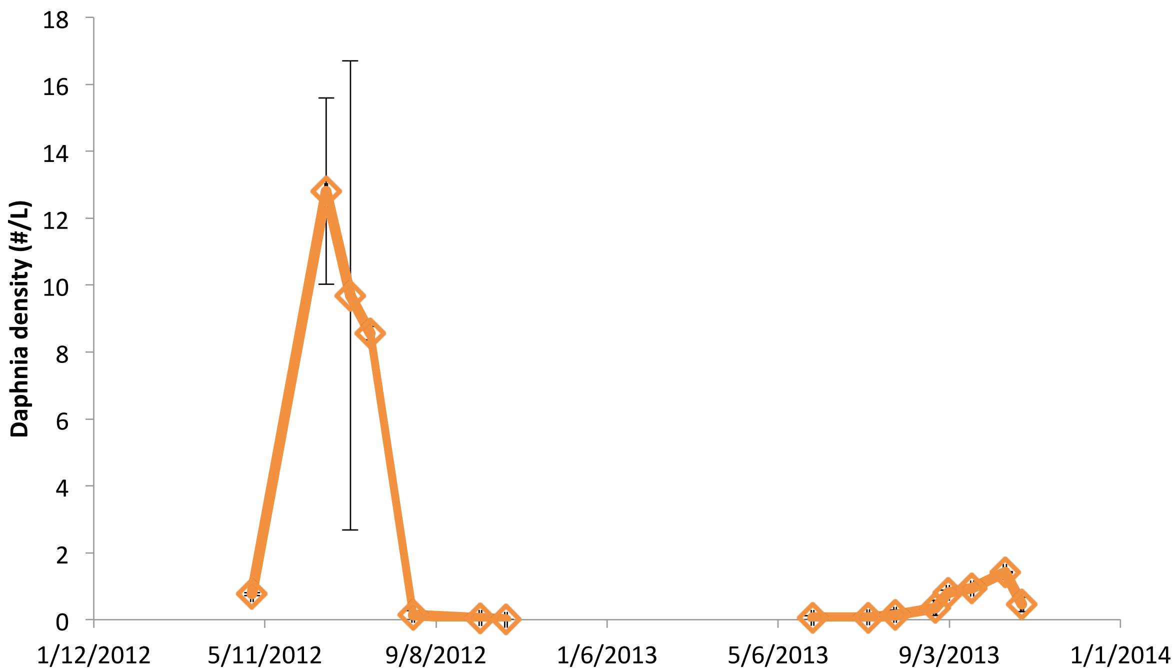
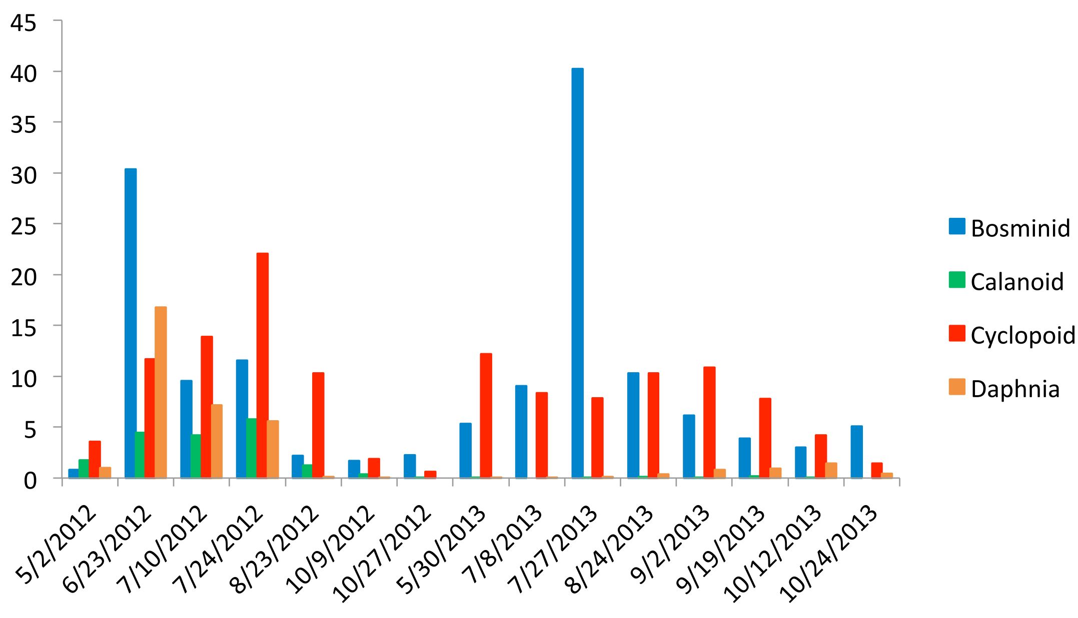


Figure 3. Mean density of zooplankton types in Silver Lake, PA. Data are from 2012 and 2013. Each date represents the mean of two replicate samples.



4) Were conditions in the lake during 2013 suitable for cold-water species, such as rainbow trout and brown trout that are our primary tool for alewife management?

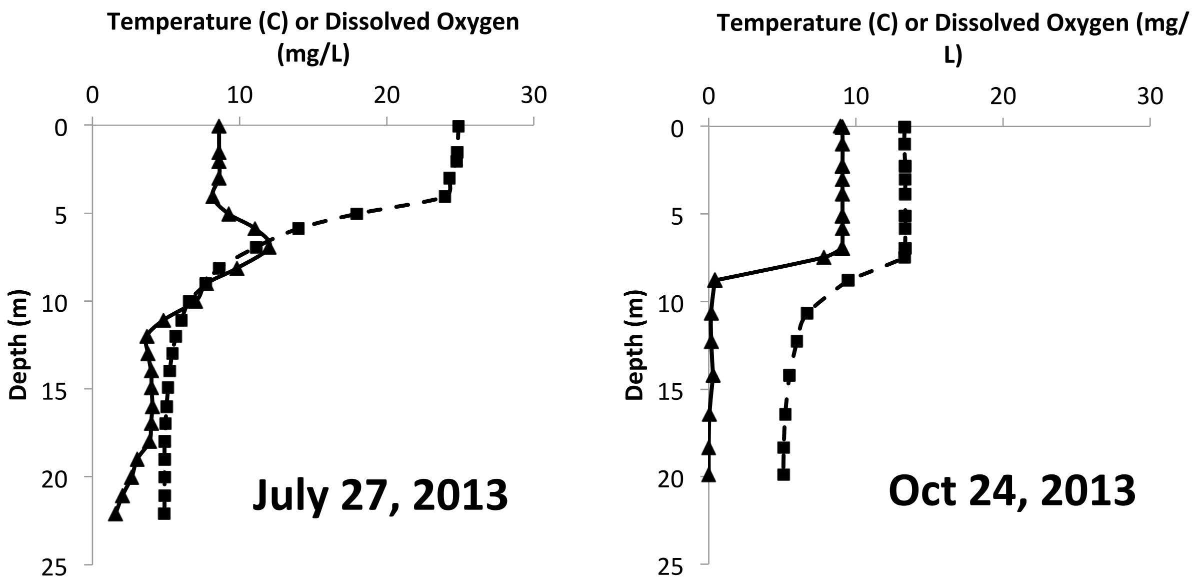
Rainbow and brown trout require cool, well-oxygenated water year-round. These species prefer water temperatures below 20 degrees Celcius (°C) (Coutant 1977) and dissolved oxygen levels above 5 milligrams/liter (mg/L) (Davis 1975). Water column profiles of temperature and dissolved oxygen were taken on July 27 and October 24, 2013. Similar profiles were taken by Cornell University in 2005-2012, and some historic data from 1946, 1992, and 2002 are also available from Silver Lake. Silver Lake stratifies in the summer with cold water (hypolimnion) below the warmer upper mixed layer (epilimnion). Temperature changes rapidly between those two layers, a region of the lake called the thermocline. Because the bottom water cannot be re-oxygenated during the summer as it is separated from the air by the epilimnion, oxygen can be depleted in the hypolimnion. If a lake is to sustain trout year-round, a large enough volume of cool, well-oxygenated water must be available within the hypolimnion to allow trout to survive throughout the summer.

Dissolved oxygen and temperature profiles taken on July 27, 2013 indicated that viable trout habitat was found in roughly 5-10 m of water (Figure 4). In October the region of water that was suitable for trout had shifted upward in the water column and included water from the surface down to 8 m depth. Both profiles indicate that suitable trout habitat is present in the lake.

This may not be the case in the future. If the oxygen in the hypolimnion is used up before the epilimnion temperature declines, the trout would be forced into warm epilimnetic water that is not suitable for these species. This can happen for two reasons. First, the rate of oxygen depletion can increase with higher productivity. Second, a warmer climate may make epilimnetic water stay warmer longer into the fall. Thus, in a longer time perspective, trout may have difficulty surviving in Silver Lake, PA.

