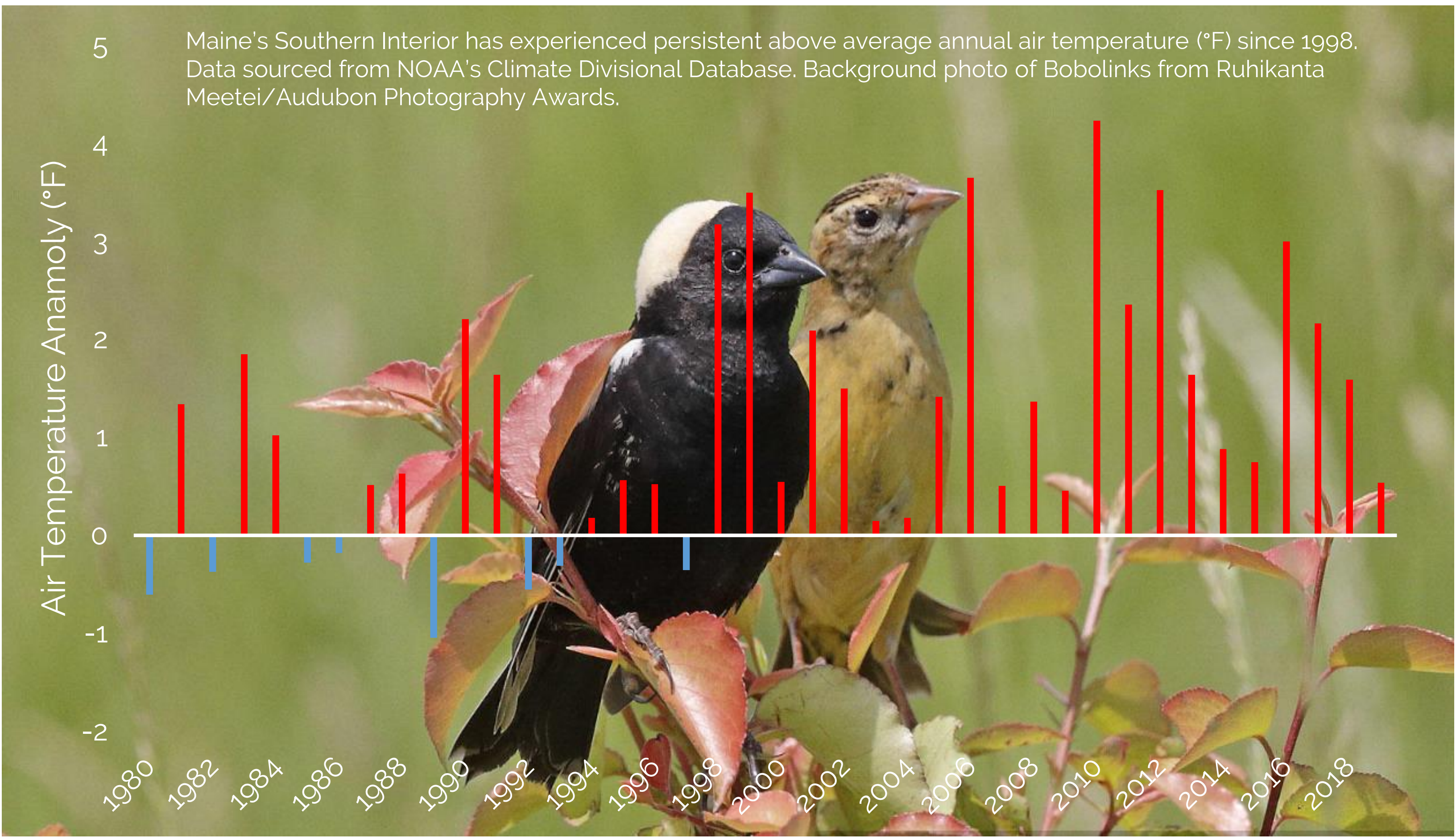
Kezar Lake

WATERSHED ASSOCIATION

P.O. Box 88, Lovell, ME 04051 www.klwa.us

CLIMATE CHANGE OBSERVATORY



2019 ANNUAL REPORT

ABOUT THE COVER

As greenhouse gas emissions and global air temperatures continue to rise and headlines are dominated by record-breaking floods, droughts, heatwaves, and fires across the world, humanity is at a critical point in history when massive reforms to our way of life must be implemented to reduce greenhouse gas emissions and curtail the catastrophic projections of climate change. One of the most significant impacts from climate change is **loss of biodiversity through species extinction** – the chosen theme for the 2019 CCO Annual Report.

In 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) issued a comprehensive report that detailed the impacts of climate change on global biodiversity and ecosystem services. The report was developed over a period of three years by 145 expert authors from 50 countries, with input from 310 contributing authors. The report determined the following (adapted from its Executive Summary):

1. We are in an era known as the Anthropocene, named so because **modern humans now have a dominant and intervening impact on nature worldwide**. Over 40% of the world's land is now agricultural or urban, though human drivers extend widely beyond these areas so that only 13% of the ocean and 23% of the land is still classified as "wilderness," and include the tundra and ocean gyres.

2. Habitat and species loss, along with their ecosystem services, are declining at an accelerated rate. **Around one million animal and plant species are currently threatened for extinction**, with unpredictable impacts to humans and local ecosystems.

3. Species have lost about 1% of their genetic diversity per decade since the 1950's, most especially due to land use change, deforestation, and landscape fragmentation.

These biodiversity losses extend to Maine and bring Rachel Carson's warning of a "Silent Spring" into stark relief. A study by the National Audubon Society found that more than 50% of Maine's 230 bird species are at risk from climate change as more than half of their current range will be lost. For instance, Bobolinks featured on the cover are at high risk for northern migration out of Oxford County and beyond in the next century.

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Design by Laura Diemer (FB Environmental Associates)

EXECUTIVE SUMMARY

Climate change is threatening the current balance of ecological systems across the globe. In New England, we can expect warmer air temperatures, more intense and frequent precipitation events, increased flooding, reduced snow cover duration, enhanced species migration and extirpation (including increased prevalence of disease-carrying ticks), and earlier lake ice-out. Lakes can provide early indications of climate change effects and have been identified as "sentinels of climate change" by the scientific community.

The Kezar Lake Watershed Association (KLWA) recognized the critical need to protect and monitor its valuable natural resources in the face of climate change. As a result, KLWA established a Climate Change Observatory (CCO), whose objective is to analyze the long-term effects of climate change on atmospheric, aquatic, and terrestrial ecosystems in the Kezar Lake watershed. The CCO is led by a steering committee and is funded through a grant, generous donations, and the KLWA General Fund. The formulation and operation of the CCO is made possible through the expert guidance of collaborating partners, including the Greater Lovell Land Trust, the U.S. Forest Service, the University of Maine Climate Change Institute, the Maine Department of Inland Fisheries & Wildlife, Manomet Center for Conservation Sciences, Plymouth State University Center for the Environment, and FB Environmental Associates.

The mission of the Climate Change Observatory is to observe, measure, and analyze long-term climate change trends and to address their impact on the waters, lands, and wildlife of the Kezar Lake watershed.

This document is the fifth CCO Annual Report, which is published annually to highlight the previous year's activities and monitoring results and to make recommendations based on the analysis of climate change-induced annual trends for available data. These data are presented by major ecological zone: climate, water, and land.

While this document showcases historical climate change trends observed and collected by the CCO, we understand and emphasize the critical importance of also showcasing future climate change projections. A new section beginning on page 61 describes Maine's climate future in several areas of economic value to Maine (e.g., farms, forests, fisheries, and recreation), as summarized from "Maine's Climate Future 2020 Update" by the University of Maine.

The CCO has accomplished the following climate change activities in the watershed in 2019:

- **Updated climate change webpages for the KLWA website** (klwa.us) to showcase observed trends in several indicator categories, but most especially water quality.
- **Deployed data loggers** to monitor water temperature and water level in several tributaries draining to Kezar Lake, as well as in the lower bay and in the outlet stream from the lake. This effort was expanded to include vertical profile monitoring of dissolved oxygen and temperature in the deep-spot of the upper and lower bays.
- **Maintained our state-of-the-art weather station** and web camera on Kezar Lake for tracking local weather conditions.
- **Collected a sediment core at Horseshoe Pond** to compare to Kezar Lake.

- **Continued a multi-year loon study** to track the health of loon populations and their habitats.
- **Attended multiple meetings with project partners**, including the Town of Lovell and PSU.
- **Obtained grant funding** to continue climate change tracking efforts in the watershed.
- **Participated in multiple education and community outreach events** to promote CCO activities.

ANNUAL REPORT ON OBSERVED THREATS & RECOMMENDATIONS

CLIMATE CHANGE THREAT	ADAPTATION & MITIGATION RECOMMENDATIONS
ACTIONS FOR THE TOWN OF LOVELL	
⊗ Increased air temperatures, fewer extreme cold days, more frequent precipitation events, earlier ice-out since 1972, and decreased annual snowfall. ⊗ Potential degradation of stable or improving trends in water clarity, total phosphorus, chlorophyll-a, and dissolved oxygen.	⊕ Improve infrastructure (roads, ditches, swales, culverts) to accommodate higher and more frequent stormwater flow volumes. ⊕ Replace the remaining high priority culverts identified by the 2015 culvert study. ⊕ Establish a Climate Change Information link on the town website that links residents to important climate change information and the KLWA/CCO webpages. ⊕ In developing the next Comprehensive Plan: 1) include provisions to deal with projected climate change-induced weather events and conditions (e.g., upgrading infrastructure); 2) include language that ensures development occurs in a sustainable and low-impact way to increase watershed resiliency to extreme weather events and prevent potential polluted runoff; 3) include current and projected flood risk maps for residents with homes in low-lying areas; 4) consider rezoning the projected flood zone for non-development; 5) add Low Impact Development (LID) description to ordinance and require LID in site design, especially for lots with >20% imperviousness; 6) increase setback distances to at least 100 ft. around vernal pools, streams, and wetlands; and 7) encourage conservation subdivisions, where applicable, with common open space and require land trusts or conservation organizations (not homeowner's associations) to undertake stewardship of common open space in conservation subdivisions. ⊕ Review and update local septic ordinances to include the following: 1) require septic systems to be evaluated and upgraded to current code or replaced, as needed, for any sale or exchange of property ownership or upon a system failure; 2) require proof of septic system pump-outs every 3 years (unless given an approved waiver for limited use). ⊕ In conjunction with KLWA, conduct a shoreline survey of properties on Kezar Lake and ponds to identify conduits of stormwater runoff (e.g., driveways, boat ramps) and develop specific recommendations for mitigation of erosion.

CLIMATE CHANGE THREAT	ADAPTATION & MITIGATION RECOMMENDATIONS
⊗ Increased threat from invasive species.	⊕ Continue the outstanding progressive watch programs that help prevent and control invasive plants, especially the LIPPC program. ⊕ Encourage local foresters to lookout for infestations of the emerald ash borer. ⊕ Support state, county, and local efforts to prohibit use of out-of-state firewood to prevent the spread of the emerald ash borer.
⊗ Reduction in aquatic bird species, esp. loons.	⊕ Post signage to encourage anglers to use non-lead sinkers and to retrieve fishing line caught in shoreline vegetation. Install "Get the Lead Out" boxes at Town landings for disposing of lead-based fishing gear. Support KLWA guidelines for keeping large boat wakes 500 feet from shorelines and stay at least 200 feet away from loons and their nests.
ACTIONS FOR KLWA	
⊗ Potential degradation of stable or improving trends in water clarity, total phosphorus, chlorophyll-a, and dissolved oxygen.	⊕ Target stormwater management and septic system maintenance outreach to shorefront and riverfront residents. ⊕ Advocate and publicize the merits of achieving LakeSmart certification through the State of Maine. ⊕ Publicize the specific recommendations for sustainable lake shore living in the KLWA's Lake Dweller's Handbook.
⊗ Historic degrading trends in alkalinity and pH in multiple waterbodies.	⊕ Conduct another alkalinity and pH study to better assess the vulnerability of waterbodies to acid rain and watershed activities across years.
⊗ Reduction in coldwater fish populations.	⊕ Continue monitoring stream conditions for supporting coldwater fish species (e.g., temperature, flow, and population size). This will help target streams in need of restoration. Restoration techniques include increasing overhead vegetative cover to help cool stream water temperatures. ⊕ Petition IF&W to make Kezar Lake catch and release only for certain sensitive fish species. Debar all fish hooks and ensure proper fishing line strength to avoid fish injury and entanglement.
⊗ Increased threat from insects and pathogens.	⊕ Contact the Maine Center for Disease Control and Prevention to determine how public notices will be issued during peak tick and mosquito season to warn residents of potential diseases, including Lyme and follow-up to see that people in Lovell receive these notices. ⊕ Educate watershed residents on the threat of the emerald ash borer (along with other invasive species).
ACTIONS FOR GREATER LOVELL LAND TRUST	
⊗ Shifts in the habitat ranges of native plant, bird, and mammal species.	⊕ Continue to conserve and protect land areas that serve as wildlife corridors. ⊕ Work with the State to set up emerald ash borer monitoring sites and inventory ash trees on trust land.

INTRODUCTION

In 2013, the Kezar Lake Watershed Association (KLWA) established a Climate Change Observatory (CCO) to observe, measure, and analyze long-term climate change trends and to address their impact on the waters, lands, and wildlife of the Kezar Lake watershed. The CCO is building upon decades of limited local data by expanding data collection activities in the Kezar Lake watershed. These data collection activities target current community interests that were identified during a Community Values Forum hosted by the CCO in July 2014. The purpose of this work is to provide the public, local government, and other stakeholder organizations with 1) ongoing information related to the effects of climate change on community interests and 2) recommendations for mitigating or adapting to these potential effects.

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CLIMATE CHANGE OBSERVATORY MANAGEMENT AND DIRECTION

The CCO is funded by a combination of grant, donations, and the KLWA General Fund. CCO activities are guided by a Steering Committee that reports to the KLWA President and supervises the activities of the CCO, by providing direction, setting goals, establishing priorities, and allocating funds.

Current Steering Committee Members

Don Griggs, Director	Bob Winship
Heinrich Wurm	Eric Ernst
Lucy LaCasse	Wes Huntress

PARTNERS AND COLLABORATING ORGANIZATIONS

The CCO collaborates with federal and state government agencies, universities, and private organizations that are involved in climate change activities. CCO members meet and exchange ideas and data with these partners on a regular basis. The recommendations and guidance the CCO have received from these collaborating partners have been immensely helpful in formulating climate change monitoring plans and activities.

Our Partners Include:

- **Greater Lovell Land Trust** – shares our vital interest in the future of our watershed;
- **U.S. Forest Service** – established a water quality data exchange plan for streams within the watershed in the White Mountain National Forest (24% of our watershed);
- **University of Maine Climate Change Institute** – provides access to internationally-acclaimed experts studying climate science;
- **Maine Department of Inland Fisheries & Wildlife** – conducts research on the effects of climate change on fisheries and wildlife;

- **Manomet Center for Conservation Sciences** – provides technical experts on climate change effects on land and water;
- **Plymouth State University Center for the Environment** – provides historical climate data from sediment core sampling, as well as a source of highly-qualified graduate interns;
- **FB Environmental Associates** – provides technical advice, planning, and monitoring support for CCO activities.

CURRENT CCO ACTIVITIES (2019)

The CCO was very active in 2019. These activities have bolstered community involvement and awareness of climate change in the Kezar Lake watershed. Our work has received support and commendations from several regional environmental organizations in Maine.

WEB SITE DEVELOPMENT

A major effort over the past year has been the continued development of webpages for the KLWA website (klwa.us) that tell the story of climate change trends for a variety of data collected within or near the Kezar Lake watershed. This website successfully summarizes the voluminous data collected over several decades in a format that is readily accessible and understandable to the public. Because of the extensive and local data available on water quality for Kezar Lake and six ponds within the watershed, most of the initial effort was placed on water quality. However, the CCO was also able to collect and summarize general climate information for the area, especially using the CCO weather station data, as well as the effects of climate change on many key wildlife and plant species. Website development will be an ongoing effort by the CCO and one of the primary methods of data communication with the public.

DATA COLLECTION

The CCO purchased, engineered, and installed a state-of-the-art weather station and web camera on the edge of Kezar Lake just south of Boulder Brook. Collecting local weather data will greatly improve the accuracy of our water quality data analyses that are dependent on temperature and precipitation readings. The weather station data and webcam images are also an important service that KLWA provides to the community. Since the installation of the weather station was completed and streamed online, the average number of "hits" on the KLWA web site has expanded from about 6 per month to about 1,200 per month.

The CCO deployed data loggers that continuously collect water temperature and water level data in two streams draining to Kezar Lake, as well as in the lower bay and in the outlet stream from the lake. Five other streams draining to Kezar Lake are continuously monitored for water temperature. The CCO and its partners are currently working to establish a stage-discharge relationship for three sites so that water level can be converted to flow data. Climate change is likely to impact water temperature and stream flow greatly; thus, establishing a monitoring program that evaluates these parameters annually will provide insight to how the watershed responds to climate change.

KLWA deployed dissolved oxygen and temperature data loggers in the deep spot of the upper and lower bays. With high-resolution data from continuous loggers, we can pinpoint spring and fall turnover, determine the onset of thermal stratification, and determine the extent and duration of anoxia. By tracking these parameters over time, we can measure whether these indices are shifting because of climate change or other human disturbances within the watershed.

SEDIMENT CORE

The CCO took a sediment core in Horseshoe Pond in the summer of 2019 to be able to compare the sediment deposition rate of Kezar Lake, which is impacted by human activities, with Horseshoe Pond, which is minimally impacted by human activities.

MEETINGS

Members of the CCO met with Lovell officials as follows:

10/09/19 Met with Planning Board to present the 2018 Annual Report.

10/15/19 Met with Lovell Selectmen to present the 2018 Annual Report.

CCO Steering Committee meetings were held on **02/18/19** and **10/01/19**.

GRANT APPLICATION AND REPORTING

The CCO submitted a required status report on our 2018 grant in February 2019. The report detailed CCO use of the 2018 grant funds. The CCO then applied for a 2019-20 grant and was awarded $15,000 to continue our climate change tracking efforts in 2020.

EDUCATION/COMMUNITY PROGRAMS

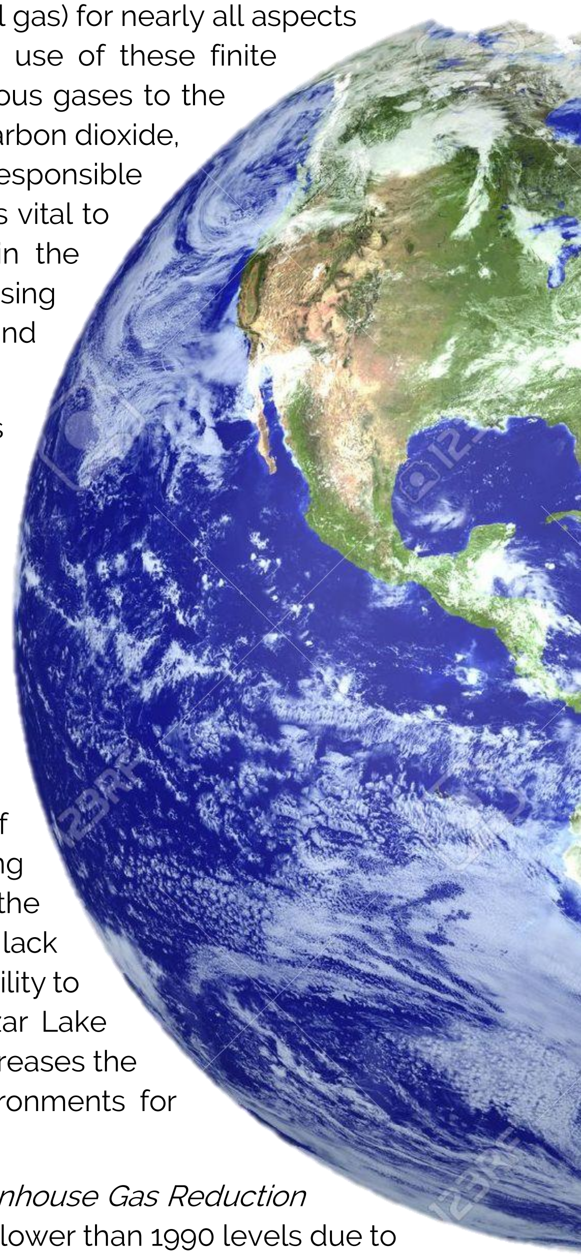
07/13/19 Presented CCO activities update at the KLWA Annual Meeting.

07/20/19 Established a climate change booth for Lovell Old Home Days with displays and informative hand-outs.

ANNUAL REPORT ON OBSERVED TRENDS

CLIMATE

Air Pollutants

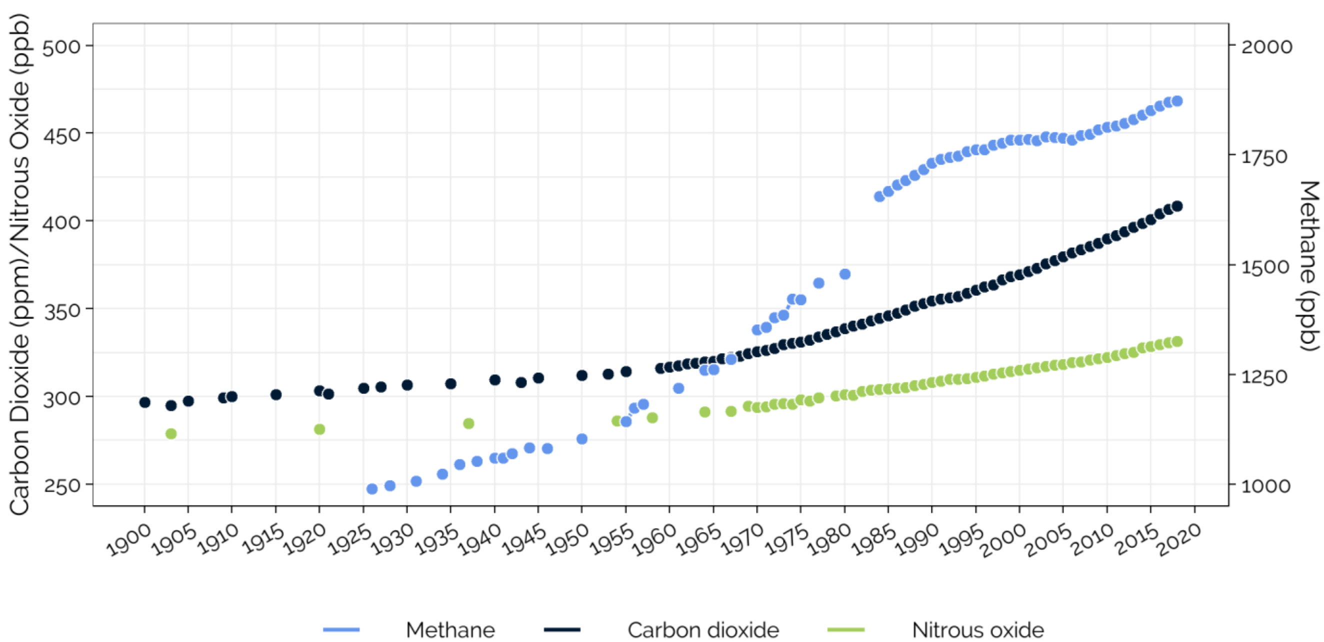


We rely on the burning of fossil fuels (i.e., gasoline, coal, and natural gas) for nearly all aspects of our everyday lives. This heightened energy demand for and use of these finite resources over the last century has introduced an excess of noxious gases to the atmosphere (see figure on next page). Some of these gases (e.g., carbon dioxide, methane, and nitrous oxide), also known as greenhouse gases, are responsible for trapping reflected heat from the earth's surface. This process is vital to maintaining a habitable planet, but excess greenhouse gases in the atmosphere enhances this effect by trapping more heat and increasing air temperatures globally. Warmer air temperatures impact rain and snow patterns, sea level rise, and species migrations.

Fossil fuel combustion also emits sulfur dioxide and nitrogen oxides to the atmosphere. These gases react with water vapor, oxygen, and other gases in the atmosphere to form sulfuric and nitric acids, which fall on water and land surfaces as acid rain. Acid rain lowers the pH of aquatic and terrestrial systems, causing reduced reproductive capacity of sensitive aquatic organisms, lower body weight of fish, decreased species diversity, and forest mortality. Substantial effort was made to reduce acid rain deposition through the 1970 Clean Air Act, which established national ambient air quality standards for controlling these noxious emissions. While emissions have decreased, and the damaging short-term effects of acid rain have been minimized, many waterbodies are still recovering from the long-term effects of acidification. In particular, the northeastern United States has thin soils with granite geology that lack carbonates, a key component of a system's buffering capacity or ability to neutralize acidic compounds. We see this in streams of the Kezar Lake watershed where low-pH rain (5.0) temporarily, but drastically, decreases the pH of surface waters. These swings in pH create stressful environments for sensitive aquatic organisms.

According to the *Eighth Biennial Report on Progress Toward Greenhouse Gas Reduction Goals* (2020), Maine's carbon dioxide emissions have remained 10% lower than 1990 levels due to the use of lower carbon-generating fuels such as natural gas, use of renewables, and better efficiency standards. Nearly 75% of Maine's electricity already comes from renewables and should increase with the passing of legislation in 2019 that incentivizes growth of solar power in Maine. Under the direction of Governor Janet Mills, the Maine Climate Council is tasked with devising policy strategies for meeting greenhouse gas emission targets of 45% reduction by 2030 and 80% reduction by 2050. An updated *Climate Action Plan* is scheduled for release by December 2020. For Maine, transportation is the largest source of greenhouse gas emissions at 53%, compared to industry (10%), commercial (10%), residential (18%), and electric power (9%). Within transportation, most emissions come from personal vehicles rather than air, rail, shipping, or marine traffic. Some proposed solutions include setting auto fuel efficiency standards, encouraging and investing in electric vehicles, and expanding public transit range and options. Other initiatives are described here: https://www.maine.gov/future/initiatives/climate/climate-council.

At the federal level, Congress issued a non-binding resolution to combat climate change – known as the Green New Deal. The Green New Deal calls for enacting immediate massive reform to help meet the global emissions target set by the IPCC (2018), including transitioning to 100% renewable energy sources, building a national "smart" grid for efficient energy conveyance, upgrading buildings to meet strict energy efficiency standards, investing in electric vehicles and high-speed rail, and investing in carbon capture projects.



Atmospheric concentrations of greenhouse gases (such as carbon dioxide, methane, and nitrous oxide) have increased over the last several hundred years to record highs as a result of human-driven burning of fossil fuels. These concentrations are unprecedented in the available record for the last 800,000 years. Data through 2015 were obtained from a variety of sources and studies compiled by the EPA[1]. Data from 2016 to present were obtained from the Mauna Loa, Hawaii station through NOAA's Earth System Research Laboratory Global Monitoring Division[2].

[1] https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases#ref5
[2]https://www.esrl.noaa.gov/gmd/dv/data/index.php?category=Greenhouse%2BGases&type=Insitu&frequency=Monthly%2BAverages

SPECIAL REPORT: 11 Policy Ideas to Protect the Planet

Post Opinions Staff, *Washington Post, January 2, 2019*

In response to the IPCC (2018), the Washington Post featured "11 policy ideas to protect the planet" to help federal, state, and local governments and private organizations or individuals reach the otherwise-daunting global emissions target. These policy ideas are summarized as follows:

Set local emissions goals: The Ferguson Township of Pennsylvania adopted a resolution calling for carbon neutrality by 2050. The township was able to select solutions that fit its needs at the local level, such as running on "100% wind power, designing a LEED Gold public works buildings, working on zoning changes to incentivize green building, low impact stormwater infrastructure," and working with the community to plant trees. The township's Climate Action Committee inventoried all municipal greenhouse gas emissions as a baseline for measuring progress as solutions are implemented. The State of Maine uses the EPA's State Inventory Tool (SIT) to estimate greenhouse gas emissions in Maine. While our state has set emissions targets, local communities such as the Town of Lovell can also enact local emissions goals in regulations.

Be smart about your air conditioner: Air conditioning units are expected to increase from 1.2 billion today to 4.5 billion by 2050. These units emit greenhouse gases, the most harmful of which are hydrofluorocarbons or HFCs that are hundreds to thousands of times more harmful than carbon dioxide by mass. Several states such as California have passed legislation that requires a 40% reduction in HFCs by 2030. Important legislation, such as this, forces manufacturers to design more efficient and environmentally friendly products that could save the consumer money in the long run.

Encourage electric vehicles: Because we still largely rely on fossil fuels for our energy, transportation is the largest source of carbon emissions in the United States. Electricity, however, has been "getting cleaner as natural gas and renewables replace coal." Electrifying vehicles and other modes of transport may help to bridge the transition of energy use from fossil fuels to renewables and reduce our global impact. Federal and state governments could enhance tax credits for use of electric vehicles and provide grants for building up the network of charging stations. Maine offers rebates up to $2,000 for electric vehicles and has added several public charging stations across the state.

Be smart about nuclear power: An analysis by the Union of Concerned Scientists found that "more than a third of the nation's 60 plants operating at the end of 2017…are either unprofitable or slated to close within the next 10 years," and "will likely be replaced primarily by natural gas," increasing carbon emissions in the United States by up to 6% by 2035. Federal and state governments should require and invest in renewable energy alternatives and require nuclear plant owners to "develop worker and community transition plans to prepare for their facilities' eventual retirement and decommissioning," most of which are "scheduled to expire between 2030 and 2050." Maine does not rely on nuclear power; nearly 75% of Maine's electricity comes from renewable sources.

Make it easier to live without cars: Walking or biking instead of taking a short car trip could save 5% of carbon emissions from vehicle use. Federal, state, and local governments can encourage "Complete Street" policies that design streets that are safe for alternative modes of transportation.

Prevent wasted food – the right way: The global food system accounts for "19-29% of global anthropogenic greenhouse gas emissions," and we waste a considerable amount of food each year – up to 40% in the United States. The United States, along with several state and municipalities, have signed on to cut food waste by 50% by 2030. Strategies for reducing food waste include food waste bans or mandated food recycling to divert food from landfills (or incur a fine). Some states such as California have passed legislation that requires at least 20% of edible food waste be recovered. More work can be also be done on the front end to reduce greenhouse gas emissions generated by the production, processing, distribution, heating, and cooling of food. Individuals can be more mindful of food waste and start a compost for food scraps.

Incentivize carbon farming: New York was the first state to introduce the Carbon Farming Act that provides financial incentive (e.g., tax credit) for farmers to implement climate-smart practices. These practices include "planting cover crops that increase water retention and soil nutrients and keep weeds down; using no-till approaches that limit aeration of surface soils and reduce erosion; and planting diverse perennial forages with deeper root systems for grazing animals." Carbon farming sequesters carbon while also improving soil health and productivity for maximum crop yields.

Curb the effects of meat and dairy: Concentrated animal feeding operations or CAFOs account for a significant portion of greenhouse gas emissions globally. Strategies for reducing CAFO emissions include setting a "moratorium on new factory farms," minimizing farm bill program subsidies to big corporations, investing in "sustainable grazing practices," and "enforcing fair market and fair contract rules for the livestock industry." Individuals can help by making informed food purchases at the grocery store.

Adopt a carbon tax: "Putting a price on carbon" may be one of the most efficient ways to curb emissions and stimulate innovation in alternative energy use across all sectors. The Market Choice Act is a bill that would "repeal the federal gas and aviation fuel taxes and swap them for a tax on carbon emissions at the source." The tax money raised would then be used to help low-income communities adapt to the effects of climate change. Maine is part of the Regional Greenhouse Gas Initiative that puts a cap on carbon emissions.

Open electric markets to competition: Local utility companies are generally given monopoly-status but with "oversight from state regulatory bodies." With little competition from other utilities, local utility companies can set rates that recover costs, providing little "incentive to retire uneconomical plants." Eliminating the monopoly and introducing competition would force local utility companies to "provide reliable power at the lowest cost," which encourages companies to switch to cleaner fuels or renewable energy sources as they become cheaper.

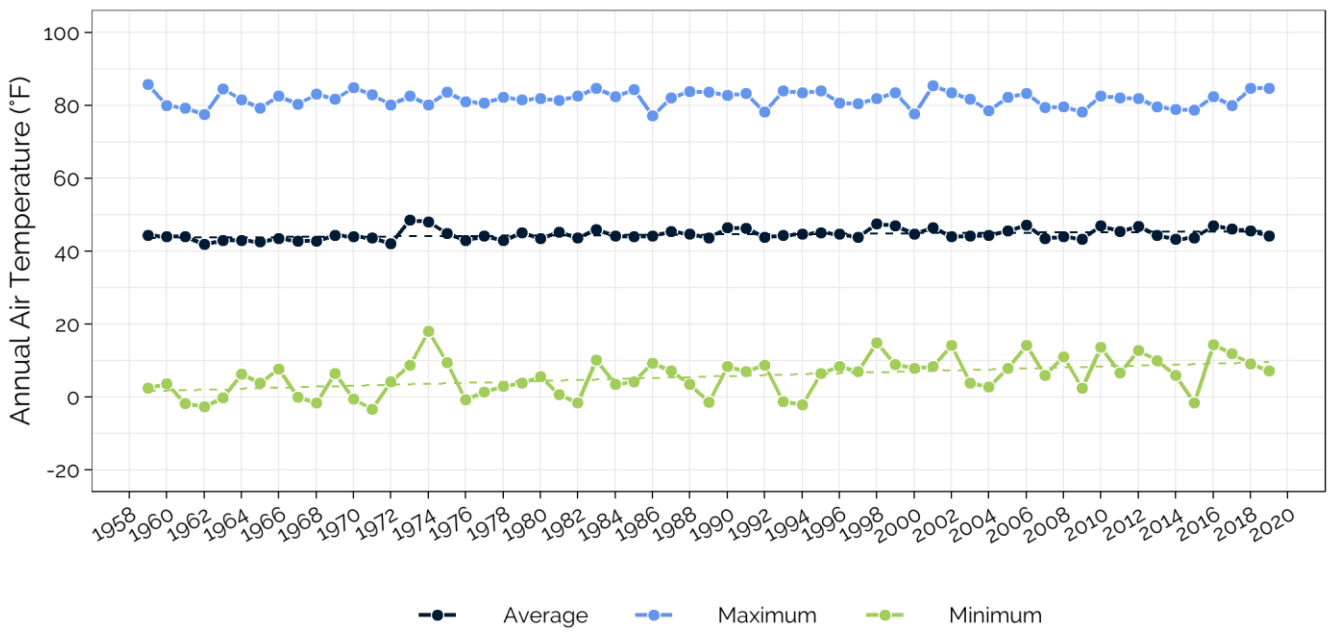
Pass a Green New Deal: To meet the emissions target that curtails the projected increase in global temperatures by the end of the century, we must enact immediately massive reform to our current way of living. The Green New Deal details such massive reforms, including transitioning to 100% renewable energy sources, building a national "smart" grid for efficient energy conveyance, upgrading buildings to meet strict energy efficiency standards, and investing in carbon capture projects. These reforms would create new jobs and grow the economy in ways that will make the United States a leader in green technology.

