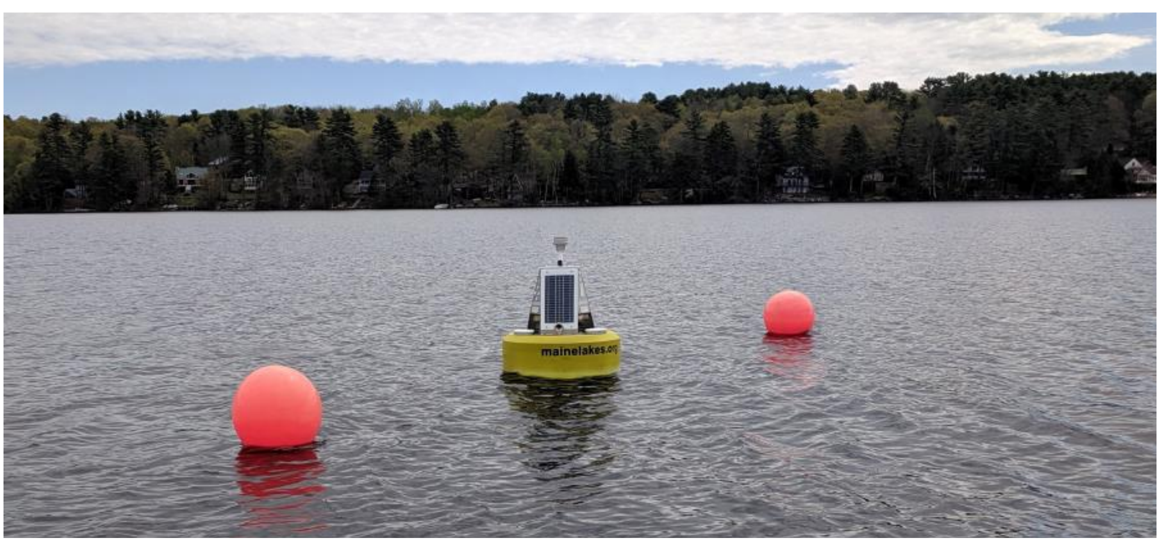
Lakes Environmental Association
2019 Water Testing Report

Chapter 2—High Resolution Automated Monitoring Buoys



LEA's Automated Testing Buoys

Each year, LEA deploys two fully automated monitoring buoys – one on Highland Lake and one on Long Lake. These buoys collect water quality information at 15-minute intervals throughout the spring, summer, and fall. This data is transmitted to us in real time, so we can see conditions change on the lake as they happen. The goals of LEA's testing buoy program are to better understand the condition of our lakes, to raise awareness of water quality issues locally, and to contribute to world-wide research and knowledge on lakes.

The Highland Lake buoy was first deployed in 2014 and contains temperature and oxygen sensors at 2-meter intervals from the surface of the lake to near the bottom. It also contains two solar radiation sensors and a chlorophyll sensor, as well as a small weather station for measuring precipitation, barometric pressure, relative humidity, wind speed and direction, and air temperature. The Long Lake buoy was first deployed in August, 2016. Like the Highland Lake buoy, it contains oxygen and temperature sensors at 2 meter intervals. It also has chlorophyll sensors located at three depths. Both buoys contain three 10-watt solar panels and a rechargeable battery as their power supply.

The Highland Lake Buoy

The advantages of these buoys are that they automate and enhance the water quality monitoring process. Using traditional (manual) water testing techniques, we are only able to collect data once every two weeks from each lake, usually around the same time of day. In contrast, the buoy automatically collects readings from each sensor at 15-minute intervals, resulting in 96 readings for each parameter every day. We are also able to leave the buoy in the water over a longer period of time than the traditional monitoring season. The wealth of additional data provided gives us a much more detailed picture of what is happening in the lake at any given time.

The information collected by the buoys allows us to better understand lake dynamics throughout the growing season. The combined and simultaneous measurements of water temperature, dissolved oxygen, algae, and weather conditions lets us see the effects of wind and precipitation events in real time, thus allowing us to better interpret how these factors affect lake conditions.

Another aspect of the buoy program is our ability to collaborate with researchers on a larger scale by sharing ideas and methods and contributing to research. Buoys similar to LEA's can be seen in lakes throughout New England and the world. An international organization called GLEON (Global Lake Ecological Observatory Network) helps to connect researchers that collect and use lake data, particularly from automated monitoring buoys, for a variety of projects. GLEON's mission is "to understand, predict, and communicate the impact of natural and anthropogenic influences on lake and reservoir ecosystems."

LEA could not have purchased either buoy without a great deal of support from several sources. The Highland buoy was funded by a grant from an anonymous foundation and contributions from landowners around Highland Lake. The Long Lake buoy was funded by a very generous donation from a resident of Long Lake, foundation funding, and contributions from lakefront landowners. LEA worked closely with Colby College professor Dr. Whitney King and Fondriest Environmental to design and set up the buoys.

2019 Results

The presentation of buoy results begins with a general summary of the deployment and findings followed by a summary of weather conditions that help drive the patterns of temperature, oxygen, and algae in each lake in 2019. Those patterns as recorded by the buoys are presented for each lake in the final two sections.

Deployment and Results Summary

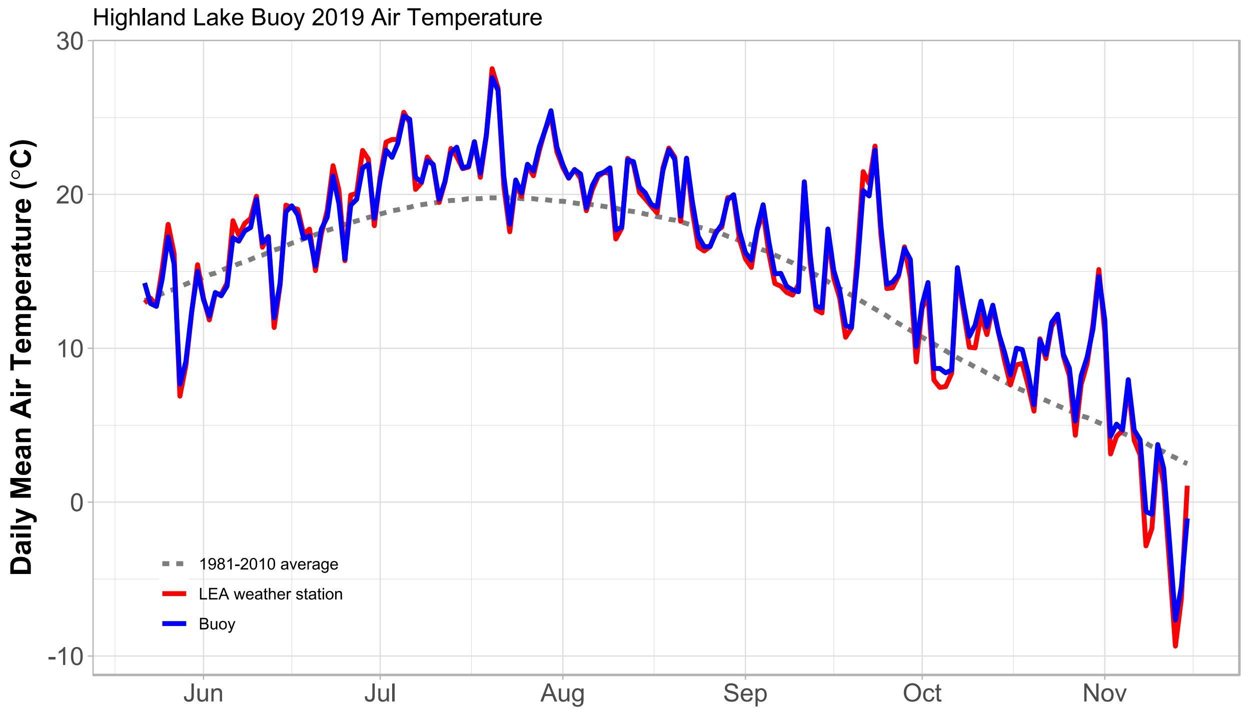
The 2019 deployment of the automated buoys began on May 22nd for Highland Lake and on May 23rd for Long Lake. Both buoys were in place recording data until November 15th, when they were removed from the lakes. Air temperatures had plummeted prior to this date and both buoys were coated with ice when they were pulled from their moorings. The deployment period captured the start of thermal stratification and went past the point of fall turnover. During this time, we performed two onsite cleaning and calibration checks for the sensors on each buoy; fortunately, no major equipment failures occurred in 2019. Combined, the buoys collected almost 34,000 complete sets of sensor readings during their time (177 to 178 days) on the water.

