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# Algae in Sierra Nevada Mountain Wilderness Areas: Potential Health Hazards

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## Introduction

Over the past 50 years, algae biomass has increased in the Sierra Nevada Mountains of California USA (Goldman 2000). If this trend is not corrected the drinking water supply that from the Sierra watershed may become a health risk by excretion of toxins by the algae (Derlet 2009). Nearly 50% of California's water originates from the Sierra, and much of this from the 10,000 square mile watershed above 6,0000 ft elevation commonly referred to as the "High Sierra." Prior to the 1850's water in the Lakes and Streams of the High Sierra Nevada mountains were nearly free of algae and clean and clear. For example, early visitors to Lake Tahoe remarked that it had exceptionally brilliant waters, with visibility exceeding 100 feet (Farhqur 1965). During the early 1900s travelers to high country lakes and streams above 6,000 ft elevation marveled at the clarity of the water. However, much has changed over the past 150 years in the sensitive habitats and wilderness of the high Sierra. Development such as roads, urbanization, forestry, and mining also brought large scale changes in land use, pollutants, and hydrology, resulting in significant and widespread deterioration of water quality. The clear relationship between development and subsequent decline in water quality in developed areas such as Lake Tahoe have been discussed, regulated, and litigated for years. Less attention has been paid to the high elevation wilderness and road-less areas of the Sierra, where most people assume and expect that water quality remain of pristine quality. Unfortunately, water quality has deteriorated in once pristine watersheds, and like Lake Tahoe, and increasing algae in high elevation wilderness areas has increased (Ursem 2009).

Globally, concern has been raised about serious threats to the planet's drinking water supply from eutrophication of watersheds (Conley 2009). One of the best markers of water quality is the amount of algae growing in the water; both suspended, and attached or so called benthic vegetation. As far back as the 1880's the detrimental effect of algae on alpine water quality was noted and cited as one of the reasons to establish Yosemite National Park in 1890 (Farhqur 1965). Visible algae in many High Sierra lakes and streams have clearly increased over the past 50 years. Increased algal growth is a global management issue, causing multiple problems including reduced water clarity and the emergence of "pea soup" colored lakes, oxygen depletion, declines in drinking water supply/increased cost of drinking water purification, and in more extreme cases resulting in blooms of toxic algae, fish kills, and clogging of waterways with water weeds (Horne 1994). All of these symptoms require costly solutions, yet can be prevented by simple land use practices and watershed management.

Eutrophication is the scientific term that describes increased algal growth caused by elevated concentrations of nutrients, especially biologically available forms of Nitrogen and Phosphorus, in lakes, rivers, and their watersheds. Algae are aquatic plant like organisms that require nutrients and sunlight to grow. When provided both, they flourish and reduce water clarity, turning it a turbid green color, or by increasing attached "weed-like" forms in shallow creeks and lakes. Eventually, increased algal matter causes several changes to the chemical and biological functions of aquatic systems. For alpine watersheds adapted to a low nutrient state, eutrophication poses a more serious threat because there are few natural filters such as large wetlands and meadows that normally absorb some of the nutrients out of the water.

## Increasing Algae in the High Sierra: Eutrophication of a Unique Environment

The Sierra Nevada has enormous economic importance from the provision of abundant quantities of fresh water for California. The Sierra Nevada watersheds provide the majority of California's fresh water for domestic use (Carle 2004). Most of this water is derived from the snow-pack of the 10,000 square miles above the 6,000 ft elevation level. Most of this high elevation watershed consists of surface or near surface granite or metamorphic bedrock, with shallow topsoil and has minimal buffering capacity (Moore 2000).

Since the discovery of gold in 1848, deposition of growth limiting nutrients such as phosphorus (P) and nitrogen (N) has resulted in eutrophication of much of the Sierra Nevada, with increases in phytoplankton production rate and biomass. Indeed, the high Sierra was so nutrient limited that even traces additions of nitrogen via atmospheric deposition is enough to stimulate algal growth in lakes (Goldman 2000). As a result, minor amounts of environmental pollution may have a significant impact on aquatic life since there is little or no biogeochemical retention, transformation, or fixation of trace elements, neither any capacity to absorb or filter major nutrients such as nitrogen and phosphorus. Relatively small amounts of nutrient addition or habitat disturbance leads to significant impacts on nutrient flux and subsequent impacts on the aquatic ecosystems of lakes and streams. Some irreversible damage may have occurred from extensive sheep and cattle grazing in remote Sierra wilderness between 1860 and 1900 (Roth 1965). In addition to this historic accumulation current deposition of rate limiting algae growth substrates will contribute to a potential massive algae blooms on the scale of the Klamath River disaster.

