# Annual Report for Silver Lake
# 2011

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## Acknowledgements

We thank the E.L. Rose Conservancy and the Actus Foundation for sponsorship of this study and continued support of Cornell research on Silver Lake. Our partnership with the Conservancy has led to a deeper understanding of factors influencing the biological and physical features of Silver Lake. Insights gained through our work on Silver Lake also have potential applications to protection and management of other lakes in the region. This work is becoming increasingly important as development pressures continue to increase and stress the natural resources of northern Pennsylvania. We thank Chris Hotaling of the Cornell Biological Field Station for processing of zooplankton and chlorophyll samples. We thank resident Russ Cole for accompanying us on our October sampling trip. Finally, we thank Patty and Billy Bloomer for the use of their boat, trolling motor, and property and the hospitality they continue to extend to us. Their assistance is greatly appreciated.


## Executive Summary


The primary focus of Cornell researchers in 2011 was on the continuing efforts to assess the status of the alewife population in Silver Lake and gauge the effectiveness of a trout-stocking program as a means of controlling impacts from alewife. The alewife (*Alosa pseudoharengus*) is a non-native fish species believed to have been introduced to Silver Lake sometime after 1992. In a classic trophic cascade, predation by this fish has subsequently caused a decrease in abundance of large zooplankton, which has, in turn, reduced water clarity due to a reduced consumption of algae.

With the goal of reducing alewife abundance, rainbow and brown trout 300 mm in size were stocked (300 fish/yr) each fall from 2006-2009. Initial improvements (increased water clarity, reduced alewife abundance, more large zooplankton) in 2008 were not sustained in 2009 and 2010. Therefore, stocking was paused in 2010 and 2011 to reevaluate the program. The abundance, condition, and growth of alewife was again estimated in 2011 to further evaluate the on-going trout stocking program and better characterize the overall status of the alewife population in Silver Lake.

**Several developments in 2011 provide optimism for the success of the stocking program.**

*1) Three large (40 cm) healthy trout (2 brown and 1 rainbow) were captured in gill nets. This was the most trout caught in gill nets since 2007. Temperature and dissolved oxygen conditions in the lake continue to be suitable for trout.*

*2) Alewife abundance was lower in 2011 than 2010 (3031 fish per hectare, down from 6165 fish per hectare), and comparable to abundance estimates in 2008-2009.*

*3) A large gap in alewife size distribution from 77 mm to 122 mm indicates a loss of age-1 fish through high mortality, possibly resulting from trout predation.*

*4) Elevated growth rates were seen in age-2 alewife. Alewife of this age were more than 20 mm larger than in previous years. This is likely a result of lower alewife abundance. However, condition (measured by % dry weight) was not higher.*

*5) Large bodied zooplankton* <u>*Daphnia*</u> *returned to levels last seen in 2008.*

We optimistically, but cautiously, interpret these recent developments as indications that predation by the larger trout may be able to control alewife. Alewife abundance was lower in 2011 and large-bodied zooplankton *Daphnia* have recovered. Predator impacts may be manifested in a reduced numbers of young alewife and older alewife that are responding to less competition with increased growth.

However, there are several caveats of these observations that we plan to more closely investigate in 2012. First, the loss of age-1 alewife may not be due to trout predation, but instead may signal an overwinter mortality event in the winter of 2010-11 that commonly structures alewife populations and particularly affects fish that are small when going into the winter. To address this, we would like to do an acoustic/gill net sampling in May or June 2012 to evaluate the effects of overwintering mortality on the alewife population. We would also like to set up a thermistor chain in the lake to provide continuous temperature profiles throughout the year. If overwinter mortality was a factor over the winter of 2010-11, alewife abundance may rebound after the winter of 2011-2012, which has been mild.

Second, alewife are still very abundant, and the growth rates of young-of-year fish are indicatively low. Previous attempts in other lakes to control alewife have found that further decreases in abundance (to hundreds of fish per hectare) is challenging because of strong compensatory responses. Basically, alewife respond to increased predation pressure with a series of life history strategies including increased reproduction, faster growth, and reduced cannibalism. We may be entering a new phase where alewife are less self-limited and, therefore, we will need to keep a close eye on the dynamics.

Third, the recovery of large bodied zooplankter *Daphnia* could be due to its use of a spatial refuge. Alewife were largely restricted to the warm surface layer in the upper 8 m of the water column. Our vertical nets sampled the entire water column so it is possible that *Daphnia* live in deeper water to avoid predation. In 2012 we will add a surface layer net to evaluate this possibility.

Fourth, we need to keep in mind our primary objective of improving the water clarity of Silver Lake. Our secchi disk readings of 2 to 2.5 m in the fall of 2011 were low and comparable to autumn values in recent years. Our goal is to achieve a 4 m secchi depth, typical to levels prior to alewife introduction. Our low 2011 observations are not conclusive, since they were preceded by the historical rainfall event (7 inches) of September 6-9, 2011, in the wake of the stalled passage of Tropical Storm Lee. With the help of resident Russ Cole, we plan to sample Secchi depth and zooplankton more frequently in 2012. He accompanied us on our October, 2011 sampling trip and we look forward to working with him, and maybe other volunteers, in the coming year.

## 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 the groups and Cornell University in an effort to understand, improve, and protect the water quality, fisheries and aquatic ecosystem associated with Silver Lake. The 2011 field season marked the eighth 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 in recent years have concentrated on investigating impacts from introduced alewife and evaluating the stocking of trout as a means to control these impacts. Eight annual (2004-2011) reports summarize the findings of these investigations to date.

