Walker Lake – Terminal Lake at the Brink

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Setting

Vast bodies of water have filled and ebbed in desert basins of North America as ice ages have come and gone. Pluvial Lake Lahontan once covered much of the western Great Basin during periods of its most recent highest stand in lake level about 14,000 years ago (Figure 1). As Lahontan dried over the succeeding millennia it left behind two major lake remnants – Walker and Pyramid Lakes, both in western Nevada. Walker Lake is fed primarily by the Walker River, with its origins in the snowy peaks of the Sierra Nevada of California, entering at the northern end of the lake. To the west, the lake is bordered by the dry Wasuk Range, and geology of the watershed mixes volcanic and granitic rock types. As in other salt lakes of the western Great Basin, water chemistry is decidedly alkaline, a mix of carbonates, chloride, and sulfate salts of sodium at a pH near 10 and total dissolved solutes approaching 25 g/L (seawater is roughly 35 g/L, but mostly sodium and chloride with pH typically around 8). Walker Lake is monomictic, stratifying in spring and mixing in fall, with thermocline at a mean depth of about 10 m and maximum depth near 22 m, and a surface elevation of 1198 m (updated from Herbst et al. 2013a).

Figure 1. Map of the extent of Pleistocene Lake Lahontan and Lake Russell showing locations of present-day remnants of Walker Lake and Mono Lake.

History of Native Fish

Historical evidence gathered from lake-bottom sediment cores indicate that Walker Lake has become very shallow and possibly dried several times since becoming isolated from Lahontan. During these dry periods, which often lasted hundreds of years, native fish were able to find refuge in the Walker River until the lake refilled and salinities were suitable for them to return. Lahontan Cutthroat Trout, *Oncorhynchus clarkii henshawii*, (LCT) were once distributed throughout Lake Lahontan, but with the drying and recession of Lake Lahontan in the late Pleistocene-early Holocene, the LCT became isolated within river systems ending in terminal lakes in northern Nevada, eastern California, and southern Oregon. During 9,000 to 11,000 years of isolation LCT have diverged into four genetically distinct stocks (Peacock et al. 2010), all of which are obligate stream spawners. Those having access to lake habitats can live 5-14 years and can reach a size of 125 cm and 18 kg, making this iconic fish a prized catch that once gave Walker Lake renown as a popular recreational fishery that is now gone. Natural spawning runs of LCT began to diminish in the mid-1800s with the development of agricultural diversion dams. Large-scale construction of dams after the turn of the century cut LCT off to all suitable spawning habitat in the upper river, so extirpating the Walker Lake strain of LCT, with the last natural spawning runs being documented in the 1950s. Since that time the Walker River has been stocked with out-of-basin strains of LCT whose origins share elevated salinity levels. LCT were listed as endangered in 1970, then reclassified as threatened in 1975.

In modern times, upstream agricultural water diversions have resulted in a loss of river inflow, a vertical drop in lake level of over 150 feet, and an increase in salinity from 2.5 g/L to nearly 25 g/L at present (Figure 2). The increased salinity and loss of a river "escape route" for fish that led to the disappearance of LCT from Walker Lake now threatens the population of Tui chub as well. Salinity tolerance differs among the various strains of LCT, but acclimated and self-sustaining wild stocks suffer lethal effects of salinity at levels of 14-15.5 g/L (Sedinger et al. 2012).

Other Aquatic Life and Falling Lake Level

In addition to the mix of native fish species, the open waters of the lake have been inhabited by zooplankton including several cladocerans, copepods, and rotifers, some of which have also disappeared with rising salinity (Beutel et al. 2001). At salinities somewhat reduced from present conditions, the nitrogen-fixing cyanobacterium *Nodularia spumigena* was the dominant phytoplankton of the lake. *Nodularia* sometimes blooms to high densities and produces high oxygen demands as it dies and decomposes, along with other organic particulate matter in the hypolimnion of the stratified lake. This can also be accompanied by the generation of sometimes-toxic levels of ammonia. During summer warming of the epilimnion that reduces oxygen availability, the anoxia of the hypolimnion can combine to produce an oxygen deficit where fish are "squeezed" to a limited area of suitable habitat at mid-depths between these surface and bottom layers.