The answer to our fourth question therefore, is that the habitat in Silver Lake was suitable for both rainbow and brown trout in 2013. That will likely continue to be the case in the short term but may not be the case in a couple of decades.

Figure 4. Temperature (°C) and dissolved oxygen (mg/L) readings for samples taken July 27, 2013 and October 24, 2013. Temperature (°C) readings are represented by a dashed line and dissolved oxygen (mg/L) are represented by a solid line. Potential trout habitat has a temperature lower than 20 °C and dissolved oxygen greater than 5 mg/L. In July, trout habitat was between 5 m and 10 m while October trout habitat was from 0 m to 8 m.



5) Has the lake maintained its historical low-mid productivity trophic state or is it showing signs of increased nutrient loading?

Lakes are classified in three productivity levels relating to low (oligotrophic), mid (mesotrophic) and high (eutrophic) productivity. Three water quality parameters (Secchi depth (m), chlorophyll (chl *a*), and total phosphorus(TP)) are used in this classification scheme. Chl *a* was measured on Silver Lake with standard lab methods (Turner bench fluorometer on filters after acetone extraction) and with an in situ flurorometer. The values from the lab measurements collected on May 30 (average of 4 discrete depths from 2 to 10m) was 5.3 ug/L (range 2.1-8.4 ug/L) and the value from October 24 (surface sample) was 2.4 ug/L. For the in situ probe measurements, we obtained chl *a* values for 1 to 10 m depths of 1.1 (range 0.3 to 1.8 ug/L) for July 27 and 1.3 ug/L (range 1.1 – 2.6 ug/L) for October 24. Note that in situ values tend to be lower than extracted values. Silver Lake is within the mesotrophic range with a 2-4 m Secchi depth and 2012 TP levels of 7.0 to 14.7 micrograms/liter (ug/L) (Table 1). Measurements by Pennsylvania DEP in July 2012 were similar to ours (Table 1).

It is useful to compare Silver Lake with regional lakes. Water clarity depends on both grazing rates (typically from *Daphnia* and mussels) and on nutrient levels. We chose data from three lakes that differ in nutrient levels and abundance of grazers. Oneida Lake is a mesotrophic lake with high abundance of both *Daphnia* and mussels (mostly the quagga mussel, a species in the same genus as the zebra mussel). The lake has similar water clarity as Silver Lake although nutrient levels are more than twice as high. Canadarago Lake is less productive than Oneida Lake with TP levels similar to Silver Lake but higher water clarity. This lake had low abundance of alewife, and relatively abundant *Daphnia*.

Finally, Cayuta Lake is a eutrophic lake with levels of TP up to 4 to 5 times higher than Silver Lake. Cayuta Lake has abundant alewife, no *Daphnia* and the lowest water clarity of any of the lakes. These comparisons stress the importance of both *Daphnia* grazing and nutrient levels for regulating water clarity in lakes. They also indicate that water clarity of around 5 m may be attainable if alewife population declined and large *Daphnia* became abundant in Silver Lake.

The answer to our fifth question about trophic status of Silver Lake is that the lake should be classified as mesotrophic. Although we do not have TP measures from all years, we believe the lake has been mesotrophic through the 2000s.

Table 1. Average Secchi depth, total phosphorus (TP), and chlorophyll *a* (Chl *a*, extracted only) concentrations in Silver Lake (average May – October). Values for several New York lakes are included for comparison. The range of annual averages for the years included are in parenthesis. Oneida Lake data is from Jackson et al. (2012), Cayuta and Canadarago Lakes from Rudstam et al. (2011). The data from 7/19/2012 was collected and analyzed by the DEP Bureau of Laboratories in Harrisburg, PA at two stations in Silver Lake and made available to us by the Rose Conservancy. Values from both stations are given. Total nitrogen (N) was 260 and 270 ug/L at the two stations, respectively. Secchi Depth was measured by Russ Cole.

Lake	Year	TP (ug/L)	Secchi Depth (m)	Chl *a* (ug/L)
Silver Lake (Cornell)	2012	10.4 (7.0-14.7)	3.7 (2.5-4.5)	
Silver Lake (Cornell)	2013	Not yet available.	3.6 (3.0-4.0)	2.4-5.3
Silver Lake (DEP)	7/19/2012	13 and 11	3.5 and 4.25	1 and 3.7
Comparison Lakes				
Oneida Lake	2000-2012	26.8 (21-31)	3.8 (2.9-4.7)	5.0 (2.6 – 7.7)
Cayuta Lake	2005-2008	39.2 (27-50)	1.1 (0.9-1.2)	No data
Canadarago Lake	2005-2008	9.4 (6.3-12.2)	4.9 (4.1-5.6)	3.1 (1.8 – 4.0)

Section 2: Historical Trends and Future Management of Silver Lake

Silver Lake, PA has been studied since 2004 and the alewife population has been studied since 2008. To date, a sufficient quantity of data has been obtained to describe long-term trends in the ecosystem with regard to the zooplankton population, water quality, alewife population and the effects of trout stocking efforts. Specific questions of interest regarding these variables are:

1) *What trends have been observed in the alewife population of Silver Lake?*

2) *Has the zooplankton community responded to changes in the alewife density?*

3) *Is water clarity (Secchi depth) in Silver Lake correlated with alewife and Daphnia density?*

Answers to these questions will allow for a better understanding of the relationship between water quality, alewife density and the effectiveness of trout stocking efforts.

1) *What trends have been observed in the alewife population of Silver Lake?*

Alewife population estimates have been conducted in Silver Lake, PA using hydroacoustics and gill net surveys since 2008. Alewives were abundant in all years since 2008, ranging from 2850 (2008) to 6165 (2010) fish/ha (Table 2, Figure 5). Growth rates and condition have varied among years, but both variables are in the low range for alewife populations in this region. The low growth rate and condition of this alewife population is consistent with high alewife abundance (Rudstam et al. 2011). Our estimates of alewife abundance increased from 2008 to 2010, declined between 2010 and 2011 and then increased again to the second highest values recorded in 2013. The length and age distribution show consistent recruitment each year. However, very few age-0 fish from 2010 survived to 2011. The lack of the 2010 year class is visible in the size distribution of 2011 and 2012. The high mortality of this age group could have been due to the cold winter of 2011. Ice duration at Oneida Lake was 107 days that winter compared to 71-85 days for the winters of 2007 to 2010. Ice duration was short in 2012 (21 days) and 2013 (78 days, Rudstam and Jackson 2013). Winter temperatures were colder than the mean in the area in 2011, especially in December and March (Figure 6; NOAA National Climatic Data Center 2014). This should have led to a long period of ice cover in the winter of 2010-2011 which is consistent with the high mortality of the 2010 year class from the fall of 2010 to the fall of 2011. In addition to the long winter, age-0 alewives were small and had relatively poor condition in the fall of 2010 indicating a population susceptible to winter survival.

We also note that only one alewife caught in the 2013 survey was aged to be older than age-2. This indicates a high mortality rate for fish age-2 and older. At least some of this mortality is due to predation by the introduced trout. One brown trout caught by Russ Cole in June, 2013 had consumed two alewife, one age-1 fish and the other likely older than age-2 (143 mm long). High mortality of age-2 fish could also be associated with spawning mortality after winter, as Silver Lake alewives are in relatively poor condition entering the winter.

Despite the influence of trout predation, we see little response of total alewife abundance to the trout stocking in Silver Lake. Both rainbow trout and brown trout have been stocked in the lake by the Lake Association since 2006 (Table 3). It may be difficult to control alewife populations through predation (Rudstam et al. 2011). Alewives have a strong compensatory response to increased mortality, due to increased growth rates and decreased cannibalism at lower densities (adult alewives feed on alewife larvae). This effect has been observed in Lake Ontario (O'Gorman et al. 2004) and in New York lakes (Rudstam et al. 2011). Similar results have been observed in Silver Lake. A strong year class was produced in 2011 after the decline of older alewife and the population increased again in 2012. Further studies on Silver Lake will add to our understanding of these compensatory responses.

Table 2. Historical estimates of alewife density in Silver Lake, PA and trends observed in the age structure of the gill net catches.

Year	Date of survey	Alewife Density (fish/ha)	Biomass (kg/ha)	Percent YOY	Percent age 1
2008	10/14/2008	2850	20.2	48.3	18.6
2009	10/19/2009	3831	27.2	38.4	25.5
2010	10/18/2010	6165	23	34.2	41.1
2011	10/3/2011	3032	26.4	64.4	0
2012	10/9/2012	3738	43.3	20.5	55.1
2013	10/24/2013	5172	35.7	28.3	33.1

Table 3. Trout stocking activity in Silver Lake from 2006-2013. Length refers to values for maximum length provided by the hatchery.

