Design and Implementation Recommendations Appendices

July 2025

Final report for SNPLMA Grant P104

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Principal Investigators

US Forest Service Pacific Southwest Research Station
Dr. Patricia Manley[1]
Dr. Gina Tarbill[1]
Shale Hunter[1]
Liraz Bistritz[1]

University of Nevada, Reno
Dr. Scott Allen[2,3]
Dr. Joanna Blaszczak[2,3]
Dr. Emily Burt[2,3]
Dr. Sudeep Chandra[2,4]
Dr. Adrian Harpold[2,3]

[1] U.S.D.A. Forest Service, Pacific Southwest Research Station, Placerville, CA
[2] Natural Resources and Environmental Sciences Department, University of Nevada, Reno, NV
[3] Biology Department, University of Nevada, Reno, NV
[4] Global Water Center, University of Nevada, Reno, NV

TEON Report Appendices

Table of Contents

TEON Appendix A:

Monitoring Programs in the Lake Tahoe Basin

July 2025

Lake Tahoe Basin Monitoring Programs (as of October 2024)

Source: LT Info and Tahoe Regional Planning Agency

Monitoring Program	Monitoring Approach
Air Quality	TRPA and its partners monitor five air quality constituents (ozone, carbon monoxide, particulate matter 2.5, particualte matter 10, oxides of nitrogen) at six air quality stations located around the Lake Tahoe Basin. All air quality monitoring is conducted according to strict EPA-standards or EPA-approved equivelant methods. The six air quality stations are operated and funded by a variety of federal, state, local, and educational partners.
Aircraft Departures/Arrivals Noise Monitoring	Lake Tahoe Airport monitored noise at six sites in the vicinity of the airport (see map above) following an approved monitoring protocol. All exceedances logged by these monitors are documented and categorized in quarterly and annual noise reports sent to TRPA. While monitoring of exceedances has continued, the ability to differentiate between aircraft and non-aircraft exceedances was not possible, therefore data quality is low and only total exceedances (including aircraft, natural sources (e.g. wind, lightning, wildlife) and other anthropogenic sources) are reported and trend is not assessed. Past monitoring data shows that an average of 17 percent of exceedances were caused by aircraft, however the percent of exceedances per year caused by aircraft varies greatly year to year, making any judgement on how many of the total exceedances are caused by aircraft in any given year inestimable.
Aquatic Invasive Species Monitoring	Monthly veliger surveys for mussel larvae are done during the boating season.
Average Daily Winter Traffic Volume, Presidents' Weekend	Caltrans measures this indicator continuously using automated counters placed in the roadway at the intersection of Park Avenue and U.S. Highway 50 in South Lake Tahoe, including on the Saturday of Presidents' Day weekend from 4 p.m. and midnight, coinciding with the historical period of the most frequent exceedance of California's carbon monoxide (CO) standards. Data are summarized by Caltrans and subsequently accessed by TRPA for reporting purposes.

Bicycle and Pedestrian	In 2015, as part of the update to the Active Transportation Plan, TRPA developed the Lake Tahoe Region Bicycle and Pedestrian Monitoring Protocol using best industry practices and national experts Kittleson & Associates. TRPA began implementation in summer of 2015, which built on and integrated previous monitoring efforts. In partnership with local agencies, TRPA has established a system for the collection of year-round active transportation data which includes permanent counting stations, biennial count locations, and spot count locations depending on need. During the first two years of implementation, TRPA produced a bicycle and pedestrian monitoring report which analyzes historical trends, provides detailed information by location, and compares use at similar sites. This report also supplemented the regional transportation monitoring report. Moving forward, all analysis and up-to-date data will be available on the transportation monitoring dashboard, in lieu of a hardcopy report. To download all Bicycle & Pedestrian data please visit Tahoe Open Data. Map Legend: Permanent Monitors-Green Trend Monitors (every other year data)- Brown Pneumatic Tubes (only 1 week of data at a time)- Blue Retired Monitors or Short- term monitoring- Gray
Carbon Monoxide Monitoring	Between 1983 and 1998, CO was monitored at the Horizon Hotel in Stateline, Nevada. In 1999, the monitoring site was relocated to Harvey's Resort parking garage in Stateline, Nevada. The site is located to monitor the highest CO concentrations in the Lake Tahoe Basin because historically this area received the highest traffic volume, and is intended to be representative of both the California and Nevada sides of the South Shore Resort District. NDEP successfully petitioned the EPA to remove this monitoring site on June 30, 2012 because of the continued compliance with established CO concentration standards. CARB provided TRPA with a CO monitor which was installed on the roof of the TRPA building in Stateline, NV in 2013.
Congestion Index	Congestion can be characterized by many metrics and sourced from a variety of different data sources. For the purpose of analyzing congestion in the Tahoe region, TRPA collects data from Inrix and has calculated a congestion index for different multidirectional roadway segments. The congestion index measures the observed speed of a roadway segment in relation to the typical speed of that roadway segment. A roadway segment with a lower (negative) value indicates higher congestion. Lower negative values indicate that the observed speed on a roadway segment is much slower than the expected speed.
Congestion-Travel Time	Congestion can be characterized by many metrics and sourced from a variety of different data sources. For the purpose of analyzing congestion in the Tahoe region, TRPA uses the Regional Integrated Transportation Information System (RITIS) probe data analytics suite, provided by the Federal Highway Administration. The data presented is median observed travel time in minutes for travel in both directions for the segment. The median is the midpoint of how long it took travelers to travel the length of the segment; 50% of trips were faster than this time and 50% were slower.

Cumulative Noise Event Monitoring	Historical monitoring consisted of gathering a single 24-hour sample in various land use areas. Threshold standard attainment status was based on a single sample representing each land use type. In contrast to single-sample historic monitoring, a more comprehensive CNEL monitoring protocol was implemented in 2011. The 2011 monitoring approach was based on recommendations provided by a noise expert (Brown-Buntin Associates 2004). The approach since 2011 monitors the same sites every year for at least seven days during the period of May 15 to October 1. This captures noise levels during the construction season and the busiest tourist seasons. Unusual noise such as lightning strikes and animal sounds are discarded from the data. The mean 24-hour dBA from each day is averaged for the final CNEL at each monitoring location. Decibel levels at night are weighted heavier to account for human's greater sensitivity to night-time noise.
Cup Lake Draba (Draba asterophora var. macrocarpa) Monitoring	Currently, a total of 10 subpopulations of Draba asterophora var. macrocarpa are monitored by various partners following standardized protocols developed by U.S. Forest Service botanists. See Program Description for more detail on monitoring approach.
Deciduous Riparian Vegetation Monitoring	Vegetation types associated with deciduous riparian vegetation (montane riparian, aspen, and mix hardwood/conifer) were queried and enumerated from the most recently available vegetation map (U.S. Forest Service - Remote Sensing Lab Pacific Southwest Region: TMU_Strata_07 [published 2009]). The Tahoe vegetation map is periodically updated with new satellite data and/or modelled and calibrated using field-based forest inventory and analysis data to assess the extent of different vegetation types and associated forest structure characteristics for the Region (USDA, 2009; Warbington et al., 2011).
Deep Water Plants Monitoring	The data used in this assessment was collected in 2008, 2009 and 2013 in an attempt to find endemic invertebrates and the deep water plants they depend on. Divers investigated the spatial extent and depth profiles of the only two known beds at Camp Richardson and the South Shore Mound during the 2013 survey. Routine monitoring is not currently underway for this indicator.
East Shore Parking Counts	Parking counts are taken annually the first Saturday and following Wednesday of August. Counts are collected hourly beginning at 10 AM and ending after 5 PM. The east shore corridor, from Incline Village to the intersection of
Fish Habitat Mapping	The monitoring approach used for evaluating the attainment status of this standard involves the mapping and classification of fish habitats in the nearshore (the lake zone that exists approximately between elevations of 6,229 to 6,199). In 1971, a cooperative survey was done by various state and federal fish and wildlife agencies to identify fish and aquatic habitats of special significance. This work produced a Prime Fish Habitat Map that TRPA adopted in 1984. This map, as amended in 1997, is still the map TRPA uses today. Byron et al. (1989) as part of their fish habitat study resurveyed and mapped fish habitat around Lake Tahoe. According to TRPA (1996), the Byron et al. work represented a more accurate picture of the types of fish habitat based on lakebed substrate. The 2006 and 2011 Threshold Evaluations Reports utilized an updated fish habitat map based on satellite imagery collected in 2002 (Metz and Herold 2004; Herold, Metz, and Romsos 2007a). O'Neil-Dunne (2016) followed simi

Freel Peak Cushion Plant Community Monitoring	Long-term monitoring plots were installed in 2006 on Freel Peak and 2 adjacent summits following GLORIA protocol. Vascular plant and groundcover are visually estimated in 16 one-meter by one-meter permanent quadrats, and species presence is recorded in eight summit area sections. In addition, continuous soil temperatures are logged in four summit areas, and detailed repeat photography is taken. Plots are remeasured every 5 years. The U.S. Forest Service Pacific Southwest Research Station has taken the lead in organizing monitoring associated with the GLORIA project throughout California. GLORIA data provide the primary indicator of the status and trend of the cushion plant community. In 2009, the LTBMU installed 4 permanent plots targeting the Tahoe draba population in the Freel Peak cushion plant community. The plots are visited every 3-5 years to provide a quantitative and consistent method for evaluating the status and trend of this sensitive species.
Galena Creek Rockcress (Boechera rigidissima var. demota) Monitoring	This species is included in the sensitive species monitoring program at the U.S. Forest Service - LTBMU. Plant population sites are visited every five years or more frequently when the occurrence is new or data suggests that the population is decreasing. Recent monitoring has focused on verification of species identity.
Golden Eagle Population Sites Monitoring	Since 2010 there have been no formal surveys as a result of cutbacks to the U.S. Forest Service wildlife monitoring program.
Grass Lake (sphagnum fen) Monitoring	See Program Description for the monitoring regimes in place at Grass Lake.
Hell Hole (sphagnum fen) Monitoring	Several monitoring regimes are in place at Hell Hole. See Program Description for an outline of these monitoring regimes.
Lahontan Cutthroat Trout Recovery Monitoring	Two populations of Lahontan Cutthroat Trout are actively monitored in the Tahoe Basin. The fluvial population in the Upper Truckee River in the Meiss Meadows area is actively managed and monitored by the USDA Forest Service. The lacustrine population in Fallen Leaf Lake is actively managed and monitored by the US Fish and Wildlife Service.
Lake Tahoe Aquatic Plant Monitoring Program: Aquatic Plant Monitoring and Evaluation Plan	Two levels of aquatic plant survey effort (spatial design) are applied to the APMP and each is performed on a different temporal scale. Once every five years a nearshore-wide aquatic plant survey is conducted via interpretation and mapping of remotely sensed data in combination with in situ diver sampling. Annually, only an in situ diver survey (or a reasonable surrogate) is performed following targeted and a stratified systematic sampling of transect lines with incorporated quadrats. The nearshore-wide aquatic plant survey (i.e., the combination of remote sensing imagery analysis with diver surveys) attempts to provide for a “baseline” status quantification of all aquatic plant beds around Lake Tahoe’s nearshore zone. The transect surveys allows for training and validation of remotely sensed data, and annual surveillance to establish trend information and the detection of new infestations of aquatic invasive plants. The sampling frame (i.e., survey area) and habitat stratification scheme used for line-transect surveys conducted in intervening years will be the same as that used for the nearshore-wide survey. Four habitat strata are used to divide the aquatic plant population into meaningful sampling units, including open-water nearshore, marshes, major tributaries, and marinas and embayments.

Lake Tahoe Interagency Monitoring Program Stream Monitoring	The Lake Tahoe Interagency Monitoring Program (LTIMP) stream monitoring program was first developed in 1979 to assess sediment and nutrient input from tributaries to Lake Tahoe, and to support research that aims to understand the drivers affecting the transparency of Lake Tahoe. The tributary monitoring focuses on both event-based conditions (large runoff events associated with rainfall and snowmelt) and baseline conditions (low inflow during summer when precipitation is negligible). Up to 10 streams have been monitored since the early 1990s; five in California (Upper Truckee River, and Trout, General, Blackwood and Ward Creeks) and five in Nevada (Third, Incline, Glenbrook, Logan House, and Edgewood Creeks). Six of these streams have been monitored since water years 1980 or 1981. In water year 2012 the number of streams routinely monitored was reduced to seven (see map above), and all streams have primary monitoring stations at or near the point of discharge to Lake Tahoe. Sampling pr
Land Coverage Monitoring	The base impervious coverage layer for the Region was sourced from a LiDAR survey completed in August 2010. LiDAR is a remote sensing technology that uses laser and light refraction to image objects and terrain. The 2010 LiDAR analysis mapped the extent of hard and soft impervious cover in the Region. The cost of acquiring LiDAR data for the Region makes quadrennial LiDAR surveys infeasible. To assess change in impervious cover without the benefit of new LiDAR imagery, information collected from project permitting by TRPA and partners was used to determine added/new coverage. Land capability as defined in the 2007 soil survey was used as the primary unit to measure coverage in a land capability class, both because it was used in the 2011 Threshold Evaluation Report (TRPA, 2012b) and because it is more detailed than the 1974 Bailey report (Loftis, 2007). Information about coverage removed was provided by the CTC, NDSL and the Parcel Tracker.
Late Seral and Old Growth Forest Monitoring	Every five years, the Tahoe vegetation map is updated with new satellite data (if available) and/or modeled and calibrated using field-based Forest Inventory and Analysis (FIA) data to assess the extent of different vegetation types and associated forest structure characteristics for the Region (USDA, 2009; Warbington et al., 2011). For this analysis, California Wildlife Habitat Relationship (CWHR) vegetation types associated with large diameter trees were queried and enumerated from the most recently available vegetation map (U.S. Forest Service - Remote Sensing Lab Pacific Southwest Region: TMU_Strata_07 [published 2009]).
Long-Petaled Lewisia (Lewisia pygmaea longipetala) Monitoring	Quantitative monitoring of long-petaled lewisia in the Region began in 2004when plants were located and counted at 3 population sites (Dick’s Lake, Triangle Lake and Azure Lake) in 6 subpopulation sites. A new subpopulation was discovered near Azure Lake in 2006, and near Triangle Lake in 2009, and new populations were discovered near Jack’s Peak in 2011, and Ralston Peak in 2012, bringing the total number of known populations to 5, with 12subpopulations. All known subpopulations are censused by LTBMU staff every 5 years at a minimum (typically more frequently), and long-term demographic monitoring occurs every 3 -5 years in permanent plots established at 2populations. An extensive survey was completed for long-petaled lewisia in 1991 and 2 long-term monitoring plots were installed at Region Peak in the Tahoe National Forest and within the LTBMU at Keith’s Dome above Triangle Lake. Plant populations are visited every 3-5 years (more frequently when data suggests the pop. is decreasi

Meadow & Wetland Vegetation Type Monitoring	Vegetation types associated with meadows and wetlands (California Wildlife Habitat Relationship type “WTM” [wet meadow] and “PGS” [Perennial Grassland]) are queried and enumerated from the most recently available vegetation map (U.S. Forest Service - Remote Sensing Lab Pacific Southwest Region: TMU_Strata_07 [published 2009]). The Tahoe vegetation map is periodically updated with new satellite data (if available) and/or modelled and calibrated using field-based forest inventory and analysis data to assess the extent of different vegetation types and associated forest structure characteristics for the Region (USDA, 2009; Warbington et al., 2011).
Nearshore Human Health	Water quality samples are taken throughout the summer at population beaches throughout the Tahoe Basin. Samples are analyzed for the presence and concentration of Escherichia coli (E. coli). E. coli is considered an indicator organism, used to identify fecal contamination in freshwater and indicate the possible presence of disease-causing bacteria and viruses (pathogens). Individuals who swim or come in contact with water with elevated levels of E. coli and other fecal indicator organisms are at an increased risk of getting sick because of potential exposure to fecal pathogens (USEPA).
Nearshore Resource Allocation Program	Umbrella coordination for nearshore monitoring efforts in lake Tahoe. The program is overseen by the Nearshore Agency Working Group, which includes representatives of five agencies, the U.S. Environmental Protection Agency, Nevada Department of Environmental Protection, Tahoe Resource Conservation District, Lahontan Regional Water Quality Control Board and Tahoe Regional Planning Agency.
Nearshore Turbidity Monitoring	A pilot monitoring program of nearshore turbidity began with the first circuit completed in November 2014, followed by similar nearshore circuits completed in April, June, August and November 2015. Measurements were made at a depth of seven meters. Routine boat operating speeds are typically around 10 kilometers per hour in the nearshore areas (Heyvaert et al., 2016). Beginning 1991, nearshore turbidity was measured offshore at the 25-meter depth contour for several locations, including 1) mouth of Upper Truckee River and Trout Creek; 2) El Dorado Beach; 3) mouth of Edgewood Creek; 4) Nevada Beach; 5) mouth of Incline Creek; 6) Burnt Cedar Beach; 7) mouth of Ward Creek; 8) Tahoe State Recreation Area; and 9) the mouth of Blackwood Creek. More recently, nearshore clarity has been measured at approximately the seven-meter contour following a continuous circuit around the lakeshore. This strategy is considered more representative of littoral conditions where people interact with the lake
Nesting Bald Eagle Population Site Monitoring	Known nest sites are visited regularly during the incubation and fledging periods to determine reproductive success. Monthly boat surveys during non-winter months are conducted to identify any new nest sites surrounding Lake Tahoe, and ad-hoc surveys are conducted in other areas in support of environmental assessments for proposed projects.

Nitrogen Dioxide Concentration Monitoring	THe California Air Resources Board (CARB) compiles data to create the criteria pollutant emission inventory, which includes information on the emissions of reactive organic gases (ROG), oxides of nitrogen (NOx), oxides of sulfur (SOx), carbon monoxide (CO), and particulate matter (PM10). Data are gathered continuously and stored in the California Emission Inventory Development and Reporting System (CEIDARS). A summary of the criteria pollutant inventory is published annually. The California emission inventory contains information on the following air pollution sources:Stationary sources - approximately 13,000 individual facilities defined as point sources. Point sources are fixed pollution sources such as electric power plants and refineries.Area-wide sources - approximately 80 source categories. An area-wide source category is made up of sources of pollution mainly linked to human activity. Examples of these sources include consumer products and architectural coatings used in a region.Mobile sources - all on-road vehicles such as automobiles and trucks; off-road vehicles such as trains, ships, aircraft; and farm equipment.The principal agencies contributing data to the stationary and area-wide source inventory are the CARB and the California air pollution control and air quality management districts. The CARB, the California Department of Transportation (Caltrans), and regional transportation agencies are the principal agencies involved in developing the mobile source inventory. Information represented in the California emission inventory is a snap-shot of a variety of dynamic and variable processes. As such, the emission inventory can only represent an estimate of what is actually occurring. In summer 2011, a new NOx monitoring station was installed at the TRPA offices in Stateline, Nevada. Data from 2013 and 2014 for this site are now available.
Noise - Highways	TRPA uses a Community Noise Equivalent Level (CNEL) meaure to assess whether noise levels are being exceeded in highway corridors. The CNEL averages decible (dB) levels over a 24 hour period, with excess noise late at night and early in the morning being weighted greater due to humans and wildlife being more sensitive to noise at these times.The highest 24-hour CNEL measured is used to assess noise levels. TRPA regularly monitors noise along highway corridors at 30 locations around the Tahoe Basin, with monitors located 300 feet from the edge of the highway. Noise monitors are deployed for 1-2 weeks during the peak highway useage period, which is generally July 4th through Labor Day. Each noise monitoring location is re-visited once every four years. Noise monitors are calibrated to industry standards to ensure accuracy.

Noise - Plan Areas	TRPA uses a Community Noise Equivalent Level (CNEL) meaure to assess whether noise levels are being exceeded in Plan Areas. The CNEL averages decible levels over a 24 hour period, with excess noise late at night and early in the morning being weighted greater due to humans and wildlife being more sensitive to noise at these times. Noise monitors are generally put out in Plan Areas for 1-2 weeks during peak noise periods (generally summer). The average 24-hour CNEL measured is used to assess noise levels. Construction noise or other unusual noise events are excluded from the data. Noise monitors are calibrated and tested to noise industry standards to ensure proper measurements. TRPA monitors 35 Plan Areas per year, and re-visits each site once every 4 years (140 Plan Areas monitored total).
Noise - Shorezone	TRPA regulalry monitors noise in the shorezone from motorized watercraft at up to ten locations around Lake Tahoe. Noise monitors are deployed for at least two weeks during peak boating season which occurs July 4th to Labor Day. Noise monitors automatically record all single noise events that exceed 75 decibles (dB), the noise limit for shorezone areas. Afterward, all noise events exceeding 75 dB are listened to by a noise technician to distinguish noise exceedancs from watercraft and non-watercraft. Noise monitors are regularly calibrated to industry standards to ensure accuracy. To download all of the shoreline noise data on this page please see Tahoe Open Data.
Northern Goshawk Population Sites Monitoring	Portions of known and potential northern goshawk habitat are surveyed following well-accepted protocols including a combination of dawn acoustic surveys, stand search surveys, and broadcast surveys. Recent survey work has been conducted in response to proposed projects and has been primarily focused at assessment of project level impacts, not assessment of population status and trends in the Tahoe Basin. The last full population survey was completed in 2010.
Osgood Swamp Monitoring	Two recent different monitoring approaches have been implemented at Osgood Swamp. See Program Description for these approaches.
Osprey Population Sites Monitoring	A shoreline survey is conducted by boat monthly during spring and summer months following standard protocols. Additional surveys are conducted at historic and likely nest sites at other lakes and upland areas. All suitable nesting habitat is surveyed for nest activity and nest success.
Oxides of Nitrogen Emissions Monitoring	CARB compiles data to create the criteria pollutant emission inventory, which includes information on the emissions of reactive organic gases (ROG), oxides of nitrogen (NOx), oxides of sulfur (SOx), carbon monoxide (CO), and particulate matter (PM10). Data are gathered continuously and stored in the California Emission Inventory Development and Reporting System (CEIDARS). A summary of the criteria pollutant inventory is published annually.
Ozone Monitoring	Ozone is monitored at a number of locations around the Lake Tahoe Basin through the years by a variety of partners. Data is collected, analysed, and reported by the respective agency.
Pelagic Water Quality (Clarity)	Measurements are taken in Lake Tahoe using a 25 centimeter, all white Secchi disk. The disk is lowered into the water column from a boat to a depth at which it is no longer visible by the observer, and then raised slowly until visible again. The midpoint of these two depths is called the Secchi depth. Between 18 and 37 individual Secchi depth measurements have been collected each year at an established index station.

	To download all of the water clarity data on this page please see Tahoe Open Data.
Peregine Falcon Population Sites Monitoring	Biologists observe historic or potential nest sites for a minimum of four hours per month, April through August following standard U.S. Forest Service protocol. All potential nesting habitat is surveyed and incidental sighting are used to help focus monitoring efforts.
Periphyton	UC Davis has monitored periphyton in Lake Tahoe since 2000. Monitoring also occurred between 1982 and 1985 and 1989 to 1993. The primary periphyton monitoring work are regular sampling work referred to "routine" sampling at nine sites annually (the number of locations has varied historically from six to ten). At each location algal biomass (as chlorophyll a) is sampled five times annually from natural rock surfaces at a depth of 0.5 meters below the water level at the time of sampling. A second type of sampling, referred to a "synoptic" monitoring occurs once a year at 40 additional sites. The timing of synoptic monitoring varies annually and is intended to capture biomass at its peak in the spring. The synoptic monitoring includes collection of chlorophyll a at a sub-set of the sites, as well as a rapid assessment method that quantifies a periphyton biomass index (PBI).
Phytoplankton Monitoring	Phytoplankton PPr measurements at Lake Tahoe have been made following the same standard operating procedure since the first observations were made in 1967 (Winder et al., 2009). Lake water is collected at the TERC west shore index station, which was found to be representative of the lake's deepwater condition (Charles Remington Goldman, 1974). For each sampling event, water samples are collected from 13 different depths (between 0-105m) spanning the photic zone (i.e., the vertical zone in the water column exposed to sufficient sunlight for photosynthesis to occur), and analysed to determine carbon assimilation rates using very sensitive methods needed for pristine or oligotrophic waters (Charles Remington Goldman, 1974). Values from the various samples are aggregated to yield a depth-integrated PPr value. These depth-integrated values are aggregated over the calendar year to generate an estimate of annual average phytoplankton primary productivity. Between 1967 and 2006, measurements w
PM10 Monitoring	Particulate matter is monitored in the Tahoe Basin by the California Air Resources Board at South Lake Tahoe, and is monitored as part of the national IMPROVE network sites at LTCC and DL Bliss State Park.
PM2.5 Monitoring	Particulate matter is monitored by Placer County in Tahoe City, and at LTCC and DL Bliss as part of the national IMPROVE national monitoring network.

Pope Marsh Monitoring	The status and trend determinations were based on a qualitative assessment of factors influencing the condition of the site, including historical alterations, ongoing hydrologic impacts, sources of recreation-related disturbance, and surrounding land use and resource management. However, in the future it will be possible to base the evaluation on quantitative vegetation monitoring data. Two permanent plots following the protocol in the Region 5 Range Monitoring Program were installed at Pope Marsh in 2004 (Weixelman 2011). These plots are on the north-east and north west portions of Pope Marsh. The protocol is designed to classify a meadow according to wetland index and plant functional types, which provides a quantitative ecological condition scorecard for that meadow type (Weixelman and Gross In Review). The plots were visited in 2009/2010 and 2014/2015 and the USFS is in the process of analyzing the data (Engelhardt and Gross 2011b; Shana Gross pers. comm.). Distance to meadow edge,
Regional Stormwater Monitoring	Monitoring is guided by the RSWMP Framework and Implementation Guidance document. During water year 2014 five catchments were monitored for continuous flow and turbidity and sampled for water quality at eleven monitoring stations: the outfalls of the five selected catchments, and the inflows to and outflows from selected BMPs located in three of those catchments. Three additional catchment outfalls were monitored in water year 2015. The catchments were chosen because of their direct hydrologic connectivity to Lake Tahoe, diversity of urban land uses, range of sizes, and a reasonably equitable distribution among the participating jurisdictions. BMP effectiveness sites were selected because of their potential efficacy in treating storm water runoff characteristic of the Lake Tahoe Basin, and the broad interest in, and lack of conclusive data regarding the efficiency of the selected BMPs in reducing runoff volumes and pollutant loads.
Regional Visibility Monitoring	Air samples needed to calculate bext were collected at least every six days at D.L. Bliss State Park. This is an appropriate site for monitoring regional conditions because it is not influenced by urban sources ((L.-W. Antony Chen, Watson, John G., and Wang, Xiaoliang 2011)). Data are collected, analyzed, and reported by the IMPROVE (national Interagency Monitoring of Protected Environments) network using nationally accepted protocols.
Safety	Safety performance measures help to assess fatalities and serious injury on all public roads regardless of ownership or functional classification. These measures are required to be incorporated into the regional transportation plan and state's Highway Safety Improvement Programs. To support meeting these targets, a Lake Tahoe Region Safety Plan is underdevelopment which outlines crash trends, risk factors, gaps in data, and recommends strategies and designs to improve safety for all roadway users. Crash data is provided by the state of California and Nevada and consolidated by TRPA. To download crash data please visit Tahoe Open Data.
Scenic Monitoring	Every four years, a team of professionals examines and evaluates the quality of scenic units and resources along major roadways, the shoreline, and at certain public recreation sites and bike trails in the Lake Tahoe Region. The team also reviews ratings from prior evaluations and updates rating based on its findings.
SEZ Basin-wide Monitoring and Assessment Plan	SEZ function is evaluated as a function of up to 10 indicators. Details on each indicator and monitoring methods are available in the plan. Results from the program are comiled on the Lake Tahoe SEZ Viewer: https://gis.trpa.org/TahoeSEZViewer/

Shrub Abundance Monitoring	Updated vegetation maps were not available for this evaluation. Instead, the most recent data from 2009 is used. Periodically, the Tahoe vegetation map is updated with new satellite data (if available) and/or modeled and calibrated using field-based forest inventory and analysis data to assess the extent of different vegetation types and associated forest structure characteristics for the Region (USDA, 2009; Warbington et al., 2011). Vegetation types associated with shrubs were queried and enumerated from the most recently available vegetation map (U.S. Forest Service - Remote Sensing Lab Pacific Southwest Region: TMU_Strata_07 [published 2009]). As shown in Table 1 California Wildlife Habitat Relationship types were queried to represent shrub vegetation in this evaluation.
Socio-Economic	The U.S. Census Bureau collects and distributes data under a handful of different programs. Two of the more commonly used programs are the Decennial Census and the American Community Survey (ACS). The Decennial Census is a definite source of demographic data but only is collected every ten years; it includes a limited number of variables such as number of households and total population. The ACS is a program that provides data estimates on a one, three, and five year timeline; ACS data is collected more frequently but the data estimates have a margin of error that must considered because the data is taken from a small sample of the total population. The ACS includes many more variables compared to the Decennial Census that relate to transportation, income, and housing. Both the Decennial and ACS datasets have similiar data structures. Each row in both datasets include a particular variable and a number the indicates the total number of households or persons that characterize that variable.
Stream Habitat Condition Monitoring	Streams are monitored using widely accepted bioassessment protocols established by the EPA and further refined by the California Department of Fish & Wildlife (CDFW) (Kaufmann et al. 1999; Ode 2007; Barbour et al. 1999). Specifically, stream monitoring is conducted using Standard Operating Procedures for Collecting Benthic Macroinvertebrate Samples and Associated Physical and Chemical Data for Ambient Bioassessments in California (Ode 2007). The TRPA stream monitoring program was developed in partnership with the EPA, CDFW, Nevada Department of Environmental Protection (NDEP), Lahontan Water Quality Control Board (Lahontan), and the U.S. Forest Service (USFS) (Fore 2007). Benthic macroinvertebrates (BMIs), as well as physical and chemical stream characteristics, are sampled at 48 streams annually. Of these 48 streams, 16 per year are probabilistic “status” sites randomly selected through EPA modelling (Olsen et al. 1999; Paulsen, Hughes, and Larsen 1998) and 24 are “trend” sites revisi
Streams	TRPA's stream monitoring program uses the Surface Water Ambient Monitoring Program bioassessment protocol, which measures Benthic Macroinvertebrate (BMI) composition and physical stream habitat to assess overall stream health. BMI composition and habitat is compared against pristine streams using the California Stream Condition Index to determine the biotic integrity of streams. Probabilistic and targeted sampling is used to assess the overall health of Tahoe streams, changes in stream health over time, and to assess large scale restoration and BMP implementation projects. 20 probabilistic, one-time "status" sites are sampled per year, as well as 73 "trend" sites re-visited every four years. Only trend sites are displayed on this page. Status site information can be found at EcoAtlas.org To download all of the stream data on this page please see Tahoe Open Data.

Sub-Regional Visibility Monitoring	Air samples needed to calculate bext were collected at least every six days at a South Lake Tahoe site. Data were collected, analyzed and reported by the IMPROVE network using nationally accepted protocols. A monitoring site was set up at Lake Tahoe Community College in 2014.
Tahoe Draba (Draba asterophora va. asterphora) Monitoring	U.S. Forest Service monitoring of Tahoe draba began in 2004 when plants were located and counted at 22 subpopulation sites (Engelhardt and Gross 2013). An additional 3 sites were added in a limited survey in 2005. All sites were re-surveyed in 2009 and 9 new sites were added. In 2013 six sites were revisited and one new site was discovered, and in 2014 14 sites were revisited. All known subpopulations are censused by LTBMU staff every 5 years at a minimum. A comprehensive long-term monitoring program for Tahoe draba was initiated in 2009 when plots were installed at seven subpopulation sites within three LTBMU populations (Engelhardt and Gross 2011a). Monitoring plots were established at three subpopulations within two populations (Relay Peak and Mt. Rose Ski Area) on the Humboldt-Toiyabe National Forest in 2011. Monitoring occurred two years after plot establishment to collect baseline data, and will occur every 3 to 5 years until the species is no longer considered sensitive.
Tahoe Yellow Cress Monitoring	Knowledge of TYC distribution has been developed through shorezone surveys since 1979. Before 2000, surveys followed a general protocol and were completed at various times during the summer. Since 2001, surveys are conducted the first week of September following a standardized protocol. During the first survey in 1979, 32 TYC sites were surveyed; this has since grown to 55 sites. A survey “site” is defined as a stretch of public beach, adjacent private parcels, or adjacent parcels under a combination of private and public ownership. Surveys include stem count estimates as a measure of TYC abundance because clonal growth makes it impossible to distinguish individuals. The amount of available shorezone habitat for TYC fluctuates widely with changes in lake level, with high lake levels leaving little habitat. On average, over 70% of surveyed sites are occupied when the lake is below 6,225 ft. in September, but less than 40% are occupied when the lake level is above 6,228 ft. To download all of the Tahoe yellow cress data on this page please see Tahoe Open Data.
Taylor Creek Monitoring Program	The status and trend determinations were based on a qualitative assessment of factors influencing the condition of the site including historical alterations, ongoing hydrologic impacts, sources of recreation-related disturbance, and surrounding land use and management. One permanent plot, following the protocol in the Region 5 Range Monitoring Program, was installed at Taylor Creek Marsh in 2004 (Weixelman 2011). Two plots were installed in 2004 in the adjacent Tallac Creek Meadow. The protocol is designed to classify a meadow according to wetland index and plant functional types, which provides a quantitative ecological condition scorecard for that meadow type (Weixelman and Gross In Review). The plots were re-visited in 2009/2010 and 2014/2015 but the data is not yet available (Engelhardt and Gross 2011b).

Traffic Volumes	Traffic volume monitoring is part of a regional strategy to create a well executed transportation management system that incorporates monitoring data, real-time information, and dynamic operations that respond to seasonal and periodic congestion. Over the last few years, intelligent transportation systems have seen significant advancements and deployments in the areas of data collection, data sharing, mobile solutions, and traffic monitoring capabilities. Both the California Department of Transportation (Caltrans) and the Nevada Department of Transportation (NDOT) manage several dozen permanent traffic count stations, which collect data on the number of vehicles traveling throughout the region. TRPA aggregates and analyzes this data for a variety of purposes, including project planning, development of our Regional Transportation Plan, and travel demand modeling. To download all of the traffic volume data on this page please see Tahoe Open Data.
Transit	TTD, TRPA, and TART work together in corridor and transit planning. Consistent transit rider surveys and operations data collection help determine the need for additional services and operating hours. Based on reporting requirements, TRPA's Productivity Improvement Program (PIP), and goals outlined in the Regional Transportation Plan, Long Range Transit Master Plan, and each transit agency's Short Range Transit Plans, the Tahoe transit monitoring program is built to track the following: Deadhead Miles and Hours, Ridership, Transit Mode Share, Productivity, On Time Performance, Operating Cost, Farebox Recovery, Rolling Stock, Equipment, Facilities, and Infrastructure. To find out more about these performance measures, take a look at the Tahoe Transit Monitoring Program: Monitoring Protocol.
Travel Behavior	The dashboard below summarises TRPA's 2018 Summer Travel Survey, which was conducted in late-August of 2018.
TRPA Recreation Threshold Monitoring	The quality of recreation experiences has been assessed through recreation user surveys conducted by recreation providers and organizations in the Region since the 2011 Threshold Evaluation Report was prepared. These surveys measure the overall satisfaction with recreation experiences. The surveys also measure satisfaction with specific components of the recreation experience, such as the condition of recreation facilities. These recreation surveys represent the best available information and they primarily apply to developed recreation resources on the south and north shores. As such, the recreation user surveys are helpful indicators focused on multiple user groups, rather than a comprehensive measure of user satisfaction with all recreation amenities in the basin. The surveys evaluated here were conducted by the City of South Lake Tahoe, El Dorado County, Tahoe City Public Utility District, Lake Tahoe Visitors Authority, and North Lake Tahoe Resort Association.

Upper Truckee Marsh Monitoring	The status and trend determinations were based on a qualitative assessment of factors influencing the condition of the site, including historical alterations, ongoing hydrologic impacts, sources of recreation-related disturbance, and surrounding land use and management. Two long term meadow monitoring plots were installed in the Upper Truckee Marsh in 2014, following the protocol in the U.S. Forest Service Region 5 Range Monitoring Program (Weixelman 2011). The protocol is designed to classify a meadow according to wetland index and plant functional types, which provides a quantitative ecological condition scorecard for that meadow type (Weixelman and Gross In Review). Distance to meadow edge, distance to stream channel, degree of channel incision, and evidence of Sierra lodgepole pine (Pinus contorta var. murrayana) encroachment data is collected at each transect. This data has been collected but the analysis methods are currently in the peer review process, and are expected to be pub
Vegetation Type Monitoring	The map of dominate vegetation types in the Region was last updated in 2009. Since then only the Angora fire burn area has been updated. In 2009, satellite imagery, aerial photographs and field reconnaissance (USFS Forest Inventory and Analysis data) were used to delineate and classify vegetation types in the Lake Tahoe Region. This information is digitized into a geographic information system and subsequently analysed to summarize vegetation community richness. Information from the Tahoe Fire and Fuels Team (a multi-agency partnership) on forest fuels treatments and disturbance events are incorporated for year to year change in vegetative composition.
Vehicle Miles Traveled Monitoring	The identification of traffic volumes is a primary component towards trackingmobility with the Tahoe Region. Published traffic volumes are counted annually within the Lake Tahoe Region by both the California Department of Transportation (Caltrans) the Nevada Department of Transportation (NDOT) and local governmental jurisdictions. In addition to modeling compliance withthe 1981 VMT Threshold, TRPA staff utilized the 1981 base year VMT estimate, and the corresponding traffic count stations that produce annual traffic counts to analyze increases or decreases in VMT.
Vertical Extinction Coefficient (VEC) Monitoring	VEC is measured at the Lake Tahoe Index Station at least 24 times annually and at least 12 times annually at the mid-lake station. VEC is measured by lowering a submersible photometer down through the water column.
Watercraft Noise Monitoring	Watercraft noise levels were measured annually from 2009 to 2013 at 10 shorezone locations for five to six sampling periods (ranging from four to 12 days) from May through September. Sampling periods are comprised of both weekends and weekdays, allowing for analysis of the differences in noise levels or exceedances between days in the week. The monitoring periods include low, medium, and high watercraft use times throughout the day (7 AM to 7 PM). All noise events are individually analyzed and categorized by a trained noise technician.