Air Temperature

Climate change is expected to increase global air temperatures, an effect that we have already observed in the last century. An important point to understand about climate change is the difference between "climate" and "weather." Climate change observations and predictions are based on "climate," which is long-term averages of weather observations across regional or global space. According to the World Meteorological Organization's *Provisional Statement on the State of the Global Climate in 2019*, global temperatures in 2019 were the 2nd or 3rd warmest on record, and the period of 2010-2019 was the warmest decade on record. The State of Maine has seen a 3.2 ˚F increase in temperature in the last century, and we expect an additional 5.0 ˚F increase in temperature by 2050. The impacts of long-term global warming are already being felt in heat waves, coastal flooding, ecosystem change, and extreme precipitation events. Local weather observations may deviate from this general trend from season to season or year to year, depending on a suite of local variables. For the Kezar Lake watershed, we used CONWAY 1 N, NH US (ID# GHCND:USC00271732) and NORTH CONWAY, NH US (ID#GHCND:USC00275995) weather stations from the NOAA National Centers for Environmental Information (NCEI) to track changes in air temperature since 1959[3].

> **“AVERAGE ANNUAL TEMPERATURE ACROSS MAINE WARMED BY ABOUT 3.2 °F BETWEEN 1895 AND 2018.” - MAINE’S CLIMATE FUTURE, 2020 UPDATE**

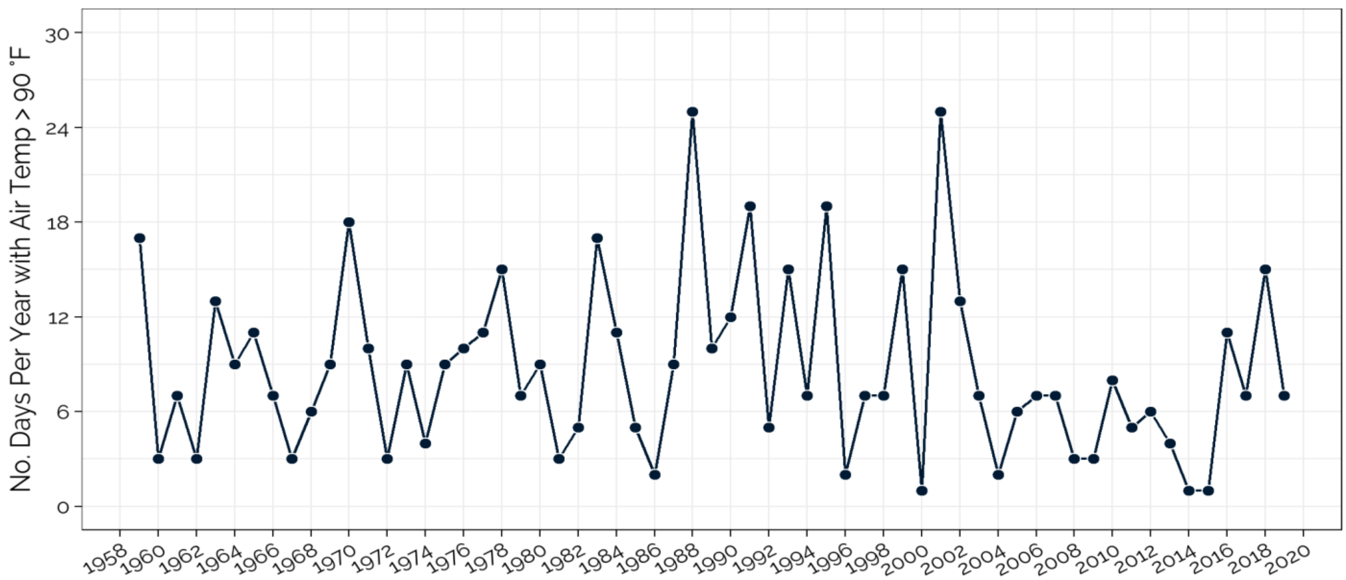
ANNUAL AIR TEMPERATURES



Average and minimum annual air temperatures have warmed by about 1 °F and 8 °F, respectively, near Conway-North Conway, NH. Maximum annual air temperatures have remained stable. In 1960, the minimum, average, and maximum annual air temperatures were 4 °F, 44 °F, and 80°F, respectively. This compares with higher minimum, average, and maximum annual air temperatures observed in 2012: 13 °F, 47 °F, and 82°F.

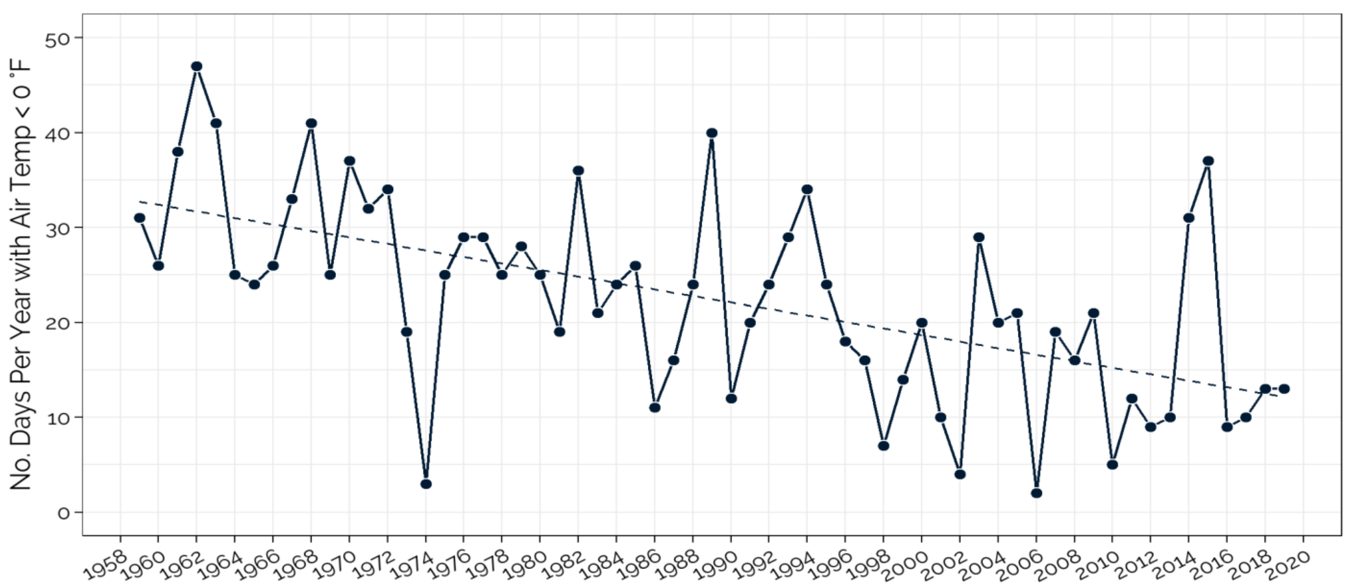
[3] These stations have collected significantly more data than more local stations, including Creeper Hill (2008-present) and the CCO at the upper basin of Kezar Lake (2017-present), and therefore, were determined to be a more appropriate dataset for the assessment of long-term climate change in the area. In 2016, KLWA analyzed other long-term weather data from Auburn and Bridgton, ME weather stations (1955-present) and found similar trends in weather compared to the Conway-North Conway stations, further confirming the Conway-North Conway stations as likely representative of the area.

EXTREME HEAT DAYS



As air temperature rises, we can expect to see more extreme heat days. However, the Conway-North Conway weather data since 1959 show no trend in the number of days per year with air temperatures over 90 °F. In fact, the number of extreme heat days seems to have declined in the last decade, though 2018 had the most extreme heat days since 2001. Several climate models show that the northeast will not experience as dramatic an increase in extreme heat days as the southern and middle portions of the United States.

EXTREME COLD DAYS

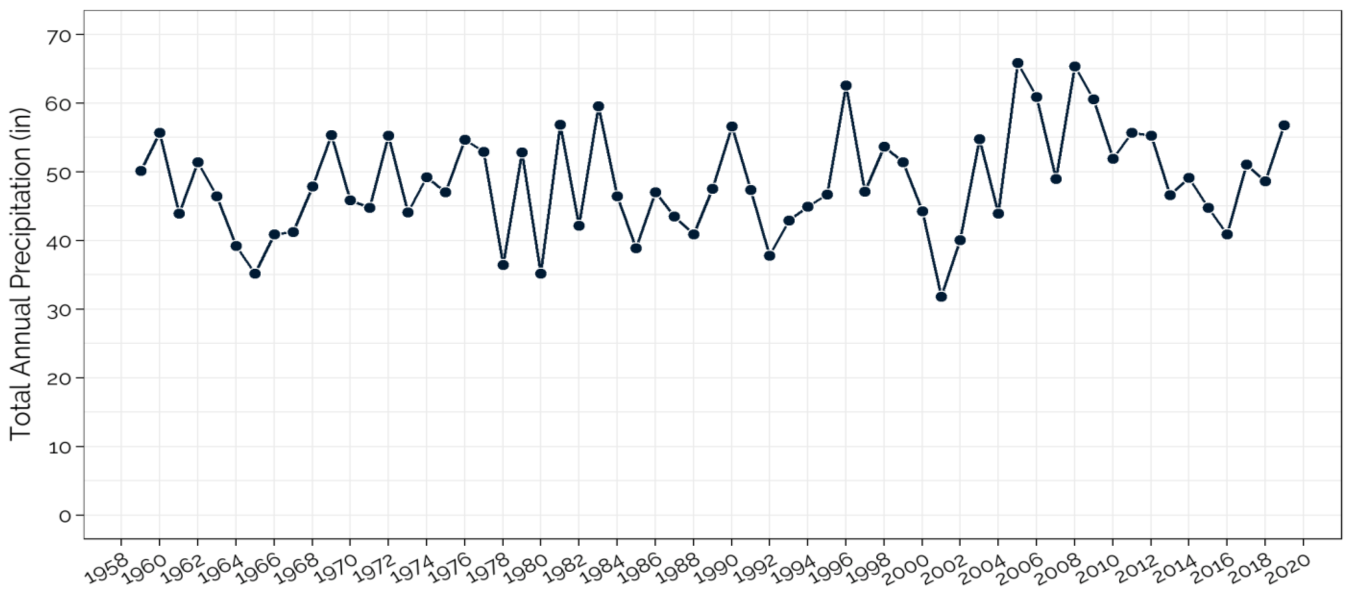


As air temperature rises, we can expect to see less extreme cold days. As expected, the Conway-North Conway weather data since 1959 show a statistically significant decrease in the number of days per year with air temperatures below 0 °F. The first half of the record shows the number of extreme cold days around 25-30, but the latter half shows the number of extreme cold days declining to around 10-15.

Precipitation

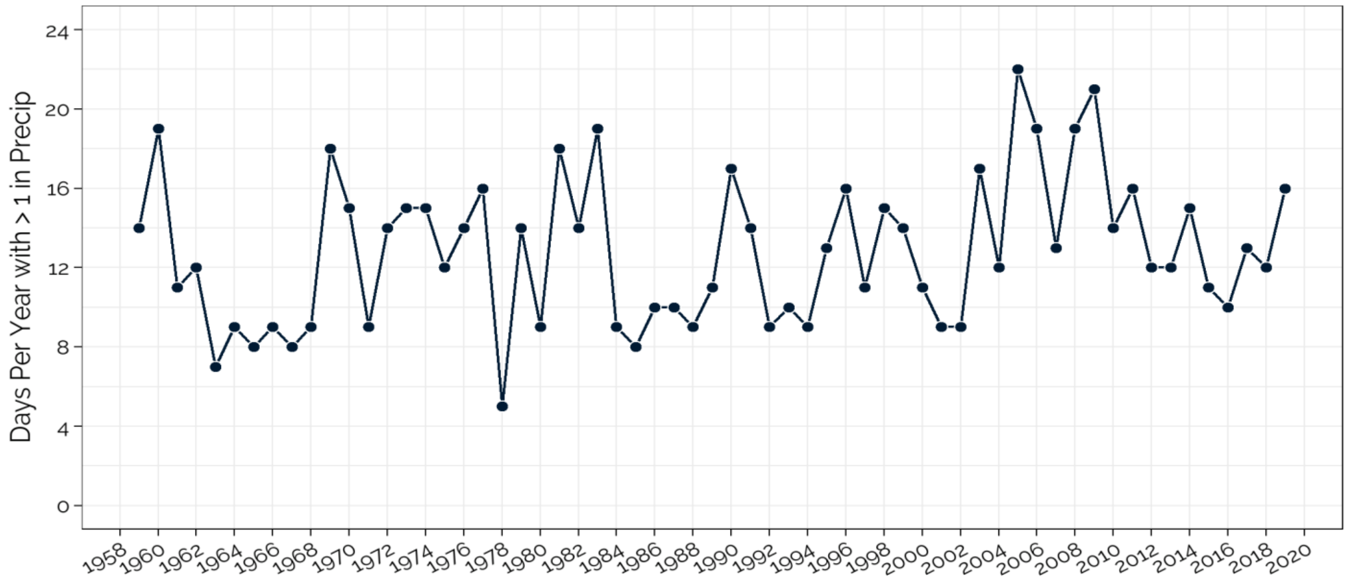
Warming air temperatures have impacted rain and snow patterns across the globe. In Maine, total annual precipitation has increased by 5.8 inches (15%) since 1895. The distribution of this precipitation is highly variable; some models predict more rain in interior Maine, while historic observations show more rain along the coast. Extreme precipitation events will also likely continue to increase in frequency and duration, particularly along the coast and in the western mountains. Maine has seen a decrease in average annual snowfall by 17% and a decrease in snowpack duration by two weeks since 1895. More frequent and intense rain events will flush excess nutrients from the landscape to receiving waterbodies, including Kezar Lake, which can fuel algal growth. Larger flow volumes will also threaten infrastructure, including road crossings and culverts. For the Kezar Lake watershed, we used the North Conway weather station to track changes in precipitation since 1959.

ANNUAL PRECIPITATION



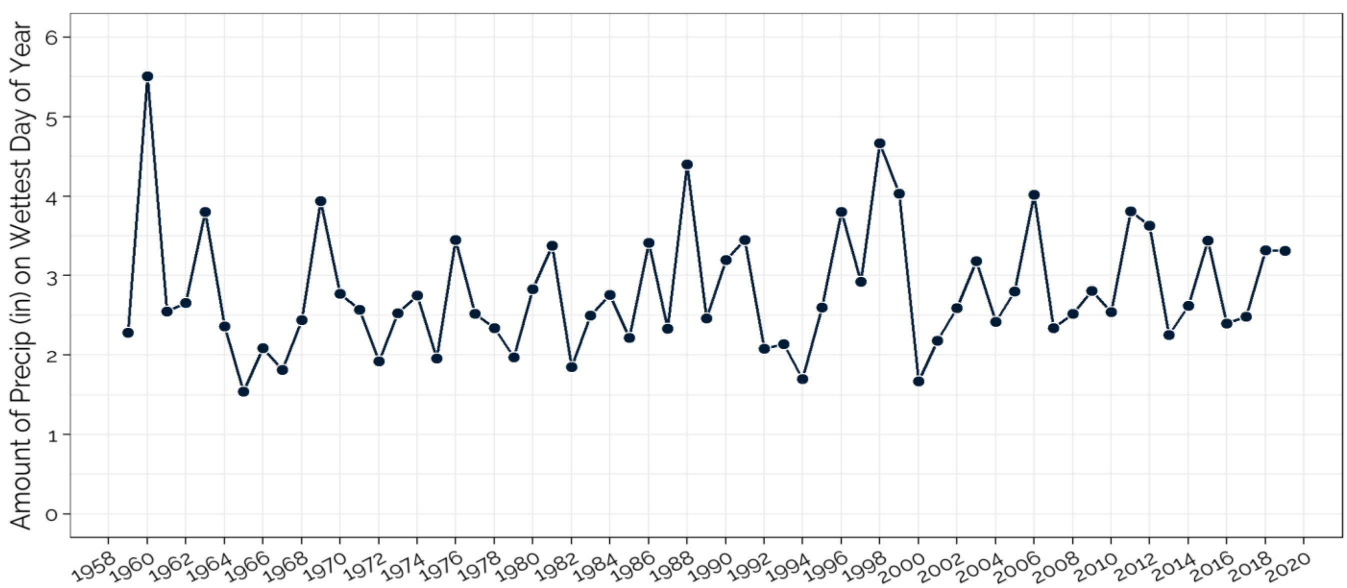
In North Conway, total annual precipitation has fluctuated greatly, but without any trend since 1959. However, three years (1996, 2005, and 2008) saw total annual precipitation above 60 inches. These were extremely wet years impacted by major storms. Total annual precipitation seems to be decreasing in the last decade but may be rebounding with a wetter 2019.

ONE INCH PRECIPITATION EVENTS



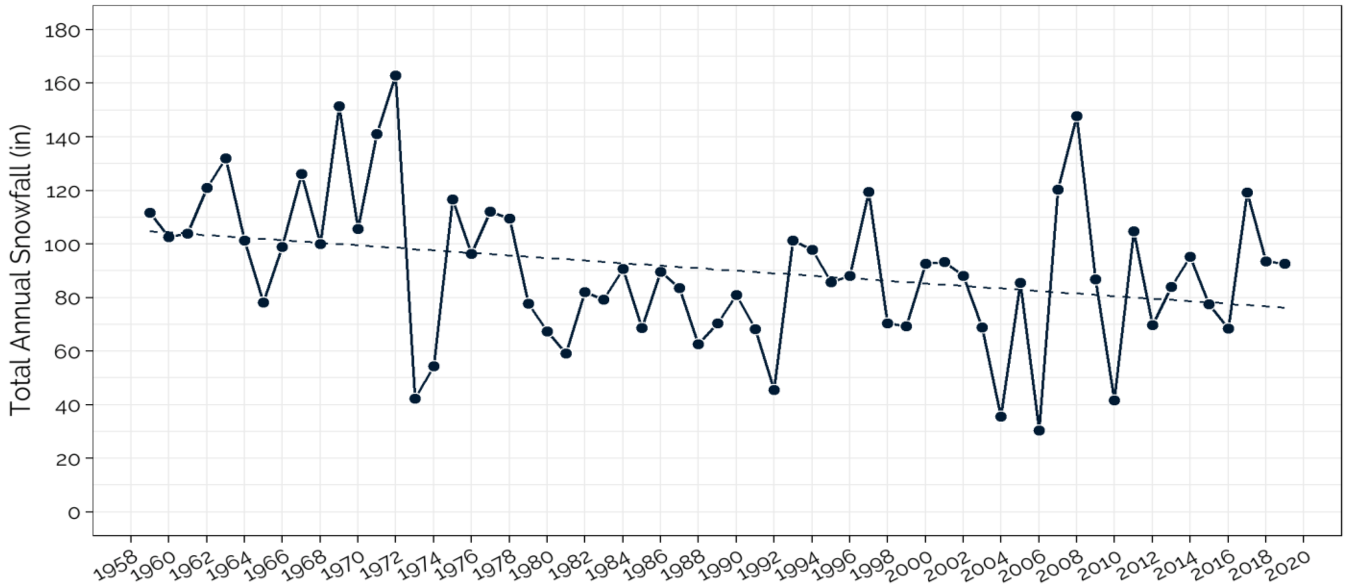
Climate change will likely cause more frequent precipitation events. For North Conway, the number of days per year receiving greater than 1 inch of precipitation has been highly variable; however, the last decade shows multiple years with greater than 12 days per year with 1 inch or more of precipitation recorded.

WETTEST DAY OF YEAR

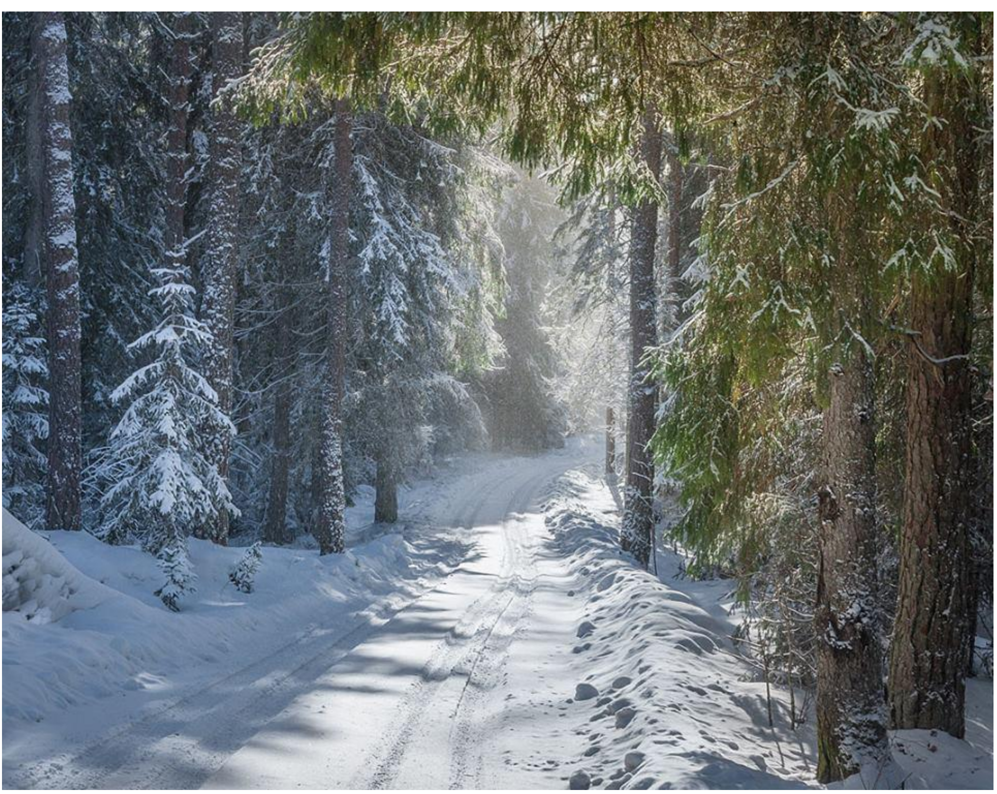


The intensity of extreme precipitation events is illustrated by finding the day from each year with the largest amount of precipitation. Since Maine has an extensive coastline, extreme precipitation events are often related to Atlantic storms. For instance, the extreme precipitation day for 1960 (5.5 inches) coincides with Hurricane Donna. The wettest day of the year precipitation amounts varied considerably throughout the record for North Conway, and no trend was observed.

SNOWFALL ACCUMULATION



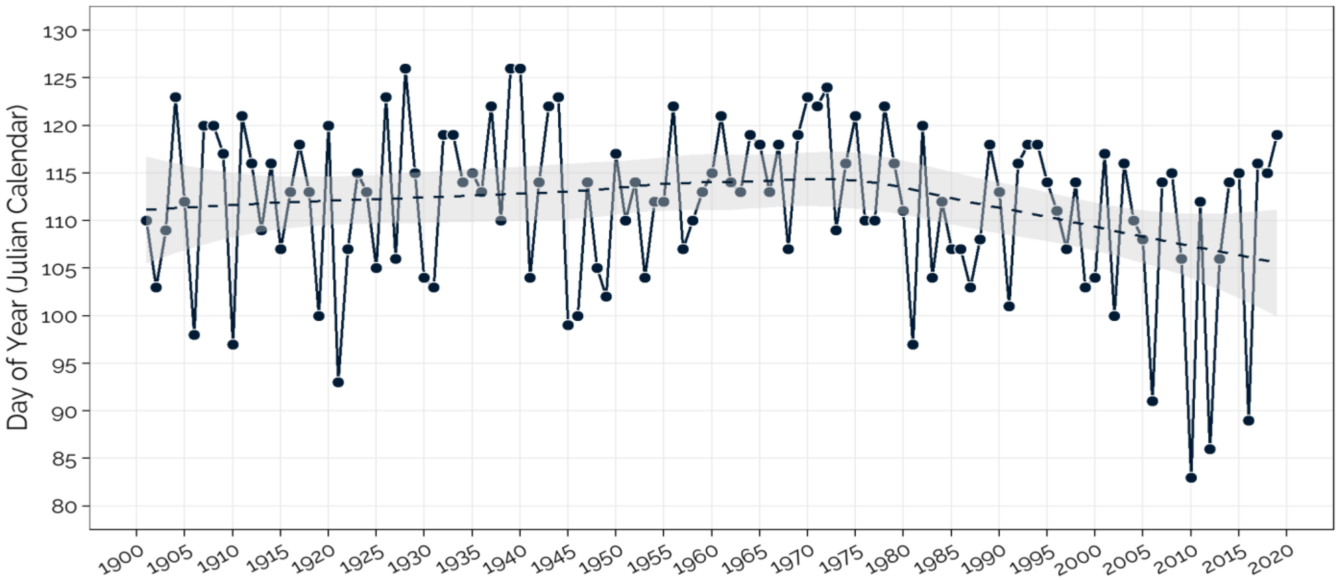
As air temperatures increase, climate change models predict less snowfall and reduced snowpack duration. Maine has already shown a statistically significant trend of decreased annual snowfall between 1950 and 2000. For North Conway, total annual snowfall has declined from an average of 105 to 75 inches of snowfall per year since 1959.



Kezar Lake watershed in winter. Photo Credit: KLWA (left); Don Griggs (right).

Ice-Out

Ice-out data has been collected for Kezar Lake since 1901, providing over a century of information about changes in the seasonal duration of winter snowpack and ice. Ice-out refers to the day when all ice covering Kezar Lake has broken up and melted. This marks the beginning of spring when the entire lake is exposed to direct sunlight, which stimulates lake productivity and drives the critical process of spring turnover.

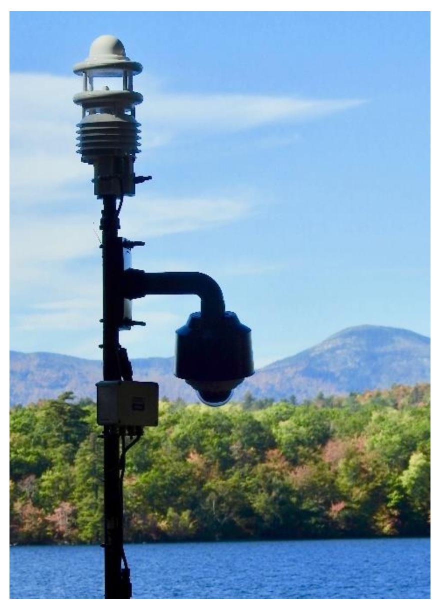


Although some years within the last decade showed abnormally early ice-out dates, no statistically significant trend was found for all data since 1901. The increasing variability and abnormally early ice-out dates within the last few decades should be monitored closely in the future to confirm the trend. Early ice-out is directly linked to warming air temperatures and changes in seasonality. The Maine's Climate Future 2020 Update showed that Kezar Lake experiences ice-out 2.4 days earlier.

KLWA Weather Station

In August-September 2017, the CCO purchased, engineered, and installed a state-of-the-art weather station and web camera on the edge of Kezar Lake just south of Boulder Brook. Collecting local weather data will greatly improve the accuracy of our water quality data analyses that are dependent on temperature and precipitation readings. The weather station data and webcam images are also an important service that KLWA provides to the community.

Our weather station is a Columbia Weather Systems Pulsar 600 with an Axis M-3025 VE HD dome camera. The weather station has no moving parts, which means it can collect weather data during snow and freezing temperatures. It measures rain and snow (both rate and accumulation) with Doppler radar; wind speed and direction with ultrasonic sensors; lake water temperature with a

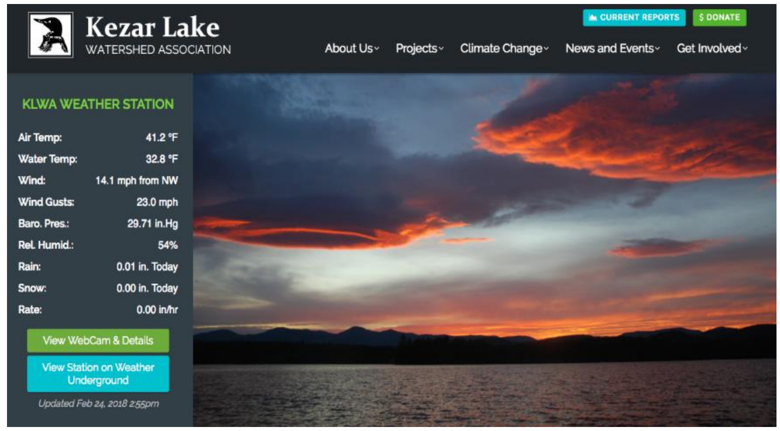


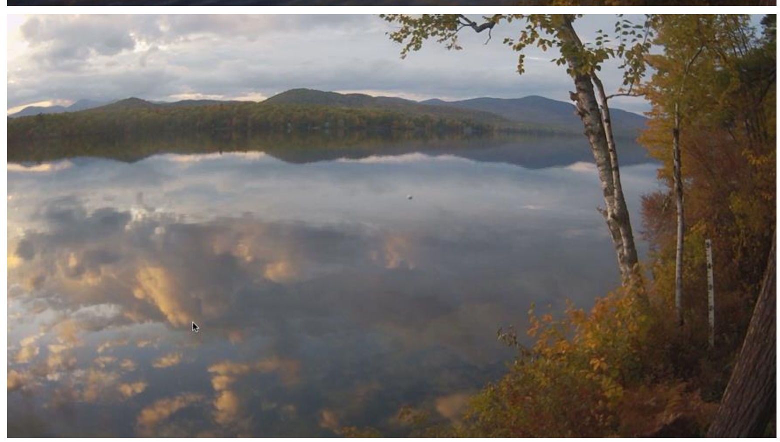
KLWA Weather Station. Photo Credit: Don Griggs.

sensor placed three feet below the water's (or ice's) surface; and air temperature, barometric pressure, and relative humidity. The webcam has a west and north view of the lake and the western mountains (from Baldface to Speckled Mountains).

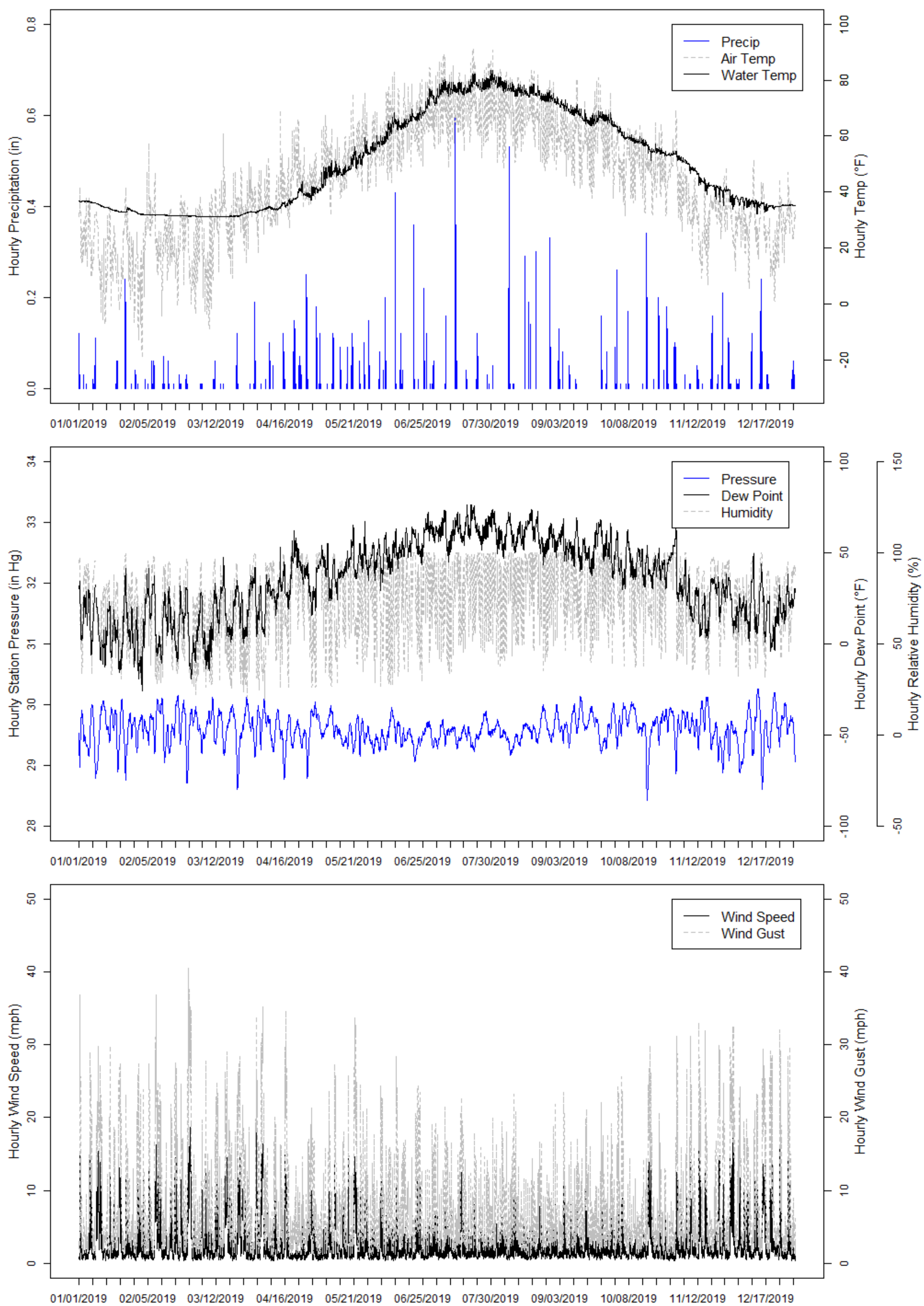
The current weather summary (updated every minute) is showcased on the KLWA website home page (klwa.us). Links from the home page to more detailed weather station information, including high-definition webcam photos, are provided. Weather Underground (KMELOVEL4) provides historical data and forecasts for the next ten days, along with other astronomical and almanac data for Lovell, ME. Lake water temperature data are only provided on the KLWA Weather Station webpages.