General water temperature patterns in both lakes showed the same basic response to the cool and wet spring, the warmer than average summer, and the warm, wet early fall of 2019. Both lakes also had a very similar thermocline depth (location in the water column where temperature changes most rapidly) throughout the period. The water temperature patterns did vary in some ways between the two lakes due in large part to contrasting size and shape. For example, the deeper Long Lake site experienced a greater summertime temperature range and mixed completely nine days later than Highland Lake. In both lakes, dissolved oxygen declined as temperature increased and as stratification strengthened. Anoxia (absence of dissolved oxygen) occurred in the each system in 2019, but as in previous years, Highland Lake's greater oxygen consumption rate meant that it developed anoxia sooner than Long Lake (mid-July as opposed to early September). Surface chlorophyll fluorescence, which is an estimate of algae concentration, was relatively low in Highland Lake throughout the deployment, but was higher during the late spring and fall. Long Lake chlorophyll fluorescence had the reverse pattern with peak values in July and much of those recorded at the deeper sensors. Light sensors on the Highland Lake buoy were used to measure water clarity, which ranged from lowest in May, July, and September to peak values in August and November.

The Long Lake Buoy

Weather Conditions

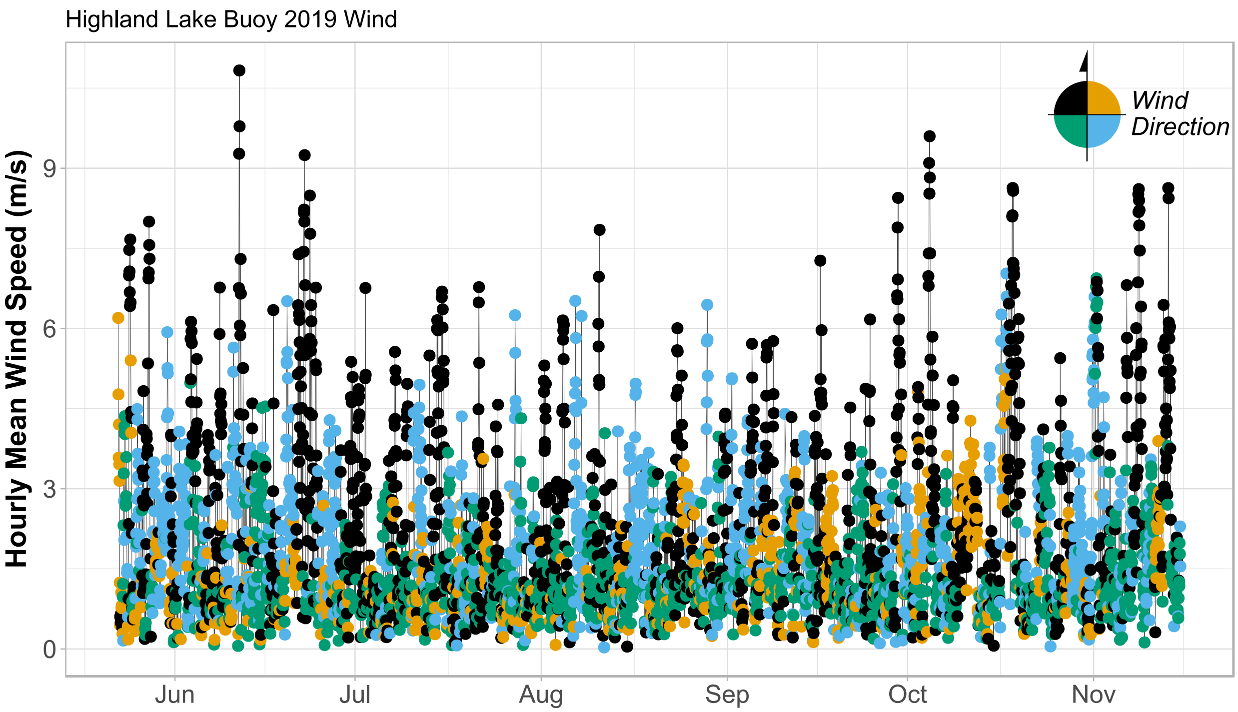
Air Temperature



Local weather conditions (air temperature, wind, rain) play a major role in controlling lake water quality. Sensors on the Highland Lake buoy collect weather and water data simultaneously, and in this section we summarize the weather results. Because the two lakes are geographically close together, the Highland Lake weather data are applicable to Long Lake as well, though the surrounding topography would affect local conditions at each site. Air temperature is important for understanding the heating, cooling, and stability of lake water. The above air temperature data (blue line) followed a typical seasonal pattern, but was cooler than normal for this area (1981-2010, gray dashed line) late May and June and warmer than normal during July through October. The latter half of September had a significant warming event. Air temperature readings on the buoy ranged from -10.5 to 31.8 °C (13.1 to 89.2 °F). Our nearby weather station (red line) near the east shore of Highland Lake recorded almost identical readings, differing only in the extreme values (maximum temperature recorded was 33.2 °C or 91.8 °F), which shows how lake water can have a moderating influence on the overlying air temperature.