Year	# and length (in) of Rainbow Trout	# and length (in) of Brown Trout	Date Stocked	Acoustic Alewife Density (fish/ha)
2006	150 / 11	150 / 12		No Data
2007	150 / 11	150 / 12		No Data
2008	150 / 11	150 / 12		2850
2009	150 / 11	150 / 12		3831
2010	--	--	--	6165
2011	--	--	--	3032
2012	600 / 10	--		3738
2013	--	600 / 11		5172

Figure 5. Historical acoustic density, gill net catches and biomass estimates of the alewife population in Silver Lake, PA. Data are from 2008-2013.

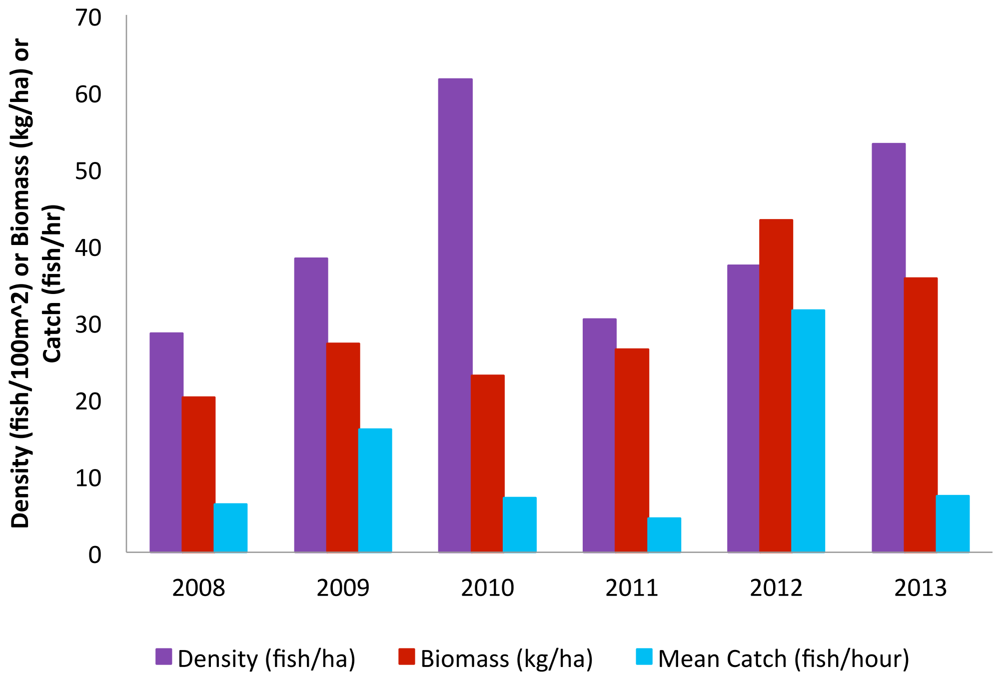
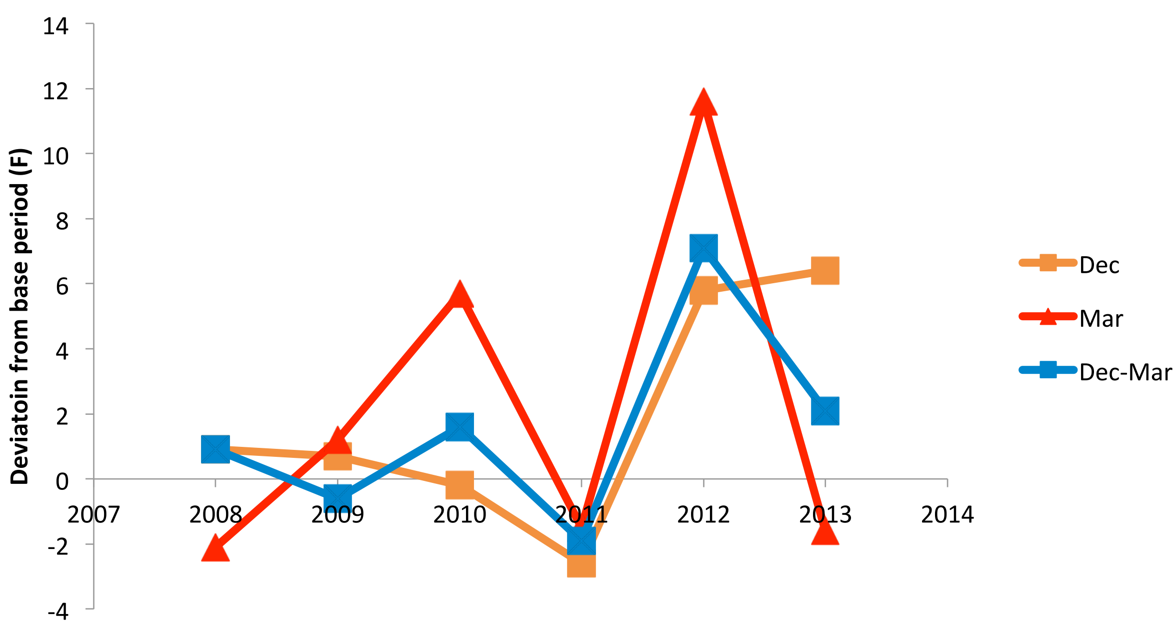


Figure 6. Winter air temperature deviation from the base period mean (1901-2000) in degrees F. Data are from NCDC Climate-at-a-glance website (NOAA National Climatic Data Center 2014). Data relate to the mean temperature for Climatic Division 6 in Pennsylvania.



2) How has the zooplankton community responded to changes in the alewife density?

The zooplankton community structure in Silver Lake has been studied using multiple annual samples since 2008. From this data we can observe long term trends for the fall since 2008. Expanded sampling in 2012 and 2013 has allowed us to obtain more detailed analyses of seasonal variation in the community structure.

In general, the zooplankton species groups present in Silver Lake, PA are: *Daphnia sp.*, cyclopoid and calanoid copepods and bosminids (small cladocerans or water fleas). Of these groups, *Daphnia* and calanoid copepods are the largest and are selectively consumed by alewives. *Daphnia* is a group of specific interest as these animals are efficient phytoplankton grazers that contribute to increased water clarity (Carpenter and Kitchell 1984). High *Daphnia* densities have been linked to decreased phytoplankton abundance in other limnological systems (Carpenter and Kitchell 1984, Mills and Forney 1988). Our observations of fall *Daphnia* densities show a fluctuating trend with peaks in 2008 and 2011 and troughs in 2006, 2009 and 2012 (Figure 7). Note that this data relates to fall zooplankton. In the summer, *Daphnia sp.* did represent a significant proportion of the zooplankton community in 2012 but not in 2013.

Other zooplankton groups also show variation among years. In the fall, bosminids and cyclopoid copepods have consistently represented a large proportion of the zooplankton community and have increased in relative abundance since 2010 (Figure 8). Calanoid copepods were abundant in the fall from 2008-2009 and decreased as a proportion of total fall zooplankton from 2010 onwards. However, they were observed to be a significant proportion of the community in summer sampling of 2012. Calanoid copepods often show similar patterns of abundance as *Daphnia* as both groups are selected by alewife (Wang et al. 2010).

Alewife density differences among years are correlated with the abundance of *Daphnia* and calanoid copepods (Figure 8). *Daphnia* densities above 2 #/L were only observed in the two years with the lowest alewife abundance. However, the zooplankton community is still dominated by smaller zooplankton (cyclopoid copepods and bosminids) with fewer large zooplankton (*Daphnia* and calanoid copepods). Such shifts in community structure have been observed in other lakes where alewife have been introduced and became abundant (Wang et al. 2010, Rudstam et al. 2011). This community structure is consistent with a high alewife population.

Figure 7. *Daphnia* and alewife abundance trends in Silver Lake, PA. Zooplankton density is the mean density of zooplankton samples collected between August and October.

