TAHOE: STATE OF THE LAKE REPORT 2020

CURRENT DIRECTIONS

Current Research Synthesis

Since 1959, UC Davis has been engaged in monitoring the status and health of Lake Tahoe and its watershed. The monitoring data are an invaluable resource for assessing the impact of changes that have occurred due to anthropogenic factors and natural variability.

Additionally, we engage in shorter-term research that seeks to answer specific questions or to gain understanding of processes and events. This research relies on the long-term monitoring data to provide a context, but it is distinctly separate. The results of this research–conducted by TERC students, postdoctoral researchers, faculty, and staff, and often in collaboration with other institutions, companies, and agencies–has made Lake Tahoe the smartest lake in the world, and arguably the most influential.

Photos: S. Hackley, K. Senft, and A. Toy

Current Research Synthesis, continued

This year, our current research synthesis covers a broad range of areas. Much of it is the result of work conducted over the last several years. Some of the research is now complete and the results are just starting to influence management and decision-making. Many of the research projects are still underway or in initial stages. The topics we are focusing on this year are:

- The examination of the historic monitoring data has connected the introduction of *Mysis* shrimp to lake clarity. Combined with the results of a pilot project in Emerald Bay, we are launching a new private-public venture to commercially remove the *Mysis* and develop a new line of Tahoe dog treats high in protein and rich in one of the purest forms of Omega-3 fatty acids. This approach has the potential to restore lake clarity, even in the face of climate change, and be a sustainable model for environmental management.
- Metaphyton and periphyton are the nuisance algae that coat the shoreline of the lake at different times of year. Using our Citizen Science Tahoe App, we can all keep track of its spread.
- Metaphyton, which are believed to be proliferating due to the presence of Asian clams, have never been systematically monitored before. Using a combination of helicopter and drone flights, TERC has developed a very efficient methodology to track and quantify their spread.
- In fall 2019, TERC partnered with the California Conservation Corps to replant over 4,000 sugar pine seedlings around the Lake Tahoe Basin. Over 72,000 sugar pines were lost between 2012 and 2016 due to drought and bark beetle infestation.

Photos: A. Wong and A. Toy

Current Research Synthesis, continued

- Sugar pine genetics are being studied through a common garden, where the traits of over 2,100 seedlings are being evaluated.
- Robotic instruments are increasingly being used in TERC's research around the world. They are being used to study harmful algal blooms (HABs) in Clear Lake, California at a much finer scale than can be achieved by satellite remote sensing.
- Ice-covered lakes are of increasing interest to scientists around the world. TERC is studying these in both the Sierra and Canada.
- Plastic pollution is garnering much attention. Both our research and education teams are starting new projects to identify microplastics in Lake Tahoe and to increase awareness of the over-use of single-use plastic.
- COVID-19 has wrought huge changes across the globe. At Tahoe it has forced major changes in how we conduct essential research and provide public education in a safe and responsible manner.
- You don't need a physics degree to enjoy paddleboarding. But knowing a little about the physics of Lake Tahoe could save your life when enjoying this fun activity.
- The lessons learned at Lake Tahoe are being exported to Patagonia, Chile. TERC is a key partner in a large collaborative effort with a Chilean foundation, industry leaders, local and national governments, and private citizens to help plan the future of Patagonia's lakes.

Photos: A. Toy

Clearly, Mysids are a Problem

Landscape-scale environmental disturbance can take decades to manifest in a measurable way. When multiple impacts are occurring at the same time, a major culprit can remain hidden in the depths, even as data continue to accumulate. Such appears to be the story of clarity change at Lake Tahoe.

The 1960s were a decade of major change in the Tahoe Basin. Rapid urban development and sanctioned species introductions were carried out with little understanding of their long-term impacts. It took Dr. Charles Goldman ringing the alarm about Tahoe's diminishing clarity, along with the fledgling League to Save Lake Tahoe and the newly created Tahoe Regional Planning Agency, to help bring attention to the issue. Attention and remediation were quickly focused on Tahoe's rapid and uncontrolled urbanization, a pattern that was observed in many places across the world. When it came to declining lake clarity, the broken linkages within the aquatic food chain were largely out of sight and out of mind, and connections between the food chain and clarity were not recognized.

TERC recently re-examined decades of data to try and understand the role that introduced *Mysis* shrimp may have played in Tahoe's decades-long quest to restore clarity. Through the reinterpretation of the data, a new picture has emerged, one that offers great hope going forward. In this new vision, trillions of tiny shrimp share a large portion of the responsibility for clarity loss and their removal could be an important component of clarity restoration, even in the face of climate change.

Mysis diluviana. Photo: P.H. Olsen

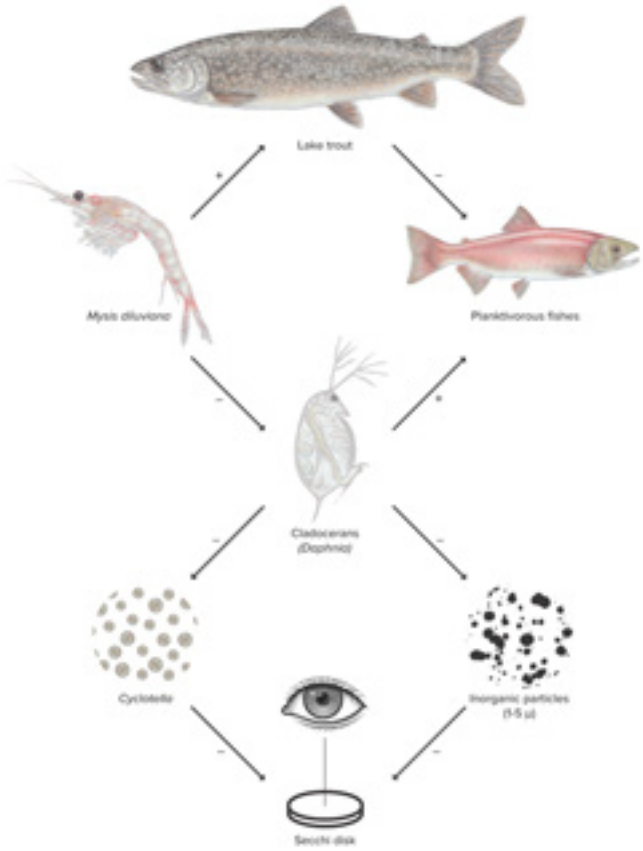
Clearly, Mysids are a Problem, continued

A population of half-inch long shrimp (*Mysis*) were intentionally deposited into Lake Tahoe and Emerald Bay in the early 1960s. By the early 1970s, they had become the dominant zooplankton species having totally consumed the much smaller and extremely efficient filter-feeding cladocerans (*Daphnia*).

Daphnia spent their time indiscriminately sweeping large quantities of small particles into their mouths. Their motivation was to consume tiny phytoplankton (open water algae) but often inadvertently ingesting fine sediment as well. Their undiscerning consumption naturally removed the fine particles known to be most critical in reducing lake clarity. These particles included fine silt and clay, and *Cyclotella* algae. The *Daphnia* packaged their waste products into larger particles that rapidly fell to the bottom of the lake.

