TAHOE: STATE OF THE LAKE REPORT 2017

CURRENT RESEARCH

UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

CURRENT RESEARCH

Metaphyton at Lake Baikal and Lake Tahoe

Lake Baikal in Russia and Lake Tahoe on the California-Nevada stateline, have a special relationship. For over 20 years, students from both the United States and Russia participated in a unique summer program at both lakes through the Tahoe-Baikal Institute, assisting with environmental research and shadowing resource managers. The two lakes are very different. Lake Tahoe is clearer and at a higher altitude. Lake Baikal is much bigger and deeper, and spends part of the year under a thick cover of ice. While different, these two great, once pristine lakes, experience the same threats ranging from local impacts to those imposed by climate change.

In recent years, both lakes have been subject to increasing growth of algae near their shorelines. This increase in algae, or metaphyton, are the result of changing environmental conditions which favor their growth. At Lake Baikal, the mats of metaphyton are mainly comprised of *Spirogyra* and are believed to be a result of an increase in nutrients from sewage inputs associated with a growth in tourism and development.

Spirogyra washed up on the shore of Lake Baikal, Russia.
Photo: http://mobile.nytimes.com/2016/11/15/science/lake-baikal-russia

CURRENT RESEARCH

Metaphyton at Lake Baikal and Lake Tahoe, continued

At Lake Tahoe, the metaphyton mats are much smaller, but have been particularly noticeable along some shallow beach areas in recent summers. *Spirogyra* is also one of the species present along with other types of filamentous green algae. Planners at Tahoe had the foresight in the 1960s to divert sewage from entering the lake, no doubt helping control nutrient loading. However, changing internal processes within the lake are likely acting to concentrate nutrients in particular areas. Warming associated with climate change, the arrival of invasive species, and extreme fluctuations in lake level associated with drought may all play a role. Efforts are currently underway to develop effective monitoring methods for algae and ultimately we hope to better understand the primary factors controlling metaphyton growth in Tahoe.

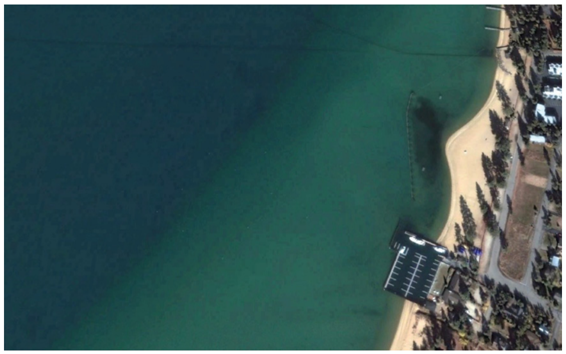
In 2017, a thick mat of filamentous *Spirogyra* and *Zygnema* was observed offshore near Lakeside, an area invaded by Asian clams. Asian clams, which are filter feeders, concentrate nutrients by a factor of ten and provide a potential source of enriched nutrients for the metaphyton. This apparent linkage between Asian clams and metaphyton is evident in a time series of satellite images taken from Google Earth and the most recent image taken of the same area from a helicopter in 2017.

Spirogyra and *Zygnema* on the shore of Lake Tahoe at Regan Beach in August, 2014. Photo: Scott Hackley

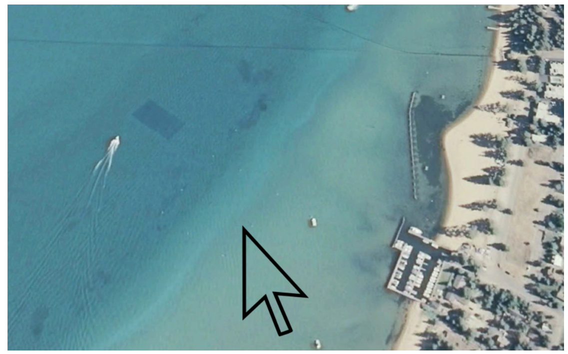
CURRENT RESEARCH

Metaphyton at Lake Baikal and Lake Tahoe, continued

Google Earth satellite images from 2007-2016 as compared with a recent helicoper photo from 2017 of Lakeside area in South Lake Tahoe. These images document the appearance of a band of clam shells in 2010 and an eventual transition to supporting metaphyton growth in this area.



Lakeside area 10/31/07 - no line of clamshells or metaphyton



Lakeside area 8/30/10 - line of clamshells apparent

Lakeside area 8/28/12 - distinct line of clamshells

Lakeside area 4/29/14 - distinct line of clamshells

Lakeside area 7/13/16 - line of clamshells co-located with metaphyton

Lakeside area 6/25/17 - Helicopter image showing band of metaphyton overlaid on clamshell region

CURRENT RESEARCH

Forest health

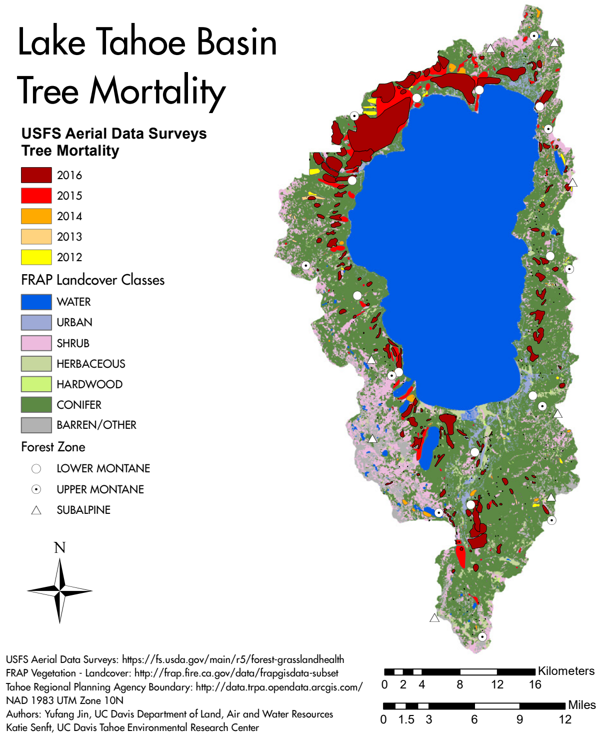
Tree mortality is a huge threat throughout the Sierra Nevada. During the drought, areas of the Tahoe basin that had large numbers of dead trees increased dramatically and tree mortality doubled from 35,000 in 2015 to 72,000 in 2016. The primary causes of mortality were water stress, and insect and fungal infestations (exacerbated by the drought-weakened trees). The north shore of Lake Tahoe had the largest increases in tree mortality, although significant areas of the east shore were also impacted.

The health of the forest is also having an effect on its ability to sequester carbon. UC Davis and TERC scientists are investigating the effects of forest insects and pathogens on carbon dynamics in the Lake Tahoe Basin through a grant from CalFire's Greenhouse Gas Reduction Fund Program. Although pests and pathogens kill many trees in the Sierra Nevada, little is known about how these biological disturbances, along with fuel reduction programs, alter the capacity of forests to mitigate greenhouse gas emissions.