The Alewife 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 overgrazing 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 and brown trout, was implemented in Fall of 2006 with the goal of reducing alewife abundance through predation by trout and subsequently increasing water clarity. Results of investigations conducted in 2007 indicated that stocking of trout was having the desired effect of reducing alewife abundance and lessening the impact of alewife on water clarity and other aquatic resources of Silver Lake. However, by 2009, it seemed that the initial success was not sustained. Therefore stocking of trout occurred in the Fall of 2007, 2008, and 2009, but was suspended in 2010 and 2011.

Over the course of the program, the primary focus of Cornell researchers has been developing annual estimates of alewife abundance in Silver Lake, primarily using hydroacoustic surveys in which alewife abundance in the open lake was estimated by sonar to detect and count fish. 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 physical and biological components of the Silver Lake ecosystem.

**Research activities conducted in 2011 included the following:**

-Hydroacoustic sampling of the open water portion of the lake was conducted on the night of October 3, 2011 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.

-Limnological sampling was conducted on September 16 and October 3, 2011, and included-

- -Water clarity measures using a Secchi disk.
- -Vertical profiles of temperature and oxygen to evaluate trout habitat.
- -Vertical profiles of chlorophyll *a* to evaluate phytoplankton productivity and measurements of turbidity to evaluate inorganic suspended material load.
- -Vertical zooplankton nets to evaluate direct impacts of alewife predation on zooplankton such as *Daphnia*.

## Part 1. Hydroacoustic and Gill Net Estimates of Alewife (*Alosa pseudoharengus*) Abundance in Silver Lake, PA, 2011.

**Abstract:** The alewife (*Alosa pseudoharengus)* population in Silver Lake, Pennsylvania, was surveyed October 3, 2011 using small-mesh pelagic gill nets and hydroacoustics (123 kHz split beam). There was a sharp thermocline, with temperature decreasing from 15.5 C at 5.5 m depth to 7.5 C at 8 m depth. Oxygen was present (over 4 ppm) down to 15 m depth. Over a period of about 3 hours, 76 fish were caught in 5 vertical nets set at different depths. This included 73 alewife, 2 brown trout, and 1 rainbow trout. The ages of the alewife were determined by examining annual rings of otoliths, small calcium carbonate structures in the inner ear. Average length of age-0 fish (young of year, or YOY) was 65 mm. No age-1 fish were collected and there was a large gap in alewife size between YOY and older fish. Average length of alewife age-2-4 was 134 mm. Three larger alewife were 5 (165 mm), 8 (208 mm) and 9 (220 mm) years old. Percent dry weight (an indication of condition) was 23% (20.4% for YOY and 24.6% for age 2-4), which is low relative to New York alewife populations. The low body condition indicates a high abundance of alewife relative to the productivity of the lake. By fall, the spring YOY had attained a size comparable to those of previous years. The absence of age-1 fish indicates high mortality from either overwintering conditions or trout predation. Older alewife may have benefited from the loss of the year-1age class; growth rates were much higher this year, reflected by the large size of alewife age 2-4 (134 mm relative to 100-110 mm in previous years). We divided the population into two groups: age-0 alewife (64% of the catch, average length 65 mm, range 52 – 77 mm, average weight 2.3 g), and age 2-4 (32% of the catch, average length 134 mm, range 122 – 150 mm, average weight 18.9 g). Fish density in October 2011 for targets > -60dB was estimated to be 3031 fish per ha for the whole water column. Almost all fish were in the top 8 m of water, within the warm surface layer. Biomass was estimated from the average weight of alewife caught in the two surface nets (0-6m – 8.7 g) and the acoustic density. The corresponding fish biomass is 26.7 kg/ha. Alewife distribution was uneven across the lake and densities among 18 separate 250 m intervals ranged from 149 to 5543 fish/ha, resulting in a relative standard error (SE/mean) of 16%.

## Introduction

The alewife, *Alosa pseudoharengus*, is an effective planktivore, and abundant alewife populations cause declines in large efficient zooplankton grazers of algae. Therefore, abundant alewife populations are usually associated with high chlorophyll levels and decreased water clarity. This is a classic trophic cascade where increases in planktivorous fish result in decreases in the main herbivore and an increase in the primary producers. Understanding water clarity changes in Silver Lake therefore requires understanding of the dynamics of the alewife population. In this report, we summarize the results of the 2011 acoustic and gill net survey for alewife in Silver Lake, Pennsylvania.

## Materials and Methods

*Acoustics.* Silver Lake was surveyed using a 123 kHz split beam echo sounder (Table 1). A total of 5300 m of acoustic transects evenly spaced across the whole lake (Figure 1) were analyzed in 250 m sections for a total of 21 intervals. The acoustic data were collected on the night of October 3 2011 between 20:58 and 21:51.

Acoustic data were recorded directly to a laptop computer in the field and analyzed with the Echoview software (version 5.1, Myriax). The unit was calibrated with a tungsten carbide 33.2 mm diameter standard target in August 26, 2011 and gains were applied to the echo integration and target strength (TS) data based on this calibration (0.60 dB gain offset). All data were visually inspected for consistent bottom detection, as well as for interference from surface bubbles and aquatic vegetation, and corrected when needed, or removed from the analysis. Noise levels were -126.4 Sv domain, corresponding to -155.1dB in the TS domain. This is low enough to register fish with a TS of -66 dB at 70 m depth without bias and thus effective for the alewife survey in Silver Lake. Analysis was done for intervals for depth layers of 2-8 m, and 8-bottom, and lake-wide averages were calculated using the average of these intervals. The near-field of this transducer is approximately 1.5 m (Parker Stetter et al. 2009), and the transducer was mounted on a rigid pole 0.3 m below the surface. Therefore, the acoustic analysis is restricted to a depth below 2 m and does not include the upper surface layer. A second 123 kHz transducer was mounted horizontally and used to insonify the surface water. However, interpretation of these side-looking data is still under development and not reported here.