The lake bottom environment consists of anoxic sediments below the thermocline, and littoral shallows of mixed rock, sand, and mud where aquatic insects and other invertebrates have been found in abundance (Herbst et al. 2013a). Extensive macrophyte beds of the widgeon grass *Ruppia* occur in summer in the littoral zone of the lake, densest between 2 to 7 m depth. Within these beds and on rocky substrates in more shallow water, the midge *Cricotopus ornatus* and damselfly predator *Enallagma clausum* have been most common in recent years. In deeper water of the littoral zone, the midge *Tanypus grodhausi*, tolerant of oxygen-poor conditions, becomes dominant. Less abundant benthic invertebrates include the alkali fly *Ephydra hians*, the biting midge *Culicoides*, the small predatory diving beetle *Hygrotus masculinus*, and aquatic oligochaetes. Prior to salinities exceeding about 15 g/L, the amphipod *Hyalella* was the most abundant invertebrate of the littoral zone, but it too has since disappeared.

Experiments exposing damselfly nymphs and midge larvae to varied salinities showed that survival was best at levels of salt concentration that occurred in the past, and the 72-hr LC50 for midges was 25 g/L, just slightly higher than present day salinity (Herbst et al. 2013b). Damselfly growth and feeding rates were significantly reduced between 20 and 30 g/L, and mortality of smaller nymphs showed these early instars even more vulnerable on average. These results suggest both that these insects were already stressed and anticipated the changes now occurring in population dynamics.

In 2010, with lake level falling and salinity rising above 20 g/L, midge numbers were low in the fall cohort of that year and coming into the spring generation of 2011 (Figure 3). A deep snowpack and high stream runoff in 2011 resulted in rebounding numbers of the fall generation of midges and similar high recruitment into the 2012 population of damselflies. After this short respite of rising lake levels, prolonged drought conditions in 2012 and continuing into 2014 in the Sierra Nevada have restricted stream flows to less than half of the historic normal runoff. With upstream agricultural irrigation diversions, much less than this reached saline Walker Lake. After a record drought, lake levels continued to drop and salinity increased into ranges that are now threatening the populations of benthic invertebrates in the lake. As of summer 2013, the populations of previously dominant insects of the lake, the midge fly *Cricotopus* and damselfly *Enallagma* have crashed (Figure 3). These changes are continuing in 2014, with snowpack lagging behind even the drought of the previous two years. As these insect populations disappear at this salinity, there has been an ascendance of the more salt-tolerant alkali fly. This

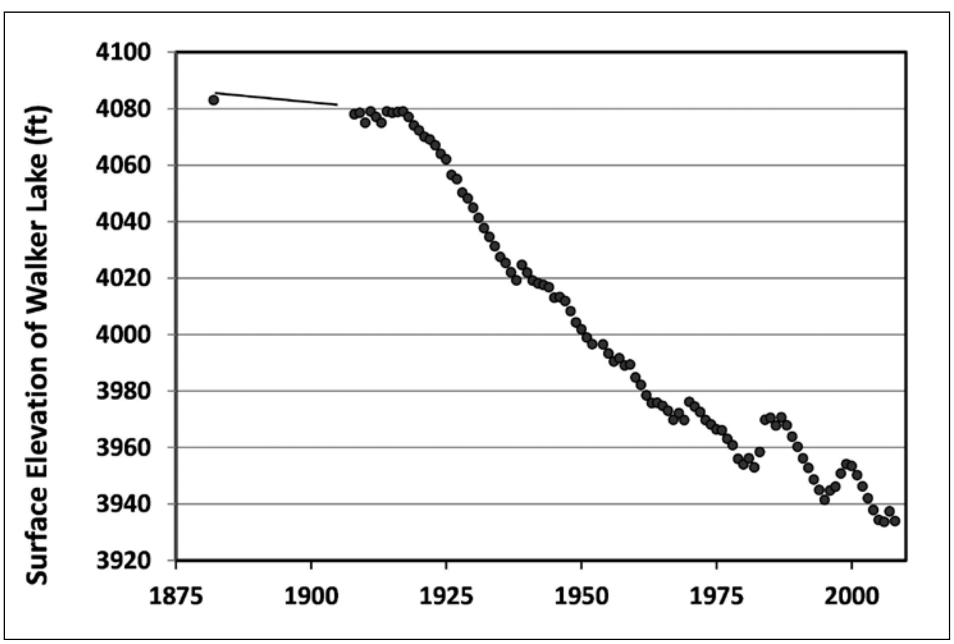

Figure 2. History of falling lake levels at Walker Lake.