This research will result in a forest-level carbon budget with direct measurements of stand carbon pools, soil respiration, and carbon sequestration within the living forest biomass.

Research to date shows that Basin forest soils release, on average, 4.8 g CO_2-C/sq. m/day, which is typical of western forests. In addition, Tahoe Basin forests have shown consistent consumption of atmospheric methane, an important greenhouse gas

Dead and dying trees are a familiar sight in the Tahoe basin.



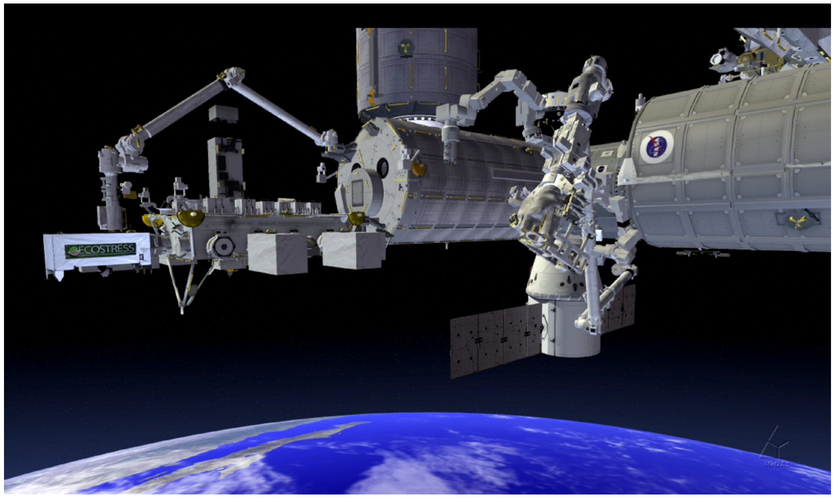
The area of tree mortality markedly grew in 2016.

CURRENT RESEARCH

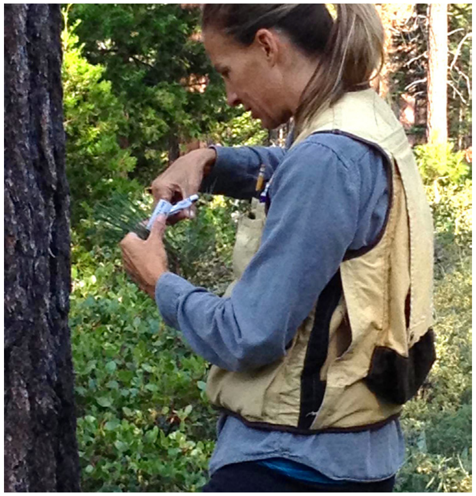
ECOSTRESS

The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station or ECOSTRESS (https://www.youtube.com/watch?v=ALZTMLH9boY&feature=youtu.be), will measure the temperature of plants and use that information to better understand how much water plants (including tress of the Sierra) need and how they respond to stress. Led by long-time TERC collaborator Dr. Simon Hook of the NASA Jet Propulsion Laboratory (JPL), the special instruments developed for this experiment will be launched for deployment on the International Space Station in early 2018.

TERC researcher Dr. Tricia Maloney is planning on using her network of 84 forest monitoring sites to help ground truth data from ECOSTRESS. These sites, from all around the Tahoe Basin and at a range of elevations, provide ongoing measurements of stand conditions, physiological and phenological assessments, forest health indices, as well as the impacts of heat stress and evaporative stress on a range of forest tree species.



The ECOSTRESS radiometer will be deployed on the International Space Station on the Japanese Experiment Module, at the far left of the image.



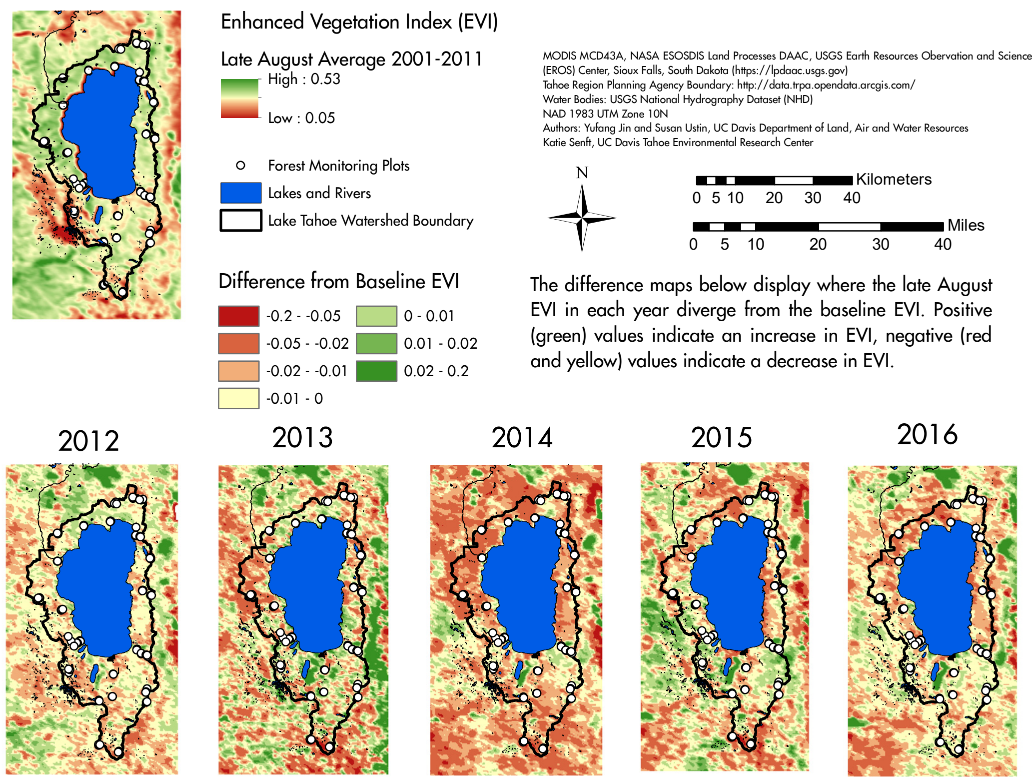
Camille Jensen sampling pine needles at a forest monitoring site. Photo: Patricia Maloney