Fish density was calculated from the average measured *in situ* TS and area backscattering coefficient (ABC). 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 the size of the fish caught in gill nets. The peak in targets smaller than -60 dB is interpreted as invertebrates such as the *Chaoborus* midge that larva occurs in Silver Lake. Therefore, fish density was calculated based on in situ target strengths 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 (Rudstam et al. 2011).

Spatial locations of the data were measured with a GPS that recorded position directly to the acoustic data stream. Total fish density was obtained from the ABC values and the in situ TS within each 250 section, and then averaged over all sections. Fish density in deeper water was calculated based on all in situ TS in deeper water, due to the limited number of targets observed deeper than 8 m. All averages and calculations were made in the linear domain and back transformed to dB units when appropriate. More details on acoustic methods are in Simmonds and MacLennan (2005), Sullivan and Rudstam (www.acousticsunpacked.org) or Parker-Stetter et al. (2009). The depth distribution was obtained in 1 m intervals using all data collected during the survey and the average in situ TS for all targets.

Fish were sampled using vertical gill nets (Table 2). 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 two locations, with one net fishing from the surface to 6 m depth, and the other from 9.5 to 14 m at location 1, and from 6.5 to 10.5 m at location 2 (Table 2). Nets were left in place for about 2.5 hours (Table 2). Fish were identified to species and the depth of catch was recorded in 2 m intervals. All fish were measured and weighed. The ages of the alewife were determined by examining annual rings of otoliths, which are small calcium carbonate structures in the inner ear. Wet-to-dry weight was determined by drying fish in a 60 C oven for 5 days.

**Results and Discussion**

*Net sampling*. A total of 76 fish were caught in the gill nets (Table 2, 1.0 to 10.3 fish/hr). Seventy-three of the fish caught were alewife. Individuals were found from the surface, to a depth of 13 m, with a peak at the top 4 m. Acoustic and net data show similar depth distribution, with higher acoustic densities in 2-4 m and another peak from 6-7 m (Figure 2).

The size distribution of alewife had two primary modes: 52-77 mm (age-0), and 122-150 mm (age 2-4) (Figures 3 and 4). Three larger fish were age 5 (165 mm), 8 (203 mm) and 9 (210 mm).

Age-0 fish represented 64% of the total catch, with an average length of 65 mm and an average weight of 2.3 g. This age-0 class represented a larger proportion of the catch in 2011 than in 2010 (38%). Alewives typically reach lengths of 60 to 90 mm by September of their first year of life in New York inland lakes (Rudstam and Brooking 2005), but can get larger, up to 140 mm, in productive lakes with large zooplankton (e.g., Canadarago Lake). For Silver Lake in 2011 both the average length and the index of condition of 20.4% dry weight were low compared to regional populations (Rudstam and Brooking 2005). Thus, both growth and condition of YOY alewife in Silver Lake was low, consistent with a low productivity lake with a relatively high alewife population.

Alewife of sizes between 122 and 150 mm were primarily age-2 fish (65%), with a few age-3 and age-4 fish. Fish in this size range represented 32% of the population and had an average length of 134 mm with an average weight of 18.9 g. They also had a low dry weight of 24.6%. However, age-2 fish had attained much a larger size than previous years when this age class averaged only 100-110 mm. Therefore, in 2011 there was a large gap in size between YOY and age-2 and older fish (Figure 3).

*Acoustic data.* Average TS of alewife in Silver Lake calculated from single fish targets larger than –60 dB was –50.7 dB in the top 8 m, and -48.6 dB in depths of 8 to 16 m (overall range -29.3 to -60dB). The expected modal TS of the alewife caught in the gill nets (length range 55 to 210 mm) ranged from -47.6 dB to -37.0 dB. We observed one large target at 17 m depth (-29dB), which may have been a trout. The mean TS expected from the average fish caught in the gill nets (90.4 mm) is -45.5 dB (Brooking and Rudstam 2009). Acoustically observed TS were smaller than predicted from the gill net catches, as also observed in 2010, but the difference was less pronounced in 2011. We may be missing small alewife in the gillnet catches. The observed average TS should result in an average length of alewife of 49 mm, a size that is too small for the mesh sizes used in the vertical gillnets (Warner et al. 2002).

Fish density calculated from the in situ TS data obtained from the 18 250-m intervals was 1930 fish/ha from 2 m to the bottom, with almost all fish in the top 8 m of water (Table 4). Densities below 8 m averaged 1.2 fish/ha. 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 is 1101 fish/ha. Total fish density in 2011 was therefore 3031 fish/ha. Relative standard error calculated for densities from 2 m to the bottom (SE/mean) was 16%. Assuming all of these fish were alewife, and an average weight of alewife of 8.7 g (from surface nets in 0-6 m of water, Table 2), the alewife biomass was calculated to 26.7 kg/ha (Table 4).

Acoustic densities obtained from the 2011 survey were similar to 2008 and 2009 (3831 and 2850 fish/ha, respectively), but lower than 2010 (6165 fish/ha). Catches in gill nets were similar to the other years. 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). 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. Also, it is possible we are missing small alewife due the size selectivity of the nets. Lower than expected average TS values suggest that this may be the case. If this is true, the biomass estimates would be biased high and the proportion of age-0 alewife in the population would be biased low. The estimate of total alewife density, however, would not be affected. The 2011-year class is therefore likely to have been relatively large. Whether these small alewives will survive the winter of 2011-2012 is uncertain because overwinter mortality increases for smaller alewives (O'Gorman et al. 2004). Such winter mortality may have been important in the winter of 2010-2011 as indicated by the absence of year-1 fish, but it is possible that low numbers are attributed to trout predation.