As noted above, prior to the discovery of gold in the Sierra foothills, the minute quantities of algae biomass found in the high Sierra Nevada were the result of natural conditions of low nutrient concentrations. Thus the water had a unique and brilliant clarity. The natural biotica a unique assemblage of phytoplankton and marsh weeds, which support an ecosystem, composed of native insects, fish, amphibians, birds, and mammals. Increasing nutrient loads into the water shifts the base of the ecosystem, causing changes in the composition of algae and plants, with consequences to other animals and water quality.

At low levels, increased rates of algal growth cause minor problems such as reduced water clarity and increased water weeds as seen in Lake Tahoe (Goldman 2000). However, even at low levels, increased algal growth indicates long term and steady trends in water quality degradation as they signal a shift in the watershed processes. If left unchecked, this shift is prone to get worse, as nutrients tend to accumulate and eutrophication has many feedback cycles, which over time, accelerate the problem. In a way, low level increases in algal growth are an early warning for highly sensitive alpine watersheds.

Lower water clarity means less sunlight for algal growth at deeper waters in lakes. Since algae produce oxygen, darker waters mean less oxygen. In other words, as more algae crowd the surface waters, there is less light and less oxygen in deeper waters. In addition to the quantity, eutrophication also changes the quality of algae. As nutrients increase, the composition of algae shift to those that are harmful or have less nutritional value. This disrupts the transfer of energy to higher animals such as fish. With most of the algae not eaten, they sink to the bottom and rot, further depleting oxygen during the slow decomposition process. The combination of reduced clarity and shifting composition of algae can create low oxygen zones causing fish kills. Algae also secrete glycolic acid, which is believed to be a contributing cause of foam now observed in many high Sierra lakes and streams (Goldman, 2009, personal communication).

Low oxygen also triggers a feedback in the Phosphorus cycle. In short, when oxygen concentrations drop below a threshold, sediments begin to release phosphorus into the water, increasing algal growth even more. During this well documented cycle, called internal loading, nutrients released by human activity result in unintended feedbacks causing even more nutrient release from the lake itself. Lake sediments can absorb Phosphorus in well oxygenated waters due to chemical qualities of iron, and release the Phosphorus when oxygen levels drop.

Eutrophication can act as a fertilizer to increase dominance of harmful algae such as cyanobacteria, which produce toxins that affect humans and animals alike, and severely degrade water quality. Increased rotting algae can also promote bacterial growth and also provide habitat for harmful pathogens such as *E-coli, Salmonella, Campylobactor and Giardia*. Human pathogens do not survive well in pure water, however the presence of algae means that the necessary nutriments for survival of harmful microorganisms are present (Yers 2005). Taken together, impacts of increased and unwanted algae affect animals and humans and can be prevented by simple management of watershed land use practices that regulate nutrient loading into surface waters.

## Health Hazards from Algae

Certain species of algae, including but not limited to blue green algae may produce toxins, which can harm humans, pets and domestic animals. When high nutrient conditions coincide with warmer water temperatures, toxic cyanobacteria (a blue green algae) can proliferate. Some species of these algae produce toxins that are harmful to aquatic organisms, animals and humans alike (Falconer 2005). The most common toxins recognized include microcystins, anatoxin, saxitoxin, physteria toxin, and others. Multiple reports of human illness and death have been reported as a result of exposure to waters containing toxic species of algae (Araoz 2009). In some instances just inhaling the vapors and mist of contaminated water has been enough to induce illness (Shoemaker 2007).

Secretion of algae toxins is not limited to swampy, stagnant waters. Death of pets and domesticated animals in remote high elevation mountain environments has been documented. Several species of native wild animals died in Spanish National Parks after drinking water contaminated with several types of toxins produced by algae (Lopez-Rodas Maneiro 2008). Cases of toxic algae blooms have been recorded in the Swiss Alps, another high mountain ecosystem (Mez 1998). Microcystin toxin from algae in the Swiss Alps has also resulted in the death of animals that drink the water, and in over 100 deaths of cattle reported at multiple mountain locations (Mez 1997).