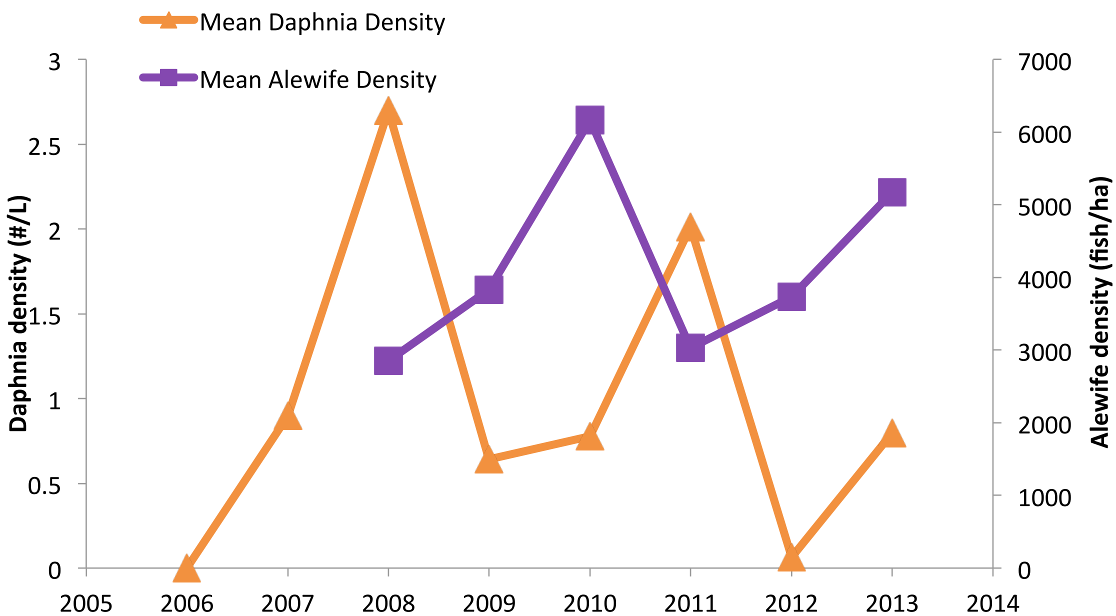
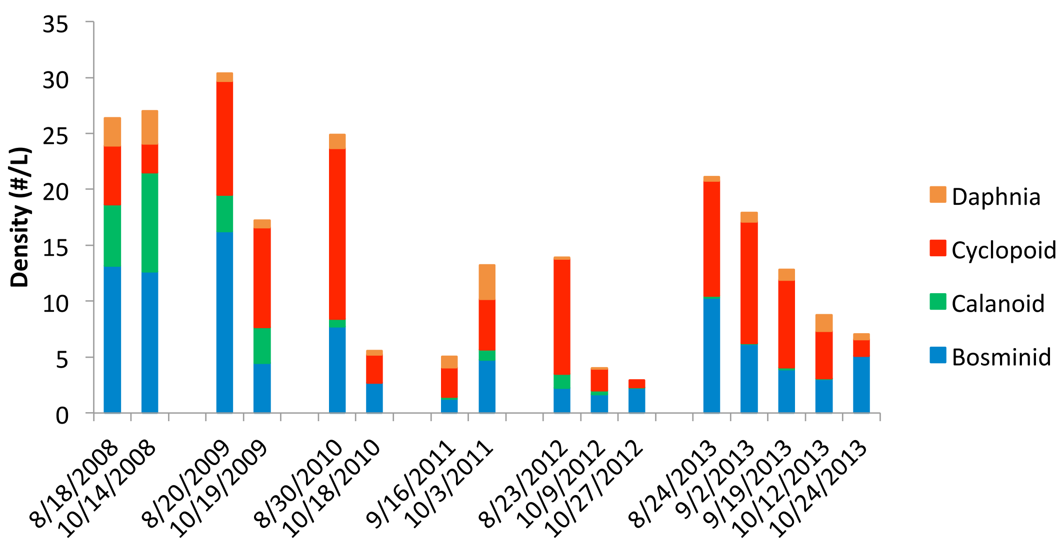


Figure 8. Historical densities of zooplankton groups in Silver Lake, PA since 2008.



3) Is water clarity in Silver Lake correlated with alewife and Daphnia density estimates?

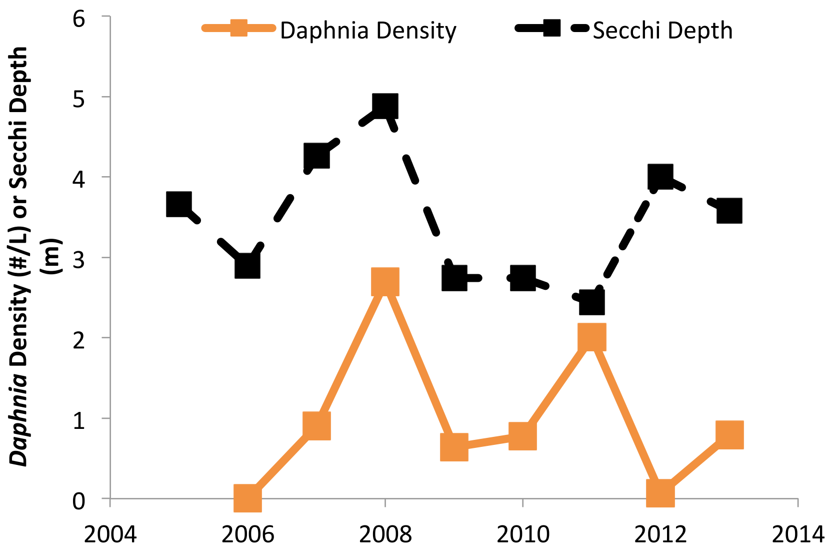
Observations in other lake ecosystems suggest a strong link between *Daphnia sp.* abundance and phytoplankton abundance. When *Daphnia* are abundant, phytoplankton abundance decreases and water clarity increases (Carpenter and Kitchell 1984). However, what is the correlation of *Daphnia sp.* density and water clarity in Silver Lake, PA? Our analyses show a correlation between increased alewife abundance and decreased *Daphnia* densities in Silver Lake. However, zooplankton grazing is not the only factor that can affect water clarity. We therefore analyzed the densities of alewife (fish/ha) and *Daphnia sp.* (#/L) in relation to observed Secchi depth (m).

Our analysis of the October alewife and *Daphnia sp.* densities since 2008, shows a negative correlation between these two variables (R^2=0.43, N = 6, P = 0.08, one-tailed test). Additionally, *Daphnia sp.* density in August was positively correlated with Secchi depth although Daphnia only explained 30% of the variation in water clarity (R^2=0.30, N=6, P=0.10, one-tailed test). This analysis indicates that high alewife populations result in decreased *Daphnia sp.* populations in Silver Lake that are associated with decreases in water clarity even though we do not yet have sufficient number of years of data and/or sufficient range in the variables to get statistically significant results at the standard $P<0.05$ level. Other factors do contribute to the variability in observed water clarity in Silver Lake.

These correlations can be visualized in Figure 9. Fall *Daphnia sp.* densities largely mirror trends in Secchi depth. Between 2006 and 2008 *Daphnia sp.* density increased with water clarity. Water clarity then declined with decreases in *Daphnia sp.* density reaching a low between 2009 and 2010. 2011-2013 data do not show as strong a correlation as *Daphnia* increased in 2011 and then decreased in 2012 while the Secchi depth decreased in 2011 and then increased in 2012. Additionally, water clarity decreased in 2013 despite increasing *Daphnia sp.* density.

Note that we only have two years of seasonal zooplankton and water clarity data. The two years we do have (2012 and 2013) show higher water clarity and *Daphnia* abundance in 2012 than in 2013. However, the region also experienced high flood events in the summer of 2013 which makes it impossible to tease out the relative contribution of increased runoff and decreased *Daphnia* abundance in 2013 for reducing water clarity that year compared to 2012. This is discussed in more detail in Section 1: The State of Silver Lake in 2013.

Figure 9. *Daphnia sp.* densities (#/L) and Secchi depth (m). *Daphnia* and zooplankton densities compare data from samples taken from August to October.



Section 3: Management Recommendations and Prospects for the Future

The data to date show little effect of the trout stocking on the alewife population in Silver Lake, and as a consequence, there has not been a significant return of *Daphnia* to the lake or changes in water clarity. We recommended an increase in trout stocking to 600 fish per year in 2012 and the lake association followed that recommendation. The lack of an effect on the alewife is therefore discouraging although trout stocking has provided anglers with a new sport fishery. As discussed in this report, alewives have strong compensatory responses to predation and may be very difficult to control by stocking predatory fish species. We do note that full effect of the 2012 stocking may not yet have materialized and that we do need to observe the lake in 2014 to determine if the 2013 stocking of 600 brown trout will be effective. Brown trout has survived better in the lake that rainbow trout as all the older trout checked by us in 2013 were brown trout.

One subject of interest this year is the possibility of a winter mortality event. The alewives were again in poor condition in the fall of 2013. Because the winter has been cold and has the potential to be longer than usual, we expect a higher than normal overwinter mortality of alewife. If so, the balance between the abundance of stocked trout and alewife may have shifted by the spring of 2014 and there may be a sufficient number of trout to control the alewife population this year. This is an exciting possibility for 2014, but is far from a certainty. Even so, another season of sampling will allow us to learn more about alewife compensatory responses and overwinter mortality and will supply useful data relating to the ecology of Silver Lake and other lakes in the Northeast. Therefore, we would like to continue sampling Silver Lake in 2014 and possibly also in 2015, hopefully with the help of resident Russ Cole who has proved to be invaluable to our sampling efforts on Silver Lake. The seasonal pattern of zooplankton abundance and water clarity helps us understand this lake and the seasonal dynamics associated with each new alewife year class. In addition, we would like to add one alewife sampling event in May or early June of 2014 to better understand the effect of winter duration and severity on alewife density. This would also allow us to analyze the maturity schedule for this slow growing alewife population.