Weather Conditions, Continued

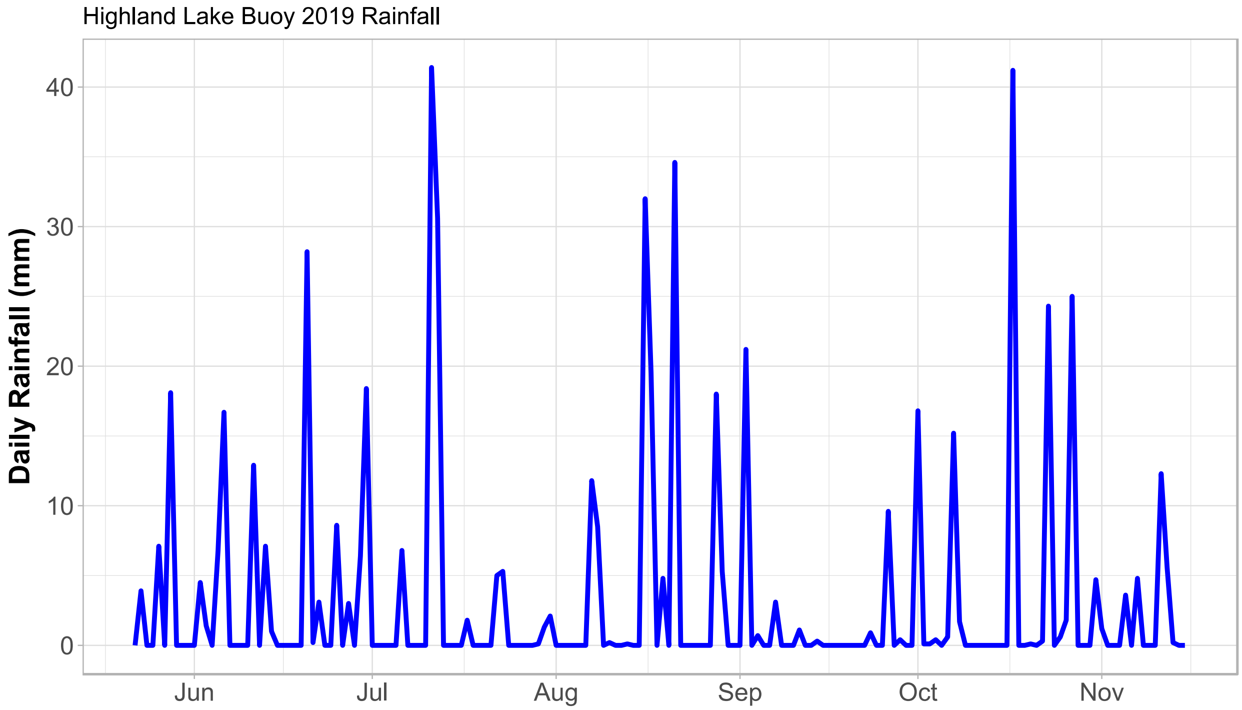
Wind



Wind also has a significant impact on conditions within a lake. Together with temperature, wind can control the physical structure of a lake, like the change from being stratified to being fully mixed. Wind speed and direction measurements recorded by the buoy were quite variable at the 15-minute scale, so broader scale patterns were examined using hourly mean values. In the figures above, the height of the point denotes the mean wind speed and the color indicates the direction from which the wind is blowing (like a weather vane); black means the wind was blowing from anywhere in the north to west quadrant, for example. Hourly mean wind speed ranged from 0.03 to 10.8 m/s (0.07 to 24.2 mph), and the buoy recorded a maximum wind speed of 17.4 m/s (38.9 mph) on November 1st. Stronger and longer wind events tended to happen in early summer and in the fall. Wind direction was highly variable, but tended to be in the NW or the SE quadrant. Stronger winds (greater than about 2 m/s or 4.5 mph) in general were from those same directions, though plenty of exceptions were evident.

Weather Conditions, Continued

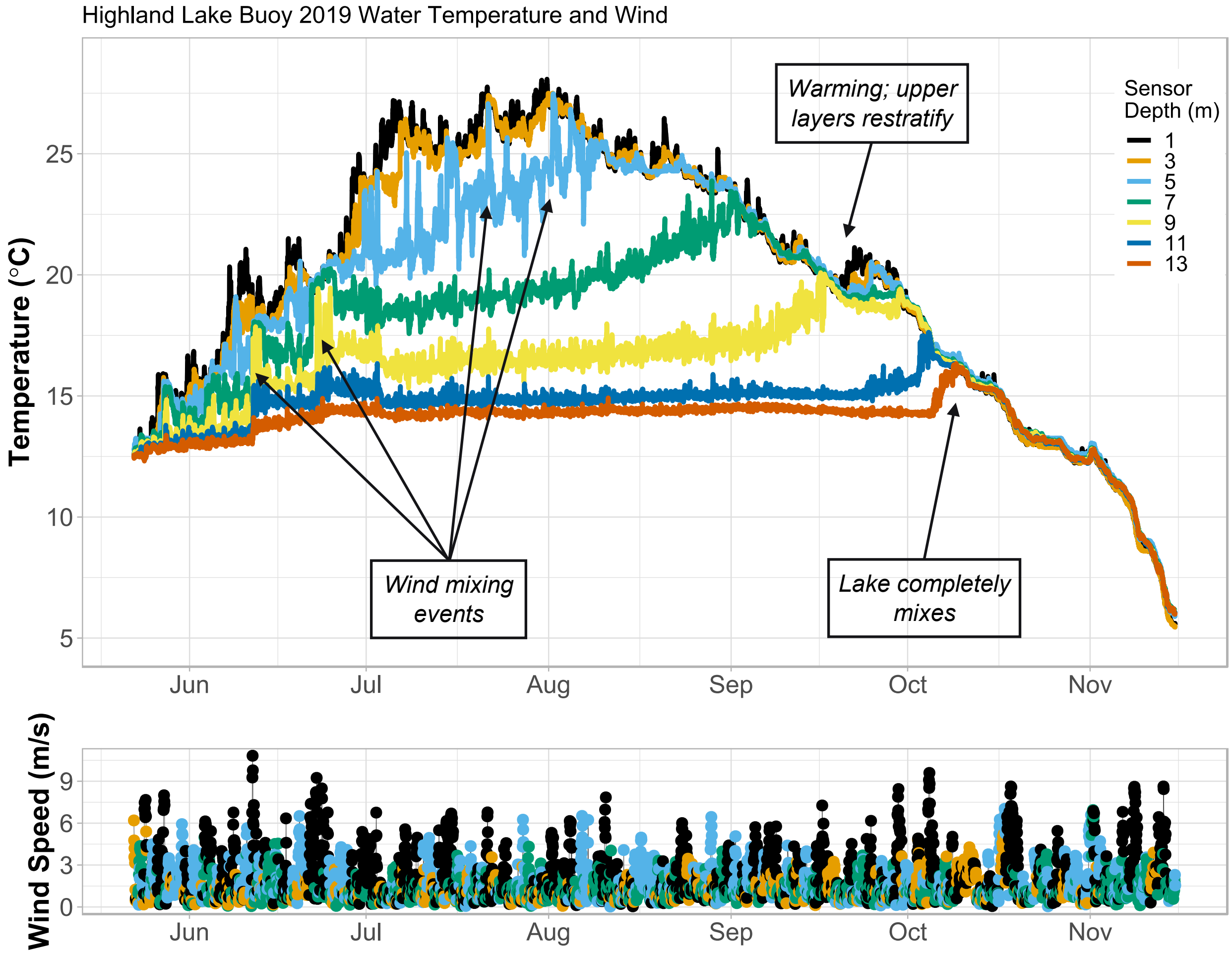
Rainfall



Rain supplies water to a lake, but sediment and nutrients can be delivered along with it, depending on rain amount and intensity. Total rain recorded by the buoy during the deployment was about 574.5 mm (22.6 in), a bit less than the 30-year normal rainfall of 612 mm (24.1 in) for May through October. This total was greater than the precipitation recorded during the same period in 2018. Rainfall events occurred fairly regularly throughout the period, except for periods in July and September. Prior to the buoy deployment, the area received above normal rain during April and May. The highest single day rain total was 41.4 mm (1.63 in) on July 11th and the most time without rain was 9 days in mid-September. High intensity storm events have the most impact on water quality because of the erosion and pollution potential. In mid-August, the buoy recorded a maximum reading for rain intensity of 36.2 mm per hour (1.43 in/hr), though most of the time when rain fell, it was at about 2.7 mm/hr.