This linkage between predatory *Mysis* and lake-clearing *Daphnia* was initially revealed in Emerald Bay between 2011 and 2017. Researchers discovered the *Mysis* population had disappeared from this small-scale analog of Lake Tahoe. Within months, *Daphnia* had returned to the bay and clarity improved beyond that of Lake Tahoe, an occurrence not recorded previously. When the *Mysis* returned after three years, the opposite effect occurred–the *Daphnia* were consumed and clarity returned to its previous low values. This story was detailed in the *2019 State of the Lake Report*.

While this is compelling for a small water body such as Emerald Bay, it begs the question whether the same response could be seen in the main body of Tahoe. An exhaustive review of 50 years of published data says yes!



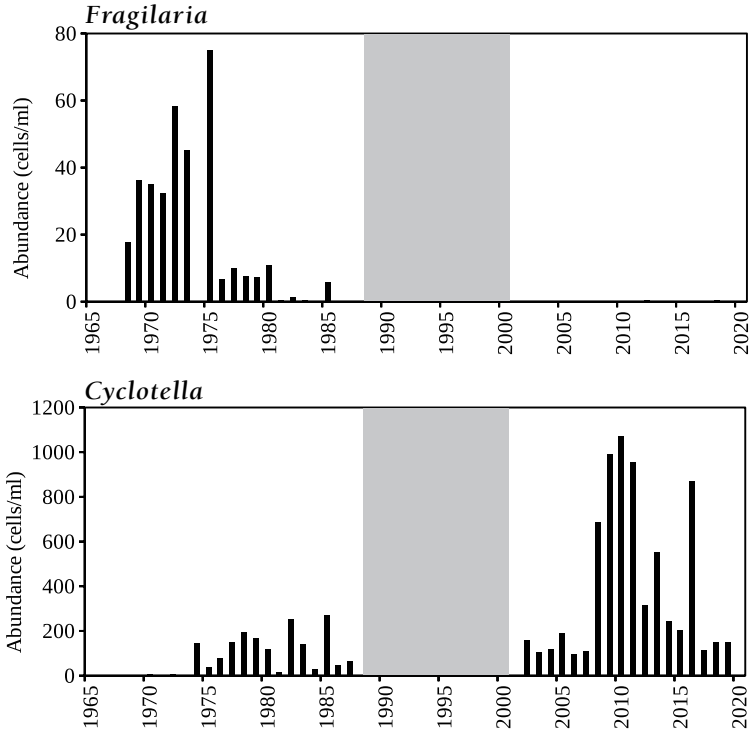
A new view of the relationship between the Lake Tahoe food web and lake clarity. Trace out what happens when you increase or decrease the Mysis. The plus and minus signs on each arrow indicate the direction of change. Illustrations: S. Adler, Figure: H. Segale

Clearly, Mysids are a Problem, continued

What is the evidence? Immediately following the establishment of *Mysis* and the subsequent loss of *Daphnia*, the size of Tahoe's phytoplankton changed radically. The once dominant alga *Fragilaria* (70 microns) was replaced by the very small alga *Cyclotella* (2-8 microns). Why did this happen? *Fragilaria* was too large for *Daphnia* consumption, so they preferentially fed on *Cyclotella*. *Fragilaria* was an ideal size for the omnivorous *Mysis*, and this larger alga was soon consumed. On the other hand, *Cyclotella*, at just one five-thousandth of the size of *Mysis*, were simply too small to bother with. With all the large, nutrient-hungry *Fragilaria* out of the picture, and a near-absence of predation pressure, *Cyclotella* flourished. But the real clincher was that the size of *Cyclotella* was ideal for reducing clarity.

So, to summarize, the *Daphnia* had kept the tiny *Cyclotella* in check while also consuming tiny particles washed in from the watershed. *Mysis* wiped out the *Daphnia*. *Cyclotella* then grew unchecked and fine sediments had no way to be removed other than sinking very, very slowly to the bottom of the lake.

Where does climate change come in? Tiny particles, whether *Cyclotella* or silt, can stay afloat in water for a long time. Climate change warms the surface of the lake for an extended period of time, helping those particles stay afloat and reducing the clarity.



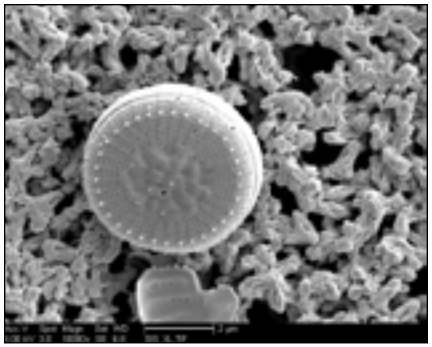
Average Fragilaria abundance at a depth of 16.5 feet and average Cyclotella abundance at a depth of 16.5 feet. Measurements at this depth were not available for the period 1988-2001 indicated by the gray boxes. For all other years a zero reading indicates a total absence of Fragilaria. Mysis were fully established by the mid-1970s.

Clearly, Mysids are a Problem, continued

Based on the review of historic Tahoe data and the lessons learned at Emerald Bay, a new approach is emerging. A reduction in the Tahoe *Mysis* population to allow the return of *Daphnia*, the Roomba® of surface waters. Abundant *Daphnia* would be expected to once again consume *Cyclotella* and other fine particles, improving water clarity, allowing for the return of larger phytoplankton such as *Fragilaria*, and thereby supporting planktivorous fish species.

This does not mean that the restoration activities undertaken at Tahoe to date, many of which were supported by scientific evidence, were the wrong ones. It would be patently wrong to say that preventing tons of nitrogen, phosphorus, and fine particles from entering was a mistake, would be patently wrong. The diversion of all sewage water entering Lake Tahoe, initiated in the early 1960s, was a very far-sighted achievement that was critically important for preserving Lake Tahoe. Likewise, the floodplain restoration projects have restored other habitat in addition to the lake itself.

What we have learned is that we now have two very powerful, science-based approaches for clarity and ecosystem restoration. The watershed restoration approach of limiting what enters the lake, and the lake ecosystem approach where the native food web provides us the environmental services of helping to restore both clarity and the natural function of the entire ecosystem.