Our recommendations for 2014 are therefore

1) Continue limnological surveys of the lake at least monthly from May through October
2) Survey the alewife population in early June and October of 2014. At that time, also sample Chaoborus larvae.
3) Consider bringing a small trawl in October of 2014 to sample smaller alewives that are not caught in the vertical gill nets.
4) Consider further trout stocking in the lake only after preliminary results in the fall of 2014 are available. If there is no decrease in the alewife population in the spring or fall of 2014, trout stocking may not be a viable control strategy in Silver Lake.

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We appreciate the opportunity to study Silver Lake and the trophic dynamics of this system. This study is not possible without the financial support of the E.L. Rose Conservancy and the Actus Foundation. We also thank Russ Cole for help with lake sampling, Patty Bloomer for logistic support, Chris Hotaling for zooplankton processing, Tom Brooking for advice on alewife aging and Dr. Jim Watkins for discussions and information from 2012.

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Appendix 1. Hydroacoustic and Gill Net Estimates of Alewife (*Alosa pseudoharengus*) Abundance in Silver Lake, PA, 2013.

Abstract: The alewife (*Alosa pseudoharengus*) population in Silver Lake, Pennsylvania, was surveyed on the night of October 24, 2013 using small-mesh pelagic gill nets and hydroacoustics (123 kHz split beam). Over a period of about 2.5 hours, 131 fish were caught in 6 vertical nets set at different depths. This included 127 alewife, 2 brown trout (*Salmo trutta*), 1 chain pickerel (*Esox niger*) and1 yellow perch (*Perca flavescens*). The ages of the fish were determined by examining annual rings on otoliths. Average length of age-0 alewife was 60 mm (range: 59-61 mm), age-1 alewife 92 mm (84-117mm) and age 2 and older alewife 121 mm (110-157 mm). The size distribution showed three distinct peaks corresponding to age-0, age-1 and older alewife. The proportion of alewife to total alewife catch in each age group was 28%, 34% and 38%, respectively. Mean percent dry weight of alewife (an indication of condition) was 20.4% (19.7% for age 0, 21.2% for age 1, 19.8% for age 2 alewife). These values indicate low condition and slow growth relative to New York State alewife populations. This in turn indicates a high abundance of alewife relative to the productivity of Silver Lake. By fall, the spring age 0 alewives had attained lengths comparable to those of previous years. Acoustic density estimates confirm high fish abundance. Fish density in October 2013 for targets > -60dB was estimated to be 5172 alewife/ha. Almost all fish were within the warmer, oxygenated top 10 m of water. Biomass was estimated from the average weight of the alewife catch (6.9g) and the acoustic density. The corresponding fish biomass is 35.7 kg/ha. Acoustically derived alewife densities were similar across the lake and densities among separate transects ranged from 3168 to 6293 fish/ha, resulting in a relative standard error (SE/mean) of 10.3%.

Introduction

The alewife, *Alosa pseudoharengus*, is an effective planktivore and abundant alewife populations cause declines in large, efficient zooplankton algae grazers. Therefore, abundant alewife populations are usually associated with high chlorophyll levels and decreased water clarity. We have followed the alewife population in Silver Lake with hydroacoustics since 2008 as part of our efforts to understand both lower trophic levels and water clarity in the lake, and to test if the stocking of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) will have an effect on alewife populations. In this section, we present the results of the 2013 acoustic and gill net survey for alewife in Silver Lake, Pennsylvania.

Materials and Methods

Silver Lake was surveyed using a 123 kilohertz (kHz) split beam echo sounder (Table 1, Figure 1). A total of 5 transects of acoustic data were collected along the major axis (north-south) of the lake during the night of October 24, 2013 and analyzed for alewife abundance (Figures 1 and 2). Acoustic transects were evenly spaced across the whole lake and analyses were conducted by transect. Spatial location of the data was measured with a GPS unit that recorded latitude and longitude directly into the acoustic data stream. All acoustic data were collected on the night of October 24, 2013 between 21:36 and 22:11.

Acoustic data were recorded directly to a laptop computer in the field and analyzed with the EchoView software (version 5.3.36 Myriax Inc. Hobart, Tasmania, Australia). The unit was calibrated on the night of the survey (October 24, 2013) with a standard -40.4 decibel (dB) 33.2 millimeter (mm) tungsten sphere (Table 1). No gain corrections were needed for the transducer (field calibrations within +/- 0.5 dB of factory calibrations). All data were visually inspected for consistent bottom detection, interference from surface bubbles and aquatic vegetation and corrected when needed (Figure 1). The ambient noise level measured in the Sv domain was -127.6 dB at 1 meter (m), which corresponds to -153.1 dB in the target strength (TS) domain. This is low enough to register fish with TS of -60 dB at 86 m depth without bias and thus is sufficient for the alewife survey in Silver Lake. Analysis was done for each transect. The near-field of this transducer is approximately 1.5 m and it was mounted on a rigid pole 0.5 m below the surface. Therefore, the acoustic analysis is restricted to depths below 2 m.

Fish density was calculated for each transect from the average measured *in situ* target strength (TS) and area backscatter cross-section (ABC) as follows. Since almost all the fish caught in the gill nets were alewife, all targets were assumed to be alewife. *In situ* TS distributions were obtained with EchoView using targets within the half power beam angle and settings for single fish determination following the Standard Operating Procedure for Great Lakes Acoustics (Table 1, Parker-Stetter et al. 2009). Alewives were assumed to be targets larger than -60dB based on the shape of the TS distribution and known range of TS from a given alewife size group (Brooking and Rudstam 2009). The peak in targets below -60 dB is interpreted as invertebrates, such as *Chaoborus* (phantom midge) larva, which occur in Silver Lake. Fish density was calculated based on average *in situ* target strengths for targets larger than -60dB. Appropriate depth varying thresholds were applied to the Sv data following Parker-Stetter et al. (2009). Fish densities in the top 2 m were calculated based on relative catches in vertical gill nets in 0-2 m versus 2-6 m and acoustic density in the 2 to 6 m depth range following Rudstam et al. (2011). Additionally, a depth distribution was obtained in 1m intervals combining data from all transects and the average *in situ* TS in each depth layer to evaluate vertical distributions of alewife. All averages and calculations are made in the linear domain and back transformed to dB units where appropriate.

Concurrent to the acoustic survey, fish were sampled using vertical gill nets. The 6 m deep and 21 m long nets consisted of 7 panels, each with a different mesh size (6.25, 8, 10, 12.5, 15, 18.75, and 25 mm bar mesh). This set of mesh sizes will catch alewife between 50 and 240 mm (Warner et al. 2002). The nets were set in pairs at three locations in the southern, western and eastern quadrants of the lake (Figure 2), with one net fishing from the surface to 6 m depth, and the other in deeper water (Table 2). The floating net set in the eastern quadrant was not set correctly, which precluded using that catch for depth distributions. Nets were left in place for 2.2 to 2.5 hours (hrs). Fish were identified to species and the depth of catch was recorded in 2 m intervals. Length in mm was measured for all fish and a subsample (N=61) was collected to obtain dry weight and age data (Table 3). The ages of the alewife were determined by examining annual rings of otoliths (N=30), which are small calcium carbonate structures in the fish's' inner ear. Scale samples were taken from all 61 fish for future reference. A muscle sample was also obtained from a subsample of alewife for future genetic analyses. Wet-to-dry weight was determined by drying fish in a 70^{o}C oven for 7 days (N=30). No further decline in weight was detected between day 5 and day 7. Weight was estimated for all fish caught using a length-weight regression derived from the subsample measured with both length and weight.

Results and Discussion

Net sampling. A total of 131 fish were caught in the gill nets (Table 2). 127 of the fish caught were alewife. Individuals were found from the surface, to a depth of 14 m, with a peak in catches between 5 and 7 m (Table 2, Figure 3). Acoustic depth distribution also showed a peak fish density in deeper water, although this peak was slightly deeper, between 7 and 10 m (Figure 3). Very few fish were caught in the nets or measured with acoustics in water deeper than 10 m.

Average length of the 127 alewife caught was 93 mm (SE 2.2, range 50 to 157 mm) and average weight 6.9 grams (g) (SE 0.4, range 1.0 – 25.9 g). Average weight was calculated for all fish based on a length-weight regression for the subsample of 59 fish with both length and weight measures (W (g) = $1.37\ 10^{-5} * L^{2.86}$, R^2=0.99, N=59, range 59 to 157 mm). The size distribution of alewife in 2013 had three modes, fish smaller than 80 mm (28%), fish between 80 and 110mm (34%) and fish larger than 110 mm (38%, Figure 4). Based on the subsample aged, we interpret these three peaks as age-0, age-1 and age-2 and older fish. The age-0 fish were a larger proportion of the catch in 2013 than in 2012 (28% compared to 11%) and averaged 60 mm (range for the 2 aged fish 59-61 mm). Alewives typically reach lengths of 60 to 90 mm by September of their first year of life in New York inland lakes, but can get larger, up to 140 mm, in productive lakes with large zooplankton (e.g., Canadarago Lake, Rudstam et al. 2011).