Since the weather station data and webcam images are accessible from the KLWA website and Weather Underground, these data and images can be viewed at anytime from anywhere over the internet on a computer, smart phone, or tablet. The KLWA and CCO are pleased to offer this service to all who live in, visit, or care about what is happening weather-wise in Lovell and on Kezar Lake. The CCO intends to use collected weather data over the years to create trend-lines that will give an accurate view of weather-related climate changes within our watershed.





KLWA Weather Station data are displayed on the KLWA website home page (klwa.us), with links to more detailed weather station information through KLWA's website or Weather Underground (top). The webcam provides high-definition photos year-round: summer, fall, and winter examples are shown from middle top to bottom. Design Credit: Level8 & Troy Web Consulting.



Summary of hourly CCO weather station data for 2019. X-axis tick marks are spaced weekly. These data can be used for water quality analyses and can provide residents with accurate local weather info.

WATER

Water Quality

Water quality data have been collected in the Kezar Lake watershed since 1970. These data provide a wealth of long-term information from which we can judge the health of the lake, ponds, and streams in the watershed. Because water quality can fluctuate significantly from year-to-year depending on local conditions and activities within the watershed, analyzing data over a longer time can reveal subtle, yet steady directional changes in water quality. It is important to identify waterbodies at risk for degrading water quality because of climate change or development, so we can act to combat the effects.

Statistical trend analyses (Mann-Kendall[4]) were performed on annual water quality data for all available water quality parameters at all monitored waterbodies in the Kezar Lake watershed. A summary of current conditions and trends are as follows:

- **Water clarity** shows improving trends at Kezar Lake; water clarity at the ponds are stable and meet DEP mesotrophic guidelines.
- **Total phosphorus** and **Chlorophyll-a** show no trends and meet DEP mesotrophic guidelines in all waterbodies. Chlorophyll-a at the upper bay and Cushman Pond is improving.
- **Alkalinity** shows degrading trends at the upper bay, lower bay, Cushman Pond, Heald Pond, and Horseshoe Pond (though improving at the middle bay and Trout Pond), and is critically, but naturally, low in all waterbodies.
- **pH** shows degrading trends at Bradley, Heald, Horseshoe, and Trout Ponds and is low (acidic) in all waterbodies.
- **Color** shows no trends and meets DEP mesotrophic guidelines in all waterbodies.
- **Dissolved oxygen** is regularly anoxic near the bottom in late summer at Bradley, Horseshoe, and Trout Ponds. **Anoxic Extent** is highest at Horseshoe and Trout Ponds.
- **Temperature** is generally good or excellent in all waterbodies, though Kezar Lake shows a warming trend in surface waters.

A list of water quality definitions is provided in Appendix A. The following section showcases annual historical and continuous data for Kezar Lake, six ponds, seven tributaries, and the outlet stream.

[4] Mann-Kendall trend tests were performed on annual water quality data to determine trends over time. Dotted trend lines were added where statistically significant. Sample stations with less than 10 years of data cannot be analyzed for statistically significant trends (too few data points). Data obtained from Maine DEP and FB Environmental Associates.

Summary of Current Conditions & Trends

Lakes and Ponds

Water Body	Water Clarity	Total Phosphorus	Chlorophyll-a	Anoxic Extent	Temp	pH	Alkalinity	Color
Kezar Lake Upper Bay	Excellent, Improving	Excellent, Stable	Excellent, Improving	Excellent, Stable	Good, Degrading	Excellent, Stable	Poor, Degrading	Excellent, Stable
Kezar Lake Middle Bay	Excellent, Improving	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent	Good, Improving	Excellent, Stable
Kezar Lake Lower Bay	Excellent, Improving	Excellent, Stable	Excellent, Stable	Excellent, Stable	Good, Degrading	Excellent, Stable	Poor, Degrading	Excellent, Stable
Bradley Pond	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Good, Degrading	Good, Stable	Excellent, Stable
Cushman Pond	Excellent, Stable	Excellent, Stable	Excellent, Improving	Excellent, Stable	Excellent, Stable	Excellent, Stable	Poor, Degrading	Excellent, Stable
Farrington Pond	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Good, Stable	Excellent, Stable
Heald Pond	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Stable	Excellent, Improving	Good, Degrading	Poor, Degrading	Excellent, Stable
Horseshoe Pond	Excellent, Stable	Excellent, Stable	Excellent, Stable	Good, Stable	Excellent, Stable	Good, Degrading	Poor, Degrading	Excellent, Stable
Trout Pond	Excellent, Stable	Excellent, Stable	Excellent, Stable	Good, Stable	Excellent, Stable	Good, Degrading	Good, Improving	Excellent, Stable

Brooks and Streams

Water Body	Total Phosphorus	pH	Dissolved Oxygen	E.coli	Temp	Flow
Great Brook	Excellent, Stable	Excellent	Excellent, Stable	Excellent, Degrading	Excellent	Excellent
Boulder Brook	Good	Excellent	Excellent	Good	Excellent	
Beaver Brook					Excellent	Excellent
Lower Bay					Excellent	Excellent
Kezar Outlet Stream					Excellent	Excellent
Coffin Brook					Excellent	
Bradley Brook					Excellent	
Sucker Brook					Excellent	
Long Meadow Brook					Excellent	

Key for Data Symbols – Current Conditions & Trends

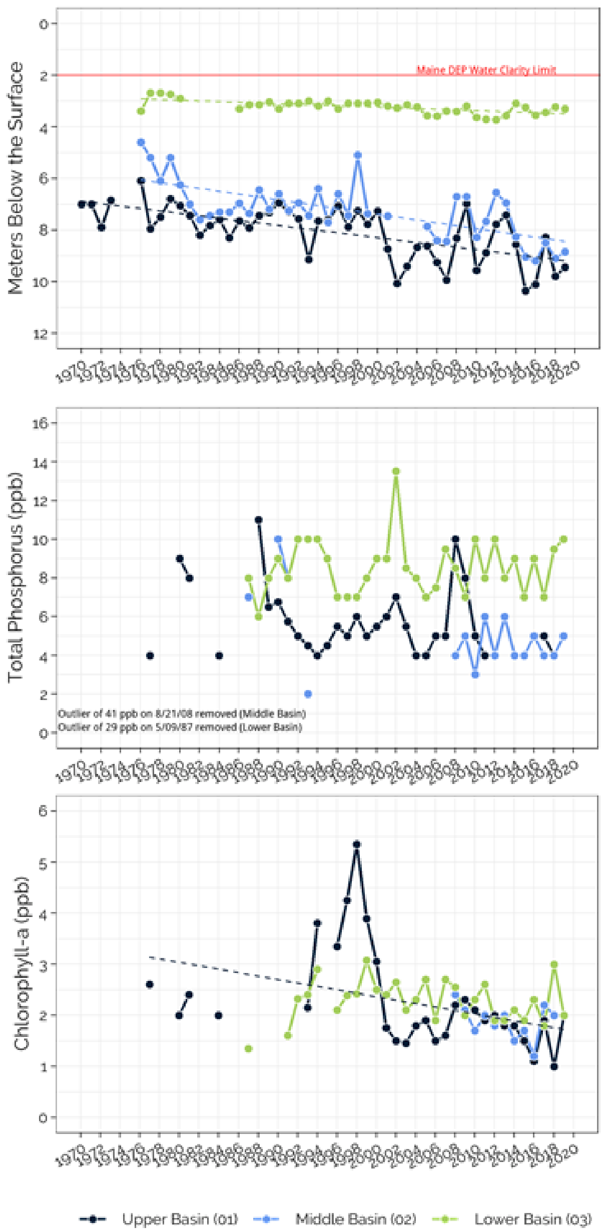
CURRENT CONDITION: EXCELLENT (blue), GOOD (yellow), POOR (red) + TREND: ↗ IMPROVING, → STABLE, ↘ DEGRADING, ○ PENDING

The **"Current Condition"** for each parameter is based on the data collected during the most recent decade and current year compared to state or federal water quality criteria or recommendations and detection of a statistically significant trend. Stop lights provide a simple visual assessment of overall waterbody condition by parameter.

The **"Trend"** indicates whether water quality is improving (up arrow), degrading (down arrow), or remaining stable with no trend (horizontal arrow) over time based on statistical analysis of the long-term data set for each parameter by waterbody.

KEZAR LAKE
WATER QUALITY TRENDS

Kezar Lake (Midas #0097) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. The lake stretches 9 miles from north to south, covering 2,665 acres (4.16 square miles) and has a maximum depth of 160 feet (49 meters) and a mean depth of 34 feet (10 meters). Water quality monitoring data have been collected since 1970 at Station 1 (upper), 1976 at Station 2 (middle), and 1976 at Station 3 (lower). Note: "stoplight" symbols ordered from left to right show status of upper, middle, and lower basins.



WATER CLARITY

Since the early 1970's, water clarity at all three basins of Kezar Lake has improved with the upper and middle basins improving by nearly 1 meter. The slight, but statistically significant, improvement at the lower basin is an artifact of changing lake depth since nearly all readings hit bottom.

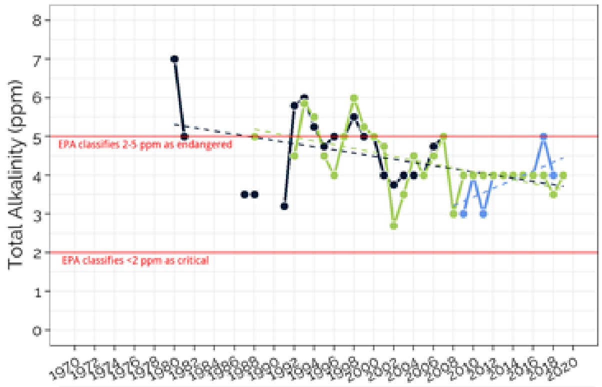
TOTAL PHOSPHORUS

Since the late 1970's, total phosphorus at all three basins of Kezar Lake has revealed no statistically significant trend over time. The generally higher median annual total phosphorus observed at the lower basin is an artifact of its shallow depth, where wave action can disturb bottom sediments that release phosphorus into the water column.

CHLOROPHYLL-A

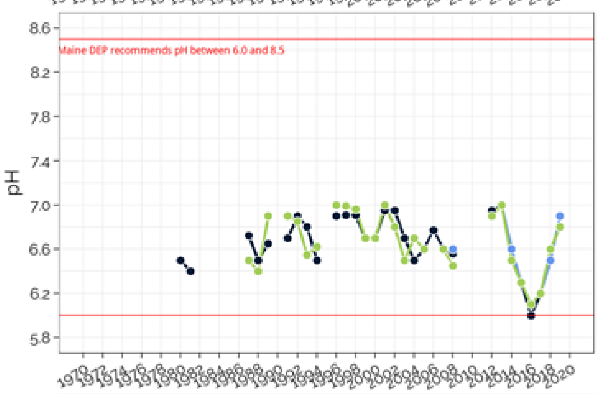
Since the late 1970's, chlorophyll-a at the upper basin of Kezar Lake has improved, while chlorophyll-a at the middle and lower basins has revealed no statistically significant trend over time. The period from 1994 to 1999 saw a marked rise in chlorophyll-a at the upper basin, but chlorophyll-a has remained at or below 3 ppb since then. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algae growth.

KEZAR LAKE
WATER QUALITY TRENDS



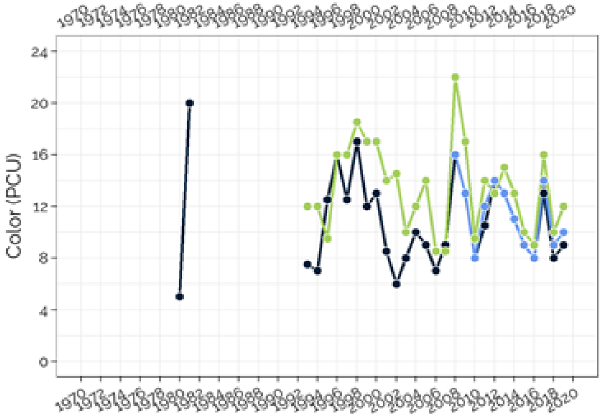
TOTAL ALKALINITY

Since the early 1980's, total alkalinity at the upper and lower basins of Kezar Lake has degraded by nearly 3 ppm, while total alkalinity at the middle basin has improved by 2 ppm. The region has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid.



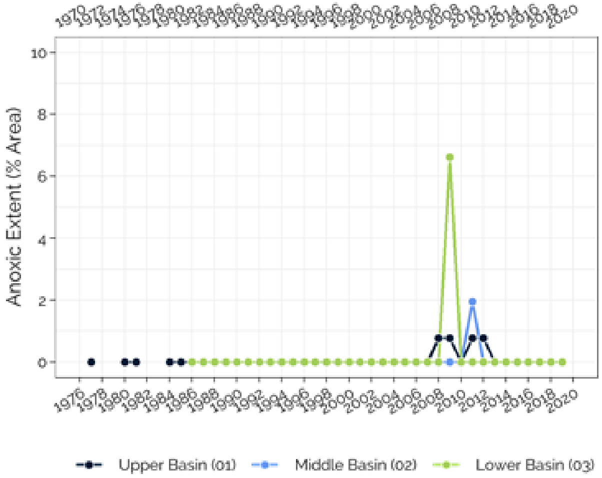
pH

Since the early 1980's, pH at Kezar Lake has revealed no statistically significant trend over time. Generally, pH becomes more acidic as total alkalinity in the epilimnion declines. Low alkalinity makes Kezar Lake susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



COLOR

Since the early 1980's, color at Kezar Lake has revealed no statistically significant trend over time. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake. The lack of trend in color is despite the increase in regional precipitation observed in the last century, suggesting that more data are needed to confirm the trend.

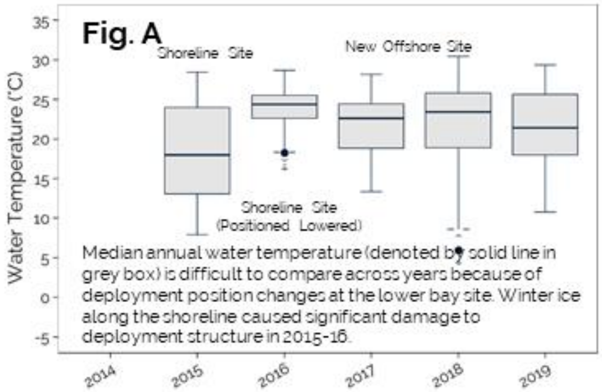


ANOXIC EXTENT

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period. While the extent and duration of anoxia is excellent at all three basins.

LOWER BAY
WATER QUALITY TRENDS

The lower bay is the southernmost basin of Kezar Lake. The sensor was deployed on Heinrich Wurm's property just offshore of the western rocky shoreline of the lake. Water quality monitoring data have been collected since 2015.



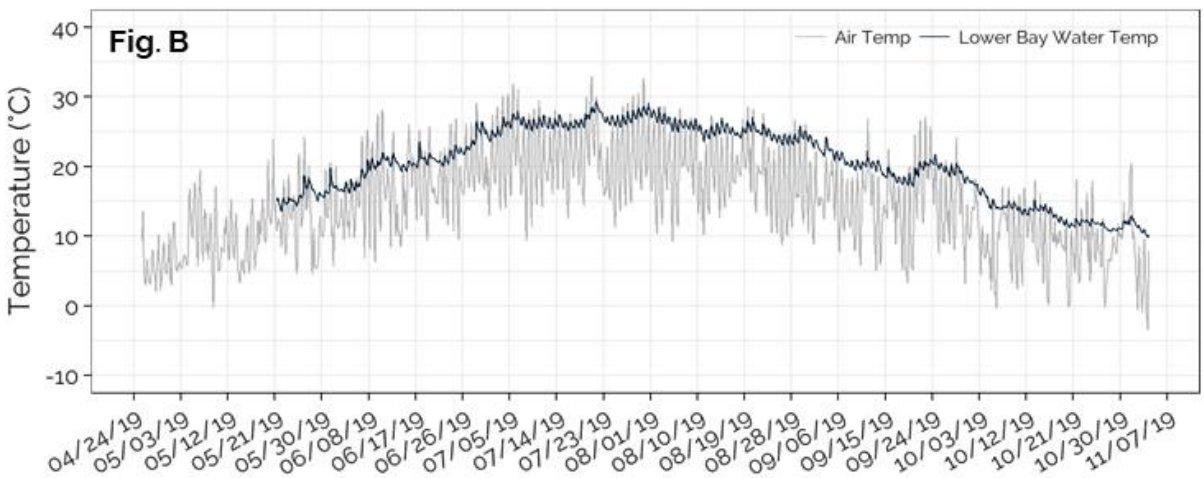
Median annual water temperature (denoted by solid line in grey box) is difficult to compare across years because of deployment position changes at the lower bay site. Winter ice along the shoreline caused significant damage to deployment structure in 2015-16.

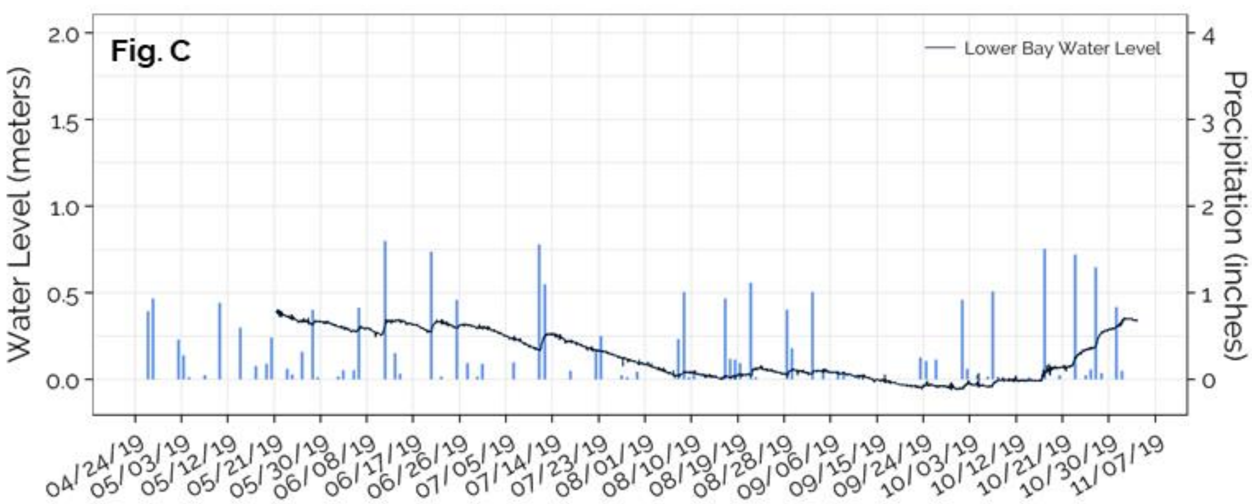
WATER TEMPERATURE

Water temperature (Fig. B) followed closely with air temperature (hourly data obtained from CCO weather station).

LAKE SURFACE WATER HEIGHT

Water level data (Fig. C) collected at the lower bay showed that lake level steadily declined from May to October due to evaporation and then responded quickly (by rising) to large precipitation events in late fall.



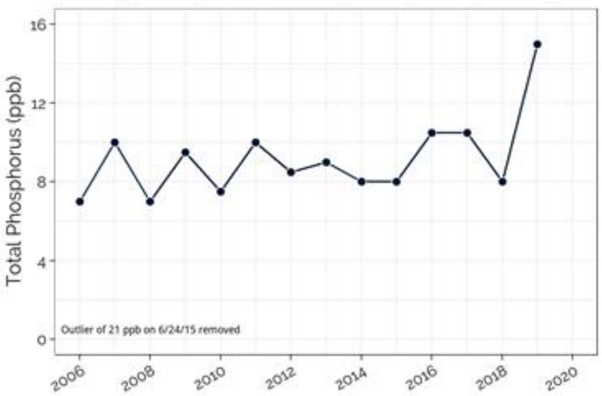


BRADLEY POND
WATER QUALITY TRENDS

Bradley Pond (Midas #3220) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 35 acres (0.05 square miles) with a maximum and mean depth of 29 and 10 feet (9 and 3 meters), respectively, the pond drains to Heald Pond, which in turn drains to a tributary to Boulder Brook and eventually Kezar Lake. Water quality monitoring data have been collected since 2006 at Station 1 (deep spot).

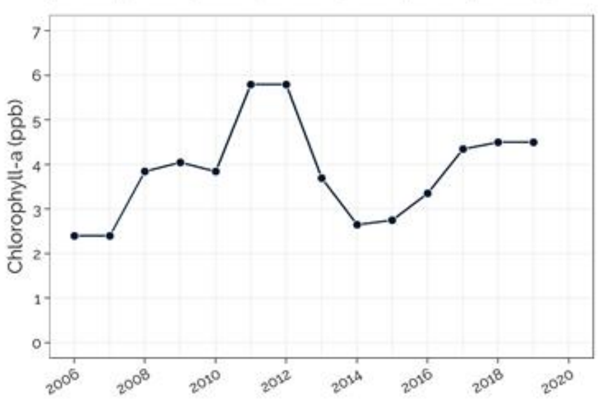
WATER CLARITY

Since 2006, water clarity at Bradley Pond has remained stable.



TOTAL PHOSPHORUS

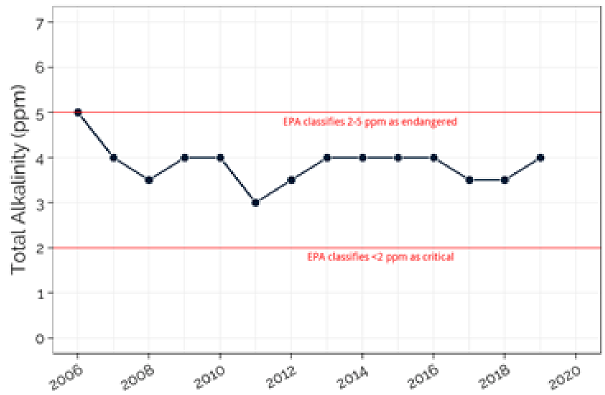
Since 2006, total phosphorus at Bradley Pond has remained stable, but 2019 experienced the highest annual total phosphorus on record.



CHLOROPHYLL-A

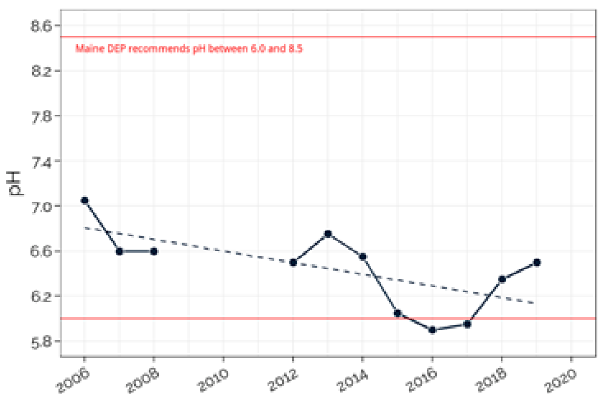
Since 2006, chlorophyll-a at Bradley Pond has ranged from about 2 to 6 ppb. The period from 2011 to 2012 saw a marked rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algae growth.

BRADLEY POND
WATER QUALITY TRENDS



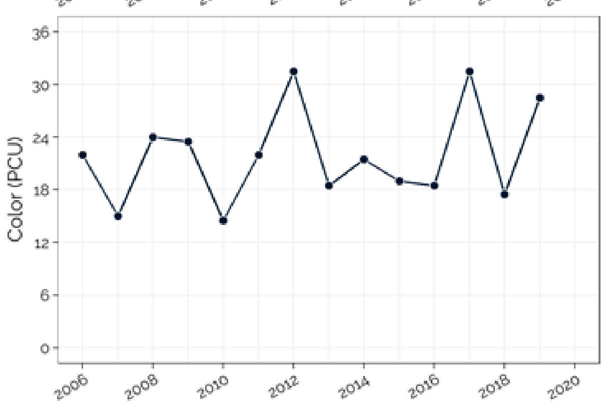
TOTAL ALKALINITY

Since 2006, total alkalinity at Bradley Pond has remained stable. Bradley Pond has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid. These low concentrations make Bradley Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



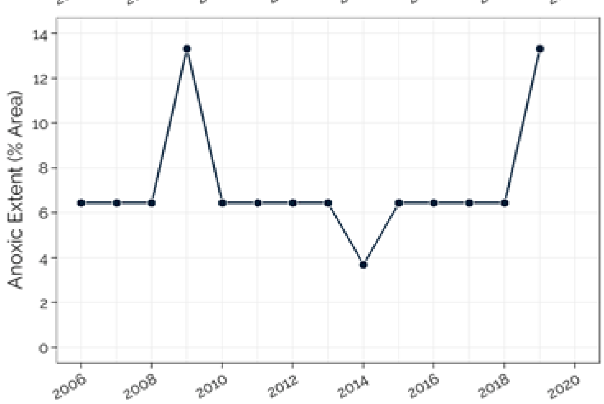
pH

Since 2006, pH at Bradley Pond has degraded by about 1.0. Mean annual pH falls within acceptable ranges for aquatic life but hit record lows below the recommended minimum threshold in 2016 and 2017.



COLOR

Since 2006, color at Bradley Pond has revealed no statistically-significant trends. High color was observed for 2012 and 2017, due in part to wetter summer conditions. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape and into the pond.

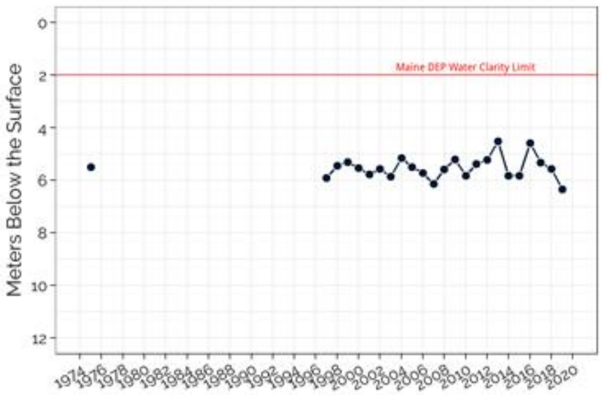


ANOXIC EXTENT

Dissolved oxygen profiles show oxygen depletion beginning 5-6 meters below the water surface (within a few meters of the bottom). The extent and duration of anoxia is overall excellent at Bradley Pond (affecting on average <10% of pond area). Dissolved oxygen at depth should continue to be monitored closely in the future.

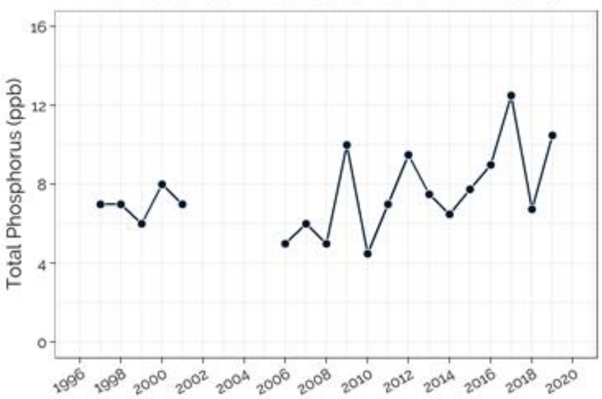
CUSHMAN POND
WATER QUALITY TRENDS

Cushman Pond (Midas #3224) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 37 acres (0.06 square miles) with a maximum and mean depth of 21 and 15 feet (6 and 5 meters), respectively, the pond drains to Heald Pond, which in turn drains to a tributary to Boulder Brook and eventually Kezar Lake. Cushman Pond is impacted by Variable Milfoil, which poses a threat to fish habitat. Water quality monitoring data have been collected since 1997 at Station 1 (deep spot).



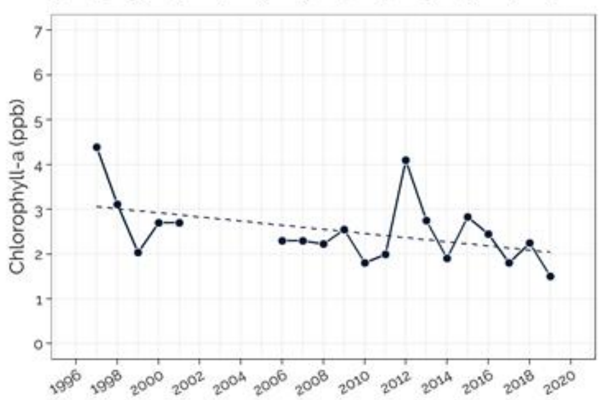
WATER CLARITY

Water clarity at Cushman Pond has remained stable with no statistically significant trend.



TOTAL PHOSPHORUS

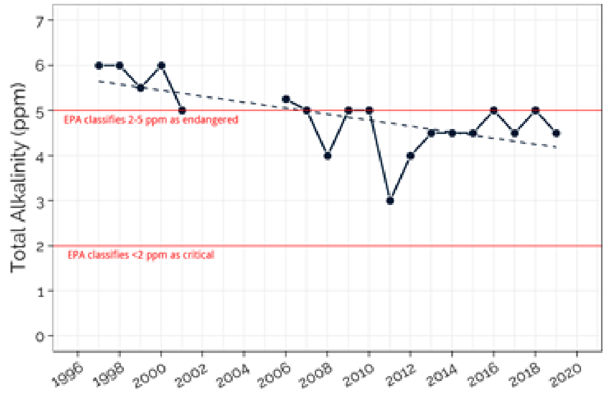
Since 1997, total phosphorus at Cushman Pond has revealed no statistically significant trend. Year-to-year variation in total phosphorus (4 to 12 ppb) is large and hit a record high in 2017.



CHLOROPHYLL-A

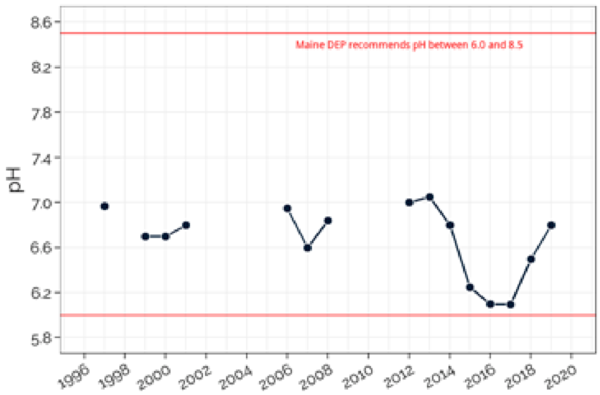
Since 1997, chlorophyll-a at Cushman Pond has revealed a statistically significant improving trend. Sampling years 1997 and 2012 saw a rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algae growth.

CUSHMAN POND
WATER QUALITY TRENDS



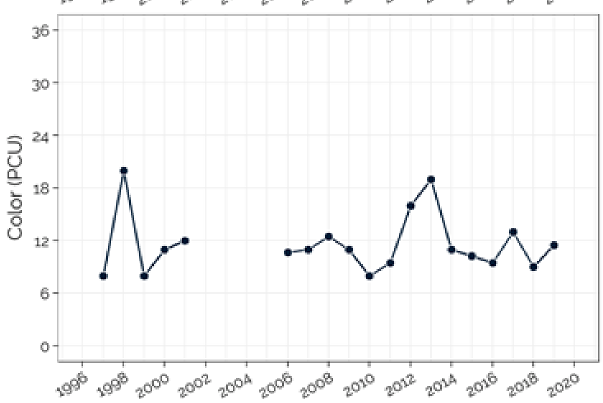
TOTAL ALKALINITY

Since 1997, total alkalinity at Cushman Pond has degraded by about 2 ppm. The region has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid.



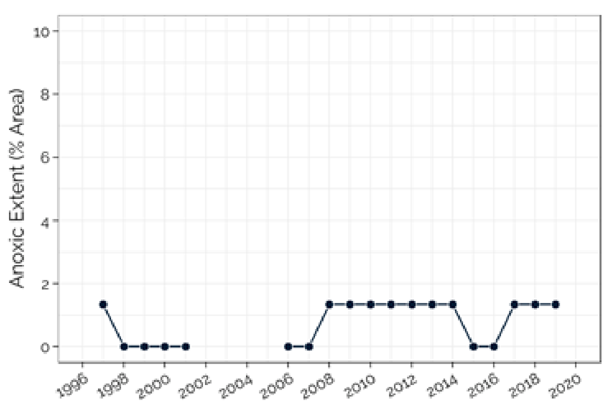
pH

Since 1997, pH at Cushman Pond has revealed no statistically significant trend over time. Mean annual pH falls within acceptable ranges for aquatic life. More consistent data are needed to confirm long-term trends. Low alkalinity makes Cushman Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



COLOR

Since 1997, color at Cushman Pond has revealed no statistically significant trend. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the pond.

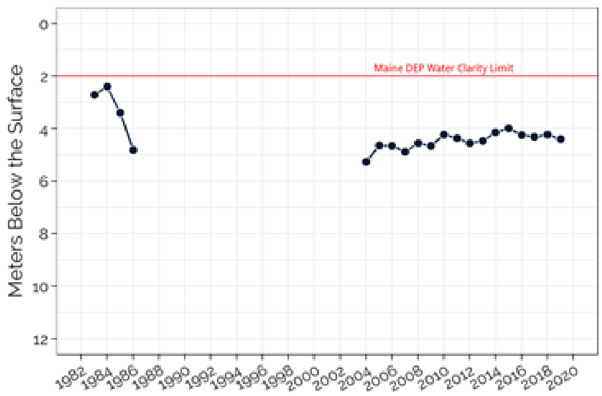


ANOXIC EXTENT

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, with some anoxia at the bottom. The extent and duration of anoxia is overall excellent at Cushman Pond (affecting <10% of pond area). Dissolved oxygen at depth should continue to be monitored closely in the future.