CURRENT RESEARCH

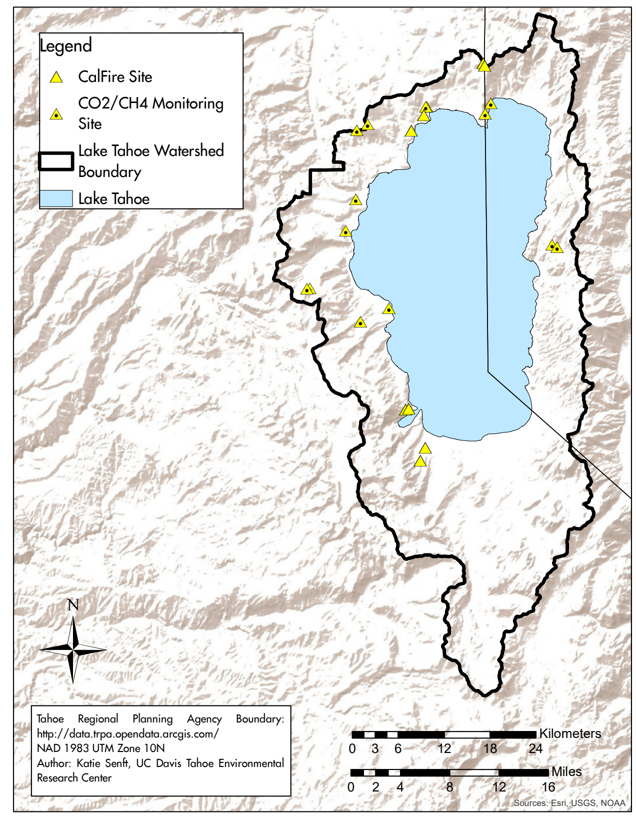
ECOSTRESS, continued

Linking satellite data from ECOSTRESS to the field-based data will provide a direct validation of the satellite data, and may advance our capabilities for predicting forest health and tree species responses to future environmental change.

The remotely sensed data from ECOSTRESS is just the latest collaboration between NASA-JPL and TERC. It will add to an already vast trove of data resulting from this 20-year partnership. The research buoys on Lake Tahoe have been used to calibrate thermal sensors on many international satellites and are an important part of the global efforts to accurately measure the rising temperatures of the world's oceans and lakes.



Tahoe Basin EVI Differences 2012-2016

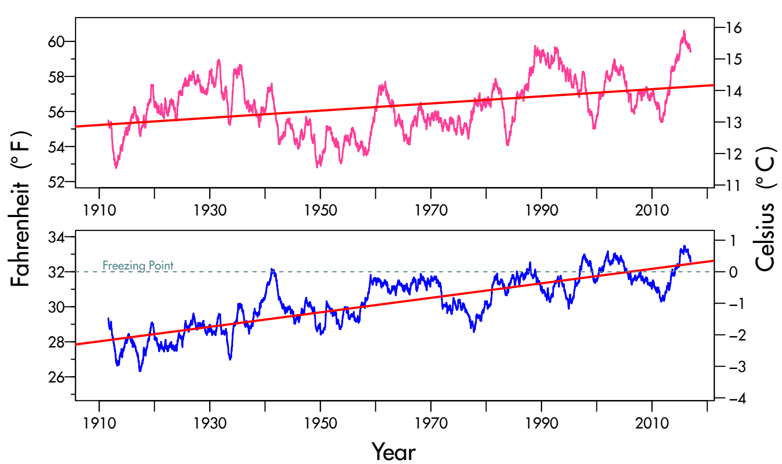


CalFire Greenhouse Gas Reduction Study Sites.

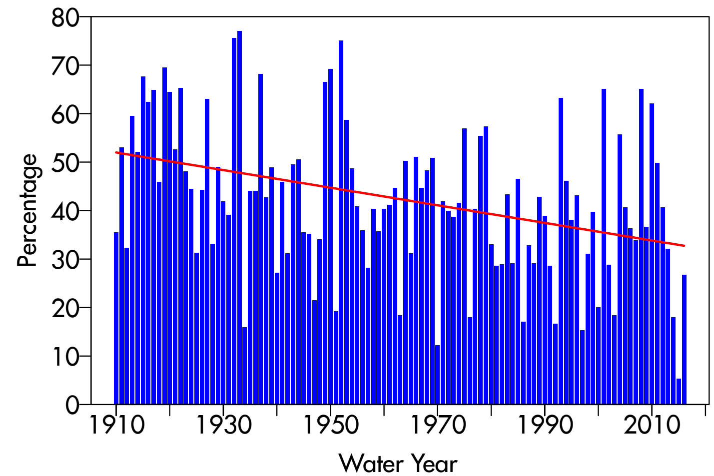
CURRENT RESEARCH

Impacts of climate change

Climate change is exerting a huge impact globally. One of the areas prone to the largest impacts in the nation is the West. The data supporting the changes in Lake Tahoe's climate are evident in the 106 year record of air temperature (see figure on the left). Other changes to the climate include a declining trend in the fraction of precipitation that falls as snow (see figure on the right). What impact does the changing climate have on the lake itself?



Maximum and minimum air temperatures at Lake Tahoe



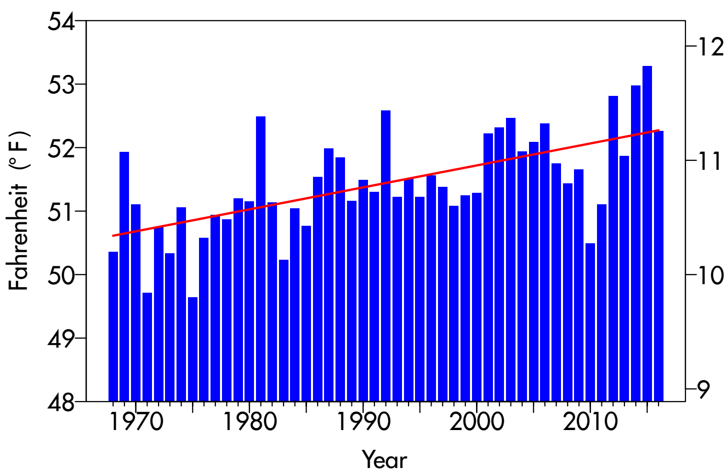
Reduction in percentage of snow as part of total precipitation

CURRENT RESEARCH

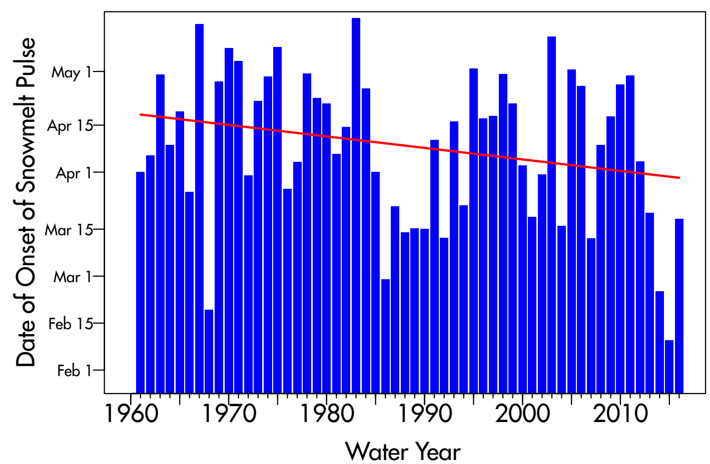
Impacts of climate change, continued

There is clear evidence that the lake itself is warming at all depths, but particularly at the surface. This warming is not continuous, but displays variability depending on the weather in each year. Warming water has a number of ecological consequences for the lake. These include the creation of niches for species that previously could not survive in the lake but could now survive if introduced; potentially disadvantaging native species that have evolved under Tahoe's clear, cold water conditions and are adapted to a specific set of predators; and increasing metabolic rates of organisms, from plankton to fish.