Highland Lake

Water Temperature

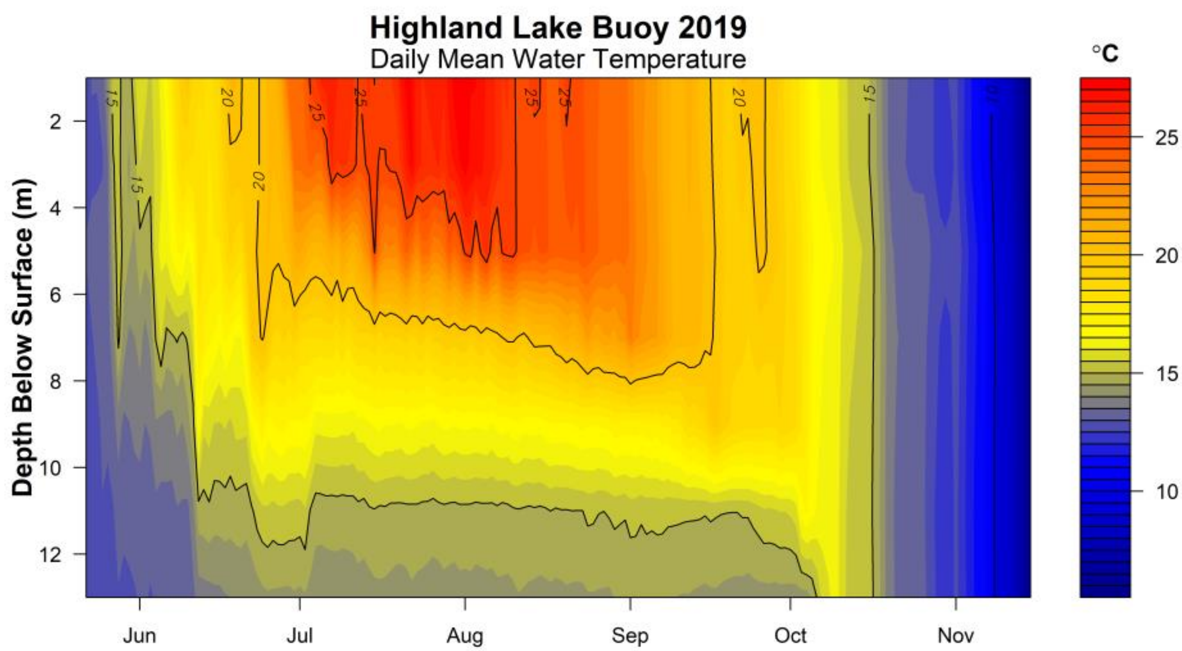


Data from the individual temperature sensors, along with daily winds, are shown in the above figure. Each colored line represents water temperature at a specific depth below the surface at a 15-minute interval. The maximum recorded temperature on Highland Lake was 28.4 °C (83.0 °F) on July 5th, and the minimum temperature was 7.4 °C (45.3 °F) right before the buoy was removed for the season. Daily heating and cooling of the surface water can be seen by the saw-tooth pattern of the 1 m sensor data. Temperature variation was more irregular and sometimes greater in the middle of the water column due to the "sloshing" of internal waves (or seiches). Stratification (indicated by wide spaces between lines) had already occurred at the beginning of the deployment and partial mixing (lines getting closer together) happened throughout the season, especially at times of high winds. Good examples of this can be seen on June 11th, June 22nd, July 21th, and August 1st, when the temperature readings at depth (as deep as 9 m in June) increased to surface values following strong winds. The June mixing events were accompanied by water cooling brought on by local weather conditions. In the latter half of September, a warming spell brought on a temporary stratification of the upper water column that had already mixed. Surface waters started cooling in August and September, which reduced the resistance to mixing in the water col-

Highland Lake, Continued

umn. Complete mixing occurred on October 9th following significant wind events that continued through the fall. This turnover date was the earliest yet recorded by the buoy (see table below). By comparison, Long Lake mixed completely nine days later than Highland Lake.

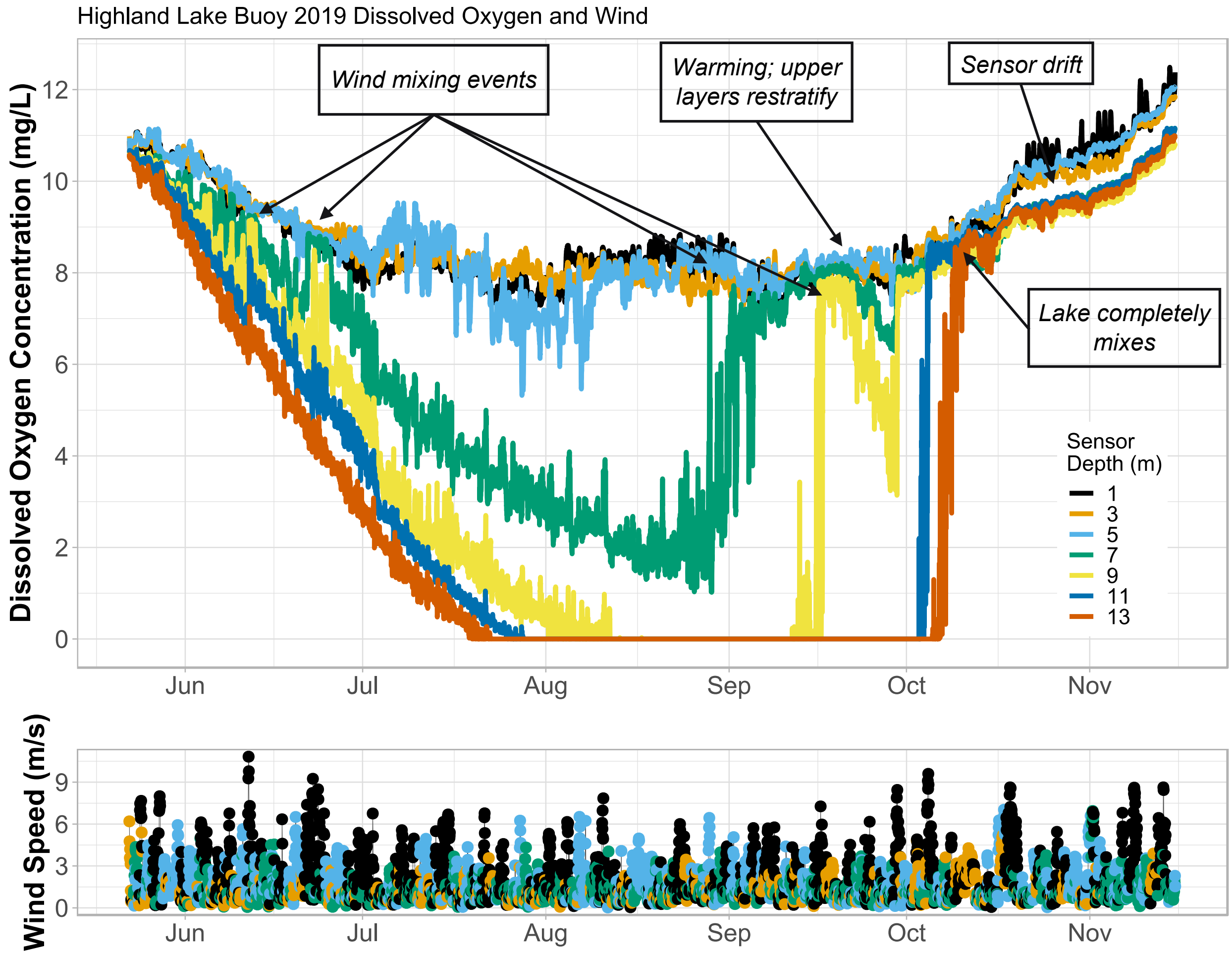
Date of Fall Turnover (Complete Mixing) by Year						
2013	2014	2015	2016	2017	2018	2019
after 10/11	10/12	10/11	10/10	11/4?	10/16	10/4



Another, perhaps easier way to visualize the temperature data is with contour plots (or heat maps). In the above figure, which uses daily mean values to help reduce the noise, temperature across depth and time is represented by colored contours, where the red to yellow to blue color range corresponds to a high to medium to low temperature range. Temperature stratification shows up as areas of the plot where colors change in the vertical direction and contour lines are roughly horizontal (from June through early October). The area where contours come closest together (i.e., temperature changes most rapidly with depth) is often referred to as the thermocline. Vertical contour lines indicate mixed conditions, and areas of a single color from top to bottom (such as November) indicate completely mixed conditions. The effect of wind, like the events previously discussed, can be seen as dips in the contour lines. Warm, stratified conditions stand out as darker red areas in July through August. The downward sloping contours show that the upper layer (epilimnion) and thermocline deepened throughout the summer; thermocline depths ranged from about 5 m in July to about 10 m before lake turnover.