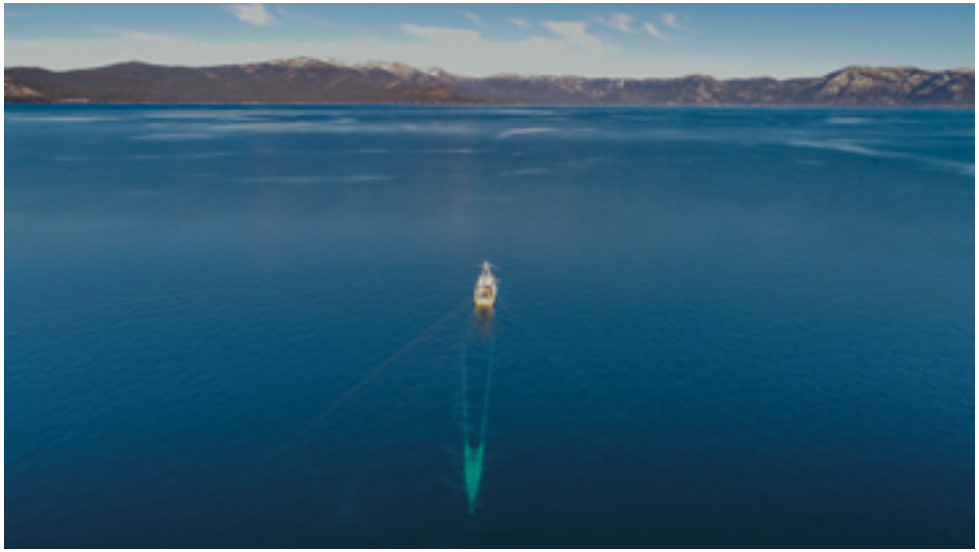
Cyclotella gordonensis

TERC researchers attach a Biosonics Split-beam Echosounder used to locate the highest abundances of Mysis shrimp to increase trawling efficiency.

Clearly, Mysids are a Problem, continued

The approach we are currently exploring to sustain reductions in the *Mysis* population is the utility of harvesting of *Mysis*. *Mysis* from Lake Tahoe happen to be one of the world's purest sources of Omega-3 fatty acids. This greatly sought-after substance is important for both human and animal nutrition, and is an essential ingredient for many food supplements. Working with the UC Davis Graduate School of Management and researchers from the UC Davis School of Veterinary Medicine, we will soon be ready to utilize the *Mysis*' Omega-3 fatty acids and launch a new venture into the world of gourmet dog treats. This venture, a non-profit-based approach, will be an opportunity for public agencies, private investors and university researchers to interact in a totally novel way.

If successful, this would not only have added a potential new tool for clarity restoration that can be combined with watershed load reduction projects, but it will also be an important step toward returning the native phytoplankton, zooplankton, and fish to Lake Tahoe. And unlike nearly all restoration efforts, it has the potential to generate funding to support continued research and restoration. Once again, Lake Tahoe will be at the forefront of environmental restoration in its broadest sense.



The UC Davis TERC Research Vessel trawling for Mysis in Lake Tahoe, 2018. Photo: B. Allen

An Alga for Every Season

Lake Tahoe's nearshore is where the public's impression of Tahoe's aesthetic quality begins. Visitors experiencing crystal clear water, clean granite rocks and beaches will leave with a more favorable impression than those wading through stringy green algae, slipping on boulders covered in slime, and smelling decaying algae washed up on beaches.

In recent years, there has been a growing number of complaints from the public about the perception of an increasing amount of nearshore algae. A 2017 report by TERC scientists Scott Hackley and John Reuter reviewed forty years of data on the abundance of attached algae (periphyton) in the nearshore and found no significant upward trend in algal biomass. A second review by UC Davis PhD student Karen Atkins, using data through 2019, came to essentially the same conclusion. Yet, public perception runs contrary. Why is that?

For over 50 years, the primary nearshore algae community was dominated by species that attach to hard surfaces, known collectively as periphyton. Periphyton can be seen throughout the year but grow to nuisance levels during the spring when they are fed by nutrients derived from lake mixing, snow melt, and ground water. Periphyton thrive until nearshore waters warm and ultraviolet radiation intensifies. Then mats of algae break free (or slough) from the substrate, buoyed by gas bubbles trapped in the algae mat. These mats may float around the lake for weeks, until they sink to the bottom or wash up on shore. This annual occurrence happens in April and May, when people are less likely to visit the shoreline, and by June, most evidence of algae is gone as a result of decomposition.

Regan Beach in South Lake Tahoe, 2014. Photo: S. Hackley

Sampling periphyton on the west shore. Photo: B. Allen

An Alga for Every Season, continued

A patch of sloughed periphyton floating near the west shore. Photo: B. Allen

Metaphyton growing near asian clam beds Photo: B. Allen

Sometime in the 2000s, a new nuisance alga began to make an annual appearance during the summer months along the south shore of the lake. Metaphyton, a class of bright green filamentous algae is now proliferating in shallow nearshore waters. Metaphyton is not attached to the substrate and is free to move with water currents. When the lake level is low, or during strong summer winds, the metaphyton can wash up on beaches turning clean, white sand into a smelly, green shoreline during the peak of the summer visitor season.

How did the metaphyton get here? Some metaphyton were known to be present in the lake in the 1910s. The difference now is that the concentrations and extent have increased, turning them into a nuisance species. The Asian clam invasion, which started in the early 2000s, around the same time that metaphyton became a nuisance, is one of the primary causes of this increase. The metaphyton blooms occur close to dense clam beds and high clam excretion rates of nutrients in summer occur just as the metaphyton begin to grow. The peak growth of metaphyton augmented with nutrients from Asian clams coincide with the height of the summer tourist season, typically in August, and may explain the increasing public comment about the condition of the nearshore.

Whether it is the furry periphyton growth in the spring and its sloughed mats, or the washed up metaphyton, or both, public perception of Lake Tahoe's nearshore is important to us and to local management agencies. With support from the Nevada Division of State Lands, we are developing new remote sensing techniques for tracking both algal communities using an unmanned aerial vehicle (drone) and a helicopter. There is also a great need for input from the public to help us track the spread.

You can assist monitoring efforts by recording your observations on our mobile Citizen Science Tahoe App (https://citizensciencetahoe.org).

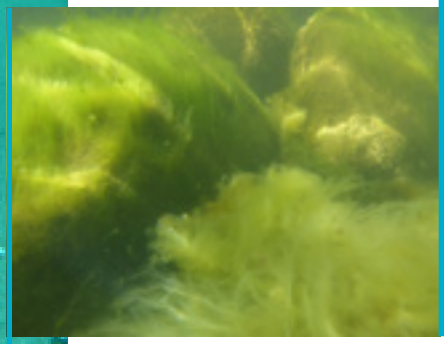
Metaphyton Detection Using a Helicopter and UAV

The health of the lake is often judged by a narrow band of shallow water around its edge. The shore zone of Lake Tahoe is where the public interacts with the lake. In recent summers, metaphyton (unattached, filamentous algae) have been observed over the sandy bottom in nearshore waters of Lake Tahoe. Coupled with seasonal periphyton (attached algae) on shallow substrates, these algae degrade the aesthetic conditions of the nearshore of Lake Tahoe.

In a study supported by the Nevada Division of State Lands' Lake Tahoe License Plate Program, TERC and other UC Davis scientists developed innovative metaphyton monitoring techniques through remote sensing utilizing a helicopter and an unmanned aerial vehicle (UAV) or drone.

The helicopter-based surveys were shown to have great potential for rapidly visualizing the entire shoreline of Lake Tahoe in under two hours. Through helicopter imaging metaphyton were often "discovered" in surprising areas including on the Tahoe City shelf near the outlet and at Skyland on the southeast shore. Researchers were unaware of the extent of growth in those areas until viewed from above in the helicopter.