Microcystins induce liver injury which can progress to hepatic necrosis and death, and is the most widespread of the algae toxins. It is found currently in the delta of the Sacramento and San Joaquin rivers in California (Ger 2009). Poisoning can be acute, if sufficient quantities of contaminated water is ingested. More commonly, chronic toxicity with progressive liver failure occurs in those who unknowingly ingest small quantities of contaminated water daily.

Anatoxins and Saxitoxins comprise another class of toxins. These are potent neurotoxins, which cause seizures and death if ingested. Relatively small amounts less than a milligram may be enough to harm humans. Thus a mouthful of poisoned water may cause symptoms. Pfiesteria toxin, which is produced by the algae species P. pfiesteria also can cause memory loss, which can be permanent (Shoemaker 2007). In higher doses this toxin also results in death. The impact of ingesting low doses over sustained periods of time can also damage the human nervous system (Araoz 2009).

Poisoning from California mountain water is not an academic theory, but a current and very serious threat already affecting to parts of California. The problems along the Lower Klamath River in Northern California serve as the warning of what may occur in the Sierra Nevada watersheds. The Klamath is not a small river; it has of the largest annual volume of water flow of all rivers in California. Years of Nitrogen and Phosphorus rich discharge from upstream agricultural operations combined with enhancing effect of dams has resulted in the overgrowth of algae. Beginning with the summer of 2007 the California State Health Department has posted warnings along the Klamath River warning persons not to drink the water even if filtered or boiled, because of toxins secreted from algae in the river water. In addition, the warning applied to pets not to drink the water. Routine Algae toxin surveillance of the Sierra Nevada waters has not yet occurred, despite California's dependence on this watershed for the majority of its drinking water.

Algae toxins are not removed by standard water treatments. Disinfection using chlorine, hypochlorate (bleach) or iodides have no effect on algae produced toxins. Backpack filters do not remove these toxins. Likewise, simple filtering applied by some municipal water districts do not remove these toxins. Ultraviolet light has variable effects, depending on the toxin.

Combined /cumulative impacts of climate change impacts and nutrient loads implies more algae and worse water quality in Sierra headwaters. Predictions for future climate in the Sierra Nevada include earlier snow melt, longer, warmer summers, which mean a longer growing period for algae as well as warmer waters, conditions that facilitate more algal growth (Coats 2006). In fact, warmer temperatures alone have increased algal growth in Lake Tahoe (Winder et al, 2008) Thus, the combined effects of nutrient loading and warmer water will most likely intensify eutrophication in the coming years for the high Sierra.