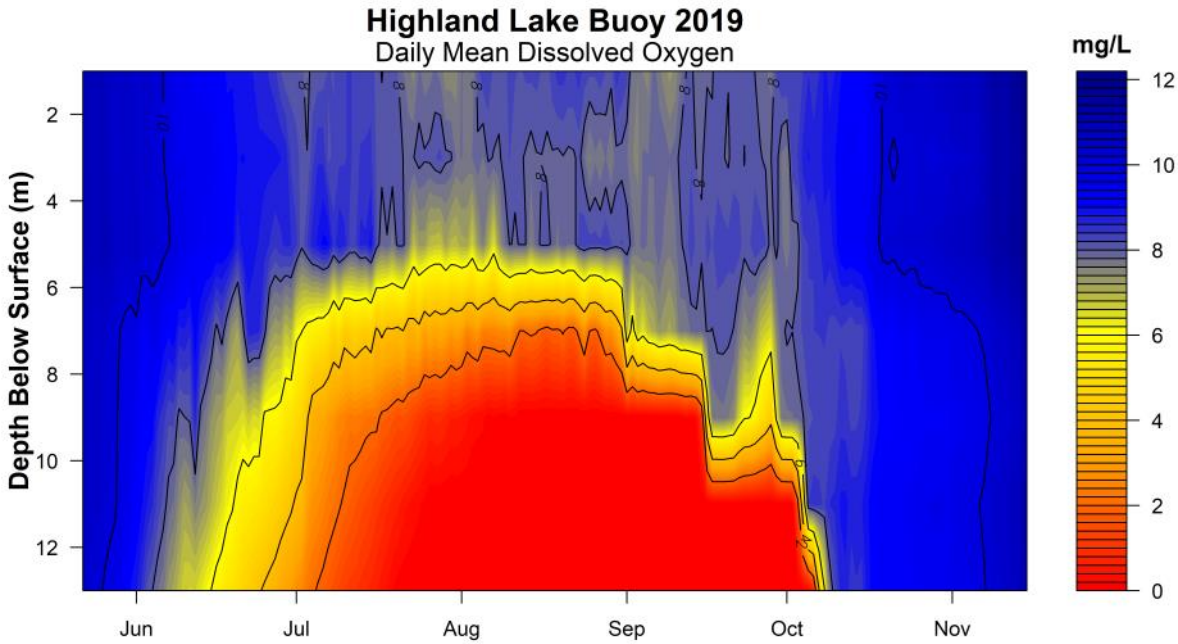
Highland Lake, Continued

Dissolved Oxygen



The same types of plots used for temperature can be used to examine the dissolved oxygen (DO) time series data from the buoy. The figure above shows a pattern of generally decreasing DO from the start of the record through early fall. Some of that is simply due to warming water, since cold water can contain more DO than warm water, all else being equal. Oxygen in the deeper waters, however, decreased more rapidly. This is due to biological consumption (animals and bacteria using oxygen) and the lack of aeration (wind mixing) because of stratified conditions; by mid-July, deep DO readings reached zero (anoxia). The effect of wind mixing on oxygen is also visible in the figure at mid-water depths (e.g., rapid increases in 7 m DO in June and late August). The lake was mixed as deep as 9 m in mid-September, followed immediately by a warming event and DO decline over the next week or so. The daily warming-cooling cycle of the air, the daily cycle of photosynthesis and respiration, and the back and forth rocking of internal waves are responsible for the smaller variations in DO concentration seen in the figure. By early October, the water column was completely saturated with oxygen after temperatures dropped and winds fully mixed the lake. The split in DO concentrations seen after the October mixing is assumed to be an artifact caused by sensor calibration drift.

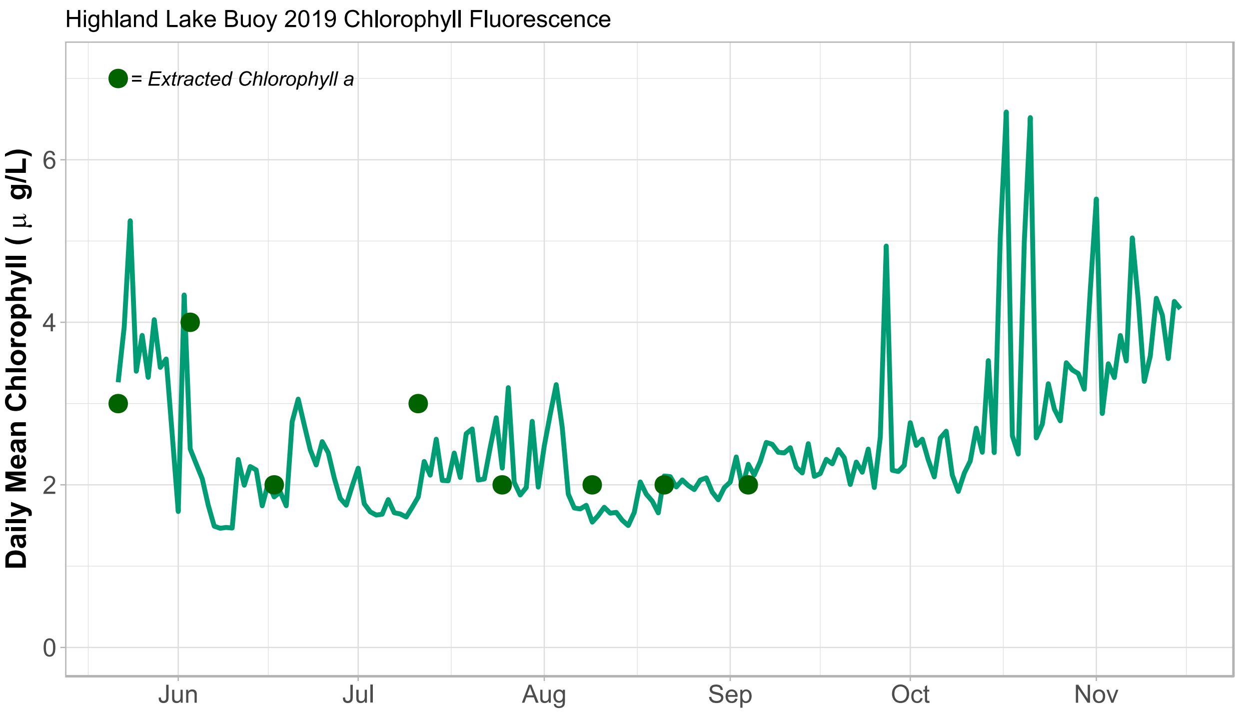
Highland Lake, Continued



Another way to illustrate the buoy dissolved oxygen (DO) data is with depth-date contour plots, though in the above figure we have reversed the color scheme used for temperature so that red and blue signify low and high DO, respectively. The contour plot highlights nicely the pattern of lower DO concentrations in summertime deep waters and provides a quick visual gauge of where and when hypoxic (< 2 mg/L) conditions occur. As was seen in the previous line plot, Highland Lake bottom water became anoxic (DO = 0) starting in mid-July and remained so until early October, when the water column mixed completely. Prior to that, more minor wind mixing events can be seen in the downward dips in the DO contours such as the mid-September event. Besides wind and water temperature, the major control of lake water DO concentrations is biological activity (i.e., respiration and photosynthesis). Oxygen is a byproduct of photosynthesis, so actively growing algae can increase DO concentrations. On the other hand, lake water DO is reduced when microbes, fish, and plants respire or "breathe". When the lake is stratified, oxygen in the bottom layers cannot be replenished easily, leading to first hypoxia, then anoxia. Fish tend to avoid and are stressed when moving through areas that have DO concentrations below about 4 mg/L, while anoxic bottom waters allow phosphorus stored in sediments to be released for use by algae; these phenomena highlight the importance of collecting DO data.