Metaphyton along bottom at Skylandia beach. Photo: B. Allen



Attached algae (periphyton) on rocks at Regan beach. Photo: S. Hackley

Metaphyton Detection Using a Helicopter and UAV, continued

The UAV proved to be cost-effective and efficient in quantifying the distribution of metaphyton over specific areas of Lake Tahoe's nearshore. The UAV monitoring process developed by TERC, coupled with in-lake biomass sampling, allows future metaphyton monitoring to efficiently assess the timing, distribution, and abundance of nearshore nuisance algae. The same UAV monitoring process also shows potential for estimating periphyton distribution during peak seasonal growth.

In addition to development of helicopter and UAV methods for determining regional distribution of metaphyton, the project studied the association of metaphyton with the occurrence of the invasive Asian clam (*Corbicula fluminea*) which were found to be a major contributing factor to the formation and sustenance of metaphyton patches in the southeast of Lake Tahoe.

These new approaches to monitoring metaphyton will allow for the accurate determination of the spread of these nuisance algae, and provide a very sensitive and cost-effective method for tracking the spread of Asian clams.

Brandon Berry flies the UAV (drone) over a Lake Tahoe site. Photo: B. Allen

Helicopter image of metaphyton (shown with white arrow) at Round Hill Pines. Photo: A. Wong

Sugar Pine Reforestation

Forest Health

From 2012 to 2016, intense drought conditions and bark beetle infestations resulted in the deaths of more than 126 million trees in California and 72,000 in the Lake Tahoe Basin. The TERC Forest and Conservation Biology Lab found significant mountain pine beetle-mediated mortality in sugar pine trees on the north shore of the Lake Tahoe Basin, from Crystal Bay to Tahoe City. Despite high levels of sugar pine mortality, there were numerous surviving sugar pine trees. In 2016, the lab cored from 100 live and 100 mountain pine beetle-killed sugar pine trees, to conduct a retrospective analysis of their tree rings. The pattern that emerged was that the live sugar pine trees utilized water more efficiently then neighboring beetle-killed sugar pines. So in September 2017, the lab collected from 100 local and diverse seed sources, essentially drought "survivors" throughout the Lake Tahoe Basin. Many of the collections came from high mortality locations on the north shore. Over 10,000 seedlings were cultivated at the U.S. Forest Service nursery in Placerville and later maintained at the UC Davis field station in Tahoe City until out-planted.

In fall 2019, TERC partnered with the California Conservation Corps (CCC) to replant over 4,000 seedlings around the Lake Tahoe Basin on state and federal lands. The rationale is to reforest with the progeny of local drought "survivors" to assist regeneration. Reforestation with this progeny will promote forest resiliency to changing and uncertain climatic conditions.

UC Davis forest ecologist Patricia Maloney plants a sugar pine seedling in Lake Tahoe Basin Management Unit. Photo: K. Kerlin

Precise geolocations allow for easier monitoring and tracking. Photo: P. Maloney

Sugar Pine Reforestation, continued

Forest Health

Plant populations can adjust to changing environmental conditions through a number of processes including local adaptation and episodic mortality. Natural resource managers are at a critical moment in how to best manage resources for adaptation and uncertainty, and the Forest and Conservation Biology Lab sees promise in these local and diverse drought "survivors."

The impact of this project, funded by the Tahoe Fund and the California Tahoe Conservancy, has attracted widespread attention to the work UC Davis TERC is conducting in the Sierra Nevada regarding reforestation and climate adaptation strategies.

It was featured on NPR (https://www.npr.org/2019/10/16/766200948/trees-that-survived-california-drought-may-hold-clue-to-climate-resilience); UCD Science & Climate News (https://climatechange.ucdavis.edu/news/the-survivors-sugar-pine-trees-and-the-future-forest/l); live at the LA Times (https://www.latimes.com/california/story/2019-11-18/sierra-trees-climate-change-adaptation-lake-tahoe); and (https://enewspaper.latimes.com/desktop/latimes/default.aspx?edid=fd40b32b-6dd0-408b-9f5d-169f84777403). The work has also attracted international attention in Der Spiegel (https://www.spiegel.de/international/world/california-survivor-trees-researchers-pin-hopes-on-resistent-pines-a-e1424af9-83b4-4433-8fff-752716e3d46b).

Sugar pine restoration planting with assistance from CCC members. Photo: K. Kerlin

Zack McHenry, CCC crew supervisor with an armload of pine seedlings for out-planting. Photo: K. Kerlin

Sugar Pine Genetics: A Test of Local and Diverse Seed Sources

Forest Health

Recovering sugar pines from drought, pest outbreaks, and fire often requires active restoration efforts. All land managers are then left with the difficult decision of selecting appropriate seed material. With funding from the California Tahoe Conservancy, the TERC Forest and Conservation Biology Lab is studying local (from within the Tahoe Basin) and diverse sugar pine seed sources used in reforestation for recovery from drought and bark beetle outbreaks. Additionally, the project is evaluating important adaptive phenotypic traits in a common garden in the lath house located at the Tahoe City Field Station. A common garden experiment is where plants from different genetic individuals are grown in a common environment to evaluate variation in a suite of plant traits (see below). The lab will also be tracking the survival and growth of over 4,000 out-planted sugar pine seedlings in the field. Both the common garden and field sources are the progeny of 100 genetically different sugar pine trees ("mother trees") from the Lake Tahoe Basin.

Trees "pitch out" resin to try and prevent Mountain pine beetles from boring into the inner bark.
Photo: P. Maloney

Sugar pine seedlings are marked to track date of bud burst in the spring.
Photo: P. Maloney

Sugar Pine Genetics: A Test of Local and Diverse Seed Sources, continued

Forest Health

Tagging a variety of seedlings at the lath house in Tahoe City. Photo: K. Kerlin

Seedlings are tested for a myriad of traits. Photo: P. Maloney

The primary research goal is to evaluate 2,100 seedlings in the common garden by measuring the following plant traits: height growth, phenology (timing of bud burst in the spring), water-use efficiency, needle nitrogen content, plant defense chemistry, root to shoot ratio, and stomatal conductance. The lab will also conduct a drought experiment using a control block of seedlings (with ambient watering) and an experimental block for a drought/dry-down treatment. After four weeks, plants are evaluated for three key traits (water-use efficiency, stomatal conductance, and plant defense chemistry) that play a critical role in drought adaptation, plant defense response to insects, and resource partitioning.

Collaboration and outreach with federal and state resource managers is a primary goal in developing seed selection strategies for restoration and reforestation in the Lake Tahoe Basin and other regions in the Sierra Nevada. Such strategies will be fundamental for future forests to adapt and be resilient to ongoing environmental change.

Rise of Robots

Toxin-producing harmful algal blooms (HABs) are increasing in severity and prevalence in lakes, reservoirs, and rivers. While they are not yet present in Lake Tahoe, TERC is at the forefront of understanding the conditions under which they occur and is using innovative new tools to study HABs and predict their occurrence. In Clear Lake, California, HABs have occurred since at least the 1980s, producing scums on the surface of the water, noxious smells, and toxins that pose severe health risks to humans and animals.

