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G188
Final Paper



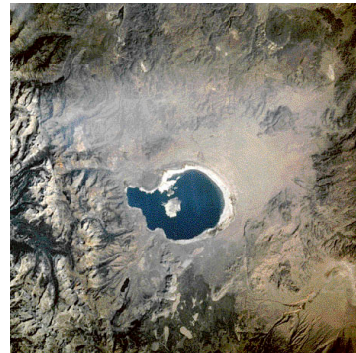
California Gulls over
Mono Lake
(Mono Committee website)

The Effects of Mono Lake's Hydrology on its Ecosystem

Situated at the foothills of the Eastern Sierra Nevada, Mono Lake has an unusual and unique hydrology that is highly influential in shaping the water chemistry (specifically the water's salinity and alkalinity) and biological life that survives there.

Mono Lake is a hypersaline, highly alkaline, hydrographically closed basin in which the only natural means of water export is through evaporation. The basin itself was carved out by faulting of tectonic plates that occurred at least 500,000 years ago. "Mono Basin contains up to 7,000 ft. of glacial, fluvial, lacustrine and volcanic deposits in a large structural depression formed in part by down-dropping along the Sierra Nevada fault" (Pakiser 1976).

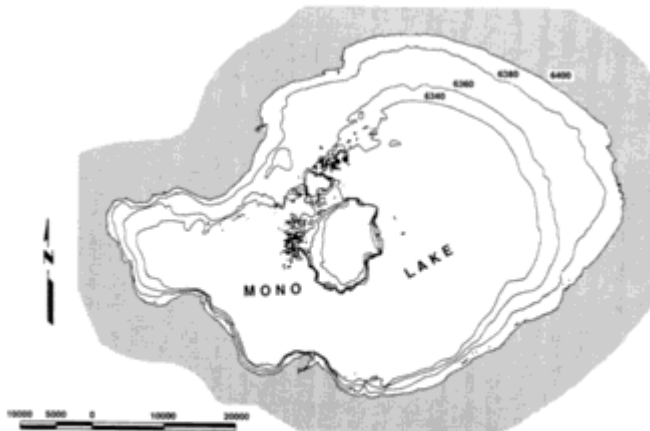
Aerial View of the closed Mono Basin
(Orbit Experience photo gallery)



In addition to the water evaporated, the Los Angeles Department of Water and Power (DWP) began diverting Mono Lake's water and approximately 58% of its natural inflow (annually) to supply 13% of the city of Los Angeles's

water supply in 1940 (Stine 1991). "Because lake volume fluctuates in response to varying inflow and evaporation, the late-water concentration and composition can

experience substantial change through time” (Rogers 1992). A high concentration of soluble compounds and salts formed inherently as evaporation occurred, and minerals and compounds were left behind.



Composite representation of Mono Lake shoreline at 6400, 6380, 6360 and 6340 ft. above sea level (The Mono Basin Ecosystem 1987)

Runoff, erosional sediments and precipitation (rain and snowfall are limited in the Eastern side due to the rainshadow effect) from the Sierra Nevada accumulate in the Mono Basin. Also ephemeral perennial streams from the Sierra Nevada flow into the Mono Basin. Because of this, a great deal of the groundwater and the groundwater hydrological system is dominated by stream losses from the mountains. Fault lines can also be highly influential to the production of groundwater.

According to USGS’s Ronald Oremland, “The lake is usually monomictic, and undergoes one complete winter mixing event induced by the sinking of cold surface waters. However, inputs of large amounts of freshwater into the lake in the early 1980s and again in the late 1990s resulted in episodes of meromixis” (Oremland 2000). Jellison predicts that the meromixis phase that is currently occurring will last several decades. Meromixis generally produces buildup of ammonia, sulfide and methane.

“In many cases diversions of freshwater inputs for irrigation or other human uses have resulted in diminished size and increased salinity” (Jellison 1992). Diverting Mono Lake’s streams has not only stirred political and environmental controversy over rights but has also led to the waters of Mono Lake being halved in lake volume, reduced by 45 ft. in lake level, and doubled in lake salinity, which has drastically effected organic and biological life at Mono Lake. “Biologists warn that as the salinity of Mono Lake rises due to the artificially induced decrease in lake volume, osmotic stress will inhibit the growth and reproduction, and ultimately preclude the existence, of the lake’s brine shrimp and alkali flies” (Stine 1991).

Salinity is directly influenced by the rise and fall of lake level. If lake levels are increasing, salinity tends to be inversely proportional, as total dissolved solids (TDS) has more solvent in which to dissolve. Conversely, if lake levels are decreasing, as has occurred historically in the Mono Basin, TDS will increase accordingly. “Recent studies of some closed-basins and related drainages in the western United States have shown that loss or gain of dissolved salts from lake waters is closely associated with fluctuations in lake level...” (Rogers 1992). Rogers goes on to cite Scott Stine (1991) and David Groeneveld (1991) in their findings on vegetation in Mono’s saline waters, “Evaporation of the saline groundwater leads to precipitation of a seasonal salt crust, a source of air pollution under high wind conditions. The high salinity and concentration of elements such as boron and arsenic in this water prevent plant establishment which would reduce salt deflation.”