Highland Lake, Continued

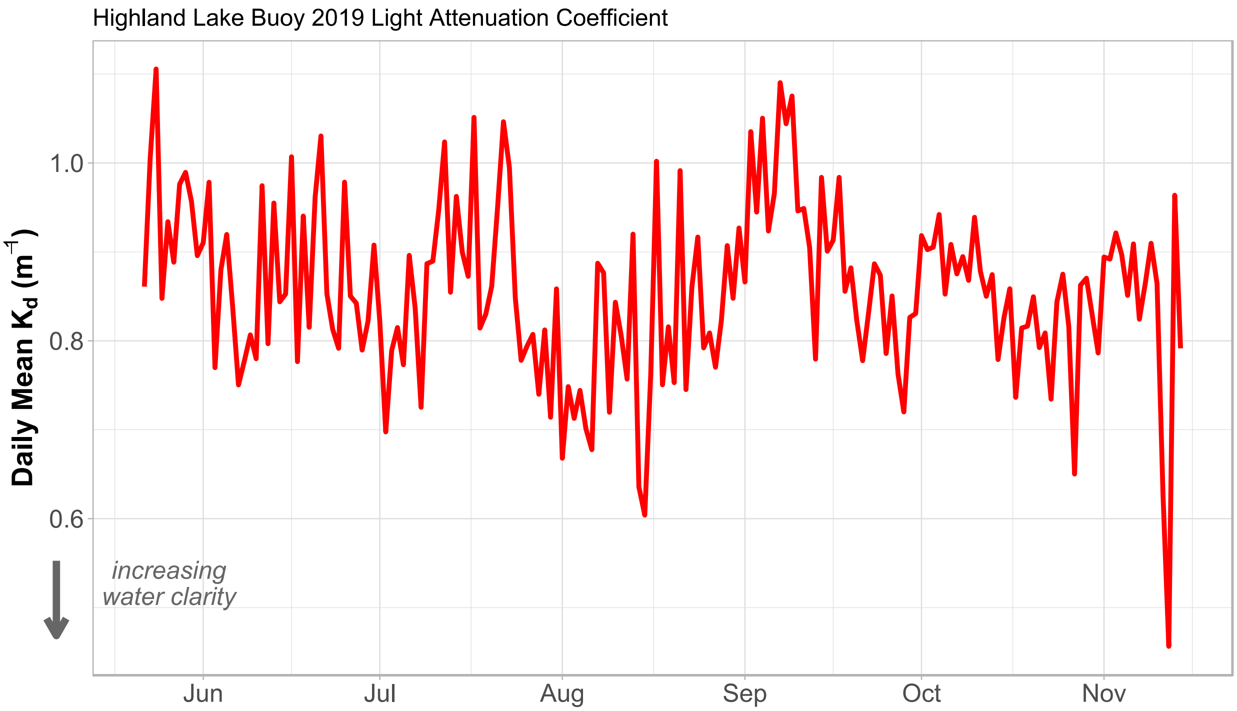
Chloropyll or Algae Biomass



The Highland buoy contains one sensor mounted 1.5 m from the lake surface that measures chlorophyll concentrations using fluorescence (same as the field fluorometer used on regular testing trips and discussed in chapter 4). The amount of this pigment (found in all plants and algae) can be used as a proxy for algae biomass and as a measure for the productivity of a lake. It is important to note that field fluorescence is a relative measure and is not as accurate as lab-based chlorophyll measurements. However, buoy chlorophyll and extracted chlorophyll a concentrations from our regular testing trips did show similar values. Daily mean chlorophyll, shown above, ranged from 1.5 to 6.6 µg/L, with generally higher readings in spring and fall and lowest readings in the summer. This is consistent with the possibility that available nutrients were elevated at those same times. Phosphorus may have been elevated in the spring due to post-ice cover mixing and higher than normal precipitation. At fall turnover, high phosphorus bottom waters can be mixed to the surface providing resources for algae. Precipitation during the fall could also be a factor; peaks in late September and mid-October coincided with elevated rainfall at those times. There are of course other factors that control algae populations, like competition between different species and zooplankton grazing, but those are beyond the monitoring capabilities of the buoy for now.

Highland Lake, Continued

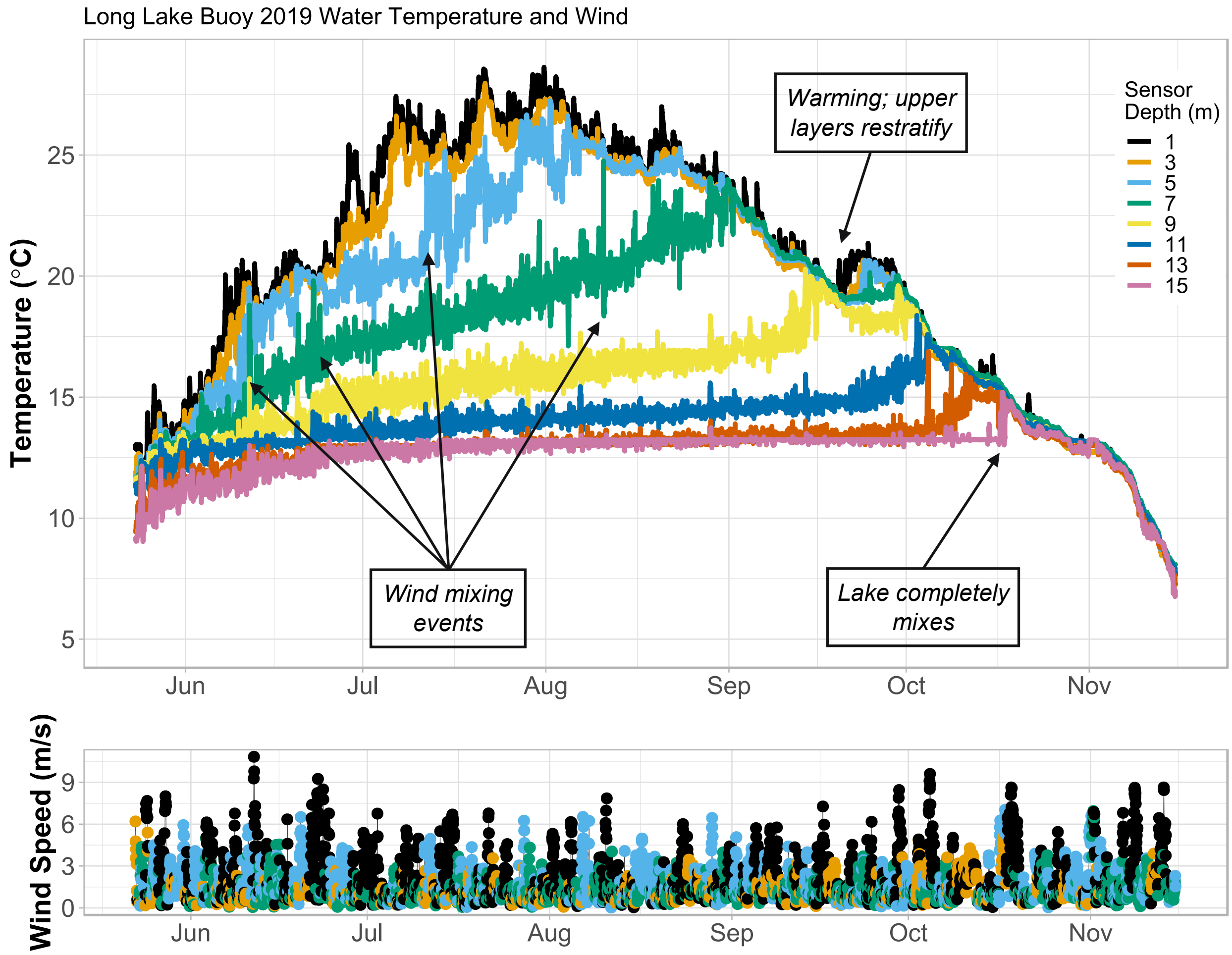
Light Attenuation (Water Clarity)



The Highland buoy has two light sensors, one mounted on top of the buoy and one mounted at 1.5 m depth below the water surface. Both sensors measure the amount of light at visible wavelengths (400-700 nm) reaching them, but the underwater sensor receives less light because the water and the matter it contains reduces or attenuates the solar energy. That attenuation can be quantified using the light attenuation coefficient, or K_d, which indicates how quickly light changes with depth and is calculated from the above- and below-water light readings. K_d is one measure of water transparency or clarity similar to Secchi depths, though in this case the smaller the K_d the clearer the lake. A K_d of 1 is equivalent to a photic zone depth (depth where light is 1% of the surface value) of 4.6 m and a K_d of 0.5 is equivalent to a photic zone depth of 9.2 m. At the buoy, daily mean K_d varied from less than 0.5 to about 1.1 m^{-1} with an overall mean and standard deviation of 0.86 (± 0.1) m^{-1}. Higher K_d values (lower clarity) occurred throughout May through early September, while lower K_d values (higher clarity) occurred in August and late fall. Secchi depths measured near the buoy (ranging from 5.6 to 7.5 m) did not always follow the K_d trends, but the two deepest Secchi depths did match with the two lowest K_d readings (data not shown). Light attenuation is a function of matter that absorb or reflect light like humic and tannic acids, soils and sediments, algae, and even water itself. Some combination of those water components caused the observed pattern of light attenuation, though the rapid changes are hard to explain. Chlorophyll data was elevated in the spring and may have contributed to the observed lower water clarity, but that was not the case in the fall when clarity increased along with chlorophyll.