Waterfowl Population Site Monitoring	The methodologies and indicators used by TRPA to evaluate the attainment status of the waterfowl standard has varied over time. The 2001 Threshold Evaluation Report used observed bird species richness and diversity along with the human activity rating system to gage threshold standard attainment status (TRPA 2001). The 2006 Threshold Evaluation Report used observation of bird species richness and diversity as well as an assessment of detrimental or non-native species, but did not use the human disturbance rating system that was used in 2001. The 2011 Threshold Evaluation Report used only a human disturbance rating system as a means to measure status (TRPA 2012a). Since 2015, the assessment method used is based on field observations and human activity levels at mapped waterfowl population sites, similar to the 2011 Threshold Evaluation Report methods. No formal waterfowl surveys were conducted. Each site was visited by a qualified observor to conduct the human disturbance rating evaluation.
Wintering Bald Eagle Population Sites Monitoring	Professional and volunteer biologists stationed at a series of observation points surrounding Lake Tahoe record all observed eagles over the same four-hour period once a year following protocols developed by the National Wildlife Federation.
Yellow Pine/Red Fir Abundance Monitoring	For this evaluation, stands dominated by trees less than 10.9-inches diameter at breast height (dbh) were enumerated from the following California Wildlife Habitat Relationship (CWHR) Types (CWHR, 2011) attributed in the U.S. Forest Service - Remote Sensing Lab Pacific Southwest Region TMU_Strata_07 map layer (published 2009). Every five years, the Tahoe vegetation map is updated with new satellite data (if available) and/or modeled and calibrated using field-based forest inventory and analysis data to assess the extent of different vegetation types and associated forest structure characteristics for the Region (USDA, 2009; Warbington et al., 2011).

TEON Appendix B:

Vegetation Change in the Lake Tahoe Basin from Historical to Present

Shale Hunter, Liraz Bistritz, Gina Tarbill, and Patricia Manley

USDA Forest Service, Pacific Southwest Research Station

Placerville, CA

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Introduction

Forested ecosystems dominate the terrestrial components of the Lake Tahoe Basin. The vegetative communities that compose these forests provide a vast array of ecological functions, including wildlife habitat, carbon storage, soil stabilization, and air filtration. Additionally, they provide fuel for wildfires, recreation opportunities for human visitors to the Basin, and have direct and indirect effects on adjacent ecosystems such as wetlands (through conifer encroachment and water use) and Lake Tahoe itself (through nutrient and sediment cycling).Thus, it is essential that we understand how the vegetation of the Basin is changing as a result of management decisions, anthropogenic influence, climate change, and other causes.

Change is an integral part of the Sierra Nevada ecosystem, built upon centuries of climatic oscillations that result in highly variable precipitation and temperature pattens, largely due to the El Nino Southern Oscillation (ENSO). Annual precipitation patterns may vary from 50-200% of the average, resulting in years of high moisture and productivity followed by drought (Dettinger et al. 2011). This climatic variability affects drought severity and length, bark beetle outbreaks, and fuel loads, impacting the fire regime, which in turn influences vegetation communities. Prior to Euro-American settlement, Tahoe forests tended to be less dense, with larger trees, and a more clumped configuration (Taylor 2004). With colonization, came timber harvest that clearcut approximately 60% of the Tahoe basin (Leiberg 1901), loss of burning by Indigenous people, and the implementation of highly effective fire suppression (Taylor 2004). More recently, development has accounted for the loss of forest, shrub, and wetland habitats (Raumann and Cablk 2008) and climate change has influenced the extent and severity of fires in the Tahoe basin (Maxwell et al. 2022).

These drivers seem to be interacting to accelerate the changes in forested habitats. We compared historical vegetation data, collected from 2003-2005 to two sets of historical vegetation data, collected from 2003-2005, provide a snapshot against which we compare modern data collected in 2024 to describe change in the Basin's vegetative communities over the past two decades.

Methods

Data collection

Two historical datasets formed the basis for TEON's extensive vegetation monitoring methods: the Multiple Species Inventory and Monitoring (MSIM) protocol and the Lake Tahoe Urban Diversity (LTUB) protocol (Manley et al 2006, Multiple species inventory and monitoring technical guide; Manley et al 2006, The Role of Urban Forests in Conserving and Restoring Biological Diversity in the Lake Tahoe Basin, Final Report). The basic structure of each site is the same across both sets of protocols, and is depicted in Figure AB-1. This structure consists of:

- Three transects extending 36.4m from plot center at 0, 120, and 240 degrees, along which are measured:
    - Vegetation cover by species and plant type
    - Ground cover
    - Vertical diversity
    - Litter depth
    - Coarse woody debris greater than 7.6cm diameter at the small end
- Three concentric subplots of radius 7.3m, 17m, and 56.4m, within which trees and snags of different size classes are measured:
    - 7.3m: trees and snags greater than 12.5cm DBH
    - 17m: trees greater than 28cm DBH, snags greater than 12.5cm DBH
    - 56.4m: trees greater than 60cm DBH, snags greater than 30.5cm DBH
- Four additional 7.3m subplots, located at the end of each transect and at plot center, in which were measured:
    - Species richness
    - Sapling count by species (center subplot only)
    - Percent cover (%) for woody plants and invasives
    - Three 1m x 1m quadrats, in which were measured:
        - Cover of all species present (%)
        - Ground cover (%)

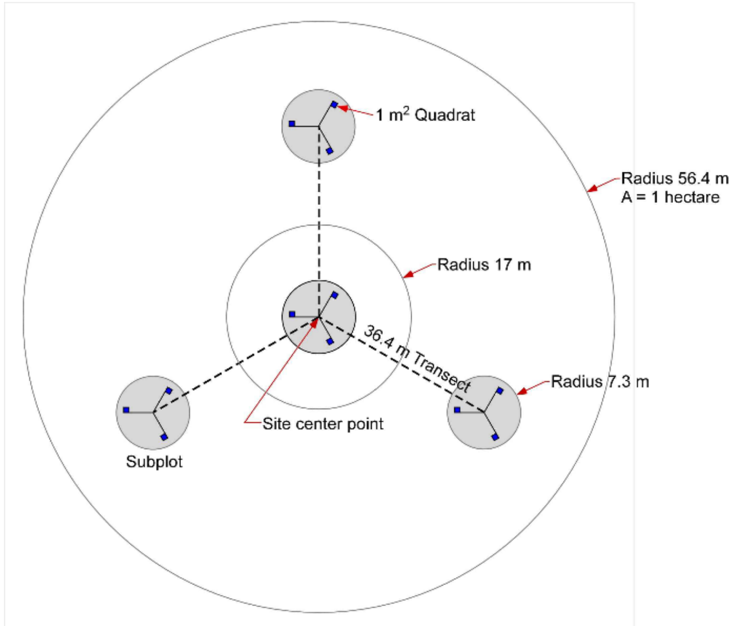

Figure AB-1. Layout of a vegetation plot.

Though the overall structure of MSIM and LTUB sites were very similar, there were several differences between the historical protocols which necessitated modifications to data collection methods to ensure data was comparable between sites as well as between time periods. Table AB-1 describes which metrics these differences apply to and how they were addressed during 2024 data collection for TEON.

Table AB-1. Differences in vegetation monitoring methods between MSIM and LTUB historical data sets.

Metric	LTUB Method	MSIM Method	TEON Method
Canopy Cover	25 individual points using a moosehorn in a 5m x 5m grid at plot center.	16 readings using a spherical densiometer, located 7.3m from plot center in each of the cardinal directions, with one reading taken facing each cardinal direction at each location.	Both moosehorn and densiometer methods used at all sites; LTUB method repeated exactly, MSIM number of observations remains 16 but locations modified to plot center and 7.3m along each transect.
Anthropogenic Impact	Within 17m of plot center: cut stump count, trash count, square meters of anthropogenic disturbance.	Area of roads, trails, or other impermeable surfaces within 30m of plot center.	Within 17m of plot center: cut stump count, trash count, square meters of anthropogenic disturbance.
Transect metrics: ground/plant cover, litter, vertical diversity	Measures collected every 3rd meter starting from 1m – 10 locations for all methods.	Measures collected every 3rd meter starting from 7m – 9 locations for plant cover, 5 locations for ground cover, 7 locations for vertical diversity; litter collected at 2.4m, 4.8m, and 7.3m from center.	Measures collected every 3rd meter starting from 1m – 11 locations for all methods, so the full spatial extend of the MSIM points can be matched (extending to 31m compared to LTUB's 28m).
Coarse Woody Debris	CWD measured along all 3 transects.	CWD measured along 2 transects: 0 degrees and **either** 120 or 240 degrees.	CWD measured along all 3 transects.

Some methods were not present in either historical protocol, but were added for TEON 2024 sampling, including:

- Height to canopy live crown (for all trees where height was measured)
- Fine woody debris (between 30-33m on each transect)

Data management and analysis

All historical data was accessed through a Microsoft Access database; 2024 data was collected through ESRI's Survey123 application and stored on ArcGIS Online. Data processing and quality control was performed in R. Initial analysis of vegetation change consisted of comparisons of summary statistics between the two time periods (2003-2005 and 2024). Species richness was compared using transect data filtered and corrected to match the appropriate historical protocol for which data was available. Change in forest structure was assessed using trees per acre (TPA), snags per acre (SPA), volume of CWD, tree species dominance, and tree to shrub ratio (TSR). TPA and SPA were calculated for three size classes as reflected in the DBH size cutoffs in each concentric subplot. Tree species dominance was calculated using number of stems by species (saplings excluded). TSR was calculated using plant type cover (%) from transect data, filtered and corrected to match the appropriate historical protocol for which data was available. The formula to calculate TSR is:

$$\frac{tree\,\% - shrub\,\%}{tree\,\% + shrub\,\%}$$

In addition to species richness and forest structure, change in forest health was assessed using decadence features present on living trees. Decadence features were split into 12 categories: conks/bracket fungi, large cavities, broken top, large broken limb, sloughing, mistletoe, dead top, split top, thin canopy, light foliar cover, leaf necroses, frass, and sap exudation. Species turnover was also calculated as the proportion of species gained or lost between time periods in relation to total species observed across both time periods (Hallett et al 2016).

Results

We observed changes to the forest in the twenty-year period in forest structure, health, and composition. Significant increases were observed in large tree TPA, shrub cover and mean litter depth; a near-significant increase was also observed in herbaceous cover. Other vegetation metrics showed no meaningful increase or decrease. An increase in large trees is in accordance with normal forest ageing (trees get bigger as they get older), and an increase in shrub cover is consistent with the management practice of fire exclusion, which has been prevalent in the Basin until recently. Though changes in snags per acre are not significant, snag concentration remains an area of importance both in terms of wildlife habitat and fuels management: SPA values of 1.7 to 3.0 for large snags have been recommended as suitable for mixed conifer forests (Ganey 2016), whereas we found concentrations substantially in excess of those thresholds both historically (7.75 SPA) and currently (9.72). For non-vegetative ground cover metrics, near-significant increases in litter and CWD ground cover were observed in addition to a significant increase in mean litter depth, all of which is consistent with an increase in trees and associated vegetative material. Other ground cover metrics (rock and bare soil) were unchanged.

Note that several tree metrics are highlighted in yellow at the bottom of the table, including tree to shrub ratio. These metrics are included not as measures of real change, but as a warning against overinterpretation of data and a reminder of the importance of consistent method implementation across sampling seasons. A look at the transect-based measure of tree species richness would lead to a conclusion of substantially increased species diversity across the Basin, backed up by an increase in tree cover (also transect-based). However, using a different metric of tree species richness derived from the stem count of tree size classes yields a very different result – no change in richness at all. Likewise, a differing measure of tree cover is available through canopy cover, which shows a non-significant result an order of magnitude smaller than the transect-based measurement. Given that stem count in particular is a much more reliable measure of trees present on a plot than transects, our conclusion is that implementation of the transect protocol was inconsistent across time periods, perhaps in technicians' observance (or lack thereof) of an upper height limit to vegetative matter considered to intersect the transect. This has cascading effects on derived metrics like TSR as well, since it requires as input a measure of tree cover which we have deemed incomparable across sampling periods. Comparison to a remotely sensed measure of TSR (see Appendix F for explanation of CECS data) shows yet again that this may not represent a true increase, rather it is attributable to inconsistent sampling.

Table AB-2. Detected change between sampling periods 2003-2005 and 2024 for different metrics of forest structure. Change is mean difference between periods, present minus historical. Significance is based on a two-tailed t-test between historical and present distributions. *Includes 100% shrub cover at site L396, which was completely burned in the 2007 Angora fire. Excluding this outlier, p=0.088

Metric	Change (mean of Present - Historical)	Significance
Canopy Cover	+2.558 percent	ns
CWD Volume	-4.437 cubic meters	ns
CWD Ground Cover	+2.327 percent	p 0.0587
TPA (12.5-28cm DBH)	-20.152 trees	ns
TPA (28-60cm DBH)	-4.299 trees	ns
TPA (over 60cm DBH)	+5.154 trees	p 0.008
SPA (12.5-30.5cm DBH)	-3.328 snags	ns
SPA (over 30.5cm DBH)	+1.965 snags	ns
Mean Litter Depth	+16.001 millimeters	p 0.0064
Maximum Litter Depth	-36.28 millimeters	ns
Litter Cover	+12.921 percent	p 0.0516
Bare Soil Cover	-3.542 percent	ns
Rock Cover	+7.502 percent	ns
Shrub Cover	+9.493 percent	p 0.048*
Shrub Species Richness	-0.40 species	ns
Grass Cover	+1.628 percent	ns
Grass Species Richness	+0.13 species	ns
Herbaceous Cover	+6.79 percent	p 0.107
Herbaceous Species Richness	-0.367 species	ns
Tree Species Richness (transects)	+1.13 species	p 0.0065
Tree Species Richness (stem count)	-0.11 species	ns (p 0.77)
Tree Cover	+25.56 percent	p 2.97e-7
TSR (transects)	+0.471	p 0.004
TSR (remotely sensed)	-1.338	p 0.587

Species composition is an important element of forest structure which is not addressed by the metrics above. Figure AB-2 shows the total count of trees and snags for the most common eight species encountered across all sites. Fir species *(Abies concolor and Abies magnifica)* continue to be the most common tree species in the Tahoe Basin, followed by lodgepole pine *(Pinus contorta)* and Jeffery pine *(Pinus jefferyi)*. However, we find that Juniper species have increased substantially over the time period studied, paired with a decrease in whitebark pine *(Pinus albicalus)*. Combined together, these two results may point to effects on forest composition by climate change: whitebark pine is expected to suffer in a warming climate due to hotter, drier conditions which reduce resistance to mountain pine beetle and white pine blister rust (Keane et al. 2017), whereas Juniper species, which have historically been uncommon in the Tahoe Basin but thrive in hotter, drier systems such as the Great Basin, may be poised to expand their population in the Tahoe Basin. Figure 2 also highlights that the increase in large trees described previously in Table 2 is consistent across all four dominant species in the Basin, instead of being limited to one or two clear "winners".

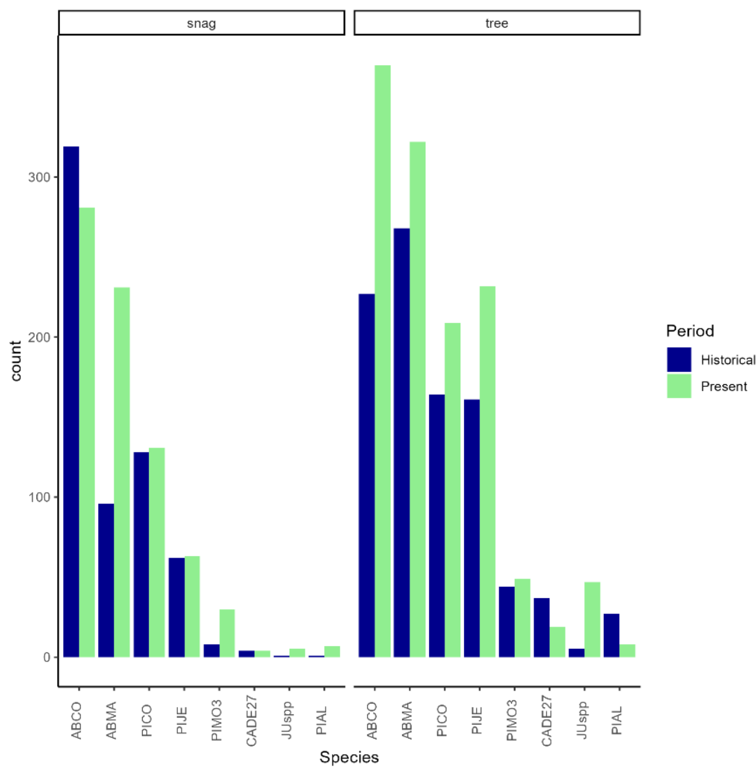

Figure AB-2. Count of the most common eight species of trees encountered across all sites, separated by trees and snags. Due to data QC differences between the two time periods, Juniper species were combined together for this analysis.

To quantify the health of the forest, we clustered trees into those individuals with 0, 1, or 2 or more decadence features observed. Figure AB-3 highlights the results: when grouped by either species or height, the majority of trees historically were found to have 0 or sometimes 1 decadence features; however, in 2024 most trees were found to have 2+ or sometimes 1 decadence features. This dramatic shift is indicative of higher environmental stresses on the forest, though it is difficult to extract the precise source(s) of that stress.

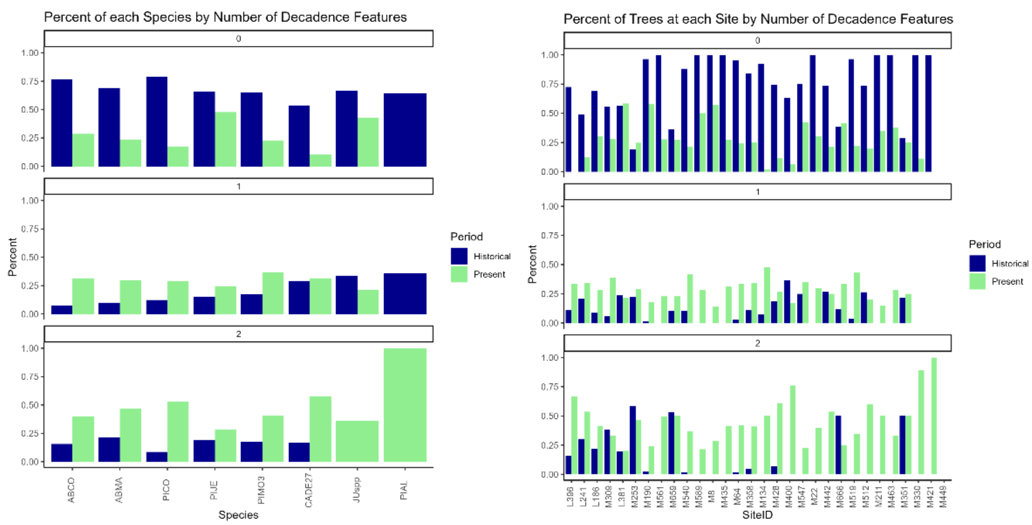

Figure AB-3. Bins of trees with 0, 1 and 2+ decadence features, organized by species and by site.

Another metric of community composition is species turnover, or the number of species that disappeared or appeared between the two time periods. Table AB-3). Twenty-three woody species were detected during the present count only, while nine species were detected historically only, resulting in a net increase of 14 species detections.

Important forage species (including serviceberries and currants) are included on both sides of the list, highlighting a mechanism by which vegetation change may affect changes in wildlife populations as well (see Appendix D). When expanded to herbaceous species, a total of 106 species were detected during the present count that were not detected historically, while 77 species were detected only historically yielding a net increase of 29 species. Every site saw at least 50% species turnover between the two time periods, and four sites had turnover rates of 100% for non-tree species. Mean site turnover was 83%, with turnover rates unaffected by elevation and development gradients.

Table AB-3. Woody species (trees and shrubs) detected in only one time period, either present (blue) or historical (in orange). Count indicates number of sites at which species was observed.

Species	Present Count	Historical Count
Singleleaf Pinyon (PIMO)	2	*0*
Ponderosa Pine (PIPO)	1	*0*
Black Cottonwood (POBAT)	2	*0*
Aspen (POTR5)	1	*0*
Douglas' spirea (SPDO)	1	0
Woods' rose (ROWO)	2	0
Geyer's willow (SAGE2)	2	0
Saskatoon serviceberry (AMAL2)	2	0
Sandbar willow (SAEX)	1	0
Pacific willow (SALUL)	1	0
Common snowberry (SYAL)	3	0
Red buckthorn (FRRU)	3	0
Whitestem gooseberry (RIIN2)	1	0
Frosted buckwheat (ERIN9)	2	0
Scabland penstemon (PEDE4)	1	0
Bastardsage (ERWR)	1	0
Gooseberry currant (RIMO2)	1	0
Parry's rabbitbrush (ERPA30)	2	0
Montara manzanita (ARMO5)	2	0
Dwarf blueberry (VACE)	1	0
Timberline sagebrush (ARRO4)	1	0
Marumleaf buckwheat (ERMA4)	1	0
Prickly currant (RILA)	1	0
Mountain alder (ALIN2)	0	3
Newberry's penstemon (PENEN)	0	1
Sticky currant (RIVI3)	0	1
Bitter cherry (PREM)	0	1
Utah serviceberry (AMUT)	0	3
Alpine gooseberry (RILA2)	0	2
Rabbitbush heath goldenrod (ERBL2)	0	1
Scouler's willow (SASC)	0	1
California mountain ash (SOCA8)	0	1

Discussion

Historical Change

Forests are dynamic ecosystems undergoing constant change, as highlighted by the high species turnover rates described above. Over the past 20 years, we have seen an expected increase in large trees, while dominant tree species have remained stable with red and white fir, Jeffery pine, and lodgepole pine consistently the most commonly encountered species across the Basin. At the same time, climate effects on forest composition may be indicated in the decline of species of concern such as whitebark pine, combined with the expansion of juniper species from the Great Basin. Across species, tree health appears to be declining as indicated by an increase in decadence features over time; while it is likely there are other factors at play, changes in local climate can play a large role in the health of long-lived and immobile organisms such as trees. The Sierra Nevada experienced one of the driest and warmest droughts on record from 2012-2015 (Griffin and Anchukaitis 2014), weakening trees to disease and insects and resulting in the massive mortality event that killed approximately 49% of trees (Fettig et al. 2019). This drought may have contributed to the increase in the signs of stress observed on trees in 2024 relative to the historical sample. High rates of plant species turnover at all sites over the 20-year period further underscores the dynamic nature of the vegetative community, and are parsimonious with other research at similar time scales that describe species distributions as highly unstable at the local scale even while being stable at a regional scale (Thuiller et al. 2007).

Monitoring Implications

Though the recent rise of remotely sensed data sources for forest monitoring have in some ways surpassed the efficiency of field-collected data at the landscape scale (see Appendix F), there are many important measures of forest structure that are best collected in the field. Species richness and cover, particularly for small plants such as grasses and herbs, are hidden beneath the overstory which prevents accurate measurements from a satellite. Likewise, although remote sensing can give estimations of overall tree mortality, a more detailed collection of early-warning signs like those provided by the change in decadence classes described above (which may provide land managers with advance notice before mortality events occur and allow time for preventative action) is only possible through on-the-ground work.

Field work is admittedly expensive; our 2024 effort also included duplicate methods for several metrics, including canopy cover, species richness and species cover, with the intention of identifying which methods provide the most information on site conditions for the least amount of time, training, or specialized equipment. A comparison of moosehorn and spherical densiometer measures of canopy cover showed that, although the moosehorn is easier and faster to use as well as cheaper, it did not adequately capture the variability in canopy cover and was more likely to underestimate cover when compared to the densiometer. Comparisons of transect, quadrat, and subplot measures of species cover and richness are ongoing. Our results additionally highlight the importance of consistent method implementation in the field (including training) as shown by the anomalous tree metric results for transect methods. Broadly speaking, small variations in methodology take the same amount of time and money to collect – but they are only useful in a long-term monitoring framework if such variation is eliminated to allow reliable comparison of values across sampling periods.

Beyond individual metrics, the number of sites visited in a season can be a limiting factor in any monitoring effort. A sample of 30 sites was enough for us to detect some Basin-wide changes, but there are several notable ecosystems of note which are underrepresented in the sample, including: burned areas (n=1), meadows (n=1), and aspen groves (n=0). Options for expanding sample sites to better represent these systems include expanding the number of stratified random sampling points, expanding stratification design to include vegetation type as a classifier, or adding targeted (non-random) points to address specific concerns related to these ecosystems. An annual rotation of sites would maximize the analytical power of sampling by achieving greater overall breadth across the Basin while also retaining the ability to examine site-level changes between rotations. A 4-year rotation of 30 sites would yield a full sample of 120 sites, while a 4-year rotation of 50 sites would yield a full sample of 200 sites. These numbers are contingent on the ability to dedicate a crew of 3 technicians full time (~50 sites per season) vs a crew which is split between multiple funded projects and can only spend part of a field season on this monitoring (~30 sites per season).

Recommended Citation

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TEON Appendix C:
Wetland Change in the Lake Tahoe Basin from Historical to Present

Gina Tarbill, Shale Hunter, and Patricia Manley

USDA Forest Service, Pacific Southwest Research Station

Placerville, CA

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Introduction

Wetlands represent a transition zone between fully aquatic and fully terrestrial systems, where the water either shallowly covers the land or is just below the surface (Cowardin 1979). Globally, nearly half of all wetlands have disappeared due to development, draining, and other human activities and the remainder is largely degraded (Zedler 2003). This is concerning because wetlands have outsized effects on biodiversity, nutrient cycling, water quality, flood abatement and carbon sequestration, despite the relatively small areas that wetlands occupy within larger ecosystems. (Mitsch et al. 2015). Furthermore, wetlands are significant to many Indigenous Peoples, due to the abundance of plants used for food, medicine, and basketry and the habitat they provide to many game species (Anderson and Moratto 1996). More recently, intact or restored wetlands have been identified as important fuel breaks that may slow the spread or reduce the severity of fire (Markle et al. 2022, Kirkland et al. 2023), acting as fire refugia (Balantic et al. 2021).

In the Lake Tahoe basin, wetlands are typically divided into marshes, meadows, and fens. Marshes are nearly always inundated with water, with vegetation adapted to saturated soil conditions. In the Sierra Nevada marshes usually occur in the poorly drained depressions near streams and along the boundaries of lakes, ponds and rivers, with most of the source water from the surface. Meadows typically lack standing water but have a high-water table that keeps the soil seasonally saturated near the surface. Fens and bogs are peat-forming wetlands that vary in acidity, nutrient availability, and water source. Since Euro-American colonization in the early 1900s, nearly 75% of marsh and 50% of meadow habitat is estimated to have been lost from the basin.

As part of the TEON project, we resampled 30 lakes and meadows that had historically been surveyed as part of the Riparian Ecosystem project in the late 1990s and mid-2000s (Manley et al. 2000, Manley and Lind 2005). There are over 300 lakes and ponds in the Lake Tahoe basin, but many are vulnerable to degradation (Manley et al. 2000, Reiner and Oehrli 2000), and a 5-yr resurvey effort of over 100 lakes in the early 2000s showed that losses were indeed occurring in this relatively short period of time. Recent ad hoc revisits to many historical sites for the purposes of selecting the 30 sample sites for this study found that many historical sites no longer existed as aquatic or wetland habitat or they had been privatized.

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Methods

We used the 2004 lake, pond, and meadow sites that were first visited in 1997-1998 as a reference set. We checked the database to see how often these meadows were reported as developed, drained, filled, or otherwise changed to another habitat type when they were resurveyed in 2003-2004, and again when we visited in 2022-2024. From 1997 to 2004, two aquatic sites were dropped due to transitioning to uplands, two were drained, and nine were developed, a loss of about 7%. Of the 74 sites we checked in 2022-2024, two more sites were dropped because they were completely dry, a loss of about 3%. The remaining eligible sites were visited in spring and fall to decide if they should still be classified as wetlands based on qualitative assessments of soil moisture, standing water, and vegetation communities. We then selected 30 sites to resample based on obtaining a geographic distribution of units, a range of sizes, and proximity to historical terrestrial sites to form a terrestrial-aquatic pair of sites.

At the 30 selected sites, both vegetation and wildlife were monitored. Vegetation cover (%) was monitored on 8 – 30 transects (3m long), depending on the size of the lake/pond/meadow. Vegetation, by species, when possible, was described as either submerged, emergent, or overhanging. Substrate (silt, sand, pebble, cobble, boulder, bedrock, or manmade) was likewise recorded along these transects. The surrounding land within 20 meters was characterized by percent cover in the following categories: meadow, shrub, alder/willow, aspen/cottonwood, granite/bedrock, urban/developed, and conifer forest. We also recorded the number, width, and depth of inlets and outlets to each aquatic site. We compared species richness of vegetative groups with a Welch two-sample t-test between historical and contemporary periods. We evaluated changes to vegetative community composition by calculating the mean frequency (number of transects containing that group divided by total number of transects at the site) for each vegetative group in both time periods, as well as percentage point change among time periods.

Wildlife monitoring included reptiles and amphibians (methods and results described in Appendix E), camera deployment for mammals (methods and results described in Appendix F), and point counts for birds (methods described in Appendix D). Some modifications were made to the terrestrial point count methods to accommodate the difference in habitat: instead of a fixed number of point counts at every site, between 1-6 counts were conducted based on the size of the lake or meadow. Because visibility and audibility are higher at aquatic sites, point counts were increased to 20 minutes (relative to 10 minutes for terrestrial sites).

Results

Site Conditions

Analysis was conducted for 23 sites at which data was present from 1997-98 and 2023. No significant change was observed in substrate composition, as highlighted in figure AC-1. Many sites are silt-dominated (75-100% of transects measured per site), while remaining sites have a heterogeneous substrate composition that frequently includes cobbles and/or boulders.

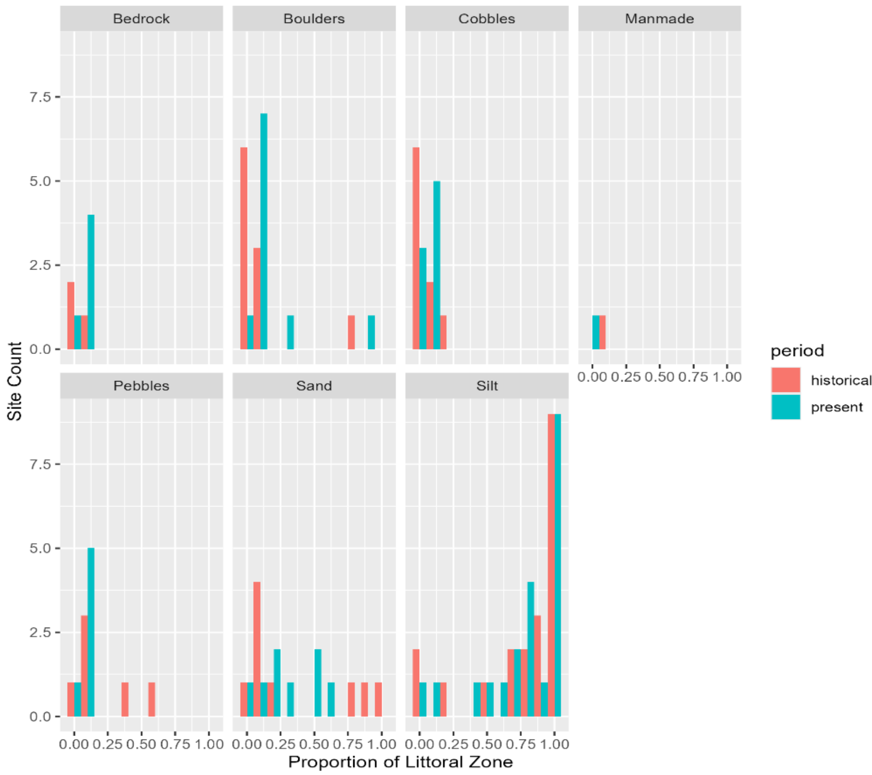

Figure AC-1. Histogram of proportion of each substrate (bedrock, boulders, cobbles, pebbles, sand, silt, manmade) at all sites compared between 1997-98 and 2023. Substrate composition is consistent across time periods.

We found modest changes to wetland vegetation over the two time periods. There was no significant difference in mean richness of vegetative groups (p = 0.095) in historical (mean= 6.04 species) and contemporary (mean=4.35) periods, although a trend of declining richness was observed. The mean frequency of some vegetative groups did change over the time periods (Table AC-1). Most notably, sedges declined by about 37% and grasses increased by about 13%, on average. Other vegetative groups that declined to a lesser extent included rushes, pondweed, common buckbean, and spikerush. Species that increased in relative frequency over time included willow and alder species.

Table AC-1. Littoral plant cover in each time period and change in percentage points between periods. Orange highlights species with >10% decrease, blue highlights species with >10% increase. Specimen not identified to genus were excluded from this list.

Taxon	Group	2023 Frequency %	1997-98 Frequency %	Change, %-points
Carex	sedge	25.22	62.57	-37.35

Juncus	rush	11.09	17.30	-6.21
Potamogeton	pondweed	2.48	7.87	-5.39
Menyanthes trifoliata	common buckbean	0.57	4.96	-4.39
Eleocharis	spikerush	0.00	4.30	-4.30
Ranunculus aquatilis	whitewater crowfoot	0.00	3.39	-3.39
Utricularia	bladderwort	0.26	3.17	-2.91
Monolepis	povertyweed	0.00	2.70	-2.70
Sparganium	5urred	0.13	2.78	-2.65
Lemna	duckweed	1.87	4.26	-2.39
Nuphar luteum	yellow pondlily	2.91	5.04	-2.13
Schoenoplectus	bulrush	0.00	1.87	-1.87
Elodea	waterweed	0.00	1.52	-1.52
Equisetum	horsetail	0.00	1.30	-1.30
Potentilla gracilis	graceful cinquefoil	0.00	1.22	-1.22
Primula	Shooting star	0.13	1.09	-0.96
Sphagum	Bryophyte	0.00	0.96	-0.96
Kalmia polifolia	bog laurel	0.00	0.78	-0.78
Myriophyllum	watermilfoil	2.04	2.78	-0.74
Drymocallis glandulosa	Ashland cinquefoil	0.00	0.70	-0.70
Drosera rotundifolia	roundleaf sundew	0.00	0.65	-0.65
Circuta douglasii	western water hemlock	0.00	0.43	-0.43
Hypericum perforatum	common St. Johnswort	0.00	0.39	-0.39
Viola	violet	0.00	0.30	-0.30
Typha	cattail	1.61	1.87	-0.26
Amelanchier utahensis	Utah serviceberry	0.00	0.17	-0.17
Genista	broom	0.00	0.17	-0.17
Pinus contorta	lodgepole pine	0.00	0.17	-0.17
Veratrum californicum	California corn lily	0.00	0.17	-0.17
Achillea	yarrow	0.00	0.09	-0.09

Allium	wild onion	0.00	0.09	-0.09
Asteraceae	Asteraceae	0.00	0.09	-0.09
Fritillaria agrestis	stinkbells	0.00	0.09	-0.09
Potentilla	cinquefoil	0.00	0.09	-0.09
Angelica capitellata	woollyhead parsnip	0.00	0.09	-0.09
Yampah	yampah	0.00	0.09	-0.09
Vaccinium	vaccinium	0.00	0.09	-0.09
Pinus jefferyi	Jeffrey pine	0.00	0.09	-0.09
Populus tremuloides	quaking aspen	0.87	0.78	0.09
Ranunculus	buttercup	0.13	0.04	0.09
Populus	cottonwood	0.13	0.00	0.13
Hydrocotyle	pennywort	0.13	0.00	0.13
Hippuris vulgaris	common marestail	0.26	0.00	0.26
Pinus ponderosa	ponderosa pine	0.30	0.00	0.30
Pinus	pine	0.30	0.00	0.30
Veronica	speedwell	0.57	0.00	0.57
Salix	willow	17.74	16.30	1.44
Alnus incana	Mountain alder	4.52	2.70	1.82
Poaceae	grass	13.30	0.13	13.17

A look at the patterns of other plants with smaller magnitude increases or decreases may still be suggestive of changing water availability across sites. We used the Army Corps of Engineers in the National Wetland Plant List (2016) to evaluate dependence on wetland habitat. Species showing modest increases include alder and willow which are wetland-facultative and shrubs and pines which are typically upland species. Plants that decreased are considered wetland-obligate: most notably sedges, but also rushes, pondweed, buckbean, bladderwort, whitewater crowfoot, spikerush.

Birds

Point count data was analyzed from all sites where data was available from both historical and current time periods (n = 25). We found no significant difference in avian species richness between time periods at aquatic sites (p = 0.42), as shown in Figure AC-2.