Climate change is also producing other physical changes beyond lake warming that may have even larger impacts on lake ecology and water quality. One of these is advancing the onset of spring and delaying the arrival of fall. Evidence of this can be found in the fact that snowmelt is starting sooner. Additionally, the lake is staying stratified longer (meaning that the surface waters are staying warm and floating on top of cold bottom waters for longer).



Annual average surface temperature of Lake Tahoe.

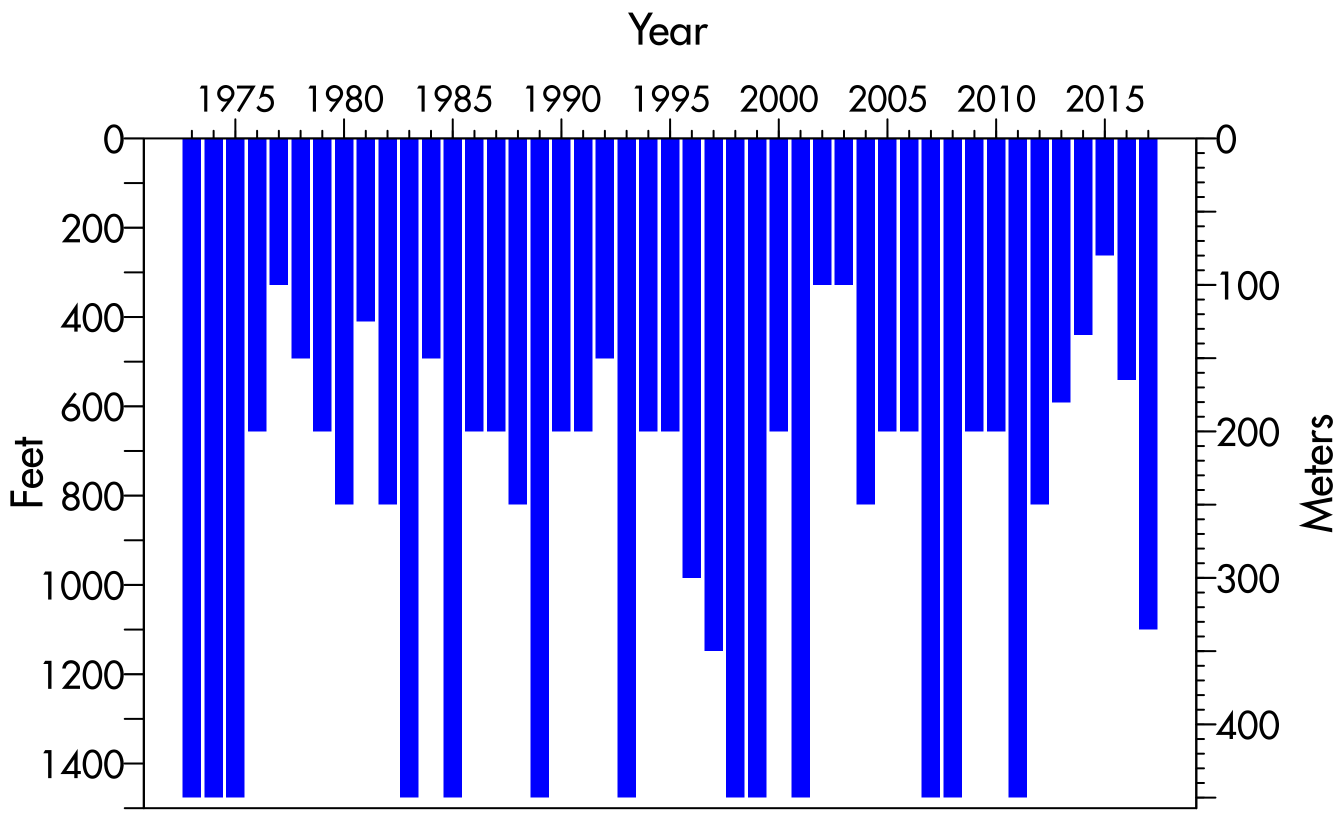


Advance of the onset of spring, as indicated by the stream snowmelt pulse.

CURRENT RESEARCH

Impacts of climate change, continued

The impacts of this are subtle, but profound. With a lengthening summer stratified season, winter is shortening. Winter is when the lake surface naturally cools, a process that makes the surface water denser. This heavy water sinks, and is the primary reason that lakes mix in the winter. This mixing is essential for transferring oxygen to the bottom of the lake where it is needed to sustain life, and for removing the accumulation of nutrients that would otherwise build up deep in the lake (see Section 9.8-9.9). With shorter winters there will be fewer weeks in the year for mixing to progress all the way to the bottom of the lake before the next spring begins.



Depth of mixing in Lake Tahoe by year.

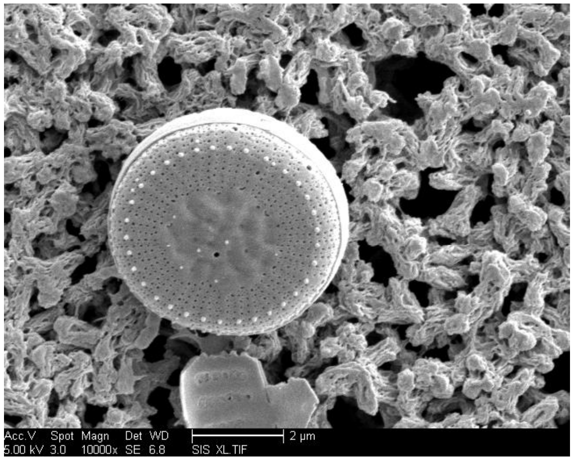
CURRENT RESEARCH

Impacts of climate change, continued

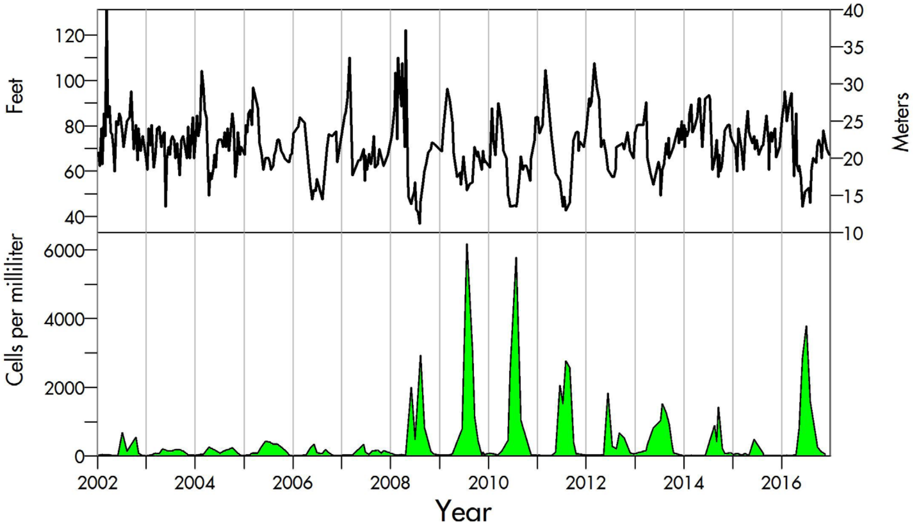
The ecology of the lake is changing in response to the changes in the stratification. Algae in a lake form the base of the food web. Most are free-floating, microscopic plants of varying types and sizes, that exist in a turbulent environment that keeps them from sinking out of the sunlight. Turbulence suppression, due to stratification, causes the larger algae to sink out of the euphotic zone, leaving only the very smallest, slow sinking algae at the surface with no competition for nutrients. One of the most common algae is *Cyclotella gordonensis*, a tiny (4 micron) diatom.