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**Table 1.** Settings used for acoustic estimates of open water fish in Silver Lake, October 3, 2011. Thresholds and detection limits according to Parker-Stetter et al. (2009) (see also Rudstam et al. 2009).

| **Parameter** | **Values** |
|---|---|
| Date and time | 20111003, 20:58 - 21:51 |
| Unit | Biosonics 123 kHz, 7.3 $^{o}$ beam width, split beam |
| Analysis software | EchoView 4.9 |
| Analyzed by | Lars G Rudstam, 2/1/2012 |
| Pulse rate/ pulse length | 3 pps / 0.2 ms |
| Lower threshold for fish | -60dB, based on TS distribution |
| Absorption coefficient and sound speed | Constant 0.0035 dB/m / 1469m/s |
| Equivalent beam angle | -20.35 dB |
| Noise at 1 m (Sv/TSu) | -126.4 dB / -155.1 dB |
| Detection limit TS -60dB without bias | 60 m |
| Calibration offset Sv/ TSu | Sv: 0.6dB, TSu: 0.6dB |
| Single fish detection criteria | |
| Max beam compensation | 12dB |
| Pulse duration min, max | 0.6, 1.5 |
| Standard Deviation of angles | 0.6, 0.6 |

**Table 2.** Summary of fish catches in the five vertical gill nets with variable mesh size set in Silver Lake on October 3, 2011. Nets were set at dusk and retrieved around 3 hours later. Most of the fish caught were alewife, with one rainbow (rt) and two brown trout (bt) caught in the floating nets. 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, and therefore variable in depths covered; surface nets were set from the surface down to 6 m depth.

| | Site 1 Floating | Site 1 sinking | Site 2 floating | Site 2 sinking | Site 3 sinking |
|---|---|---|---|---|---|
| Latitude N | 41 55.914 | 41 55.912 | 41 56.029 | 41 56.043 | 41 56.064 |
| Longitude W | 75 57.001 | 75 57.017 | 75 57.260 | 75 57.260 | 75 56.981 |
| Set time (h) | 19:20 | 19:30 | 19:40 | 19:50 | 20:05 |
| Retrieve time (h) | 23:10 | 23:20 | 22:40 | 22:50 | 22:30 |
| Soak time (h) | 3h 50min | 3h 50 min | 3 h | 3 h | 2h 25 min |
| Upper depth (m) | 0 | 9 | 0 | 6.5 | 2 |
| Lower depth (m) | 6 | 14 | 6 | 10.5 | 8 |
| # alewife caught | 30 | 4 | 31 | 3 | 5 |
| Catch / hour All | 7.8 | 1.1 | 10.3 | 1.0 | 2.0 |
| Upper 1/3 | 3.8 | 0.3 | 5.3 | 0.7 | 1.2 |
| Median 1/3 | 3.0 | 0.8 | 3.7 | 0 | 0.4 |
| Lower 1/3 | 1.0 | 0 | 1.3 | 0.3 | 0.4 |
| **Alewife** | | | | | |
| Mean Length (mm) | 89.0 | 81.0 | 82.3 | 144.0 | 124 |
| Range (mm) | 52-150 | 58-143 | 54-144 | 134-165 | 52-220 |
| Mean Weight (g) | 8.3 | 7.1 | 5.8 | 22.7 | 29.1 |
| Range (g) | 1.0-25.0 | 1.3-23.1 | 1.4-22.6 | 17.4-32.6 | 1.2-70.0 |
| Prop <80mm (%) | 63 | 75 | 71 | 0 | 60 |
| Other Fish | 1 bt, 1 rt | | 1 bt | | |

**Table 3.** Percent dry weight and length-at-age for alewife from Silver Lake caught in October of 2008-2011.

| Age | Length | Range | N | % DW | Range | N |
|---|---|---|---|---|---|---|
| **2008** | | | | | | |
| 0 | 69.2 | 58-80 | 6 | 22.3 | 17.7-25.3 | 12 |
| 1 | 92.0 | 85-97 | 10 | 22.9 | 20.2-24.3 | 10 |
| 2 | 111.8 | 105-120 | 10 | 25.0 | 22.7-28.2 | 18 |
| 3 | 130.7 | 119-144 | 3 | | | |
| 4 | 140.7 | 133-152 | 3 | | | |
| **2009** | | | | | | |
| 0 | 63.8 | 55-69 | 10 | 23.4 | 21.0-25.9 | 15 |
| 1 | 86.7 | 80-92 | 4 | 23.8 | 22.3-26.4 | 8 |
| 2 | 105.5 | 99-110 | 6 | 25.2 | 22.9-27.2 | 17 |
| 3 | 126.0 | 118-136 | 7 | | | |
| 4 | 137.0 | 133-143 | 3 | | | |
| **2010** | | | | | | |
| 0 | 65.0 | 55-75 | 10 | 22.4 | 19.3- 24.7 | 17 |
| 1 | 76.0 | 70-82 | 2 | 21.7 | - | 1 |
| 2 | 90.2 | 83-108 | 9 | 22.2 | 29.3-22.5 | 22 |
| 3 | 113.5 | 106-121 | 4 | | | |
| 6 | 175 | | 1 | | | |
| 7 | 187 | | 1 | | | |
| **2011** | | | | | | |
| 0 | 65.0 | 52-77 | 12 | 20.4 | 15.8-25.0 | 27 |
| 1 | | | 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 | | | |
| 5 | 165 | | 1 | 24.9 | | 1 |
| 8 | 208 | | 1 | 24.7 | | 1 |
| 9 | 220 | | 1 | 26.0 | | 1 |