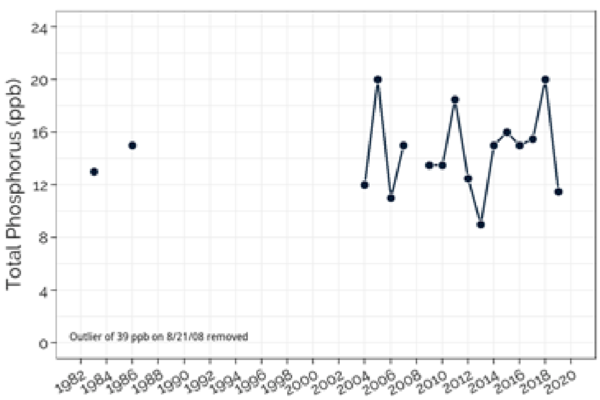
FARRINGTON POND
WATER QUALITY TRENDS

Farrington Pond (Midas #3200) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 57 acres (0.09 square miles) with a maximum and mean depth of 15 and 5 feet (5 and 2 meters), respectively, the pond drains directly to Kezar Lake. Water quality monitoring data have been collected since 1983 at Station 1 (deep spot).



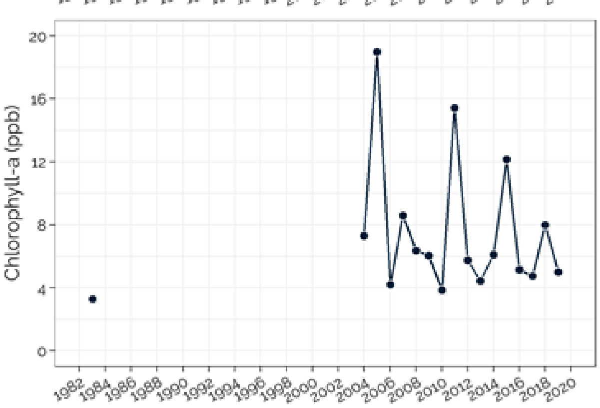
WATER CLARITY

Since 1983, water clarity at Farrington Pond has revealed no statistically significant trend, but data collected since 2004 show a possible degradation in water clarity by about 1 meter.



TOTAL PHOSPHORUS

Since 1983, total phosphorus at Farrington Pond has revealed no statistically significant trend. Year-to-year variation in total phosphorus (10 to 20 ppb) is large at Farrington Pond, which also has the highest mean annual total phosphorus of all the ponds. Farrington Pond is highly susceptible to internal loading of phosphorus due to its shallow depth, where disturbance of bottom sediments can release phosphorus into the water column.



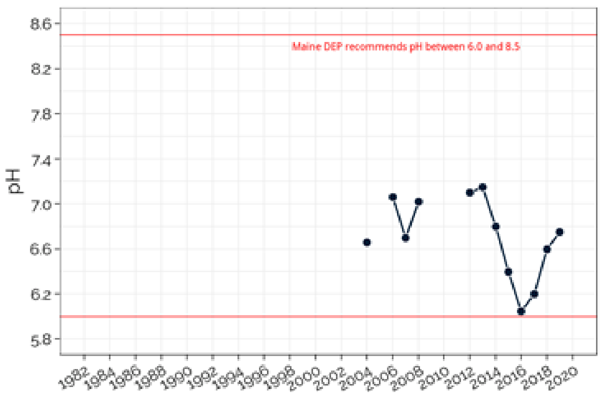
CHLOROPHYLL-A

Since 1983, chlorophyll-a at Farrington Pond has revealed no statistically significant trend, and typically experiences the highest annual concentration of chlorophyll-a of the other ponds. Sampling years 2005, 2011, and 2015 saw a marked rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algae growth. Chlorophyll-a generally increases with increasing total phosphorus.

FARRINGTON POND
WATER QUALITY TRENDS

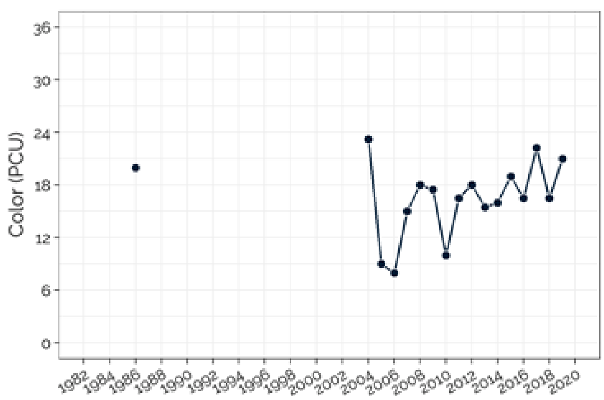
TOTAL ALKALINITY

Since 1986, total alkalinity at Farrington Pond has revealed no statistically significant trend, unlike the other ponds that largely show degrading trends (and may actually be improving in the last 10 years). The region has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology.



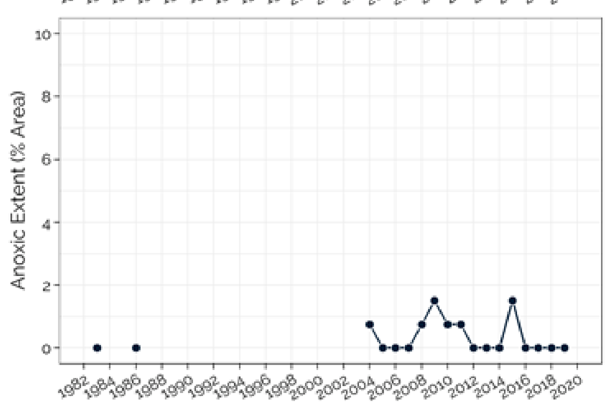
pH

Since 2004, pH at Farrington Pond has revealed no statistically significant trend. Mean annual pH falls within acceptable ranges for aquatic life. Low alkalinity makes Farrington Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



COLOR

Since 1983, color at Farrington Pond has revealed no statistically significant trend, though year-to-year variation is moderately large (~8 to 23 PCU). Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake.

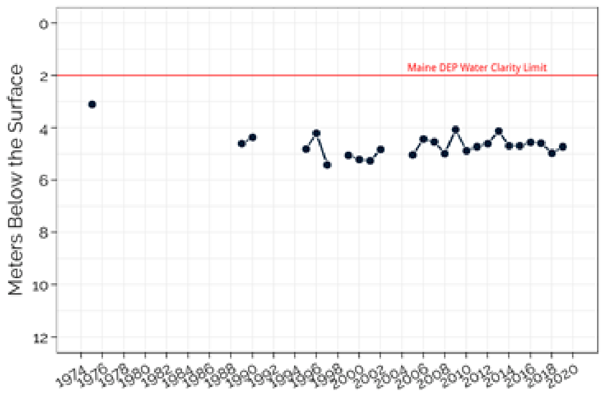


ANOXIC EXTENT

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, with some anoxia at the bottom. The extent of anoxia is overall excellent at Farrington Pond (affecting <10% of pond area). Dissolved oxygen at depth should continue to be monitored closely in the future.

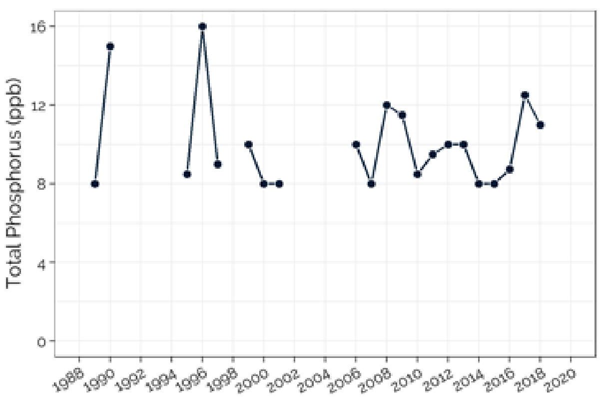
HEALD POND
WATER QUALITY TRENDS

Heald Pond (Midas #3222) is a non-colored waterbody located in the Town of Lovell, Oxford County, Maine. Covering 106 acres (0.17 square miles) with a maximum depth of 17 feet (5 meters), the pond drains directly to Kezar Lake through a tributary to Boulder Brook. Water quality monitoring data have been collected since 1975 at Station 1 (deep spot).



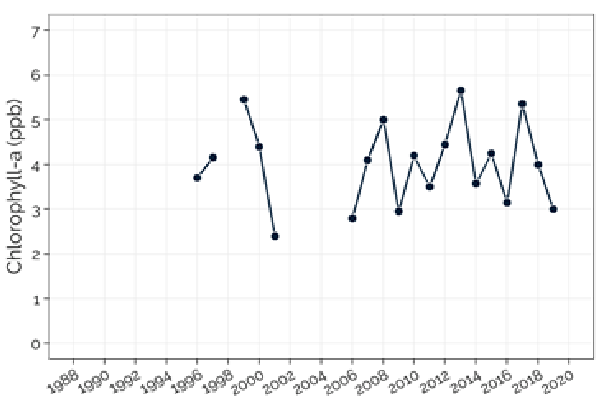
WATER CLARITY

Since 1975, water clarity at Heald Pond has remained stable with no statistically significant trend.



TOTAL PHOSPHORUS

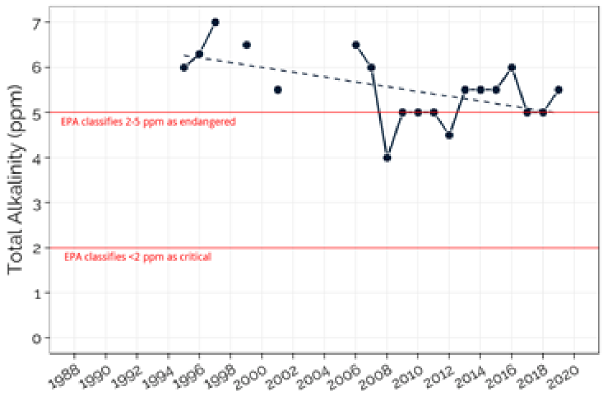
Since 1989, total phosphorus at Heald Pond has revealed no statistically significant trend. Higher phosphorus generally corresponds to wetter years at Heald Pond. Sediment in runoff entering the pond during rain events carries limiting nutrients. Heald Pond is highly susceptible to internal loading of phosphorus due to its shallow depth, where disturbance of bottom sediments can release phosphorus into the water column.



CHLOROPHYLL-A

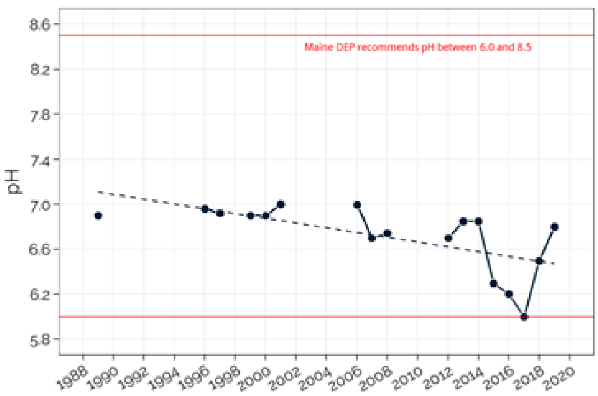
Since 1996, chlorophyll-a at Heald Pond has revealed no statistically significant trend. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algae growth.

HEALD POND
WATER QUALITY TRENDS



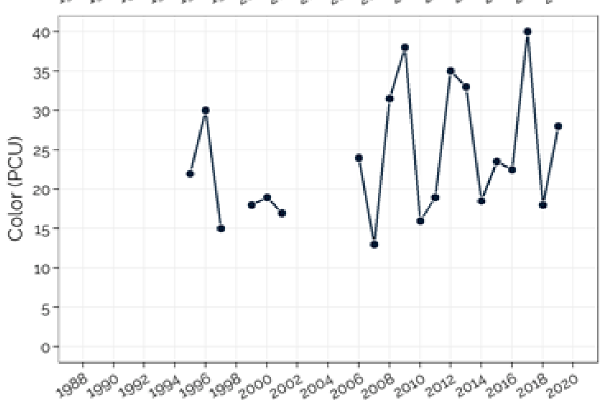
TOTAL ALKALINITY

Since 1995, total alkalinity at Heald Pond has degraded by about 1 ppm. Heald Pond experiences the highest (best) annual alkalinity compared to the other ponds. However, Heald Pond is still susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



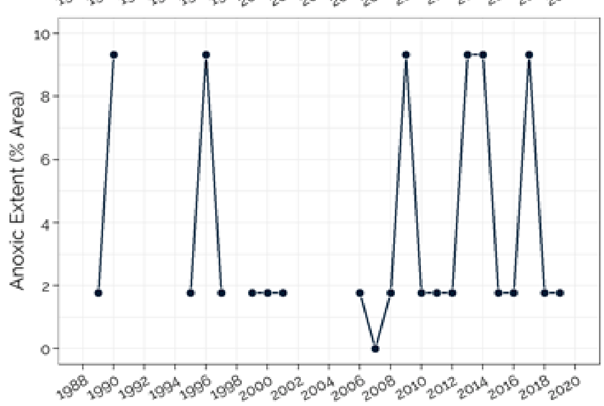
pH

Since 1989, pH at Heald Pond has degraded by about 1.0. Mean annual pH falls within acceptable ranges for aquatic life but hit a record low in 2017. More consistent data are needed to confirm long-term trends.



COLOR

Since 1995, color at Heald Pond has revealed no statistically significant trend. Heald Pond consistently experiences the highest annual color compared to the other ponds. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the lake.

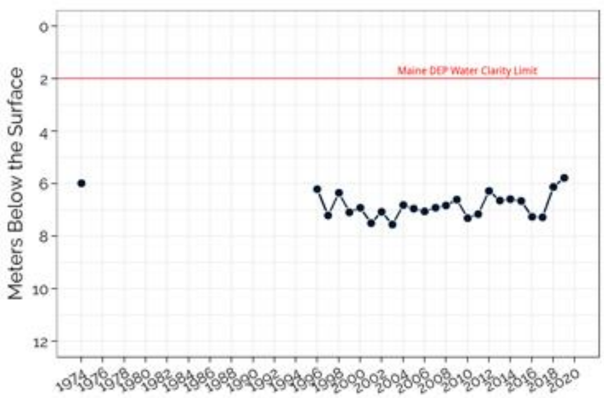


ANOXIC EXTENT

Dissolved oxygen profiles show good oxygenation throughout the water column over the collection period, with some anoxia at the bottom. The extent of anoxia is overall excellent at Heald Pond (affecting <10% of pond area). Dissolved oxygen at depth should continue to be monitored closely in the future.

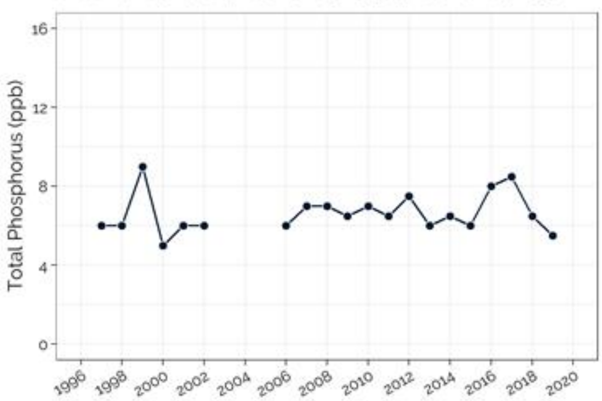
HORSESHOE POND
WATER QUALITY TRENDS

Horseshoe Pond (Midas #3196) is a non-colored waterbody located in the Town of Lovell and Stoneham, Oxford County, Maine. Covering 136 acres (0.20 square miles) with a maximum and mean depth of 40 and 12 feet (12 and 4 meters), the pond drains to Moose Pond, which in turn drains directly to Kezar Lake. Water quality monitoring data have been collected since 1974 at Station 1 (deep spot).



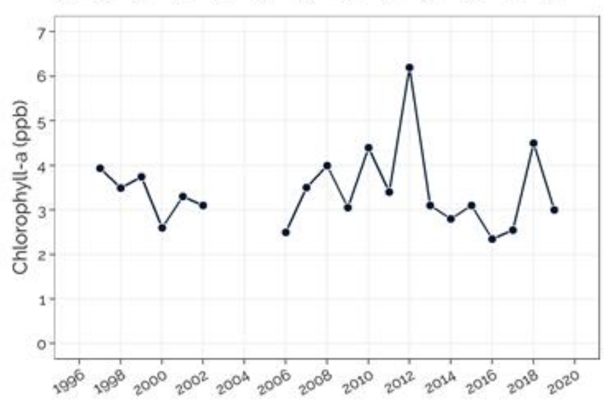
WATER CLARITY

Since 1974, water clarity at Horseshoe Pond has remained stable with no statistically significant trend.



TOTAL PHOSPHORUS

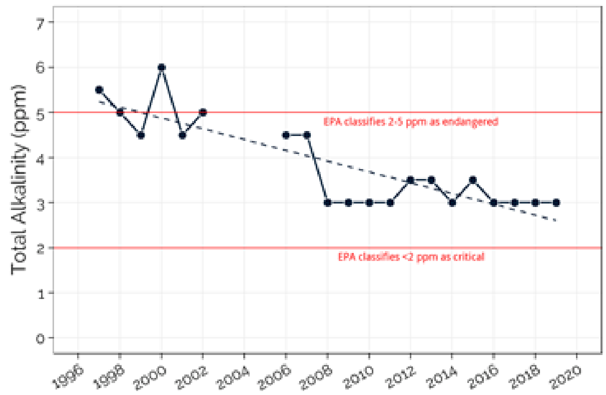
Since 1998, total phosphorus at Horseshoe Pond has remained stable with no statistically significant trend. Horseshoe Pond experiences consistently low phosphorus compared to the other ponds.



CHLOROPHYLL-A

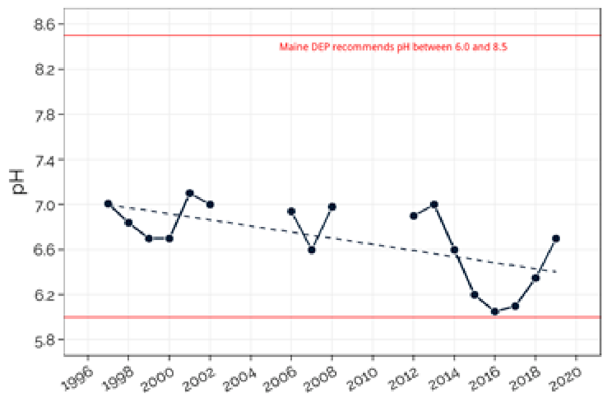
Since 1997, chlorophyll-a at Horseshoe Pond has revealed no statistically significant trend. Sampling year 2012 saw a marked rise in chlorophyll-a. Nutrient-rich runoff entering the lake during wetter years, combined with warmer air temperatures, can fuel algae growth.

HORSESHOE POND
WATER QUALITY TRENDS



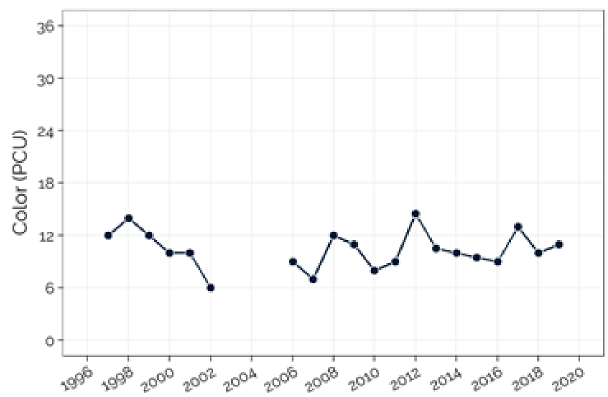
TOTAL ALKALINITY

Since 1997, total alkalinity at Horseshoe Pond has degraded by more than 2 ppm. Horseshoe Pond experiences the lowest (worst) alkalinity compared to the other ponds. The region has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology.



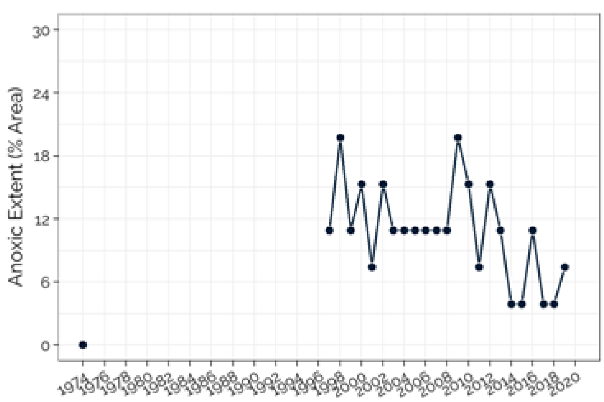
pH

Since 1997, pH at Horseshoe Pond has degraded by nearly 1.0. Mean annual pH falls within acceptable ranges for aquatic life but hit record low in 2016. Low alkalinity makes Horseshoe Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



COLOR

Since 1997, color at Horseshoe Pond has remained stable with no statistically significant trend. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the pond.



ANOXIC EXTENT

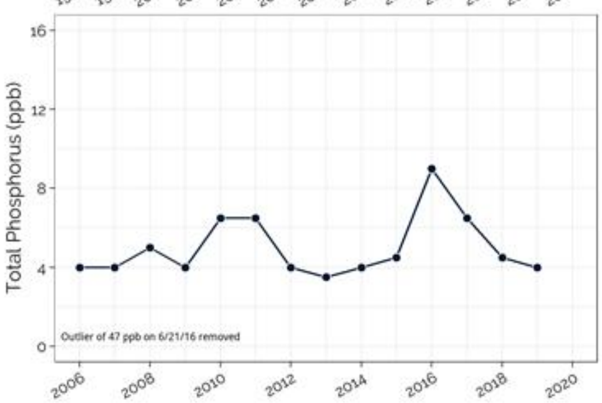
Dissolved oxygen profiles show oxygen depletion from 8 to 12 meters below the water surface in late summer. The extent of anoxia is overall good at Heald Pond (sometimes affecting >10% of pond area). Dissolved oxygen at depth should continue to be monitored closely in the future.

TROUT POND
WATER QUALITY TRENDS

Trout Pond (Midas #3212) is a non-colored waterbody located in the Town of Stoneham, Oxford County, Maine. Covering 64 acres (0.10 square miles) with a maximum and mean depth of 68 and 27 feet (21 and 8 meters), respectively, the pond drains to Cushman Pond, which in turn drains to Heald Pond, then to a tributary to Boulder Brook and eventually Kezar Lake. Water quality monitoring data have been collected since 1997 at Station 1 (deep spot).

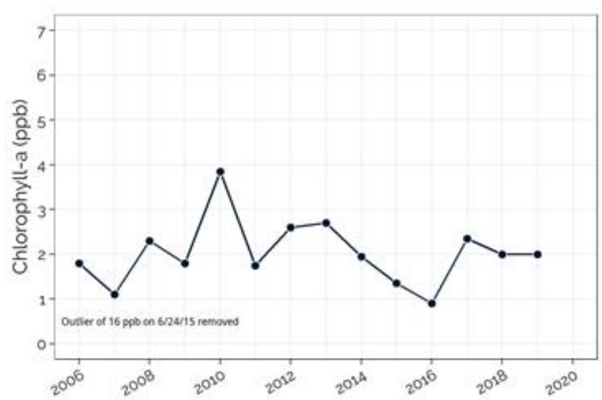
WATER CLARITY

Since 1997, water clarity at Trout Pond has revealed no statistically significant trend. Trout Pond has the deepest water clarity compared to the other ponds.



TOTAL PHOSPHORUS

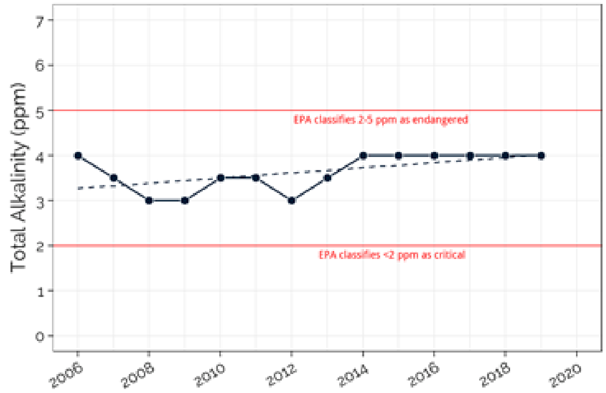
Since 2006, total phosphorus at Trout Pond has revealed no statistically significant trend. Trout Pond experiences the lowest concentration of total phosphorus compared to the other ponds.



CHLOROPHYLL-A

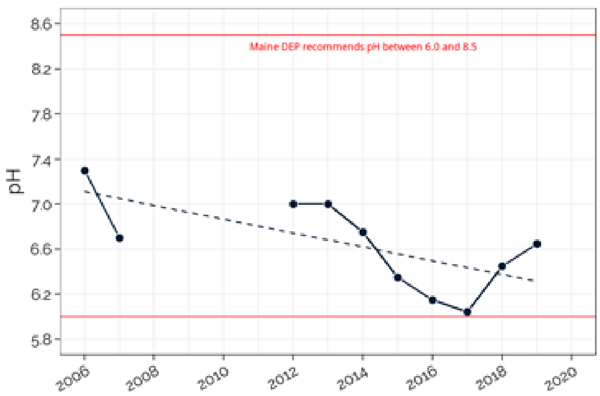
Since 2006, chlorophyll-a at Trout Pond has ranged from about 1 to 4 ppb. Trout Pond experiences the lowest concentration of chlorophyll-a compared to the other ponds.

TROUT POND
WATER QUALITY TRENDS



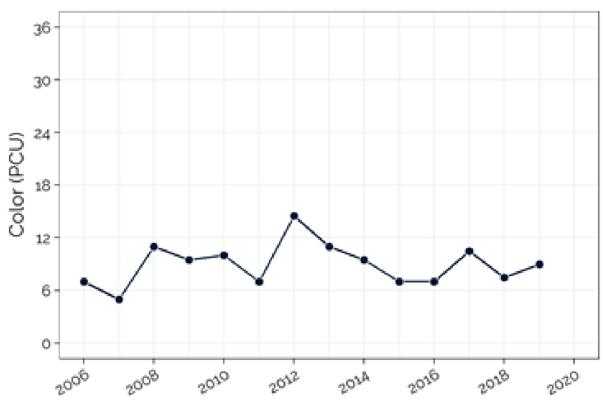
TOTAL ALKALINITY

Since 2006, total alkalinity at Trout Pond has improved slightly. The region has naturally-low alkalinity (or buffering capacity) as a result of its contributing geology (i.e., granite) that lacks carbonates, bicarbonates, and carbonic acid.



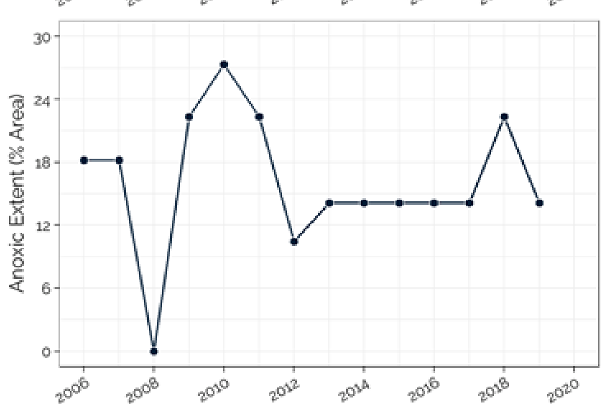
pH

Since 2006, pH at Trout Pond has degraded by nearly 1.0. Mean annual pH falls within acceptable ranges for aquatic life but hit record low in 2017. Low alkalinity makes Trout Pond susceptible to changes in pH, particularly from acidic deposition in the form of rain or snow, which can jeopardize the health of freshwater fish species.



COLOR

Since 2006, color at Trout Pond has generally remained stable. Trout Pond has the lowest (best) color compared to the other ponds. Higher color was observed for 2012, likely due to the wet summer conditions. Color is highly related to summer precipitation; wetter years show higher color as more materials are washed off the landscape to the pond.

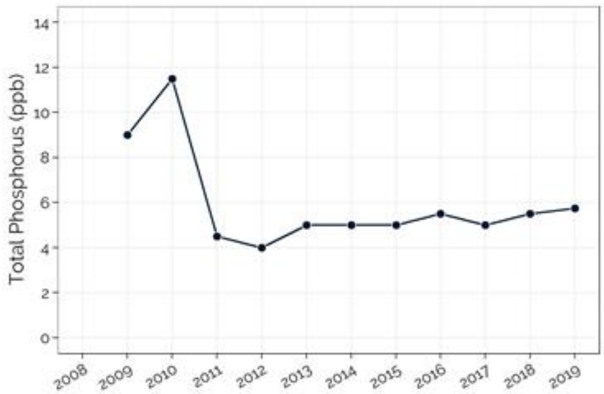


ANOXIC EXTENT

Dissolved oxygen profiles show oxygen depletion beginning at 15 meters below the water surface. The extent of anoxia is overall good at Trout Pond (typically affecting >10% of pond area). Dissolved oxygen at depth should continue to be monitored closely in the future.

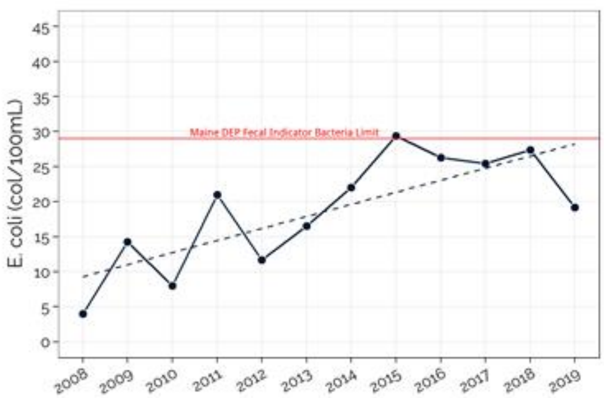
GREAT BROOK
WATER QUALITY TRENDS

Great Brook is located on the northwest end of Kezar Lake off West Stoneham Road. Great Brook drains a large portion of the White Mountain National Forest. Water quality monitoring data have been collected since 2008.



TOTAL PHOSPHORUS

Since 2009, total phosphorus at Great Brook has remained below 12 ppb.



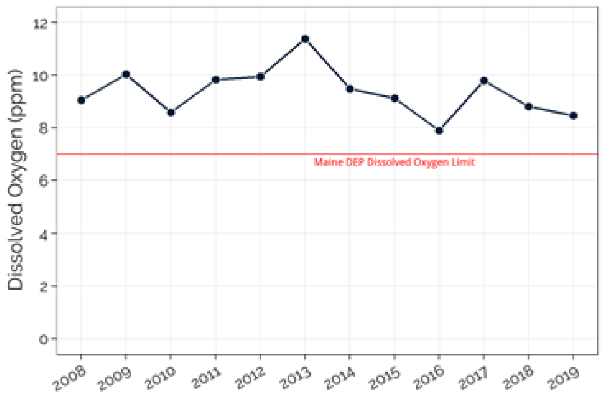
E. COLI

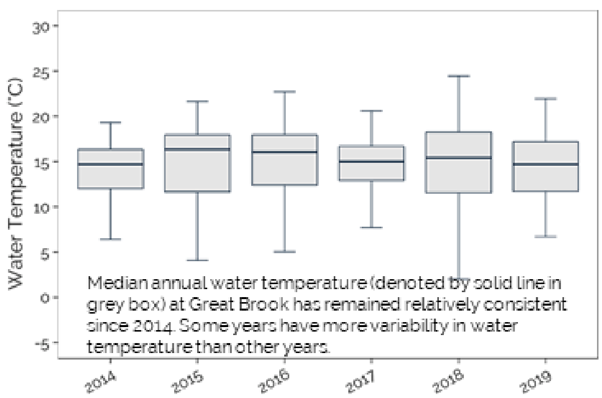
Since 2008, E. coli at Great Brook has been less than the Class A stream geometric mean of 29 col/100mL, except for 2015 (30 col/100mL). However, E. coli at Great Brook has been increasing in the last ten years.

pH

Minimal pH data are available for Great Brook, but pH fell below the range suitable for aquatic life from 2015-2017.

GREAT BROOK
WATER QUALITY TRENDS





DISSOLVED OXYGEN

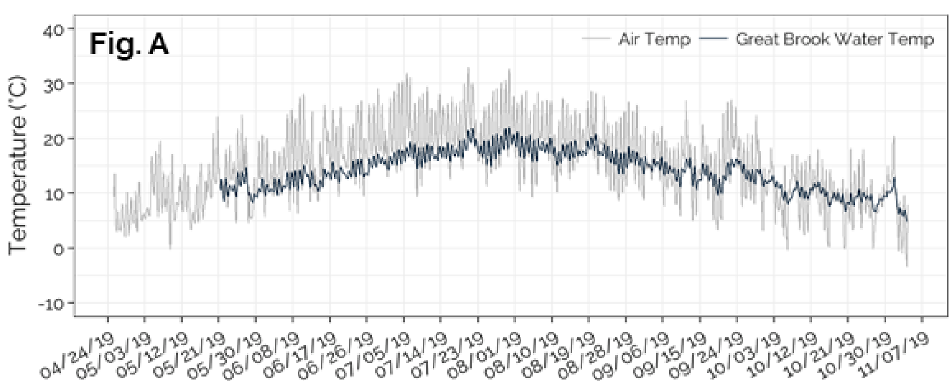
Dissolved oxygen at Great Brook remains above the Maine DEP standard of 7 ppm for Class A streams. Note that dissolved oxygen readings are collected mid-day and do not represent the lowest oxygen readings for that day. Dissolved oxygen is typically lowest in early morning when decomposition processes dominate over photosynthesis.