In 2016, it was present in exceptionally high numbers when the lake was strongly stratified in summer, corresponding to a decrease in Secchi depth. Because *Cyclotella gordonensis* is so small, it acts like a clay particle, remaining suspended in the water column for extended lengths of time, scattering light and decreasing Tahoe's exceptional clarity. Years with high concentrations of *Cyclotella gordonensis* generally correspond to years with low Secchi depth. While the more frequent appearance of *Cyclotella gordonensis* is not the only cause of clarity decline, it does present an additional, climate-induced challenge. To make matters worse, as clarity decreases, greater warming of the surface water takes place, increasing stratification and the likelihood of more small algal cells like *Cyclotella gordonensis*. It is a very vicious cycle.

What can be done to control the deleterious impacts of *Cyclotella gordonensis* on lake clarity? In the long-term, addressing climate change is critical. In the short-term algae are best controlled by either reducing the availability of the nutrient that is limiting its growth ("bottom up control"), or by altering the food web, to increase grazing by the lake's zooplankton ("top down control"). Both of these strategies are currently high priorities for further research.



The silicon frustule of *Cyclotella gordonensis* – this cell is 4 microns in diameter



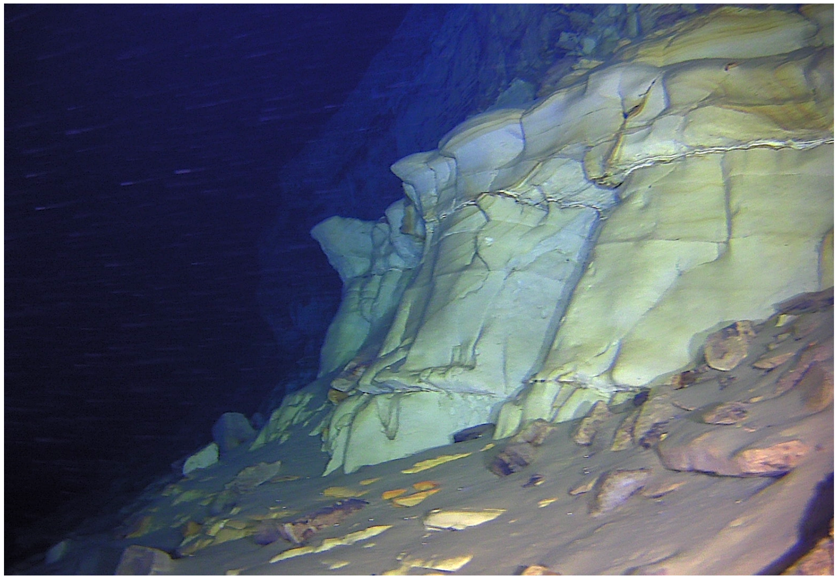
Secchi depth since 2002 along with concentration of *Cyclotella gordonensis* at a depth of 16.5 feet (5 m).

CURRENT RESEARCH

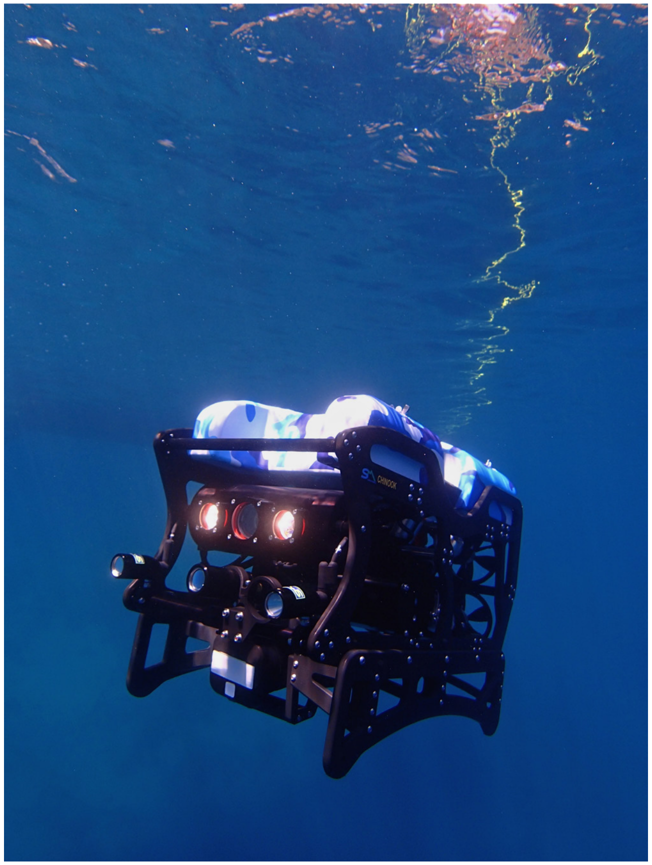
The bottom of the lake

Over 1600 feet below its surface, lies the bottom of Lake Tahoe, a place unimaginable by most. On April 14, 2017, TERC researchers had an opportunity to “see” the bottom of the lake using a Remotely Operated Vehicle (ROV) being demonstrated by Seamor Marine Ltd.

The center of Lake Tahoe is dominated by several huge outcroppings some up to a mile across and hundreds of feet tall. These are remnants of a massive underwater landslide that took place thousands of years ago.



The edge of an underwater mound in Lake Tahoe at a depth of over 400 m. The layering indicates its origin as the sedimentary shelf on the west side of Lake Tahoe. In the foreground is a blanket of sediment that has built up over thousands of years. Photo: Seamor Marine Ltd.