**Table 4.** Results from acoustic estimates of alewife in Silver Lake October 3, 2011, using a 123 kHz split beam unit. Density includes the whole water column (see methods). Density is calculated from ABC/$\sigma_{bs}$, where $\sigma_{bs}$ is target strength in the linear domain (back scattering cross section: $\sigma_{bs} = 10^{(TS/10)}$). Fish density is calculated based on interval specific *in situ* TS. Biomass is the density multiplied with the average weight of all alewife caught in gill nets in 0-6 m (8.7g). Note that mean TS for water deeper than 8 m is calculated for all targets found 8 m, and deeper and therefore the same for each interval. Also, the density in the 0-2 m portion of the water column is calculated based on average 2-6 m density and catch in the nets, and therefore the same for all intervals. Interval 1, 11, and 17 were not included because of areas with bad data.

| Interval # | Length (m) | Mean Depth (m) | Mean TS (dB) 2-8m | Mean TS (dB) 8-12m- | Density 0-2m (fish/ha | Density (f/ha) 2-8m | Density (f/ha) 8m-bottom |
|---|---|---|---|---|---|---|---|
| 2 | 250 | 16.2 | -49.9 | -39.3 | 1101 | 1924 | 0 |
| 3 | 250 | 9.4 | -51.7 | -39.3 | 1101 | 329 | 0 |
| 4 | 250 | 24.3 | -51.5 | -39.3 | 1101 | 1449 | 0 |
| 5 | 250 | 17.7 | -49.7 | -39.3 | 1101 | 943 | 0 |
| 6 | 250 | 26.0 | -50.6 | -39.3 | 1101 | 843 | 0 |
| 7 | 250 | 25.1 | -50.8 | -39.3 | 1101 | 1544 | 0 |
| 8 | 250 | 17.9 | -50.8 | -39.3 | 1101 | 1450 | 0 |
| 9 | 250 | 8.7 | -49.9 | -39.3 | 1101 | 520 | 12 |
| 10 | 250 | 8.7 | -52.3 | -39.3 | 1101 | 139 | 8 |
| 12 | 250 | 26.3 | -51.0 | -39.3 | 1101 | 2066 | 1 |
| 13 | 250 | 25.4 | -50.6 | -39.3 | 1101 | 3224 | 0 |
| 14 | 250 | 10.1 | -51.4 | -39.3 | 1101 | 3510 | 0 |
| 15 | 250 | 8.6 | -50.4 | -39.3 | 1101 | 1295 | 0 |
| 16 | 250 | 15.8 | -51.4 | -39.3 | 1101 | 5385 | 0 |
| 18 | 250 | 17.3 | -50.6 | -39.3 | 1101 | 3475 | 0 |
| 19 | 250 | 17.5 | -49.1 | -39.3 | 1101 | 1556 | 0 |
| 20 | 250 | 17.7 | -50.9 | -39.3 | 1101 | 2884 | 0 |
| 21 | 250 | 16.7 | -51.0 | -39.3 | 1101 | 2186 | 0 |
| **Mean** | **250** | **17.1** | **-50.7** | **-39.3** | **1101** | **1930** | **1** |
| **Biomass (kg/ha)** | | | | | **9.6** | **16.8** | **0.0** |

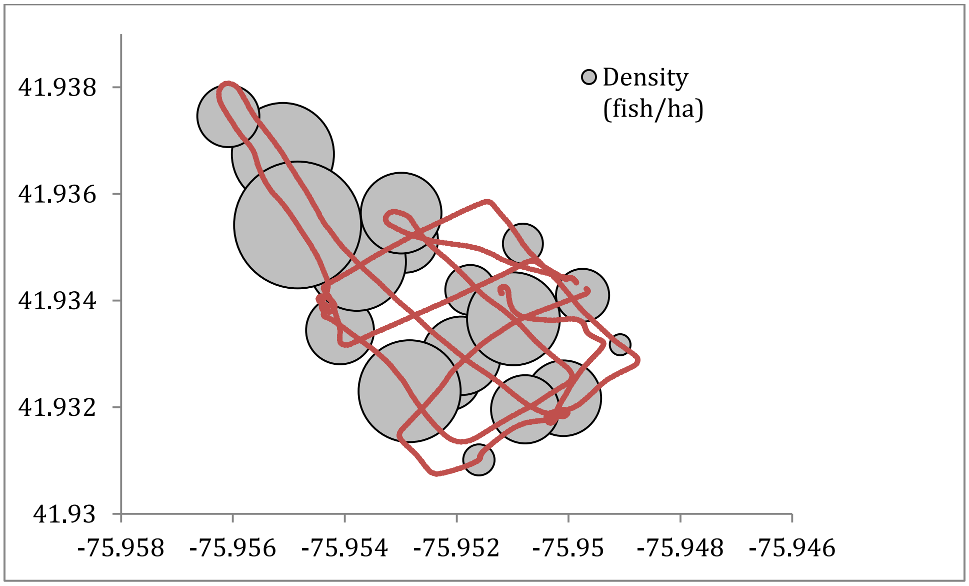


**Figure 1.** Cruise track used in 2011 in Silver Lake. Transects are in red. X axis is Longitude and Y axis is Latitude. Bubbles represent the fish density from 2 m to the bottom for the 22 250-m-long intervals analyzed (Table 4).