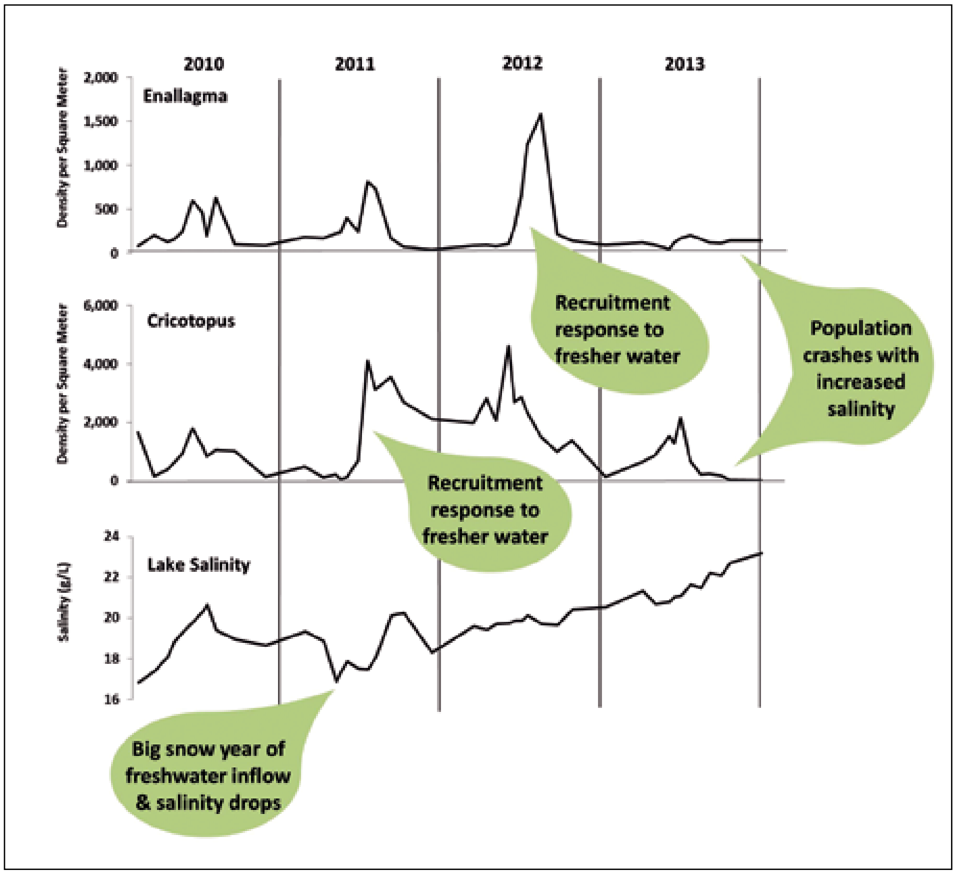

*Figure 3. Recent population dynamics of midges (*Cricotopus*), damselflies (*Enallagma*) and varied salinity in Walker Lake.*

could be re-stocked given the return of river flows and reduced salinity.

Conservation

Walker Lake has been the subject of considerable conservation focus, and terminal lakes in Nevada have benefited from being championed by U.S. Senator Harry Reid, who successfully passed the Desert Terminal Lake Act (P.L. 107-171). Since its original passage in 2002, Senator Reid has been able to amend the Act, including a provision in 2009 that establishes a Walker Basin Restoration Program administered and managed by the National Fish and Wildlife Foundation (NFWF). Under the Program, NFWF has been actively acquiring water rights and engaged in revegetation of retired farmland associated with water sales, water conservation measures, and other efforts to protect water in stream for Walker Lake. By 2014, NFWF has acquired approx. 27,000 AF of surface water storage rights, and over 6,300 acres of land from willing sellers for approximately $45.1 million. NFWF has been working through the legal process to protect and transfer the water rights

marks a transition in ecosystem structure that portends an altered food web (Figure 4), but also shows the conditions necessary for recovering the community that would exist at higher lake levels.