A subsample of 30 fish were aged using otoliths. All but one fish were between age 0 and age 2. The ages and measured lengths correspond well with the three size groups in the length distribution. Three of the fish considered age-1 were between 115 and 117 mm and would have been considered age-2 from the size distribution. However, aging is difficult due to the slow growth of these alewives. One larger fish (157mm) was aged as age-3, but could have been older. Length at age is summarized in Table 3.

Another subsample of fish were weighed and then dried in a drying oven for 7 days at 70^{o}C. No weight decrease occurred from day 5 to day 7 indicating that all the water had evaporated from the samples. These fish were used to calculate the dry/wet weight ratio: an index of condition. The dry/wet weight ratios were attributed to the different age groups based on the lengths of the fish (<80mm as age-0, 80-110 mm as age-1 and 110mm and larger as age-2 and older). Dry/wet ratios were similar across ages and ranged from 19.7% for age-0, 21.2% for age-1 and 19.8% for older fish (Table 3). The overall average dry/wet weight ratio was 20.4% (range 16.7% - 26.7%, N=30).

For Silver Lake in 2013 both the average length of 93 mm for all fish caught and the average index of condition of 20.4% (dry/wet weight ratio) were low compared to other regional populations (Rudstam et al. 2011). These data are consistent with a low productivity lake with a relatively high alewife population.

Four fish other than alewife were also caught in the gill nets (Table 2). One male brown trout (*Salmo trutta*; 575 mm) was caught in the east sinking net set #1 and one ripe female brown trout (566 mm) was caught in the south floating net set. One chain pickerel (*Esox niger*; 444 mm) and one yellow perch (*Perca flavescens*; 277 mm) were also caught in the south floating net and the east sinking #2 net, respectively. In addition, one 686 mm brown trout was caught by Russ Cole (angling) in June 2013 with two alewives (143 and 105 mm) in its stomach.

Acoustic data. Average TS of alewife in Silver Lake calculated from single fish targets larger than –60 dB was –50.7 dB (Table 3). The TS distribution was similar in water 2-6 m and 6 m to the bottom (Figure 5). We therefore analyzed the whole water column as one depth layer. The expected modal TS of the alewives caught in the gill nets (length range 50 to 157 mm) calculated using the equation in Brooking and Rudstam (2009) ranged from -48.8 dB to -39.4 dB. The mean TS expected from the average fish caught in the gill nets is -45.3 dB. Observed mean TS in 2013 was -50.7 dB (Table 4). As in 2010 to

2012, acoustically observed TS were smaller than predicted from the gill net catches in 2013. A mean TS of -50.7dB is expected from a 48 mm alewife. Catches of fish smaller than 60 mm fish are biased low with these nets (Warner et al. 2002). Despite this, some alewives smaller than 60 mm were caught. This may indicate that small alewife are present and are more abundant than suggested from the gillnet catches. In light of this, it is possible that our methods are underestimating the proportion of age-0 alewives in the Silver Lake population.

Mean target density calculated from the *in situ* TS data obtained from the five transects and weighted by transect was 4333 fish/ha from 2 m to the bottom. Almost all targets were found in the top 10m of the water column (Table 4, Figure 3). Densities from 0-2 m were calculated from acoustic densities from 2-6 m assuming the catchability in the gill nets are the same from 2-6 m and 0-2 m of water (see Rudstam et al. 2011). This value ranged from 339 (transect 5) to 1091 (transect 2) fish/ha. The near-field estimate was added to the target density for each transect and the mean density was weighted by transect length resulting in a density of 5172 fish/ha (range 3168 fish/ha (transect 1) to 6293 fish/ha (transect 2)). Relative standard error calculated for densities from 2 m to the bottom (SE/mean) was 10.3%. Assuming all of these fish were alewife, and an average weight of alewife of 6.9 g (see above), the alewife biomass was calculated to be 35.7 kg/ha.

Acoustic densities obtained from 2013 (5172 fish/ha) were somewhat lower than those observed in 2010 (6165 fish/ha) but higher than those seen in 2008, 2009, 2011 and 2012 (2850, 3831, 3032 and 3738 fish/ha, respectively). For comparison, densities around 2000 to 3000 fish/ha are common in New York lakes (Fitzsimons et al. 2005, Wang et al. 2010, Rudstam et al. 2011) and densities of over 6000 fish/ha were observed in Onondaga Lake in 2013 (Rudstam et al. 2014). Low YOY growth rate and condition are also indicators of high alewife abundance.

It should be noted that high densities of fish close to the surface add uncertainty to the acoustic density estimates because they rely on interpolation from limited net catches. Small alewife may also have lower catchability due the size selectivity of the nets. Lower than expected average TS values as well as the small size of age-0 fish that we did catch suggest that this may be the case. If this is true, the biomass estimate is biased high and the proportion of age-0 alewife in the population is biased low. The estimate of total alewife density, however, would not be affected.

Acknowledgment

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Table 1. Settings used for acoustic estimates of open water fish in Silver Lake, October 24, 2013. Thresholds and detection limits according to Parker-Stetter et al. (2009).

Parameter	**Values**
Date and time	10/24/2013 21:36:38-22:11:40
Unit	Biosonics 123 kHz, 7.5 ^{o} beam width, split beam
Analysis software	EchoView 5.3.36
Analyzed by	Per G Rudstam, 1/13/2014
Pulse rate/ pulse length	3 pps / 0.2 ms
Lower threshold for fish	-60dB
Absorption coefficient; sound speed	Constant 0.0042058 dB/m ; 1458m/s
Equivalent beam angle	-20.12 dB
Noise at 1 m (Sv/TSu)	-127.6 dB / -153.1 dB
Detection limit TS -64dB without bias	86 m
Calibration offset Sv	0 dB
<u>Single fish detection criteria</u>	
Max beam compensation	6 dB
Pulse duration min, max	0.6, 1.5
Standard Deviation of angles	0.6, 0.6

Table 2. Summary of fish catches in the six vertical gill nets with variable mesh size set in Silver Lake on October 24, 2013. Nets were set at dusk and retrieved between 2.2 and 2.5 hours later. Most of the fish caught were alewife, with two brown trout, one yellow perch and one chain pickerel also caught. Upper and lower depth is the depth of the upper and lower net line (measured with acoustics for the sinking nets). Sinking nets were set from the bottom up 6 m and surface nets were set from the surface down to 6 m depth.

	Site 1 (West) floating	**Site 1 (West) sinking**	**Site 2 (East) sinking #1**	[a]**Site 2 (East) sinking #2**	**Site 3 (South) floating**	**Site 3 (South) sinking**
Latitude N	41°55.995’	41°55.995’	41°56.077’	41°56.083’	41°55.919’	41°55.921’
Longitude W	75°57.244’	75°57.244’	75°57.035’	75°57.031’	75°56.986’	75°57.000’
Set time (h)	19:50	20:00	20:17	20:07	20:44	20:44
Retrieve time (h)	22:21	22:30	22:47	22:39	23:03	22:55
Soak time (h)	2.5	2.5	2.5	2.5	2.3	2.2
Upper depth (m)	0	8	5	--	0	7
Lower depth (m)	6	14	11	--	6	13
# alewife caught	29	2	29	21	44	2
Catch / hour alewife	11.6	0.8	11.6	8.4	19.1	0.9
Upper 1/3	0.62	0.50	0.71	--	0.49	0.50
Median 1/3	0.28	0	0.29	--	0.32	0.50
Lower 1/3	0.10	0.50	0	--	0.19	0
Alewife						
Mean Length (mm)	89	93	80	84	110	60
Range (mm)	65-124	75-110	53-134	51-157	69-135	50-69
Prop <80mm (%)	17	50	59	48	2	100
Other Fish	None	None	Brown Trout 575 mm	Yellow Perch 277 mm	Brown Trout 566 mm; Chain Pickerel 444 mm	None

a) The second net at site 2 did not set properly and has been excluded from the calculations of depth distributions.

Table 3. Length-at-age and percent dry weight for alewife from Silver Lake, PA caught in October of 2008-2013.