Rogers hypothesizes several origins of the saline deposits of Mono Lake, including “drainage and flushing of former lake water deposited with sediments during

previous lake highstands,” an increase of “solute load due to evaporative concentration of recharge entering the basin with contributions from dissolution of saline soil coatings” and “recirculation of deep basinal saline water along a brine/freshwater interface causing a discharge of water at the surface.”

In an intense study by SNARL’s own Dr. David Herbst, Mono Lake’s most common insect-- the alkali fly (*E. hians*) was monitored closely as to its survivorship in relation to fluctuation in Mono Lake’s salinity and changing lake level. He stated, “Increased salinity has direct effects on the alkali fly, such as lower survival, slower growth, reduced size at maturity and delayed reproduction. An indirect effect on flies is also exhibited in the decreased growth rates of some of their algal food sources when exposed to increased salinities.”

Swarm of Alkali Flies
(G188 course website!)



He observed three instars, finding that at there is defined lethal limit at which survival of alkali flies can no longer exist abundantly at 150 g/L. He states, “For each increment of salinity level, growth rate decreases by about

30 percent. Although larval development time was extended under the slower growth limits of high salinity, this was insufficient to prevent a reduction in the size at maturity (of pupae) over this same range of increasing salinity.”

Herbst also identifies the water diversions as being a clear inhibition on the ecological life, specifically in the production of the flies. “These results suggest that water diversions have already put limitations on production of the alkali fly and that

continued diversions will further reduce benthic habitat availability and population productivity” (Herbst 1992). His studies show that at this rate, within fifty years, salinity will reach an excess of 200 g/L, a point at which alkali flies will not survive readily. In Scott Stine’s 1991 study, he predicts that with “uncurtailed diversions by the DWP, the lake at its predicted stabilization level of 6,330 ft. will reach a salinity of around 248 g/L.” LADWP’s predicted salinity chart from 1986, shown below, shows that at their estimated stabilization level of 6325 ft., salinity will reach an even higher TDS of 273.1 g/L.

TABLE 6.2 Predicted Salinity Values for Lake Elevations Below the Present-day Level of Mono Lake (LADWP, 1986)

Lake Elevation (ft)	Salinity (g/l total dissolved solids)
6370	101.6
6365	110.9
6360	121.4
6355	133.6
6350	147.8
6345	164.6
6340	184.5
6335	208.2
6330	237.2
6325	273.1

(The Mono Basin Ecosystem 1987)

In order to survive the harsh extremities of saline life at Mono Lake, the flies must be willing to adapt. “This crucial adaptation to life in saline waters is also more effective in alkaline (carbonate) than non alkaline (high chlorine content) chemical conditions” (Herbst 1992). He suspects that larval physiology will most likely be able to alter its metabolic energy used accordingly with differed salinity. But in any case, a continued increase in salinity will be detrimental and cause severe challenges to the procreation of alkali flies. “This principle forms the basis for an operational hypothesis that increased

salinities at Mono Lake will have a limiting effect on alkali fly development and survival” (Herbst 1992).

In a similar study done by Dana and Lenz (1986), Mono Lake’s abundant brine shrimp were monitored at varying salinities finding that at a salinity of approximately 130 g/L, brine shrimp hatching drops to one third of its present level.

Enlarged photo of Brine Shrimp
(USGS website photo gallery)