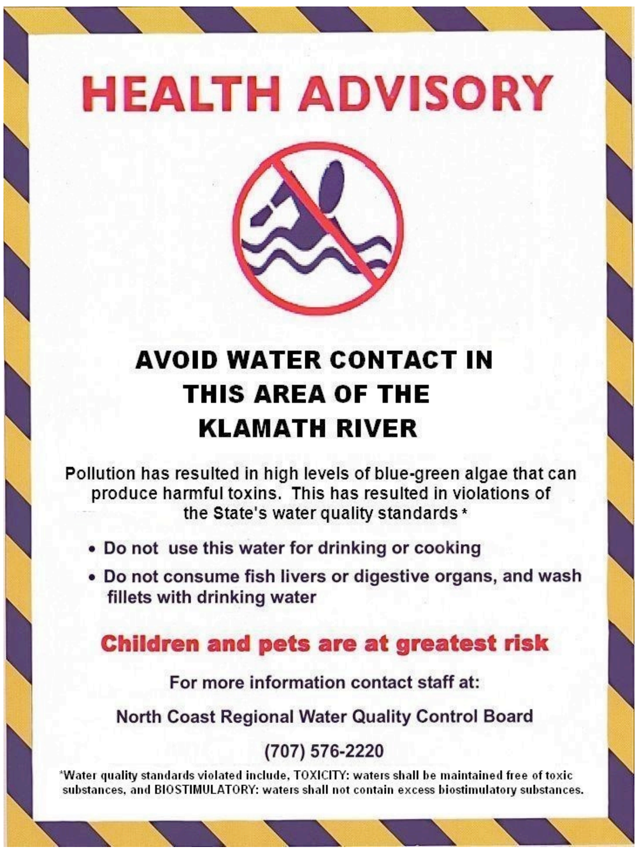


**Figure 1. Warning sign posted along lower Klamath River by the State of California Water Quality Control Board.**

## Causes of High Sierra Algae Overgrowth

Summer cattle grazing in the Sierra Nevada promotes the majority of algae growth in Wilderness Areas (Derlet 2009). Manure from grazing cattle can be washed into both lakes and streams and also dropped directly into the water. This type of non-point pollution introduces and also provides nutrients such as nitrogen and phosphorus which increase algae growth causing eutrophication of otherwise naturally nutrient poor mountain lakes and streams. It is estimated that 40,000 head of cattle are moved to Sierra Nevada mountain areas for summer pasturing (USDA). On average, each head of cattle excretes 50 kg of manure and deposit in additional nitrogen containing urine into the alpine landscape every day (Ohio State University, 2006). In contrast, healthy human waste amounts to less than 0.15 kg/day. Therefore each head of cattle produces over 300 times as much wastes as a human in a single day. Each summer the 40,000 cattle in the high Sierra produce amounts of untreated sewage equivalent of 12 million people .In contrast, using trail quotas, it is estimated that no more than 20,000 human visitors are in roadless areas of the Sierra on an average summer night. The disproportionate impact by cattle becomes obvious when the data is compared this way. Such use of mountain range grazing in the Sierra predates the establishment of the National Forests in 1906, but currently is regulated through the granting of summer grazing permits by the U. S. Forest Service. Cattle manure contains high amounts of both N and P compounds, and 100 head of cattle will deposit 50 kg of P and 40 kg of N each day on the range (Ohio State University 2006). Thus, fecal matter from cattle with P and N as well as other nutrients has contributed substantially to the eutrophication process, and in roadless areas are the major and most significant source of P, N, and trace elements. In addition, this has promoted conditions which increase bacteria, other microorganisms, and the frequency of noxious algal blooms (Conley et al. 2009, Yers et al. 2005). Non-point pollution from cattle waste poses a serious eutrophication threat to both surface and ground water sources at both higher and lower elevations. This promotes imbalance in the ecosystems with accelerated eutrophication through fertilization of algae favoring the undesirable cyanobacteria at the expense of the more desirable diatoms and green algae in downstream lakes and rivers (Horne 1994).

In addition to increasing eutrophication, cattle change the physical habitat of sensitive mountain meadows and creeks, destroying riparian vegetation, promoting increased stream bank erosion, and reducing the natural filtering qualities of shallow marshlands and meadows. The loss of physical and biological filters in sensitive headwaters further facilitates the delivery of nutrients added by cattle.

Pack animals, and to a lesser extent backpackers can contribute to excessive algae growth. Pack include horses, mules, and in some cases lamas. Similar to cattle they excrete significant amounts of nitrogen and phosphorus containing manure, along with trace elements that stimulate algae growth. Although National Parks work hard to regulate and limit the concentration and impact of pack animals, some areas of the Sierra have excessive numbers which damage the watershed, such as in the Bear Creek watershed of the John Muir wilderness, or in Emigrant wilderness above Kennedy Meadows trailhead. Each pack animal provides the equivalent to 100- 150 times what humans contribute in terms of algae stimulating waste material (Ohio State University 2006).

In wilderness areas of the Sierra, Humans have only small amounts of waste that is left in the watershed compared to cattle and pack animals. In addition, nearly all human waste is buried, thus much of the phosphorus is fixed by the bacteria and fungi within the ground, and never reaches the waterways. However humans do wash themselves or dishes with soap and other cleaning agents directly in streams and lakes, even though it is illegal in National Parks and wilderness areas. This contributes in a small, yet cumulative deposition of rate limiting substances including zinc, phosphorus, and dissolved carbon.

Wildlife in the Sierra has been present for thousands of years. They are part of the natural ecosystem, and despite their presence the High Sierra has remained oligotrophic. Their current impact on water and ecosystem changes is minimal.

## Air Pollution

Air pollution has been observed to contribute to algae biomass in certain regions of the world. Some of the nitrogen loading of Lake Tahoe has been documented to occur from nitrate compounds blown into the Tahoe basin from the Central Valley (Goldman 2000).The southern Sierra has been subject to increasing levels of air pollution. In addition particles from as far away as Asia have been detected in California. It is possible that substances from air have contributed to the algae problem in the Sierra.