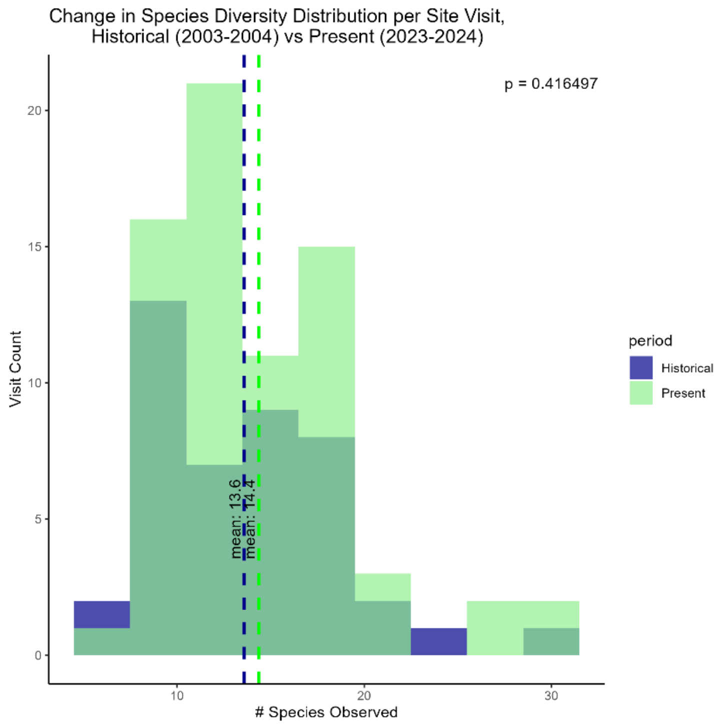

Figure AC-2. Histogram of species diversity per site visit, historical vs present. Mean increase in species richness of 1.2 species is not significant. Bar heights appear substantially different between periods due to a reduced number of visits per site during the 2003 sampling season.

Linear Analysis

Linear modeling confirmed the lack of effect of time period on species richness, while highlighting the significant effect of other variables as described in Table AC-2. Elevation was the most important factor, with species richness declining by about 1 species for every 200 meters of elevation gain. Sites with greater than 25% development also had on average 3.8 fewer species than sites with 0% development, and sites in the Xeric High Montane climate class had on average 6.5 more species than sites in the Cool Dry High Montane climate class.

Table AC-2. Summary of coefficients for a linear model of Elevation, Climate Class (CC), Development, and Time Period. Elevation is numeric, other variables are factors with listed values in comparison to first levels (CC: Cool Dry High Montane; Dev: 0%; Period: Historical). Adjusted R-squared: 0.278.

Coefficient	**Estimate**	**Std. Error**	**p value**
Intercept	25.94	3.55	$5.41e^{-11}$
Elevation (m)	$-5.57\ e^{-03}$	$1.50\ e^{-03}$	$3.35\ e^{-04}$
CC: Cool Dry Mid Montane	-0.22	1.03	0.83
CC: Cool Mesic High Montane	1.01	1.32	0.45
CC: Xeric High Montane	6.45	1.21	$5.16\ e^{-07}$
Dev: 1-25%	-0.38	0.87	0.66
Dev: 25-50%	-3.77	1.66	0.04
Period: Present	-0.05	0.84	0.95

Species Change

Though overall avian species richness has not changed substantially at aquatic sites over the past 20 years, there have been some shifts in species composition. Table AC-3 shows changes in detection rates for the 68 species included in this analysis. 9 species had greater than 10% decrease in detections, while 27 species had greater than 10% increase in detections; the remaining 32 species showed minimal change, with a less than 10% change in either direction.

Table AC-3. Detection rates (number of sites a species was detected at divided by total number of sites) for 68 bird species, including unknown codes. Orange highlights species with >10% decrease, blue highlights species with >10% increase.

Species Code	Common Name	Historical Detection Rate	Present Detection Rate	Change in Detection Rate
RUHU	rufous hummingbird	0.32	0.04	-0.28
BRCR	brown creeper	0.56	0.32	-0.24
PISI	pine siskin	0.32	0.12	-0.20
BTPI	band-tailed pigeon	0.24	0.08	-0.16
CAFI	Cassin’s finch	0.44	0.32	-0.12
WBNU	white-breasted nuthatch	0.36	0.24	-0.12
UNHU	unidentified hummingbird	0.12	0.00	-0.12
PIGR	pine grosbeak	0.16	0.04	-0.12
MODO	mourning dove	0.16	0.04	-0.12
NOFL	northern flicker	0.52	0.44	-0.08
CAVI	Cassin’s vireo	0.20	0.12	-0.08

DOWO	downy woodpecker	0.08	0.00	-0.08
CLSW	cliff swallow	0.08	0.00	-0.08
STJA	Steller's jay	0.92	0.88	-0.04
HEWA	hermit warbler	0.12	0.08	-0.04
CLNU	Clark's nutcracker	0.44	0.40	-0.04
HOWR	house wren	0.24	0.20	-0.04
DEJU	dark-eyed junco	0.92	0.92	0.00
BRBL	Brewer's blackbird	0.20	0.20	0.00
WISA	Williamson's sapsucker	0.16	0.16	0.00
MOUQ	mountain quail	0.12	0.12	0.00
TOSO	Townsend's solitaire	0.28	0.32	0.04
DUFL	dusky flycatcher	0.40	0.44	0.04
RWBL	red-winged blackbird	0.28	0.32	0.04
CANG	Canada goose	0.08	0.12	0.04
TRES	tree swallow	0.08	0.12	0.04
BUFF	bufflehead	0.04	0.08	0.04
PBGR	pied-billed grebe	0.00	0.04	0.04
TUVU	turkey vulture	0.00	0.04	0.04
EVGR	evening grosbeak	0.16	0.20	0.04
AMRO	American robin	0.76	0.80	0.04
MOCH	mountain chickadee	0.96	1.00	0.04
MGWA	MacGillivray's warbler	0.36	0.40	0.04
SOSP	song sparrow	0.40	0.48	0.08
BHCO	brown-headed cowbird	0.28	0.36	0.08
SOGR	sooty grouse	0.04	0.12	0.08
OCWA	orange-crowned warbler	0.04	0.12	0.08
OSPR	osprey	0.04	0.12	0.08
CORA	common raven	0.12	0.20	0.08
RECR	red crossbill	0.12	0.20	0.08
WIWA	Wilson's warbler	0.48	0.60	0.12
LISP	Lincoln's sparrow	0.12	0.24	0.12
HAWO	hairy woodpecker	0.36	0.48	0.12
FOSP	fox sparrow	0.32	0.44	0.12
RBNU	red-breasted nuthatch	0.60	0.72	0.12
NAWA	Nashville warbler	0.12	0.24	0.12
RTHA	red-tailed hawk	0.04	0.16	0.12
BAEA	bald eagle	0.00	0.12	0.12
HOFI	house finch	0.00	0.12	0.12
GWTE	green-winged teal	0.00	0.12	0.12
COME	common merganser	0.08	0.20	0.12
WHWO	white-headed woodpecker	0.16	0.28	0.12

ROWR	rock wren	0.08	0.24	0.16
PYNU	pygmy nuthatch	0.12	0.28	0.16
OSFL	olive-sided flycatcher	0.40	0.60	0.20
HETH	hermit thrush	0.16	0.36	0.20
SPSA	spotted sandpiper	0.08	0.28	0.20
WCSP	white-crowned sparrow	0.00	0.20	0.20
MALL	mallard	0.36	0.60	0.24
BHGR	black-headed grosbeak	0.08	0.32	0.24
GTTO	green-tailed towhee	0.00	0.24	0.24
CHSP	chipping sparrow	0.04	0.28	0.24
WAVI	warbling vireo	0.44	0.68	0.24
WEWP	western wood pewee	0.72	1.00	0.28
GCKI	golden-crowned kinglet	0.16	0.44	0.28
RBSA	red-breasted sapsucker	0.04	0.32	0.28
YRWA	yellow-rumped warbler	0.64	0.96	0.32
WETA	western tanager	0.36	0.68	0.32

Discussion

Vegetation

We observed a marginally significant decline in species richness in aquatic sites from the historical to contemporary time period. When the species compositions were compared over time, we found that turnover was largely attributed a decline in sedges and other wetland-dependent species, and an increase in grasses and woody species that are typically found in drier habitats. Aquatic sites may be drying, allowing species that are more sensitive to the oxidative stress of saturated soils to establish (Ratliff 1985, Allen-Diaz 1991). Changes to hydrology are often caused by land use changes, such as overgrazing, logging, or channel modifications to support development. Willows and alders and willows, once established, tend to be more tolerant to water table drops than wetland-obligate species, as their roots can extend140–380 cm into the soil (Purdy and Moyle 2006). Grasses also can tolerate drier conditions than sedges and rushes (Ratliff 1985, Allen-Diaz 1991). However, this is an early sign of wetland drying, with high restoration potential, if the seedbank is intact and the hydrology is restored (Purdy and Moyle 2006). Further analysis of these and other aquatic data are needed to identify the most vulnerable sites and management options.

Birds

Though no significant decline in bird richness was observed over the past 20 years (a reassuring sign, particularly given that such a decline was observed in at terrestrial sites), there are certain factors which may reduce avian biodiversity across time periods. In particular, higher human development is significantly associated with reductions in species richness, and lower elevations are associated with higher richness. The interaction between these effects is of particular importance given that most human development in the basin is focused at lower elevations around Lake Tahoe itself: this means that the habitats which naturally support the greatest diversity of bird species are those most likely to be threatened by human impacts.

The differences between terrestrial and aquatic sites in terms of avian richness highlights both the importance and vulnerability of wetland systems in the basin: while upland sites saw substantial declines in richness over the past 20 years, wetland systems were resilient to this change. On the other hand, richness at terrestrial sites is largely unaffected by human development in the immediate vicinity, while we found aquatic sites to be distinctly vulnerable to such disturbance.

Monitoring Design Implications

There are several data products that may be used to evaluate meadow condition on a yearly basis, such as topographic wetness indices, water storage deficit, and the Normalized Difference Vegetation Index (NDVI). In addition to our remote-sensed data efforts, the LTBMU and Region 5 regularly (every five years) collect field data on a set of meadows located around the basin to monitor vegetation, hydrology, and soil conditions. This provides an opportunity to calibrate remotely sensed data and identify how well it captures the changes that are observed less frequently on the ground. The meadow monitoring protocol is a robust survey that incorporates vegetation structure and composition, soil moisture and texture, channel incision, and geomorphology. This also provides finer-scale information that is not possible to collect with LiDAR. We recommend continuing these surveys in addition to the remotely sensed data processing for TEON.

Recommended Citation

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Appendix D:

TEON Bird Community Change from Historical to Present

Shale Hunter, Gina Tarbill, and Patricia Manley

USDA Forest Service, Pacific Southwest Research Station

Placerville, CA

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Introduction

Birds comprise a major component of the vertebrate biodiversity in the Lake Tahoe basin, with over 100 species residing in the basin for some part of the year (Table AD-1). They perform a host of ecosystem functions and services that are critical to ecosystem resilience in the basin. Likewise, they are also sensitive to anticipated ecological changes from climate change (Siegel et al. 2014). Birds are commonly included in broad-scale monitoring networks and systems because they are readily detected by sight or sound using omnibus (multiple species) survey methods, and the number of species in bird communities is typically high, making bird species and community metrics a relatively sensitive measure of change and valuable measure of biological diversity (Manley et al. 2006).

Table AD-1. All species detected at any point during monitoring, marked with an "X" for the time period(s) it was detected. Subsequent figures will refer to species codes, this table can be used as reference. Unidentified species are excluded from this list. Some non-avian species that were detected in point counts are included and shown in italics.

Species Code	Common Name	Historical	Current	Species Code	Common Name	Historical	Current
AGOS	American goshawk	X	X	MODO	mourning dove	X	X
AMCO	American coot	X		MOUQ	mountain quail	X	X
AMDI	American dipper	X	X	NAWA	Nashville warbler	X	X

AMKE	American kestrel		X	NOFL	northern flicker	X	X
AMRO	American robin	X	X	NOPI	northern pintail	X	
ANHU	Anna’s hummingbird		X	NRWS	northern rough-winged swallow	X	X
BAEA	bald eagle		X	OCWA	orange-crowned warbler	X	X
BAGO	Barrow’s goldeneye		X	OSFL	olive-sided flycatcher	X	X
BARS	barn swallow		X	OSPR	osprey	X	X
BBWO	black-backed woodpecker	X	X	PAWR	pacific wren	X	X
BEKI	belted kingfisher	X		PBGR	pied-billed grebe		X
BEWR	Bewick’s wren		X	PIGR	pine grosbeak	X	X
BGGN	blue gray gnatcatcher	X		PISI	pine siskin	X	X
BHCO	brown-headed cowbird	X	X	PIWO	pileated woodpecker	X	X
BHGR	black-headed grosbeak	X	X	PUFI	purple finch	X	X
BRBL	Brewer’s blackbird	X	X	PYNU	pygmy nuthatch	X	X
BRCR	brown creeper	X	X	RBME	red-breasted merganser		X
BRSP	Brewer’s sparrow	X	X	RBNU	red-breasted nuthatch	X	X
BTGW	black-throated gray warbler	X		RBSA	red-breasted sapsucker	X	X
BTPI	band-tailed pigeon	X	X	RCKI	ruby-crowned kinglet	X	
BUFF	bufflehead	X	X	RECR	red crossbill	X	X
BUSH	bushtit	X	X	RNDU	Ring-necked duck	X	X
CAFI	Cassin's finch	X	X	ROWR	rock wren	X	X
CAHU	calliope hummingbird	X	X	RTHA	Red-tailed hawk	X	X
CANG	Canada goose	X	X	RUDU	ruddy duck	X	
CANW	canyon wren		X	RUHU	rufous hummingbird	X	X
CATE	Caspian tern	X		RWBL	red-winged blackbird	X	X
CAVI	Cassin's vireo	X	X	SACR	sandhill crane		X
CHSP	chipping sparrow	X	X	SAND	sanderling		X
CLGR	Clark's grebe	X		SAVS	savannah sparrow	X	X

CLNU	Clark's nutcracker	X	X	SOGR	sooty grouse	X	X
CLSW	cliff swallow	X		SORA	sora		X
COHA	Cooper's hawk	X	X	SOSP	song sparrow	X	X
COME	common merganser	X	X	*SPBE*	*California ground squirrel*	X	
CONI	common nighthawk	X		*SPBL*	*Belding's ground squirrel*	X	
COPO	common poorwill	X		SPSA	spotted sandpiper	X	X
CORA	common raven	X	X	SPTO	spotted towhee	X	X
DEJU	Dark-eyed junco	X	X	SSHA	sharp-shinned hawk	X	
DOWO	downy woodpecker	X	X	STJA	Steller's jay	X	X
DUFL	dusky flycatcher	X	X	SWTH	Swainson's thrush		X
EUCD	Eurasian collared dove		X	*TAMI*	*least chipmunk*	X	
EUST	European starling	X		*TAQU*	*long-eared chipmunk*	X	
EVGR	evening grosbeak	X	X	TOSO	Townsend's solitaire	X	X
FOSP	fox sparrow	X	X	TOWA	Townsend's warbler	X	
GADW	gadwall	X		TRES	tree swallow	X	X
GCKI	golden-crowned kinglet	X	X	TUVU	turkey vulture		X
GCRF	gray-crowned rosy finch	X		VASW	Vaux's swift		X
GTTO	green-tailed towhee	X	X	VGSW	violet-green swallow	X	X
GWTE	green-winged teal		X	WAVI	warbling vireo	X	X
HAFL	Hammond's flycatcher	X	X	WBNU	white-breasted nuthatch	X	X
HAWO	hairy woodpecker	X	X	WCSP	white-crowned sparrow	X	X
HETH	hermit thrush	X	X	WEBL	western bluebird	X	X
HEWA	hermit warbler	X	X	WEFL	western flycatcher	X	X
HOFI	house finch		X	WEGR	western grebe		X
HOSP	house sparrow	X		WETA	western tanager	X	X
HOWR	house wren	X	X	WEWP	western wood pewee	X	X

HYRE	*pacific treefrog*	X		WHWO	white-headed woodpecker	X	X
KILL	killdeer	X		WIFL	willow flycatcher		X
LAZB	lazuli bunting	X	X	WIPH	Wilson's phalarope	X	
LEGO	lesser goldfinch	X	X	WISA	Williamson's sapsucker	X	X
LEOW	Long-eared owl		X	WISN	Wilson's snipe	X	X
LEWO	Lewis's woodpecker		X	WIWA	Wilson's warbler	X	X
LISP	Lincoln's sparrow	X	X	WODU	wood duck	X	
MALL	mallard	X	X	WTSW	white-throated swift	X	
MGWA	Macgillivray's warbler	X	X	YEWA	yellow warbler	X	X
MOBL	mountain bluebird	X	X	YRWA	Yellow-rumped warbler	X	X
MOCH	mountain chickadee	X	X				

Methods

Sampling design and survey methods

Avian monitoring was conducted as a subset of the Tahoe Environmental Observatory Network (TEON), a broader study investigating habitat and occupancy changes across a range of aquatic and terrestrial communities throughout the Lake Tahoe Basin. Thirty pairs of terrestrial and aquatic sites were chosen to represent the range of elevations and orientations (east/west) present throughout the basin and its subwatersheds. This chapter is focused on the 29 terrestrial sites that were sampled in both the historical (2003-2005) and contemporary (2023-2024) time periods. Each terrestrial site was sampled in one year historically while eight sites were sampled in both 2023 and 2024 and the remaining 22 were visited only in 2024. In each year a site was sampled, it was visited two or three times during the breeding season (late May to early July),, with a minimum of four days between visits. Each site visit consisted of five point counts spread out on a hexagonal grid as shown in Figure AD-1. Each point count was ten minutes in duration, and all counts were conducted between 15 minutes after sunrise and 10am to align with avian activity patterns. Sampling in 2023 occurred between June 20th and June 29th, with two observers. Sampling in 2024 occurred between May 28th and July 5th, with five observers, one of whom was an observer in 2023. Observers rotated site visits, ensuring each site was visited by multiple observers to minimize observer bias.

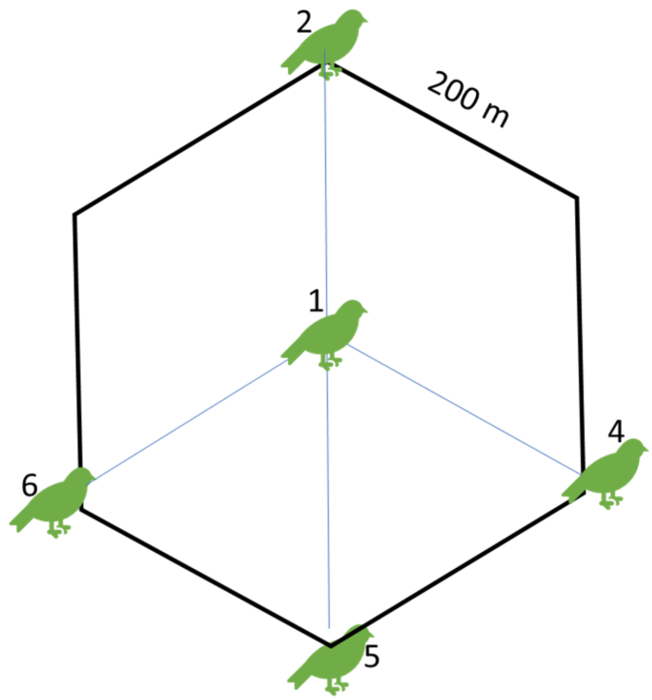

Figure AD-1. Layout of point count locations in relation to plot center.

Additionally, acoustic recording units (ARUs) were deployed at 15 sites with the goal of comparing species detection and identification between automated systems and human observers. ARUs provide substantial cost savings per sampling effort compared to point counts, but to date there is limited evidence comparing the accuracy of data collected. Each unit was deployed for 4 days and set to record between the hours of 1600 to 1100 in 10-minute increments (to mimic point count observation time) with a rest time of 10 minutes, for a total of 4.5 hrs of recording time per day.

Data analysis

The primary analytical goal of this research was to identify changes in avian community distribution across the Lake Tahoe Basin. To do this, we compared species richness at all sites across the two sampling periods to gain a broad sense of the scale of change. We also used generalized linear models to identify important environmental covariates related to community change. Finally, we conducted cluster analyses within each time period and compared their outputs to characterize changes in between-site variation.

Species observations were aggregated at the visit level to minimize spatial autocorrelation between individual point counts. To ensure that our models only include species that were contributing meaningfully to the avian community of the basin as a whole, as well as reduce the effect of false positives resulting from observer error, species observations were filtered to only those species with 3 or more detections in either the historical or modern counts. This resulted in a set of 73 species, a reduction from the 134 species detected at least once (Table AD-2).

Table AD-2. A total of 73 species detected at three or more sites in either time period. Some birds were identified lower taxonomic resolution than species. Decreased abundance in orange; increased abundance in green; stable abundance in blue.

Species	Average Historical Abundance	Average Current Abundance	Percent Change
unidentified sapsucker	0.10	0.00	-100.00
unidentified sparrow	0.21	0.00	-100.00
tree swallow	0.72	0.00	-100.00
calliope hummingbird	0.41	0.00	-100.00
mourning dove	2.76	0.07	-97.50
rufous hummingbird	3.59	0.10	-97.12
western bluebird	0.72	0.03	-95.24
western flycatcher	0.59	0.03	-94.12
spotted sandpiper	1.17	0.07	-94.12
pygmy nuthatch	3.24	0.31	-90.43
brown creeper	11.17	1.14	-89.81
American goshawk	0.31	0.03	-88.89
red-winged blackbird	5.41	0.72	-86.62
unidentified hummingbird	1.00	0.14	-86.21
unidentified woodpecker	3.24	0.45	-86.17
downy woodpecker	0.24	0.03	-85.71
mallard	1.31	0.21	-84.21
pine grosbeak	1.48	0.24	-83.72
brown-headed cowbird	12.17	2.10	-82.72
Steller's jay	50.48	9.48	-81.22
black headed grosbeak	1.45	0.28	-80.95
white-breasted nuthatch	5.48	1.10	-79.87
Williamson's sapsucker	3.14	0.66	-79.12
American robin	24.83	5.21	-79.03
Clark's nutcracker	18.52	4.24	-77.09
hermit warbler	3.38	0.79	-76.53

dark-eyed junco	45.31	11.00	-75.72
mountain quail	3.24	0.79	-75.53
pine siskin	4.66	1.17	-74.81
northern flicker	6.97	1.79	-74.26
Cassin's vireo	2.69	0.72	-73.08
mountain chickadee	51.93	16.48	-68.26
Townsend's solitaire	5.03	1.69	-66.44
hermit thrush	5.83	1.97	-66.27
red-breasted nuthatch	19.38	6.86	-64.59
Cassin's finch	6.34	2.31	-63.59
song sparrow	2.79	1.03	-62.96
evening grosbeak	4.97	1.90	-61.81
western tanager	14.86	6.14	-58.70
dusky flycatcher	12.45	5.28	-57.62
olive-sided flycatcher	8.10	3.45	-57.45
hairy woodpecker	4.59	2.03	-55.64
mountain bluebird	0.93	0.45	-51.85
fox sparrow	18.79	9.38	-50.09
orange-crowned warbler	0.34	0.17	-50.00
band-tailed pigeon	1.17	0.62	-47.06
MacGllivray's warbler	3.55	1.90	-46.60
yellow-rumped warbler	23.28	12.69	-45.48
white-headed woodpecker	2.34	1.52	-35.29
western wood pewee	14.03	9.21	-34.40
warbling vireo	5.03	3.31	-34.25
golden-crowned kinglet	5.90	3.97	-32.75
Lincoln's sparrow	0.79	0.55	-30.43
black-backed woodpecker	0.24	0.17	-28.57
red-tailed hawk	0.14	0.10	-25.00
white-crowned sparrow	3.31	2.59	-21.88
pileated woodpecker	0.17	0.14	-20.00
Brewer's blackbird	1.52	1.31	-13.64
sooty grouse	0.48	0.45	-7.14
green-tailed towhee	4.00	3.83	-4.31
Nashville warbler	4.38	4.21	-3.94
yellow warbler	0.41	0.41	0.00
Wilson's warbler	2.62	2.83	7.89
house wren	0.97	1.07	10.71
red-breasted sapsucker	0.55	0.72	31.25
common raven	0.62	0.93	50.00
chipping sparrow	1.07	1.83	70.97

red crossbill	0.66	1.21	84.21
rock wren	0.97	1.86	92.86
lazuli bunting	0.07	0.14	100.00
Hammond's flycatcher	0.03	0.17	400.00
osprey	0.00	0.24	NA
unidentified finch	0.00	0.10	NA

ARU data was used in an exploratory context only, to compare the efficacy of ARUs vs human observers at detecting species in the field as well as compare analysis methods for interpreting audio files (human listening to the audio files directly, or using the software BirdNET, a product of the Cornell Lab of Ornithology which uses machine learning to identify bird calls in an audio recording). An 85% confidence cutoff was used for BirdNET observations, informed by CDFW protocols. For each method (point count, human x ARU, and BirdNET x ARU) two metrics were calculated: total species richness and species detected by that method which were missed by one of the other methods.

All analysis was conducted using R: the stats package was used to create linear models and perform tests of significance, while the vegan and cluster packages were used for cluster analysis using agglomerative hierarchical clustering with the ward method. Two-sided T tests were used for all comparisons, and tests were considered statistically significant at alpha=0.05.

Results

Revisit Sampling Effort

During 2023 and 2024, all 60 sites were revisited, including 2-3 visits per season. Eight terrestrial-aquatic pairs of sites were sampled in 2023 (INC&M253; SPO&M589; MER&M540; BLA&M561; U34&M309; BAR&L241; SAW&L396; CFP&M190) as well as 2024, allowing for a comparison of inter-annual variation in addition to the historical-present comparison. Figure 2 shows that there is no significant difference between species richness values from 2023 to 2024 at those sites ($p = 0.59$). Among the six sites that visually appear to have a difference between 2023 and 2024, only two are terrestrial sites, suggesting that there may be more interannual variability in waterbird populations, possibly due to changes in timing of spring snowmelt (2023 was a particularly heavy snow year). Additionally, this further reinforces our confidence that interannual variability is not a confounding factor in the analysis of terrestrial sites that follows.

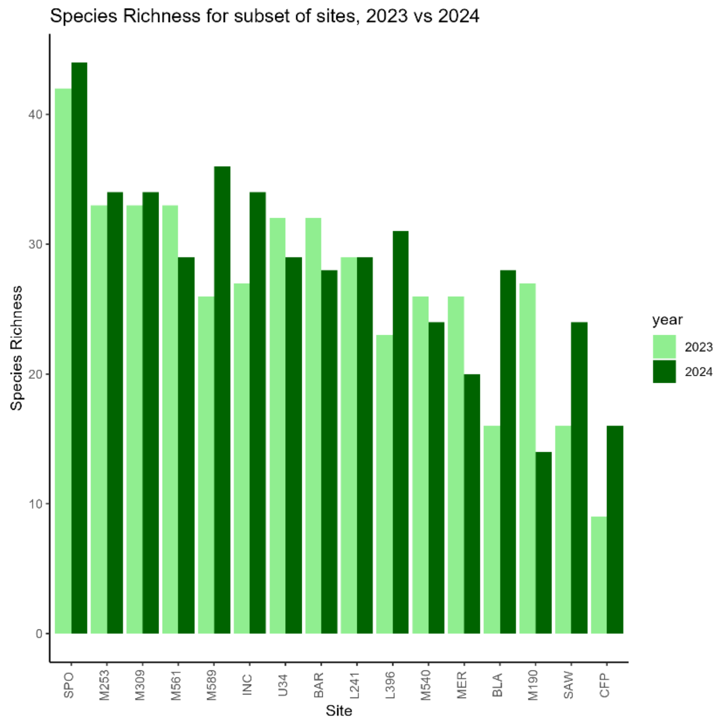

Figure AD-2. Comparison of species richness between 2023 and 2024 sampling at 16 sites, aquatic and terrestrial.

Historical Comparison Results

Ten species showed increased abundance (current abundance as a percent of historical abundance > 110%), five species showed no change (change < 110% and > 90%), while the remaining 58 species showed a decline in abundance (current abundance < 90% of historical) (Table AD-2).

We found mean species richness was significantly lower in the contemporary period than the historical period, by about three species per visit (18 vs 21.2 species respectively) on average ($p < 0.001$) (Figure AD-3). While the distribution of historical richness data is noticeably right-skewed, with a large proportion of visits detecting 23 or more species (45.9%) and many fewer visits detecting 15 or fewer species (9.5%), the distribution of modern observations shows very little skew: few visits encountered either 23 or more species (12.9%) or 13 or fewer species (15.3%).

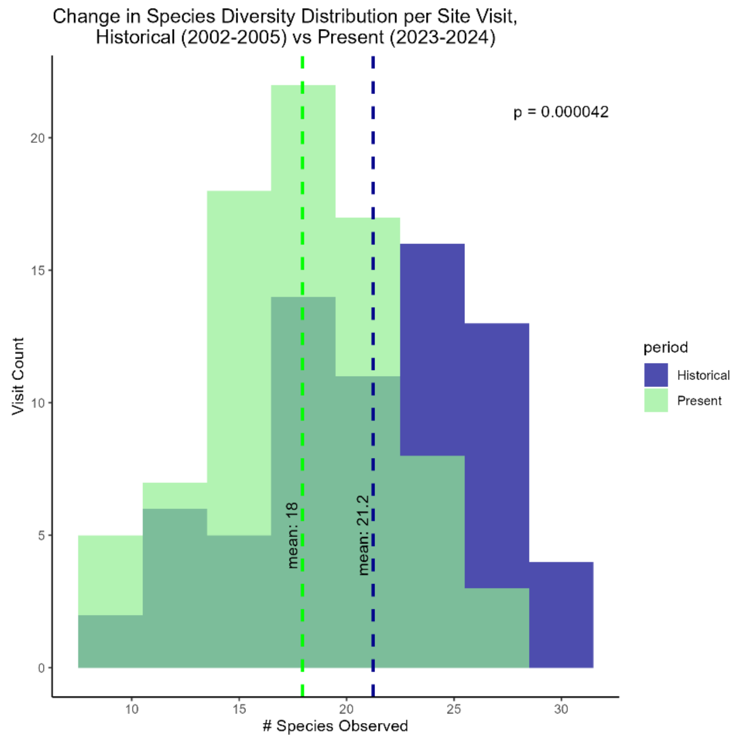

Figure AD-3. Histogram of species diversity per site visit, historical vs present. Decline in mean species per visit is significant (p <0.001, paired t-test).

Linear Models

To investigate potential factors that may have impacted this decrease, we ran several linear models (Table AD-2) that included time period, elevation, climate class, development, and tree-to-shrub ration (TSR) as covariates.

Table AD-2. Covariates and their predictive capacity for species richness when used as the only independent variable to a linear model. A model including all variables listed above did not perform better than a model including only Time Period and Elevation.

Variable	Adj. R^2	p value	Direction of correlation with species count
Time Period (P/H)	0.10	3.23e-5	Negative
Elevation	0.11	2.87e-5	Negative
Climate Class	0.003	ns	N/A

Development	0.02	ns	N/A
Tree Dominance (TSR)	0.02	0.044	Negative

The two covariates that were most impactful in predicting a site's species richness were the binary variable for time period (present or historical) and elevation, with higher species richness associated with the historical time period and lower elevations. Climate class and development level were not significant; tree to shrub ratio (TSR) as a metric of tree dominance was significant with higher species richness associated with lower tree dominance, though it contributed very little to the model's predictive ability.

Cluster Analysis

A cluster analysis was performed to identify the inter-site variability between sites. Figure AD-4 depicts the dendrograms for associations of sites by historical and present bird communities. The reduction in height of the branches of the present dendrogram when compared to that of the historical one is indicative of a broad scale loss of heterogeneity across the basin: all sites are more similar to each other now than they were 20 years ago. This is of particular note for the two sites (highlighted in purple) which were most different from the rest in 2003-2004: L241 and L186 are characterized as urban sites, which may once have constituted a specific niche in the basin. However, the reduction in difference of these two sites from the rest in 2023-24 suggests that this may no longer be the case, with environments across the basin perhaps resembling urban sites more than they once did in ways that matter to bird communities. Conversely, L396, which historically was quite similar to many other sites, now is a distinct outlier. This is due to the 2007 Angora fire, which burned the site between sampling periods and substantially changed the vegetation structure in the area, shifting from dense forest to shrubland. Impacts of fire on bird communities is well documented (Bock & Lynch 1970, Raphael et al. 1987) so it is expected to see a shift in the avian community in post-fire habitat.

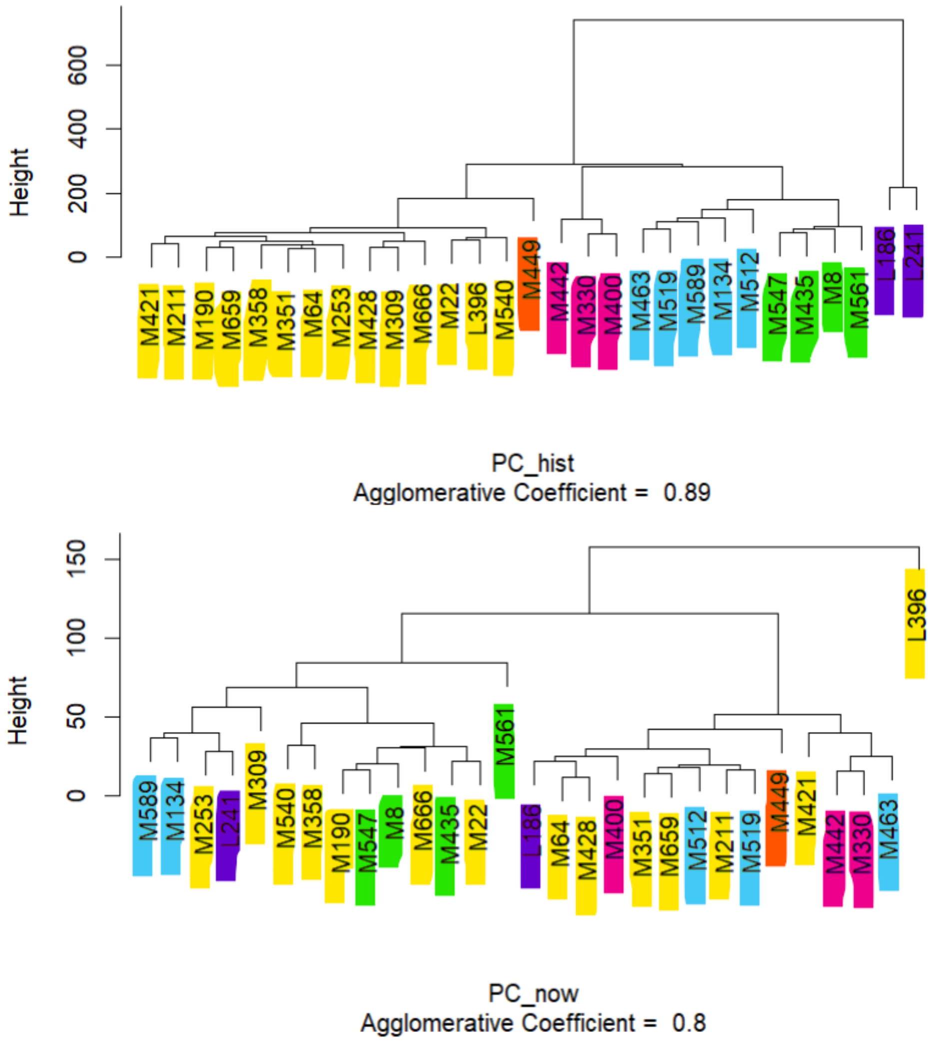

Figure AD-4. Dendrograms for historical (PC_hist) and present (PC_now) agglomerative clustering of 29 terrestrial sites. Colors indicate more similar sites in the historical period; sites retain historic colors in the present dendrogram to highlight changes in grouping structure.

ARU Results

A comparison between methods of bird detection revealed that tried-and true methods such as point counts perform well when implemented correctly, while more experimental Machine Learning methods are still catching up. Figure AD-5 shows that overall, the point count method with 3 revisits was able to detect the highest species richness at most sites, followed by a human listening to ARU recordings. The BirdNET software applied to only a subset of the ARU data to match the sampling effort of one day's worth of point count stations detected the least number of species at every site.