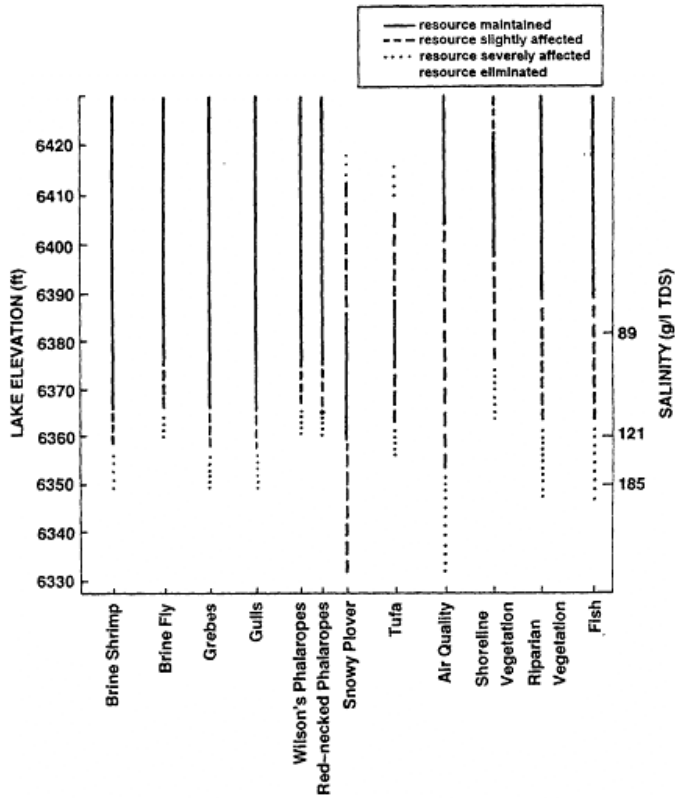


Providing that saline predictions are accurate at a long-term stabilization between 200 and 248 g/L conservatively, it

can be deduced that the future of Mono Lake’s two most thriving organisms as well as the many organisms that need the alkali fly and brine shrimp as their primary food source (including the many gulls and bird life that use Mono Lake as a pit stop during migration) may be at stake.

“Concern is not only with the shrimp and flies themselves, but with the hundreds of thousands of eared grebes and phalaropes that depend on these animals for food during their annual migratory stopover at the lake” (Stine 1991). Though current lake level salinity as recorded by the Mono Lake Committee’s recently updated website (updated January of 2004) is lingering at a manageable salinity of 80.8 g/L at a lake level of 6382.8 ft.

Salinity in g/L TDS vs. Lake Elevation in ft. above sea level
 vs. Survivorship of organisms at Mono Lake, CA
 (Mono Basin Research website)

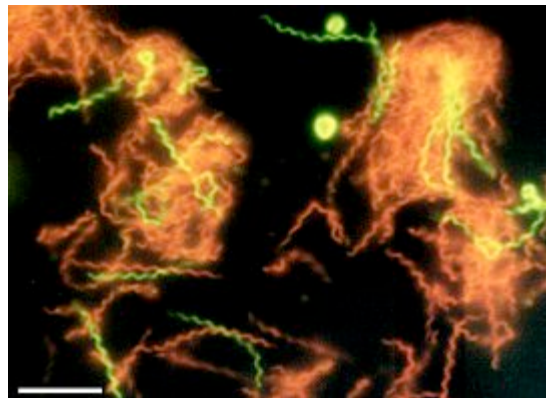


Other than the high concentration of salt, Mono Lake water also contains a great deal of other ions. “Sodium is the major cation, and chloride and carbonate are the major anions, while sulfate, borate, silica and phosphate concentrations are also high” (Mason 1967). Oremland also addresses the “exceptionally high” concentrations of inorganic arsenic. He states, “Arsenate is potentially an important electron acceptor for bacterial respiration in the lake, having abundance, comparable to that of dissolved oxygen, but well below sulfate” (Oremland 2000). According to the Mono Lake Committee, the lake contains the highest concentration of boron than any other lake and also has a significant amount of potassium. “An estimated 280 million tons of solids are dissolved within the lake, and it is 2-3 times saltier than the ocean depending on its water level fluctuation

over the years. Periodic eruptions of volcanic ash have also added considerably to Mono's chemical mix" (Mono Lake Committee 2004).

Because of the high carbonate concentration, Mono Lake water is extremely alkaline, with a pH concentration of 9.8, which deems it a strong base. With a pH of about 10, the water is about as alkaline as Milk of Magnesia. Mono Lake Committee states that at such a high alkalinity, it makes fish life nearly impossible. No fish live at Mono Lake, but that might actually be considered a benefit as fish would serve as competition for the bird life (in consuming the brine shrimp and alkali flies). Despite this fact that fish cannot survive at these high alkaline waters, some microorganisms actually crave the harsh and extreme conditions presented at Mono Lake.

Recently, NASA scientists studying Mono Lake found that the bacteria *Spirochaeta americana* (shown to the right) is one of those bacteria called "extremophiles," which thrives on challenging conditions. NASA astrobiologist Richard Hoover said, "By studying microorganisms found in Earth's



Spirochaeta Americana (Hoover 2003)

extreme places, like Mono Lake, we begin to understand how life might exist on Mars or on other worlds" (Hoover 2003). NASA plans to research microbes at Mono Lake to a greater extent soon. They have also been interested in the creation of tufa at Mono Lake and any microfossils that may exist in the tufa. Tufa (shown left), limestone towers that

originate naturally by the mixing of calcium-rich spring water and bicarbonate-rich lake water, is also a landmark biological creation caused by the water's strong alkalinity.