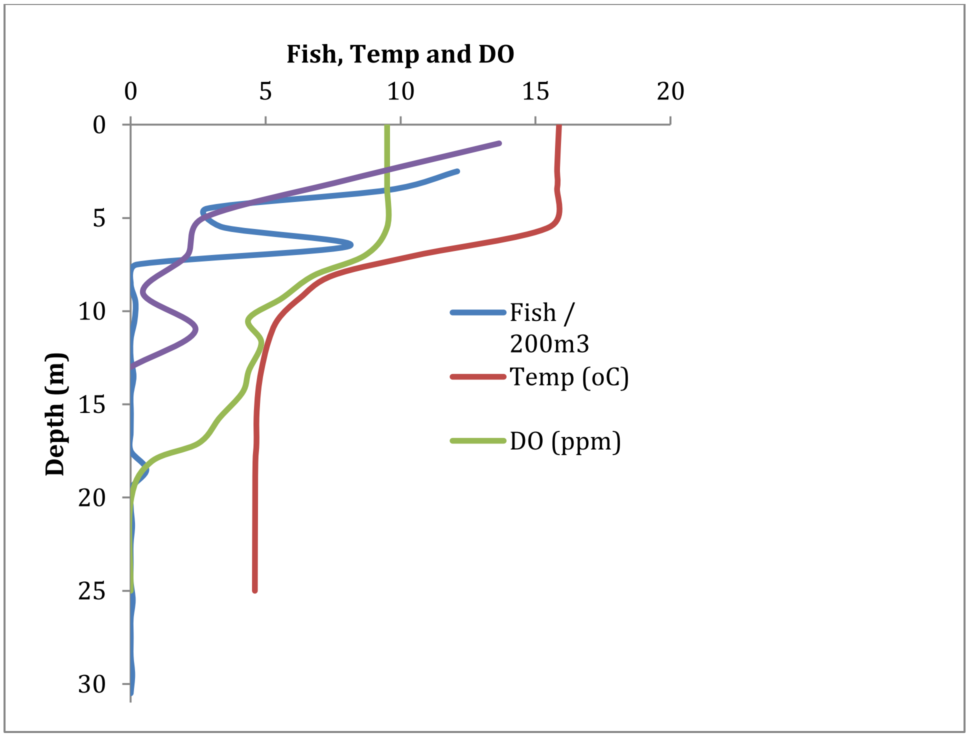


**Figure 2.** Depth distribution in acoustics and temperature and dissolved oxygen profiles. Data from Silver Lake, October 3, 2011. Note that units are adjusted to allow for similar scales on the x-axis for all parameters.

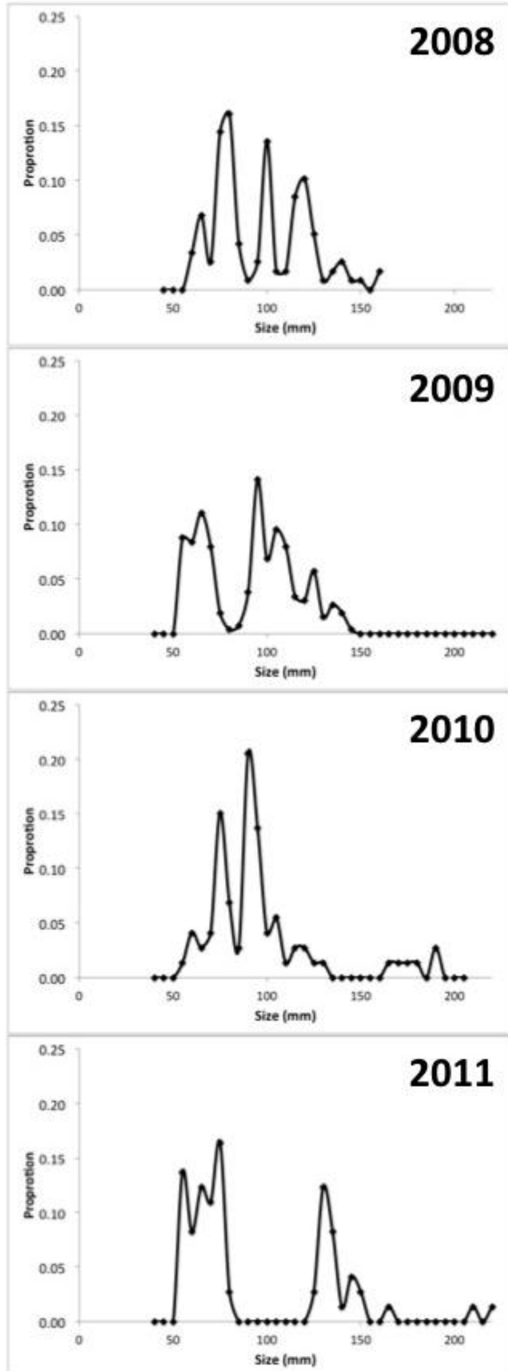


**Figure 3.** Size distribution of measured alewife in Silver Lake in 2008-2011. Note the absence of age-1 sized fish in 2011.

**Figure 4.** Alewife caught in floating net at site 2. Top panel shows young-of-year while bottom panel shows alewife age 2-4.

## Part 2. Limnology of Silver Lake

Continued limnological monitoring of Silver Lake is critical for answering four key questions for assessing the success of the alewife management project.