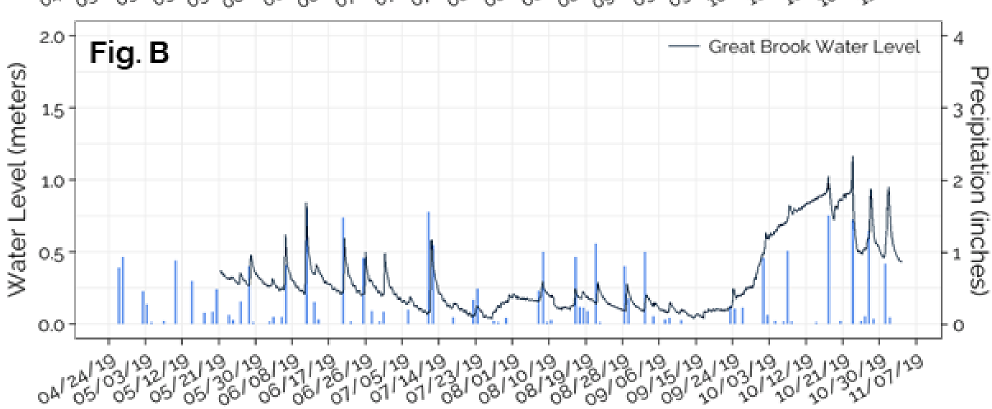
WATER TEMPERATURE

Water temperature (Fig. A) increased at Great Brook from May to August and then steadily declined until retrieval in November, following closely with observed air temperature. (hourly data obtained from CCO weather station).

STREAM FLOW

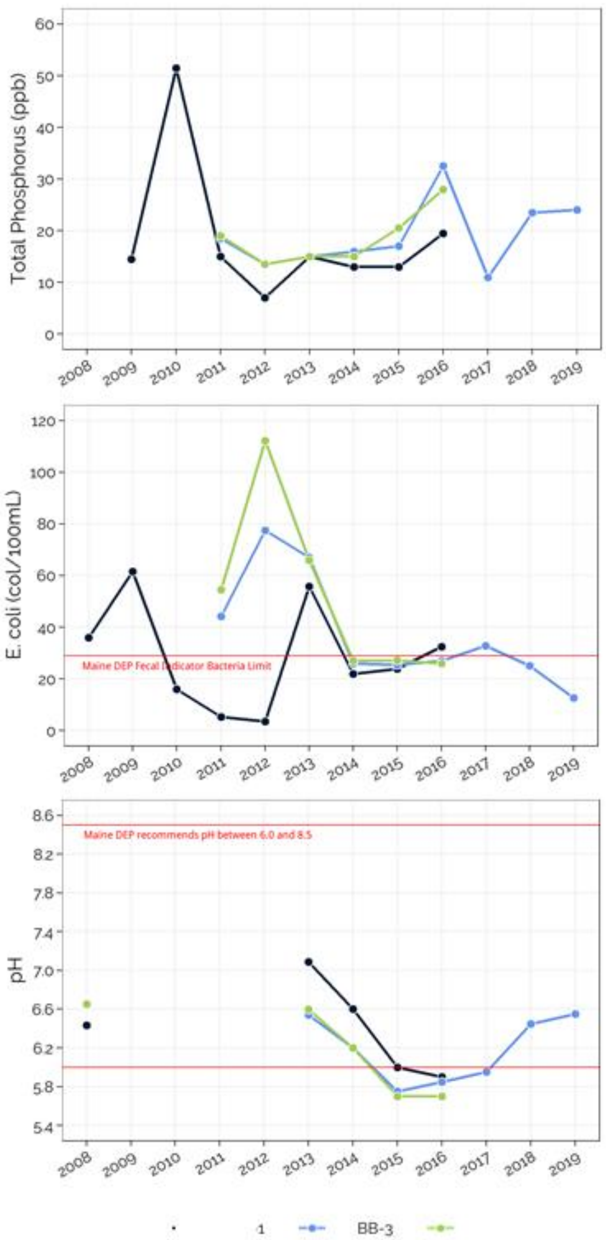
Water level data (Fig. B) collected at Great Brook shows that the stream responds quickly to precipitation (daily data obtained from CCO weather station).





BOULDER BROOK
WATER QUALITY TRENDS

Boulder Brook drains an area that includes Bradley, Trout, Cushman, and Heald Ponds. Boulder Brook crosses under Route 5 north of Center Lovell, and flows past the Boulder Brook Club before entering the east side of Boulder Brook at the swimming area. Water quality monitoring data have been collected since 2008 at multiple stations (BB-1, BB-2, BB-3, and BB-4) along Boulder Brook. Only BB-3 was sampled in 2017.



TOTAL PHOSPHORUS

Total phosphorus in Boulder Brook in 2016 was elevated despite dry summer conditions and hit record low in 2017.

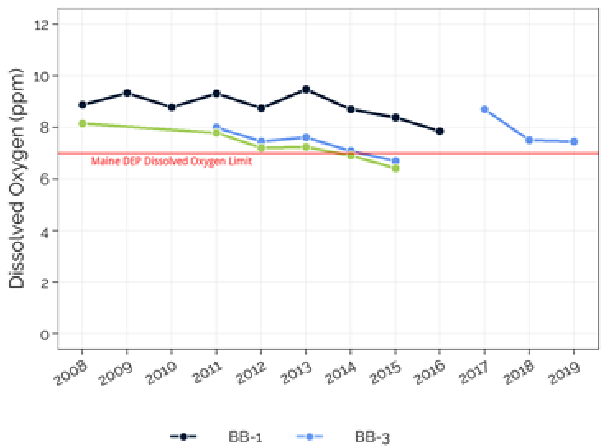
E. COLI

Since 2008, E. coli at Boulder Brook has largely exceeded the Class A stream geometric mean of 29 col/100mL but hit a record low in 2019.

pH

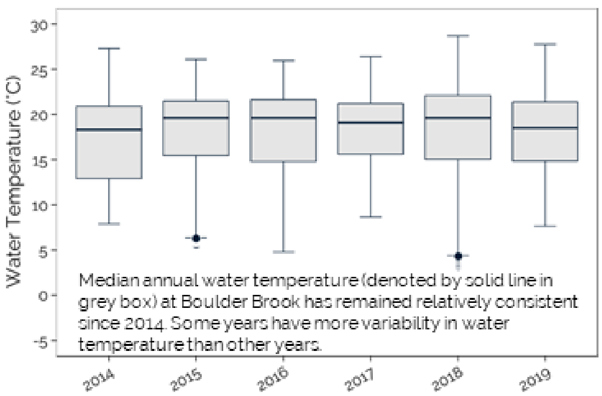
Minimal pH data are available for Boulder Brook, but pH fell within the range suitable for aquatic life up until 2015 when pH dropped below 6.0. pH has since recovered from 2017-19. Low pH (acidic) waters can threaten fish and other aquatic life.

BOULDER BROOK
WATER QUALITY TRENDS



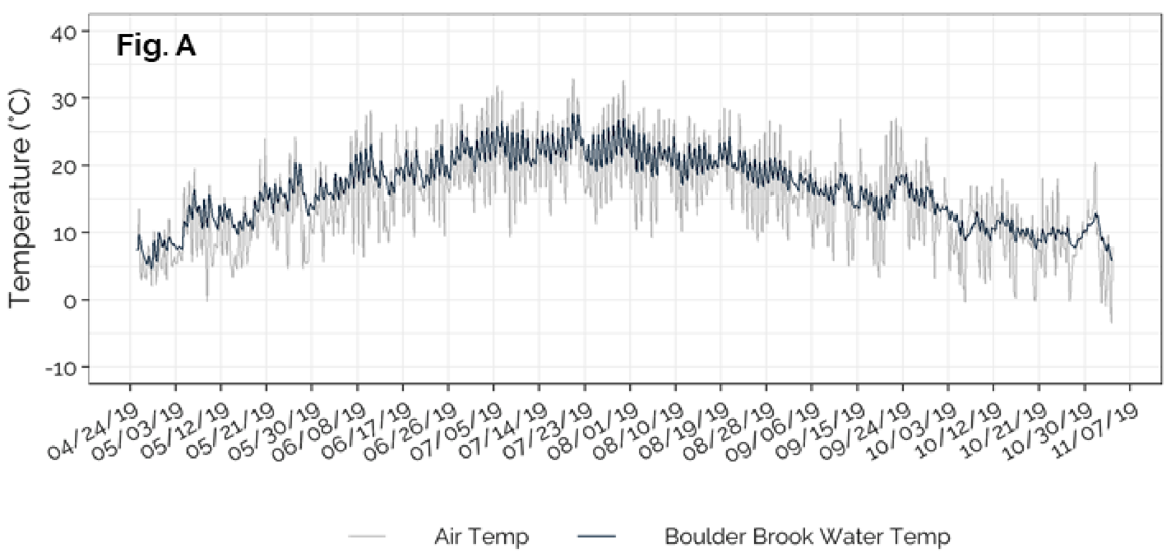
DISSOLVED OXYGEN

Dissolved oxygen at Boulder Brook generally remains above the Maine DEP standard of 7 ppm for Class A streams, except for 2014-2015. Note that dissolved oxygen readings are collected mid-day and do not represent the lowest oxygen readings for that day. Dissolved oxygen is typically lowest in early morning when decomposition processes dominate over photosynthesis.



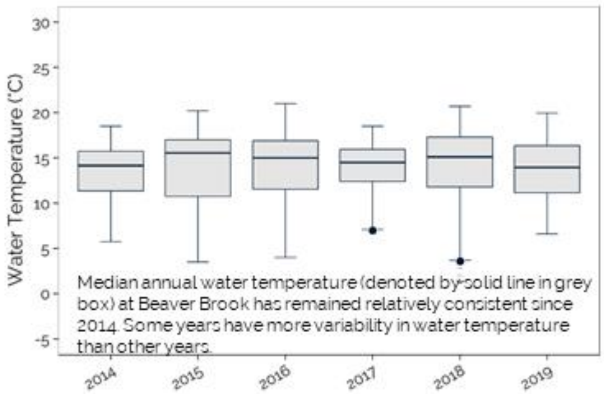
WATER TEMPERATURE

Water temperature (Fig. A) increased at Boulder Brook from May to August and then steadily declined until retrieval in November, following closely with observed air temperature (hourly data obtained from CCO weather station). Boulder Brook experienced some of the highest water temperatures compared to the other streams. July 2019 showed water temperatures above 24 °C, which may threaten coldwater fish species.



BEAVER BROOK
WATER QUALITY TRENDS

Beaver Brook is a major tributary to Great Brook, located on the northwest end of Kezar Lake off West Stoneham Road. Beaver Brook drains a portion of the White Mountain National Forest. Water quality monitoring data have been collected since 2014.



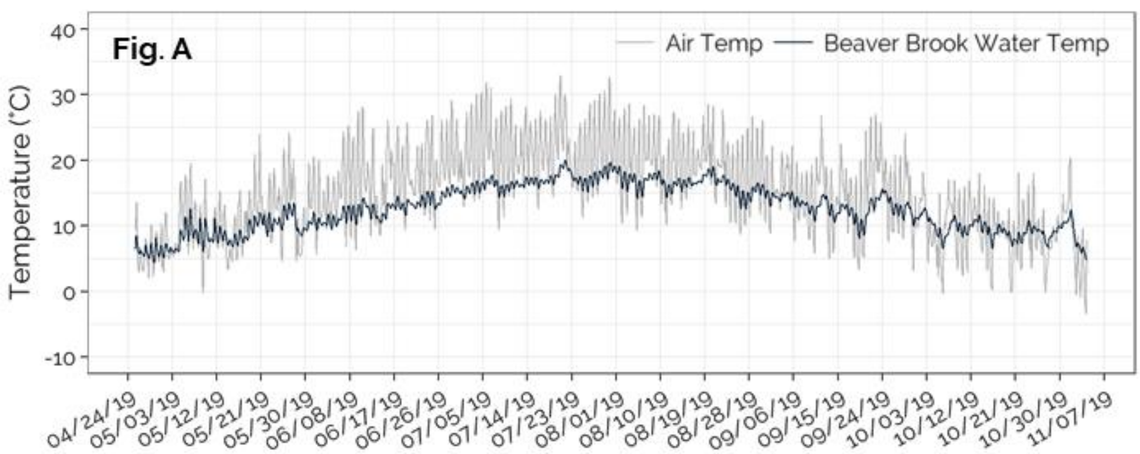
Median annual water temperature (denoted by solid line in grey box) at Beaver Brook has remained relatively consistent since 2014. Some years have more variability in water temperature than other years.

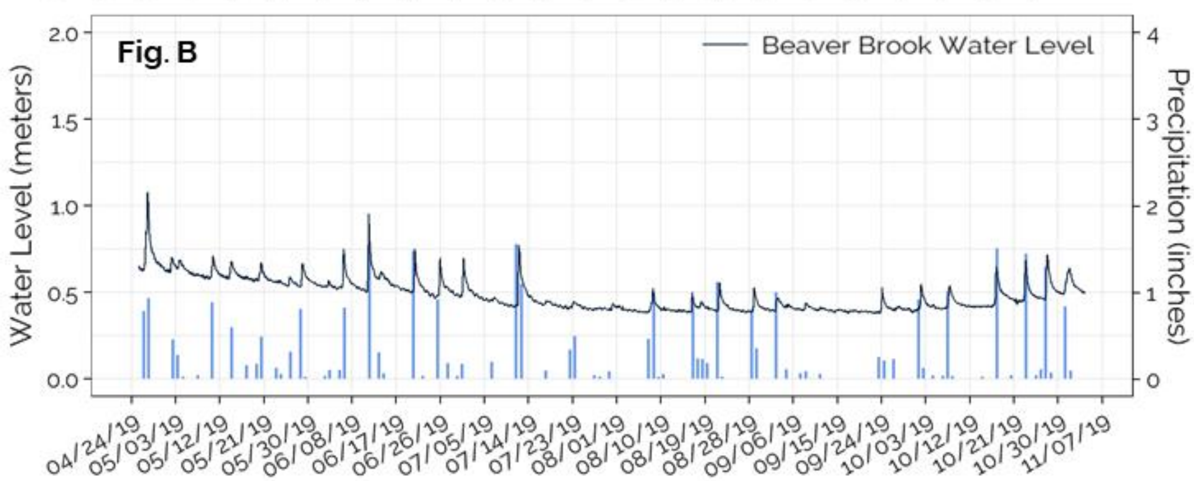
WATER TEMPERATURE

Water temperature (Fig. A) increased at Beaver Brook from May to August and then steadily declined until retrieval in November, following closely with air temperature (data obtained from CCO weather station).

STREAM FLOW

Water level data (Fig. B) collected at Beaver Brook shows that the stream responds quickly to precipitation (daily data obtained from CCO weather station).

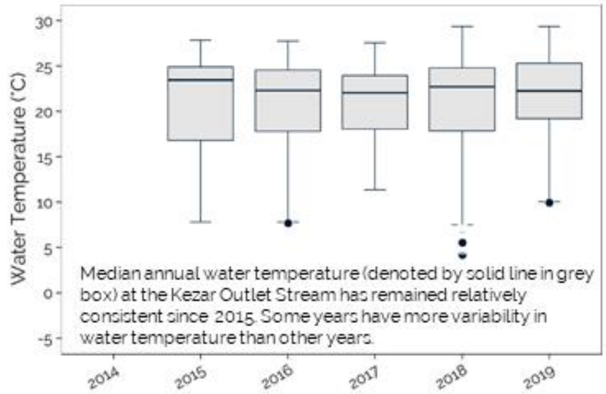




KEZAR OUTLET STREAM

WATER QUALITY TRENDS

The Kezar Outlet Stream flows south from the lower bay of Kezar Lake. The stilling well was attached to an old fish dam structure just upstream of Harbor Road. Water quality monitoring data have been collected since 2015.



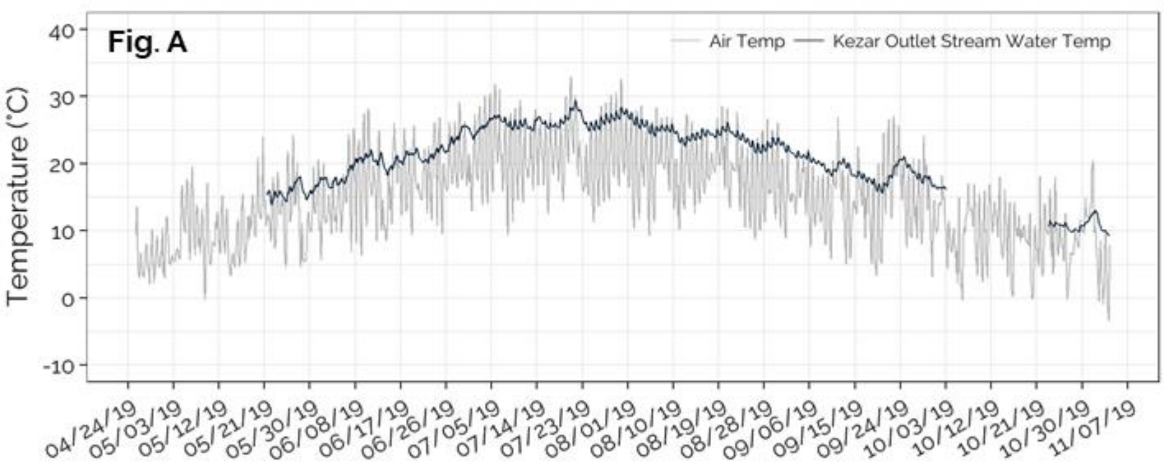
Median annual water temperature (denoted by solid line in grey box) at the Kezar Outlet Stream has remained relatively consistent since 2015. Some years have more variability in water temperature than other years.

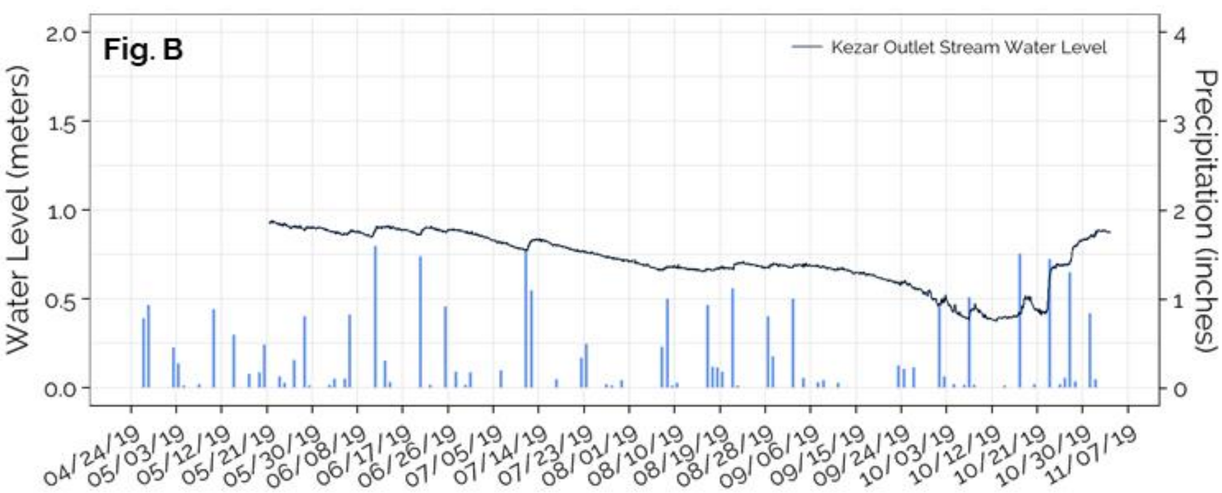
WATER TEMPERATURE

Water temperature (Fig. A) followed closely with air temperature (data obtained from CCO weather station).

STREAM FLOW

The large, but delayed volume of water flowing from the lake through the Kezar Outlet Stream allowed water level (Fig. B) to increase and decrease much more gradually compared to headwater streams. Precipitation data obtained from CCO weather station.



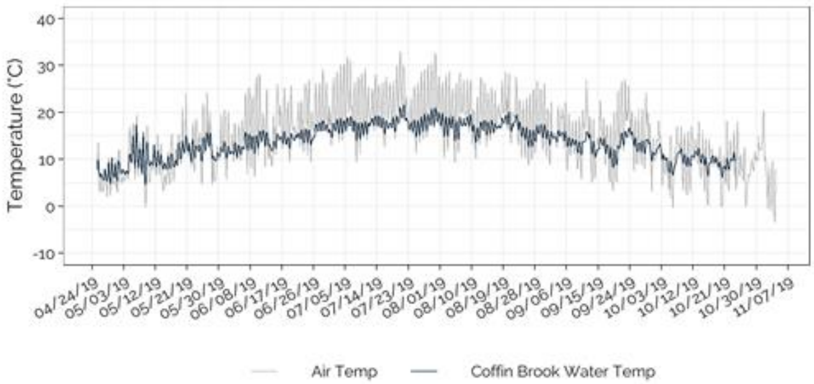


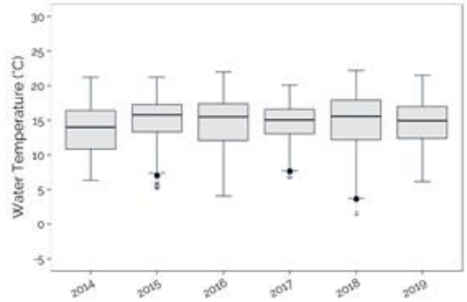
COFFIN BROOK
WATER QUALITY TRENDS

Coffin Brook drains to the eastern side of the upper basin of Kezar Lake, crossing Rt. 5 just south of West Stoneham Road. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature (below, left fig.) increased at Coffin Brook from May to August and then steadily declined until retrieval in November, closely tracking air temperatures (data obtained from CCO station).





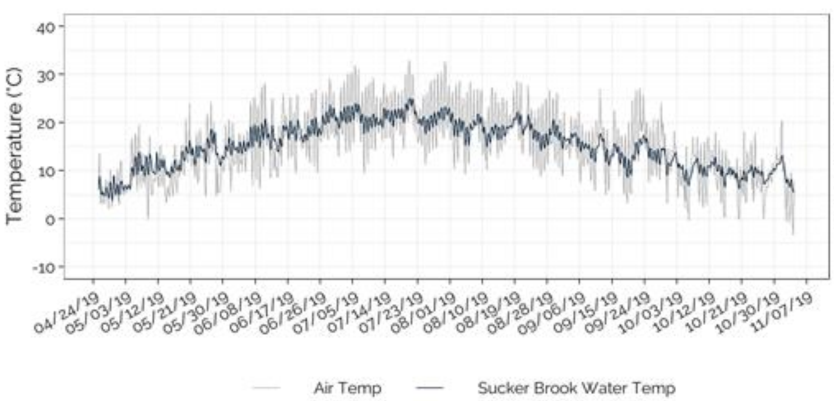
Median annual water temperature (denoted by solid line in grey box) at Coffin Brook has remained relatively consistent since 2014. Some years have more variability in water temperature than other years.

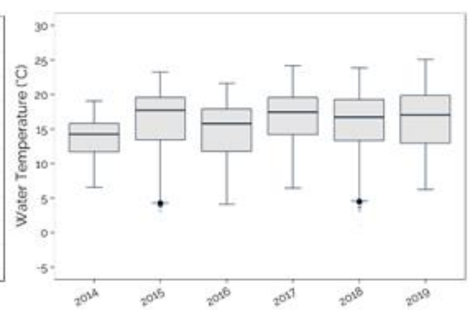
SUCKER BROOK
WATER QUALITY TRENDS

Sucker Brook begins at the outlet to Horseshoe Pond and drains to the western side of the lower basin of Kezar Lake after converging with Bradley Brook. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature (below, left fig.) increased at Sucker Brook from May to August and then steadily declined until retrieval in November, closely following air temperatures (data obtained from CCO station).





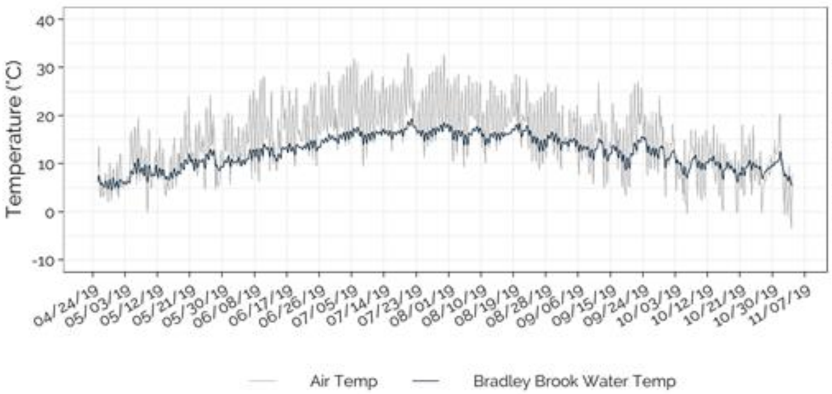
Median annual water temperature (denoted by solid line in grey box) at Sucker Brook has been more variable since 2014 than other streams.

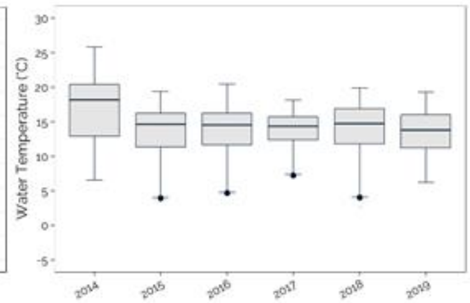
BRADLEY BROOK
WATER QUALITY TRENDS

Bradley Brook is a tributary that drains to the western side of the lower basin of Kezar Lake. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature (below, left fig.) increased at Bradley Brook from May to August and then steadily declined until retrieval in November, closely following air temperatures (data obtained from CCO station).





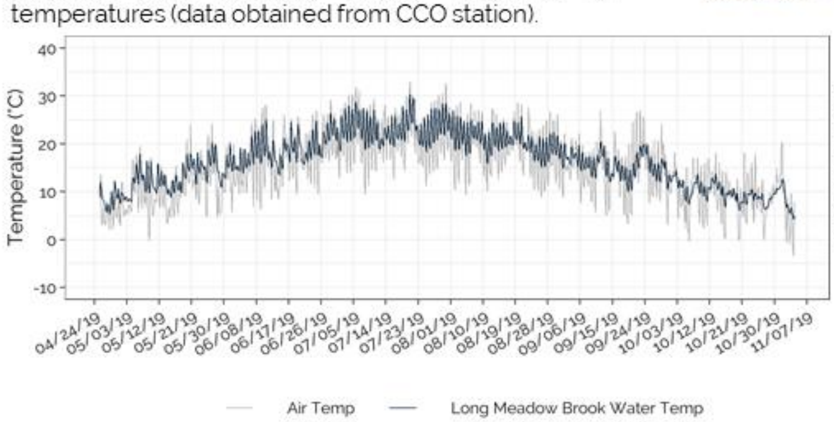
Median annual water temperature (denoted by solid line in grey box) at Bradley Brook has remained relatively consistent since 2015. Some years have more variability in water temperature than other years.

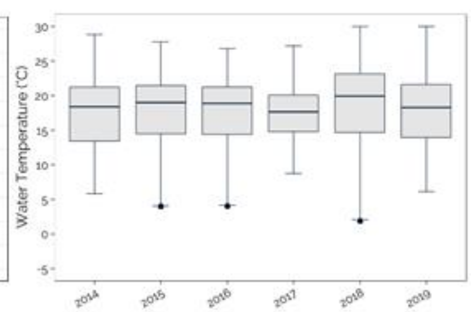
LONG MEADOW BROOK
WATER QUALITY TRENDS

Long Meadow Brook is a tributary that drains through a large wetland complex to the southwestern side of the lower basin of Kezar Lake. Water quality data have been collected since 2014.

WATER TEMPERATURE

Water temperature (below, left fig.) increased at Long Meadow Brook from May to August and then steadily declined until retrieval, closely following air temperatures (data obtained from CCO station).





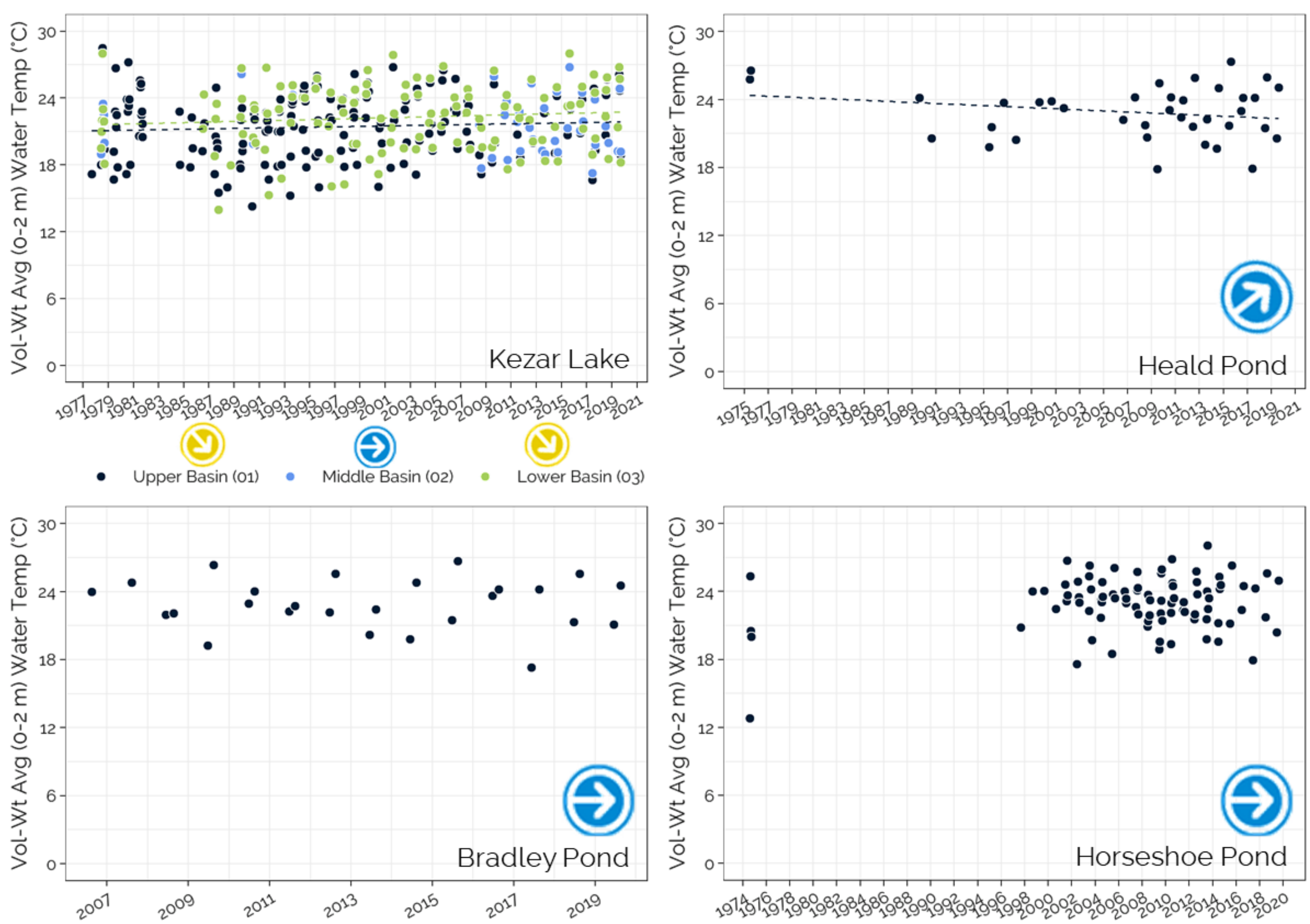
Median annual water temperature (denoted by solid line in grey box) at Long Meadow Brook has remained relatively consistent since 2014. Some years have more variability in water temperature than other years.

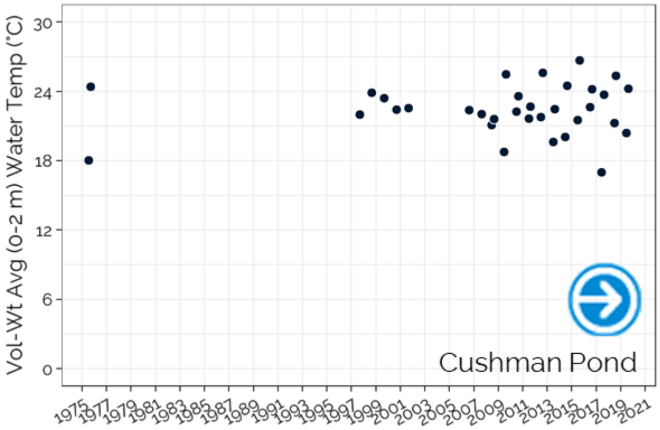
LAKE SURFACE WATER TEMPERATURE

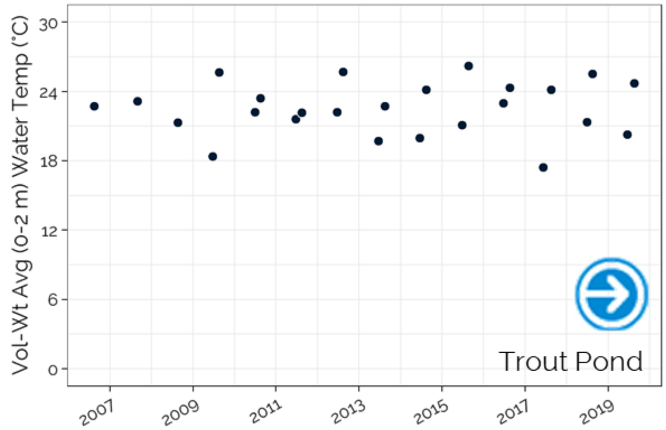
Climate change is predicted to increase surface water temperatures at a much faster rate than the observed increase in air temperature. Temperature affects the density of water (e.g., cooler water sinks), the solubility of gases (e.g., cooler water holds more dissolved oxygen), the rate of chemical reactions, and the activity of aquatic organisms (e.g., metabolic growth rates peak at different temperatures for different species; some species such as trout and salmon prefer cooler, more oxygen-rich waters; others such as bass prefer warmer waters). Thus, water temperature serves as a critical indicator of climate change impacts to ecological systems.