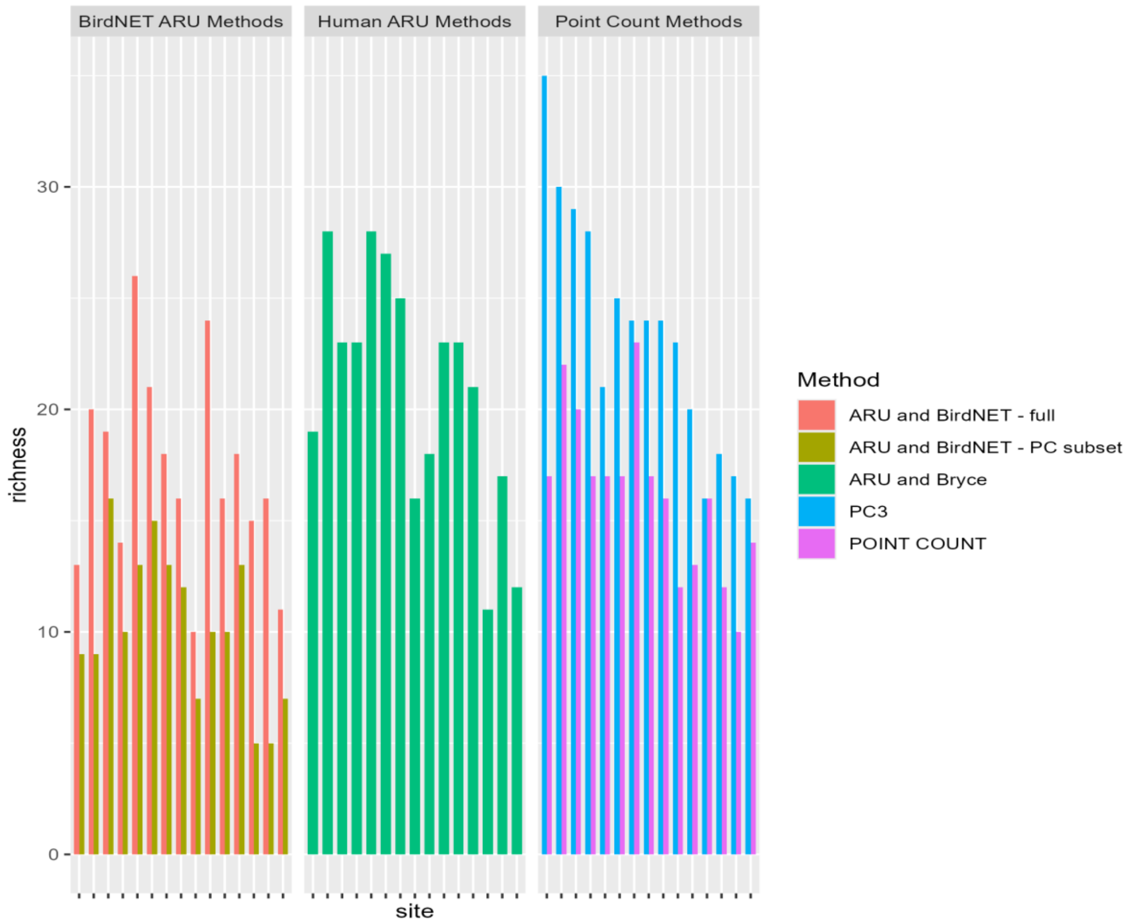

Figure AD-5. A comparison of five methods of bird detection at 15 survey sites in the Lake Tahoe basin: a single point count survey [POINT COUNT], 3 point count surveys [PC3], human listening to one day of ARU recording [ARU and Bryce], human-validated BirdNET interpretation of ARU recording (using the full 2-4 day ARU dataset [ARU and BirdNET - full]) and a subset of ARU files that match the time and date of a single point count survey [ARU and BirdNET – PC subset].

To determine if there were other differences in the efficacy of these methods beyond total number of species detected, we conducted a pairwise comparison of species detection mismatches, summarized in Figure AD-6. Point counts were notably worse than other methods in detecting Evening Grosbeak (EVGR), while BirdNET was notably worse than other methods in detecting American Robin (AMRO), Fox Sparrow (FOSP), Red-breasted Nuthatch (RBNU), Red-breasted Sapsucker (RBSA), Song Sparrow (SOSP), and Yellow-rumped Warbler (YRWA). Though BirdNET has the fewest detections of Unknown Woodpecker (XXWO), this does not correlate with fewer woodpecker detections overall because when it does identify a woodpecker, it does so to species: WHWO, WISA, HAWO are all species of woodpecker that show some level of detection by BirdNET that were missed by other methods and presumably make up much of the XXWO observations. No conclusions should be drawn in regards to BirdNET's detections of the Pacific chorus frog, as neither other method included this species as target taxa.

Figure AD-6. Pairwise comparison of species detection methods. ABxNET = detected by a human listening to ARU recording but missed by BirdNET; ABxPC = detected by a human listening to ARU recording but missed by Point Count; NETxAB = detected by BirdNET but missed by human listening to ARU; NETxPC = detected by BirdNET but missed by Point Count; PCxAB = detected by Point Count but missed by human listening to ARU; PCxNET = detected by Point Count but missed by BirdNET.

Discussion

Historical Change

Our results describe an overall reduction in avian species richness over the past 20 years, a concerning trend no matter whether it is viewed through the lens of biodiversity, ecological function, or pure recreational enjoyment. This change is not uniform across the basin, with greater losses at lower elevations. This correlation is particularly concerning given the higher species density observed at lower elevations compared to high: the most diverse bird communities are those at highest risk of impact. Anthropogenic influence and severe wildfire were also identified as drivers of community composition, a correlation which, while not new or groundbreaking, brings home the reality that management actions in the Lake Tahoe Basin can have a real impact on the forests we manage and live in.

Monitoring Implications

The historical comparison results presented and discussed above indicate that point counts are an effective means of monitoring for change in bird populations at scales appropriate for the Lake Tahoe Basin. However, the point count methodology is a labor-intensive approach that depends on highly skilled field technicians for a relatively short field season (~6 weeks), which can be problematic for hiring and retaining an appropriate workforce for adequate monitoring of bird populations. ARUs provide a partial workaround to this issue insofar as they separate the need for highly trained staff from the time-sensitive monitoring season, allowing for a more distributed workload by reducing the skillset necessary for data collection (ARU deployment requires minimal training) and data analysis (staff with bird-recognition skills can spread out ARU analysis throughout the year). Of the two methods we explored for analysis of ARU data files, we found the BirdNET software to be overall less effective than a skilled human observer at detecting the full range of species present at a given site. This was true even when comparing a human listening to 50 minutes of recording per site and BirdNET processing 17 hours of recording per site. These results are in agreement with existing research, which has also found that for smaller geographic areas like the Tahoe Basin, and especially for species which vocalize infrequently (such as woodpeckers), point counts outperform ARUs in detecting species richness (Klingbeil & Willig 2015). While a semi-automated system such as BirdNET is appealing because of its ability to eliminate inter-observer variation and potential for time savings, the data obtained using the suggested 85% confidence cutoff was not robust when compared to other methods. A lower cutoff would be expected to increase species detections, but more false positives would be included and human validation effort would increase; at the extreme, the validator would end up listening to the entire file anyways, which we determined was a more accurate method separately. A suitable middle ground may exist at a lower confidence threshold, but for overall accuracy in interpreting ARU data skilled human listeners are as yet unsurpassed.

Recommended Citation

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TEON Appendix E:

Amphibian and Reptile Change in the Lake Tahoe basin from Historical to Present

Gina Tarbill, Shale Hunter, and Patricia Manley
US Forest Service, Pacific Southwest Research Station
Placerville, CA
July 2025

Introduction

Lakes, ponds, and associated meadow habitats support many dependent wildlife species, thus making an outsized contribution to regional biodiversity. In the dry mixed conifer and subalpine forests of the Sierra Nevada, these habitats occupy a relatively small proportion of the landscape but make a substantial contribution to the biodiversity of the region. Furthermore, some species, such as amphibians and garter snakes, are partially or completely dependent on aquatic habitats for some portion of their life cycle, making them particularly vulnerable to loss or degradation. Life history traits, such as the highly permeable membranes of amphibians and their eggs mean they are primarily limited to moist habitats, and are particularly sensitive to changes in precipitation patterns, temperature and aridity, and chemical contaminants. Threats to herpetofauna include habitat loss or degradation, pollution, disease, and invasive species, such as bullfrogs (*Rana catesbeiana*) and introduced trout (that are predators on frog species and thus competitors of garter snakes (Stuart et al. 2004, Halliday 2008). These threats are intersectional with the impacts of climate change, further driving declines (Matthews et al. 2002, Viers et al. 2013, Campbell Grant et al. 2020).

In the Sierra Nevada, climate change is already discernable in the decline in snowpack (Mote et al. 2005, Belmecheri et al. 2016), increased frequency and severity of drought (Griffin and Anchukaitis 2014, Diffenbaugh et al. 2015) and other extreme weather events (Halofsky 2020), increase in high-severity fire (Abatzoglou and Williams 2016, Williams et al. 2023, Turco et al. 2023), and higher water temperatures in lakes (Coats et al. 2013, Streib et al. 2021). These changes may accelerate the declines in amphibians and aquatic reptiles already that are already observed from habitat loss (Roche et al. 2012, Campbell Grant et al. 2020), predation by nonnative fish (Matthews et al. 2002, Knapp 2005, Knapp et al. 2005), and parasitism by the amphibian chytrid fungus, *Batrachochytrium dendrobatidisa, Bd* (Bradford et al. 1994, Green et al. 2002, Knapp 2005, Vredenburg et al. 2010). Recent studies in other regions of the Sierra Nevada have found that while most amphibians are resilient to variability in precipitation, occupancy varied depending on species, wetland type, precipitation pattern, and whether fish were present (Halstead et al. 2023). However, it is largely unknown if and how this community has changed in recent years in the Tahoe basin. We resampled a historical dataset of amphibians and garter snakes in the Lake Tahoe Basin of California to determine how diversity and abundance has changed over time. The original data were collected in 2003-2004, with visual encounter surveys conducted for frogs and toads (Order: Anura), salamanders (Order:Urodela), and garter snakes (Order: Squamata: Colubridae: Thamnophis) in lakes, ponds, and meadows.

Our objectives were to determine the current status of amphibian and aquatic reptile populations, describe the change in the status of populations over the past ~20 years, and provide recommendations on the design and implementation of a monitoring program for aquatic amphibians and reptiles and associated lentic habitat conditions. We hypothesized that herpetofauna community metrics would depend on moisture levels, with lower richness and abundance in years with lower precipitation. Because meadows and smaller ponds and lakes will be more transient in the system, and may concentrate any pollutants, we predicted that richness and abundance would be lower here than in larger water bodies. Lastly, we hypothesized that higher elevations may act as refugia from climate and other anthropogenic impacts, thus we predicted higher richness and abundance at higher elevations.

Methods

Study Area

The study area is the Lake Tahoe basin of California and Nevada (Fig. AE-1). The basin drains nearly 1,300 km^2 from 63 subwatersheds into one of the largest and deepest alpine lakes (~50,000 ha) in North America. Elevation in the basin ranges from approximately 1,900 m at lake level to 3,300 m at the crest of the Carson Range to the east and 2,700 m along the crest of the Sierra Nevada to the west. The climate is typical of the Sierra Nevada, with warm dry summers and cold snowy winters, although the orientation, aspect, and elevation create numerous microclimates that vary in temperature and precipitation (Daly et al. 2002). The Lake Tahoe basin has 63 major watersheds, over 330 lakes, 3 marshes, 2 fens, and hundreds of hectares of meadow, which support a diverse community of amphibians and aquatic reptiles (Table AE-1).

Table AE-1. Herpetofauna that may occur in the Lake Tahoe basin, with status from NatureServe (2024) and California Natural Diversity Database (2024).

Common name	Scientific name	Status
Long-toed salamander	*Ambystoma macrodactylum*	Widespread
Mount Lyell salamander	*Hydromantes platycephalus*	Endemic to Sierra Nevada, CA Watch List
Sierra tree frog	*Pseudacris sierra*	Secure
Sierra yellow-legged frog	*Rana sierrae*	Federally endangered, CA threatened
American bullfrog	*Lithobates catesbeianus*	Invasive
California toad	*Anaxyrus boreas halophilus*	Common, relatively stable at species-level
Sierra garter snake	*Thamnophis couchii*	Locally common, relatively stable
Mountain garter snake	*Thamnophis elegans elegans*	Common, relatively stable at species-level
Common garter snake	*Thamnophis sirtalis fitchi*	Common, relatively stable at species-level

Sampling design

This research was developed as part of a larger study investigating change in habitat and occupancy for a suite of aquatic and terrestrial species and conditions. Working with the historical dataset of over 400 points located across the Lake Tahoe basin in uplands, lakes, ponds, and meadows, we attempted to locate two pairs of terrestrial and aquatic sites in each of the 63 subwatersheds, one at lower elevations (< 2300 m) and one at higher elevations (> 2300 m).

The original sampling design used three environmental gradients to stratify lakes and ponds from the USGS waterbody digital data layer for the Lake Tahoe basin: elevation (high or low), aquatic site size (small: < 0.5ha, medium: 0.5- 5 ha, large: > 5ha), and orientation (east or west side of basin). A total of 72 lakes and ponds were randomly selected in roughly equal proportions from the 12 elevation-size-orientation classes. Because no complete map of meadows was available for the Lake Tahoe basin at the time, four 1-mi^2 areas were randomly selected in each elevation-orientation class, and one meadow was selected from each area, resulting in 16 meadows that were sampled. Because site selection for the TEON study included additional goals and parameters, the sites we selected for 2023 were not sampled every year in the historical dataset for aquatic herpetofauna; thus, of the 38 sites sampled in 2023, 26 were sampled in 2003 and 30 were sampled in 2004. To balance the historical and contemporary sampling among years, we randomly selected an additional 12 sites from 2003 that were also sampled in 2004, so each year had 38 sites sampled. If a site was visited multiple times in a season, a single visit was randomly selected to equalize sampling effort over the time periods.

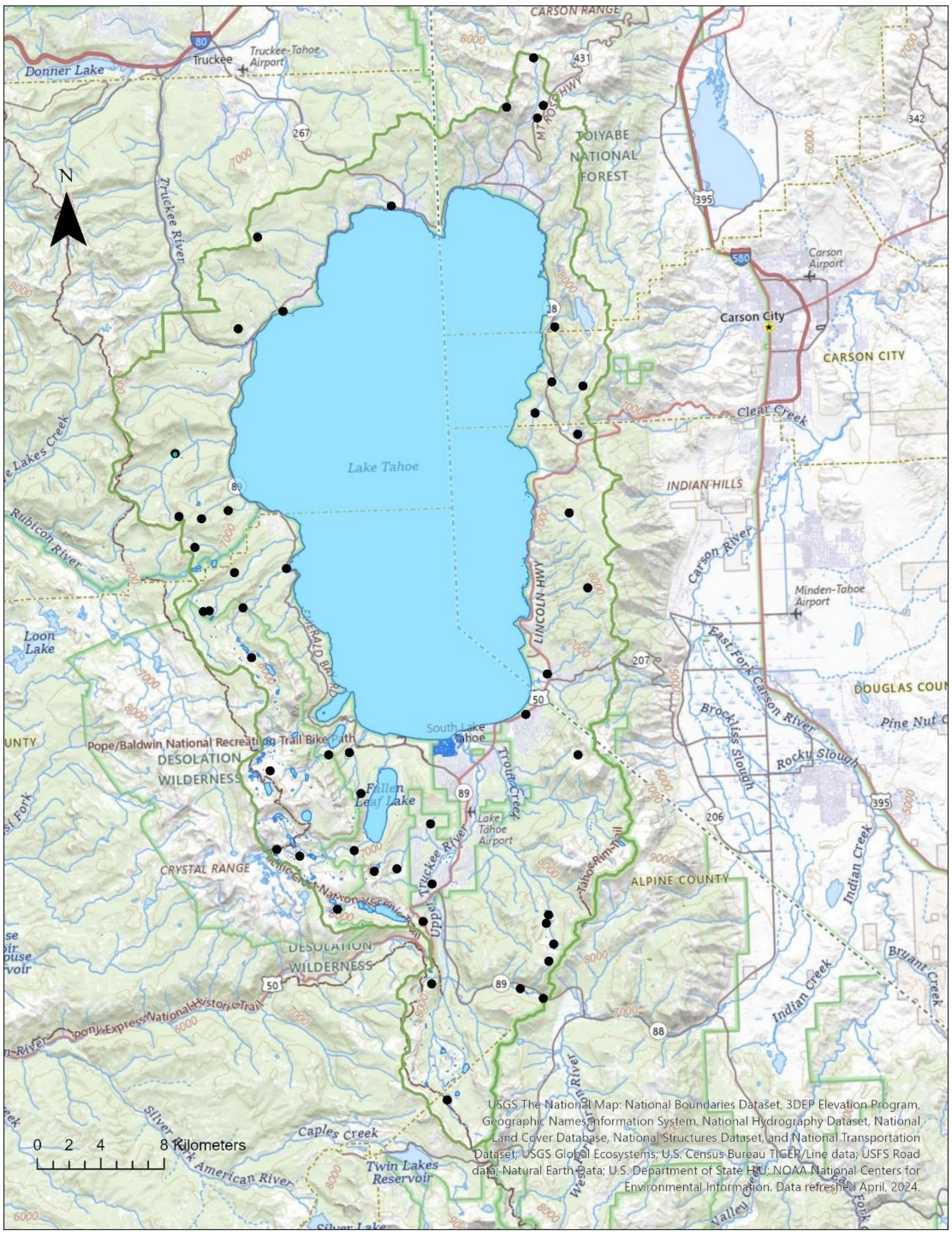

Figure AE-1. Map of Lake Tahoe basin with historical and contemporary sites that were sampled in elevation, size, and orientation classes.

Amphibian and Reptile Survey Methods

Visual encounter surveys consisted of walking 100% of the perimeter of lakes and ponds, or by walking 100% of the interior of wet meadows (Fellers and Freel 1995; Fig. AE-2). At lakes, observers walked one to several meters inside the bank of the lake or pond unit while following the perimeter (Fig. AE-2a). When two observers were present, they began to survey at the same point and moved in opposite directions until they met. In meadow habitats, observers meandered from side to side covering the entire width of the meadow with each new trajectory (Fig. AE-2b). In meadows, when standing water was too deep to walk through, observers walked the perimeter of the water body.

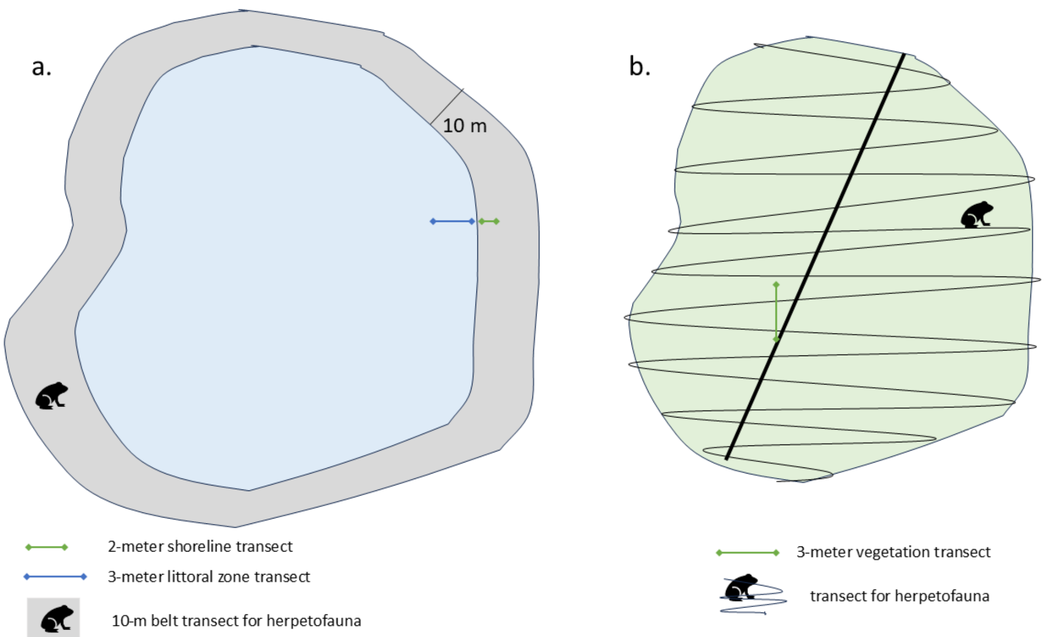

Figure AE- 2. Schematic of herpetofauna survey strategy for a. lakes and ponds and b. meadows. The distance between transects was estimated in order to ensure at least 30 but no more than 50 transects were sampled for each site. For lakes and ponds, transects were placed around the perimeter of the water bodies. For meadows, a randomly selected starting point was selected, from which a line was laid to capture the length of the meadow. A random compass bearing determined the angle from the line for every vegetation transect.

Surveys were conducted between 0800 and 1700 hrs. Observers recorded the duration and extent of the search, with observers spending approximately 15-20 minutes per 100 m surveyed. The clock stopped when extra time was needed to identify species, count tadpoles, or maneuver around obstacles. Observers spent most of the time walking in the water, searching through emergent vegetation and overturning rocks, logs, and debris to reveal amphibians and reptiles (Fellers and Freel 1995). All amphibian and reptile species seen or heard were recorded, including species, life stage (egg, tadpole, juvenile, adult; Corkran and Thoms 2006), and number of individuals (or egg masses); associated substrates were also recorded (e.g., on rock, silt, bank etc.). Because egg and larval stages were often difficult to count, we also assigned each amphibian species to a categorical abundance class (Table AE- 2).

Table AE-2. Abundance categories used to estimate number of individuals observed.

Category	**0**	**1**	**2**	**3**
Estimated number of individuals	Not detected	1 to 10	11 to 100	>100

eDNA Sampling

We also attempted to test a novel method for evaluating aquatic communities: environmental DNA (eDNA). This method involves collecting and filtering water to capture the DNA that organisms shed throughout their lives, leaving a biochemical footprint of their presence. We used prepackaged kits from Jonah Ventures to collect eDNA from the thirty meadows and lakes we evaluated with visual encounter surveys to compare how the methods differed in their ability to detect aquatic species. Samples were collected near the end of the 2023 summer season, when eDNA is more concentrated due to reduced flow.

Filters were then sent back to Jonah Ventures to identify the species detected at each site. The eDNA is then extracted, amplified, sequenced in a process called metabarcoding. Metabarcoding allows for the simultaneous identification of an entire assemblage of species by extracting and amplifying DNA with generalized polymerase chain reaction (PCR) primers that can target communities rather than a single species. We targeted amphibians and reptiles; however, it is possible to use highly conserved primers to assess all vertebrates. Unfortunately, there was an issue with the samples and they were not processed, thus we are unable to directly compare methods.

Environmental Measurements

We used ArcGIS Pro (v 3.2, ESRI) to generate environmental variables for each aquatic site. We assigned an elevation (m), size (ha), and mean annual precipitation (mm) value to each site. Elevation and water body size were estimated from the USGS Digital Elevation Model (1 km-resolution, accessed 2024) and National Hydrography Dataset (accessed 2024), respectively. For meadows we used the Sierra Nevada Multisource Meadow Polygons Compilation dataset (v 2.0, UC Davis and USDA Forest Service 2017) to estimate the area of each meadow. We used the Parameter-elevation Regression on Independent Slopes Model Climate Group dataset (4 km-resolution) to assign an average annual precipitation to each site for each water year of the study (PRISM 2024).

Data Analysis

To evaluate the changes to the herpetofauna community, we compared relative abundance, and richness estimates over the two sampling periods (2003-2004, 2023). Abundance class was the class assigned to a particular species at a site for each year of sampling. Richness was calculated as the number of unique species that were observed at a site in a given year. We used generalized linear mixed models in a Bayesian framework to understand how communities changed over time. We modeled abundance, abundance class, and richness as functions of year, lake size, elevation and mean annual precipitation and included sites as random effects to account for dependence of observations that occurred at the same sites in different years. All continuous covariates were standardized and centered. Abundance class of amphibian species was modeled with ordinal logistic regression to account for the ranked structure of the classes, with the probit link function. Raw relative abundance of garter snakes and species richness were modeled with Poisson mixed linear models. We expected the effect of the sampling period to be positive if herpetofauna abundance or richness was higher in the historical time period relative to the contemporary time period. Parameter estimates that had a Bayesian credible interval (BCI) that did not overlap zero were considered significant. All analyses were run with the brms package (Burkner 2017) in the R statistical program (R core team 2024). We used Rhat values (Gelman and Hill 2006) to evaluate model convergence; all models converged with Rhat values<1.1. We used Bayesian R^{2} to evaluate fit of linear models, with acceptable values between 0.1 and 0.9.

Results

Results from the 2003-2004 study can be found in the final report for that project (Manley and Lind 2005). In 2023, we detected six species across all sites: long-toed salamander, Sierra tree frog, California toad, American bullfrog, mountain garter snake, and common garter snake (Table AE-3). In addition, we observed several garter snakes that escaped before they could be definitively identified to species (*Thamnophis* species). Sierra tree frogs were detected at the most sites in all years of the study. American bullfrogs, an invasive species, were detected at four sites: Beaver Pond, Sawmill Pond, Seneca Pond, and Spooner Lake. We detected bullfrogs at two sites in the contemporary dataset, Sawmill Pond and Lake Baron. We did not detect them at Spooner Lake. Seneca Pond has since been restored to a wetland, and was excluded from resampling, and Beaver Pond was not re-surveyed.

Table AE-3. Frequency of sites with detections by species and year. Thirty-eight sites were sampled in each year, but not all sites were sampled in all years.

Species	2003	2004	2023
Long-toed salamander	6	9	4
Western toad	4	2	5
Sierra tree frog	16	19	13
American bullfrog	3	2	2
Mountain garter snake	8	3	9
Common garter snake	3	4	5

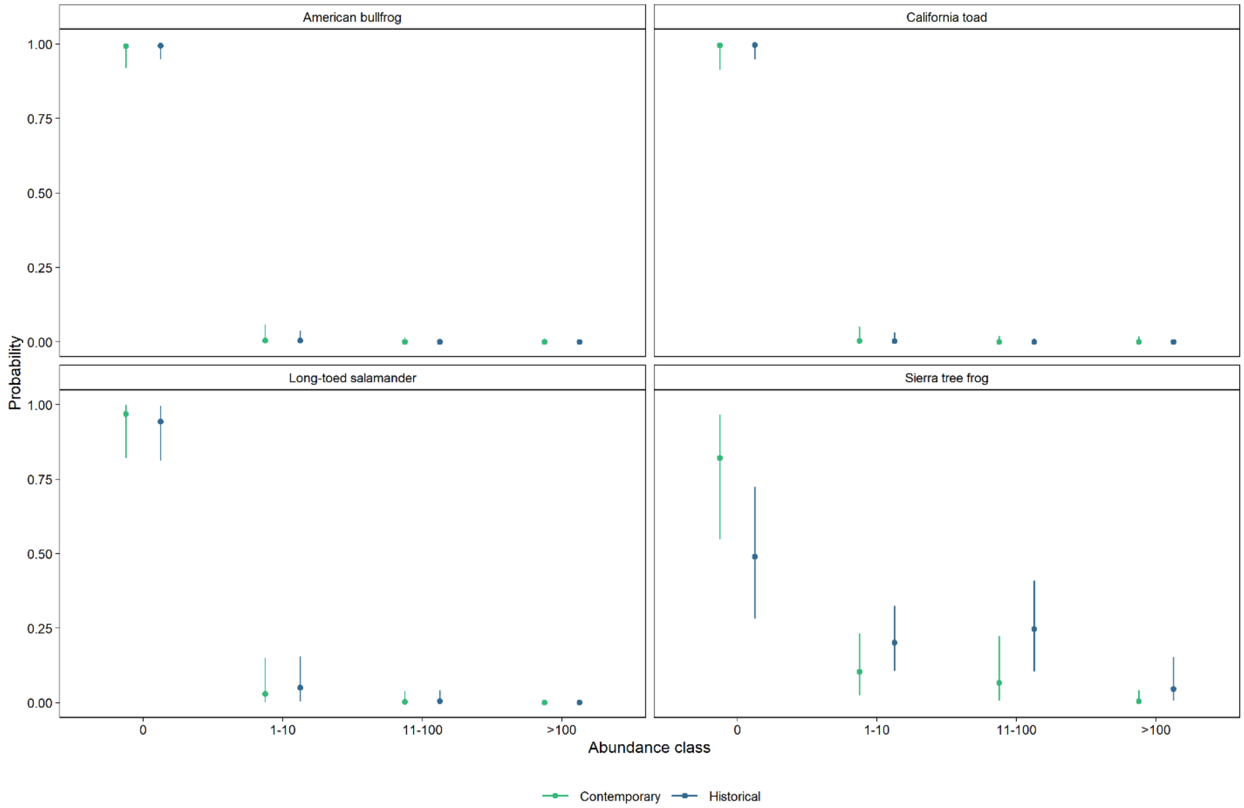

Figure AE-3. Probability of each abundance class in historical and contemporary periods for amphibians in the Lake Tahoe basin USA. The effect of sampling period was significant for Sierra tree frog only, with higher probability of the abundance class of 0 in the contemporary time period, and higher probability of the other classes in the historical period, indicating that abundance of this species was higher when sampled in 2003-2004 relative to 2023.

Models for abundance and abundance class found that species differed in their responses to time period, precipitation, elevation, and lake size (Table AE-4, Fig. AE-3, AE-4). There was no significant effect of sampling period on abundance for the common garter snake or abundance class for long-toed salamander, Western toad, or American bullfrog. The historical time period had higher abundances than the contemporary period for Sierra tree frogs and mountain garter snakes (Table AE-4). Precipitation was positively associated with abundance of mountain garter snakes, but no other species. Mountain garter snake abundance was also positively associated with lake size. Elevation was positively associated with Sierra tree frog abundance but negatively associated with American bullfrog abundance.

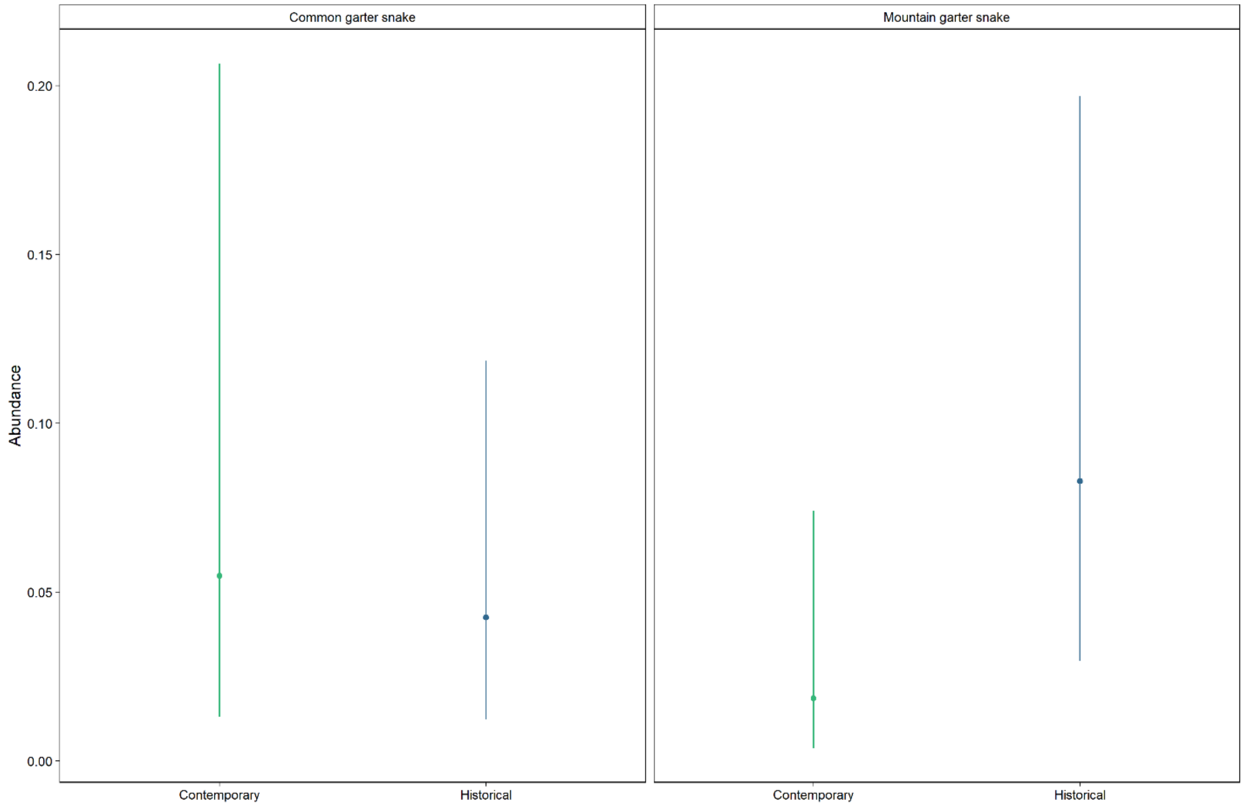

Figure AE-4. Relative abundance of common and mountain garter snakes by sampling period in the Lake Tahoe basin. The historical sampling period had higher relative abundance for mountain garter snakes than the contemporary period.

Mean species richness was very similar in all years of the study, with most sites having a single species detected, with a minimum of zero and maximum of four species observed on each site. We did not find a significant difference in richness from historical to contemporary time periods (Table AE-4, Fig. AE-5). Precipitation was positively associated with richness. Neither elevation nor lake size significantly affected richness.

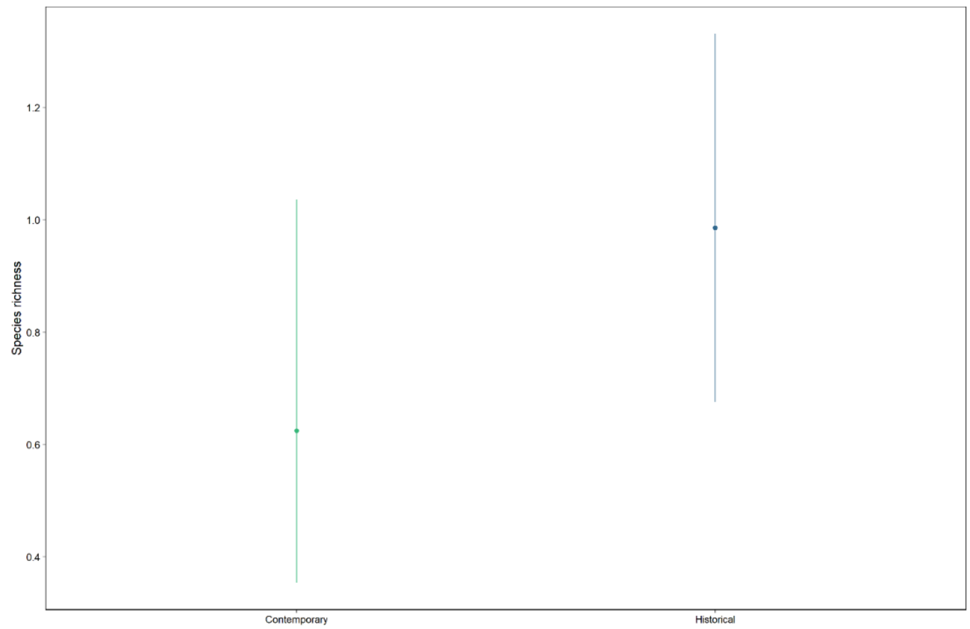

Figure AE-5. Species richness of herpetofauna by sampling period in the Lake Tahoe basin. There was no effect of sampling period on richness.

Table AE-4. Results from modeling for species-level abundance class for Long-toed salamander, California toad, Sierra tree frog, and American bullfrog, abundance class for common and mountain garter snakes, and species richness of herpetofauna in the Lake Tahoe Basin, USA. When the 95% Bayesian credible interval (BCI) does not overlap zero, the effect of the covariate is significant (bold). Abundance class models used ordinal regression; thus, intercepts are given for each class break.

Species	**Parameter**	**Estimate**	**Error**	**lower BCI**	**upper BCI**
Common garter snake	Intercept	-2.83	0.7	-4.27	-1.54
Common garter snake	Elevation	-0.1	0.54	-1.17	0.95
Common garter snake	Precipitation	-0.26	0.65	-1.65	0.94
Common garter snake	Lake size	-0.04	0.08	-0.22	0.1
Common garter snake	Historical	-0.26	0.8	-1.88	1.32
Mountain garter snake	Intercept	-5.06	1.11	-7.51	-3.13
Mountain garter snake	Elevation	-1.29	0.79	-3.01	0.15
Mountain garter snake	**Precipitation**	**2.45**	**0.7**	**1.17**	**3.94**
Mountain garter snake	**Lake size**	**0.17**	**0.08**	**0.02**	**0.34**
Mountain garter snake	**Historical**	**1.83**	**0.66**	**0.62**	**3.2**
Long-toed salamander	Intercept[1]	1.4	0.52	0.46	2.48
Long-toed salamander	Intercept[2]	2.36	0.58	1.33	3.59
Long-toed salamander	Intercept[3]	3.71	0.78	2.32	5.34
Long-toed salamander	Elevation	0.35	0.29	-0.2	0.97
Long-toed salamander	Precipitation	0.07	0.35	-0.63	0.79
Long-toed salamander	Lake size	-0.11	0.08	-0.31	0.03

Species	Parameter	Estimate	Error	lower BCI	upper BCI
Long-toed salamander	Historical	0.23	0.53	-0.77	1.28
California toad	Intercept[1]	2.48	0.72	1.17	3.97
California toad	Intercept[2]	2.97	0.76	1.6	4.58
California toad	Intercept[3]	3.36	0.81	1.9	5.07
California toad	Elevation	0.27	0.46	-0.65	1.16
California toad	Precipitation	0.42	0.47	-0.51	1.33
California toad	Lake size	0	0.08	-0.19	0.15
California toad	Historical	-0.11	0.63	-1.35	1.14
Sierra tree frog	Intercept[1]	0.84	0.43	0.03	1.73
Sierra tree frog	Intercept[2]	1.4	0.45	0.58	2.34
Sierra tree frog	Intercept[3]	2.57	0.51	1.67	3.65
Sierra tree frog	**Elevation**	**0.54**	**0.27**	**0.03**	**1.08**
Sierra tree frog	Precipitation	0.35	0.31	-0.27	0.97
Sierra tree frog	Lake size	0.01	0.04	-0.07	0.08
Sierra tree frog	**Historical**	**0.92**	**0.46**	**0.04**	**1.84**
American bullfrog	Intercept[1]	2.66	0.66	1.54	4.1
American bullfrog	Intercept[2]	3.33	0.73	2.07	4.93
American bullfrog	Intercept[3]	3.74	0.78	2.39	5.37
American bullfrog	**Elevation**	**-0.89**	**0.43**	**-1.78**	**-0.09**
American bullfrog	Precipitation	-0.1	0.48	-1.08	0.83
American bullfrog	Lake size	0.02	0.04	-0.05	0.1
American bullfrog	Historical	-0.06	0.56	-1.12	1.02
Richness	Intercept	-0.43	0.26	-0.98	0.06
Richness	Elevation	0.03	0.14	-0.24	0.31
Richness	**Precipitation**	**0.4**	**0.2**	**0.01**	**0.78**
Richness	Lake size	0.01	0.02	-0.02	0.05
Richness	Historical	0.45	0.32	-0.16	1.09

Discussion

There is some evidence that herpetofauna communities have changed in the past two decades. We found that both Sierra tree frogs and mountain garter snakes had higher abundance in the historical time period relative to the contemporary time period, suggesting that declines have occurred for these species. However, other species appear to be relatively stable, with no indication that populations have declined. The basin has changed in many ways in the past twenty years, with increasing temperatures, high-severity fire, and drought (Mote 2006, Miller et al. 2009, Coats et al. 2013). However, climate variability is inherent to the Sierra Nevada system, largely due to the El Niño-Southern Oscillation (ENSO) at high frequency (i.e., 2-5 years) and the Pacific Decadal Oscillation at longer (interdecadal) time scales (Taylor and Beaty 2005). Both systems have been attributed to extreme weather and climatic events over multiple years and decades in both the recent and historical past (Taylor and Beaty 2005, Fierro 2014, Lee et al. 2018). Thus, we would expect native species that evolved in this highly variable climate to have adaptions to both drought and extreme weather and as has been observed in the southern Sierra Nevada range (Halstead et al. 2023). For example, Western toads have relatively short time to reach adulthood, thus they may complete their life cycle prior to the drying of water bodies in summer (Moss et al. 2021).

