Mono Lake: Streams Taken and Given Back, But Still Waiting

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Mono Lake lies at the western edge of the Great Basin desert and the eastern scarp of the Sierra Nevada Mountains, just east of Yosemite National Park. An isolated remnant of Pleistocene Lake Russell, the lake is set in a volcanic basin, with crater islands pushed up from beneath the lakebed adding to the scenic surroundings of mountain and desert vistas. Covering an area of about 70 square miles, the lake is renowned for limestone tufa towers emerging from underwater around the shores, and the throngs of birds that come to feed on abundant brine shrimp (*Artemia monica*) and alkali flies (*Ephydra hians*). This ancient volcanic-tectonic lake, estimated at more than 700,000 years old, has passed through long histories of glaciation and expansion, drought and contraction, and in modern times has set historic legal precedence for the protection of ecological values of terminal lakes.

Namesake

The name Mono is derived from the Native American Yokut word "fly," applied to the Monache people living on the eastern slopes of the Sierra at Mono Lake – the Kuzedika Paiutes. These people from the lake of the fly may have been known as such because of the commerce provided by the harvesting of pupae of the alkali fly as food from the lake. Early explorers such as Israel Russell observed the gathering of fly pupae "kutsavi" during which pupae attached to shallow submerged rocks were dislodged by kicking, and the floating pupae gathered from the water surface, dried in the sun, and the puparium case crushed and removed from the fat-rich pupa, about the size of a grain of rice. Flies were so productive that this was a staple food to not only the Kuzedika, but provided a valuable source of trade with coastal Indians (Davis and Logan 1965).

Chemistry and Tufa Towers

At the current surface elevation of 6,380 feet above mean sea level (MSL), the lake has an average depth of 60 feet and salinity of about 83 g/L total dissolved solutes consisting of an alkaline mix of carbonate, bicarbonate, sulfate, and chloride salts of sodium at a pH near 10. It is this high-carbonate alkalinity that promotes the formation of the lakes iconic tufa towers (Figure 1). These are formed as spring water, rich in dissolved calcium, bubbles up into the lake from submerged springs and precipitates as calcium carbonate limestone structures that accrete gradually into towers. Pumice blocks cast out from volcanic eruptions also serve as nucleation sites for the formation of gaylussite crystals that may also eventually turn into limestone (Bischoff et al. 1991). Still more exotic is the limestone that is added to tufa from excretions of alkali fly larvae. These insect larvae drink in carbonate-rich lake water, then remove these ions from the blood of their open circulatory system by combining with calcium inside the lime glands – modified Malpighian tubules, the kidneys of insects (Herbst and Bradley 1989). When larvae pupate and attach themselves to tufa for protection from

Figure 1. Tufa towers in Mono Lake.

waves, the contents of the lime glands are discharged and this cements to the tufa, adding to the complex reef-like surface of these exquisite rock formations.

History of Lake Level and Salinity

Although there have been natural fluctuations in climate, lake level, and salinity over the ages of this lake basin, diversion of tributary streams in 1941 for Los Angeles water supply began a period of protracted inflow deficit at Mono Lake. Without streams to balance evaporative losses, the lake declined rapidly, losing 45 feet and reaching a low in 1981 (Figure 2). Salinity doubled in that time from about 50 to 100 g/L, dust flats emerged on the dried margins of the lake, islands with breeding bird colonies were bridged to land where predators could gain access, and aquatic life was stressed by the concentrated salt load. In 1978 the Mono Lake Committee formed to publicize the plight of the lake, document the problems, and seek conservation solutions that would both protect the lake and save water in Los Angeles (www.monolake.org).

In 1994, the State Water Resources Control Board ordered that streams be returned to Mono Lake and determined that a lake level of 6,392 feet MSL could provide a compromise that preserved ecological values of the lake, minimized air pollution from dust, restored stream ecosystems, and could still deliver a modicum of water and power to the city. Hydrologic models suggested that this could be achieved in 20 years but now in 2014, that has yet to be realized. This may be due to models based on inaccurate optimistic assumptions for Sierra runoff, underestimated evaporation rates, and to changing climate.

Climate Change Forecasts

Mountain stream flow has been shifting to more coming from rain than snowmelt, earlier melting runoff, and being more prone to drought and extreme variations such as winter flooding. Forecasts for the Mono Basin based on climate change models suggest a significant hydrologic shift by the end of the century (Ficklin et al. 2013). Modeling predicts 15 percent decrease in annual streamflow, peak runoff earlier by a month, from June to May, plus the likelihood of wet water year types declines and droughts become more frequent. The challenge of water management and sustaining the health of habitats of all kinds is contingent on planning that incorporates this likely future.