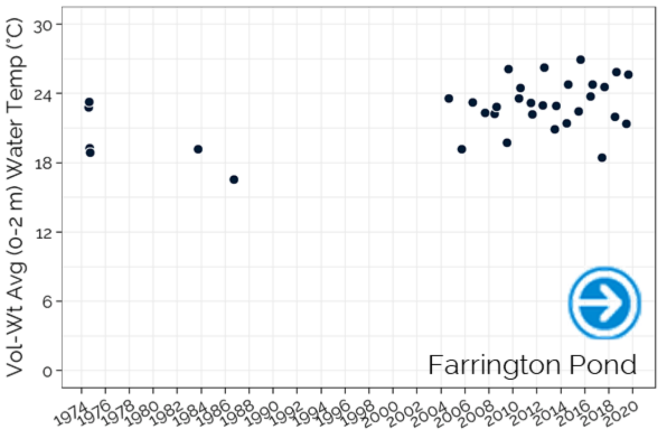
Volume-weighted average surface water temperature (0-2 m) for each profile measurement was calculated using rLakeAnalyzer. This method allows comparison of surface water temperatures across multiple waterbodies with different morphological characteristics. Mann-Kendall trend tests were performed on annual water quality data to determine trends over time. Dotted trend lines were added where statistically significant.

The volume-weighted average surface water temperature for the top 2 meters showed a statistically significant degrading trend of about 0.5-1 ˚C at Kezar Lake (but an improving trend at Heald Pond). This is likely a signal of climate change; correlations with air temperature and precipitation may help tease out the relative contribution of weather variables on lake surface temperature. All other waterbodies showed no statistically-significant trend in water temperature over the available record.









LAKE MONITORING BUOYS

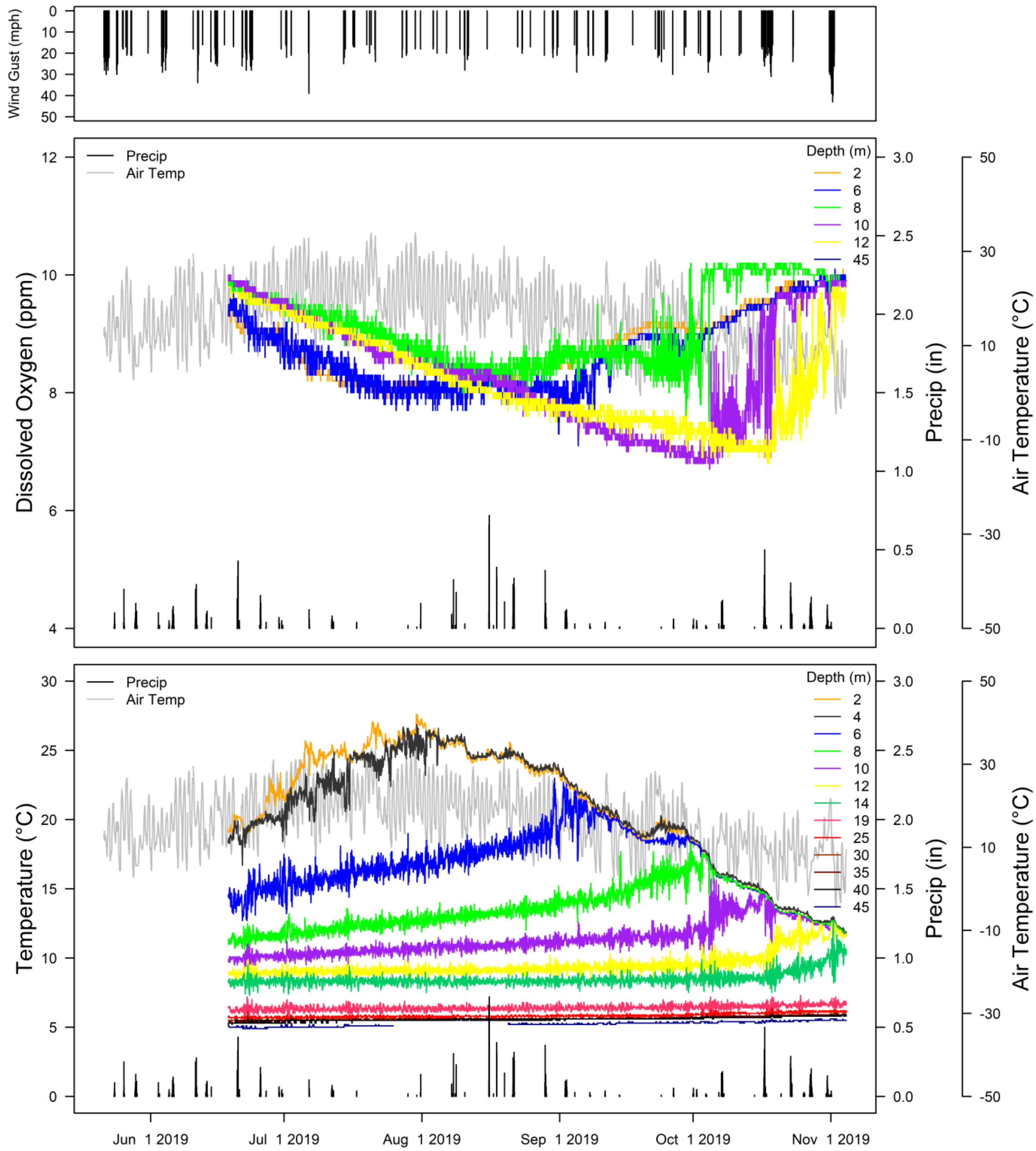
Climate change will alter the physical, chemical, and biological processes within surface waters of the Kezar Lake watershed. The culmination of the impact of these processes can be readily observed in dissolved oxygen (DO) and water temperature within the vertical profile of the water column. With high-resolution data from continuous loggers, we can pinpoint spring and fall turnover, determine the onset of thermal stratification, and determine the extent and duration of anoxia. By tracking these parameters over time, we can measure whether these indices are shifting because of climate change or other human disturbances within the watershed.

Buoy deployed at the lower basin. Photo Credit: FBE.

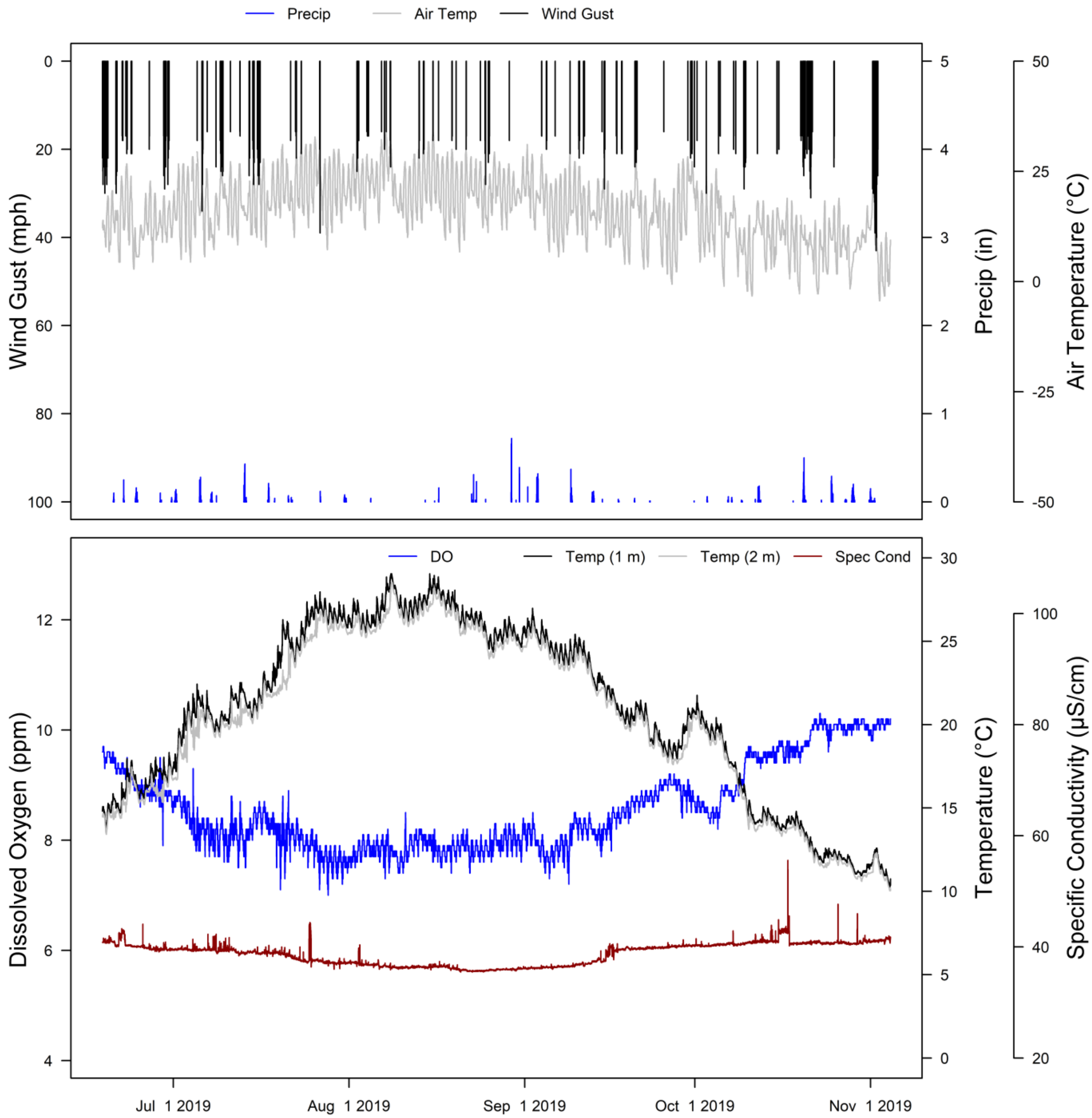
FB Environmental Associates, with assistance from KLWA, deployed monitoring buoys with Onset HOBO® continuous logging devices for temperature and dissolved oxygen at the upper and lower basins. The lower basin also included a conductivity sensor; conductivity can serve as a surrogate measure for the ionic materials (including nutrients) present in water. These buoy-logger systems were deployed from May to November and left intact with logging temperature sensors over winter. Refer to the 2019 Kezar Lake Water Quality Monitoring Report for further details on deployment configuration and maintenance methods.

These data will serve as a baseline for future comparisons of water quality to assess long-term changes in temperature and dissolved oxygen. Until more data are collected over the next few years to begin to account for interannual variability, no major conclusions or analyses can be made on this limited dataset aside from general patterns.

- DO at the upper basin gradually declined at all depths from near supersaturation in late May to 7-8 ppm in August, at which point the upper layers from the surface down to 8 meters began to steadily increase in oxygen (possibly due to wind action and/or biological processes as algal growth peaked in the water column).
- Temperature at the upper basin showed that the onset of stratification occurred shortly after spring turnover on 5/1/2019. The water column in the upper 14 meters continued to stratify with warm surface waters reaching a maximum of 27.6°C at 2 meters depth on 7/30/2019.
- As air temperatures declined into the fall and large storm events (wind and rain) occurred, subsequently deeper layers began to mix with upper layers until dissolved oxygen and temperature readings converged (down to 12 meters). The lake had not yet experienced complete fall turnover by 11/4/2019 when the loggers were retrieved.
- Surface waters at the lower basin reached a maximum of 29.1°C at 1-meter depth on 7/21/2019. Temperature and dissolved oxygen displayed an inverse relationship throughout the deployment (e.g., as temperature rose, oxygen declined). Warmer waters hold less oxygen and stimulate algae/plant growth, the organic material of which can be decomposed via oxygen consumption.
- Conductivity spikes at the lower basin throughout the deployment period largely corresponded with rain events, likely due to transport of ion-rich water from the landscape to the lake. Spikes in conductivity not associated with rain events (unless very localized) may have been due to wind or wave action (from motorized boats) or from an algal bloom.



Hourly maximum wind gust (top), and dissolved oxygen (middle) and temperature (bottom) readings taken every 15 minutes during the summer at various depths at the deep spot of Kezar Lake's upper basin. Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI station at Fryeburg. Refer to the 2019 Kezar Lake Water Quality Report.

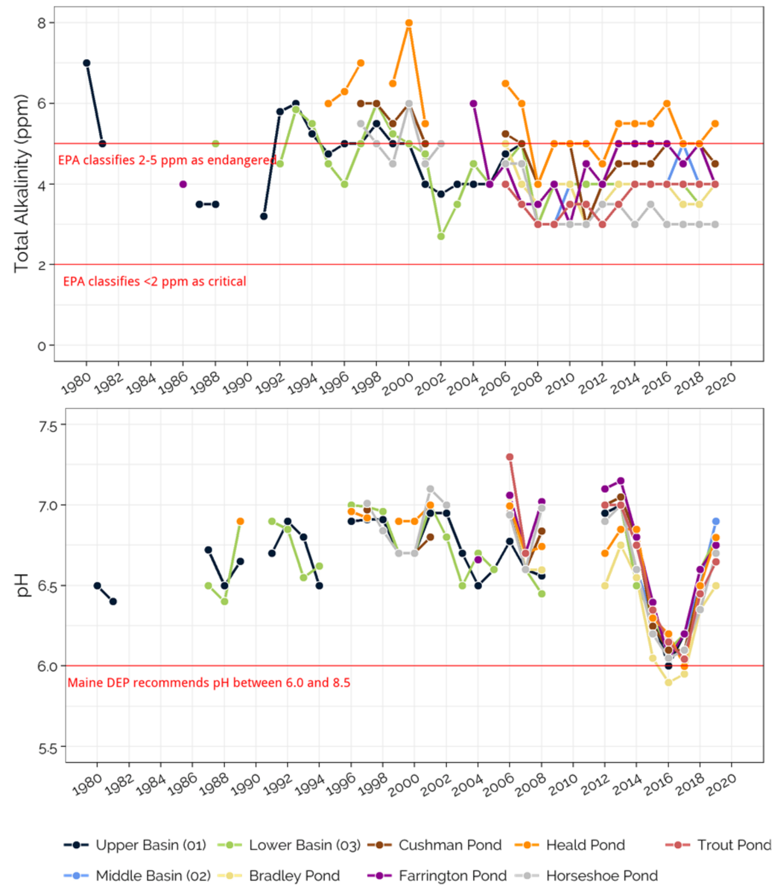


Hourly maximum wind gust, air temperature, and precipitation (top). Dissolved oxygen, temperature, and specific conductivity readings taken every 15 minutes during the summer at 2 meters depth (temperature also included 1 meter depth) at the deep spot of Kezar Lake's lower basin (bottom). Precipitation, air temperature, and wind gust data were obtained from NOAA NCEI station at Fryeburg.

BASELINE ACIDITY STUDY

Due to its natural granitic geology, Kezar Lake and its ponds suffer from extremely low alkalinity (typically < 5 ppm), which has significantly degraded by 1 ppm or more in the last few decades at Kezar Lake, Cushman Pond, Heald Pond, and Horseshoe Pond. Without adequate alkalinity to remove excess hydrogen ions in rain (~ pH 5.0) or acidic groundwater, pH in surface waters can fall below levels deemed safe for aquatic life (pH 6.0-8.5).

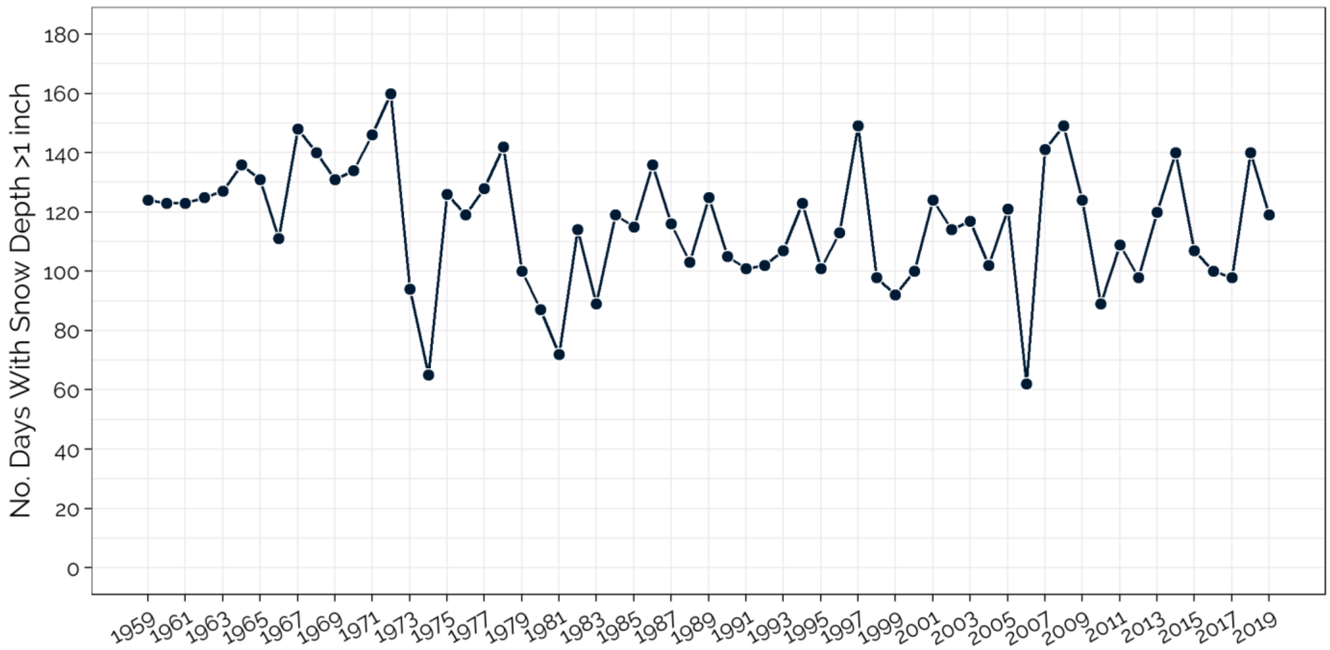
pH in Kezar Lake and its ponds over the same period shows a statistically significant decline at Bradley, Heald, Horseshoe, and Trout Ponds. While most waterbodies with a longer record showed recovery from acidification following the Clean Air Act Amendments of 1990, pH in waterbodies of the Kezar Lake watershed, including tributaries, showed a marked decline from 2014-2017 with recovery in 2018-2019.



Mean annual total alkalinity (top) and pH (bottom) from 1980-2019 in Kezar Lake and six ponds.

One theory for the chronic acidification in surface waters of the Kezar Lake watershed from 2014-2017 was that multiple back-to-back mild winters with little snow cover resulted in loss of soil CO_2 (degassing from soil horizons to the atmosphere) and thus lower alkalinity in spring runoff, leaving these systems more vulnerable to acidification. Drought (as we have experienced in recent summers) can also lower water tables and result in evaporative concentration of acid deposition and slowed rates of mineral weathering of buffering elements, causing enhanced acidification. Acidification leaches critical nutrients like calcium (Ca^{+2}) and magnesium (Mg^{+2}) and increases the availability of toxic metals like aluminum (Al), causing reduced reproductive capacity of sensitive organisms, lower body weight of fish, decreased species diversity, and forest mortality.

In response to concerns of the impacts of acidification, KLWA obtained funding for a study that determined a baseline for acidity metrics, including alkalinity, pH, Al, and Ca^{2+}, for eight major tributary streams to Kezar Lake. Refer to the 2017 Kezar Lake Watershed Baseline Acidity Study: A Report on the Current State of Tributary Acidity to Kezar Lake for details on methodology. Results showed that aquatic life in the tributaries to Kezar Lake may be impacted by low alkalinity, pH, and Ca^{2+}, and elevated Al, especially during episodic (rainfall or snowmelt) acidification events. Future studies in the Kezar Lake watershed should build on the existing baseline data set for acidity metrics to track changes in these metrics over time.



Number of days with snowpack depth of more than one inch. Data taken from the NOAA National Climatic Data Center for station CONWAY 1 N, NH US (ID# GHCND:USC00271732) for 1959-73 and station NORTH CONWAY, NH US (ID#GHCND:USC00275995) for 1974-present. Mann-Kendall trend test was performed. No statically significant trend was found.

ADDITIONAL WATER TEMPERATURE MONITORING

In partnership with former Prof. Daniel Buckley from the University of Maine at Farmington, KLWA participated in a high-resolution lake temperature monitoring study that used Onset HOBO sensors to record water temperature in over 30 Maine lakes. These automated thermometers were installed to gather data on surface water temperature in each of the three lake basins and Horseshoe Pond (at docks along the shorelines). This effort was discontinued in 2018. Analyses of these data will be forthcoming in the 2020 CCO Annual Report.

OTHER AQUATIC INDICATORS

Kezar Lake Sediment Core Study, 2015

One of the most effective ways to understand the long-term effects of climate change on lake ecosystems is to compare past conditions with current ones. Since sediments that accumulate at the bottom of a lake are the result of the biological, geological, and climatological changes within each lake's watershed, they provide a sequential record of past conditions in lake productivity, stratification, oxygenation, and material inflows from streams and watershed runoff. The sediment core study of Kezar Lake aimed to better link water quality with climate and land use and to determine which stressors have put Kezar Lake water quality at greatest risk for future impairment.

A full description of preliminary results was presented in the 2016 CCO Annual Report. No new analyses for the Kezar Lake cores were completed in 2019, so only a summary of major findings is presented below.

SUMMARY


Sediment core collection in June 2015. Photo Credit: KLWA.

- Natural processes affecting water quality within the Kezar Lake watershed were relatively stable until the Europeans arrived in the 1800's.
- The Europeans logged forests, plowed fields, raised farm animals, trapped beavers, and built roads, resulting in significant changes to the landscape.
- The Industrial Age added other stressors and pollutants, such as acid rain, heavy metals from the burning of fossil fuels, chemicals from fertilizers and other uses, and high-powered boats that create wakes and disturb bottom sediments.
- The synergistic effect of human activities and rising temperatures due to climate change is having a measurable impact on our environment.

MAJOR STUDY FINDINGS

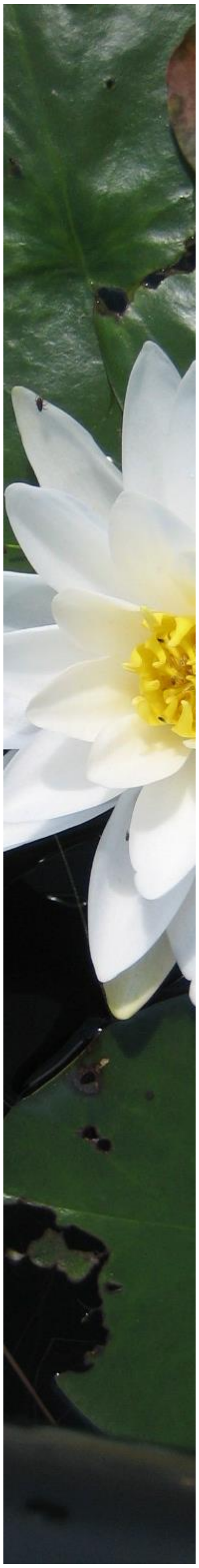
- Between A.D. 2000-2015, the sediment accumulation rate and organic content of both the deep spot of Kezar Lake and the area near Great Brook increased dramatically, likely the result of intensified watershed runoff and erosion from climate change effects, as well as possibly shoreline erosion due to boating activities. This recent intensification of larger-scale flood and erosion events caused a notable increase in particle-size and decrease in aluminum concentrations in lake bottom sediments at both sites. An alternative hypothesis for the increase in organic content in Kezar Lake may be enhanced soil organic matter solubility following recovery from acid rain deposition.
- Preliminary diatom results indicate that a marked change in algal composition accompanied the increase in sediment accumulation rates after 2008. This supports the idea that the lake is not currently as stable as it was just a decade ago.
- The particle-size record at the deep spot of Kezar Lake suggests that no large-scale events have occurred in the Kezar Lake watershed since the large hurricanes in the 1600's, despite forest clearances in the 1800's and fires in the 1930's. The Great Brook core record showed the influence of many smaller-scale events that are likely associated with minor flood events.
- The deep spot of Kezar Lake showed a steady rise in lead and zinc from the burning of coal and gasoline since the 1800's, then a sharp decline in the 1970's after the ban of leaded gas. The Great Brook core record did not show as sharp a decline in lead and zinc as at the deep spot, which may indicate a continued source of heavy metal contamination from dredged or disturbed lake sediments with legacy contamination.

Horseshoe Pond Sediment Core Study, 2019

Concerned with the marked increase in sediment accumulation rate (from increase in erosion rate) in Kezar Lake, the CCO collected a sediment core in Horseshoe Pond (minimally impacted from human activity) to compare to the Kezar Lake core as a way to determine whether increased sediment accumulation rate is likely due to direct human impact or climate change effects.

A team of KLWA/CCO volunteers took a sediment core from Horseshoe Pond on July 18, 2019 in collaboration with Plymouth State University (PSU). Supervised by Dr. Lisa Doner, PSU is doing a scientifically robust paleolimnology study of the Horseshoe Pond core and comparing results to their analyses of Kezar Lake's core samples. Noting differences between the two bodies of water may help us to better understand the increasing sediment accumulation rate and whether we can mitigate the increase. Results of this study should be available later in 2020.

Volunteers assisting PSU staff with collecting a sediment core from Horseshoe Pond in 2019. Photo Credit: KLWA.



Aquatic Plants

Warming water temperatures, longer growing seasons, and changing precipitation patterns will cause shifts in the extent and abundance of native aquatic plant species. Many aquatic plant species that thrive under cooler conditions will die out, giving opportunity for southern plant species to take root. This will cause a gradual change in aquatic plant species composition and distribution within the lake and ponds. Different aquatic plant species have varying levels of nutrient and water needs, a change in which will alter cycling dynamics within the lake and ponds. An immediate threat to Kezar Lake is the invasion of non-native plants that can outcompete native plants. This threat is being addressed by the Lovell Invasive Plant Prevention Committee (LIPPC). A list of aquatic plants native to waterbodies within the Kezar Lake watershed was compiled using data collected by the Lake and Watershed Management Association from 2011-2015, as well as published survey reports funded by the LIPPC. Cushman Pond has already been invaded by variable-leaf milfoil and efforts to eradicate this invasive have taken place over the last 20 years.

Fish

Fish, especially land-locked salmon, are a keystone species for the Kezar Lake fishing community, who have relied on abundant populations of coldwater fish for their recreational enjoyment. These coldwater fish species are extremely sensitive to changes in water temperature and chemistry. Coldwater fish will seek cold, deep areas of lakes, ponds, and streams to avoid warm surface waters in late summer. This can be problematic in productive lakes that have depleted oxygen in bottom waters, leaving little habitat for these fish species to survive. pH is particularly critical to fish species and other aquatic life as it affects their metabolic functioning and reproductive capacity. This is a concern for Kezar Lake and its ponds given the naturally-low buffering capacity of the soil and water in the watershed. Low-pH rain (5.0) will temporarily decrease the pH of surface waters, placing significant stress on aquatic organisms residing in those waters. If climate change enhances the frequency and duration of precipitation events, then sensitive fish populations may face high disturbance, low pH environments that may be fatal. Because of this, fish can be a good indicator of climate change and should be monitored.

As an invasive species in Maine, the northern pike is a voracious predator of other fish, frogs, crayfish, small animals, and birds. It was originally introduced into the Belgrade Lakes and resembles the native chain pickerel. There are no effective control mechanisms for this sport fish other than catch and kill. A compilation of invasive species of concern in Maine is provided in Appendix B, which provides a description and image of these invaders and lists sources for more information on each species' identification and mitigation.

Water Lily.
Photo Credit:
Don Griggs.

Aquatic Birds

Warmer air temperatures, variable precipitation patterns, and changes in vegetation will very likely reduce the abundance and diversity of aquatic bird species, including the iconic common loon. Earlier snowmelt means changes in seasonal duration and timing, which greatly impacts life cycles, including growth and survival rates of loons and other bird species. Monitoring these populations will help assess the effects of climate change on native species in the watershed.

In 2019, supported by a grant from the Stephen & Tabitha King (STK) Foundation, Loon Conservation Associates (LCA) continued a collaborative study with KLWA to conduct comprehensive common loon monitoring surveys in the Kezar Lake watershed. More than fifteen volunteers helped conduct over 450 independent surveys of seven waterbodies between 5/15/2019-8/30/2019. Out of sixteen documented territorial pairs, seven of twelve pairs successfully nested and produced ten chicks. Eight adult loons were captured and banded on Kezar Lake and ponds using traditional night-lighting techniques. Eight chicks survived to fledge (defined as more than six weeks of age). Overall productivity in the Kezar Lake watershed in 2019 was 0.50 fledged young per territorial pair. Three pairs used rafts to nest, two of which successfully hatched a chick. The rate of success was 66% for raft nesting loons compared to 50% for natural nests. These results were much improved from 2018 and indicate that the productivity of loons in the Kezar Lake watershed are above the 0.48 threshold needed to sustain a healthy loon population. Poor reproductive success is likely attributed to one or more causes, including predation, human disturbance, water level fluctuation, as well as contaminants such as lead (Pb) and mercury (Hg) and wintering hazards such as fishing nets and oil spills. High levels of Hg were measured in blood samples of an adult and chick in the upper bay.

Overall, the adult loon population at Kezar Lake has been constant with some annual changes in the last 36 years (Fig. 1). No statistically significant trend (based on Mann Kendall Trend Test) was found for either adults or chicks over the observation period.

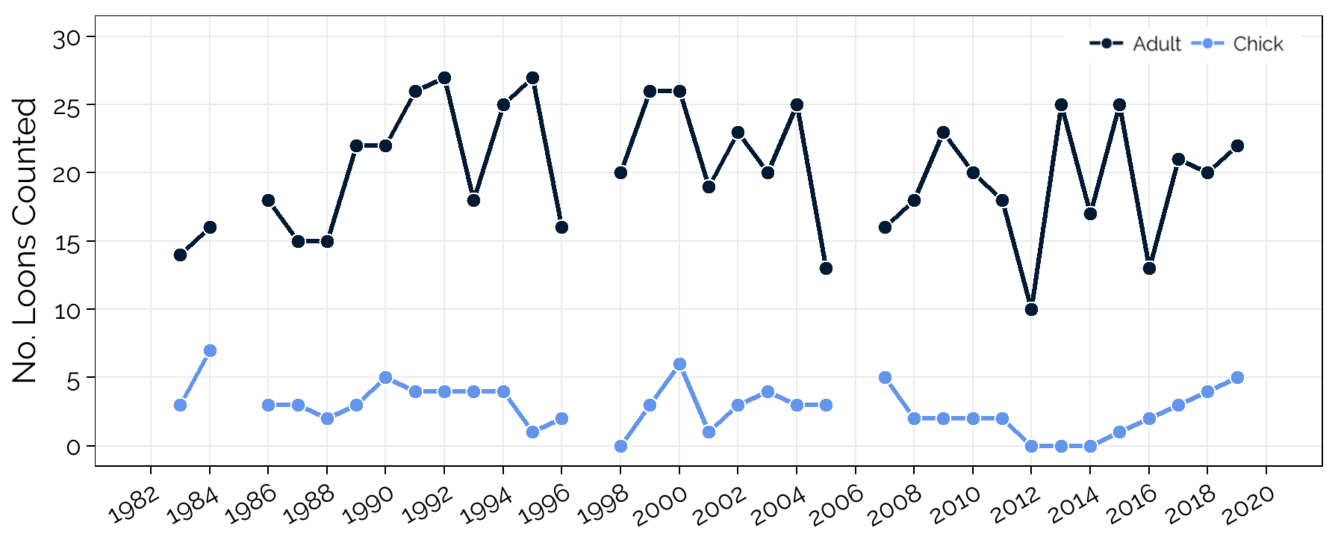


Fig. 1. Annual loon counts for adult and chick populations observed at Kezar Lake from 1983-2019.

The ponds have a much sparser data set:

- Based on 16 non-consecutive years of observations, Horseshoe Pond hosts an annual chick population varying from zero to three, and Farrington Pond hosts a few adult loons with only two chicks seen in 2016. One nesting pair was documented on Horseshoe Pond in 2019 with one successful chick fledging. One territorial pair with a nest was documented on Farrington Pond in 2019.
- Based on 20 non-consecutive years of observations, Heald Pond hosts an annual adult population varying from zero to three. The first chick was documented in 2015. One nesting pair was documented on Heald Pond in 2019, but the chick did not survive to fledge.
- Based on 31 years of non-consecutive observations, Cushman Pond hosts an annual adult population varying from zero to three. The first and only two chicks were documented in 2011. One territorial pair was documented on Cushman Pond in 2019.
- Based on 12 non-consecutive years of observations, Trout Pond hosts an annual adult population varying from zero to two. The first two chicks were documented in 2017. One nesting pair was documented on Trout Pond in 2019, and two chicks survived to fledge.
- Surveys were completed on Bradley Pond in 2019 but no loons were found.

Estimation of loon population in southern Maine conducted by the Maine Audubon shows an increase in loon population despite climate change impacts. The study suggests that if lakes are clear, the food supply is abundant, and any adverse human impacts are avoided, the loon population will likely remain stable and/or increase.

Nest camera captured loon defending nest from snapping turtle, Kezar Lake, Outlet River Marsh, 2018.
Photo Credit: KLWA, Loon Conservation Associates.

SPECIAL REPORT: Climate Change Impact on Loons

Mark A. Pokras, **DVM,** *Associate Professor Emeritus, Wildlife Clinic & Center for Conservation Medicine, Cummings School of Veterinary Medicine, Tufts University*

Climate change is likely to impact the well-being of our loons, sooner or later. Dr. Mark Pokras, who consulted on our loon study, has offered some observations on how loons are likely to be impacted by variations in ambient air temperature and increased pathogens because of climate change.

Dr. Pokras is concerned about our loons' ability to tolerate higher air temperatures. On water, loons can dilate blood vessels on their feet and dump excess body heat into the water, but on land during nesting, loons, chicks, and developing eggs become less tolerant of or adaptive to elevated air temperatures. Adult loons have thick, insulating plumage that allows them to stay warm in icy lake waters in early spring and frigid oceans in winter, but that may become too much insulation when sitting on nests out of water in warmer summer months. Loons can erect their feathers, alter posture, or vasodilate the vessels in their foot webbing to try to dissipate some heat when on land, but observers have noticed more adult loons on nests vigorously panting to try to cool themselves. If adult loons leave their nests to cool off in the water, this leaves the developing eggs more susceptible to predators and overheating (especially with their dark shells).