In collaboration with the State Water Resources Control Board, the San Francisco Estuary Institute, and the Big Valley Band of Pomo Indians at Clear Lake, TERC is using multiple measurement techniques simultaneously to understand HABs. Robotics is at the core of the work, as sampling HABs can be both hazardous and time intensive. The work to date has involved Gavia, our autonomous underwater vehicle (AUV), aerial drones (UAVs), and satellite imagery to capture how these blooms are behaving both above and below the water. This project received a boost when PhD student Samantha Sharp was awarded a prestigious NASA Fellowship to extend this work both at Clear Lake and at Lake Tahoe.

While HABs are not currently an issue at Lake Tahoe, Samantha's work integrating multiple remote technologies to study algal blooms is something that is very applicable to Lake Tahoe and other lakes around the world.

HAB in Soda Bay, Clear Lake, CA (June, 2020). Photo: M. Swann

The Gavia AUV in Clear Lake, CA (August 2019).Photo: A. Forrest

Ice Fishing for Physics

UC Davis PhD candidate Katie Hughes (left) and local resident Naisi LeBaron augering through 15" of ice at Lake Massawippi (February 2019) Photo: A. Forrest

It may have been thousands of years ago when Lake Tahoe was last frozen over in winter. However, many of the smaller lakes in the Tahoe basin and the Sierra do have annual ice cover. Ice-covered lake studies are not very common due to harsh winter conditions, treacherous working environments, and the lack of appropriate tools to measure the very subtle changes in temperature, oxygen, and other water quality variables that exist in the water under the ice. One example of the delicate balance that exists under the ice is the presence of slowly rotating gyres, natural phenomena that arise in part because of the Earth's rotation. These are believed to be one of the major processes that control water quality in this quiescent environment.

Since 2018, researchers from TERC have been working with the University of Sherbrooke (Quebec) and the École Polytechnique Fédérale de Lausanne (Switzerland) to study an ice-covered lake—Lake Massawippi, Quebec, Canada. The lake's size, reliable ice-cover, and low snow conditions make it an ideal in situ laboratory. The team uses instruments installed under the ice to identify physical processes and to calibrate computer models.

Initial results from last winter are demonstrating the existence of these gyres and increasing our understanding of how these gyres drive mixing under the ice. Additionally, this documentation provides baseline conditions that improve predictions of how warmer future climates will impact the duration of ice cover, water supply, pollutant transport, and ecosystem health.

Plastics in Lake Tahoe

Microplastics, tiny pieces of plastic smaller than five millimeters, are impacting ecosystems worldwide. Microplastics have also been found at Lake Tahoe, despite efforts to clean up beaches and prevent litter.

TERC has been studying the location and extent of microplastic pollution in the lake and has launched efforts to educate visitors and change local consumers' plastic habits as part of the Drink Tahoe Tap® and Take Care Tahoe campaigns. With funding from the Nevada Division of Environmental Protection, the microplastics work is a collaboration between TERC researchers, educators, and several local partners.

A day at the beach (top) goes awry when plastic that is left behind ends up in the lake. Many of those plastics are broken apart and become microplastics. Photos: A. Toy

Photo: B. Wynne

Plastics in Lake Tahoe

Research

In 2016, TERC researchers began sampling the shoreline of Lake Tahoe to search for microplastics. The surprising quantity of microplastics found at all the beaches sampled has led researchers to begin sampling the lake itself.

For the deep (pelagic) waters, representative water samples are taken at multiple depths every three months. A specialized net (a manta trawl) is also towed across the lake surface and at a depth of 100 feet. Bottom sediment samples are collected with a box core sampler to capture denser plastics that have settled out of the water column. As drinking water comes directly from the Lake, water samples are collected quarterly from drinking water treatment facilities operated by Incline Village General Improvement District on the north shore and by Edgewood Water Company on the south shore.

Bioindicators are also an important part of this research. Asian clams, an invasive, filter feeding organism from the south shore and kokanee salmon stomachs provided by fishing guides will also be collected. These samples are sent to the Gjeltema Lab at UC Davis for Raman analysis using microspectroscopy. This provides data on particle size, chemical composition, and possible sources of the identified polymers. Our goal is not just determining where the Tahoe environment is impacted but knowing how we as a community contribute to microplastic pollution, and what actions can be taken to eliminate this self-inflicted harm.

Manta net trawling for microplastics in 2020 while researcher Katie Senft reviews some of the macroplastics found in a trawl sample (inset). Photos: B. Allen and K. Senft

Plastics in Lake Tahoe

Education and Outreach

In winter of 2019, TERC educators launched a campaign to reduce reliance on single-use plastics in the Tahoe basin. This campaign includes an exhibit, direct classroom programming, a community forum, and development of an outreach campaign to sell reusable water bottles at local Raley's grocery stores.

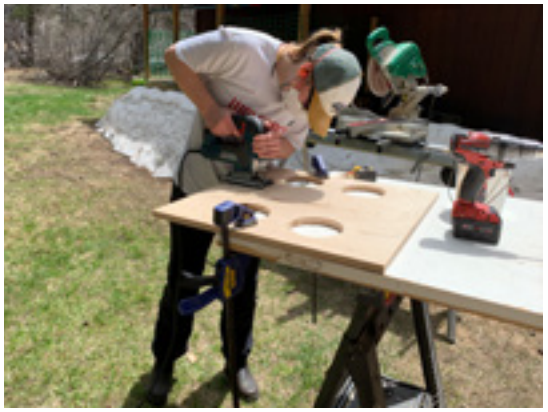
The exhibit on display at the Tahoe Science Center was also intended as an installation in the "Below the Blue: Lake Tahoe's Litter Crisis" art exhibition. The exhibit features a five-panel wall display, three tables of hands-on activities, and demonstrates how plastic items such as water bottles, straws, zip-top plastic bags, and plastic utensils go from just "a day at the beach" to impacting the entire ecosystem.

In collaboration with the Tahoe Water Suppliers Association (TWSA) and Sierra Watershed Education Partnership (SWEP), TERC has developed curricula to teach Tahoe students about the plastic problem facing Lake Tahoe. TERC educators met with Incline High School's Roots and Shoots Club and AP Environmental Science class to encourage students to investigate and discuss solutions to their school's plastic consumption and to eventually participate in broader local efforts to reduce usage of single-use plastic.

TERC organized a free online viewing of the documentary "The Story of Plastic." This was followed by an open forum where community members engaged with expert panelists from UC Davis TERC, UC Davis Gjeltema Lab, Desert Research Institute, League to Save Lake Tahoe, TWSA, Clean up the Lake, and California State Parks.

In partnership with Take Care Tahoe, Tahoe Fund, and Raley's grocery stores in Incline Village, TERC is encouraging residents and visitors to purchase Drink Tahoe Tap®-branded reusable water bottles. These bottles are displayed next to educational signage in Raley's stores. By using the Tap App we can all find locations in the Lake Tahoe Basin to refill reusable water bottles with the best tasting tap water in the world and avoid purchasing single-use plastic water bottles.