Long Lake (North Basin)

Water Temperature

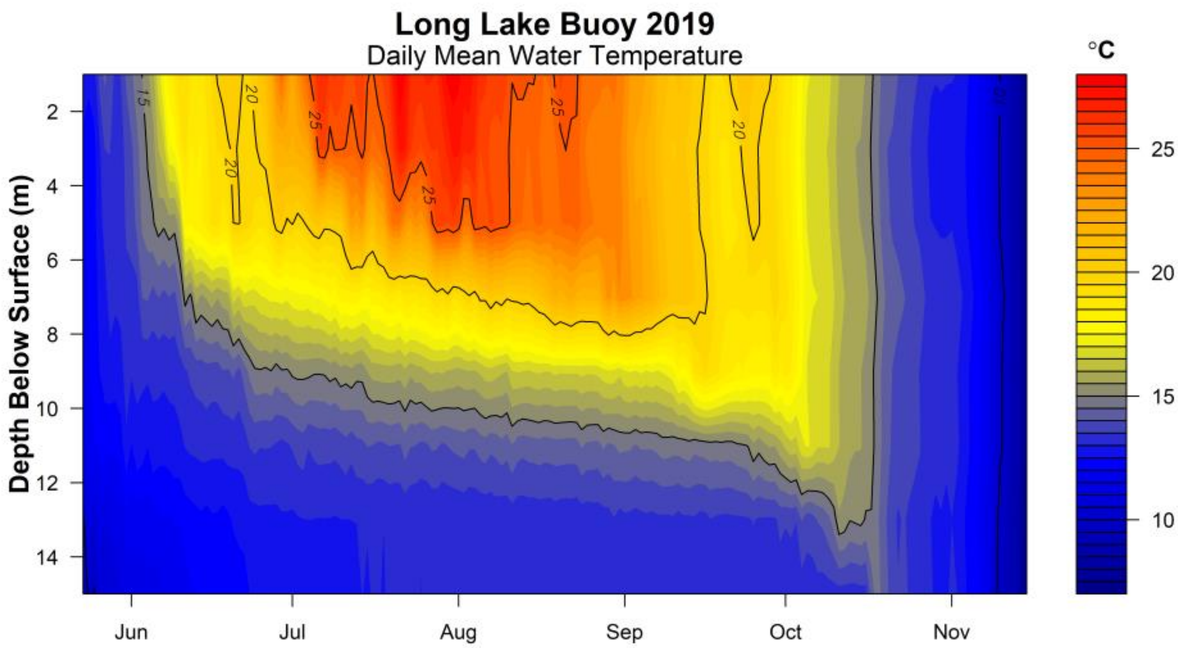


Water temperature data forms the foundation for most water quality measures and is essential for understanding lake physical dynamics, nutrient cycling, and habitat availability for fish and other aquatic organisms. Data from the individual temperature sensors, along with hourly winds, are shown in the above figure. Each colored line represents water temperature at a specific depth below the surface at a 15-minute interval. The maximum recorded temperature on Long Lake was 28.6 °C (83.5°F) on July 31st, and the minimum temperature was 6.8 °C (44.2 °F) right before the buoy was removed for the season. Daily heating and cooling of the surface water can be seen by the saw-tooth pattern of the 1 m sensor data. Temperature variation was more irregular and sometimes greater in the middle of the water column due to the "sloshing" of internal waves (or seiches) caused by wind energy. Stratification (indicated by wide spaces between lines) began soon after the deployment started and partial mixing (lines getting closer together) happened throughout the season, especially at times of high winds. Good examples of this can be seen on June 11th, June 22nd, July 11th, and August 10th, when the temperature readings at depth increased to surface values following strong winds. The June mixing events were accompanied by water cooling brought on by local weather conditions. In the latter half of September, a warming spell brought on a temporary stratification of the upper water column that had already mixed. Surface

Long Lake (North Basin), Continued

waters started cooling in August and September, which reduced the resistance to mixing in the water column. Complete mixing occurred on October 18th following significant wind events that continued through the fall. This turnover date was the same as in 2018, and still on of the earliest known mixing dates recorded by the buoy (see table below). By comparison, Highland Lake mixed completely nine days prior to Long Lake.

Date of Fall Turnover (Complete Mixing) by Year						
2013	2014	2015	2016	2017	2018	2019
10/25	10/23	No Data	No Data	11/4	10/18	10/18



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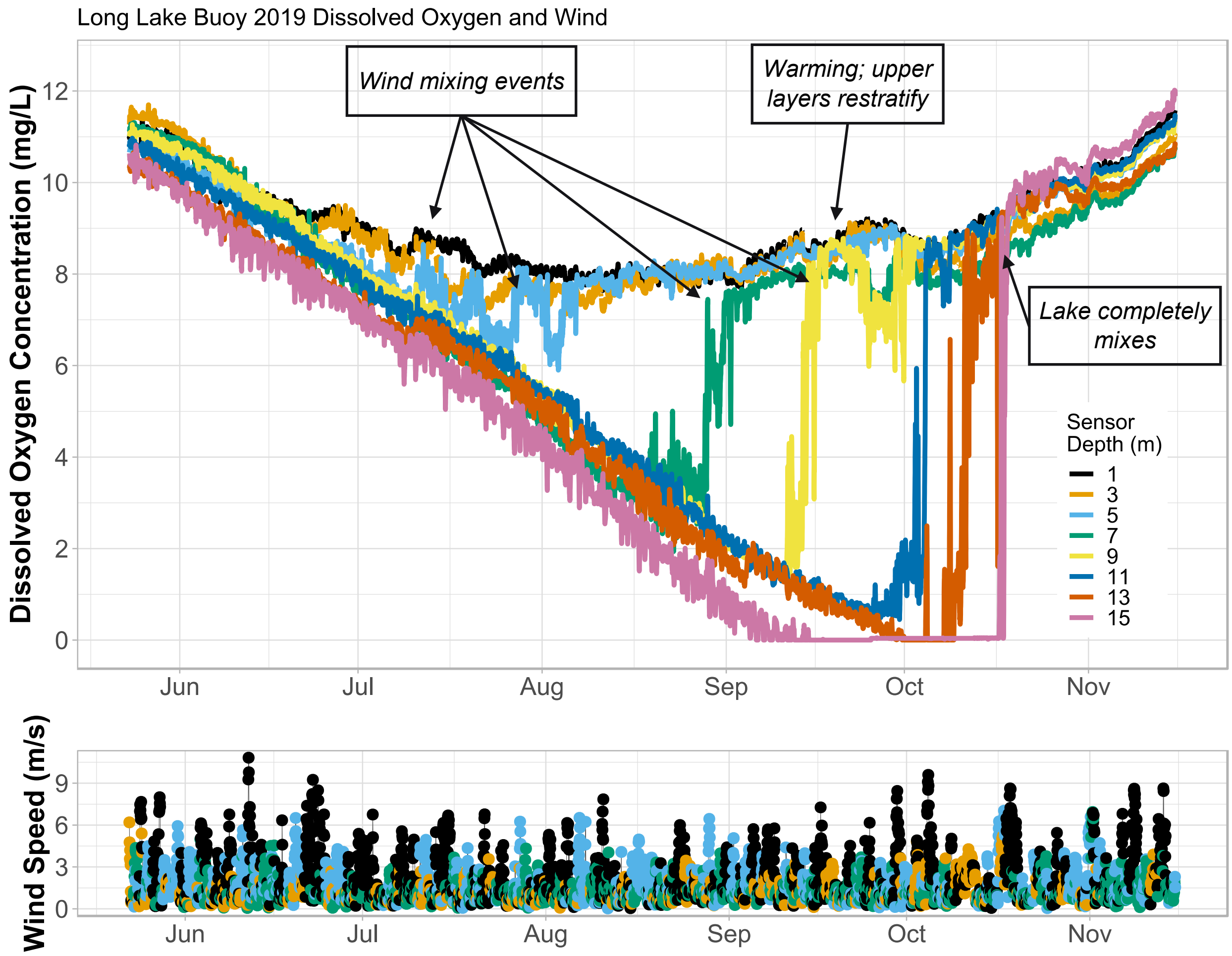
Long Lake (North Basin), Continued