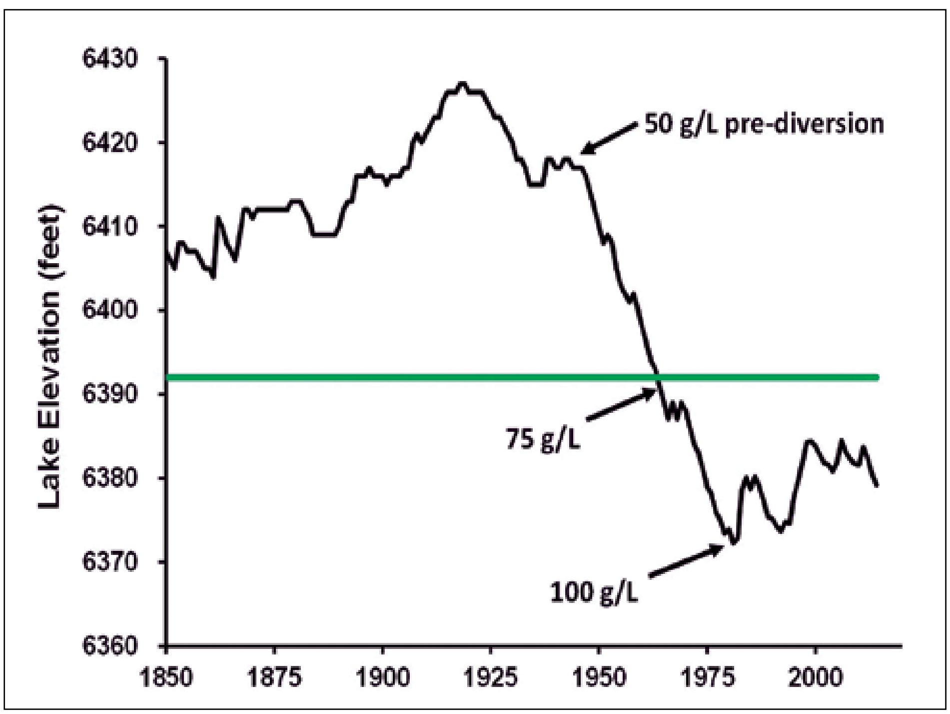

Figure 2. Mono Lake water level changes since 1850 with the line at 6392' elevation showing the management level ordered by the California State Water Resources Control Board.

Simple Ecosystem and Severe Chemical Environment

There are few species capable of tolerating the harsh chemical environment of the lake, but for those adapted, there is little competition for resources and few predators. The brine shrimp *Artemia monica*, a species endemic to the lake, thrives in the open water plankton. It is even harvested for commercial sale (often in aquaculture). This primitive crustacean filter feeds on phytoplankton with feathery legs that also serve as gills and is capable of osmoregulation in high salinity, but at a price – slower growth and reduced reproduction (Dana and Lenz 1986). The abundance of this species is affected by wet-year meromictic conditions whereby the lake fails to mix when inflowing freshwater layers over more saline, deep nutrients become unavailable, and the phytoplankton food to shrimp is scarce and limits growth and reproduction (Melack and Jellison 1998).

Meanwhile, living in the shallows of the littoral region, especially in the rocky tufa tidal zone, are the larvae and pupae of the alkali fly, also capable of osmoregulation (Herbst et al. 1988). Adults of the alkali fly are capable of crawling underwater, enveloped in a film of air, where they feed on, and lay eggs in algae. Although they maintain ionic and osmotic equilibrium over a wide salinity range, as the concentration rises, the growth rates of larvae and size at maturity of pupae decrease, resulting in fewer adults emerging and those that do are smaller, have less fat reserve, and lower reproductive success, and are further limited by less algae food resources (Figure 3). This inhibitory influence of salinity on aquatic life at Mono Lake and other salt lakes is an important factor to consider in setting lake levels for conservation management of productive habitat.