*1) Is water clarity improving?*

*2) Are large-bodied zooplankton Daphnia recovering?*

*3) Are conditions in the lake still suitable for cold-water species, such as rainbow trout and brown trout that are our primary tool for alewife management?*

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

### Water Clarity

*1) Is water clarity improving?*

Water clarity in Silver Lake is 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. Our two measurements of Secchi depth for 2011, 2.5 m for September 16 and 2.0 m for October 3, were both lower than our 4 m goal that represents pre-alewife conditions (measurements in 1946 and 1992). The goal was reached in the summers of 2007 and 2008 soon after the initiation of trout stocking but not in more recent years. It is important to note that our measurements were taken soon after a major rainfall event on September 6-9, 2011 that yielded more than 7 inches of rainfall in the region during the passage of Tropical Storm Lee. Therefore, we do not consider this year's low Secchi depths to be a conclusive indicator of seasonal conditions. We intend to improve our sampling coverage for 2012 as in 2010, with the help of resident Russ Cole and maybe other volunteers.

### Zooplankton Community

*2) Are large-bodied zooplankton Daphnia present?*

Alewife preferentially consume large zooplankton that graze upon the phytoplankton that are responsible for algal blooms in lakes. 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. To measure zooplankton, samples are collected near mid-lake using a Wisconsin-style plankton net that is lowered to a depth of 20 m (~66 ft) and slowly lifted vertically to the surface. The absence of *Daphnia* in zooplankton samples collected in 2006 supported the hypothesis that alewife were the cause of decreasing water clarity These observations led to the initiation of a trout-stocking program.

Zooplankton samples in 2011 indicated an increase in *Daphnia* abundance to levels near 3 per L, a finding consistent with lower alewife abundances as determined by hydroacoustics. These are levels of *Daphnia* not seen since 2008 (Figure 5). The presence of *Daphnia* in 2007 and 2008 suggested that the stocking of trout since October 2006 was having a positive impact on the zooplankton community by reducing the abundance of predatory alewife. However, in 2009 and 2010, average density (number/liter of water) of *Daphnia* declined from 2008 values by anywhere from 52-88%. The decline in *Daphnia* in 2009 coincided with the decline in water clarity during this same period, suggesting that alewife abundance had increased since 2008 and the greater abundance of alewife was negatively affecting the abundance of efficient phytoplankton grazers like *Daphnia*. The rebound of *Daphnia* in 2011 is a positive sign for the Silver Lake ecosystem and suggests that alewife management is working. However, an alternative hypothesis must be acknowledged that *Daphnia* are seeking refuge in deep water with low oxygen concentrations to avoid alewife predation. Note that alewife were most abundant in the upper 8 m of water. In 2012 we intend to evaluate this possibility by including a separate surface layer zooplankton tow.

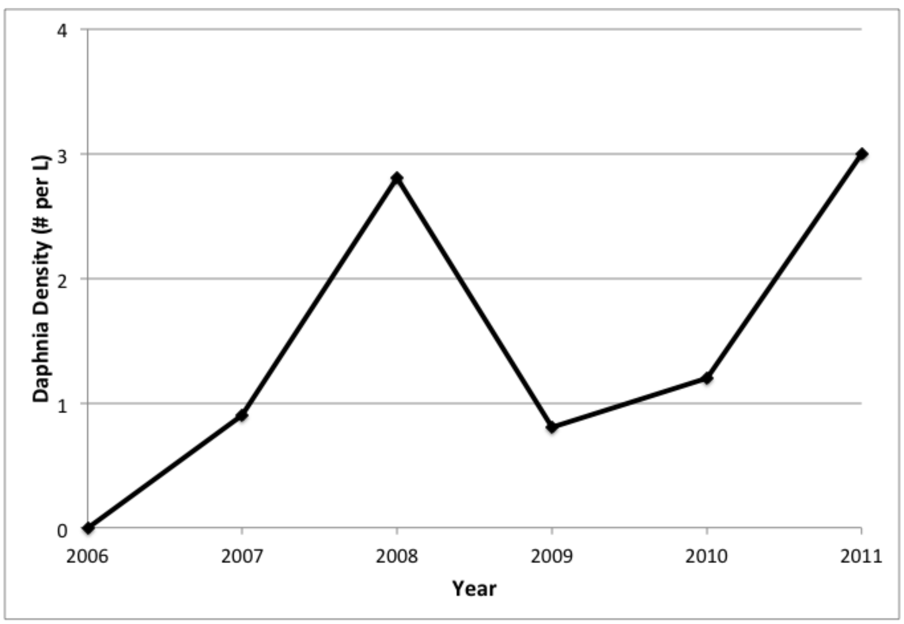


**Figure 5. Abundance of *Daphnia* in Silver Lake from 2006-2011.**

**Dissolved Oxygen/Water Temperature**

*3) Are conditions in the lake still 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 72°F (22°C) and dissolved oxygen levels above 5 mg/L. Dissolved oxygen and water temperature profiles were measured near mid-lake on September 16 and October 3, 2011 to further assess the suitability of Silver Lake for long-term survival of trout. Similar profiles were measured by Cornell in 2005-2010, and some historic data from 1946, 1992, and 2002 are also available from Silver Lake.

Data collected on September 16 and October 3, 2011 were consistent with similar data collected in recent years and continues to indicate that thermal stratification in this lake is fairly consistent during late summer (i.e., a layer of warm, less dense water overlays a dense, colder water layer) (Figure 6). The transition area between these water layers, known as the thermocline, was near 5 m in depth. Typically, trout are limited to waters below the thermocline (known as the hypolimnion) during summer because waters shallower than the thermocline are unsuitably warm. However, dissolved oxygen levels can sometimes be depressed within the deep hypolimnion due to minimal mixing with more oxygenated surface waters and biological oxygen demand associated with bottom sediments. 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. Note that for our fall sampling in 2011, the surface layer had cooled by September 16 (18.2 C) and October 3 (15.8 C) to temperatures suitable for trout. Dissolved oxygen levels were > 5 mg/L to a depth of 13 m in September and 10 m in October. Our capture of three trout within surface (0-6 m) gill nets is consistent with these measurements, which indicate suitable conditions. Past years' data indicate that even during the warmest time of the year, a sufficiently large volume of the hypolimnion in Silver Lake remains sufficiently oxygenated and cool enough to support trout.