High school students sort through mesoplastics as a part of TERC's in-class laboratory session.
Photo: H. Segale



AmeriCorps member Anne Graham working on a portion of the hands-on microplastics exhibits.
Photo: H. Segale

AmeriCorps member Elise Matera teaching about the different types of microplasics and their sources.
Photo: H. Segale

Pandemic Limnology

Boat Captain Brant Allen in protective gear and ready to perform only the most essential research duties. Photo: B. Allen

When COVID-19 emerged as a serious threat to health and life, it abruptly transformed how we worked, played, interacted with our communities and basically lived our lives. Within a day, we were all adjusting to working at home, sharing workspace with kids and roommates, and wondering how long it would last. At the same time, mother nature continued her transition from winter to spring, perhaps celebrating the reduced human impacts.

As scientists, we measure changes in the environment. Landscapes and large water bodies, like Lake Tahoe, respond to environmental changes at timescales of seasons and years, not days. So missing a week of data collection was unlikely to disrupt long-term studies. However, missing an entire season raised the specter of not being able to explain the next six months of environmental conditions and ensuing changes.

For our many graduate students, the stakes are even higher. Missing a season or a year of field data could interfere with spring plans to walk across the stage, diploma in hand. Professors must consider extending financial support to students beyond expected timelines and straining grant budgets. Funding agencies are also not in a position to help—nobody knows what future budgets will be.

In response to these concerns, TERC staff carefully evaluated what research was essential and how to safely get it done within the confines of local, state, federal, and University guidelines. Critical measurements, as winter turned to spring, were the depth and timing of lake mixing which transports stored nutrients to the surface waters, the erosive snowmelt runoff into the lake, and the response of nearshore algae growth to seasonal nutrient loads. Similarly, the maintenance of critical equipment, such as the instrument buoys on the lake, had to continue as failure in mooring lines could result in a tragedy. These were the measurements and activities that continued, albeit under new working conditions.

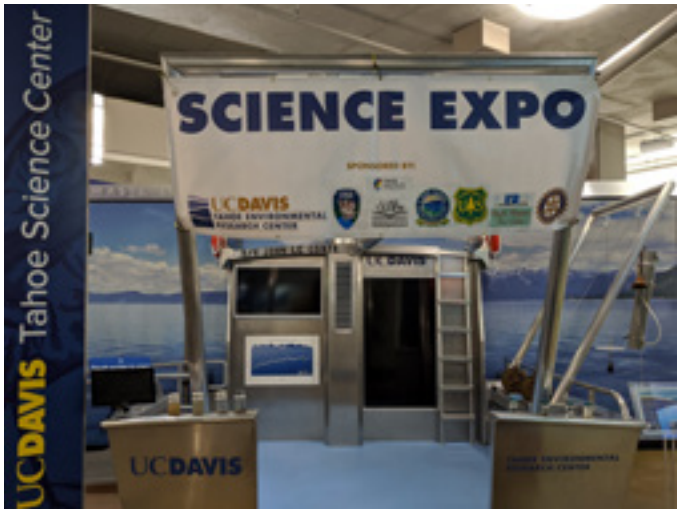
New safety procedures were designed, drafted, and submitted for approval. Under these new operating procedures, researchers worked alone to collect water samples and deploy instruments, and in teams of two when one researcher had to enter the water or extreme conditions warranted it. Personal protective equipment (PPE), long part of TERC's laboratory staff attire, was donned for field work. Face masks and latex gloves were worn at all times on the boats and only removed when replaced with a dive mask, snorkel, and neoprene gloves. Before leaving the marina, and upon return, the boats were thoroughly disinfected. The additional precautions added time and discomfort to the workday, but allowed researchers to maintain on-going projects and collect the most critical data needed for research to progress.

Reshaping Science Education in a Pandemic

March 6, 2020, it's the Friday before the launch of the 2020 Science Expo, TERC's annual week-long learning extravaganza that brings science to every 3rd, 4th, and 5th grade student in the Tahoe-Truckee area. This was also the same day San Francisco made a public health recommendation that at-risk populations limit outings and travel, and cancel non-essential large gatherings.

In the weeks before, we had recruited hundreds of volunteers, fine-tuned designs on over 30 hands-on science activities, and secured supplies. With hand-sanitizer, bleach wipes, and cleaning supplies unavailable, and with news updates coming with increasing frequency, TERC made the painful decision to cancel the event. By the following week all TERC staff were working remotely. The Science Expo banner hung in the empty science center for months to follow serving as a reminder of how quickly things can change.

On March 10, TERC closed the science center to public tours and school field trips and postponed in-person education programming. From March through June, the self-supported education program has experienced a loss of over $22,000. The small education team of two dedicated staff members and three AmeriCorps members had to shift gears and adjust to offering education programs virtually.



A Science Expo banner left hanging in an empty science center. Photo: B. Goodwin

Earth and space science activities set-up for the thousands of students who would miss out this year. Photo: A. Toy

Reshaping Science Education in a Pandemic, continued

Not content to simply wait out the pandemic, the TERC education team launched a massive effort to convert almost all programming to virtual modes. Visit the UC Davis Tahoe YouTube page to see videos of science experiments, volunteer docents explaining phenology and water conservation, and new thematic field trips. The team is currently developing a virtual tour of the Tahoe Science Center for the thousands of visitors who would, in better times, be visiting in-person.

New educational efforts have emerged. A Science-in-Place social media campaign with themes such as Tahoe Tuesdays, Watershed Wednesdays, and Fun Fridays increased our social media following by nearly 50 percent. Garden workshops, which are normally limited to 40 in-person participants averaged 420 viewers per workshop.

As part of a soft opening to new outdoor education programs, TERC is collaborating with the Tahoe Truckee Unified School District to run the Summer Literacy Program with a handful of students from the Tahoe Vista neighborhood. Books are selected with a Science Technology Engineering Math (STEM) emphasis and are complemented by engaging science activities. TERC is also collaborating with the Incline Village General Improvement District to deliver a summer science camp program. In accordance with current state mandates for both programs, all participants are required to wear masks, to answer a health questionnaire each day before participating, and to hand sanitize at the start and throughout programming.

The TERC education team is staying the course to fulfill our mission of using interdisciplinary education to advance knowledge of Lake Tahoe and the many interdependent forces that impact its watershed.