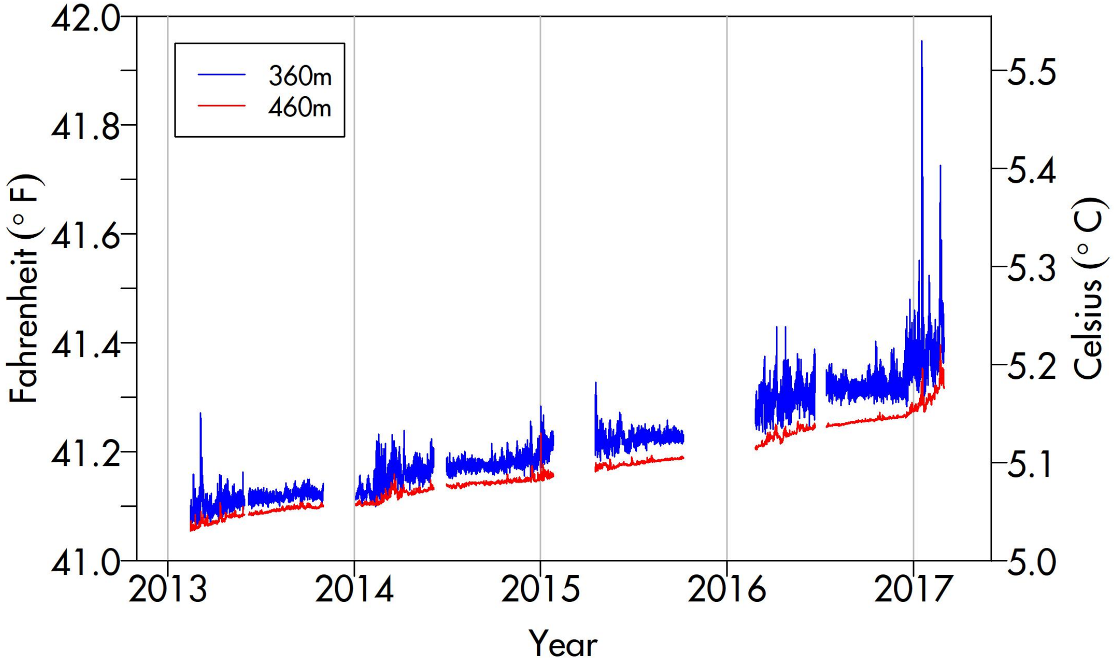
The ROV commencing its descent to the bottom of Lake Tahoe. Photo: Brant Allen

CURRENT RESEARCH

The bottom of the lake, continued

A vertical array of thermistors (temperature measurement instruments) is located a few miles from where the ROV descended. Data from the bottom thermistor at 1,500 feet (460 meters) and a higher thermistor at 1180 feet (360 meters) provides us with some new perspectives into what conditions are like near the bottom of the lake. The thermistors, which take a measurement every 30 seconds, have been deployed for 4 years (gaps in data are periods where the array was removed for servicing).

It is clearly a very quiescent environment, particularly at the very bottom. Fluctuations in temperature at the very bottom are less than 1/100 °F. The temperature difference over the 320 feet separating the two instruments is only 5/100 °F. However, conditions are slowly changing, as evidenced by the fact that both temperature traces are warming. Up till the end of 2016, this was a period when deep mixing did not occur, so the warming is not coming from climatic change. Rather, it is due to geothermal heating that takes place at the bottom of Lake Tahoe. This very slight amount of warming, on average 0.054 °F per year, is sufficient to drive a very slight amount of motion at the very bottom of the lake. The role of this motion in controlling conditions at the bottom is currently being studied.



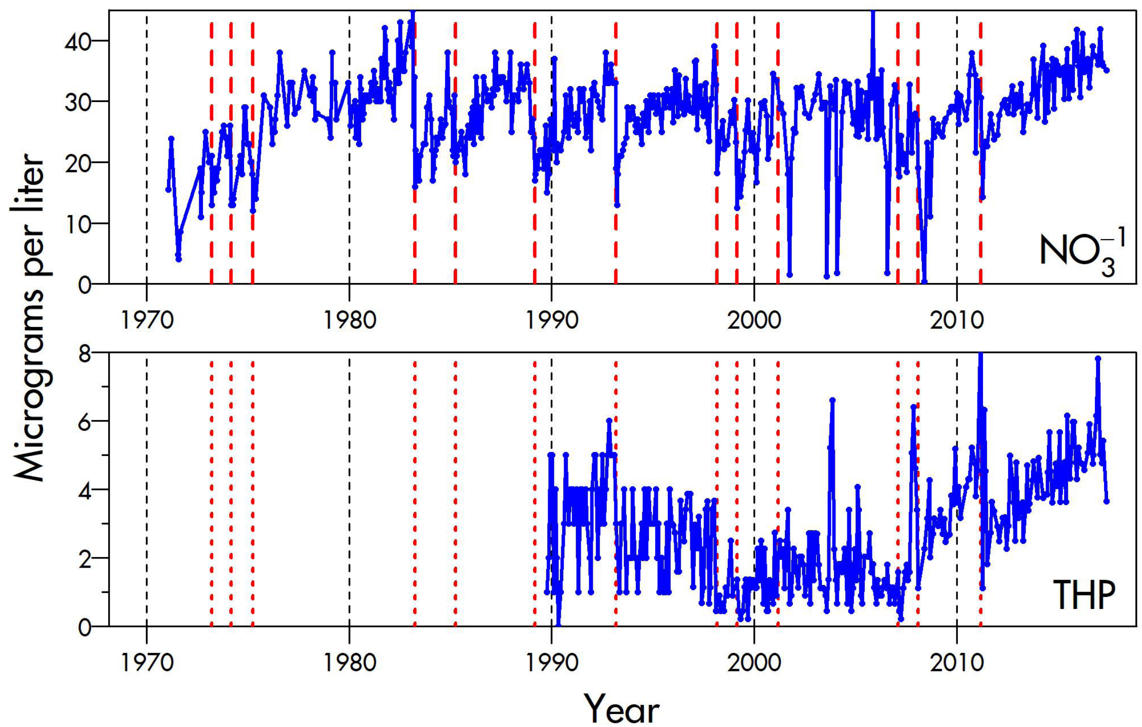
Temperature at 460 m (1500 ft.) and 360 m (1180 ft) from the Glenbrook thermistor chain.

CURRENT RESEARCH

The bottom of the lake, continued

The lack of deep mixing allows for nutrients to accumulate at the bottom of the lake. The nutrients are from the decomposition of algae and other organic matter that sink to the bottom of the lake. The long-term data for nitrate (NO3) and total hydrolysable phosphorus (THP) show this effect very clearly. The dashed red lines indicate times of complete lake mixing. In years when complete mixing occurs both the NO3 and the THP drop, as the bottom waters get diluted through mixing with the overlying waters. When it does not occur, the mean concentration tends to increase.

Both NO3 and THP are increasing in the lower portions of the lake since the last deep mixing in 2011, creating a reservoir of nutrients that will become available when the lake undergoes deep mixing. The sudden decreases in both are clearly evident in 2011 when mixing occurred. The same type of buildup in NO3 was evident between 1975 and 1983, when deep mixing was absent for years.



NO3 and THP measured at a depth of 1480 feet (450 m). Both build up when deep mixing does no occur. Dashed red lines are times of deep mixing.