As the insects of the lake have been in decline so have the Tui chub. Falling numbers of the remaining fish in the lake over the past several years have now been joined by losses in the fish-eating birds of the lake, notably pelicans and cormorants (Figure 5). While it is tempting to conclude from these developments that the Walker Lake ecosystem is a lost cause, the fact is the lake is recoverable. As observed here and at other lakes of varied salinity, invertebrates can recolonize quickly from refuges in seepage areas around the lake shores or by flight, and hatchery-raised LCT

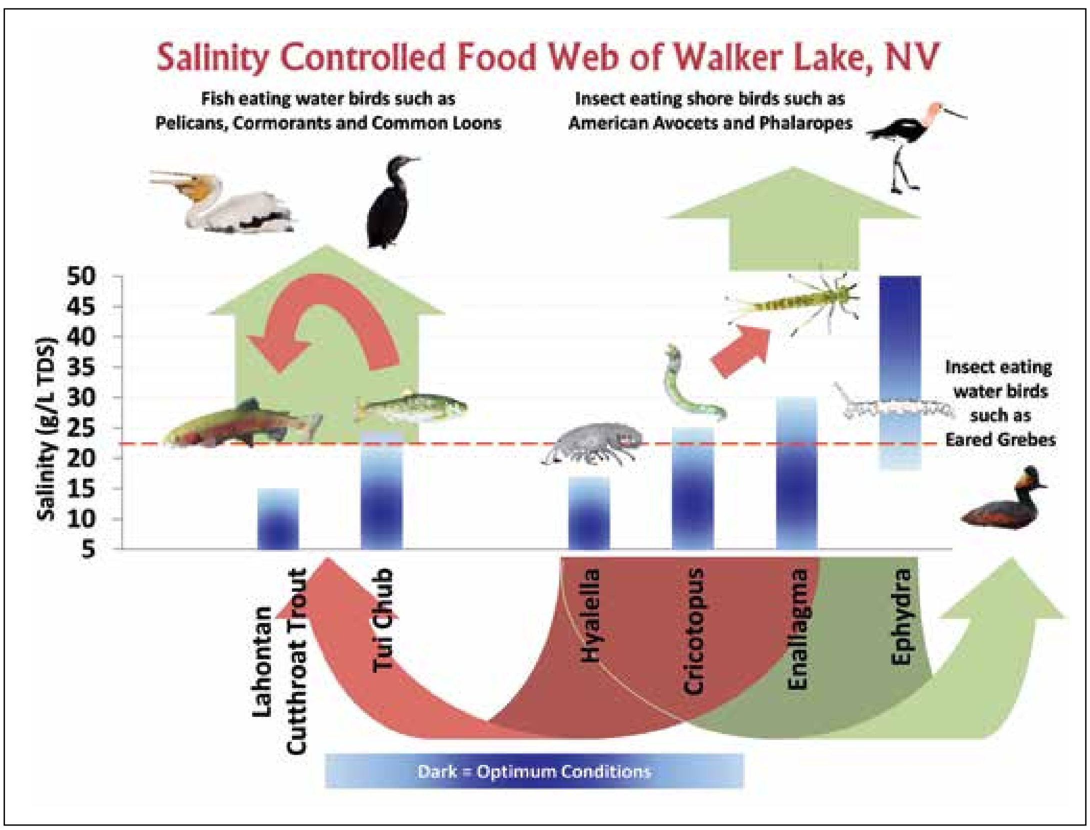

*Figure 4. Abundance increase of the more salt-tolerant alkali fly (*Ephydra*) as salinity rises.*