Mono Lake is a haven for bird life, especially shorebirds, coming to feed along the shores or in the shallows, on the prolific alkali fly. All life stages of the flies serve as aggregated food – the larvae in shallow areas on algae mats or on tufa, pupae floating on the surface, and adults along the edges of the water (Figure 4). Notable are the tens of thousands of Wilson's and Red-necked Phalaropes, migratory species that refuel at productive

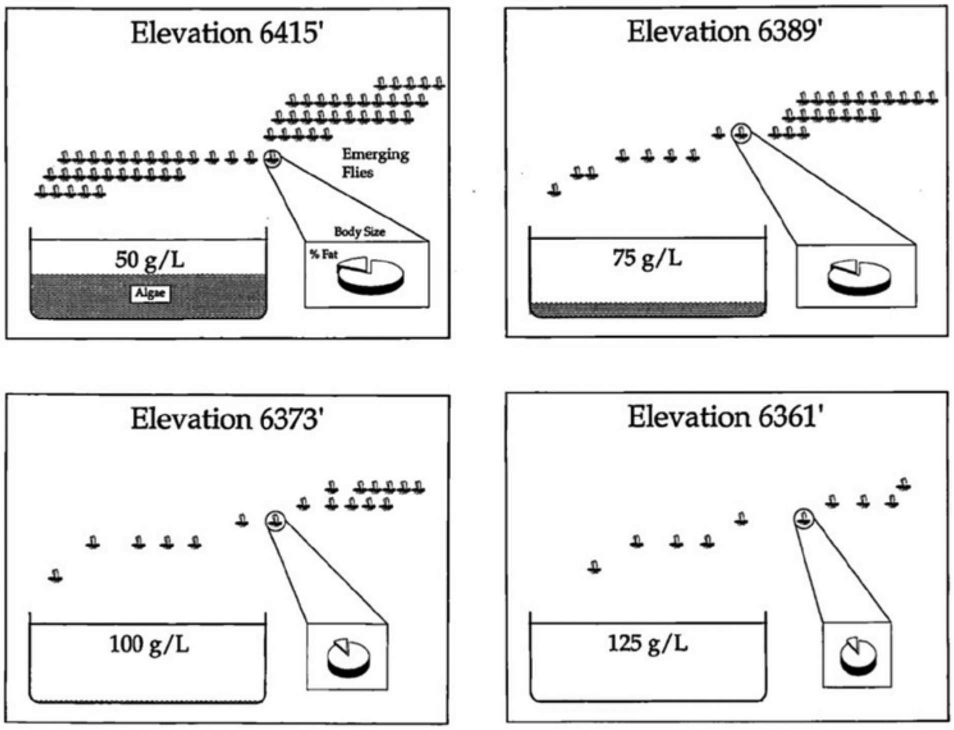

Figure 3. Results from 500-L mesocosm experiments at Mono Lake showing the production of emerging flies at different salinities and equivalent lake levels. As salinity increases, fewer flies emerge, the size of flies (the pies) is smaller, they contain less fat (pie slice), and growth of benthic algae is reduced (dark area at bottom of tanks). From Herbst and Blinn (1998).

Figure 4. Adult flies aggregated along the edges of the lakeshore, providing a readily available food source to shorebirds.

saline lakes, wintering in South America (often the altiplano desert) and breeding in North America (Canada and the Arctic). These birds can be seen spinning on the water surface near shore where they create a vortex of water that brings fly larvae or other invertebrates to the surface where they pick them off. Eared Grebes are also abundant, in excess of a million birds on migrations, stopping to dive and feed on shrimp and flies.

Mono Lake is also host to island colonies of the California Gulls. When lake levels drop, these islands become land-bridged, giving access to predators like coyotes that have decimated the colony. Waterfowl were once abundant on the lake and in onshore wetland marshes that were extensive at higher lake levels. Millions of mixed migratory ducks including Northern Shovelers, Ruddy Ducks and others came to feed on mixed insects and vegetation. Water in the streams that had been dried has been restored for fishery and riparian values, supporting planted trout and many birds in the re-growing streamside forests. Keeping in-stream flows for fish habitat as a requirement of law delivers water to the lake in turn, and so encompasses restoration of the watershed from source to sink.

Conservation Victories Highlight the Integration of Science and Public Trust Water Law

The Mono Lake Committee was founded on scientific research showing the impacts of lower levels and rising salinity. Conservation efforts began with scientific documentation of how salinity affected the health of aquatic life, the value of the lake to hundreds of thousands of water birds, and the stream habitat lost on Rush and Lee Vining Creeks. Combined with this evidence, legal arguments to protect the lake as a public trust resource set a precedent for laws that preserve natural values of waters as a common heritage of people and wildlife. The State has a duty to maintain this public trust doctrine. The prescription for Mono Lake was return of stream flow until it reached an elevation where aesthetic, recreation, and ecological values would be balanced with urban water needs. The lake essentially won back rights to half of the water volume it had lost, to be returned to a salinity near

75 g/L. We don't yet know how long that will take or if that long-range goal can be achieved.

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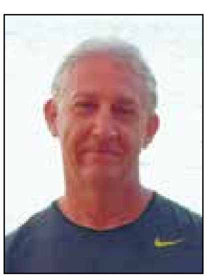

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