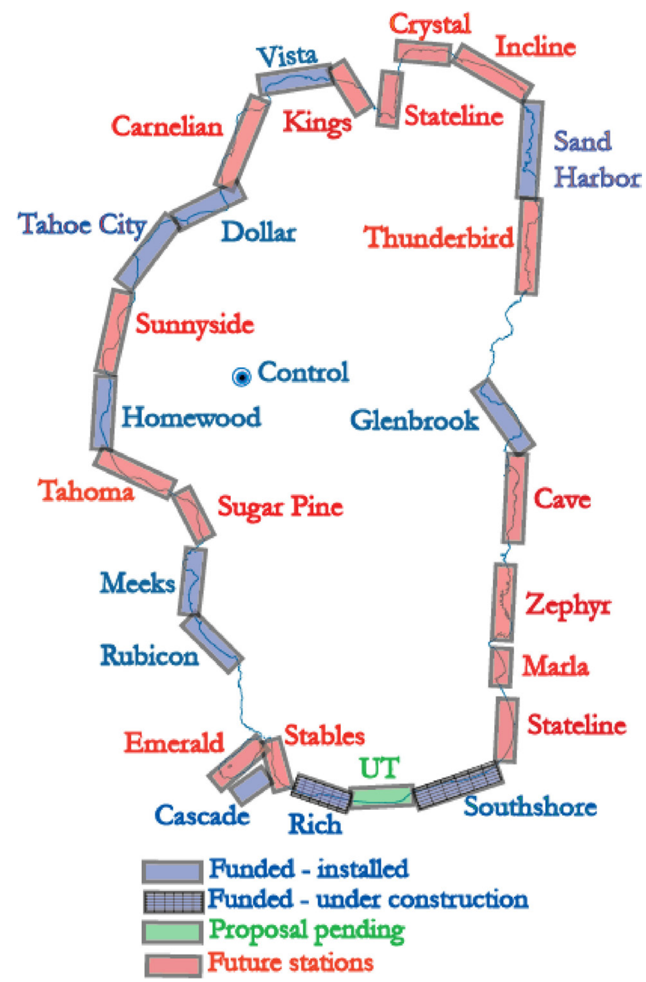
CURRENT RESEARCH

The nearshore of Lake Tahoe

The nearshore of Lake Tahoe is the most varied and least studied part of the lake. There are 63 streams and a greater number of stormdrains and culverts that flow into the lake, each one bringing a unique mixture of contaminants. Each part of the shoreline is oriented differently and each has different uses such as private homes, public beaches, or marinas. This is also where people come to use the beaches, where waves break, and where the land meets the lake.

To what extent do natural processes cause variations in water quality along the shoreline? To what extent are impacts in nearshore water quality caused by our human activities? Knowing the answers to these questions is important in setting meaningful and achievable water quality standards.

TERC's Nearshore Water Quality Network (the Nearshore Network) is helping to provide answers. The Nearshore Network currently comprises 11 stations around the shore of Lake Tahoe and Cascade Lake. These sensor stations are being funded by a growing group of lakefront property owners, private citizens, homeowner associations, and regulatory agencies. Each station measures water quality variables every 30 seconds at a water depth of approximately 7 feet and at a location several inches above the lake bed.



Location of nearshore stations at Lake Tahoe.

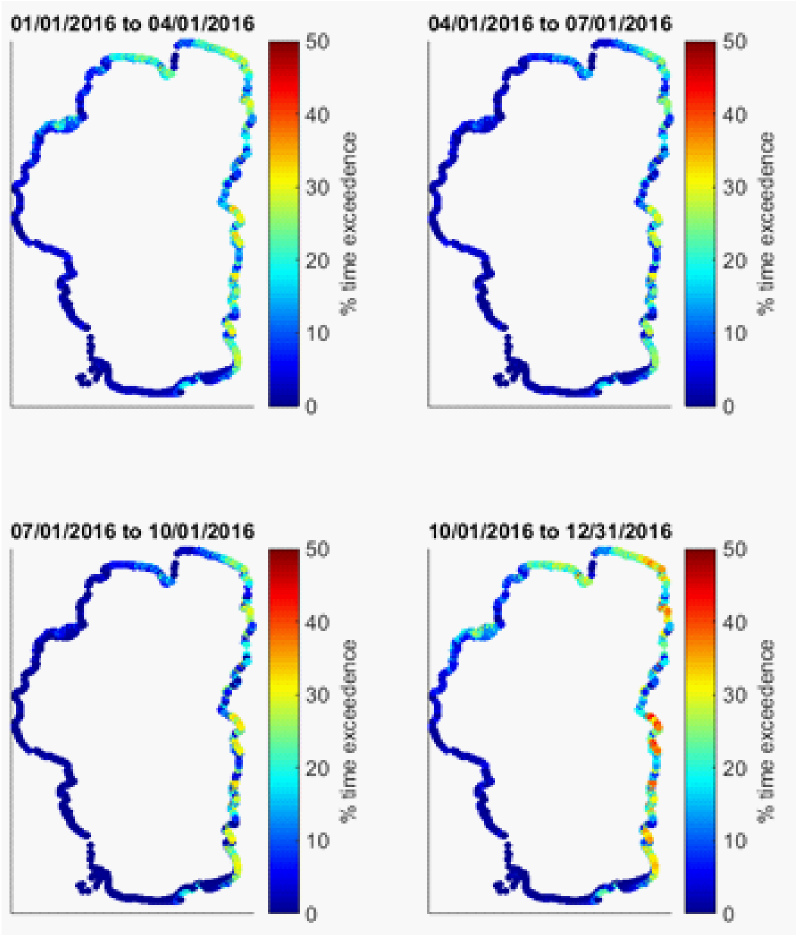
CURRENT RESEARCH

The nearshore of Lake Tahoe, continued

The utility of the Nearshore Network can be demonstrated using turbidity, a measure of the cloudiness of the water caused by the presence of fine particles. The water quality standard for turbidity at Lake Tahoe is 1 NTU, except in the vicinity of stream mouths where it is 3 NTU. Using turbidity measurements from the Nearshore Network together with a model of wind-generated waves, graduate student Derek Roberts and his Chilean collaborator Dr. Patricio Moreno were able to make estimates of wave-induced turbidity at any point around the shoreline. The results showed that turbidity at the measurement point varies considerably around the lake, largely in response to the exposure to prevailing winds (from the west-southwest). There was also considerable variability between seasons.

Most importantly the results showed how frequently a particular turbidity value is exceeded in the nearshore region due to waves. The colored dots around the shore indicate the percentage of time that turbidity exceeds the standard of 1 NTU at a depth of 7 ft near the lake bed. For example a pale green dot indicates that the standard was exceeded 25% of the time in a given season. It is evident that the eastern shore, because of its exposure to winds, has the highest number of exceedances, particularly during the Fall cooling period from October-December.

If we look at the results for 10 NTU, exceedances occur less often, but they are still surprisingly high. For example, there are numerous sections of the shore where 10 NTU is exceeded near the bed for more than 20% of the time in certain seasons.



Percentage of time that turbidity exceeds 1 NTU near the sediment bed, at a depth of 7 ft.