Age	Mean Length (mm)	Range	N	% DW	Range	N
2008						
0	69	58-80	6	22.3	17.7-25.3	12
1	92	85-97	10	22.9	20.2-24.3	10
2	112	105-120	10	25.0	22.7-28.2	18
3	131	119-144	3	--	--	0
4	141	133-152	3	--	--	0
2009						
0	64	55-69	10	23.4	21.0-25.9	15
1	87	80-92	4	23.8	22.3-26.4	8
2	106	99-110	6	25.2	22.9-27.2	17
3	126	118-136	7	--	--	0
4	137	133-143	3	--	--	0
2010						
0	65	55-75	10	22.4	19.3- 24.7	17
1	76	70-82	2	21.7	--	1
2	90	83-108	9	22.2	22.5-29.3	22
3	114	106-121	4	--	--	0
6	175	--	1	--	--	0
7	187	--	1	--	--	0
2011						
0	65	52-77	12	20.4	15.8-25.0	27
1	--	--	0	--	--	0
2	128	122-135	15	24.7	21.8-25.5	9
3	137	132-140	5	25.2	23.4-27.4	3
4	148	147-150	3	--	--	0
5	165	--	1	24.9	--	1

8	208	--	1	24.7	--	1
9	220	--	1	26.0	--	1
2012						
0	57	54-59	5	18.6	15.8-25.2	5
1	114	96-123	35	25.5	23.2-29.8	87
2	127	116-133	19	26.9	22.6-30.9	17
3	153	139-166	11	24.2	21.5-26.9	11
4	169	157-190	5	24.6	23.5-27.3	5
5	234	--	1	31.7	--	1
7	244	235-252	2	31.1	30.7-31.5	2
2013						
0	60	59-61	2	19.7	16.7-22.7	2
1	92	84-117	16	20.9	17.5-26.7	14
2	118	110-130	11	[a]20.0	17.2-22.0	14
3	157	--	1	--	--	0

a) The dry weight to wet weight ratios in this row represent all alewife age 2 and older.

Table 4. Results from acoustics estimate of alewife in Silver Lake October 24, 2013, using a 123 kHz split beam unit. Density includes the whole water column (see methods). Density is calculated from ABC/σ_{bs}, where σ_{bs} is target strength in the linear domain (back scattering cross section: $\sigma_{bs} = 10^{(TS/10)}$). Target density is calculated based on transect specific *in situ* TS. The alewife density in 0-2 m was calculated based on average 2-6 m density and catch in the gill nets and was added to the target density to calculate alewife densities from 0m-bottom. Biomass is the alewife density multiplied with the average weight of alewife caught in the gill nets (6.9 g).

Transect #	Transect Length (m)	Average TS (dB)	ABC (m2/ha)	Target Density (>-60 dB) below 2m (#/ha)	Alewife Density 0m-bottom (fish/ha)
1	452	-50.6	0.022	2498	3168
2	454	-51.4	0.038	5201	6293
3	925	-50.7	0.036	4188	5110
4	888	-50.3	0.049	5278	6147
5	284	-50.6	0.029	3383	3723
Average	601	-50.7	0.035	4333	5172
Biomass (kg/ha)					35.7

Figure 1. An example of an echogram in the Sv domain. The echogram represents transect 3 of the October 24, 2013 hydroacoustic survey of silver Lake, PA. Colors are indicative of the strength of the signal returned (red is the strongest and black, the weakest). Note the high concentrations of targets from 7 to 10m and the absence of targets below 10m (grid lines are in 5 m increments).

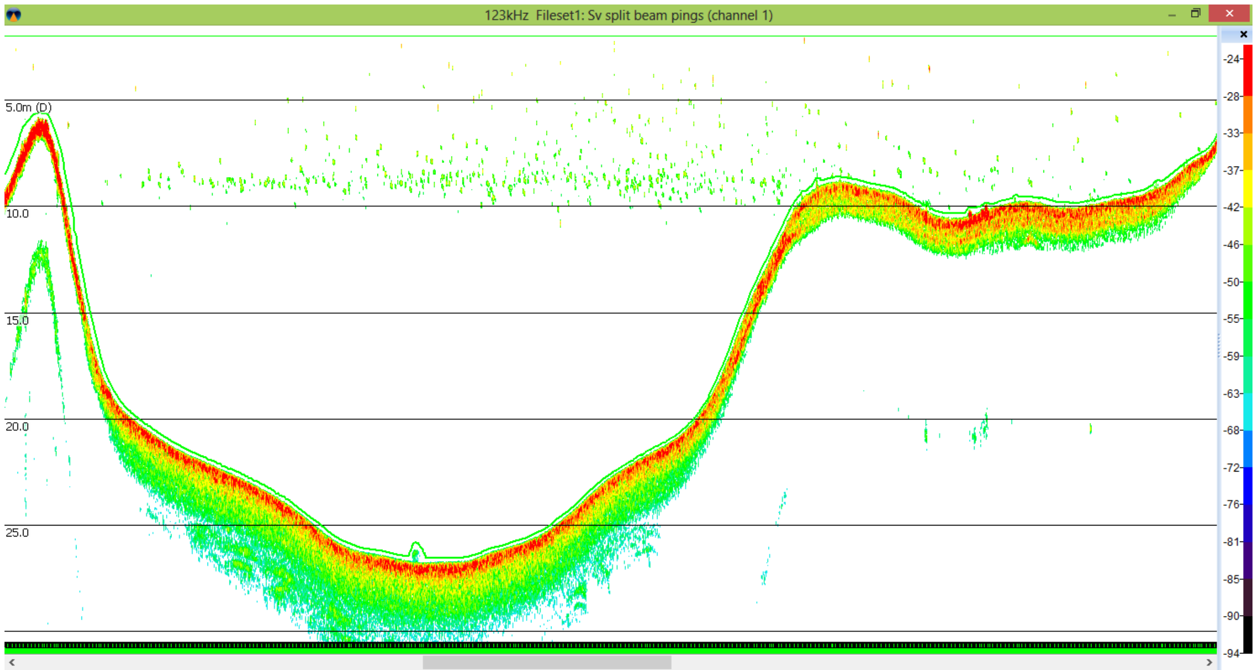

Figure 2. Acoustic and gill net sampling in Silver Lake on the night of October 24, 2013. The cruise track for the acoustic survey is represented by the blue line and consists of 3 S-N and 2 N-S transects. Transect one begins in the southeast corner of the lake. Gill net sites are represented by red dots.

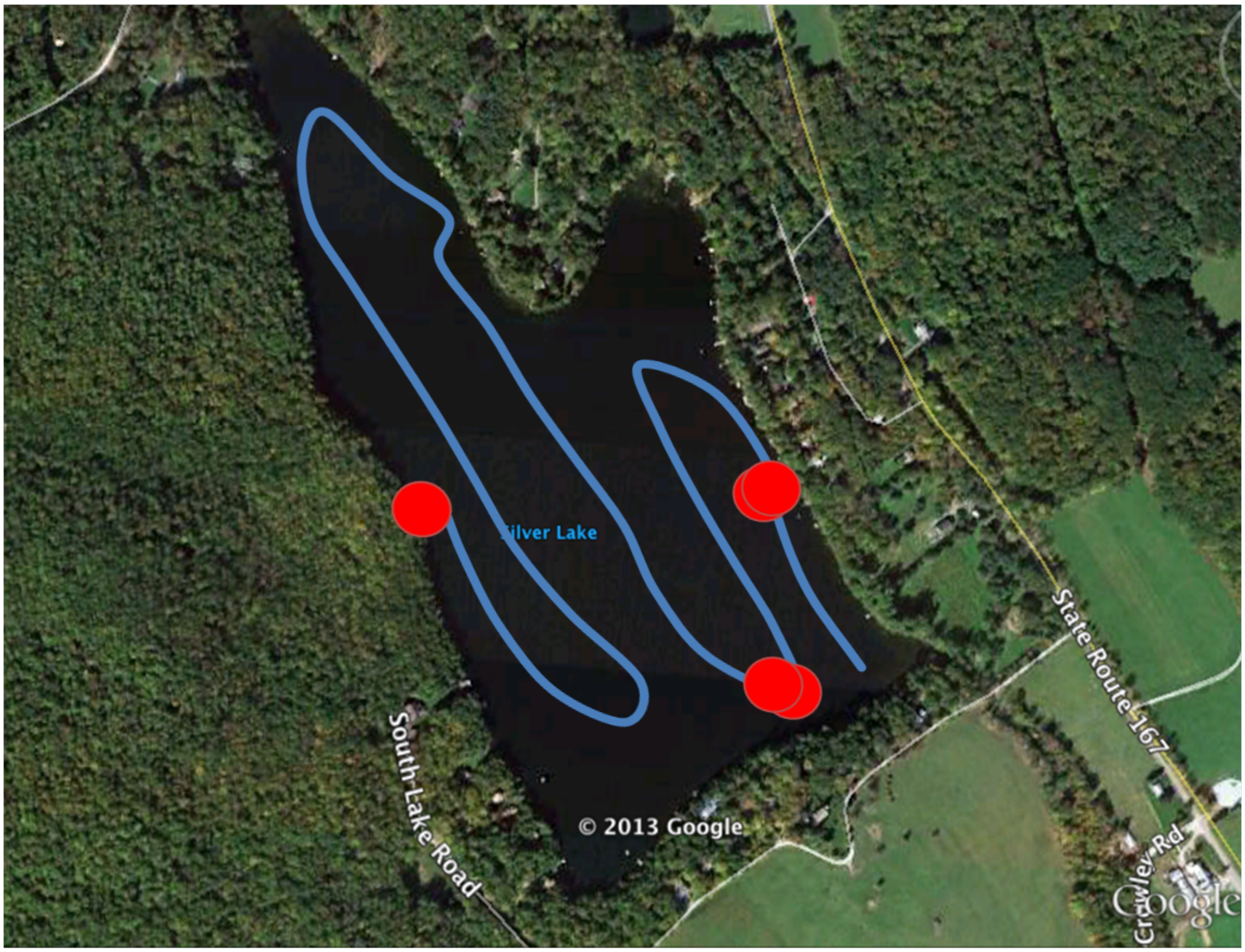

Figure 3. Depth distribution of gill net catches and acoustically determined fish density in one meter increment. Profiler (Hydrolab Sonde 3) temperature and dissolved oxygen are represented by the black lines. Samples were taken on October 24, 2013. Note that the fish distribution is an average for the whole lake whereas the temperature and oxygen profiles are for one station in the middle of the lake. It is likely the reason for the mismatch between the acoustic peak and the bottom of the oxygenated epilimnion.