Tufa at Mono Lake (Mono Committee website)

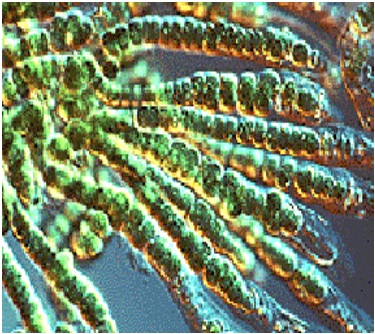


In Herbst's study on benthic alkali fly survival, he also studied the effects of lake level fluctuation and salinity changes on tufa and other substrates, as they pose as an essential habitat for the alkali flies. With even a comparatively slight fluctuation of 10 ft. in lake level recession, the tufa and alkali fly population is greatly effected. He states, "Censusing of the larvae and pupae on different substrates around the lake demonstrated that densities are greatest on the hard tufa substrate. Tufa habitat is maximized at an elevation of 6,380 ft. and almost 60 percent of this becomes lost by exposure with a drop in lake level to 6,370 ft. An associated proportional decrease in the abundance of the alkali fly assumes that other substrates will not serve as an alternate habitat and that the density of this insect cannot be increased without negative feedback."

In another study conducted by NASA, astrobiologists looked specifically for bacteria and the core functional groups of organic life (including phospholipid fatty acids and amino acid proteins) which could withstand the challenging pH levels of Mono Lake. The reasoning behind this intense study of Mono Lake is that because it is hypersaline and highly alkaline, it serves as a direct analog to the open waters found previously on Mars's surface. "We have examined the total bacterial population (as judged by epifluorescence microscopy), cultivable aerobic heterotrophs, and sulfur-reducing facultative anaerobes of Mono Lake near-shore sediment. The number of non-

autofluorescent microbial cells (as seen by DAPI fluorescence) was 5.6×10^9 cells/g of wet sediment. Up to 1×10^7 colony forming units (CFU) per ml were obtained using a defined medium based on Mono Lake water.”

Not only did they find a flourishing microbial life, but also a very prominent presence of proteins. “Amylase-, lipase-, and protease-producers (determined by plate assays) were found at CFU of 4.0×10^5 , 1.5×10^5 and 2.1×10^6 per g, respectively. Sulfur (polysulfide) reducing bacteria were found at CFU of 5.0×10^3 per g.”



Cyanobacteria (Google images search)

They also studied the cyanobacteria (blue green algae, shown above) growth, which serves as the primary food source for the brine shrimp population. The report states, “In addition, we have detected and isolated photosynthetic cyanobacteria from inside the mineral matrix of tufa from Mono Lake. These communities provide an especially useful model for the study of biosignature formation. A continuous biotic zone beneath the surface of large rock boulders is a defined target for automated in situ life detection. Bacterial activities result in physical and chemical alterations of the rock matrix, which are likely to survive over geological time scales under appropriate conditions. Also, the rock matrix serves as a mechanism to immobilize organic biosignatures, preventing their dispersal.” (McDonald 1999).

The Mono Lake Committee stresses the importance of acknowledging Mono Lake's flourishing ecological diversity. It states, "The chemical richness of the lake fosters a spectacularly productive but relatively simple food web that begins with the growth of microscopic algae several times each year. Together with other sources of food, these algae feed the growth of trillions of specialized brine shrimp (*Artemia monica*) and alkali flies (*Ephydra hians*) that swarm in the shallows and along the shoreline of the lake."



Flock of Wilson's Phalaropes over South Tufa
(Mono Committee Website)

It goes on to say, "These rich sources of protein in turn attract nesting California gulls (*Larus californicus*) and hundreds of thousands of migratory shorebirds, including Wilson's phalaropes (*Phalaropus tricolor*), red-necked phalaropes (*P. lobatus*), eared grebes (*Podiceps nigricollis*), snowy plovers (*Charadrius alexandrinus*), killdeer (*C. vociferus*), western sandpipers (*Calidris mauri*), and many others" (Mono Lake Committee 2004). Mono Lake has an incredible variety of birds not only because of the tasty and appealing food options, but also because Mono Lake is situated along the general migratory path that hundreds of flocks of birds take annually. It serves as a perfect destination for birds to come, hang out on the tufa and eat the delicious brine shrimp. What a great life.

Sierra Nevada Aquatic Research Laboratory (SNARL!) is currently working in accordance with the Mono Lake Microbial Observatory project whose goal is to “examine the distributions of Mono Lake microbes and to understand the response of microbial assemblages to the gradients of physical and chemical variables in relation to temporal changes driven by hydrodynamics.” This is an incredibly important project as very little is known about the microorganisms living at Mono Lake and the chemical and biological conditions in which they are able to survive.

Due to Mono Lake’s incredible hydrology of being a closed basin with no outlets (other than evaporation and the man-made diversions of water), it has inherently become a hypersaline and highly alkaline lake, which has shaped the ecosystem which can survive under those conditions. Fluctuations in lake level, volume, salinity and concentration of runoff sediments and ions also help to shape the organic life.

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