This resilience to extreme weather may also explain the lack of response demonstrated by most species to mean annual precipitation. Only mountain garter snakes and species richness responded positively to precipitation in the current water year (October-September). Mountain garter snakes, like the common garter snake, hunt in aquatic systems for amphibians, fish and invertebrates, although mountain garter snakes may be better at diving for prey (Kephart 1981) and tend to be found in more stream or lake habitats than common garter snakes (White and Kolb 1974). This may lead to a positive association between precipitation and garter snake abundance if more rain or snow results in bigger or longer lasting bodies of water to hunt for this semi-aquatic snake. The positive association between species richness and precipitation may similarly reflect that in years with more snow and rain, meadows and smaller ponds may may larger and longer lasting, offering more breeding and feeding opportunities for a more diverse suite of herpetofauna.

Surprisingly, lake size did not have a significant effect on most species. We expected smaller lakes, ponds, and meadows to be more sensitive to the effects of weather, with cascading effects on herpetofauna communities. However, we specifically chose sites that were still aquatic to resample after twenty years; many other sites were drained, developed, or otherwise dried out such that sampling was not possible. Perhaps the sites that were still wetlands in the contemporary time period were those that were robust to stochasticity and extreme weather events through their hydrogeomorphology.

Interestingly, elevation was negatively associated with American bullfrogs but positively associated with Sierra tree frogs. An invasive species, American bullfrogs are likely limited by life history traits to lower elevations (< 2100 m). For example, bullfrogs have a relatively long developmental phase that is not conducive to the short summers of the Sierra Nevada (Moss et al. 2021). They are closely associated with warm winter temperatures and lower elevations in California (Nelson and Piovia-Scott 2022). While shorter summers and colder winters may have historically limited bullfrogs in the Tahoe basin, it is important to note that under climate change, those constraints may be loosened. Monitoring, and perhaps controlling bullfrog populations may be a crucial step in maintaining aquatic biodiversity in the region. American bullfrogs are a predator of smaller frog species, including Sierra tree frogs, and bullfrog presence at lower elevations may have negatively impacted Sierra tree frog populations. Tree frogs in other regions use chemical and aural cues to avoid bullfrogs (Chivers et al. 2001, Both and Grant 2012) and this may be the case here as well. These tree frogs are typically found throughout the state, so no obvious elevational limitation is known.

The wetlands and aquatic systems of the Tahoe basin are complex and highly variable, from dry meadows to deep, cold lakes, and fast-moving streams. It was not possible to sample the full range of conditions with visual encounter surveys, limiting our ability to detect the full suite of aquatic and semi-aquatic species. Additionally, although fish were sampled in the historical dataset, we were unable to repeat these surveys due to budget and time constraints, despite previous research that indicates that non-native trout species predate frog species (Knapp 2005, Knapp et al. 2005), and may have indirect impacts on garter snakes as well (Matthews et al. 2002, Pope et al. 2008). This is an important aspect of this community that needs further research.

Our research indicates that Sierra Nevada herpetofauna communities tend to be resilient to the changes thus far to climate and land use in the Tahoe basin. However, there are physiological and ecological limits that may be reached in the near future under climate change. For example, increasingly warm winters may promote American bullfrog range expansion while longer and more extreme droughts may reduce available breeding sites for all species. Regular monitoring of this community can inform management of aquatic communities in the basin, such as prioritization of restoration efforts or nonnative species removal. Furthermore, we may be able to tie acute loss of community diversity or abundance to specific factors that may be ameliorated or prevented, resulting in a more resilient aquatic environment.

Management and Monitoring Implications

The visual encounter surveys used for herpetofauna are time consuming, with lower detection probability that is often confounded by the timing of sampling and the life stage of each particular species. Additionally, species are highly variable in what type of aquatic habitat they use at particular life stages. For example, mountain yellow-legged frogs (*Rana sierrae*) were not detected at all in our surveys, perhaps due to their rarity or their tendency to use streams in this part of their range (Brown et al. 2019, Yarnell et al. 2019). We also did not detect the Sierra garter snake species (*T. couchii)* that is known to use the basin, which could be due to the rarity of this species or the difficulty in differentiating among the three species.

Due to the limitations of visual detection surveys, we recommend that future sampling use eDNA sampling, with periodic visual encounter surveys to verify species of concern or invasive species. Based on existing literature, eDNA is superior for evaluating aquatic species richness. A recent meta-analysis found that when compared to visual encounter surveys, eDNA was cheaper, more sensitive, and more accurate, particularly for amphibian species (Fediajevaite et al. 2021) In a study on 33 Ecuadorean amphibian species, 13 species were identified with eDNA only, five with visual encounter surveys only, and 15 with both methods (Quilumbaquin et al. 2023). The eDNA surveys also had much higher detection probabilities, although using both methods resulted in higher sensitivity of detection. They do note that for species that are semi-aquatic, such as the garter snakes in the Tahoe basin, there may be less DNA in the water, making them more difficult to detect. For rare and semi-aquatic species, visual encounter surveys are most effective when repeated multiple times per season and eDNA can help verify absence when visual encounter surveys are negative (Bailey et al. 2019). One important limitation of eDNA is that it is best used for occupancy and not abundance, and does not provide information about breeding, age or sex that may be obtained in visual encounter surveys (Ruppert et al. 2019).

By strategically sampling at the foot (i.e., downstream end) of lakes, ponds, and meadows, we can effectively sample a large area and potentially pick up species that are restricted to lotic systems while still capturing species that use the adjoining lentic habitat (Pope et al., 2020, Bedwell et al. 2021). This sampling is relatively quick and easy, with higher detection probabilities for rare species than visual encounter surveys. One caution of eDNA sampling is that it may indicate the presence of species that are not occupying an area due to the persistence of genetic material in the system. Typically, DNA degrades in a few days to a few weeks an aquatic setting, depending on species, ultraviolet radiation, temperature, and pH (Dejean et al. 2011, Barnes et al. 2014), although DNA trapped within the sediment is likely to last longer. Careful sampling may reduce this risk, but we also recommend confirmation visual encounter surveys for any new or unexpected observations.

Recommended Citation

Tarbill, G., Hunter, S., and P.N. Manley. 2025. TEON Appendix E: Amphibian and reptile community change in the Lake Tahoe basin from historical to present. *In* Manley, P.N., S.

Allen, G. Tarbill, A. Harbold, J. Blaszczak, S. Chandra, E. Burt, S. Hunter, and L. Bistritz. 2025. Tahoe Environmental Observatory Network: A monitoring system for the Lake Tahoe basin. Final report, grant deliverable submitted to the Tahoe Regional Planning Agency, United States Geological Survey, and Lake Tahoe Basin Management Unit. Lake Tahoe, California, USA.

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TEON Appendix F:

Camera Monitoring of Terrestrial Mammals in the Lake Tahoe Basin

Liraz Bistritz, Shale Hunter, Gina Tarbill, and Patricia Manley

US Forest Service, Pacific Southwest Research Station

Placerville, CA

July 2025

Introduction

Remotely triggered camera traps are a valuable tool for surveying terrestrial mammals, particularly carnivores, due to their ability to operate continuously and capture visual data on elusive and cryptic species. This study was conducted in the Lake Tahoe Basin and aimed to survey mammals with varying body sizes, home range areas, and ecological roles. By employing a nested sampling design, this study aimed to address species-specific detection challenges and evaluate the efficacy of baiting as a method to enhance detection probabilities. This effort also sought to align with prior studies (e.g., Multi-species Inventory and Monitoring (MSIM) program, Lake Tahoe Urban Biodiversity (LTUB) study) to facilitate comparative analysis of mammalian communities and assess changes over time. Results from this study will inform future monitoring efforts, particularly where baiting is infeasible, while maintaining compatibility with established protocols.

Methods

Survey Design

We used a nested sampling design to address species' varying home ranges and detectability. Sampling units were nested within 2 km^2, 4 km^2, and 8 km^2 clusters and distributed throughout the basin. Overall, we sampled 44, 2-km^2 clusters, 25, 4-km^2 clusters, and 13, 8-km^2 clusters. Each deployment consisted of 40 cameras across terrestrial and lentic sites, adhering as closely as possible to the protocols established by MSIM and LTUB. Cameras were rotated across sampling units to ensure comprehensive coverage of the study area.

Camera Placement and Installation

Cameras were installed at designated point count stations, such as Point Count #1 for MSIM and LTUB sites and other specified locations for UPFU and FORR sites. Cameras were positioned within 100 m of the center point and oriented northward to minimize false triggers from sunlight. Features such as game trails, forest openings, and abandoned dirt roads were prioritized to maximize detections. Cameras were installed on live trees at a height of approximately 1.5 m and within 2 m of the intended field of view. In most cases, bait - chicken wrapped in wire - was used to attract animals, though a subset of cameras operated unbaited for 10-14 days before baiting.

Deployment and Maintenance

Three deployments were conducted between July and October 2023:

- Deployment 1: July-August (38 sites: 30 terrestrial, 8 aquatic)
- Deployment 2: August-September (38 sites: 21 terrestrial, 17 aquatic)
- Deployment 3: September-October (16 sites: 14 terrestrial, 2 aquatic)

Each deployment was a minimum of 28 days and generally approximately four weeks in duration. Cameras operated 24/7, capturing three images per detection. Maintenance activities included ad-hoc checks (at least once during the 4-week period) for battery levels and SD card storage, with dates of checks and replacements recorded. Wildlife Insights software was used to process and analyze the images, providing species identification and summary statistics. Photos were tagged by nine individuals, with efforts focused on eliminating blanks and verifying AI-based tags.

Results

Cameras were deployed across 91 sites around the Lake Tahoe Basin in 2023, including the 60 resample points plus additional historical points that filled out a test of hierarchical camera sampling (Appendix F). The 91 sites consisted of 63 terrestrial and 28 aquatic sites. Out of the 91 sites, 28 were on the Eastern side of the Tahoe Basin, ten were on the Northern side, 25 were on the Southern side, and 28 were on the Western side. Sixty-one of the sites were located at low elevations (<7500 ft), and 30 sites were in high elevations (>7500 ft) (see Appendix I).

Across the three deployments, a total of 120,592 images were captured over 2,930 sampling days. Of these, 47,894 images contained wildlife, representing 56 different species. Deployment 1 included 35,310 images, out of which 21,222 were blanks. Deployment 2 included 46,811 images, 18,826 blanks. On average there were 1,325 images per deployment. Across all deployments, we detected 56 species, excluding humans and non-animal objects (Table AF-1). The most common species detected, in decreasing frequency of detection, were chipmunks (*Neotamias* species), golden-mantled ground squirrel (*Callospermophilus lateralis*, 21% of the observations), Douglas's Squirrel (*Tamiasciurus douglasii*, 13.4%), American Black Bear (*Ursus americanus*, 12%), Coyote (*Canis latrans*, 9.6%), California Ground Squirrel (*Otospermophilus beecheyi*, 6.4%), and Steller's Jay (*Cyanocitta stelleri*, 3%) (Figure AF-1). The major Orders observed are Rodentia (69.1%), Carnivora (24%), Passeriformes (4.3%) and Cathartiformes (1.2%) (Figure AF-2).

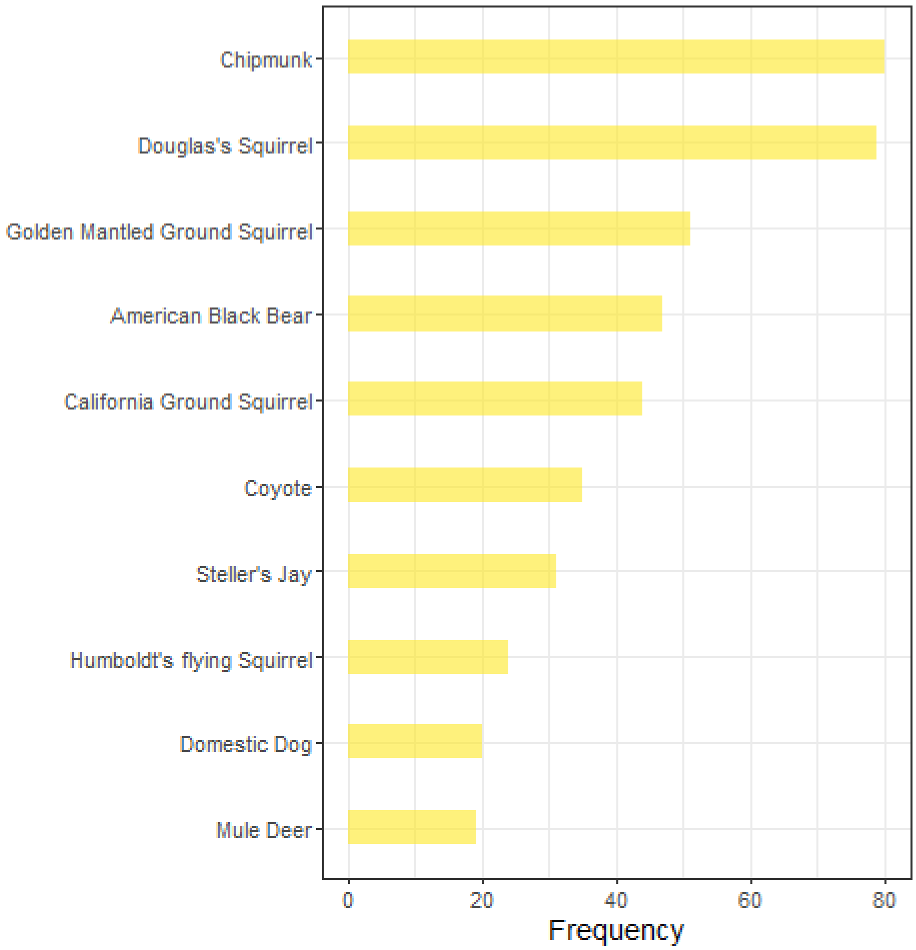

Figure AF-1. The top ten most common animals that were identified to genus in camera surveys conducted at 91 sites across the Lake Tahoe basin in 2023.

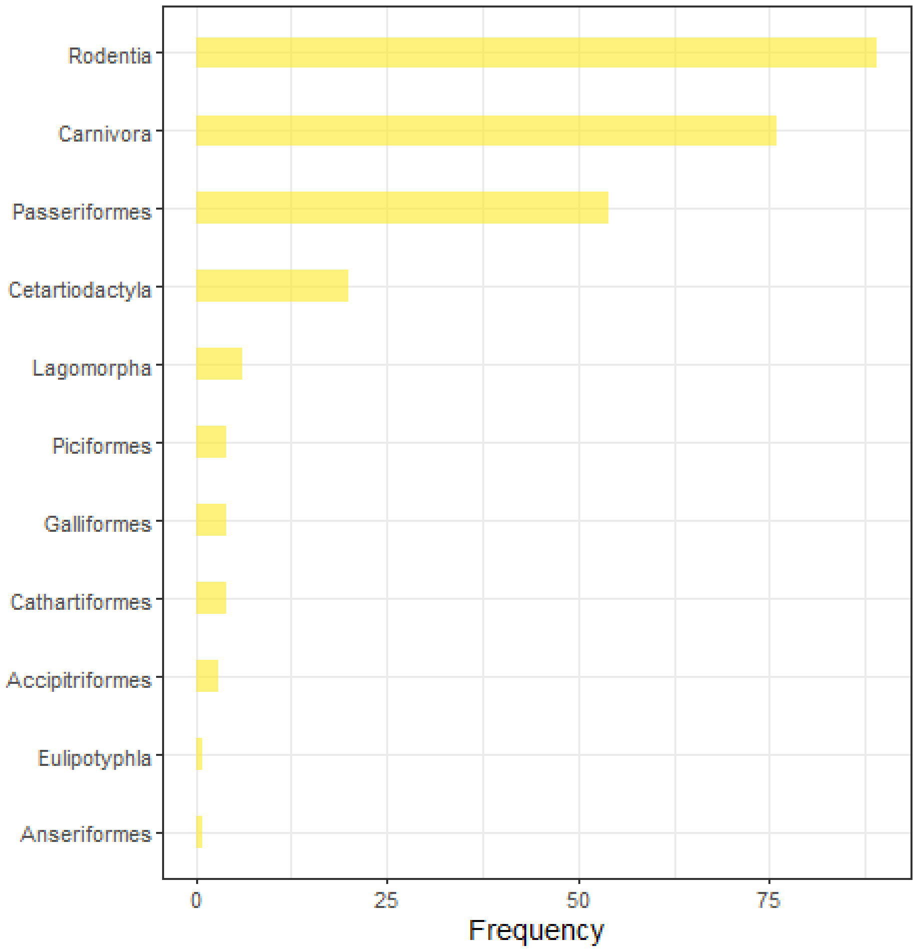

Figure AF-2. The most common taxonomic orders by frequency of sites with detections in camera surveys conducted at 91 sites across the Lake Tahoe basin in 2023.

Table AF-1. Mammals observed in camera surveys at 91 sites across the Lake Tahoe basin in 2023 by observations (number of photographs) and frequency (number of sites with detections).

Common name	observation	frequency
Chipmunk	9248	80
Golden-mantled Ground Squirrel	9016	51
Coyote	7760	35
American Black Bear	6459	47
Douglas's Squirrel	5562	79
California Ground Squirrel	3280	44
Unknown rodent	854	31
Humboldt's flying Squirrel	718	24
Domestic Dog	577	20

Squirrel family	547	60
Northern Raccoon	440	6
Mule Deer	363	19
Western Gray Squirrel	288	13
Bobcat	163	9
Rabbit and Hare Family	116	6
Yellow-bellied Marmot	40	2
Pacific Marten	39	4
Puma	36	1
Bushy-tailed Woodrat	36	7
Snowshoe Hare	32	2
Long-tailed Weasel	31	5
North American Porcupine	26	2
Canine Family	17	5
Weasel Species	18	7
Unknown carnivore	16	10
North Pacific Jumping Mouse	10	1
Skunk Family	7	1
Cat Family	2	1
Domestic Cattle	2	1
Mole and shrew family	2	1

Table AF-2. Birds observed in camera surveys at 91 sites across the Lake Tahoe basin in 2023 by observations (number of photographs) and frequency (number of sites with detections).

Common name	observation	frequency
Steller's Jay	1435	31
turkey vulture	513	4
American robin	141	18
Clark's nutcracker	85	6
common raven	73	1
white-crowned sparrow	58	2
Unknown songbird	57	7
dark-eyed junco	56	7
sooty grouse	26	2
hermit thrush	24	4
fox sparrow	15	3
Corvidae family	11	5
yellow-rumped warbler	11	4
hairy woodpecker	10	1
Canada goose	6	1
unknown thrush	9	1
mountain quail	7	1

house wren	4	1
Macgillivray's warbler	4	1
white-breasted nuthatch	4	1
Empidonax flycatcher	3	1
green-tailed towhee	3	1
mountain chickadee	4	1
northern flicker	3	1
pine grosbeak	3	1
Williamson's sapsucker	3	1
Cassin's vireo	2	1
song sparrow	2	1
accipiter species	2	1
unknown raptor	1	1
orange-crowned warbler	1	1
unknown sparrow	1	1
black-backed grosbeak	1	1
unknown woodpecker	1	1
red-breasted nuthatch	1	1
russet-backed thrush	1	1
white-headed woodpecker	1	1

Recommended Citation

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TEON Appendix G:
Remotely Sensed Environmental Change in the Lake Tahoe Basin from Historical to Present

Patricia Manley, Ryan Conway, Chelsea Andreozzi, and Liraz Bistritz
US Forest Service, Pacific Southwest Research Station
Placerville, CA

July 2025

Introduction

Remotely sensed data are increasingly a high value contribution to, and a complementary to field-based measurements of, condition data for broad-scale monitoring systems. Remotely sensed (satellite) data are freely and reliably available from a wide range of sources, and provide valuable information across 100% of a landscape (the basin, in this case). Satellite sources can vary over time, but there are now institutionalized mechanisms within the US Forest Service and other federal agencies dedicated to acquiring, interpreting, and generating spatial data layers from available satellite imagery. Further, new products are being innovated and made available on a regular basis.

Information on land cover types (e.g., rock, water, vegetation), vegetation cover, some aspects of vegetation condition (e.g., wetness and greenness), and burns (extent and severity) can be derived directly from satellite data, but more commonly satellite imagery is being used in combination with other data sources (e.g., FIA plot data, Lidar data, topographic features, substrate and soil features) to model suites of more detailed metrics across 100% of the landscape using imputation and related spatial modeling techniques. In most cases, the scale of the modeling units are 30-m pixels, but in some cases they can be as small as 3-m pixels (Planet data) or even sub-meter resolution (Lidar data). As such, remotely sensed data, and satellite imagery in particular, form an important building block for many modeled and mapped landscape vegetation and fire monitoring metrics.

One of the unique values of Landsat data is that it provides the opportunity to have an annual snapshot of conditions back to 1985. At present, that is nearly a 40-year time span, and looking backward in time enables scientists and managers to evaluate where and potentially why changes are occurring, and provide insights into potential future changes. In terms of monitoring, long-term data sets are highly valuable and informative, particularly when the methods are consistent.

Methods

We used data from The Center for Ecosystem Climate Solutions (CECS) to evaluate change across the basin over the past 38 years (Goulden et al. 2012, Goulden et al. 2019, Clark et al. 2023). CECS is a team of nearly 50 scientists at 8 research institutions that developed remote sensing and geospatial tools to consistently quantify current conditions and the effects of past and ongoing management on an integrated, statewide scale. This data covers numerous categories of land surface characteristics, including:

- Biomass stocks and carbon dynamics
- Water balance and the delivery of runoff to rivers and groundwater
- Vegetation cover, and management or disturbance history
- Surface fuels and wildfire spread and severity.

CECS provides valuable data on the status and trends of ecological conditions in the Lake Tahoe Basin. This data spans from 1986 to present, allowing users to examine the effects of past management or disturbance. Updated annually, CECS encompasses vegetation cover types, vegetation structure and composition (e.g., late seral class), and water balance and fluxes.

Utilizing four remote sensing layers from CECS, we assessed historical to present changes across the basin in terms of seral stage, water availability, tree vulnerability, and tree cover. CECS data representations were available for every year from 1985 through 2023 in California, but the data were more temporally limited in NV, going back only to 2000 and only in 5-year increments (2000, 2005, 2010, 2015, 2020) and 2023.

Late Seral Forests

Late seral forests are of concern and value in the basin given the important and unique ecosystem properties and services that they support. Historically, late seral forests covered over 50% of the landscape, whereas in the year 2000 estimates were that approximately 5% of the basin remained in late seral forest. There are many different definitions of late seral and old growth forests, each of which reflects aspects of late seral conditions that are relevant to a particular. Our interest in continuous and consistent change over time limited our data source to Landsat data products. We used CECS remotely sensed data to assess changes in late seral stage (diameter at breast height greater than 24 inch) across the Lake Tahoe Basin from 1985 to 2023. Data on seral stage was limited to California, so our summaries are missing the Nevada portion of the basin. The analysis summarized conditions at 5-year intervals examining temporal patterns across multiple scales: the entire basin, by cardinal direction, and across two elevation bands: high elevation (above 7,500 ft; 2273 m) and low elevation (below 7,500 ft).

Tree Cover

The Tree Cover CECS metric represents the percent of the areas that is covered by trees, the values are percent multiplied by 100, such that for example an area with 90% tree cover corresponds to a value of 9000. This metric covers only strata that is visible from above. The metric was mapped using Randon Forest and synthetic Landsat imagery. We used this data to explore the temporal patterns of tree cover across the Tahoe Basin, from 1985 to 2023. Tree cover was aggregated to classes: 10% tree cover increments, and 20% tree cover increments.

Tree Vulnerability to Drought

The tree vulnerability metric measures the vulnerability of tree canopy to severe drought. It is calculated as the product of the CECS Vegetation TreeFrac and Evapotranspiration Fraction metrics. It serves as a relative metric if the risk of tree die-off during severe drought. A low value (5000) indicates progressively greater risk. We used this metric to explore temporal patterns of forest drought vulnerability across the basin.

Water Availability

CECS Annual Water Production (runoff) metric represents the Annual water discharge (surface runoff plus subsurface percolation) predicted for a year with average precipitation. It is calculated as the difference between Actual Evapotranspiration (AET) during the water year, and average precipitation. It assumes no net change in soil moisture content. This metric provides a relative indication of water production based on vegetation density (AET) and mean precipitation, the annual precipitation is held constant and these data do not account for year-to-year differences in precipitation.

We used the Annual Water Production metric to explore temporal patters in water production as mediated by shifts in vegetation, across the Lake Tahoe Basin. Mean water discharge was averaged per HUC12 watershed, for two scale and time stamps: five years intervals from 1985 to 2023 for the California side of the Basin, and for four time stamps: 2000, 2010, 2020 and 2023 for the full Basin.

Results

Late Seral Forests

The definition of late seral used for this analysis was limited to one criterion – average diameter – which does not capture many of the additional characteristics considered as essential to supporting many of the important old forest functions, such as snags, downed woody material, structural complexity, and plant species diversity. As a result, our representation of late seral is likely to be more inclusive and higher than representations with additional criteria.

CECS data show a decline in the proportion of the landscape occupied by late seral forests from 32% to 18% over the past 38 years representing a 41% decline (Fig. AF-1), with low elevation areas (< 7500 ft) experiencing a more rapid decline than high elevation areas (>7500 ft) (Fig. AF-2). At low elevations, the proportion of the landscape in late seral forest in 1986 was 37%, and it showed a fairly steady decline, and dropped 18 percentage points to 19% by 2023, a 49% decline. At high elevations, the proportion of the landscape in 1986 was 25%, and it also showed a more shallow but steady decline over time, dropping 9 percentage points to 16% by 2023, a 36% decline.

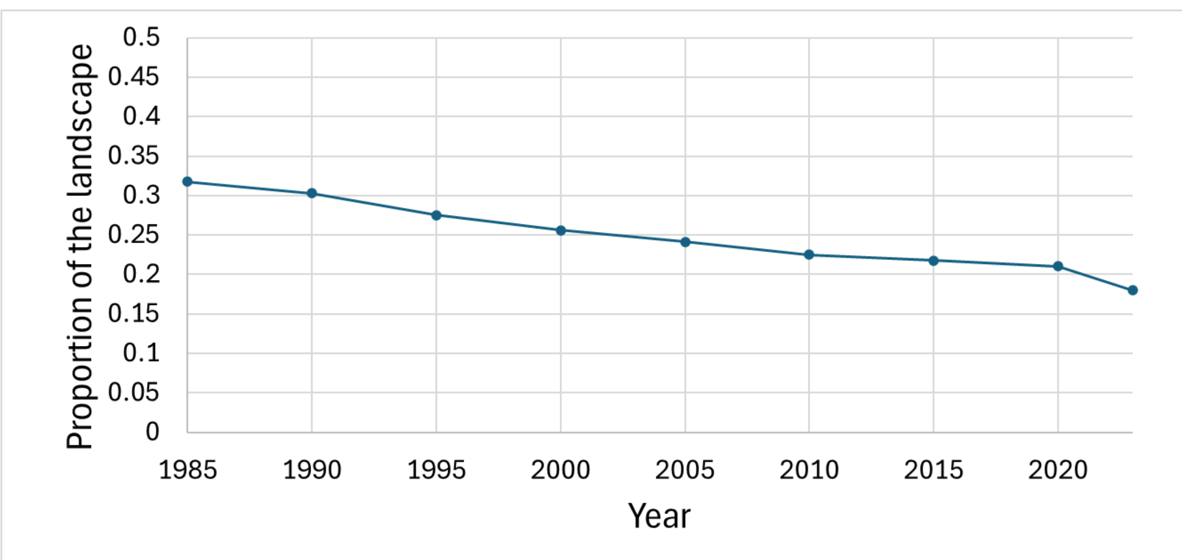

Figure AF-1. Proportion of the Lake Tahoe Basin in late seral stage (>24 inch average tree diameter) from 1986 to 2023 based on CECS data.

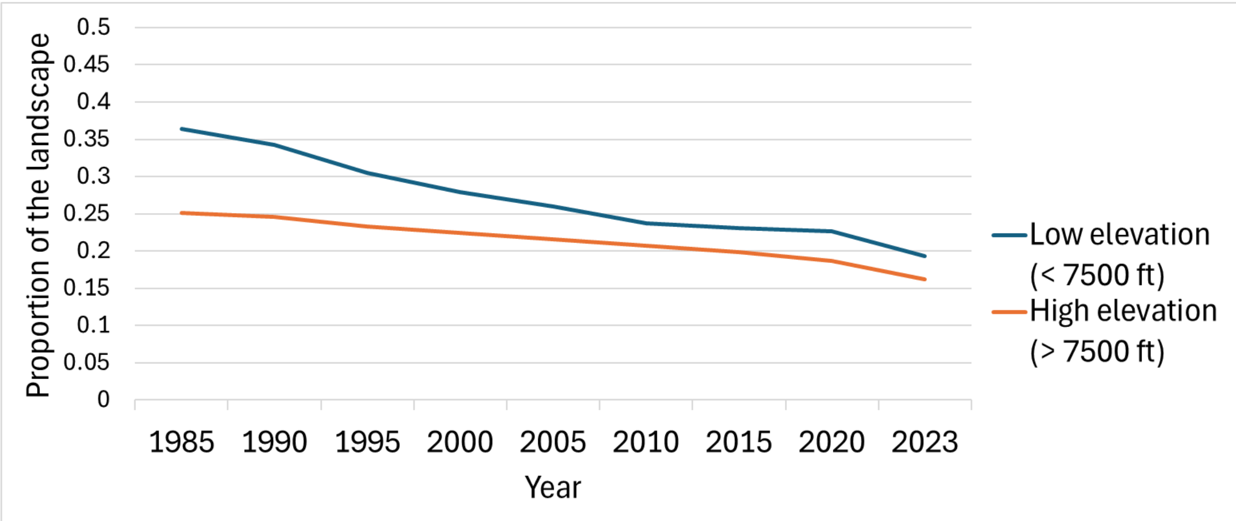

Figure AF-2. Proportion of the Lake Tahoe Basin in late seral stage (> 24 inch average tree diameter) from 1985 to 2023, across two elevation bands: high elevation (above 7,500 ft) and low elevation (below 7,500 ft) based on CECS data.

We also looked at trends in late seral conditions based on location around the California side of the basin (Fig. AF-3). All three aspects of the basin had similar downward trends in the amount of late seral conditions. The north and south sides of the basin started in 1985 with similar proportions of the landscape, with the north having the highest proportion at 41%, followed closely by the south side at 37%, and the west side had the least at 27%. All of the aspects had a decline of > 10%, with the south side of the basin showed the steepest decline (17 percentage points) probably a result of the Caldor Fire in 2021, followed by the north side (13 percentage points), and finally the west (11 percentage points). It is likely that fires in the west and south are the primary source of declines over the past 3 years, but it is less clear what is contributing to the steady decline across the basin to where only the north side of the basin exceeds 20% in late seral conditions.

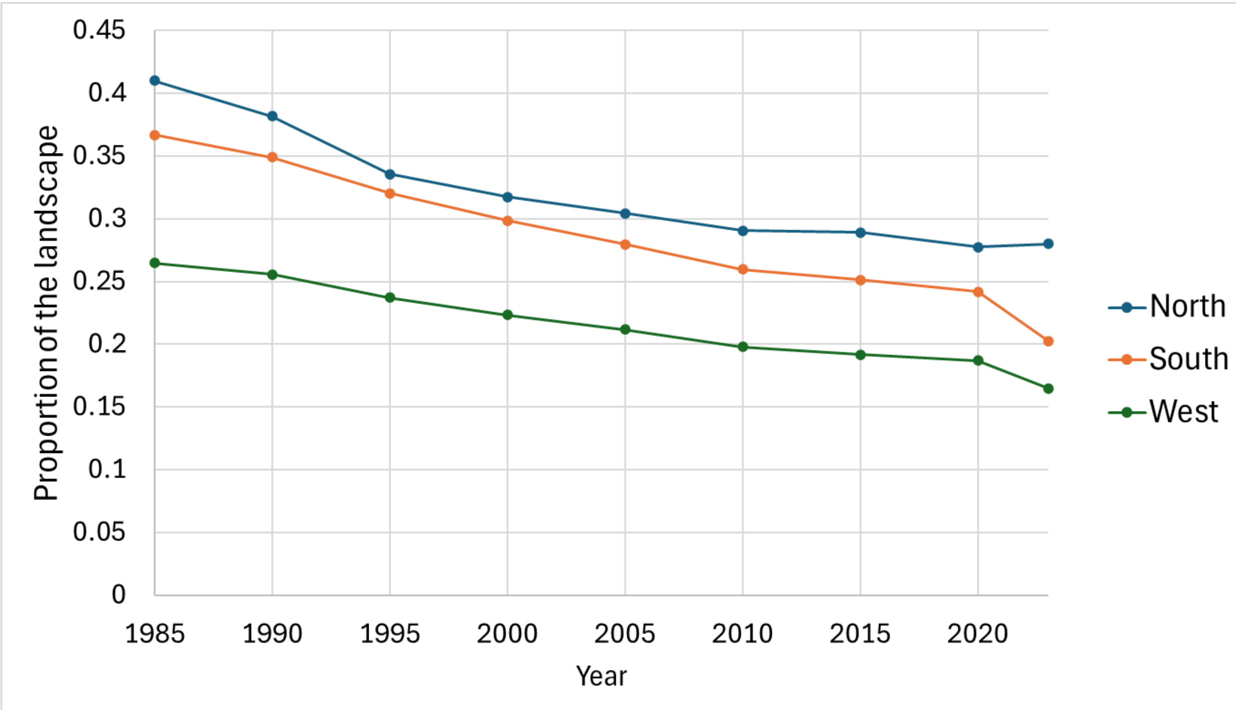

Figure AF-3. Proportion of the Lake Tahoe Basin in late seral stage (> 24 inch average tree diameter) from 1986 to 2023, by cardinal direction based on CECS data.

Tree Cover

The proportion of the California basin in forests with different tree covers is a simple but fundamental metric of landscape change. We found there was variability in the degree of change based on total tree cover. Low tree cover classes (<20%) had intermediate abundance, they were the most variable from year to year, and they experienced a uptick since 2020. The highest tree cover class (90-100%) had the lowest abundance, and experienced a steady increase until 2004, then leveled out, and then showed a slow decline since 2010, with a more marked decline since 2000. The next highest tree cover classes – 70-80% and 80-90% - were the most abundant classes, with the 80-90% class tracking the same temporal pattern as the 90-100% class, and the 70-80% class showing a slow decline over the course of the 38-year time span. All other classes showed little change over time. These results suggest that increases in lower tree cover were likely to be driven by declines in the most abundant and highest tree cover classes 70-90% cover.

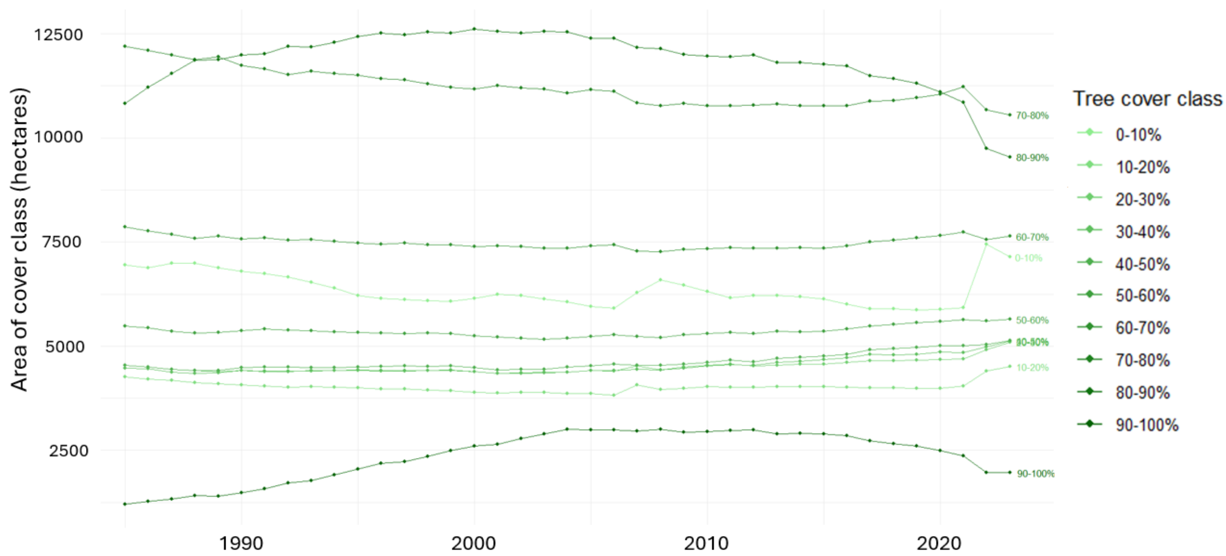

Figure AF-4. Change in area of tree cover classes (10% increments) in Lake Tahoe Basin, California portion of the basin only, in 5-year intervals from 1985 to 2023.