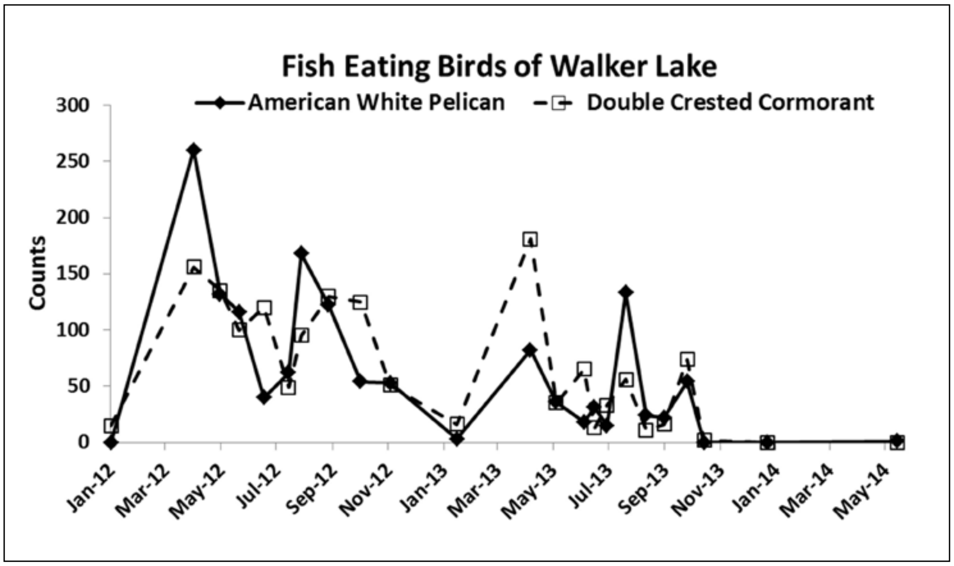

Figure 5. Decreased numbers of fish-eating pelicans and cormorants at Walker Lake.

for in stream use to benefit Walker River and Walker Lake. An important victory occurred in March 2014 when the Nevada State Engineer approved NFWF's initial application for transfer of approximately 2,200 AF of water rights. Before water from these water rights flows to the lake, the Federal Decree Court will review and rule on the proposed transfer. While a lengthy process remains to complete the objectives of the Program, Walker Lake is the beneficiary of an active water acquisition program that is hoped will provide secure and sustained water flows through the Walker River system for the future sustainability of the lake and ecosystem.

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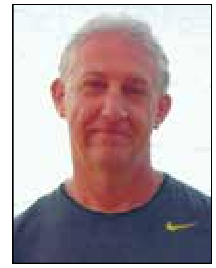
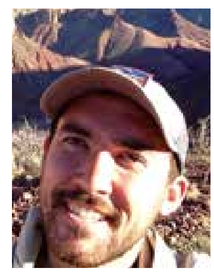
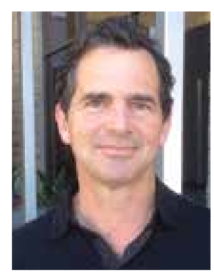


David Herbst is a research scientist with the Sierra Nevada Aquatic Research Laboratory of the University of California. He has studied the physiology and ecology of saline lake algae and invertebrates of the Great Basin since 1976. His interests extend into the headwater streams of the Sierra Nevada Mountains, where he investigates the effects of drought and climate change on watershed ecology.

Bruce Medhurst joined the Herbst lab team at the Sierra Nevada Aquatic Research Lab in 2001. His research interests have included aquatic toxicology and food web dynamics. He enjoys recreating year-round with his family in the vast outdoor laboratory of the Sierra Nevada.



Ian Bell is a laboratory assistant at the Sierra Nevada Aquatic Research Lab, where he loves the chance to get in the field and study Sierra streams and desert lakes. He will be studying water resources management at the University of California, Santa Barbara in the fall of 2014.



Graham Chisholm, co-founder of Great Basin Bird Observatory, has been active on land and water conservation projects in the Great Basin for the past two decades, helping protect and restore lands on the Truckee, Carson, and Walker Rivers, and acquiring in-stream flow water rights for Pyramid Lake, the Truckee River, and the Lahontan Valley wetlands.