Successful incubation and hatching of eggs must occur within a narrow range of temperature and humidity so that the developing eggs can breathe and metabolize. Gas and water vapor must be able to move back and forth through the eggshell and shell membranes to support adequate respiration, growth, and development of the embryo. The size and number of microscopic pores in eggshells that allow this diffusion of gases are specifically adapted to the loons' metabolic needs and determine the preferred range of temperature and humidity for loon egg incubation. Environmental contaminants that bioaccumulate in adult loons can alter egg properties, such as the size and number of pores or the thickness of shells, and lead to embryonic death. Increasing air temperatures can speed up embryo metabolism needs, triggering increased rates of gas and water vapor diffusion through the eggshell. If increased metabolic needs outstrip the permeable capacity of the eggshells, developing embryos will die. If air temperatures increase too quickly for a species to evolve, then we might expect more embryonic deaths, most likely late in development. For example, for some ducks and geese, optimal incubation temperature is around 37.7 °C with 50-55% humidity. Air temperatures just a couple of degrees higher can kill embryos in 15-30 minutes, depending on the species and stage of development.

Changes in air temperatures and moisture can also increase the potential for infectious diseases and parasites. Several studies support the observation that southern pathogens and parasites, some of which carry diseases, are moving north into new territory. Mosquitoes, biting flies, and ticks are most prone to migrate and spread diseases. In recent years, a significant increase in the incidence of avian malarial parasites in loons (with one direct mortality) and thorny-headed worms (*Acanthocephala)* have been documented. Preliminary evidence shows that fungal respiratory disease may be increasing in loons. The first case of a fatal fungal disease, *Cryptococcus*, was reported in New York. There is speculation that some parasites (like thorny-headed worms) are being carried in by invertebrate hosts introduced to New England lakes. These pathogenic risks to loons are still unknown but will likely have a significant impact on New England loon populations. We must be vigilant in keeping watch over the health of the loons and notify officials of any cases so that the spread of these pathogens and parasites can be tracked.

Zooplankton

Zooplankton play an important role in a lake's ecosystem and are useful indicators of food web stability. As microscopic animals that consume phytoplankton, zooplankton serve as a valuable food source for fish. KLWA supported a study of zooplankton in Kezar Lake from 2004-2007, the results of which were published in a 2008 article titled, "Cladoceran and copepod zooplankton abundance and body size in Kezar Lake, Maine (MIDAS 0097)" by Nichole M. Cousins and Katherine E. Webster from the School of Biology and Ecology at the University of Maine, Orono. The results of the study show that the zooplankton population in Kezar Lake was consistent during the sampling period and can be used as a baseline for future studies. The CCO supports future zooplankton studies to assess long-term trends in zooplankton population because of climate change or other stressors.

Mollusks & Crustaceans

KLWA supported a brief study of crayfish in Kezar Lake in August-September 2008. The study was conducted by Dr. Karen Wilson at the University of Southern Maine. The study found three native species and caught a total of 29 crayfish, which were mostly found around rocky islands. The spatial and temporal sample size were too small to gain any significant conclusions on population size, species composition, or size trends. No evidence of invasive crayfish was found. Anecdotal evidence suggests that the crayfish population has declined in Kezar Lake. The CCO supports a new, more comprehensive, crayfish study in the future.

Invasive aquatic mollusks and crustaceans on Maine's watch list include some that have already invaded Maine's waters like the Chinese mystery snail, as well as others that are poised to invade in the future, such as the spiny water flea, zebra and quagga mussels, Asian clam, rusty crayfish, and the Chinese mitten crab. A compilation of invasive species of concern in Maine is provided in Appendix B, which provides a description and image of these invaders and lists sources for more information on each species' identification and mitigation.

Insects & Pathogens

Warmer water temperatures, along with increased population growth, will increase the risk of aquatic pathogens, including bacteria, protozoa, and parasites. While it is difficult to control the spread of these pathogens due to climate change, we can make sure proper waste disposal techniques are used for all existing and future development in the watershed and along the shoreline of Kezar Lake and its ponds.

LAND

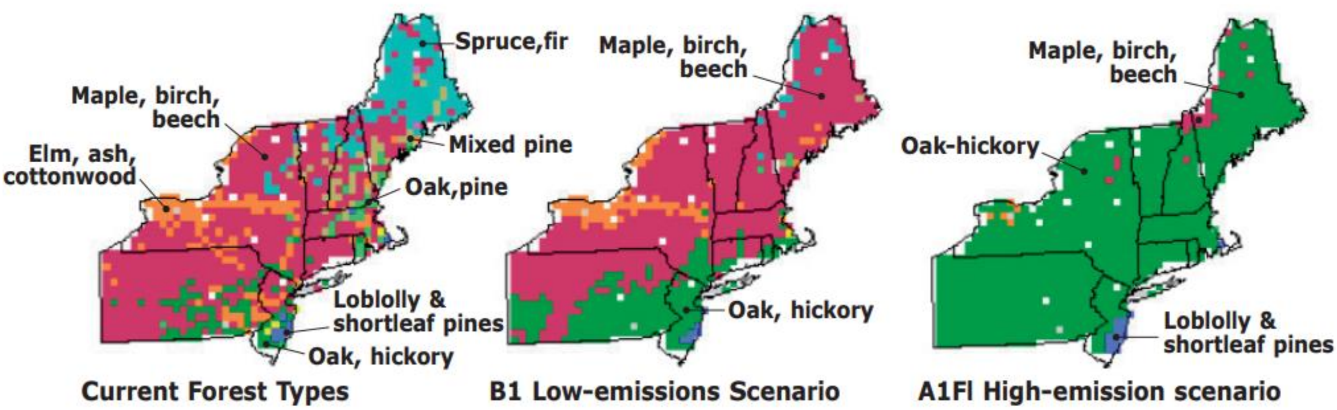
Climate affects the abundance, extent, and diversity of all life on the planet – plants and trees, birds, mammals, and insects and pathogens. As the climate changes, terrestrial species will need to adapt to or move from these changing environments. Two-thirds of Maine's animal and plant species are predicted to be at risk from climate stress. We can watch for change in these populations as indicators of climate change. The CCO intends to collaborate with existing phenology networks across the country to better understand the periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors.

An outstanding, detailed climate change vulnerability assessment of Maine's wildlife species of greatest conservation need has been published by the Manomet Center for Conservation Sciences, titled *Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species*[5]. This will serve as an excellent resource for the CCO as we formulate adaptation strategies.

Plants & Trees

Earlier and warmer summers will continue to lengthen the growing season, which has already increased by two weeks since 1950 (mostly due to later frosts in the fall). But potentially more days above 90 degrees, variable precipitation patterns (with wetter and cooler springs), and unpredictable frost conditions may mitigate any benefits for farming in the region. Watermelon, tomatoes, peppers, peaches, and others will benefit from higher air temperatures, but corn, wheat, and oats will have lower yields. Cabbage, potato, apples, blueberries, and winter wheat that need cool weather and cold winters will also decline. Flowering, fruit set, and seed production will decline in many species due to loss of pollinators.

Warming air temperatures and changing precipitation patterns will cause shifts in the geographic extent of native plant and tree species in the area. Many plant and tree species that thrive under cooler, drier conditions will die out, giving opportunity for southern plant and tree species to take root. This will cause a gradual change in plant and tree species composition and distribution within the watershed. For example, spruce and fir will move farther north and to higher elevations. The sap season for maples will come earlier and sugar maples may be restricted to northern Maine. Different plant and tree species have varying levels of nutrient and water needs, a change in which will alter ecosystem cycling dynamics.



Adapted from Rustad et al. (2014), Figure 7. **Current and projected suitable habitat for major forest types in New England under low and high emissions scenarios. Under the low emissions scenario, conditions will favor maple-birch-beech forests, while under the high emissions scenario, conditions will favor oak-hickory forests. Kezar Lake watershed is currently in an area dominated by mixed pine, oak-pine, and maple-birch-beech. This will transition to maple-birch-beech and oak-hickory under various climate change scenarios.**

[5] https://www.manomet.org/sites/default/files/publications_and_tools/2013%20BwH%20Vulnerability%20Report%20CS5v7_0.pdf

University of Maine studies over the last 30 years show that, due to increased temperatures and precipitation, the abundance of beech trees have increased at the expense of birch and maple in the forests of the northeast, notably in the White Mountains, echoing other work that environmental changes are squeezing out important tree species. Beech, often used for firewood, is a less valuable commodity than hardwoods used for furniture and flooring.

Joshua Halman, a Forest Health Specialist with the Vermont Department of Forest, Parks and Recreation, has been monitoring trees in Underhill State Park for 25 years by recording color change and leaf drop. These data show that the timing of peak color and leaf drop have come later in the season by about eight days in the last 25 years. Comparable data are not available for Lovell; however, Underhill State Park is at approximately the same latitude, and therefore, can be extrapolated as relevant to the White Mountain National Forest and the Kezar Lake watershed.

In 2004, a survey was undertaken to document non-native and invasive species on all GLLT-owned properties. Surveys documented the presence of non-native species sheep sorrel (*Rumex acetosella*) and coltsfoot (*Tussilago farfara*). While some might consider these plants to be invasive, they are not often targeted for management efforts. Later that year, GLLT conducted surveys in the town targeting areas where invasive plants would most likely occur, such as power lines, roadsides, logging roads, informal camping spots, playing fields, and disturbed areas. Japanese knotweed (*Fallopia japonica*), sheep sorrel, coltsfoot, black locust (*Robinia pseudoacacia*), and non-native honeysuckle (*Lonicera sp.*) were detected during these surveys. Of all observed non-native plants, Japanese knotweed was observed to be the most pervasive. GLLT also surveyed 12 private properties, which revealed the presence of additional non-native invasive plants, including Japanese barberry (*Berberis thunbergii*), non-native honeysuckle, autumn olive (*Elaeagnus umbellata*), asiatic bittersweet (*Celastrus orbiculatus*), and purple loosestrife (*Lythrum salicaria*). Anecdotally, Tom Henderson of GLLT reported that an infestation of purple loosestrife was also found on a member's property but was eradicated. Other non-native, invasive plant species known to occur in neighboring towns include glossy false buckthorn (*Frangula alnus*) and yellow iris (*Iris pseudacorus*).

Non-native and invasive species are an increasing concern in Maine because of their potential to outcompete native species and upset the native ecosystem. Maine has identified 33 invasive terrestrial plants that are illegal to import, export, buy, or intentionally propagate for sale, including Japanese barberry and asiatic bittersweet. The State of Maine takes responsibility for combating the spread of invasive plants with integrated management tools such as prescribed fire, mechanical treatments, and herbicides. A compilation of invasive species of concern in Maine is provided in Appendix B, which provides a description and image of these invaders and lists sources for more information on each species' identification and mitigation.

Birds

Bird counts and movements can be monitored easily and can serve as an indicator of climate change. Changes in air temperatures and precipitation amounts can shift habitat ranges and limit mating and nesting seasons. Late spring storms can kill migrating birds and cause behavioral shifts. Available food sources can change, forcing birds to find new suitable habitat. Birds in the Kezar Lake watershed that are most likely to decline due to climate change include the Black-capped Chickadee (Maine State Bird), Evening Grosbeak, Ruffed Grouse, Wood Thrush, and all highelevation species. Birds that may increase or move into Maine include the Tufted Titmouse, Canada Goose, House Finch, Brown-headed Nuthatch, and Loggerhead Shrike.

Long-term (1966-2010) and short-term (2000-2010) population trends based on data from the North American Breeding Bird Survey for 5 songbird species in Maine (and likely within the Kezar Lake watershed) showed two species declining (Barn swallow and Bobolink), one species stable (Ovenbird), and two species increasing (Northern Cardinal and Tufted titmouse). Under the high emissions scenario, western Maine is projected to show a net increase in bird species richness as a warming climate allows southern species to invade (Rustad et. al. 2014).

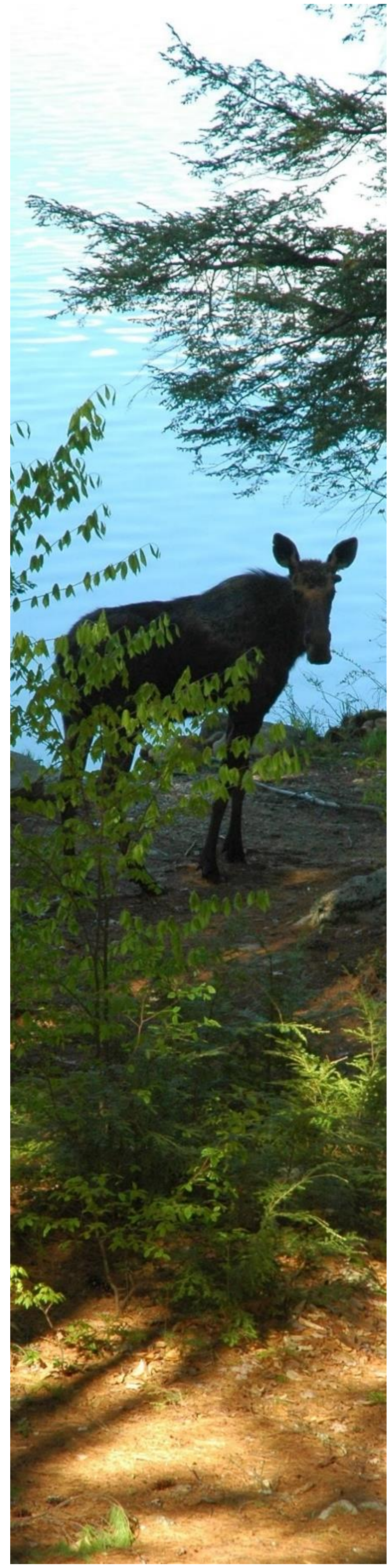
A study by the National Audubon Society found that more than 50% of Maine's 230 bird species are at risk from climate change as more than half of their current range will be lost.

Mammals, Reptiles, and Amphibians

Moose are an iconic mammal in Maine and a local inhabitant of the Kezar Lake watershed. This iconic species is vulnerable to heat stress and ticks that proliferate following mild winters. Moose studies have shown that ticks are killing 70% of calves in Maine and New Hampshire due to mild winters. The observed decline of moose in Maine from disease or migration north is a clear signal of climate change.

Attempts by the KLWA to find detailed information on historical moose populations in Lovell were not successful (this included an evaluation of the Statewide permit and harvest data). The last estimate of moose population was in 2012 when the State of Maine reported a population of 76,000. While hunting permit numbers are not linearly related to the total population, Maine Inland Fisheries and Wildlife (MIFW) reports moose harvests by individual towns. Very few moose harvests have been recorded in Lovell with the maximum in 2009 at only two individuals. Moose are also unevenly distributed throughout the State and primarily occupy the commercial forestlands in northern Maine. The state division that includes Lovell (Division 15) receives 25 permits per year and reports approximately a 50% success rate (ranging from 24% - 60% historically).

Detailed statewide information is needed to make assessments of the moose population in Lovell. Unfortunately, data on other mammals, such as bear, deer, and wild turkey are also limited. Generally, bat populations are declining from white nose syndrome (some areas like Vermont by as much as 90% in the last decade). MIFW has more information regarding these mammals on their website.



Moose in the Kezar Lake watershed. Photo Credit: KLWA.

Insects & Pathogens

With the onset of climate change, more warm and wet weather pests are moving into New England. Migratory insects are arriving earlier with earlier snowmelt and rising air temperatures, and insects that are only marginally-adapted to the region are beginning to invade as the climate warms. Increases in balsam woolly adelgid, spruce budworm, Beech bark disease, and winter moth are already causing serious injury and death of large tree populations. Inadequate winter chill will adversely affect agriculture by increasing populations of insects and disease, including flea beetle and Steward's wilt. Wetter conditions will also increase the likelihood of white pine needle disease caused by pathogenic fungi.

Maine has been invaded by many exotic and destructive species beginning with the colonization of the North American continent via the import, both accidental and deliberate, of European and Asian species. Non-native invasive species compete for natural resources and alter the native dynamics of forests, wetlands, rivers, lakes, and ponds. Some of these non-native species have been in New England since the beginning of colonization but most have arrived in recent decades by the increase in overseas and local commerce. They spread mainly by transport on boats, trucks, birds, animals, and plants. Changing climatic conditions, including shorter winters, reduced snowpack, and increased air temperatures, allow increased survival of non-native species and expedite the spread of more southern species into New England. Before European settlement, insect and disease outbreaks in forests were caused by native species such the spruce budworm and forest tent caterpillar. More recently, insect and disease outbreaks have occurred at an increasing frequency because of the introduction of non-native insects and disease agents. The introduction of the hemlock woolly adelgid insect has caused complete mortality of eastern hemlock in parts of Massachusetts and Connecticut, and this damaging pest has now crossed the Maine border. In addition to damaging insect pests, the introduction of earthworm species by the colonists into previously-glaciated regions of the northeast has dramatically altered soil composition and structure, changed organic matter decay rates and processes and made seedbed and germination conditions less favorable for some native plants.

Of great concern is the invasive emerald ash borer (*Agrilus planipennis*), which was first seen in northern Aroostook County, Maine in the spring of 2018. Several more sightings were reported in western York County, Maine in the fall of 2018. The emerald ash borer (EAB) is an Asian, wood-boring beetle that has cleared a destructive path in 45 states (including the entire eastern seaboard, except Florida) and four Canadian provinces. It likely hitchhiked to North America across oceans in packing crates and shipping materials (Cappaert, Mccullough, Poland, & Siegert, 2005). It is the lifecycle of EAB that is so perilous for trees. The adult beetle lays its eggs in the cracks of ash trees (*Fraxinus sp.*). When the eggs hatch, the larvae burrow into the tree and feed on the inner bark and phloem, which disrupts the transport of nutrients and water throughout the tree. The beetle's eating pattern creates distinct "S"-shaped carvings in the bark. In Maine, there are three species of ash trees, and this beetle poses a threat to all of them. Preference is given to black and green ash (*Fraxinus pennsylvanica* and *Fraxinus nigra)* and to trees that are already compromised or sick. When trees are infected, leaves sprout from roots and trunks, bark splits, and the canopy dies.

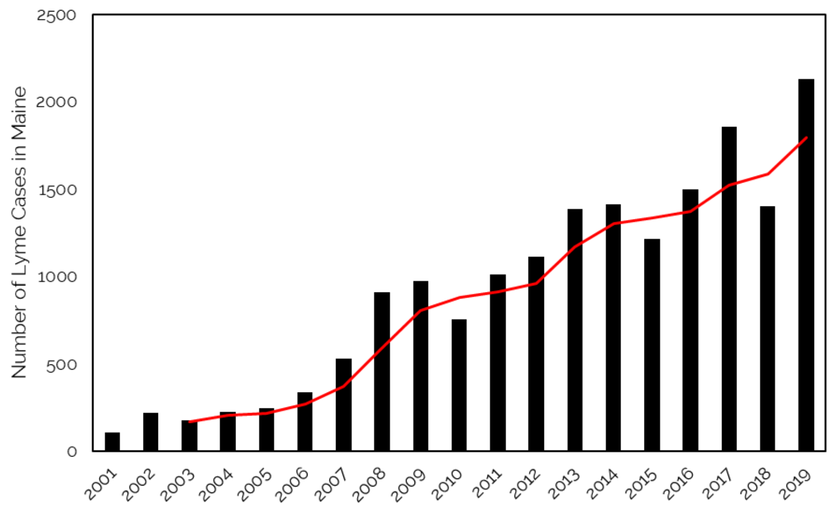
Loss of black ash trees in Maine will not only have ecological impacts but cultural impacts as well. The black ash tree is a cultural keystone species and an important economic resource for the Wabanaki people, who use black ash trees for basketmaking.

Communities have learned a lot in the last seventeen years since EAB was first sited in the Midwest in 2002. Although climate change is enhancing the EAB's preferred habitat into northern regions like Maine, Maine is also in a unique place to have a delayed invasion of EAB by taking advantage of research and trial and error management strategies used in other states. Non-infested communities should monitor and prepare for the spread of the invasive beetle to ensure early detection and action. Sticky, purple traps can be set out to trap and monitor for the EAB. Woodpeckers and wasps are natural predators and natural monitors for the EAB because they feed on the EAB and will increase activity on host trees. Firewood has been cited as the predominant mode of travel for the EAB, so it is critical that vacation communities like those of Kezar Lake be extremely vigilant about people bringing in firewood from other places in Maine or other states. When the EAB is found in an area, property owners or land managers can selectively harvest ash trees to reduce the food source and employ biological controls on the EAB, such as increasing the populations of native woodpeckers and native or imported parasitic wasps.

The Surveillance, Outreach, Involvement section on Maine's EAB page (www.maine.gov/EAB) provides a wealth of resources for getting involved with state-wide monitoring efforts. The State of Maine takes responsibility for the mitigation of invasive insects with integrated pest management tools, including prescribed fire, mechanical treatments, and herbicides. If Maine communities work together, it is possible to mitigate the risks associated with these invasive insects to ensure sustainable native populations and tree resource for decades to come.

A compilation of invasive species threatening Maine is provided in Appendix B, including aquatic fauna, wetland plants, algae, forest fauna, and forest insects. A description and image of each invader is provided, along with sources for more information on each species' identification and mitigation.


Emerald ash borer and S-shaped tunnels shown with a nickel for scale (left). Ash tree with crown dieback and epicormic shoots (middle). Monitoring for emerald ash borer using a sticky, purple trap (right). Photos: maine.gov (left, middle), usda.gov (right).



The number of Lyme disease cases in Maine is rising. Data were obtained from the Centers for Disease Control and Prevention (CDC).

The Maine Center for Disease Control and Prevention (Maine CDC) data shows that the number of reported Lyme disease cases in Maine is increasing. This increase in reported cases is likely due to a combination of climate-induced factors. Warming air temperatures (especially in winter), more precipitation, a longer growing season, and a proliferation of their primary hosts (mice, chipmunks, and other small mammals) are promoting the northern migration of and thus increasing populations of disease-carrying ticks in the state. Although deer, moose, and other large mammals are also hosts to ticks, small mammals are considered their primary hosts and generate a far greater threat to humans because small mammals live closer to where we live, work, and play.

Deer ticks carrying Lyme disease can be found in wooded areas or open, grassy areas, especially along the edges of forests. To best control tick populations around your property, clear brush and leaves and deter deer, mice, and chipmunks. Be vigilant in checking for ticks and seek immediate medical help if you were bitten by a deer tick. Lyme disease can be easily treated with antibiotics, but if left untreated, can cause severe illness, arthritis, and neurological problems.

There are several other tick-borne diseases that threaten public health and may increase with a changing climate. These include anaplasmosis, babesiosis, ehrilichiosis, powassan virus, spotted fever rickettsiosis, as well as other less common diseases. Each of these has shown an increase over the years, especially anaplasmosis. A study conducted by the University of Maine's Cooperative Extension Tick Lab found that 40% of the 2,000 deer ticks tested in 2019 were positive for Lyme disease (8% were positive for anaplasmosis and 16% were positive for babesiosis).

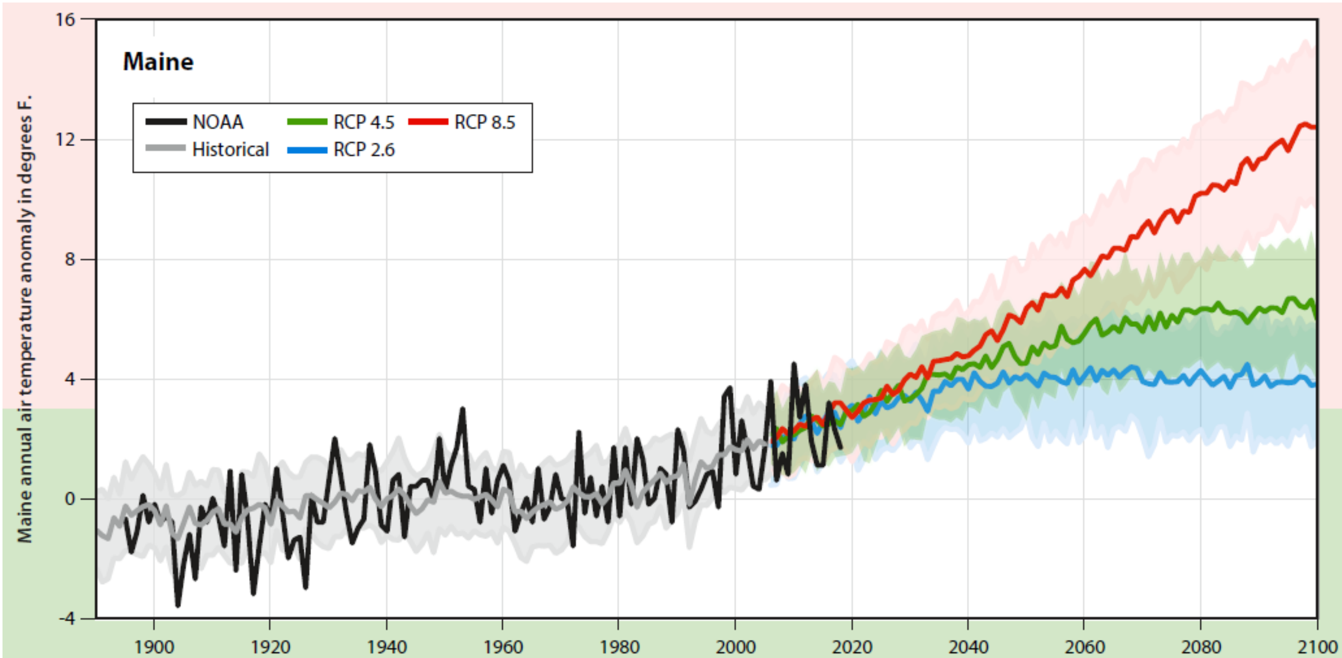
For more information on prevention and treatment, please visit https://www.cdc.gov/ticks and http://www.maine.gov/dacf/php/gotpests/bugs/ticks.htm. Ticks can be submitted to the University of Maine's Cooperative Extension Tick Lab to be tested for a small fee. Contact the lab by emailing tickID@maine.edu or by calling 207-581-3880.

ANNUAL REPORT ON FUTURE PROJECTIONS

Just as important as it is to look back on historical observed trends to understand where we are today with respect to climate change conditions, it is also important to look ahead at future projections to prepare for where we will be in the future. The *Maine's Climate Future 2020 Update* warns of a "great acceleration" in climate change that we are experiencing both in Maine and around the world. Each passing year sets a record for hottest global air or ocean temperature or highest rate of melting polar sea ice and arctic permafrost. As climate models are updated with new information, revised projections point to an even warmer earth than previously thought. This phenomenon is likely due to the positive reinforcement of three simultaneous factors: "1) we are still increasing the emissions of greenhouse gases to the atmosphere, 2) governments are cleaning up other air pollutants faster than are being accounted for in the climate models, and 3) the planet may be entering a natural warm phase." Given this, we are at a critical time in history when we must make massive reforms to our way of life in order to adapt to these unpredictable and challenging conditions.

The figure on the following page depicts Maine's Temperature Future. The green projection line shows moderate change in air temperature and can be described as follows:

> "With moderate controls on greenhouse gas emissions, warming in Maine still results in a 5 °F increase by 2050, and 6.5 °F by 2100. Maine cities experience 14–23 more high heat index days, when it feels like 90 °F or hotter (Dahl et al. 2019). Warm climate insects and pathogens spread, with hundreds of more cases of West Nile Virus each year (EPA 2017). Precipitation continues to increase in frequency and intensity, and to shift from snow to more rain. The snowpack will likely be reduced by 50 percent by 2100 for the southern half of the state, or one-third fewer snow days; northern Maine experiences 12 percent fewer snow days. The majority of the losses in the snowpack will occur at the beginning of the spring season, which might have direct impacts on spring streamflow peaks (Demaria et al. 2016). The Gulf of Maine in 2050 is 1.5 °F warmer, which is similar to conditions in 2010. In this climate, 2008 would be a cool year, and 2012 would be warm, but not extreme (Gulf of Maine 2050). Sea level rises at least 1 foot by 2050, leading to a tenfold increase in flooding to 98 events per year in Portland; by 2100, sea level could rise between 3.6 and 6.5 feet (Slovinsky 2019; Sweet et al. 2017), the latter being the recommended scenario for planning purposes, given uncertainty in the contributions of melting ice sheets to global sea levels (Bamber et al. 2019)."



"Statewide annual temperature anomalies (departure from average), 1895-2018 (black line) and 2006-2100 model-projected (gray and colored lines) under different emissions scenarios or Representative Concentration Pathways (RCPs) from the Coupled Model Intercomparison Project Version 5 (CMIP5) (Taylor et al. 2012). RCP numbers indicate the projected radiative forcing (W/m^2) on the climate system from greenhouse gas emissions by the year 2100. Colored lines represent multi-model means (one ensemble member per model) for each RCP, whereas the corresponding spread denotes the standard deviation from the mean as calculated from all utilized model outputs. The number of available models is different for each RCP: 32 (RCP 2.6), 42 (RCP 4.5), and 39 (RCP 8.5). The gray line and shaded area represents the multi-model CMIP5 historical simulation (38 models). Observational values shown in black are from the NOAA U.S. Climate Divisional Database (NOAA CAAG). FutureCMIP5 multi-model temperature time series were obtained using the KNMI Climate Explorer for land-only grid cells spanning Maine."

The following draws extensively from *Maine's Climate Future 2020 Update*, which highlights the major natural resource-based economic areas in Maine: farms, forests, tourism, and recreation.

FARMS

The farming community has shown incredible resilience to changing growing conditions in the last century. Farmers will continue to adapt to new growing conditions through regenerative agriculture, aquaculture, conservation tillage, improving soil health, and other practices. There may one day be state financial incentives to assist farmers with making transitions to these practices.

Adaptation Approaches

- Use of targeted weather products (such as Ag Radar for apple growers) and more accurate weather forecasts help farmers to mobilize faster to protect crops from unfavorable weather conditions.

- Use of raised bed systems, smaller fields, berms, and fast-growing turf grass species to prevent erosion and adapt to variable wet/dry conditions.
- Use of drought-resistant pasture grass.
- Elimination of vegetable crops not suited for cool, wet springs.
- Use of four-wheel drive turf harvesters better made for maneuvering on wet fields.
- Use of irrigation systems and cover crops to enhance soil health.

FORESTS

Maine's forests are projected to look much different by the end of the century, with spruce, fir, and sugar maple being pushed out of the state. Though the impact from the spread of insect pests, deer browsing pressure, and invasive species on trees makes projections rather uncertain.

Adaptation Approaches

- Use of climate-adapted trees in regeneration or restoration projects.
- Control for invasive species to make room for native species.
- Management of forests for carbon sequestration and storage.

TOURISM & RECREATION

Maine's tourism and recreation will be much different in the future, most especially winter recreation activities such as skiing and ice fishing. These winter businesses are already making plans to expand into off-season opportunities to cover expenses and lost revenue with a shrinking winter season. Warming stream temperatures will greatly diminish the habitat range of cold-water fish species relied on for recreational fishing. Some of the remaining strongholds for cold-water fish species like salmon and trout will be in the White Mountains of western Maine, making Kezar Lake's watershed of utmost importance for fish habitat restoration and monitoring.

Adaptation Approaches

- Expansion of business venues in off-season.
- Maintenance of critical cold-water fish habitat in western Maine.

CLIMATE CHANGE REFERENCES

The following table provides references to key documents related to climate change.

ARTICLE TITLE	DATE	DESCRIPTION	LINK
Maine Adaptation Toolkit	Updated Regularly	An online resource providing a centralized source for information related to implementing climate adaptation measures or strategies.	https://www.maine.gov/dep/sustainability/climate/adaptation-toolkit.html
World Meteorological Organization Statement on the State of the Global Climate	Annual Update	Each year, the WMO issues a Statement of the Global Climate based on data provided by the National Meteorological and Hydrological Services and other national and international organizations.	https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate
Maine's Climate Future	2020	Assessment of climate change and key indicators in Maine	https://climatechange.umaine.edu/wp-content/uploads/sites/439/2020/02/Maines-Climate-Future-2020-Update-3.pdf
IPBES Global Assessment on Biodiversity and Ecosystem Services	2019	Impact assessment of human activities and climate change on species diversity and services globally.	https://ipbes.net/sites/default/files/ipbes_global_assessment_chapter_2_2_nature_unedited_31may.pdf
National Audubon Society: How Climate Change Will Affect Maine's Birds	2019	Interactive webpage that highlights climate change impacts to bird species in Maine.	https://www.audubon.org/climate/survivalbydegrees/state/us/me
National Audubon Society: Survival by Degrees: 389 Bird Species on the Brink	2019	Full report that assesses the vulnerability of birds across North America to climate change.	https://www.audubon.org/sites/default/files/climatereport-2019-english-lowres.pdf
IPCC Report	2018	Provides information on the impacts and associated risks of global warming by 1.5 deg. C, and how to strengthen the global response to climate change.	https://www.ipcc.ch/sr15/

ARTICLE TITLE	DATE	DESCRIPTION	LINK
Fourth National Climate Assessment	2018	Details climate change impacts on topics such as communities, economy, health, infrastructure, ecosystems, and oceans in 16 national-level topic chapters, 10 regional chapters, and 2 chapters focused on societal response strategies.	https://nca2018.globalchange.gov/
New England and Northern New York Forest Ecosystem Vulnerability Assessment & Synthesis: A report from the NE Climate Change Response Framework project	2018	Evaluates the vulnerability of forests across the New England region under a range of future climates. It synthesizes information on the contemporary landscape, provides information on past climate trends, and describes a range of projected future climates.	https://www.nrs.fs.fed.us/pubs/55635
Northern Institute of Applied Climate Science	2018	Develops synthesis products and pursues science on climate change, carbon science and management, and bioenergy.	https://www.nrs.fs.fed.us/niacs/
U.S. Forest Service Transportation Resiliency Guidebook	2018	Describes vulnerabilities within the FS Transportation Network due to climate change impacts and highlights ways of implementing those strategies through FS plans and programs.	http://onlinepubs.trb.org/onlinepubs/Conferences/2017/Parks/Cruz.pdf
The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment	2016	Interactive online assessment by the U.S. Global Change Research Program that examines how climate change is already affecting human health and the changes that may occur in the future.	https://health2016.globalchange.gov/
EPA Climate Change Indicators in the US	2016	Communicates information on the science and impacts of climate change, assesses trends in environmental quality, and informs decision-making	https://www.epa.gov/sites/production/files/2016-08/documents/climate_indicators_2016.pdf

ARTICLE TITLE	DATE	DESCRIPTION	LINK
Climate Change in Southern New Hampshire	2014	Describes how the climate of southern NH has changed over the past century and how the future climate of the region will be affected by a warmer planet due to human activities	https://sustainableunh.unh.edu/sites/sustainableunh.unh.edu/files/images/southernnhclimateassessment2014.pdf
Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species	2014	Summarizes a climate change vulnerability assessment of Maine's wildlife Species of Greatest Conservation Need, state-listed Threatened or Endangered plant species, and Key Habitats of the Maine Comprehensive Wildlife Conservation Strategy	https://www.manomet.org/sites/default/files/publications_and_tools/2013%20BwH%20Vulnerability%20Report%20CS5v7_0.pdf
Lakes as Sentinels of Climate Change	2014	Lakes are effective sentinels for climate change because they are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2854826/
New Hampshire Ecosystems and Wildlife Climate Change Adaptation Plan	2013	Strategies to address vulnerabilities from climate change in NH.	http://www.town.hillsborough.nh.us/sites/hillsboroughnh/files/file/file/eco_wildlife_cc_adapt_plan.pdf

FUTURE PLANS

CCO plans for 2020 include the following activities:

- Continue to develop and expand the climate change portion of the KLWA website to include more trend data, especially information on parameters for climatology, flora, and fauna.
- Continue to improve the easy public access to climate change data and trends.
- Analyze and date the sediment core samples collected from Horseshoe Pond to determine the rate of sediment accumulation for comparison to the data from Kezar Lake.
- Continue to collect and archive year-round local weather data and provide webcam views of the lake and land conditions as a service to the community.
- Expand collaboration with other organizations involved with climate change monitoring.
- Continue to research and gather data pertinent to climate change in the watershed.