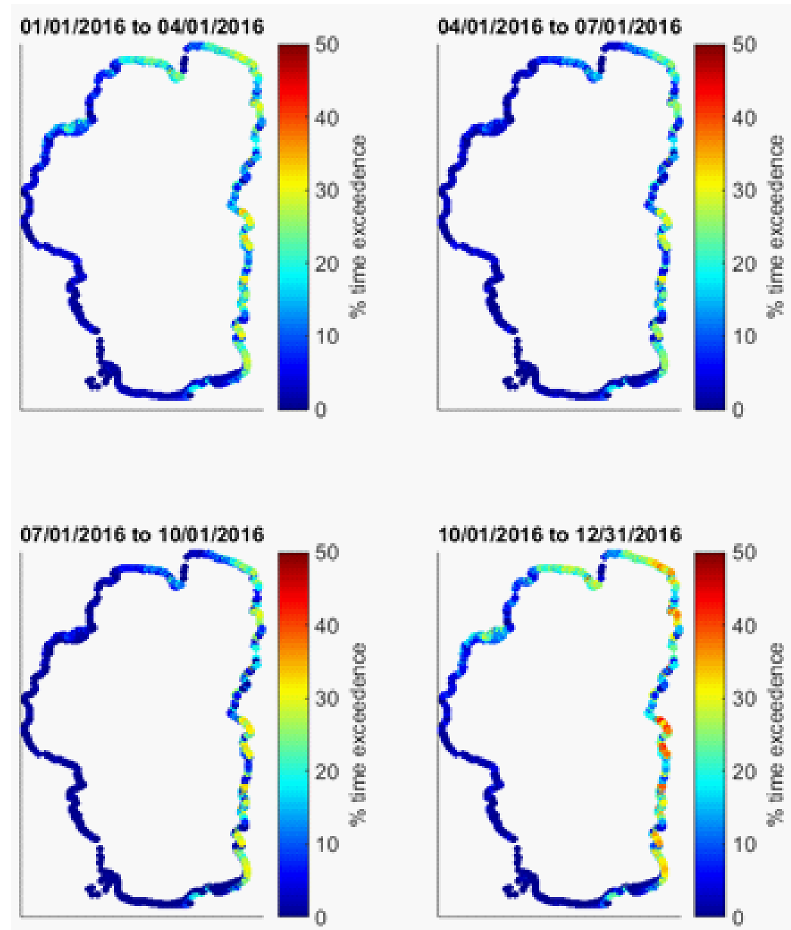
CURRENT RESEARCH

The nearshore of Lake Tahoe, continued

One of the clear messages from these results is that water quality around the shoreline is inherently variable in both space and time. It is not possible for a single scientist to be taking measurements everywhere, but it is possible for an army of citizen scientists to come close to doing just this.

TERC's Citizen Science Tahoe app has been redesigned and upgraded to enable everyone to become a citizen scientist and help gather observations around the lake. Anybody with a smartphone can download the mobile app from CitizenScienceTahoe.org, and in a matter of minutes can make observations about algae, local species, water quality, and beach conditions. Observations from around the shore of Lake Tahoe will allow us to see how conditions are changing over time and at different locations around the lake. This will include the cloudiness of the water, the presence of washed up weeds, invasive species, and the slipperiness of the rocks. This data is incredibly important to us. It is the only way we can be in more places at more times.

The TERC Citizen Science Tahoe app is providing data from all around the lake for all seasons. Photo: Alison Toy



Percentage of time that turbidity exceeds 10 NTU near the sediment bed, at a depth of 7 ft.

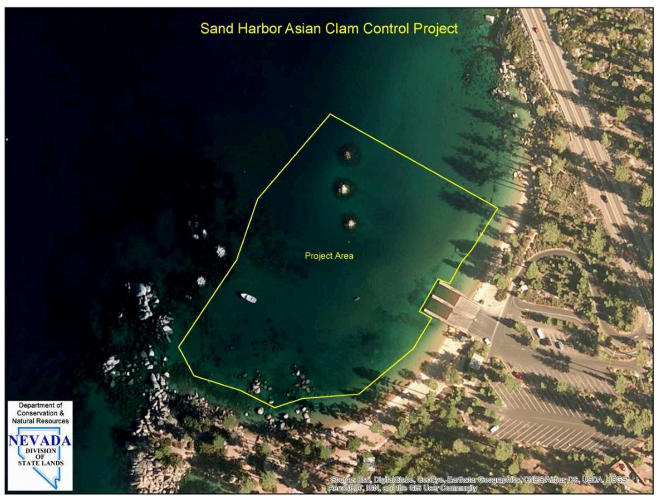
CURRENT RESEARCH

Invasive species and the role of boating

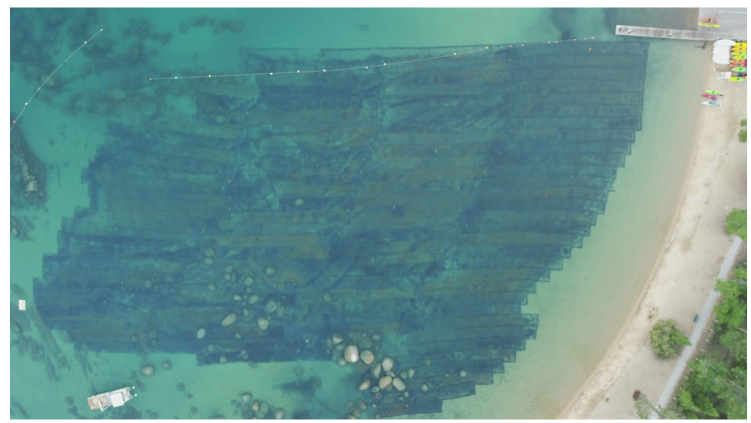
The Nevada Division of State Lands has commenced a project to control the emergence of a satellite population of Asian clams adjacent to the boat ramp at Sand Harbor State Park, Nevada. While Asian clams are now widespread along the southern shore of Lake Tahoe, their recent appearance at one of the most scenic locations on the north shore would seem puzzling. A multi-agency boat inspection program prevents new invasive species from entering the lake from outside. The currents in the lake are such that the rapid transport from south to north is inconceivable.

The most likely scenario is that Asian clams are now being transported within Lake Tahoe by boats. The boating activity that seems to have the greatest potential for this is wakeboarding. A boat outfitted for wakeboarding would typically fill its ballast tanks with up to 600 gallons of water. If this water happened to be drawn from a clam infested area in summer, it is very possible that veligers (the larval offspring) would also be drawn in. At the end of a fun day, if the ballast tanks were emptied at a different, clam-free area, then in-lake transport would have occurred.

Two obvious actions can prevent this accelerated spread from occurring. First, all filling and emptying of ballast tanks should take place at least one mile from shore. The deep waters there are less likely to contain veligers, and any would invariably sink to the cold depths where they cannot reproduce. Secondly, it would be extremely prudent to require that all ballast tanks be equipped with filters that can effectively remove all particulate material.



Sand Harbor demarcated Asian clam area.



Bottom barriers partially installed at Sand Harbor for Asian clam control.