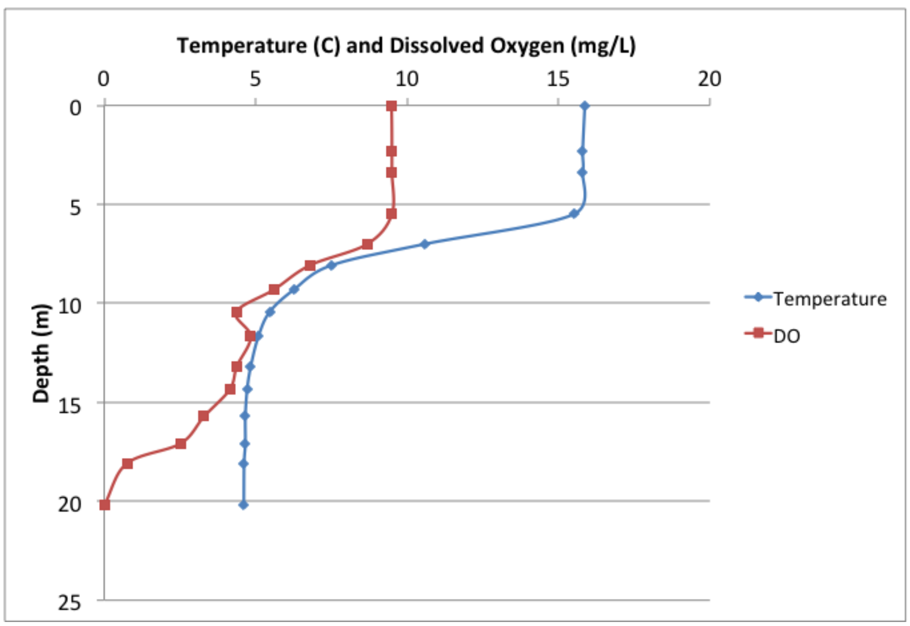


**Figure 6.** Vertical profiles for temperature and dissolved oxygen for October 3, 2011 in Silver Lake.

**Trophic State**

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

Lakes are ranked according to three productivity levels- low (oligotrophic), mid (mesotrophic) and high (eutrophic). Four water quality parameters (Secchi depth, chl *a*, hypolimnetic oxygen depletion, and total phosphorus) are used in this classification scheme. Silver Lake generally lies near the dividing line of low and mid productivity lakes, which corresponds to a Secchi depth of 4 m, chl *a* level of 4 ug/L, a hypolimnetic oxygen depletion of 10%, and total phosphorus of 10 ug/L. Silver Lake is within the mesotrophic range of 2-4 m Secchi depth, 4 to 10 ug/L chl *a* , some oxygen depletion and TP at 10-20 ug/L. Our measurements of a 2 m Secchi depth, surface chl a levels of 5.0 ug/L, and a TP of 12 ug/L confirm a mesotrophic state. Continued monitoring is important for detecting shifts in trophic state, and especially if nutrient loading increases.

**Part 3. Management Recommendations for 2012**

Our findings for 2011 indicate we could be at a turning point for the success of the management program. We have put together a list of management recommendations for the board and to educate and involve local residents on this issue for 2012.

-Develop a “resident scientist” program that provides early detection of changes in the lake. Resident Russell Cole has volunteered to take routine measurements of Secchi depth and zooplankton throughout the summer of 2012. We are encouraging a similar participation of other volunteers and citizen scientists. This information will provide key information on seasonal patterns of water clarity and alewife impact on zooplankton, along with other measures of water quality.

- If trout are harvested, anglers can act as resident scientists and provide important information on trout growth and general characteristics. The effectiveness of the trout-stocking program is best if anglers maintain a catch and release fishery. Freezing the heads of harvested fish to provide age information, recording length and weight, taking photographs (including a reference size scale), checking gut contents, and keeping fishery diaries are examples of easy but vital information. Trout are not expected to be able to reproduce naturally in Silver Lake, but any new observations would be important. Look for evidence of spawning nests in shallow areas, anatomical changes in males (lengthening of jaws), or females carrying eggs.

-Consider reinstating a trout stocking regimen. The annual stocking of 300 rainbow and brown trout (12 inches in length) was suspended in 2010 and 2011, in order to reevaluate the plan and learn more about the alewife population. Our 2011 findings suggest that the growing trout population may be having an impact on alewife. One option for future stocking is to pulse the stocking effort at higher levels in a single year. In addition, stocking of smaller trout (down to 6 inches in length) could ease the financial burden, but the smaller fish may be subject to predation by the current trout population.

-Keep inputs of nutrients and pollutants to the lake low. Educate residents on reducing lawn and septic sources, minimize surface and sub-surface runoff into the lake, and minimize impacts of lakefront development.

-Take care not to introduce invasive plant and animal species through boats, trailers, and equipment used first in other waters. Educate residents on cleaning and prevention techniques. The eyes of resident scientists provide important early detection, enabling rapid response to control any newly arrived invasives before they take hold. For example, the Asian Clam (*Corbicula*) and the submerged plant *Hydrilla* have been recently found in nearby lakes in New York.