Tree Vulnerability to Drought

We observed variability over time, but no discernable trends in tree vulnerability to drought (Fig. AF-5). Drought vulnerability is a function of the ratio of precipitation (water input) and vegetation water demand (water use). On average, approximately half of all forested areas in basin are vulnerable to drought and have been for over 20 years (since 2000). We can go back further in time for the California portion of the basin (Fig. AF-6), and this longer time period reveals that prior to 2000 (1985-1995), vulnerability was consistently lower than any 5-year time step since that time.

The 38-year time series, although limited to California, suggests that tree drought vulnerability generally has been trending upward, but with substantial temporal variability (Fig. AF-7). Annual data help reveal the timing of events that contribute to overall trends. Trends across the entire basin (including the Nevada side) appear to be in line with trends seen in California alone, but the temporal resolution at 10-year intervals makes it challenging to provide more definitive interpretations about the Nevada side of the basin (Fig. AF-8). Vulnerability is most likely to change as a function of changes in vegetation water use and changes in the 30-year average in precipitation. In the case of the Lake Tahoe basin, it is likely that both factors are contributing to observed trends.

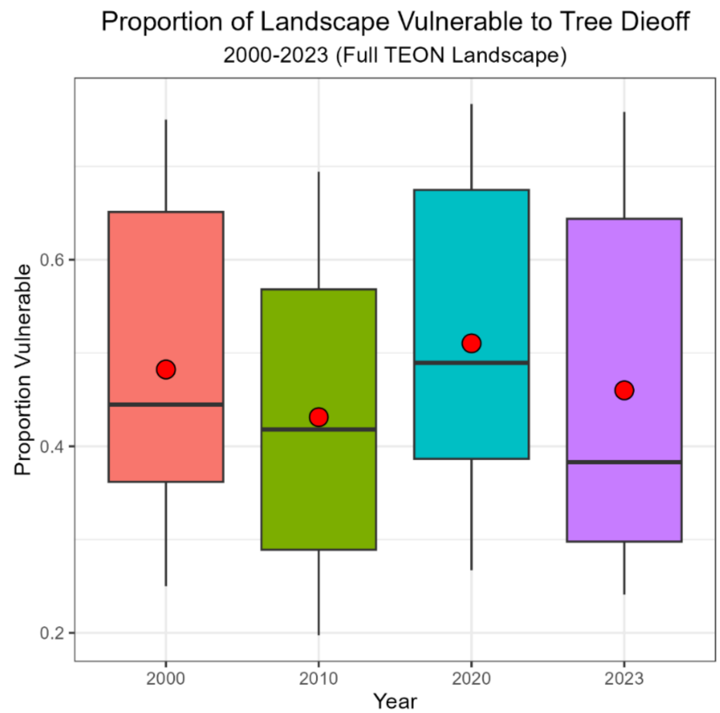

Figure AF-5. Proportion of the landscape vulnerable to tree die-off, full Lake Tahoe basin landscape, for four time steps: 2000, 2010, 2020 and 2023 based on the CECS data.

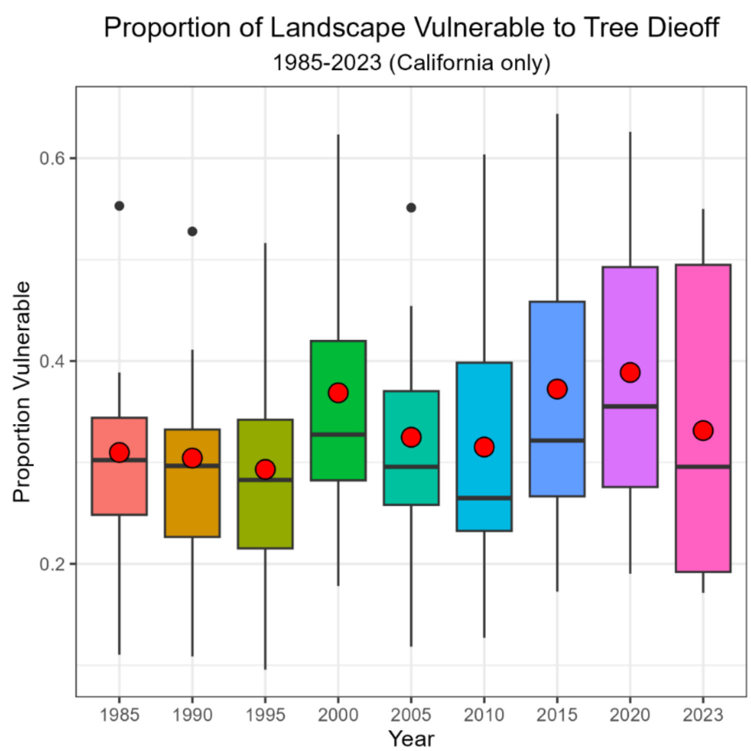

Figure AF-6. Proportion of the landscape vulnerable to tree die-off, California portion of the Lake Tahoe basin only, five years intervals from 1985 to 2023 based on CECS data.

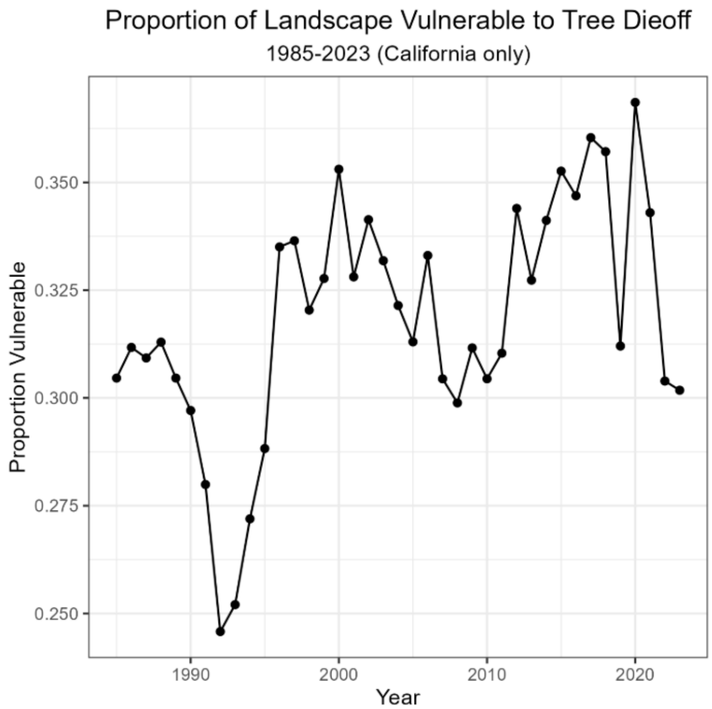

Figure AF-7. Proportion of the landscape vulnerable to tree die-off, California portion of the Lake Tahoe basin only, annual intervals from 1985 to 2023.

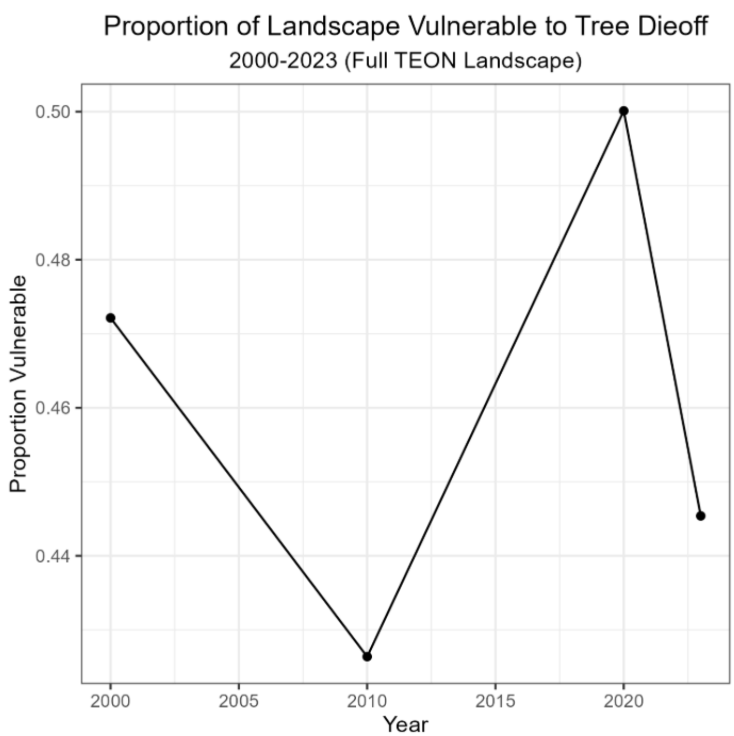

Figure AF-8. Proportion of the landscape vulnerable to tree die-off, entire basin, for four time stamps: 2000, 2010, 2020 and 2023.

Water Availability

Water availability across the California side of the basin showed variability over the past 38 years, even at 5-year time intervals, but generally water availability has declined (Fig. AF-9). Dips in water availability were pronounced at the 2015 and 2020 time steps, reflecting the severe drought conditions that prevailed during that time period. The year 2000 was also reflected low water availability but slightly better than the 2015 and 2020 time periods. Conditions across the entire basin reflect a similar pattern of decline (Fig. AF-10).

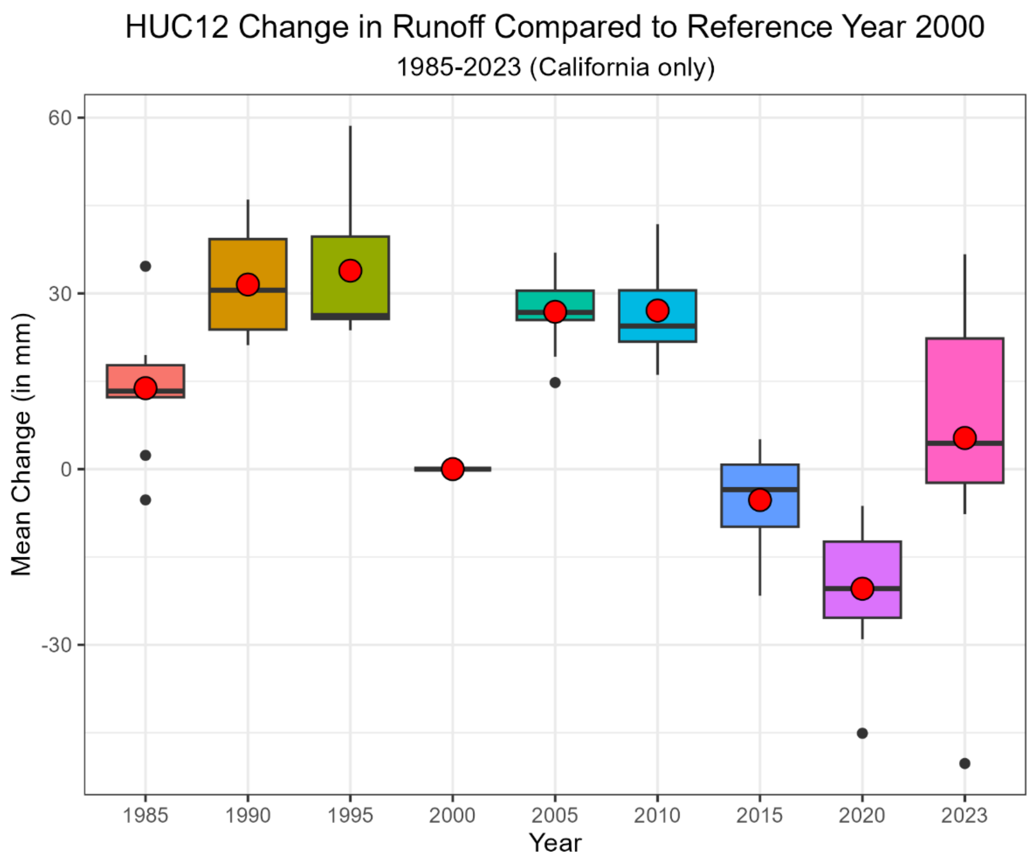

Figure AF-9. HUC12 change in runoff compared to reference year 2000, California portion of the Lake Tahoe basin, five years intervals from 1985 to 2023.

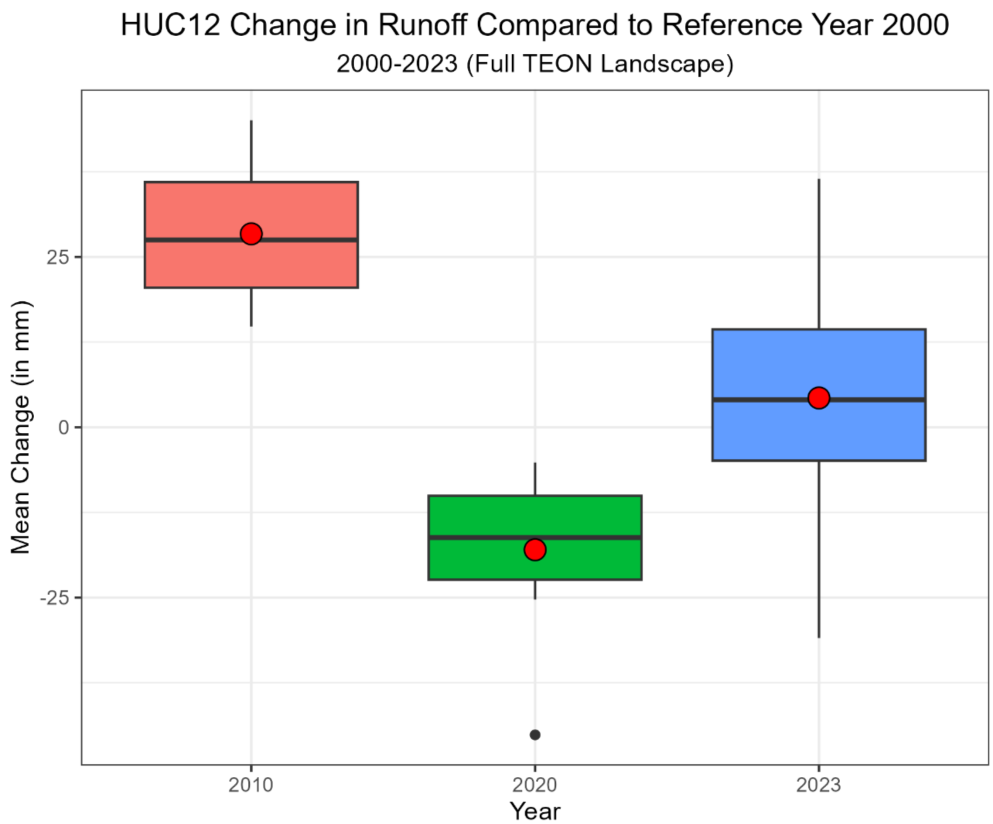

Figure AF-10. HUC12 change in water runoff compared to reference year 2000, Lake Tahoe basin, for three time stamps: 2010, 2020 and 2023.

Recommended Citation

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TEON Appendix H: Sentinel Watershed Monitoring Approach for the Lake Tahoe Basin

Scott Allen, Joanna Blaszczak, Sudeep Chandra, Adrian Harpold, and Emily Burt
University of Nevada, Reno

July 2025

Introduction

This report discusses the development of a sentinel watershed monitoring plan through synthesis of existing information and field testing. The main goal of this effort is to set up a demonstration project to that informs the design and monitoring of Lake Tahoe's watershed from land to streams including important climate variables and initiate a pilot project to test the utility of novel tools (e.g., environmental DNA in measuring biodiversity). Lessons from the demonstration efforts are utilized to make recommendations related to the development of a monitoring network that can be accessible to a diverse set of constituents including management agencies and the general public.

The demonstration project, focused on two watersheds that have contrasting climate and occur in two different state jurisdictions, Blackwood Creek (CA) and Glenbrook Creek (NV), with additional testing in Incline Creek (NV). Two questions focused on understanding discrete climate-to-watershed-to-stream processes guided the implementation of the development project:

1. How do precipitation gradients and movement of water change tree water stress across forested hillslopes in Tahoe watersheds with wetter and drier climates?
2. What internal processes and watershed characteristics are responsible for changing the linkages from the land to stream water quality entering Lake Tahoe?

Surprisingly, given the focus on protecting Lake Tahoe, this is one of few efforts to create a near-real time, monitoring network that quantifies the connections between climate-to-land and land-to-stream/lake processes. This is needed to inform how management actions and ecological changes influence Lake Tahoe's water quality and clarity along with the biodiversity and function within the greater Lake Tahoe basin.

Sentinel Watershed Selection

Overall Sentinel Watershed Approach and Priorities

The sentinel watershed approach for the demonstration project is to select a subset of basins within the broader Lake Tahoe basin that allows for studying key linkages and processes that can be measured: across climate to land, and then to streams exporting materials and nutrients into Lake Tahoe. The approach utilized the Tahoe Science Council's Action Planning documents (tahoesciencecouncil.org) to help guide the generation of key parameters and data types that could be important for understanding the linkages across these areas. In the selection of sentinel watersheds, considerations are given to a few key factors (Table AH-1):

1) Existing instrumentation and the quality of the data with existing "off the shelf" instrumentation,
2) Complementarity among watersheds to enhance representation,
3) Permission to install and access instrumentation,
4) Year-round accessibility and feasible access,
5) Ability to access power for sensors and communications for data transfer to a central data repository.

Table AH-1. Lake Tahoe sub-basins that were considering during the demonstration project which also have stream monitoring gauges at the basin outflows supported by the US Geological Survey (USGS) or additional resources to USGS provided by the University of Nevada, Reno.

Watersheds	State	Upland Summer Accessibility	Upland Winter Accessibility
Glenbrook	NV	Yes	Moderate (from Rt 50)
Incline	NV	Yes	Yes (from NV 431)
Third	NV	Yes	Yes (from NV 431)
Ward	CA	Limited	Limited
Blackwood	CA	Limited*	Limited*
General	CA	Limited	Limited
Upper Truckee	CA	Yes	Moderate (from Rt 50 and Rt 89)
Trout	CA	Limited	Limited

*proximity to Homewood Resort provides a means of facilitated access in winter and summer

Further considerations related to climate (wetter west shore versus drier east shore) and elevation (gradient and similar elevation) so comparisons can be readily made within and across the watersheds. Given the breadth of landownerships and management structure within the greater Lake Tahoe basin, the diverse set of watershed considerations, and funding outlook and need to coordinate and support a network across geopolitical boundaries, we had a number of considerations that influenced the selection of watersheds for this demonstration project.

1. Collocation of sites on land with existing hydrologic records.

If we are going to understanding linkages across climate to land and then stream to lake, as outlined by the Tahoe Bi-state Science Council in their Tahoe Science Action Plans (tahoesciencecouncil.org), then building a network that utilizes the existing Lake Tahoe Interagency Monitoring Plan (LTIMP) streams is key to the development of watershed models (e.g., loads of nutrients or matter to the lake), perturbation, or trend analysis. We considered sentinel selection with USGS gauge stations that are part of the LTIMP network. These streams are often at the outflow of sub-basins so future measurements should consider the cocreation and development of sites in the middle to upper subbasins.

2. Complementarity among the chosen watersheds while avoid redundancy.

One of the most prominent sources of variation in the basin is the differing precipitation inputs between the east-side versus west-side. The west-side receives substantially more precipitation, justifying the need to select both an eastern and western watershed. To isolate this effect, ideally watersheds would be similar with respect to other traits, especially ones that control precipitation input amounts (elevation) and snowmelt timing (North versus South aspects). Another consideration in site locations is to fill in gaps of other monitoring networks, towards maximizing complementarity and avoiding redundancy. The primary other network collecting similar data is SNOTEL (Figure AH-1). Elevations of those SNOTEL sites is provided in Table AH-2, showing that there is a deficit of sites on the east side of Lake Tahoe in general, but especially at low-to-mid elevations.

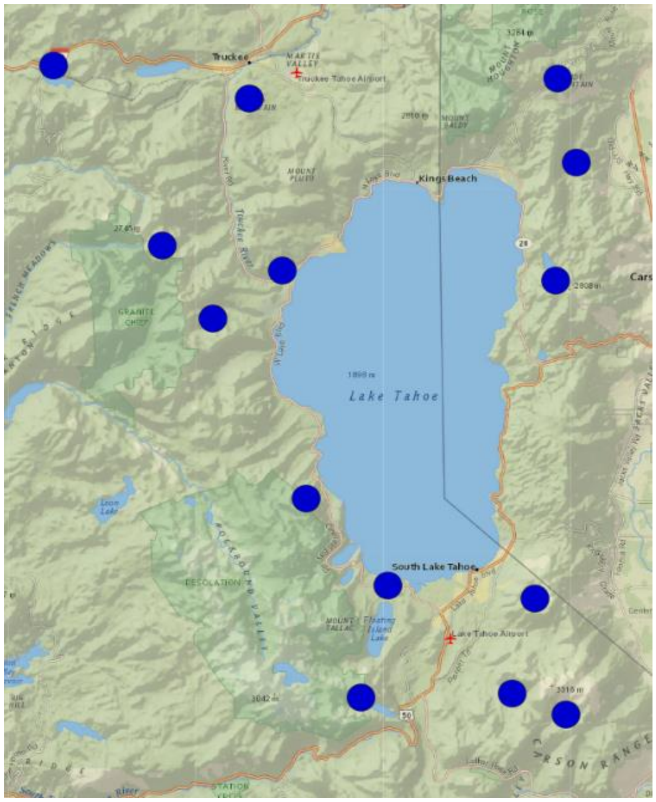


Figure AH-1. Map of SNOTEL stations, as of Jan 12,2025; accessed on https://nwcc-apps.sc.egov.usda.gov/

1. Permission to place sensors including communications and power at a location.

The upper basin of the watershed is managed by the US Forest Service Lake Tahoe Basin Management Unit. Obtaining permission to deploy instrumentation across federally managed or states lands can involve a multistep and time-consuming process that are not often considered in funding allocations for these efforts. While were able to obtain "temporary" permission for this implementation project through cooperation from US Forest service supported research scientists, developing long-term solutions for permitting the sensors will require a sustained and committed federal agency staff and funding to scientists to codevelop the placement and permissions required for a monitoring network. Discussion with others running monitoring networks has emphasized that a 30-year permit is the starting point for building a monitoring network. Use of private property has the potential to bypass lengthy permit processes, but exploration of this option has yielded varied success.

Table AH-2. Details on existing SNOTEL sites which provide an opportunity to inform climatic conditions within the Lake Tahoe watershed and across the region.

Site	Start Date	Latitude	Longitude	Elevation (ft)
Burnside Lake (1051)	2003-October	38.72	-119.89	8180
Horse Meadow (1050)	2003-October	38.84	-119.89	8580
Echo Peak (463)	1980-October	38.85	-120.08	7650
Hagans Meadow (508)	1978-October	38.85	-119.94	7740
Heavenly Valley (518)	1978-October	38.92	-119.92	8540
Fallen Leaf (473)	1979-October	38.93	-120.05	6250
Rubicon #2 (724)	1980-October	39	-120.13	7570
Ward Creek #3 (848)	1979-October	39.14	-120.22	6750
Marlette Lake (615)	1978-October	39.16	-119.9	7860
Tahoe City Cross (809)	1980-October	39.17	-120.15	6760
Palisades Tahoe (784)	1979-October	39.19	-120.27	8010
Little Valley (1242)	2013-October	39.25	-119.88	6500
Truckee #2 (834)	1980-October	39.3	-120.18	6500
Mt Rose Ski Area (652)	1980-October	39.32	-119.89	8810
Css Lab (428)	1980-October	39.33	-120.37	6880
Independence Lake (541)	1978-October	39.43	-120.31	8340
Independence Camp (539)	1978-October	39.45	-120.29	6970
Big Meadow (340)	1983-October	39.45	-119.94	8240
Independence Creek (540)	1980-October	39.49	-120.28	6440

2. Year-round accessibility.

A monitoring network should capture event driven and ecologically relevant conditions that allow for an understanding of environmental changes across and within the watersheds. While the sensors deployed on land and water gather information at high frequency in time, year-round accessibility is key to a) maintaining the sensor systems, and b) to complement the snapshot, manual sampling of creeks and snowpack which is needed to collect specific parameters that can assist in the interpretation of data collections that is not possible through “off the shelf” sensors. Thus, where possible, proximity to maintained roads or trail networks is crucial (Table AH-1). The US Forest Service has an extensive network of roads that are useful in the drier summer to fall conditions (with exception of the West-side watersheds, Ward, Blackwood, and General). Winter access is limited along many roads thus additional design considerations related to sensor maintenance and development need to considered or alternative transportation methods and investments (e.g., ski, snow cat) should be considered.

3. Sensor, power and communications.

While most sensors used in this effort are "off the shelf" they have been packaged and developed to communicate data in near real time which required connections to a network (e.g., cell, radio). Using existing sensors and packaging together allows for a costs savings related to the development of sensors. The package of sensors requires power to support the instrumentation. We considered the placement of sensors based on their ability to communicate to a network, but not all locations have communications access. Placement of sensors near existing power sources could reduce the footprint of the sensor packages while minimizing the cost of the network infrastructure and maintenance.

Selection of Blackwood and Glenbrook as Sentinel Watersheds

Blackwood Creek and Glenbrook Creek were selected as the initial sentinel watersheds for this demonstration project to determine the efficacy and possibilities for creating a Tahoe Environmental Observatory Network. In addition to consideration of the factors listed above, there were several key attributes that established them as ideal candidates.

- Blackwood Creek and Glenbrook are not dominated by lakes, to minimize water residence times and more directly observe climate-stream and upland-stream linkages.
- Elevations and relative levels of development are similar between Glenbrook and Blackwood (Table AH-3), which is untrue of other East-shore watersheds: Third creek is almost 22% developed and has a max elevation of 3150m and mean elevation of 2508 m, and Incline is 15% developed with a max elevation of 2804 m and mean elevation of 2358 m.
- A history of research at Blackwood and Glenbrook watersheds facilitates understanding challenges and expectations, to optimize sensing and measurement approaches (see section 3.3)

Incline Creek was also identified as a potential candidate because of expected administrative ease using University of Nevada, Reno Lake Tahoe campus. The campus also allows for availability of line power which is of major benefit for reliable sensor installations. A limitation of this site is that soil moisture and tree water status are influenced by irrigation; these factors are likely to indirectly influence air temperature and humidity as well. While climate and upland measurements are currently underway at the

University's Lake Tahoe campus. We are continuing to evaluate the value of a single climate station at UNR-Tahoe, putting effort towards developing an Incline transect, or re-allocating the instrumentation to other sites.

Table AH-3. Watershed characteristics of basins defined by locations of sensor stations.

Metric	Glenbrook 1	Glenbrook 2	Blackwood 1	Blackwood 2
Location	East	East	West	West
Total stream length (km)	6.1	4.7	21.0	18.6
Annual precip (cm)	60.8	60.8	143.4	143.4
Mean Elevation (m)	2249	2287	2214	2244
Min Elevation (m)	1902	1973	1899	1932
Max Elevation (m)	2687	2687	2686	2686
Mean Slope (%)	28.8	28.0	31.8	32.8
Area (km2)	10.4	8.7	29.7	25.6
Percent forest	85	88	74	73
Percent wetland	< 1	0	1	1
Percent shrubland	11	9	23	25
Percent developed	4	3	2	<1

Selection of Sample Sites within Sentinel Watersheds: Blackwood and Glenbrook

The goal in instrumenting each watershed is to establish a transect that span from outlet to ridge, with aquatic sensor stations at the outlet and up gradient. Terrestrial sensors are paired to aquatic sensors in riparian areas and also in uplands at higher elevations. Having a pair of aquatic sensors (upper and lower) allows for isolating the lower reaches of these streams to identify changes due to in-stream nutrient processes as well as the greater development along the lower riparian areas (although it should be noted that development is minimal for both of Glenbrook and Blackwood watersheds). We piloted this approach for both Glenbrook and Blackwood (Table AH-4).

First, we have leveraged the already established USGS stations and measurements already underway (defining the Glenbrook 1 and Blackwood 1 sites) by the Lake Tahoe Improvement Monitoring Program (LTIMP). We are collaborating to increase the suite of aquatic measurements underway, which was evaluated as a cost-saving measure. Glenbrook is instrumented with four stations that closely match the intended ridge-to-lake concept. Two riparian stations (climate, forest, and aquatic measurements) are at 1909 m and 1985 m elevation, and two upland stations are at 2309 m and 2422 m elevation (climate and forest measurements). The lowest site is on private property, and the other three are on National Forest lands. Permission was provided for a third intermediate-elevation site, but we concluded that steepness and thick vegetation made it infeasible to install a station without substantial modifications to the site.

Table AH-4. Established sensor stations in Blackwood and Glenbrook sentinel watersheds.

Site Name	Site Coordinates (approx.)	Elev. (m, approx.)	Terrestrial sensors	Stream sensors	Data Telemetry
Blackwood 1	39° 06'26.67"N, 120° 09'43.69"W	1906	USGS gauging site, no additional sensors added		N/A
Blackwood 2	39°06'40.2" N, 120°11'12.8" W	1938	2 soil moisture sensors; 1 air temp/RH sensor; 8 tree dendrometers; 1 heated rainfall/snowfall gauge	Stream level logger; Aqua Troll 400 multiparameter geochemical sonde	No cell signal - other data telemetry options needed
Glenbrook 1	39° 05'17.00"N, 119°56'20.73"W	1909	2 soil moisture sensors; 1 air temp/RH sensor	N/A	Cellular data telemetry
Glenbrook 2	39°05'09.2"N, 119°55'19.3"W	1985	Installation not yet begun	Installation not yet begun	Installation not yet begun
Glenbrook 3	39°05'14.1"N, 119°54'36.8"W	2081	Proposed site determined to be inaccessible; monitoring will not be carried out here		
Glenbrook 4	39°05'36.4"N, 119°54'05.4"W	2309	2 soil moisture sensors; 1 air temp/RH sensor	N/A	Cellular data telemetry
Glenbrook 5	39°04'28.7"N, 119°53'28.5"W	2422	2 soil moisture sensors; 1 air temp/RH sensor	N/A	Cellular data telemetry
Incline– UNR Tahoe Campus	39°14'35.03"N, 119°56'25.21"W	1924	1 soil moisture sensor; 1 air temp/RH sensor	N/A	Cellular data telemetry

In addition to the USGS Blackwood 1 site, we have also instrumented another riparian site: Blackwood 2. However, upland Blackwood sites were deemed unrealistic because they could not be maintained in winter, due to the lack of roads into backcountry areas. However, logistical challenges could be circumvented by establishing upland stations outside of the topographic watershed boundaries, without losing representativeness of that watershed. We are exploring possibilities of leveraging adjacent resort infrastructure for winter access as a practical cost-saving option.

One limitation with our current design is that forest and climate sensors are located in riparian zones at lower elevations and on hillslopes in higher elevations. Thus, the comparison of climate data is not solely capturing elevation differences but also hillslope versus riparian-zone differences, which could have important implications for interpreting temperature and humidity data, as well as soil moisture and tree stress.

Quantitative Hydrologic Modeling

Snowpack Observations

We used a subset of recently collected SWE observations from the Airborne Snow Observatory Inc. to better understand snow (and precipitation) distributions and validate the hydrologic model (see section below). The comparison between the SNOTEL and the ASO 50-m SWE product helps to illustrate the challenges of resolving spatial snow information. In general, the ASO product matches the patterns of the SNOTEL observations showing higher SWE at Echo Peak and Ward Creek and lower SWE at Truckee #2 and Independence Creek stations (Table AH-5). However, there are discrepancies that are primarily due to scale mismatches between 4-m^2 snow pillows used by NRCS and the 250 m^2 ASO product, as well as errors in the lidar-derived product, that are evident in the ASO product estimate only 60-75% of the SWE measured at the SNOTEL. These discrepancies are why lidar-derived snow paths have gained favor for mapping watershed-scale snowpack distributions (Figure AH-2).

We use a dry year (2022) and a wet year (2023) to consider how snowpacks vary across watersheds in the Tahoe Basin (Figure AH-3; Table AH-6). We focus on six watersheds that are gauged by the USGS as well as an additional eight watersheds that have been gauged in the past. The results show the wide distribution of average SWE and total water yield (volume of SWE in ac-ft) across the basins and between the two watersheds. Generally, there is about 3.5 times more SWE in 2023 than in 2022 (Figure AH-4). The average and volume of SWE varies dramatically, with Glenbrook having the lowest values in 2022 and Blackwood Creek have the highest SWE.

Table AH-5. Comparison of SNOTEL snow water equivalent observations to lidar-based estimates from ASO at the sites with the Tahoe Basin.

Site	ASO April 2022 SWE (m)	SNOTEL April 2022 SWE (m)	ASO May 2023 SWE (m)	SNOTEL May 2023 SWE (m)
Echo Peak (463)	0.05	0.31	1.12	1.71
Hagans Meadow (508)	0.04	0.00	0.47	0.80
Heavenly Valley (518)	0.14	0.15	1.01	1.12
Fallen Leaf (473)	Missing	Missing	Missing	Missing
Rubicon #2 (724)	0.26	0.27	1.15	1.37
Ward Creek #3 (848)	0.30	0.32	0.99	1.45
Marlette Lake (615)	0.10	0.31	0.79	1.06
Tahoe City Cross (809)	0.05	0.00	0.41	0.31
Palisades Tahoe (784)	0.16	0.24	1.12	1.52
Truckee #2 (834)	0.00	0.00	0.18	0.33
Independence Lake (541)	0.53	0.85	1.62	2.00
Independence Camp (539)	0.00	0.05	0.62	0.81
Independence Creek (540)	0.00	0.00	0.07	0.19

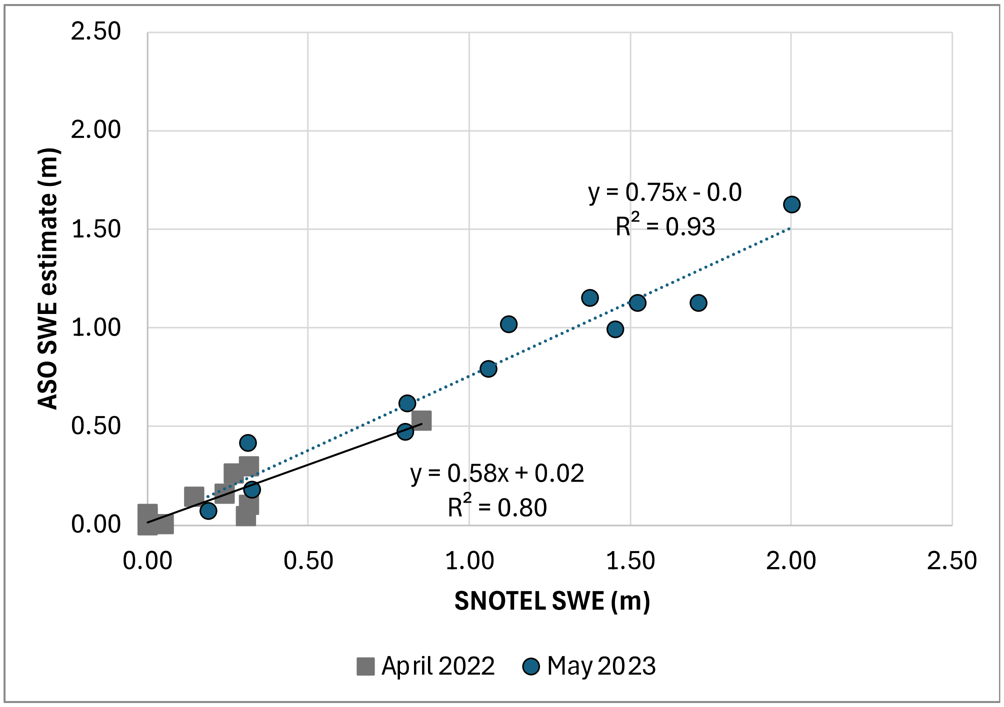


Figure AH-2. Comparison between SNOTEL and ASO at locations in the basin for the dry (2022) and wet (2023) snowpack.

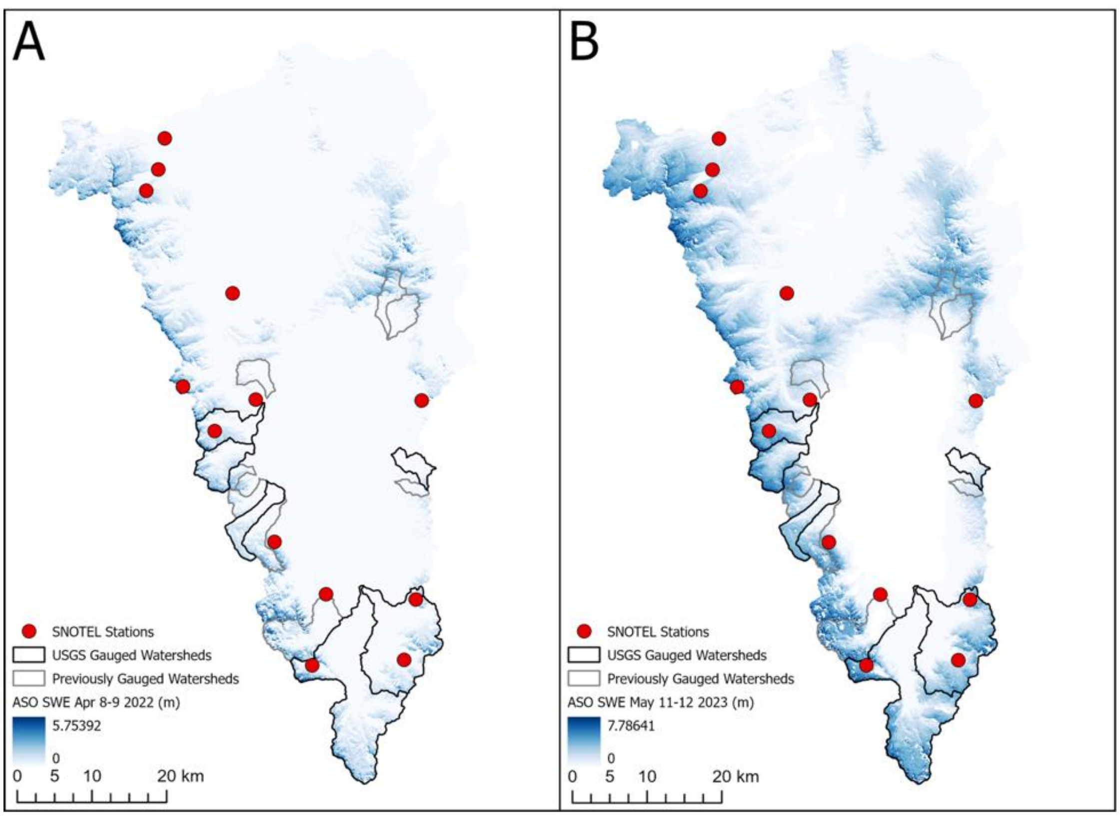


Figure AH-3. Spatial maps of ASO SWE product from a dry year in 2022 (A) and a wet year in 2023 (B).