Masked students (siblings) in science summer camp collect beach samples for microplastics analysis. Photos: E. Matera

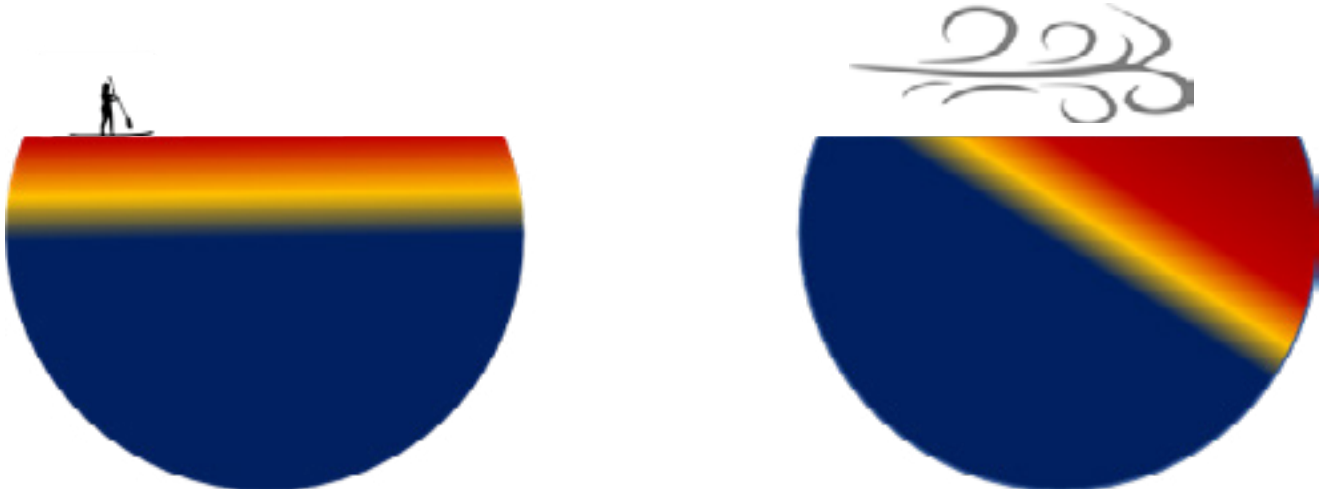
Docent Christie James continues to volunteer at TERC programs, reading to students in the science literacy program. Photos: A. Toy

The Perils of Paddleboarding

Stand up paddleboarding is a wonderful form of recreation and exercise. It is especially wonderful in Lake Tahoe on crystal clear waters, surrounded by beautiful forests and mountains, and in absence of creatures swimming below who might be tempted to eat you. But things are not as idyllic as they seem and serious danger may lurk below, albeit without teeth.

When strong and sustained winds blow at Lake Tahoe and other large lakes, an "upwelling" is produced. Warm surface waters get pushed downwind, and cold water rises (or upwells) from the depths below on the upwind shore. The figure (left) indicates a calm day when paddleboarding is a relaxing, enjoyable experience. Compare this with the figure on the right during a wind event where the effect of the upwelling on the lake is evident. Few people would care to go paddleboarding on such a windy day. The true danger lurks on the following day when the wind has died down, but the lake has not.

Typically, upwellings can occur almost weekly in the spring, but are possible throughout summer and fall. This work was motivated by previous field measurements of temperatures and currents where strong southern currents on the west shore after upwelling events were first observed.

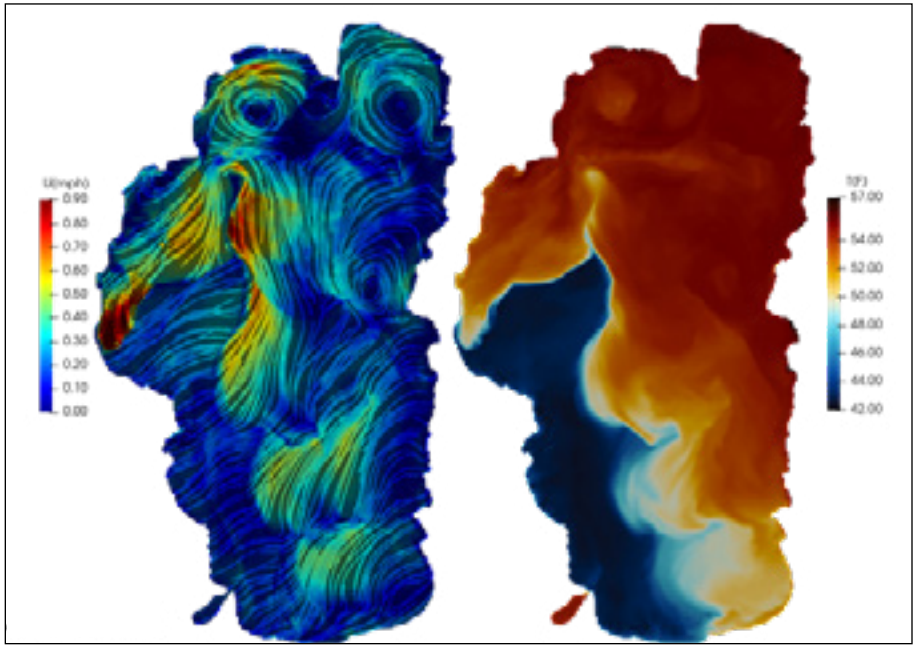


Using a 3-D hydrodynamic model, PhD student Sergio Valbuena has been examining what happens to Lake Tahoe after an upwelling has occurred.

The Perils of Paddleboarding, continued

The figures to the right are from a computer simulation and show lake surface conditions at 3:00 p.m. on June 10, 2018. This was 15 hours after the wind had dropped below 11 mph and 9 hours after the wind had dropped below 4 mph. After the warm water accumulated on the east shore, it flowed across the lake from east to west and then down the west shore, driven in part by the rotation of the Earth (seriously!). The figure on the right shows the surface water temperature with most of the warm water on the east side of the lake. While most of the lake is a brisk 55 ºF, the water in the south-west quadrant is a hypothermia-inducing 42 ºF. As if that isn't enough, the figure on the left shows the surface current patterns occurring at the same time. The red coloration, evident near Tahoma, indicates currents of over 1 mph. That may not seem very fast, but imagine falling off your paddleboard into frigid 42 ºF water. While you are catching your breath, you may or may not notice your paddleboard being carried away at 2 feet per second.

The solution is not to give up paddleboarding, but be aware of complex conditions that prevail at Lake Tahoe. Be wary of the day after strong wind events, as there may be icy water on the side of the lake where the wind came from. There may also be unexpectedly strong currents. Take proper safety precautions by wearing a life preserver and keeping yourself tethered to your board.