SUMMARY & RECOMMENDATIONS

Climate change is a real and imminent threat to our local, regional, and global ecosystems, most especially our treasured lakes. Lakes are recognized as "sentinels of climate change" because their physical, chemical, and biological responses to climate change can provide the first signal of the effects of climate change. In New England, we can expect warmer air temperatures, more intense and frequent precipitation events, increased flooding, reduced snow cover duration, enhanced species migration and extirpation (including increased prevalence of disease-carrying ticks), and earlier lake ice-out. In reaction to these predictions, a Climate Change Observatory (CCO) was established with the objective to analyze the long-term effects of climate change on atmospheric, aquatic, and terrestrial ecosystems in the Kezar Lake watershed.

The CCO has accomplished a great deal since its establishment in 2013. To continue this vitally important work, the following adaptation and mitigation strategies are recommended for the Kezar Lake watershed community. Both adaptation (i.e., changing behavior/actions in response to the impacts of climate change) and mitigation (changing behavior/actions to reduce the causes of climate change) strategies are needed to effectively address climate change.

ADAPTATION & MITIGATION RECOMMENDATIONS

ACTIONS FOR THE TOWN OF LOVELL

- Improve infrastructure (roads, ditches, swales, culverts) to accommodate higher and more frequent stormwater flow volumes.
- Replace the remaining high priority culverts identified by the 2015 culvert study.
- Establish a Climate Change Information link on the town website that links residents to important climate change information and the KLWA/CCO webpages.
- In developing the next Comprehensive Plan: 1) include provisions to deal with projected climate change-induced weather events and conditions (e.g., upgrading infrastructure); 2) include language that ensures development occurs in a sustainable and low-impact way to increase watershed resiliency to extreme weather events and prevent potential polluted

runoff; 3) include current and projected flood risk maps for residents with homes in low-lying areas; 4) consider rezoning the projected flood zone for non-development; 5) add Low Impact Development (LID) description to ordinance and require LID in site design, especially for lots with >20% imperviousness; 6) increase setback distances to at least 100 ft. around vernal pools, streams, and wetlands; and 7) encourage conservation subdivisions, where applicable, with common open space and require land trusts or conservation organizations (not homeowner's associations) to undertake stewardship of common open space in conservation subdivisions.

- Review and update local septic ordinances to include the following: 1) require septic systems to be evaluated and upgraded to current code or replaced, as needed, for any sale or exchange of property ownership or upon a system failure; 2) require proof of septic system pump-outs every 3 years (unless given an approved waiver for limited use).
- In conjunction with KLWA, conduct a shoreline survey of properties on Kezar Lake and ponds to identify conduits of stormwater runoff (e.g., driveways, boat ramps) and develop specific recommendations for mitigation of erosion.
- Continue the outstanding progressive watch programs that help prevent and control invasive plants, especially the LIPPC program.
- Encourage local foresters to lookout for infestations of the emerald ash borer.
- Support state, county, and local efforts to prohibit the use of out-of-state firewood to prevent the spread of the emerald ash borer.
- Post signage to encourage anglers to use non-lead sinkers and to retrieve fishing line caught in shoreline vegetation. Install "Get the Lead Out" boxes at Town landings for disposing of lead-based fishing gear. Support KLWA guidelines for keeping large boat wakes 500 feet from shorelines and stay at least 200 feet away from loons and their nests.

ACTIONS FOR KLWA

- Target stormwater management and septic system maintenance outreach to shorefront and riverfront residents.
- Advocate and publicize the merits of achieving LakeSmart certification through the state.
- Advocate and publicize the specific recommendations for sustainable lake shore living in the KLWA's Lake Dweller's Handbook.
- Conduct another alkalinity and pH study to better assess the vulnerability of waterbodies to acid rain and watershed activities across years.
- Continue monitoring stream conditions for supporting coldwater fish species (e.g., temperature, flow, and population size). This will help target streams in need of restoration. Restoration techniques include increasing overhead vegetative cover to help cool stream water temperatures.
- Petition IF&W to make Kezar Lake catch and release only for certain sensitive fish species. Debar all fish hooks and ensure proper fishing line strength to avoid fish injury and entanglement.
- Contact the Maine Center for Disease Control and Prevention to determine how public notices will be issued during peak tick and mosquito season to warn residents of potential diseases, including Lyme and follow-up to see that people in Lovell receive these notices.
- Educate watershed residents on the threat of the emerald ash borer (along with other invasive species).

ACTIONS FOR GREATER LOVELL LAND TRUST

- Continue to conserve and protect land areas that serve as wildlife corridors.
- Work with the State to set up emerald ash borer monitoring sites and inventory ash trees on trust land.

LITERATURE SOURCES FOR REPORT

Boeck, M., Jackson, R., and H. Shaftel. Global Climate Change Temperature website. NASA. July 28, 2015. http://climate.nasa.gov/interactives/climate-time-machine

Cappaert, D., Mccullough, D. G., Poland, T. M., & Siegert, N. W. (2005). David Cappaert, Deborah G. McCullough, Therese M. Poland, and Nathan W. Siegert. American Entomologist, 2003 (October 2003).

Clark, Neal. Birds on the Move: A guide to New England's Avian Invaders. North Country Press: Unity, Maine. (1988).

Cousins, N.M., and K.E. Webster. "Cladoceran and Copepod Zooplankton Abundance and Body Size in Kezar Lake, Maine (MIDAS 0097)". (2008).University of Maine, School of Biology and Ecology.

Duchesne, L., and D. Houle. "Interannual and spatial variability of maple syrup yield as related to climatic factors." PeerJ 2 (2014):e428.

Fernandez, I., S. Birkel, C. Schmitt, J. Simonson, B. Lyon, A. Pershing, E. Stancioff, G. Jacobson, and P. Mayewski. 2020. Maine's Climate Future 2020 Update. Orono, ME: University of Maine. Available online at: https://climatechange.umaine.edu/wp-content/uploads/sites/439/2020/02/Maines-Climate-Future-2020-Update-3.pdf

Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. "Maine's Climate Future: 2015 Update." Orono, ME: University of Maine (2015): 24. climatechange.umaine.edu/research/publications/climate-future

Fleming, D. Winter ticks raise concerns about future of Maine's moose herd. Portland Press Herald, 14 June 2014.

Groisman, Pavel Ya, et al. "Changes in the probability of heavy precipitation: important indicators of climatic change." Climatic Change 42.1 (1999): 243-283.

Hodgkins, Glenn A., Ivan C. James, and Thomas G. Huntington. "Historical changes in lake ice-out dates as indicators of climate change in New England, 1850–2000." International Journal of Climatology 22.15 (2002): 1819-1827.

Huntington, Thomas G., et al. "Changes in the proportion of precipitation occurring as snow in New England (1949-2000)." Journal of Climate 17.13 (2003): 2626-2636.

IPBES. (2019). Global Assessment on Biodiversity and Ecosystem Services. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Chapter 2.2, Draft, May 2019. Available online at:

https://ipbes.net/sites/default/files/ipbes_global_assessment_chapter_2_2_nature_unedited_31may.pdf

IPCC [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." IPCC, Geneva, Switzerland: (2014): 151. http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf

IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, Maycock, M. Tignor, and T. Waterfield (eds.)]. *World Meteorological Organization, Geneva, Switzerland, 32 pp.*

Iverson, Louis R., Mark W. Schwartz, and Anantha M. Prasad. "How fast and far might tree species migrate in the eastern United States due to climate change?" Global Ecology and Biogeography 13.3 (2004): 209-219.

Karl, Thomas R., and Richard W. Knight. "Secular trends of precipitation amount, frequency, and intensity in the United States." Bulletin of the American Meteorological society 79.2 (1998): 231-241.

Karl, Thomas R., Richard W. Knight, and Neil Plummer. "Trends in high-frequency climate variability in the twentieth century." (1995): 217-220.

Leighton, P.A., J.K. Koffi, Y. Pelcat, L.R. Lindsay, and N.H. Ogden. "Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector *Ixodes scapularis* in Canada." Journal of Applied Ecology 49 (2012):457–464

Maine Department of Environmental Protection (Maine DEP). (2019). Eighth Biennial Report on Progress toward Greenhouse Gas Reduction Goals. Final Version, January 13, 2020. Report to the Joint Standing Committee on Environment and Natural Resources, 129th Legislature, Second Session. Available online at: https://www.maine.gov/dep/commissioners-office/kpi/details.html?id=606898

Maine Inland Fisheries & Wildlife. "Songbirds." (2018). Online at: https://www.maine.gov/ifw/fish-wildlife/wildlife/species-information/birds/songbirds.html

McGuire, P. (2019). Reducing emissions from transportation is a long, difficult road for Maine. Portland Press Herald, December 15, 2019.

Meyer, Judy L., et al. "Impacts of climate change on aquatic ecosystem functioning and health." Journal of the American Water Resources Association 35.6 (1999): 1373-1386.

Monthly Summaries of the Global Historical Climatology Network - Daily (GHCN-D). COOP:275995 & 271732. NOAA National Climatic Data Center.

Robinson, S. Infectious Disease Epidemiology Report: Lyme Disease Surveillance Report—Maine, 2013. Augusta, ME (2014): Maine Center for Disease Control and Prevention.

Rodenhouse, N. L., et al. "Potential effects of climate change on birds of the Northeast." *Mitigation and Adaptation Strategies for Global Change* 13.5-6 (2008): 517-540.

Rustad, L. et al. "Changing climate, changing forests: the impacts of climate change on forests of the northeastern United States and Canada." US Forest Service: General Technical Report NRS-99 (August 2014). Online at: https://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs99.pdf

Skinner, C.B., A.T. DeGaetano, and B. Chabot. "Implications of twenty-first century climate change on Northeastern United States maple syrup production: impacts and adaptations." Climatic Change 100 (2010):685–702.

Smith, T.M., R.W. Reynolds, T.C. Peterson, and J. Lawrimore. "Improvements to NOAA's Historical Merged Land–Ocean Temp Analysis (1880–2006)." Journal of Climate 21 (2008):2283–2296.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). "Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge, United Kingdom and New York, NY: Cambridge University Press (2007): 996. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

Stewart, Iris T., Daniel R. Cayan, and Michael D. Dettinger. "Changes toward earlier streamflow timing across western North America." Journal of climate 18.8 (2005): 1136-1155.

Venette, R. C., & Abrahamson, M. (2009). *Cold Hardiness of Emerald Ash Borer, Agrilus Planipennis: A New Perspective*. St. Paul Minnesota.

Wilsey, C, B Bateman, L Taylor, JX Wu, G LeBaron, R Shepherd, C Koseff, S Friedman, R Stone. (2019). Survival by Degrees: 389 Bird Species on the Brink. National Audubon Society: New York. Available online at: https://www.audubon.org/sites/default/files/climatereport-2019-english-lowres.pdf

Whittle, P. "Beach booming as climate changes, and that's bad for forests." New Jersey Herald (Feb. 25, 2018). Online at: http://www.njherald.com/article/20180225/AP/302259862#//

Whitman, A., et al. "Climate Change and Biodiversity in Maine: Vulnerability of Habitats and Priority Species." Brunswick, ME (2013): Manomet Center for Conservation Sciences.

WMO. (2019). Provisional Statement of the State of the Climate 2019. World Meteorological Organization. Available online at: https://library.wmo.int/doc_num.php?explnum_id=10108

APPENDIX A

Anoxic Factor: a method that summarizes individual dissolved oxygen profiles as annual values that represent the extent and duration of anoxia (depth at which dissolved oxygen falls below 2 ppm) in lakes and ponds. This method normalizes complex, 2-dimensional data into a single factor that can be used to assess within-lake changes over time or compare among other waterbodies. Waterbodies can reach "tipping points," when the extent and duration of anoxia in late summer increases to a point when major ecological changes take root (e.g., algal blooms).

Chlorophyll-a (Chl-a): A measurement of the green pigment found in all plants, including microscopic plants like algae. It is used as an estimate of algal biomass; higher Chl-a equates to greater amount of algae in the lake.

Color: The influence of suspended and dissolved particles in the water as measured by Platinum Cobalt Units (PCU). A variety of sources contribute to the types and amount of suspended material in lake water, including weathered geologic material, vegetation cover, and land use activity. Colored lakes (>25 PCU) can have reduced transparency readings and increased total phosphorus concentrations. When lakes are highly colored, the best indicator of algal growth is chlorophyll-a.

Dissolved Oxygen: The concentration of oxygen that is dissolved in the water. DO is critical to the healthy metabolism of many creatures that reside in the water. DO levels in lake water are influenced by a number of factors, including water temperature, concentration of algae and other plants in the water, and amount of nutrients and organic matter that flow into the waterbody from the watershed. Too little oxygen severely reduces the diversity and abundance of aquatic communities. DO concentrations may change dramatically with lake depth. Oxygen is produced in the top portion of a lake (where sunlight drives photosynthesis), and oxygen is consumed near the bottom of a lake (where organic matter accumulates and decomposes).

Epilimnion: The top layer of lake water that is directly affected by seasonal air temperature and wind. This layer is well oxygenated by wind and wave action, except when the lake is covered by ice.

Escherichia coli (E. coli): An indicator of the presence of fecal contamination in the water.

Eutrophication: Refers to lakes with high productivity, high levels of phosphorus and chlorophyll-a, low Secchi disk readings, and abundant biomass with significant accumulation of organic matter on the bottom. Eutrophic lakes are susceptible to algal blooms and oxygen depletion in the hypolimnion.

Integrated Epilimnetic Core: A water sample that is collected with a long tube extending from the surface of the lake to the upper part of the thermocline to determine average nutrient concentration in the epilimnion.

MIDAS: unique four-digit identification code for each Maine lake.

pH: The standard measure of the acidity of a solution on a scale of 0-14. Most aquatic species require a pH between 6.5 and 8. As the pH of a lake declines, particularly below 6, the reproductive capacity of fish populations can be greatly impacted as the availability of nutrients and metals changes. pH is influenced by bedrock, acid rain or snow deposition, wastewater discharge, and natural carbon dioxide fluctuations.

Platinum Cobalt Units (PCU): A unit of measurement used to determine the color of lake water. Lake water with 30 PCU will look slightly brown or tea-colored (formerly reported as SPU - Standard Platinum Units).

Sample Station: Location where water quality readings and samples are taken. Some of the larger lakes or basins are sampled at more than one location, resulting in multiple station numbers. In lakes with more than one basin, at least one station is usually located in each basin.

Water Clarity: A vertical measure of water transparency (ability of light to penetrate water) obtained by lowering a black and white disk into the water until it is no longer visible (a.k.a., Secchi disk transparency). Measuring water clarity is one of the most useful ways to show whether a lake is changing from year to year. Changes in transparency may be due to increased or decreased algal growth, or the amount of dissolved or particulate materials in a lake, resulting from human disturbance or other impacts to the lake watershed area. Factors that affect transparency include algae, water color, and suspended sediment. Since algae are usually the most common factor, transparency is an indirect measure of algal populations.

Thermocline: The markedly cooler, dynamic middle layer of rapidly changing water temperature. The of this layer is distinguished by at least a degree Celsius change per meter of depth.

Total Alkalinity: A measure of the buffering capacity of a lake, or the capacity of water to neutralize acids. It is a measure of naturally-available bicarbonate, carbonate, and hydroxide ions in the water, which is largely determined by the geology of soils and rocks surrounding the lake. Alkalinity is important to aquatic life because it buffers against changes in pH that could have dire effects on animals and plants.

Total Phosphorus (TP): The total concentration of phosphorus found in the water, including organic and inorganic forms. TP is one of the major nutrients needed for plant growth and is generally present in small amounts. Humans can add phosphorous to a lake through stormwater runoff, lawn or garden fertilizers, and leaky or poorly maintained wastewater disposal systems. Excess phosphorus can lead to increased plant and algae growth in lakes.

Trophic State Indicators: Indicators of biological productivity in lake ecosystems, including water clarity, total phosphorus, and chlorophyll-a. The combination of these parameters helps determine the extent and effect of eutrophication in lakes and helps signal changes in lake water quality over time.

Watershed: An area of land that drains water to a point along or the outlet of a stream, river, or lake.

APPENDIX B

A Guide to Invasive and Destructive Plants, Animals, and Insects in Maine

Author: Wes Huntress

There is a significant number of animal, plant, and insect species invading, or poised to invade, the State of Maine. These invaders act to upset and destroy the native ecosystems. They arrive by transport on plants, boats, birds, and other animals. Warmer weather and shorter winters in recent decades have eased their survival in Maine. Invasive insects are destroying native plants and trees in Maine forests and spreading pestilence such as Lyme disease. Invasive plants take over and monopolize native soil and wetland resources, crowding out native plants. The animals, birds, and fish dependent on these resources are forced out.

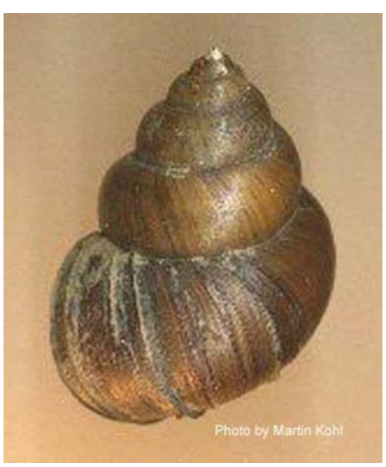
The invaders of most concern to Maine are described here, except for invasive terrestrial and aquatic plants. These are described in documents publicized by the Lovell Invasive Plant Prevention Committee (LIPPC) and also at http://www.mainevlmp.org/mciap/herbarium/invasive.php.

What can an individual do to help prevent the import and spread of these invasive species? Most of the sources listed at the end of this appendix provide information on what individuals can do. For aquatic and wetland species, report sightings of invasive plant, animal, or algae to LIPPC. For invasive insects, the State of Maine maintains a database of sightings and takes responsibility for mitigation services. If you believe you have come across one of these pests, then please contact the Maine Department of Agriculture, Conservation and Forestry at DACF@Maine.gov, 207-287-3200, or at specific webpages/phone numbers listed on the insect-specific State of Maine references given at the end of this appendix.

Invasive Aquatic Fauna

Northern Pike - *in Maine*

Popular sport fish first stocked in the Belgrade Lakes in the 1970s and spread from there to lakes in the Kennebec and Androscoggin watersheds. A very adaptable fish that can live in wide conditions of temperature, clarity, and dissolved oxygen. A voracious predator, it hunts in quiet weed beds to attack fish, frogs, crayfish, small mammals, and birds. Average size about 20 in. but can grow to over 40 in and 30 lb. Very similar markings to native chain pickerel. Known to have destroyed brook trout and landlocked salmon populations. No effective control mechanisms known. Catch and kill.

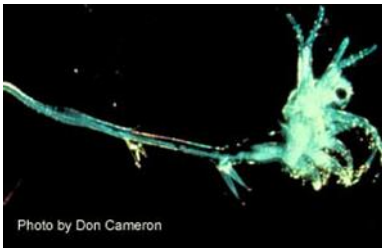


Chinese Mystery Snail - *in Maine*

A distinctively-large snail, up to the size of golf ball, about twice the size of native snails. Originally imported for Asian food markets and probably introduced in local waters for harvest. They often wash up on the shore after dying, releasing a foul smell. Transported via bait buckets and water storage tanks on boats. A vector for other parasites and diseases.

Asian Clam - *Mass, Conn, not yet in Maine*

These small clams, up to 2 inches across, were imported from China perhaps as food by immigrants. Commonly used in aquaria and as bait. They form large, dense communities in sandy lake bottoms, competing with native zooplankton, mussels, and fish. Infestations can cause fouling of pipes and canals. These clams release toxic ammonia when stressed by cold.



Spiny Water Flea - *not yet in Maine*

Native to northern Europe and Britain, this small creature was probably imported in ballast water. They prefer deep, cold lakes but can be found in warmer lakes as well. It is small (up to 1/2 in), has a transparent body with large black eye spots, four pairs of legs, and a long, barbed tail spine. The sharp spine prevents many fish from eating them. They are voracious eaters compared to similar native species and can disturb the aquatic food web.

Rusty Crayfish - *not yet in Maine*

Maine harbors several non-native crayfish, two of which pose the greatest threats - rusty crayfish and red swamp crayfish. Rusty crayfish are native to mid-western waters and were probably introduced to Maine by anglers using them as bait. They feed on a variety of aquatic plants, benthic worms, snails, leeches, clams, insects, crustaceans, and decaying plants and fungi. Both invasive crayfish displace native crayfish by direct competition, and reduce both plant and invertebrate diversity and abundance through predation, impacting native fish and waterfowl populations.

Zebra Mussels - *not yet in Maine*

Zebra mussels are thought to have been imported on the hulls or in ballast water of ships from Europe. They are a major aquatic pest in the Midwest and have spread to New England by transport on boats. Zebra mussels are small (~1/2-inch-long), voracious filter feeders consuming large quantities of phytoplankton, thereby starving out native zooplankton and causing a cascade through the entire ecosystem. Infestations can clog pipes, alter benthic substrates, and compete with native zooplankton, mussel, and fish species.

Quagga Mussels - *not yet in Maine*

Native to the Caspian Sea, most likely imported in ballast water of ships. They live in a large range of water depths and temperatures, prefer silty or sandy bottoms, and create large colonies. Generally about the size of a thumbnail. Infestations can clog pipes and compete successfully with native zooplankton, mussel and fish species, altering the benthic substrate.

Chinese Mitten Crab - *not yet in Maine*

Omnivorous and voracious predator first found in Chesapeake Bay in 2005 and later in Delaware Bay. Probably imported in commercial vessel ballast tanks. Lives in either salt or fresh water. Burrows along the shore and can migrate across land.

Invasive Aquatic Plants

Purple Loosestrife - *in Maine*

Native to Europe and Asia, purple loosestrife arrived in North America about 200 years ago and is now rampant across the US with large infestations in the northeast including Maine. Purple loosestrife is a wetland perennial preferring open sunny areas and wet soil. It can be found in floodplains, wet meadows, along stream banks, and the edges of ponds, lakes and marshes. Purple loosestrife displaces native plants such as cattails, sedges, bulrush, and ferns, decreasing native biodiversity and the quality of wetland habitats for migrating wading birds and waterfowl.

Flowering Rush - *in Maine*

Native to Eurasia, this hardy aquatic perennial grows in shallow fresh water up to several feet deep. Leaves are up to 3 feet long, triangular cross-section, and twisted at the ends. The flowing stem can rise 3 feet above the surface. Flowing rush can also be found in forested floodplains.

Yellow Iris - *in Maine*

A perennial flowing plant with sword-like leaves and large, bright yellow flowers. Occurs in freshwater wetlands, as well as brackish coastal marshes. An invasive plant, it spreads rapidly to outcompete native plants and form impenetrable thickets. Sometimes used in water treatment to remove heavy metals.

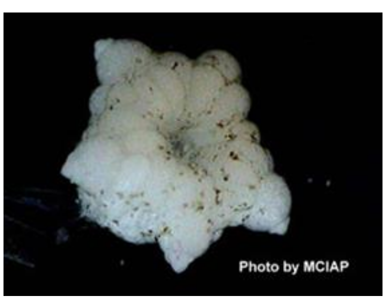
European Common Reed - *in Maine*

The European form of common reed is aggressive and robust, creating dense growths in freshwater and brackish tidal wetlands. When this plant invades a wetland, it alters the structure and function of the ecosystem, changing nutrient cycles and hydrological regimes and decreasing the native biodiversity and quality of wetland habitats for migrating wading birds and waterfowl.

Invasive Algae

Didymo (Rock Snot) - *not yet in Maine*

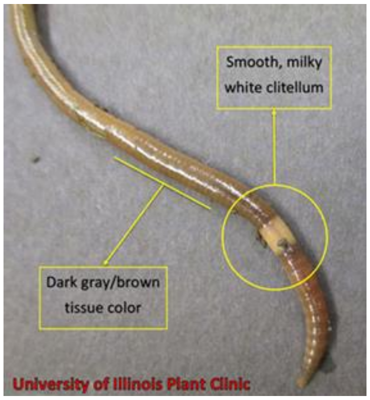
Didymo is a freshwater diatom generally found in clear, cool streams and rivers, and more rarely along rocky shores of lakes and ponds. It produces stalks to attach to rocks and vegetation creating small bubbly colonies on submerged rocks, vegetation and gravel. It then blooms into a thick, yellowy-brown mat. These mats are not green or slimy like other algal mats but feel more like wet cotton or thick wet felt. Prolonged severe blooms can negatively impact the habitat, depleting the food sources of brook trout and water dwelling birds. Blooms can also restrict water flows, deplete oxygen levels, and smother native mussel beds. Historically found in far northern regions of Europe and North America, Didymo has recently taken on the characteristics of an invasive plant in its original range and expanding into warmer, more nutrient rich waters. The mechanism is not well understood, but climate change is suspected of playing a role. It has recently appeared in New York, Vermont, and New Hampshire.



Starry Stonewort (macroalga) - *not yet in Maine*

Starry Stonewort is a green macroalga that resembles a plant, just like Maine's native stoneworts Nitella and Chara, and like them will form dense colonies of upright, plant-like stems sprouting whorls of tentacle-like branches. Tiny, cream-colored, star-shaped reproductive 'flowers' occur at the base of branch clusters. The Starry stonewort was probably brought to North America through ballast water contamination and has infested many sites along the St. Lawrence river and Great Lakes. Not yet present in New England, but proximity to the St. Lawrence is a concern.

Invasive Forest Fauna



Snake Worm (Asian Jumping Worm) - *in Maine*

Due to past glaciation, there are no native earthworms in Maine. About a dozen non-native earthworm species were imported by colonists. Beneficial to gardens, earthworms have destructive effects on forests. Snake Worms (aka Crazy Worm, Asian Worm, Jumping Worm) are sold for composting and bait but are illegal in Maine. When disturbed these worms thrash like a threatened snake. These worms can cause serious damage to horticultural crops and the forest ecosystem. They turn good soil into grainy, dry worm castings that can't support the native understory plants. Eliminate by killing when found - do not discard.

Invasive Forest Insects

Emerald Ash Borer - *in Maine*

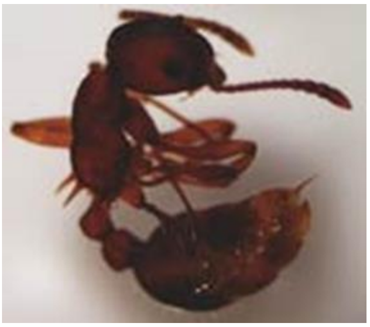
The Emerald Ash Borer is one of the most destructive invasive species threatening Maine forests, spreading readily via firewood, and capable of destroying entire ash tree stands. This pest is established in New Hampshire and has now been found in Aroostook and York Counties. Small metallic-looking beetles lay eggs on trees which hatch larvae that tunnel under the bark killing the trees in 3-5 years. Maine is using a quarantine strategy to control spread.

Brown Marmorated Stink Bug - *in Maine*

Originally from Asia, this bug was first discovered in Pennsylvania in 2001 and has caused significant damage to fruit trees, vegetable crops, and other plants in the mid-Atlantic states. It overwinters in structures and homes to emerge in the growling season. Like all stink bugs, it emits a strong disagreeable odor when trampled. Professional extermination is the recommended mitigation strategy.

Spruce Budworm - *in Maine*

The eastern Spruce Budworm is a native moth whose caterpillars are perhaps the most damaging forest insect in Maine and North America. Cyclical outbreaks occur every 30 to 60 years when host trees mature. The last outbreak in Maine was in the late 1980s. The caterpillars feed on buds of balsam fir and white, red, and black spruce resulting in loss of growth and mortality. Some defoliation has been noted in 2017 on the New Brunswick and Quebec sides of the Maine border. Pheromone trapping is the current mitigation strategy.



European Fire Ant - *in Maine*

The European Fire Ant is a very small red ant only about 3/16-inch-long and distantly related to tropical and sub-tropic fire ants. The sting is very painful and leaves a large inflamed area on the skin 1-4 inches in diameter. Native ant species have difficulties competing with them. They do not nest in houses or make large mounds. They are transported on potted plants, soil, wood chips and soil. Insecticide is the only current mitigation method.

Winter Moth - *in Maine*

Introduced from Europe likely in the soil of landscape trees and plants. The small, pale-green inchworm larvae defoliate deciduous trees and shrubs in early spring. An infested tree exhibits branch dieback followed by mortality in about 3 years. Preferred hosts include oak, maple, apple, elm, ash, crabapple, cherry, and blueberry. Pesticides are currently the main method of control.

Hemlock Woolly Adelgid - *in Maine*

Introduced from Japan, Hemlock Woolly Adelgid is an invasive aphid-like insect that feeds on hemlocks, resulting in damage that leads to decline and mortality. Eggs and the hatched crawlers, the only non-attached part of the lifecycle, are readily dispersed by wind, birds, deer and other mammals. Spread also occurs through plant transport. Control methods are limited.

Balsam Woolly Adelgid - *in Maine*

The Balsam Woolly Adelgid has decimated large volumes of balsam fir in Maine in the past several years. The lifecycle is complex, but the most commonly-observed forms are the "gout" and "trunk" phases. "Gout" is a heavy swelling of the twigs at the nodes. In the "trunk" phase, the tree bole is covered with white woolly spots. Effective control measures have not yet been developed. Colder interior winters generally keep this pest confined near the coast.

Flea Beetle - *in Maine*

Small leaf-feeding beetles that can jump. There are many species of flea beetles, and they are common pests on many vegetable crops. Some attack shrubs and trees. These pests can rapidly defoliate and kill plants.

Corn Flea Beetle and Stewart's Wilt - *in Maine*

Stewart's wilt is an endemic bacterial disease of corn spread by the Corn Flea Beetle. This disease is periodically a concern for corn growers and field corn seed producers.

Beech Scale and Beech Bark Disease - *in Maine*

The Beech Scale insect arrived from Europe over a 100 years ago. The insect causes beech bark disease by feeding on beech bark, creating cracks through which native canker fungi can enter the tree and eventually kill it.

Asian Long-horned beetle - *not yet in Maine*

The Asian Long-horned beetle is a wood-boring beetle native to China. A large insect up to 1.5 inches long with up to 4-inch-long antennae, it develops and reproduces in deciduous hardwood trees such as maple, birch, poplar, horse chestnut, willow, elm, and ash, eventually killing them. Established in New York and Massachusetts but not yet found in Maine. Transported mainly by firewood, the only current mitigation strategy is quarantine.

Resources

Lake Stewards of Maine:

lakestewardsofmaine.org/mciap/otherinvaders/

State of Maine:

https://www.maine.gov/dacf/php/caps/BMSB.shtml

https://www.maine.gov/dacf/php/caps/ALB/index.shtml

https://www.maine.gov/dacf/mfs/forest_health/insects/winter_moth.htm

https://www.maine.gov/dacf/mfs/forest_health/insects/hemlock_woolly_adelgid.htm

https://www.maine.gov/dacf/mfs/forest_health/insects/balsam_woolly_adelgid.htm

https://www.maine.gov/dacf/mfs/forest_health/insects/spruce_budworm_2014.htm

https://www.maine.gov/dacf/mfs/forest_health/insects/emerald_ash_borer_id.htm

https://www.maine.gov/dacf/php/gotpests/bugs/flea-beetles.htm

https://www.maine.gov/dacf/mfs/forest_health/documents/beech_bark_disease.pdf

https://www.maine.gov/dacf/mnap/features/invasive_plants/iris.htm

https://www.maine.gov/dacf/php/horticulture/crazyworms.shtml

https://www.maine.gov/dacf/php/horticulture/documents/InvasivePlantListHandout.pdf

https://www.maine.gov/dacf/mnap/features/invasive_plants/invsheets.htm

Univ. of Maine:

https://extension.umaine.edu/publications/2551e/

https://extension.umaine.edu/home-and-garden-ipm/common-name-listing/flea-beetles/

https://extension.umaine.edu/home-and-garden-ipm/common-name-listing/asian-longhorned-beetle/

Univ. of Vermont:

University of Vermont. "Earthworms invade New England." ScienceDaily. ScienceDaily, 29 October 2013. www.sciencedaily.com/releases/2013/10/131029133126.htm.

Portland Press Heald:

https://www.pressherald.com/2018/05/29/experts-wondered-when-the-destructive-emerald-ash-borer-would-come-to-maine-its-here/

Bangor Daily News:

https://bangordailynews.com/2017/10/19/special-sections/head-defoliation-by-spruce-budworm-a-problem-at-maines-border/

https://bangordailynews.com/2018/05/21/homestead/dont-be-fooled-by-these-pretty-invasive-flowers-that-are-bad-for-maine/

Go Botany:

An excellent source for information on plants: http://gobotany.newenglandwild.org