Dissolved Oxygen



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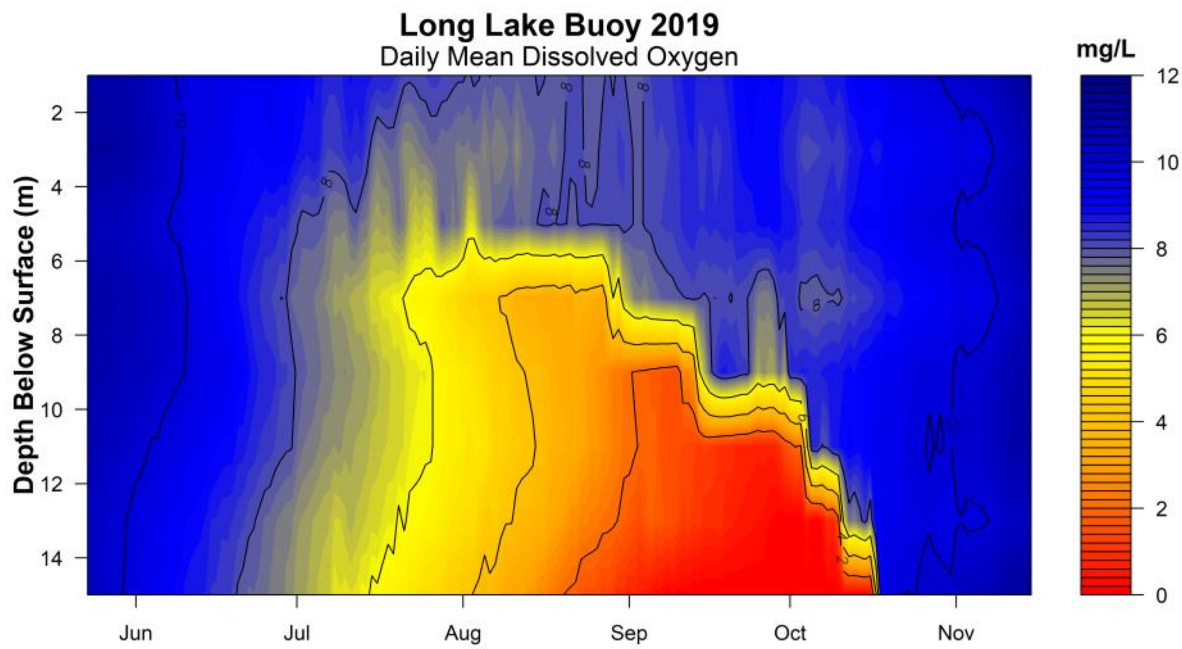
Long Lake (North Basin), Continued



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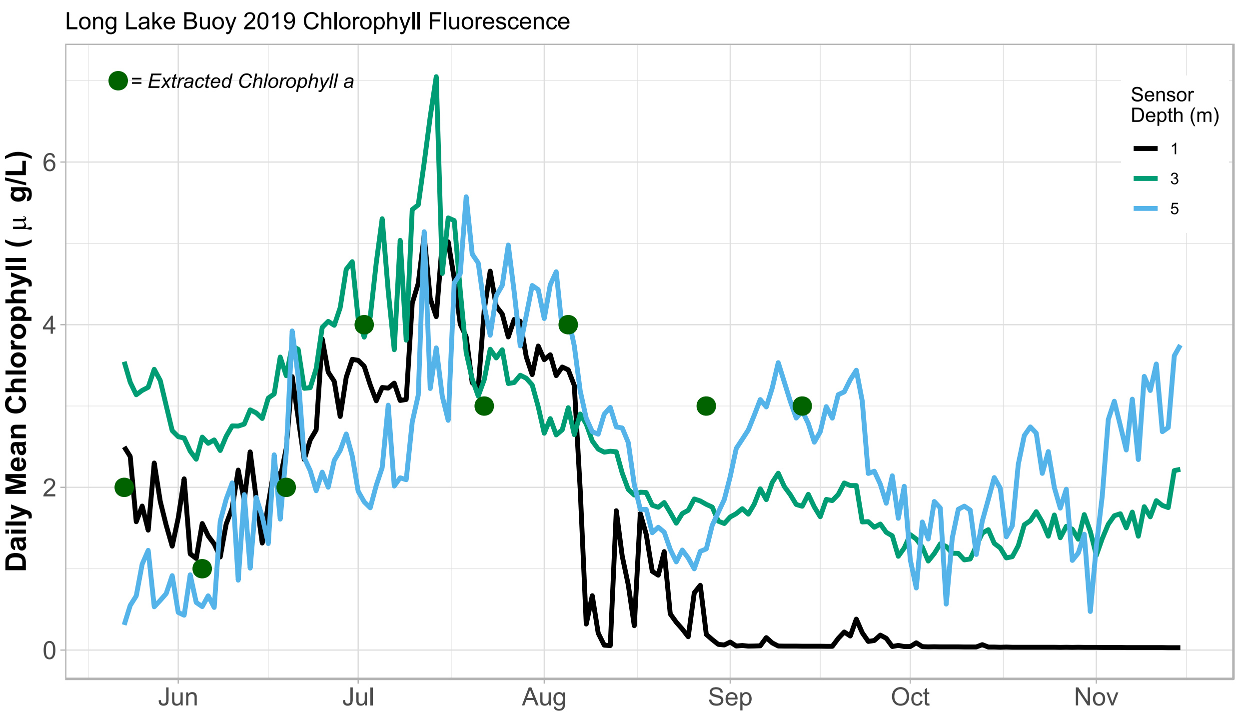
Long Lake (North Basin), Continued

Chlorophyll or Algae Biomass



The Long Lake buoy contains sensors at three different depths (1, 3, and 5 m) below the lake surface that measure chlorophyll concentrations using fluorescence(same as the field fluorometer used on regular testing trips and discussed in chapter 4). The amount of this pigment (found in all plants and algae) can be used as a proxy for algae biomass and as a measure for the productivity of a lake. It is important to note that field fluorescence is a relative measure and is not as accurate as lab-based chlorophyll measurements. However, buoy chlorophyll and extracted chlorophyll a concentrations from our regular testing trips showed similar values. Daily mean chlorophyll, shown above, ranged from near 0 to 7.0 µg/L, with generally higher readings in summer and lower readings in the spring and fall. The 1-m data after September is suspicious because it dropped so low for such a long time; it most likely was an error or fouling and it will be tested prior to next deployment. Chlorophyll concentrations often varied across the depths (separation between lines on the plot) and the sensors at 3 and 5 m often had the highest chlorophyll reading on a given day. This indicates an unequal distribution of algae throughout the water column, and is likely a result of algae growing better at depths with lower light levels and preferring conditions right above the thermocline. This pattern was observed on multiple lakes in LEA's service area that were monitored using a hand-held fluorometric probe in 2019 (see chapter 4). The peak values in July do correspond with a major rain event, which may have added nutrients like phosphorus that enriched the system. There are of course other factors that control algae populations, like competition between different species and zooplankton grazing, but those are beyond the monitoring capabilities of the buoy for now.