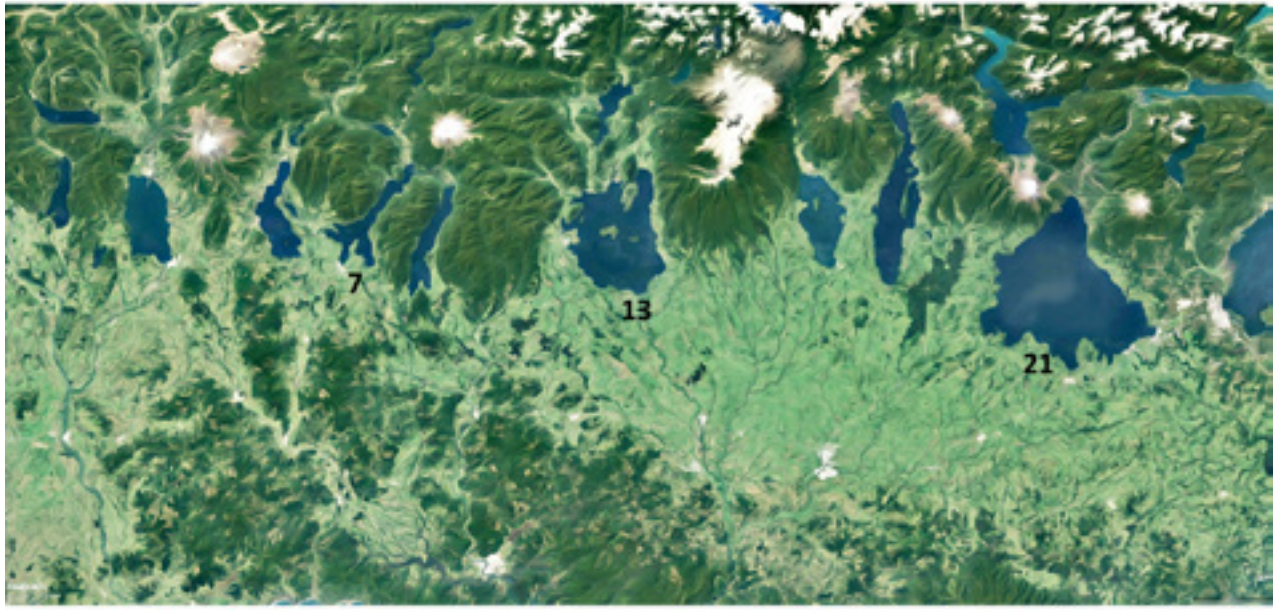


While everyone in this group of paddleboarders is wearing personal protective equipment, very few of them are tethered to their board. Photo: A. Toy

Lake Tahoe's Sister Lakes in Patagonia

A special relationship has been growing between the northern Patagonia lakes of Chile and Lake Tahoe. Why? For one thing, they are both beautiful and iconic regions. Like Tahoe, Patagonia's lakes are deep, near-pristine, offer boundless recreation and eco-tourism potential, and are highly valued by its residents and visitors. There are differences too. Lake Tahoe, known for snowy winter conditions, is perched at over 6,000 feet and is surrounded by the Sierra Nevada, while the Patagonian lakes are snow free at only a few hundred feet above sea level, but with the backdrop of the snow-covered Andes rising precipitously to over 10,000 feet.

Another connection between the lakes is the environmental threats they share. At Lake Tahoe, we have been aware of threats such as over-development, climate change, and poor land-use decisions for over 50 years. In that time, a sophisticated system of management actions and stakeholder engagement was developed to minimize threats and to balance human activities with environmental protection. These actions have usually been predicated on guidance provided by science.

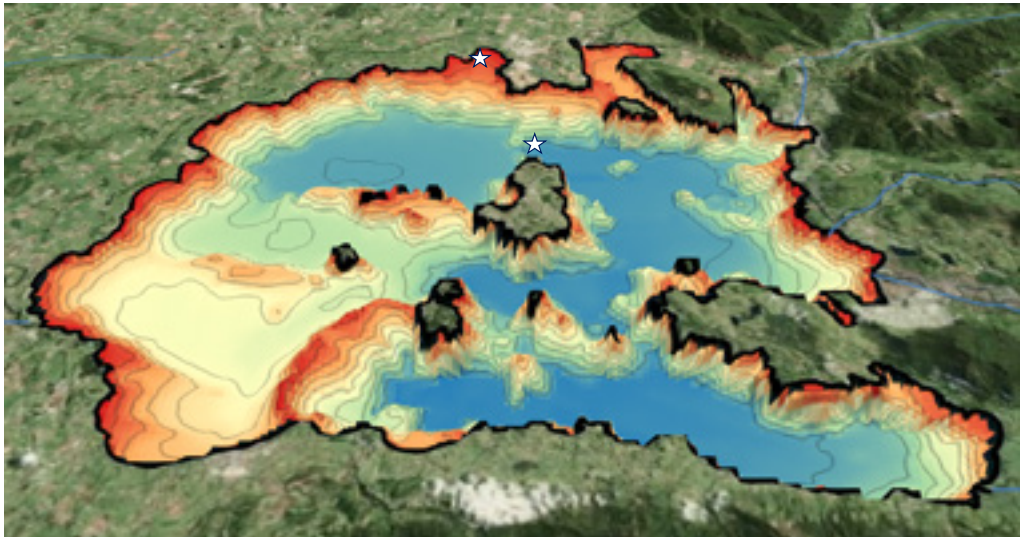


The 23 major lakes of the Northern Patagonia Region. The white areas at the top of the image are the permanently glaciated volcanos of the region. The numbers 7, 13 and 21 indicate the instrumented lakes: 7-Lago Panguipulli, 13-Lago Ranco and, 21-Lago LLanquihue. Image: Land Architects

Lake Tahoe's Sister Lakes in Patagonia, continued

Chile, in contrast, is at a far earlier stage of development and protection but is looking to Lake Tahoe for both inspiration and guidance. As Chile's economy grows, there is increasing pressure for holiday homes, tourism growth, and agriculture. All of these can greatly impact lake water quality if not located in the appropriate parts of the watershed, or in some cases are simply incompatible with maintaining a pristine lake. Investments in more benign options such as ecotourism, sustainable agriculture, and renewable energy can readily be explored to minimize impacts.

TERC has been working with Fundación Chile Lagos Limpios (ChLL), or Chile Clean Lakes, to bring the "Tahoe Process" to Chile. Starting with the installation of water quality instruments in Lago Panguipulli and Lago Ranco, high frequency water quality data are being collected to provide new information on these lakes. With a volume almost identical to Lake Tahoe, the largest lake in the region, Lago Llanquihue has a more ambitious monitoring plan. Through a new partnership with the second largest salmon production company in the world, AquaChile, and the Chilean technology company Innovex, 12 real-time monitoring stations will be installed in this giant lake.



The complex bathymetry (underwater topography) of Lago Ranco. The two TERC instrument stations are indicated by the white stars on the north side of the lake. For scale, the lake is 17 miles from north to south. Image: M. Swann

CHILE LAGOS LIMPIOS FUNDACIÓN

Lake Tahoe's Sister Lakes in Patagonia, continued

The data collected will be used to calibrate three-dimensional lake models that will explore the possible changes from combinations of climate change, future land-use options, and evolving government regulations. The development of these models and the lake data analysis will be part of the doctoral research of UC Davis graduate student Micah Swann. Climate modeling, hydrology modeling, as well as lake sampling will be done through an extensive set of collaborations with Chilean universities, private consultants, and government agencies.

As part of this project, a California delegation is scheduled to visit government representatives in Northern Patagonia in January 2021. In a reciprocal visit funded by the U.S. Embassy, a Chilean delegation will visit Lake Tahoe in June 2021. Funding for this project comes primarily from local stakeholder groups and Chilean foundations.

Lago Panguipulli, with the active Villarrica Volcano in the background. Photo: Guy Welborne Photography

Divers recovering a thermistor chain in Lake Panguipulli, Chile. Photo: G. Schladow