Table AH-6. Estimates of SWE and water yield derived from two ASO data collections.

USGS Gauged Sites	ASO April 2022 SWE (m)	ASO April 2022 water yield (ac-ft)	ASO May 2023 SWE (m)	ASO May 2023 water yield (ac-ft)
Blackwood Creek	0.275	670	1.222	2970
General Creek	0.152	288	0.745	1412
Ward Creek	0.224	602	1.000	2691
Upper Truckee Creek	0.172	2041	0.771	9148
Trout Creek	0.130	1126	0.654	5669
Glenbrook Creek	0.047	49	0.257	271
Previously gauged sites				
Third Creek	0.269	340	1.000	1265
Incline Creek	0.098	138	0.574	808
Meeks Creek	0.216	397	0.906	1665
Taylor Creek	0.219	225	0.997	1022
McKinney Creek	0.129	163	0.849	1074
Burton Creek	0.054	64	0.550	658
Madden Creek	0.323	153	1.380	656
Logan House Creek	0.073	33	0.485	220

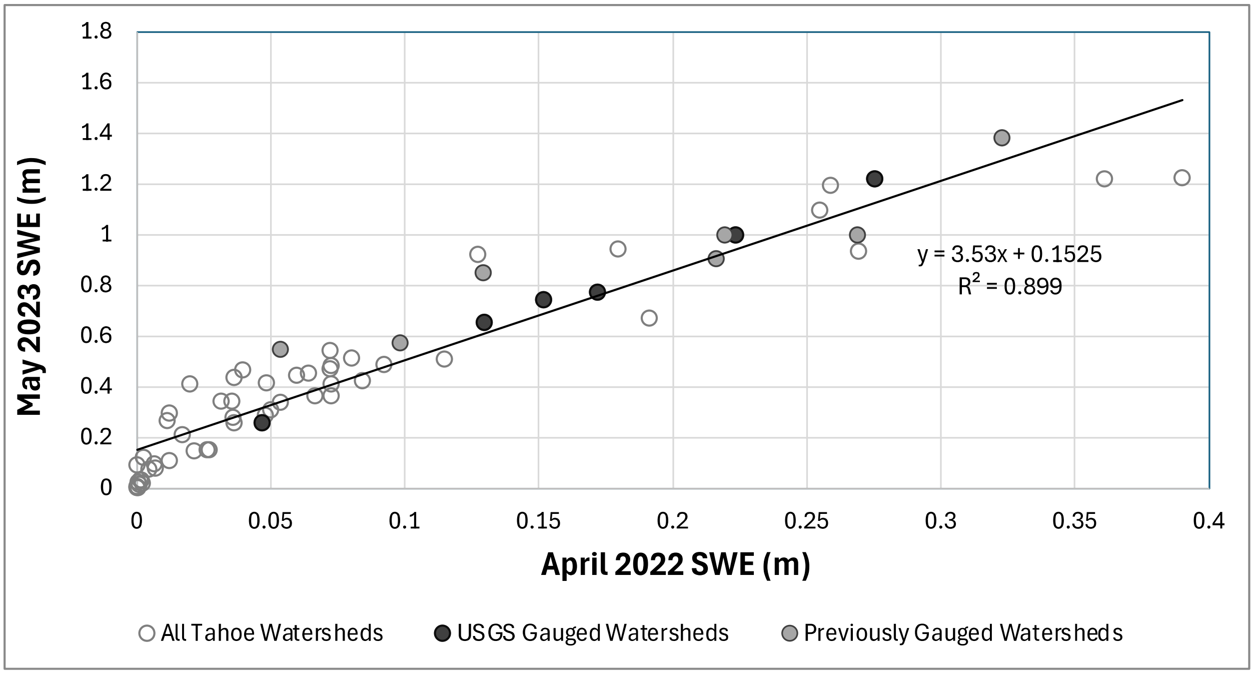


Figure AH-4. Comparison between wet (2023) versus dry year (2022) SWE across all Tahoe watersheds

Hydrologic Modeling

Hydrological modeling is an imperfect way to simulate water storage and movement at catchment-scales that are not possible to observe directly. In this study, we used hydrological modeling with the DHSVM model (Wigmosta et al., 1995) to quantify water budgets under climate change (with no change in vegetation cover). This modeling was part of work done as part of a USFS project to investigate forest restoration in the Tahoe Central Sierra Initiative (TCSI).

The modeling results generally match the historical streamflow observations, showing large variability in water yields across six gauged watersheds (Figure AH-5). The value of hydrological modeling however, is to extend beyond our observations by simulating different future climate scenarios: a wetter future climate (CNRM) and a drier future climate (MIROC). Under the wetter future climate scenario, we generally observe increases in water yield (Figure AH-5) but little changes in low flows (Figure AH-6). Conversely, under a drier future climate we also observe broad increases in water yield (Figure AH-5), but focused in the East-side watersheds, and small decreases in summer low flows (Figure AH-6). These modeling results help to show that the selection of Blackwood and Glenbrook Creeks as the initial sentinel watersheds capture the two predominant watershed responses to future climate: 1) small increases in future water yields, and moderate changes to peak and low flows in the west-side watersheds (i.e., Blackwood Creek) and 2) larger increases in future water yields, peak flows, and low flows in the east-side watersheds (i.e., Glenbrook C reeks).

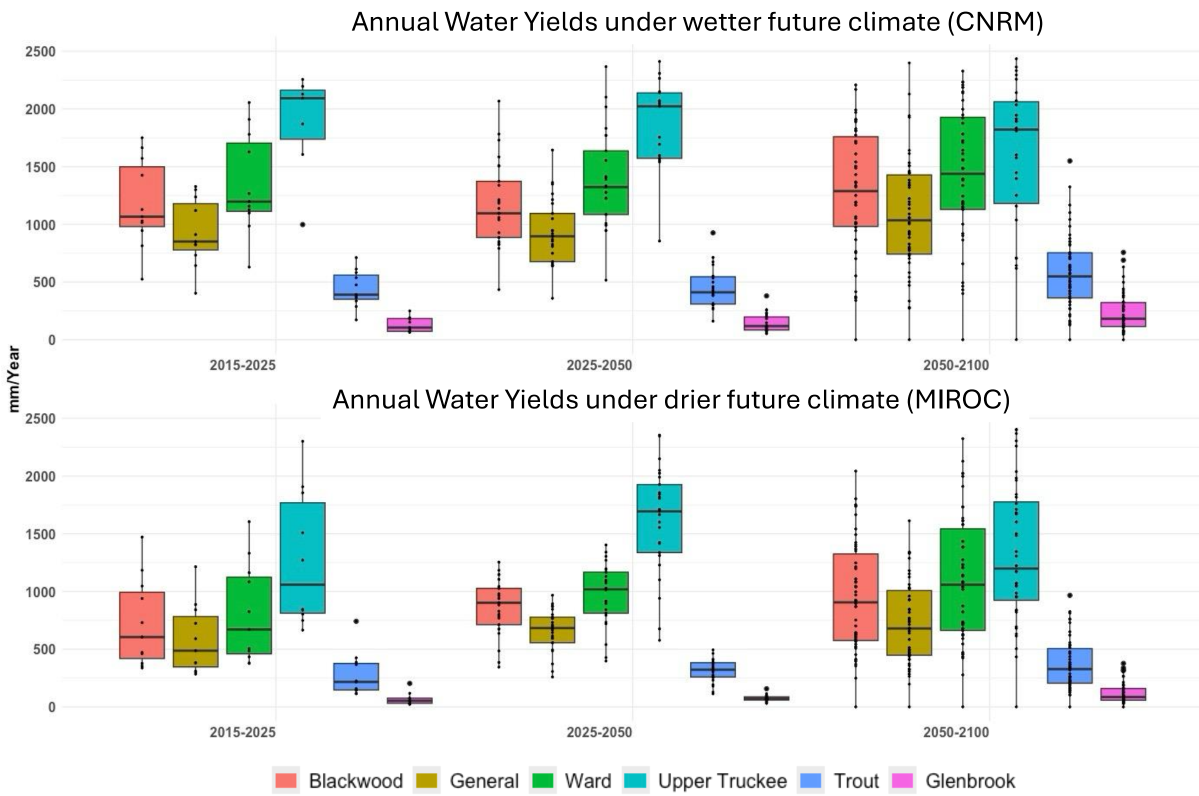


Figure AH-5 Annual water yields in six Tahoe tributaries as predicted by DHSVM in wetter (top) and drier (bottom) future climates, in 2015-2025 (left)/, 2025-2050 (middle column), and 2050-2100 (right).

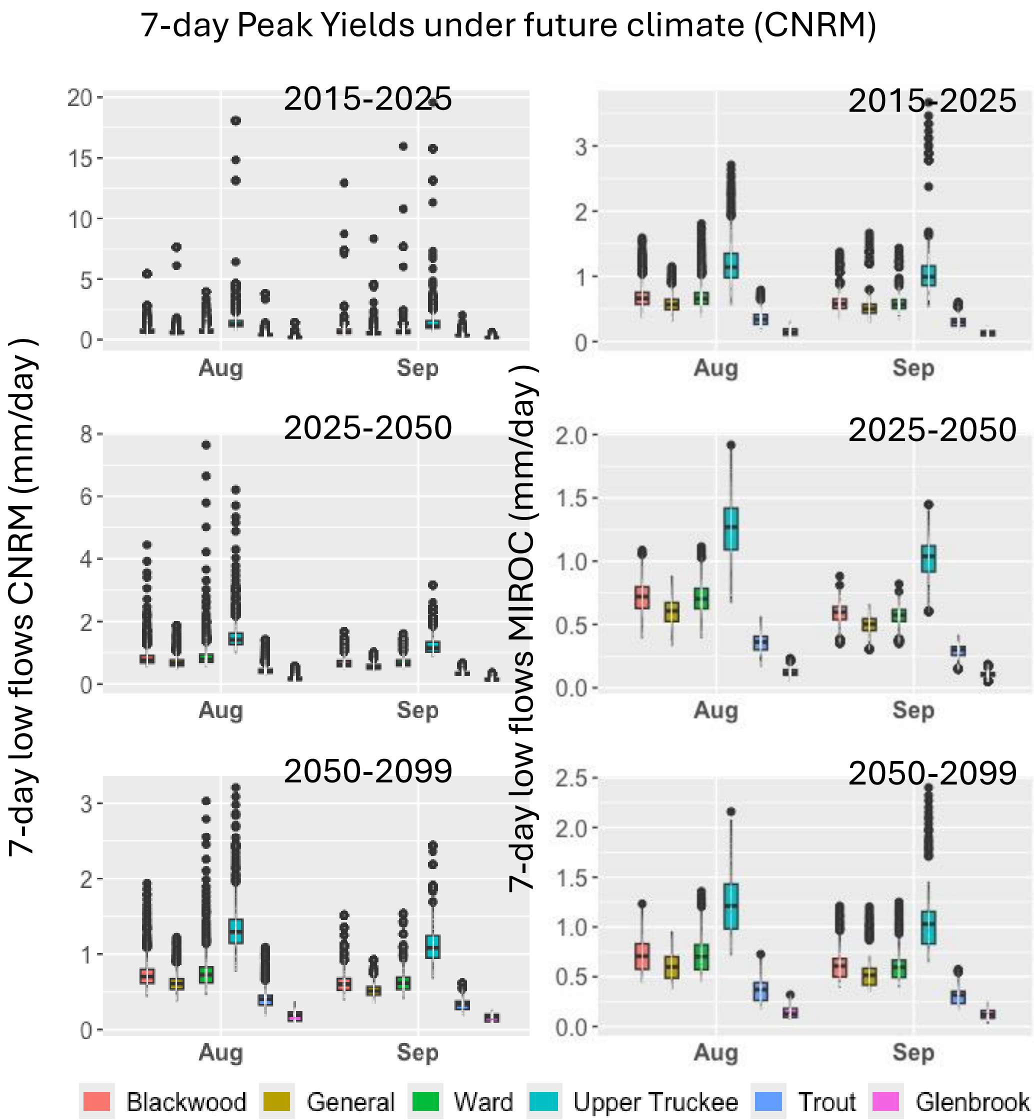


Figure AH-6. Simulations from the DHSVM model for low-flow months at the six USGS gauged watersheds for historical, and mid and later 21st century with the wet (CNRM) GCM projections in the left columns and the drier projections from the Model for Interdisciplinary Research on Climate (MIROC) on the right.

Watershed Experiments to Inform Sampling Approaches

Metabolism, tracers, nutrient spiraling

A suite of field measurements and analyses were conducted to determine which in-stream monitoring and manual sampling protocols would be most likely to yield useful information. Prior to and during the funded work, we monitored stream reaches at paired locations in both Glenbrook Creek and Blackwood Creek (Figure AH-7). The four total locations included a lower and upper location in Blackwood Creek (Blackwood lower - BWL and Blackwood upper - BWU), a lower and upper location in Glenbrook Creek (Glenbrook lower - GBL and Glenbrook upper - GBU). The lower location was chosen to be in proximity to the USGS located near the outlet of each watershed. The upper locations were chosen to be upstream of a meadow within both watersheds.

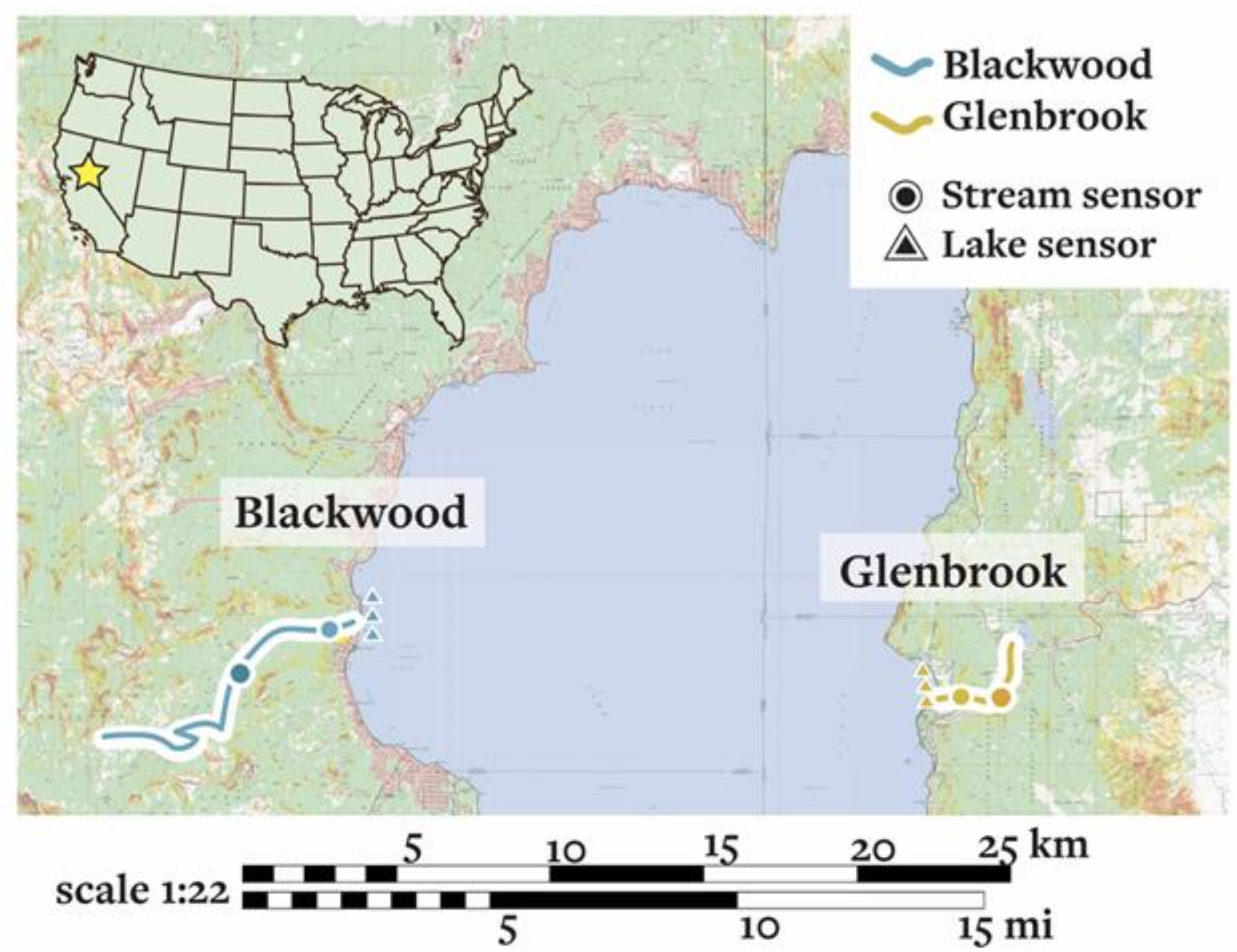


Figure AH-7. Map of focal reach locations Blackwood Creek (west, denoted in blue) and Glenbrook Creek (east and denoted in gold). The stream flow line is highlighted, and intersecting circles represent background monitoring stations at each of our focal reaches within the streams. We instrumented upper as well as lower reaches within each stream.

<u>Sensor deployment and maintenance</u>

We deployed miniDOT dissolved oxygen and water temperature sensors (Precision Management Engineering) at 5-minute observation intervals to model daily stream metabolism (Appling et al.2018b) as described below (Figure AH-8). We also deployed

HOBO U-24 conductivity sensors (Onset) to measure specific conductance (SPC). We conducted monthly nitrogen uptake rate measurements via the Tracer Additions for Spiraling Curve Characterization (TASCC) method to determine the instream biota's affinity for both nitrate and ammonium at different seasonal intervals (Covino et al. 2010; Covino et al. 2018).

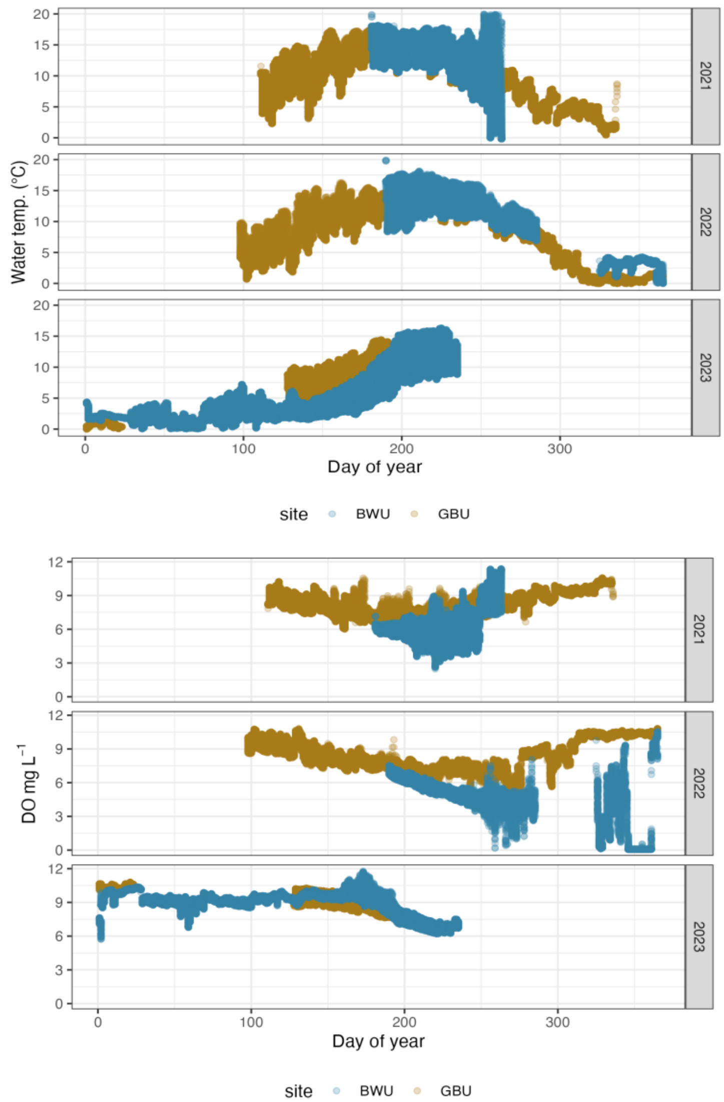


Figure AH-8. Time series of dissolved oxygen and temperature from the upper and lower locations in both Blackwood and Glenbrook Creeks.

To inform our modeling efforts, we used station data from nearby meteorological stations at Homewood (HMDC1, 39.08°N, 120.17°W, and at 2170 m ASL) and Glenbrook (F9917, 39.10°N, -119.90°W, and at 2202 m ASL) for 15 minute observations of solar radiation (Wm2s), barometric pressure (millibar), and air temperature (°C). For specific precipitation measurements we used Snow Telemetry (SNOTEL) station data from nearby sites (848, 39.14°N, -120.22°W, and at 2056 m ASL) and (615, 39.16°N, -119.9°W, and at 2403 m ASL) for precipitation events, accumulated precipitation, as well as snow water equivalent (SWE). Lastly, we used USGS stations for (10336660, 39.11°N, -120.16°W, and at 1900 m ASL) and (10336730, 39.09°N, -119.94°W, and 1901 m ASL) for 15-minute observations of streamflow and water depth.

Water and benthic sample collection

We measured dissolved oxygen (DO), temperature, specific conductance (SPC), and pH, within 1 m of the stream sensor deployments using a multiparameter sonde (YSI Professional Plus, Yellow Springs, OH, USA; Orion pH probe, Thermo Fisher Scientific, Waltham, Massachusetts, USA) (Figure AH-9). We collected duplicate filtered water samples from the same location using acid-washed syringes and combusted Whatman GF/F filters (0.7 μm pore size, Whatman, Piscataway, NJ, USA) and stored in acid-washed 60 mL HDPE bottles frozen at -20°C for later chemistry analysis. We passed a total of 300 mL of water on each filter and stored them frozen at -20°C for later chlorophyll-a analysis. We sampled epilithic biomass by scraping three rocks selected at a random transect using a 6 cm2 plastic delimiter and toothbrush. We poured the composite scrape slurry into a 1000-500 mL volume plastic bottle, diluted the slurry to the final bottle volume using stream water, and kept it chilled for later AFDM and chlorophyll-a analysis. We sampled sediment with a hand shovel to collect composite samples of the top 5-10 cm at three randomly selected transects, collecting three scoops per transect. We sieved using a stainless steel #10 2 mm opening sieve (VWR, Radnor, PA, USA) and collected subsamples off of this composite for bulk density, AFDM, pore water, sediment pH, and sediment chlorophyll-a.

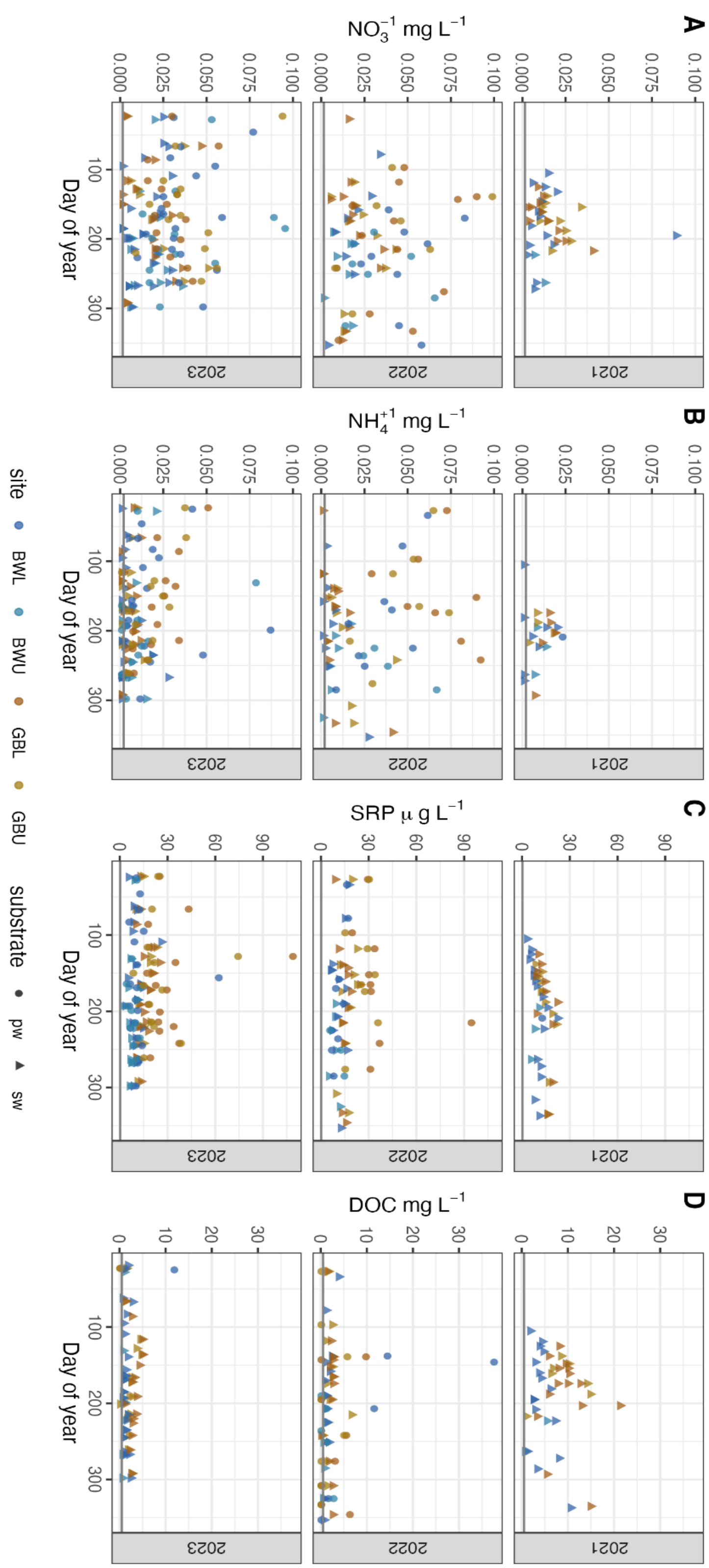


Figure AH-9. Time series of ammonium, nitrate, SRP, and TOC concentrations in grab samples from Blackwood and Glenbrook Creeks.

Laboratory analysis

In the laboratory, we weighed 10 mL of wet sediment to determine bulk density of every sediment sample collected. For sediment AFDM, we dried sediment samples at 60°C for 48 h and then combusted them at 500°C for 8 h to determine ash free dry mass (AFDM) and percent organic matter (%OM = ((dry weight – AFDM)/dry weight) × 100). For epilithic AFDM, we filtered 100-250 mL of composite epilithic material on to a combusted Whatman GF/F filter (0.7 µm), dried the filtrate at 60°C for 48 h, and then combusted it at 500°C for 8 h to determine ash free dry mass and percent organic matter. We corrected for the amount of diluted composite processed and the area scraped (108 cm) (%OM = ((dry weight – AFDM)/dry weight) × 100 x percentage analyzed of total sample / 108 cm). For soil pH, we used an Orion Star A211 Benchtop pH Meter (Thermo Fisher Scientific, Waltham, Massachusetts, USA) to measure the pH of a mixture of 3 g of dried sediment in 5 mL of 0.01 mol/L CaCl2, the addition of which lowers sediment pH by ~0.5 pH units compared to water pH but is advantageous for taking measurements (Carter & Gregorich, 2008). For porewater solutes, we added 3 ± 0.25 g of wet sediment and 25 mL of deionized to a falcon tube and vortexed it every 30 minutes for 4 h. We then rested the falcon tubes in a fridge overnight and centrifuged them the next day. We then filtered the supernatant through Whatman GF/F filters (0.7 µm) and stored it in acid-washed 60 mL HDPE bottles in a freezer at -20°C, until analyzed.

We analyzed pore water solutes and filtered water samples for dissolved organic carbon (DOC), total dissolved nitrogen (TDN), ammonium, orthophosphate, and nitrate. We used a TOC analyzer with a TN module (TOC-V CPH; Shimadzu, Kyoto, Japan) for DOC and TDN. Additionally we used SEAL AQ2 discrete analyzer (SEAL Analytical, Mequon, Wisconsin, USA) to analyze samples for ammonium (NH4+- N) with a detection limit of 0.002 (mg N L-1), orthophosphate (o-P) concentrations based on US EPA method 350.1 revision 2.0 and USEPA method 365.1 revision 2.0 (US EPA, 1993a, 1993b) with a detection limit of 0.402 (µg P L-1), as well as nitrate (NO3 - N) based on US EPA Method 353.2, Revision 2.0. with a detection limit 0.003 (mg N L-1) respectively. Chlorophyll-a was analyzed on a Turner Designs Trilogy benchtop fluorometer.

Stream metabolism

Daily gross primary productivity (GPP) and ecosystem respiration (ER) in a stream reach can be estimated from sub-daily patterns in DO concentrations (Odum, 1956). To model metabolism in Blackwood and Glenbrook creeks, we combined DO and water temperature via PME miniDOT sensors, measurements of average reach depth (Blaszczak

2019), barometric pressure and light from nearby weather stations (HMDC1 and F9917), and stream flow from USGS (10336660 and 10336730) (Figure AH-10). MiniDOT sensors were deployed horizontally, strapped to cement blocks oriented downstream with sensor membrane covered in an antifouling mesh copper plate. Sensors were downloaded monthly, cleaned every two weeks, and intercalibrated annually. We used a Bayesian state-space model to estimate three parameters: GPP, ER, and the O2 specific gas exchange rate coefficient normalized to Schmidt number of 600 (K600) in the general equation implemented in the in the stream Metabolizer package in R (Appling et al. 2018).

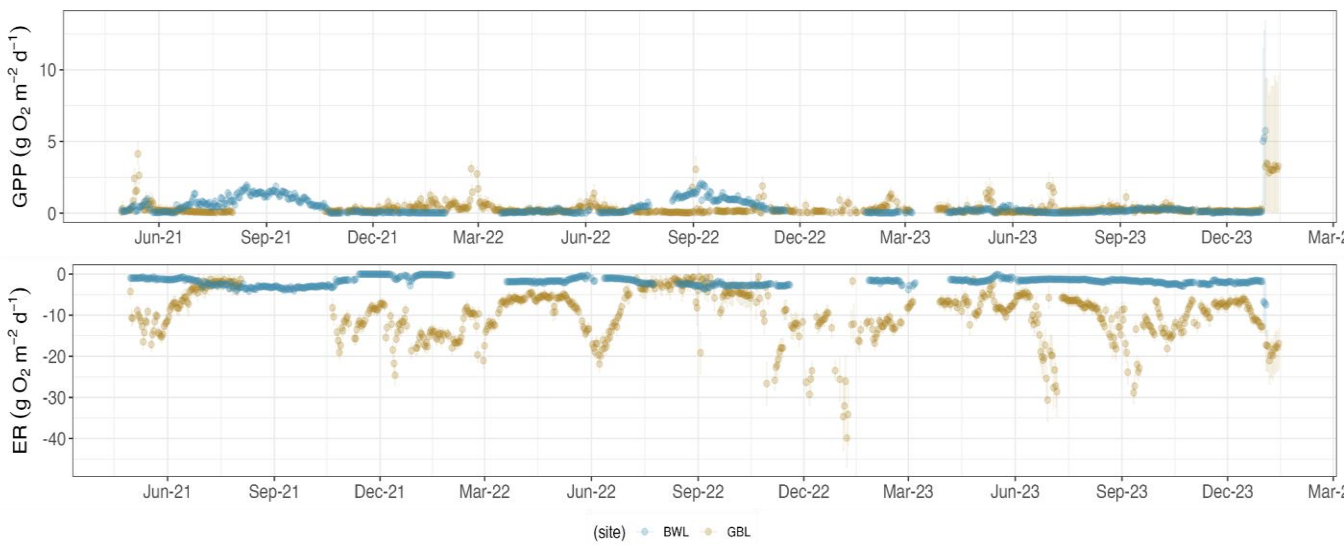


Figure AH-10. Stream ecosystem metabolism estimates from the upper Blackwood and Glenbrook Creek sensor locations.

In-stream nitrogen uptake

The tracer addition for spiraling curve characterization (TASCC) method is commonly used to estimate uptake length (SW) and its associated metrics (i.e., areal uptake rate, Udd in µg m-2 min-1; and uptake velocity, Vf in mm min-1) from pulse additions (Covino et al. 2010). The TASCC method evaluates the tracer recovery (TMR) based on the ratio of N : Cl in surface water grab samples taken through pulse concentrations at the downstream sampling location during a “breakthrough curve” or BTC of an injected tracer. Under saturating conditions both tracers will be transported conservatively. Conservative transport results in nearly equal mass recovery of both tracers and stable nutrient to conservative tracer ratios during the pulse of a BTC. Results of TASCC experiments performed in Blackwood and Glenbrook watersheds are summaried in Table AH-5.

Table AH-5. All performed TASCC experiments and a brief evaluation of them (acceptable/not/estimated parameters). Summary of experimental conditions discharge (Q in L s-1), mean water temperature (°C) and preliminary results: mean uptake metrics length (SW in m), mean uptake rate (Udd in mg m-2 min-1) for NH4+ - N and NO3- - N ambient N concentrations and N supply during NO3 and NH4 BTC spirals in 2021, 2022, 2023.

Site	N sp.	Date (yy-mm-dd)	Q (L s^{-1})	Temp (°C)	mean S_W (m)	mean U_{dd} (mg m^{-2} min^{-1})	Ambient NO_3 (mg L^{-1})	NO_3 supply (g day^{-1})	Ambient NH_4 (mg L^{-1})	NH_4 supply (g day^{-1})	uptake detection?
BWL	NH4	22-05-26	1087	9.0	156.1	0.303	0.010	1.026	0.004	0.424	possible
BWL	NH4	22-08-24	60	15.6	74.5	0.243	0.023	0.174	0.040	0.304	possible
BWL	NH4	22-10-12	37	11.0	127.0	0.001	0.006	0.015	0.002	0.007	yes
BWL	NO_3	22-10-12	47	12.2	58.3	0.011	0.004	0.016	0.002	0.007	possible
BWL	NH4	22-11-21	60	0.4	53.0	0.358	0.019	0.100	0.000	0.000	possible
BWL	NO_3	22-11-21	71	0.9	81.1	0.147	0.005	0.031	0.000	0.000	possible
BWL	NH4	22-12-19	124	0.3	131.9	0.27	0.001	0.011	0.006	0.123	possible
BWL	NO_3	22-12-19	192	0.5	53.3	0.118	0.006	0.208	0.007	0.243	possible
BWL	NO_3	23-02-15	420	1.9	83.3	0.558	0.014	0.772	0.007	0.361	possible
BWL	NH4	23-04-05	939	3.9	155.7	0.069	0.002	0.183	0.001	0.122	possible
BWL	NO_3	23-07-18	1314	11.4	56.5	0.244	0.001	0.112	0.005	0.560	possible
BWU	NH4	22-08-24	9	15.9	44.5	0.013	0.022	0.098	0.018	0.077	possible
GBL	NO_3	22-10-03	5	9.6	32.3	0.002	0.009	0.051	-	-	yes
GBL	NH4	22-12-12	27	-0.1	138.9	0.014	0.014	0.269	0.039	0.730	yes
GBL	NO_3	22-12-12	36	-0.1	49.2	0.003	0.001	0.050	0.039	0.984	yes
GBU	NO_3	21-07-22	5	14.9	67.2	0.002	0.021	0.051	-	-	possible
GBU	NH4	22-10-03	5	9.3	68.8	0.001	0.027	0.196	0.015	0.107	yes

Summary of key knowledge gained

Across all years, we found net ecosystem productivity, and epilithic biomass were positively associated with ammonium concentrations at both streams. From dry to wet years ammonium concentrations decreased by 33% (from 15.15 to 10.05 µg L-1) at the larger stream and by 42% (from 24.79 to 14.27 µg L-1) at the smaller stream (June-October samples). Gross primary productivity (GPP) and ecosystem respiration (ER) were greatest (GPP: 80% higher 2.30 relative to 0.44 g O2 m-2 d-1 and ER: 23% lower -11.55 relative to 8.23 g O2 m-2 d-1) during dry years at the larger stream. GPP was generally negligible in the smaller stream ranging from (0.01 to 0.03 from dry to wet years), while ER increased 60% (from -4.05 to -10.20 g O2 m-2 d-1) from dry to wet years.

These results suggest even within basins, the ecological responses of streams to variable hydroclimatic conditions and changing nutrient conditions differ with stream size. This work highlights the value in characterizing variation in regional stream ecosystem function, especially given the potential for climate-induced shifts in precipitation and drought to amplify episodic nutrient export and alter the productivity regimes of mountain streams. While streams have the potential to importantly remove nutrients sourced from headwaters before reaching the nearshore lake environment, long-term monitoring is needed to understand how long these effects persist from wet to dry periods, across a distinct watershed.