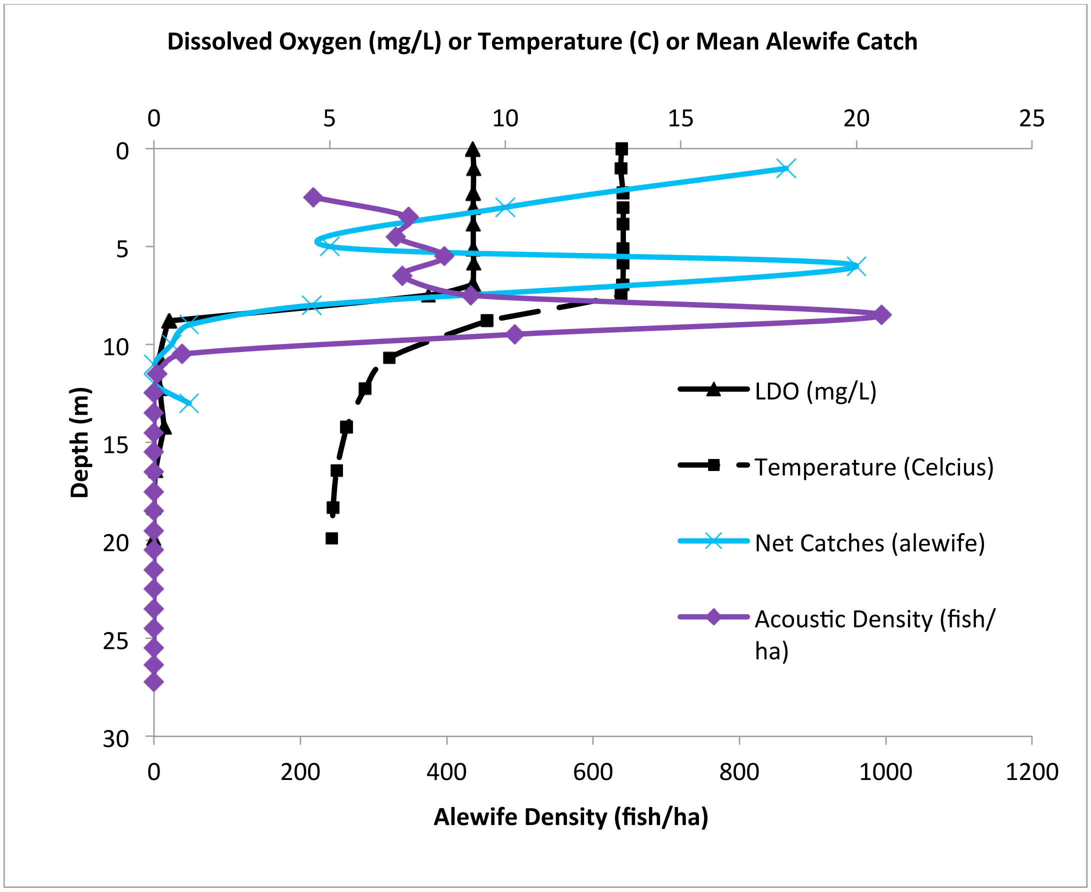

Figure 4. Size distribution of measured alewife in Silver Lake in 2008-2013. Note the absence of age-1 sized fish in 2011. The 2011 age class is represented by fish <80mm in 2011 (age-0), fish 100-140 mm in 2012 (age-1) and fish 110 to 145 mm in 2013 (age-2). The three modes in the length distribution in 2013 correspond to age 0, age-1 and age-2 fish. Only one older fish was caught in 2013. Note that we can follow the 2011 year class through 2012 and 2013 and that the 2010 year class disappeared from fall 2010 to fall 2011 likely due to winter mortality.

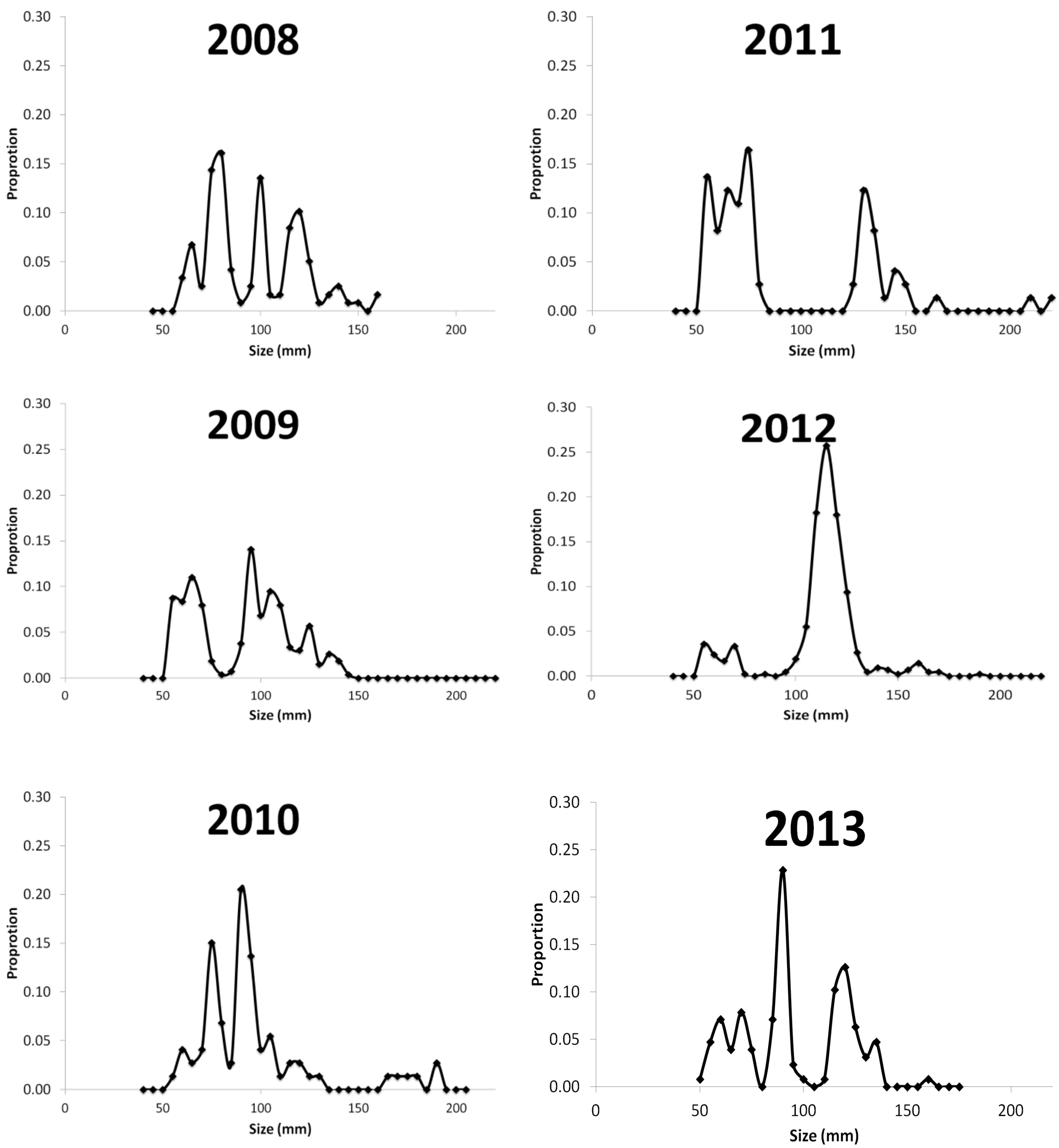

Figure 5. Target strength distribution from Silver Lake in 2013 for two depth layers. The predicted TS distribution is based on the relationships between alewife length and target strength in Brooking and Rudstam (2009) applied to the gill net catches from Silver Lake. This suggest we are underestimating the number of age-0 alewife in the lake.