Application of Tree-Radius Dendrometers

Tree-radius dendrometers were evaluated as a method for simultaneously monitoring tree growth, and tree water status (Figure AH-11). Manual readings of dendrometers have long been used to measure trends in tree growth at annual or sub-annual time scales, and thus have been crucial to understanding the timing of diameter growth by trees (Monk, 1959). However, these dendrometers continuously measure small-scale fluctuations in tree diameters using a potentiometer: as diameters change, a small plunger pressed up against the tree will depress or extend, registered as a voltage reading recorded by a datalogger. With resolution to observe diel diameter fluctuations, researchers have found that these shorter time scale fluctuations are controlled by water stress and the refilling of stem xylem (Dietrich et al., 2018). Whereas when water is abundantly available in soils, stems will show large diameter fluctuations as stems refill at night, those fluctuations shrink as water becomes more limited and trees are less able to

refill. Thus, these sensors reflect both seasonal growth patterns through the within-season trends, and also reflect physiological water stress, representing an efficient method for forest monitoring. Other forest monitoring networks have adopted dendrometers as a key sensor (Zweifel et al., 2021).

Figure AH-11. Photograph of radius dendrometer (Ecomatik) measuring diameter of a Red Fir at Blackwood 2 site.

In complement to the dendrometers, sites are also instrumented with a vertical profile of soil moisture measurements. While it might be expected that plant-water status (from dendrometers) and soil moisture availability will be strongly intercorrelated, suggesting that they provide redundant information. However, it is known that trees in the Sierra Nevada often rely on subsoil water storages that can maintain trees through multi-year droughts. That storage can be depleted, resulting in critical conditions for forest stress and mortality (Goulden & Bales, 2019). Thus, by co-measuring soil moisture and dendrometers, we can better understand those crucial thresholds where trees shift to using deeper water reservoirs, and when trees lose access to them.

In pilot-testing dendrometer measurements, we wanted to explore two questions: (a) which tree species should we sample in polytypic forest stands, and (b) how do micro-scale variations in position within sites matter? To do so, we instrumented eight trees at Blackwood 2, two red fir trees and two lodgepole pines on a terrace above the riparian area, and two red fir trees and two lodgepole pines that are sitting ~2 meters lower, clearly within Blackwood Creek's riparian zone (i.e., certainly influenced by alluvial groundwater inputs).

The dendrometers were installed in late June of 2024, and measurements showed large diameter fluctuations through August (albeit with a substantial fraction of July missing due to us still calibrating power demands of these systems) (Figure AH-12). All eight trees showed declines in diameter fluctuations from September into October. Coarsely, we found the position to have more impact than species, with the terrace trees having smaller diameter fluctuations (less daily 'refilling'), especially in the early growing season. Responses seen in red firs are largely matched by those seen in lodgepole pines.

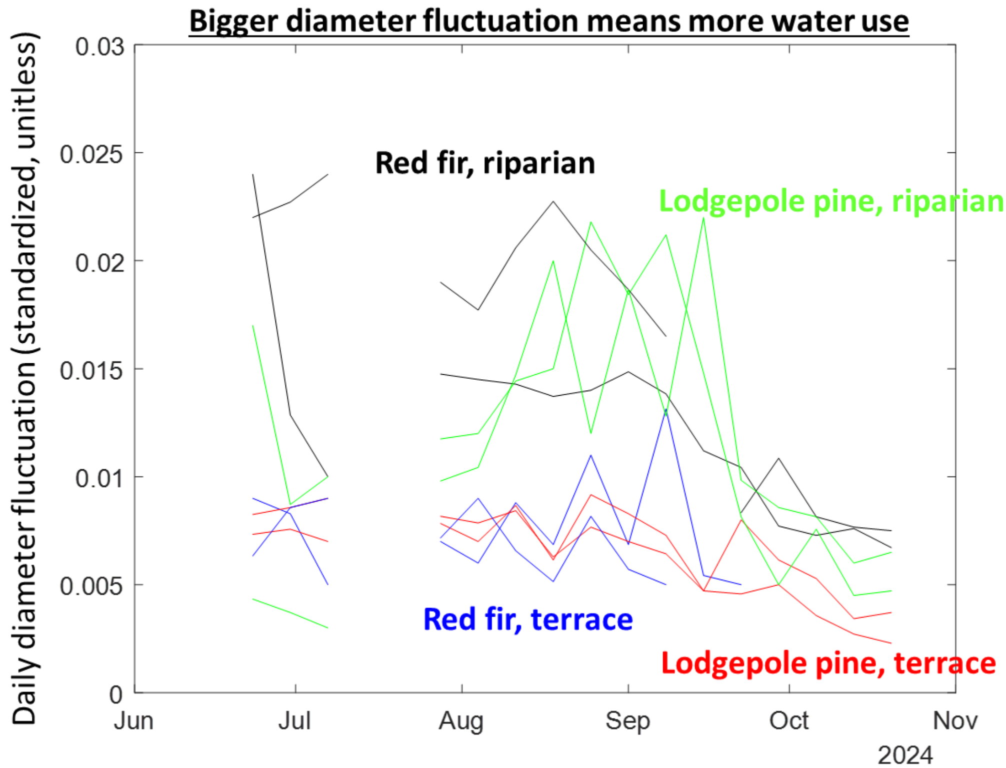


Figure AH-12. Measurements from radius dendrometers at the Blackwood 2 site.

Stable Isotope Measurements

Stable isotope analysis of stream water provides a potential method for evaluating the source of water in the creeks. Throughout the year, there are hypothetically variations in which part of the watershed is provisioning water to creeks. For example, warm periods in winter can melt snow and result in substantial streamflow, however, it's like that this precipitation is disproportionately coming from lower elevations where temperatures are warm enough to ripen snowpacks. In spring, as the snowmelt season progresses, the major sources of water likely moves up slope as the snowpack melts away at lower elevations. After snow is melted, is streamflow still largely generated from the higher elevations where precipitation far exceeds evapotranspiration? Such dynamics have not been described at Tahoe, and understanding them could reveal causes of varying water chemistry across seasons, as different parts of the watershed drain into creeks.

This analytical approach is modeled after a study that uses stable isotopes to describe the elevations provisioning streams draining the cascades into the Willamette valley and how it varies among seasons (Brooks et al., 2012). This analysis relies on a) precipitation having a distinct isotopic trend with elevation, and b) annual precipitation isotope ratios being dominated by precipitation from winter, so that elevation signals are not conflated with seasonal signals. A literature review and data synthesis were used to evaluate the potential for using stable isotopes in such an application.

First, we searched both the Waterisotopes.org data repository (Bowen et al., 2014) and the Global Network of Isotopes in Precipitation (IAEA/WMO, 2020) for relevant datasets. All data were downloaded in the Tahoe basin vicinity, bounded with Reno defining Northern and Eastern edges of the bounding box, Emigrant gap defining the western edge, and Deadwood Peak defining the southern edge. Extant publicly available isotope data are surprisingly scarce for this region. A dataset of snowpack cores were sampled for stable isotope ratios, with those cores sampled along following I-80 from Donner Pass down to the Western Sierra Foothills (Ingraham & Taylor, 1991). Figure AH-13 shows these data, detailing a strong elevation gradient in snow isotope ratios.

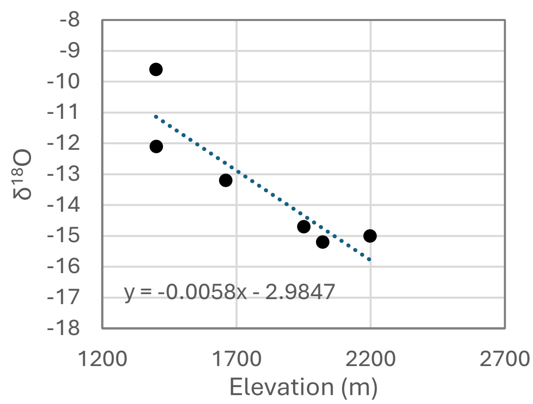
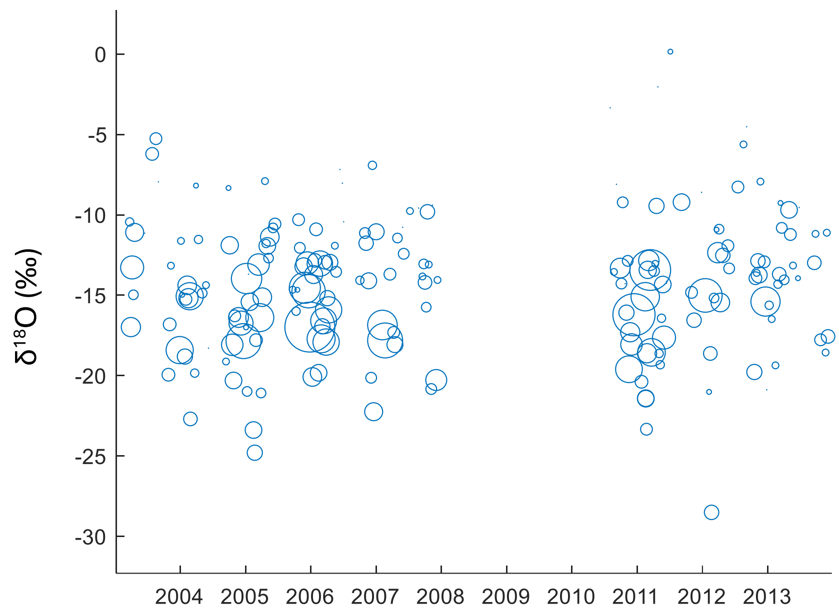


Figure AH-13. Relationship between snow δ18O and elevation, sample northwest of Lake Tahoe (Ingraham and Taylor, 1991).

Another study found precipitation at Tahoe Meadows to average -14.4±0.3 ‰ at 2525 m and precipitation at Pyramid Lake to average -9.9 ± 0.6 ‰ at 1164 m, implying a slope of -0.0033 ‰ per meter of elevation (Benson, 1994); however, these values were not amount weighted and thus they over-represent influence of the isotopically heavier summer precipitation. Several stable isotope studies have been conducted at the Sierra Snow laboratory (2100 m) near Soda Springs (Lee et al., 2010). Lee et al., (2010) found snowpack isotope ratios to be -16 ‰ to -14 ‰ in snow pack at in April, but also observed it to enrich with progression into the spring (as isotopically heavier rain fell on the snowpack, filled pores, and froze). Together, these past studies provide confidence that we should expect a lapse rate of lighter preciptiation falling at higher elevations. Indeed, this is a globally expected pattern that is expected for well-understood mechanstic reasons (Allen et al., 2019). That said, further synoptic sampling could be useful for constraining the relationship between elevation and isotope ratios, and how it varies between east-side and west-wide watersheds.

We also evaluated whether (isotopically heavier) summer precipitation importantly influences the bulk of precipitation inputs. As a demonstration in a nearby watershed where data are available, this was done using time series of precipitation stable isotope measurements at Sagehen Creek Experimental Watershed (Figure AH-14). These several years of data confirmed that precipitation inputs are overwhelmingly controlled by winter precipitation, with amount-weighted mean precipitation of -15.7±0.4 ‰ throughout the



whole year, -13.4 ± 0.9 ‰ in summer, and 16.0±0.4 ‰ in winter.

Figure AH-14. Stable isotope measurements of precipitation at Sagehen Creek watershed (1931 m), north of Lake Tahoe. Marker size is proportional to precipitation amount.

Available streamflow data from Sagehen were evaluated to see if there are consistent trends, which would lead to the expectation that the sentinel watersheds (which have more elevation range) would also show such trends. Figure AH-15 shows five years of streamflow data, with distinct intra-annual patterns. Higher values imply contributions of lower-elevation precipitation to streamflow, which tended to peak in April-May, but with occasional spikes in November or December. Otherwise, late-sumer and fall tended to be dominated by the highest elevation water sources. These data suggest that we should sample at higher temporal resolution than the monthly that was done at Sagehen because transitions values occur rapidly in spring and summer.

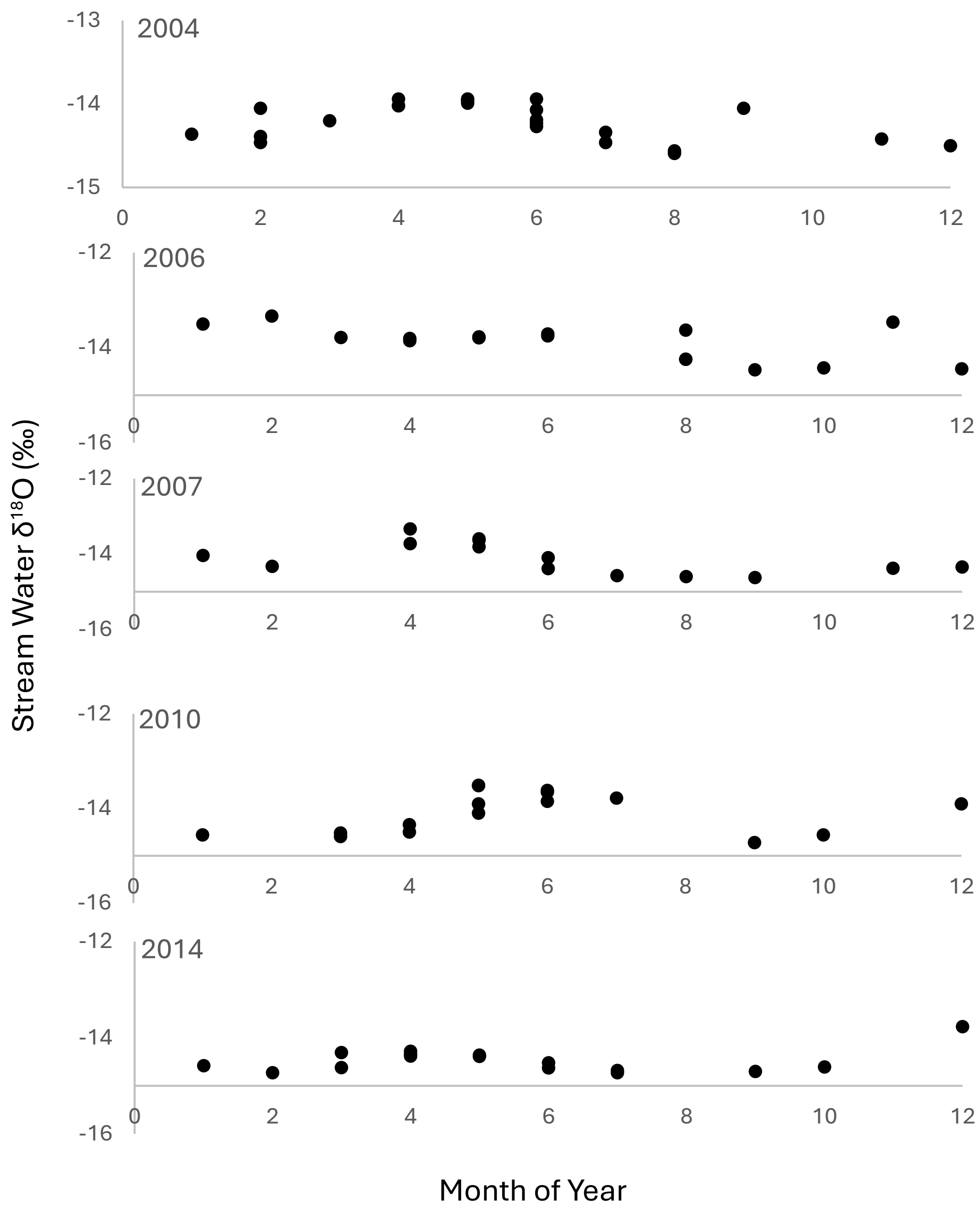


Figure AH-15. Stable isotope ratios of stream water throughout years at Sagehen Creek.

Environmental DNA as a Tool for Measuring Biodiversity

Environmental DNA (eDNA) sampling provides high resolution biodiversity data that can be highly complementary to, and in some cases more sensitive than traditional surveys. In recent years, eDNA metabarcoding has been studied in freshwater systems around the world to improve the understanding of how to design eDNA sampling and analysis protocols to maximize species detection. There have been few studies of eDNA metabarcoding in the Lake Tahoe Basin but those studies that have been used to detect invasive species like clams and crayfish show promise (Cowart et al. 2018, Larson et al. 2017). Additional, research suggest utilizing eDNA in Lake Tahoe's waters may be problematic for several reasons including the low detectable amounts of DNA within the water depending on the physical location and sampling (Jerde 2021).

We collected 15 samples for eDNA from the nearshore of Lake Tahoe including marinas and streams. We also collected 30 samples for eDNA from lakes around the basin selected for historical resample (see Appendices B-E). We intended to compare the eDNA results with historical surveys describing the fish biodiversity at each location. Samples were collected with single-use eDNA collection kits containing a 5 μm filter (Jonah Ventures, Boulder, CO, USA), and collected filters were preserved with Longmire's solution to stabilize captured DNA and then sealed with sterile plastic caps to prevent contamination during transport to the laboratory. An effort was made to filter as large a volume as possible using the 60 mL syringe before the filter became clogged with sediment and other particles. Samples were shipped to Jonah Ventures for metabarcoding analysis using MiFish primers. These primers target the mitochondrial 12 S ribosomal RNA (rRNA) gene and have been shown to have good discriminatory power for the identification of fish families, genera, and species.

Recommendations

Site Selection

As discussed in Section 2, the major considerations are: Permission to place sensors including communications and power at a location; Year-round accessibility; Collocation of sites on land with existing hydrologic records; Complementarity among the chosen watersheds while avoid redundancy; and Sensor, power and communications. Background information leading to the following discussion was presented in Section 2 and Tables 1-3.

We recommend the selection of Glenbrook, Blackwood and Incline for long-term aquatic monitoring because a) the baseline understanding and data available, b) their complementarity to one another (see Table 3), and the other reasons details in Sections 2. However, there are important logistical details that should be noted. Blackwood 2 does not have a cellular signal, making data telemetry more challenging. This is a surmountable problem, even using off-the-shelf items sold by Campbell Scientific that interface with loggers. The Blackwood 2 datalogger could be set up with a microwave antenna to convey data to another datalogger at a down-stream location (at the outlet). This requires an additional station and additional equipment. Alternatively, these data would have to be manually downloaded and uploaded, thereby eliminating the possibility of real-time data to be publicly available. While site visits are costly with respect to personnel time, this does not add any cost because biweekly visits to each site are warranted for site maintenance and water sampling. Additionally, there is also no possibility to have upland sites within the Blackwood Watershed that are easily accessible. However, both of these limitations are true of the other West-side watersheds gauged by the USGS (Ward and General).

Instrumented Measurements and Sensor systems

We recommend two systems with distinct sets of measurements for aquatic sites and upland forest sites.

Upland Sensors

For the upland sites, we recommend instrumenting 3 trees with dendrometers and soil moisture probes at 15 cm, 50 cm, and at 1 m or depth of refusal. For soil moisture probe choice, CS655 probes (Campbell Scientific, Inc.) are moderate cost, they easily interface with Campbell Scientific dataloggers, have a large sampling volume, and, in our experience, are more durable than alternatives; the latter is perhaps the most important factor when working in rocky soils.
In addition, we recommend instrumenting these stations with temperature / humidity sensors. They are an easily added measurement that is broadly useful and interpretable. We have tested use of both HMP60 and HygroVue 5 sensors. Both are reasonable options and have identified no clear reason to select one over the other. Windspeed conditions are sufficient to use a louvered radiation shields rather than aspirated, especially if measurements are taken at 2-m height, below forest canopy.

Precipitation is a critically important metric for understanding Tahoe hydro- and eco-systems, and it is highly complementary to our other proposed measurements. We considered and evaluated several potential methods to measure precipitation. Any tipping-bucket or non-heated method is not useful for measuring precipitation inputs because the majority of precipitation is snowfall. To measure precipitation continuously, the Ott Pluvio heated precipitation gauge is the considered the gold-stand of available off-the-shelf options. It can be ordered with an altar shield fitted to it, dramatically mitigating snowfall undercatch. Without, snowfall can be undermeasured by >50% as the aerodynamics of the gauge diverts snowflakes away from the orifice. However, adding these precipitation gauges to the measurement systems introduces numerous obstacles. First, due to high snowfall totals at the high elevation sites, we will need to construct custom bases for the precipitation gauge so that it does not become buried by snow. Second, the size and weight of these gauges demands that a substantial concrete footer be used (the manufacturer recommends that it be 80 cm deep). Third, the heater has a power demand that exceeds that of all of the other instrumentation combined, necessitating much more solar power and battery capacity. Fourth, these gauges are visually obvious from a distance, increasing the likelihood of vandalism or, if installing on private property, they are visually unappealing (whereas most of the sensors can be installed discretely). Last, the cost of these precipitation measurements, especially after adding the cost of altar shield and a custom-made base, far exceeds the cost of all other sensors and dataloggers combined (Table 6). We have also tested using a digital camera at these stations that can communicate with the datalogger.). A camera could also be used to measure snow depth and rate (at much lower resolution), but not snow water equivalent.

We tested installing drive point piezometers and found this to be infeasible due to rockiness. Installation of piezometers would likely require heavy equipment, outside of the scope of permits we can obtain without NEPA review, which would dramatically set back our timeline.

Aquatic Sensors

For aquatic chemistry monitoring, the Aquatroll (In-situ) Multi-Parameter sensor is the recommended sensor. It is capable of simultaneously measuring dissolved oxygen (DO), pressure, pH, and electrical conductivity. The DO sensor is optical, and thus requires less maintenance than other options. The Aquatroll can interface with Campbell Scientific (and other) dataloggers, unlike MiniDOT, which are an alternative, lower cost for DO measurement (Table 6). However, if MiniDOTs were to be used, a paired conductivity meausurement system (HoboU24) would also be needed (and this also would not interface with the datalogger, excluding the possibility of real-time data access. By choosing streams that are already gauged by the USGS, we save costs (sensors and especially field labor) that would be required to install a pressure transducer and develop a stage-discharge rating curve.

To complement sensor measurements, we recommend biweekly sampling of streamwater at sensor locations. This is crucial for understanding change s in nutrient loading and how that varies seasonally, inter-annually, and with disturbance. This is a step towards model development. Ammonium-N, Nitrate-N, and soluble reactive phosphorus, stable isotope ratios. Real-time sensing of some of these parameters is possible using an S::CAN sensor, including total suspended solids, Turbidity, Total Carbon, Nitrate, and UV Absorbance. This sensor has a high up-front cost (Table 6), and requires careful calibration for the data to be useful; this would imply an explicit need for more highly trained staff to run with the use of these data.

Power, Communications, and Infrastructure

For power, our preliminary field work in 2024 has shown that 50 W solar panels combined with 12V batteries of at least 18 amp-hours are sufficient for powering equipment over summer months (our current sensor maintenance interval). This will have to be re-evaluated throughout the winter season.

For communications, Sites Glenbrook 1, 4 and 5, as well as the Lake Tahoe Campus site are equipped with Campbell Scientific CELL-210 cellular modules and data can be accessed via cellular data telemetry. Site Blackwood 2 does not have cellular signal – data is instead downloaded in person on a monthly basis. Campbell provides different cellular plans for different data amounts. Transmitting photos would substantially increase the data usage relative to other data collected. It is important to note that cellular communications not only allow for accessing data, but also for checking on status of sensors and batteries. Moreover, the datalogger programming can be changed remotely if needed (e.g., if we wanted to increase photo capture rates throughout a storm storm). Connecting the datalogger to the router is power intensive and thus an ideal routine would be to have it turn on for a short period per day, at which time it is queried and the data downloaded.

For physical infrastructure, we have found different options to be appropriate for different sites. At the highest elevation and steepest site, Glenbrook 5 (2422 m), we secured the sensor system using a guy-lined pole (Figure AH-16). Glenbrook 1 and 4 as well as Blackwood 2 were secured using buried concrete footers. For the UNR-Tahoe Campus, we used a metal frame base secured with 18” anchors. All datalogger boxes are locked with a padlock, and none have shown any signs of attempted tampering.

Figure AH-16. Guy-lined pole at Glenbrook 5

eDNA Methods

Four areas of recommendations are offered for eDNA sampling as part of sentinel watershed monitoring.

- Develop sequence coverage of DNA markers for species of interest in the Lake Tahoe basin. Coverage may vary across taxa with more information about certain taxa but not others (e.g., endemic Lake Tahoe stonefly). So depending on the need for species specific coverage, species specific coding may be needed.
- Consider screening of primer pairs for amplification bias. Amplification biases occur when a primer pair preferentially amplifies DNA from certain taxa and not others, and this can lead to unanticipated false negatives when DNA present in a sample is not amplified and not detected. This is of particular concern with more universal genetic markers.
- Compare eDNA to field surveys from Lake Tahoe's different habitats (bottom waters, open flowing waters) and across seasons with varying flow and temperatures (Marchetti et al. 2023).
- In addition, eDNA collections from sediment-water interfaces may be optimal for benthic species. Collection of DNA that are homogenized in a laboratory, may yield more information than simple water collections from the lake. These methods need to be tested however in Lake Tahoe already has low detectable DNA. These may involve (but are not limited to) issues related to collecting eDNA samples from low productivity (oligotrophic) waters.

Data Management

An ideal data management system will involve receiving information from sensors and grab sampling and establishing quality control assurance plans and determinations for each constituent. A user friendly, web portal with the ability to display the information, generate figures in real time, and support downloading of provisional data until quality control is a goal but research into this has shown that developing such a webpage would potentially be a multi-million dollar pursuit. Maintenance of a website and server requires dedicated full-time staff, as is usually employed by similar size networks (e.g., National Ecological Observatory Network, USGS Lake Tahoe stream gauging program).

At this time, a practical path forward is to use a cloud server and develop a web platform where data files are cataloged and available for download on a daily interval. A reasonable approach would be to have a folder scheme: Year\month\day\station, whereas .csv file is available for download. A program can be set up so that each datalogger (connected to telemetry) is connected at a given time, and the data are downloaded and automatically saved in their appropriate folder. The storage demands of such a system are minimal for time series, where we are generating ~10^1-10^2 kilobytes of data per day. Photographs cannot be saved as time series within .csv files and thus an additional folder is required for images. For cost management, at this time, we recommend hourly photos to be taken at each station, and be stored in an analogous folder system: Year\month\day\station, with files named by data and time of day.

Operating Costs

In addition to up-front costs per sensor system outlined in Table AH-6, there are additional continued costs. A data plan through Campbell Scientific will cost $200-$300 per year (with this limiting us to 1gb /month). That limit, 1gb per month, is sufficient for any anticipated data streams other than photos; photos are data intensive and thus rate of photo capture needs to be limited (~3 per day) in order to stay within a $300 communications budget.

Table AH-6. List of sensors per station and associated costs

Sensor	Metrics / insights	Freq of sampling	Cost per unit	Total Cost (including infrastructure to set up sensor)
Camera	Climate/Vegetation visualization	Daily*		$4-6k
Precipitation	Precipitation rates	15 min	$6k	$10k
Dendrometer	Tree stress	15 min	$0.3k	$1.2k
Soil Moisture		15 min	$0.3k	$1k
Temp/Humidity		15 min	$0.5k	$0.5k
MiniDOT	DO, temperature	5 min		$1.2k
Hobo U24	Conductivity	5 min		$1k
Aquatroll	DO, pressure, pH, conductivity	5 min	$6k	$7k
S::Can	TSS, Turbidity, Total carbon, Nitrate (continuous), uv absorbance	15 min		$26k
Data logger	Data recording and communications interface	Daily	$2.3k	$2.3k
Cellular Telemetry	Communications	Daily		$600-
Battery & Solar Panel			$0.8 k	$1.0k
Sensor Mast & infrastructure			$0.5 k	$1k

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TEON Appendix I:

Basin-wide Monitoring Sample Sites in the Lake Tahoe Basin 2023-2024

Liraz Bistritz, Shale Hunter, Gina Tarbill, and Patricia Manley

USDA Forest Service, Pacific Southwest Research Station

Placerville, CA

July 2025

Table AI-1. Basin-wide monitoring sampling sites for 2023-2024 as part of the Tahoe Environmental Observatory Network pilot testing and design project.

Site	Habitat	Longitude	Latitude	Basin side	Orient	Lake size	Elevation (m)	NYears Visited	Camera	nest8km	nest4km	nest2km
ANG	Aquatic	-120.064	38.8632	South	East	L	2265	2	yes	J	18	42
BAR	Aquatic	-120.025	38.85327	South	East	M	1923	3	no			
BLA	Aquatic	-120.204	39.1025	West	West	S	1950	3	yes	O	32	67
BUC	Aquatic	-120.189	39.05051	West	West	M	2274	NA	yes	O	35	71
CAG	Aquatic	-120.096	38.84256	West	West	M	2362	2	yes	J	23	48
CAR	Aquatic	-120.081	39.23989	North	West	S	1955	NA	yes	B	3	6

CFP	Aquatic	-120.098	38.93058	West	East	M	2185	3	yes	L	26	55
COL	Aquatic	-119.957	38.9023	South	East	M	1939	NA	yes	G	11	27
DIX	Aquatic	-120.021	38.73252	South	West	M	2533	2	yes	I	17	39
ELL	Aquatic	-120.202	39.06781	West	West	M	2490	3	yes	O	33	69
GIA	Aquatic	-119.932	39.32122	East	East	S	2851	2	yes	C	34	9
GOO	Aquatic	-120.186	39.10305	West	West	M	2362	1	yes	M	29	62
GRS	Aquatic	-120.111	38.87183	West	West	L	2196	NA	yes	J	23	49
HEA	Aquatic	-120.137	38.87569	West	West	L	2407	2	no			
HID	Aquatic	-120.151	38.98704	West	West	M	2284	1	yes	M	28	59
INC	Aquatic	-119.927	39.2962	East	East	L	1918	3	yes	C	5	10
L121	Terrestrial	-120.034	38.84031	South	East		2008	NA	yes	J	21	44
L181	Terrestrial	-120.014	38.90774	South	East		1932	NA	yes	K	24	51
L186	Terrestrial	-120.03	39.2463	North	West		1951	2	no			
L196	Terrestrial	-120.096	39.21388	North	West		1996	NA	yes	A	2	3
L226	Terrestrial	-119.978	38.88648	South	East		1969	NA	yes	G	11	26
L236	Terrestrial	-119.986	38.87882	South	East		1966	NA	yes	G	11	26
L241	Terrestrial	-120.026	38.84618	South	East		1932	3	yes	J	21	44

L271	Terrestrial	-120.078	39.23465	North	West		1960	NA	yes	B	3	6
L316	Terrestrial	-120.01	38.84968	South	East		1960	NA	yes	J	21	45
L321	Terrestrial	-119.927	38.97299	East	East		1966	NA	yes	F	9	23
L331	Terrestrial	-119.938	38.957	East	East		1928	NA	yes	F	9	23
L341	Terrestrial	-120.021	39.2551	North	West		2041	NA	yes	B	4	7
L351	Terrestrial	-120.045	38.84912	South	East		2011	NA	yes	J	18	41
L366	Terrestrial	-119.947	38.9053	South	East		2026	NA	yes	G	11	27
L381	Terrestrial	-119.922	39.17275	East	East	M	1971	1	yes	D	6	13
L391	Terrestrial	-120.001	39.2496	East	East		2049	NA	yes	B	4	8
L396	Terrestrial	-120.041	38.88978	South	East		2072	2	yes	K	24	50
L406	Terrestrial	-119.931	38.98761	East	East		1985	NA	yes	I	17	38
L411	Terrestrial	-119.931	39.11856	East	East		1973	NA	yes	D	7	16
L86	Terrestrial	-120.101	39.21804	North	West		2041	NA	yes	A	2	3
LOM	Aquatic	-119.917	39.06098	East	East	S	2263	1	no			
LPM	Aquatic	-120.161	39.03539	West	West	M	2022	3	yes	O	35	72
LUT	Aquatic	-119.951	38.78827	South	West	M	2356	2	yes	I	16	36
M120	Terrestrial	-120.004	38.75342	South	West		2457	NA	yes	I	17	38

M134	Terrestrial	-120.131	39.22685	North	West		2302	2	yes	A	1	2
M141	Terrestrial	-119.994	38.76606	South	West		2429	NA	yes	I	16	37
M190	Terrestrial	-120.103	38.93268	West	East		2102	3	yes	L	26	55
M211	Terrestrial	-120.094	38.85163	West	West		2536	2	yes	J	23	48
M218	Terrestrial	-120.101	38.87424	West	West		2132	NA	yes	J	23	49
M22	Terrestrial	-119.934	39.12955	East	East		2015	2	yes	D	7	18
M239	Terrestrial	-120.17	38.98087	West	West		2480	NA	yes	M	28	73
M253	Terrestrial	-119.919	39.28481	East	East		2492	3	yes	C	5	10
M260	Terrestrial	-119.906	39.2721	East	East		2486	NA	yes	C	5	11
M267	Terrestrial	-119.926	39.27281	East	East		2463	NA	yes	C	5	11
M288	Terrestrial	-120	39.25649	East	East		2243	NA	yes	B	4	8
M295	Terrestrial	-120.097	39.24148	North	West		2119	NA	yes	A	1	1
M309	Terrestrial	-120.161	39.17398	West	West		2159	3	yes	N	30	63
M330	Terrestrial	-119.939	39.32227	East	East		2900	2	yes	C	34	9
M351	Terrestrial	-120.218	39.07488	West	West		2339	2	yes	O	33	69
M358	Terrestrial	-120.176	39.06212	West	West		2427	2	yes	O	35	71
M36	Terrestrial	-119.929	39.02941	East	East		2134	NA	yes	F	8	21

M365	Terrestrial	-120.18	38.99207	West	West		2400	NA	yes	M	28	73
M400	Terrestrial	-119.924	38.8207	South	East		2827	2	no			
M407	Terrestrial	-120.194	39.15674	West	West		2151	NA	yes	N	30	64
M421	Terrestrial	-119.963	39.2884	East	East		2662	2	yes	C	34	12
M428	Terrestrial	-119.904	39.14674	East	East		2434	2	yes	D	7	14
M435	Terrestrial	-120.062	38.86948	South	East		2221	2	yes	J	18	42
M442	Terrestrial	-119.911	38.91839	East	East		2900	2	yes	G	10	25
M449	Terrestrial	-119.968	38.79192	South	West		2347	2	yes	I	16	36
M456	Terrestrial	-120.182	39.16212	West	West		2038	NA	yes	N	30	64
M463	Terrestrial	-120	38.73465	South	West		2600	2	yes	I	17	39
M484	Terrestrial	-120.006	38.84442	South	West		2131	NA	yes	J	21	45
M512	Terrestrial	-120.137	38.89268	West	West		2477	2	no			
M519	Terrestrial	-120.142	38.92556	West	West		2489	2	yes	L	26	54
M526	Terrestrial	-120.001	38.89384	South	East		1930	NA	yes	K	24	51
M540	Terrestrial	-120.149	39.01426	West	West		2024	3	yes	M	28	58
M547	Terrestrial	-120.173	39.01946	West	West		2198	2	yes	M	29	62
M561	Terrestrial	-120.198	39.09442	West	West		2189	3	yes	O	32	67

M575	Terrestrial	-119.939	38.97978	East	East		1925	NA	yes	I	17	38
M589	Terrestrial	-119.924	39.11215	East	East		2152	3	yes	D	7	16
M617	Terrestrial	-119.978	38.77338	South	West		2402	NA	yes	I	16	37
M64	Terrestrial	-119.9	39.02148	East	East		2437	2	yes	F	8	20
M645	Terrestrial	-119.967	38.89618	South	East		1925	NA	yes	G	11	27
M659	Terrestrial	-120.162	38.99422	West	West		2273	2	yes	M	28	59
M666	Terrestrial	-120.153	39.04923	West	West		2090	2	yes	O	35	72
M680	Terrestrial	-120.105	39.24462	North	West		2156	NA	yes	A	1	1
M701	Terrestrial	-120.05	38.84294	South	West		2227	NA	yes	J	18	41
M722	Terrestrial	-119.937	39.01399	East	East		1958	NA	yes	F	8	21
M8	Terrestrial	-119.932	39.06387	East	East		2058	2	no			
M99	Terrestrial	-119.958	38.91239	South	East		1940	NA	yes	G	11	27
MEL	Aquatic	-119.926	39.13559	East	East	S	2095	2	no			
MER	Aquatic	-120.158	39.0157	West	West	S	2036	3	yes	M	28	58
MUD	Aquatic	-119.953	39.29337	East	East	S	2814	3	yes	C	34	12
NCM	Aquatic	-119.903	39.13273	East	East	S	2276	2	no			
PIL	Aquatic	-119.923	39.16708	East	East	S	1974	2	yes	D	6	13

PUR	Aquatic	-119.942	38.83357	South	West	S	2497	2	no			
QUA	Aquatic	-120.165	39.06845	West	West	L	2072	2	no			
ROU	Aquatic	-120.007	38.75264	East	East	M	2008	NA	yes	I	17	38
SAW	Aquatic	-120.025	38.88742	South	East	M	1931	3	yes	K	24	50
SCM	Aquatic	-120.039	39.24113	North	West	M	1900	3	yes	B	4	7
SKI	Aquatic	-120.141	38.92266	West	West	M	2497	2	yes	L	26	54
SKY	Aquatic	-119.918	38.92475	East	East	M	2612	2	yes	G	10	25
SPO	Aquatic	-119.91	39.11276	East	East	L	2125	3	yes	D	7	16
U34	Aquatic	-120.155	39.17369	West	West	S	2069	2	yes	N	30	63
WAT	Aquatic	-120.139	39.22564	North	West	M	2365	3	yes	A	1	2
ZEP	Aquatic	-119.907	39.0186	East	East	S	2281	3	yes	F	8	20

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