## Solutions to decrease aquatic algae growth in the Sierra Nevada:

Protection of the 10,000 square miles of high Sierra watershed should be a high priority for the state of California. Limiting the increase of algae growth, and reversal of over grown areas is important to prevent health harming toxins from contaminating California's fresh water. The Klamath River misadventure can be avoided through taking a number of steps that would have only limited impact on the economy.

Approximately 2,500 square miles of the High Sierra is well protected as this is within the 3 Sierra National Parks: Yosemite, Kings Canyon and Sequoia. The proposal to add the Sequoia National Monument to the National Park System will boost this protected area to close to 3,000 square miles. The remaining 7,000 square miles need urgent attention. Initial first steps should include better protection of the 3,000 sq. miles of public land already designated as official Wilderness areas by the USDA Forest Service:

1. Phase out summer cattle grazing from sensitive alpine watersheds in the Sierra Nevada Mountains. The land area on the Western slope above 5,000 ft elevation are sensitive, and above 6,000 ft on the eastern slope. Although Lake Tahoe water flows east, its ecology and watershed importance define it as western slope ecologically.
2. Pack animal traffic in heavily used areas of the wilderness and non-wilderness watersheds should be limited. Trail quotas similar to National Parks in the Sierra should be adapted
3. Limit riparian damage from pack animals by excluding their free range in wetland meadows, riparian corridors and stream crossings.
4. Require pack animal users to burry pack animal manure in 6 inches of soil, just like humans are required to do.
5. Provide more strict enforcement to prevent washing by humans with soap in soap and streams.
6. Extensively utilized backpack corridors such as the John Muir trail may benefit from real time removal of human waste. Requiring backpackers to use "wag bags" would accomplish this goal.

To provide protection to the remaining areas, additional wilderness can be added, as well as conservation districts, provided these districts adapt our proposals for Forest Service wilderness areas.

## Conclusion.

California's water supply from the High Sierra is at risk. Continued pollution into the waterways in combination with global warming provides the conditions that favor the overgrowth of algae capable of producing harmful toxins.
We believe that adopting the initial proposals listed above would be of benefit to California's water supply and to the people of the state of California. Full protection of 10,000 sq mile area of the High Sierra watershed will prevent a future water disaster that would impact nearly every resident and visitor to the State.

## References

Araoz R., Molgo J., Tandeau de Marsac N. 2009. Neurotoxic Cyanobacterial Toxins. Toxicon. (in Press)

Carle D. 2004. Introduction to water in California. University of California press, Berkeley, CA. 1-32 pp.

Coats, R., Perez-Losada, J., Schladow, G., Richards, R., and Goldman, C. 2006. The warming of Lake Tahoe. Journal of Climatic Change;76:121-148.

Conley D.J., Paerl H.W., Howarth R.W. et al. 2009. Controlling Eutrophication: Nitrogen and Phosphorus. Science 323: 1014-1015.

Derlet R.W., Goldman C.R. and Connor M.J., 2009. Summer Cattle Grazing in the Sierra Nevada Mountains of California: A proposal. Journal of Water and Health. In Press.

Duff J.H., Carpenter K.D., Snyder, D.T., et al; 2009. Phosphorus and Nitrogen Legacy in a Restoration wetland, Upper Klamath Lake, Oregon. Wetlands. 29:735-746.

.

Falconer I.R, and Humpage A.R. 2005. Health risk assessment of cyanobacterial (blue-green algae) toxins in drinking water. Int J Environ Res Public Health. 2:43-50.

Farquhar F.P. 1965. History of the Sierra Nevada. University of California Press, Berkeley;201-215

Goldman, C. R. 2000. Four decades of change in two sub Alpine lakes. Verh. Internat. Verein. Limnol.;27:7-26.

Horne, A. and Goldman, C. 1994. Streams and rivers. In: Limnology. 2nd ed. New York: NY: McGraw-Hill:356-383.

.

Lopez-Rodas Maneiro E, Lanzarot MP, et al. 2008.Mass wildlife mortality due to cyanobacteria in the Donana National Park in Spain. Vet record 162;317-323.

Mez K., Beattie K., Codd G.A., et al. 1997. Identification of a Microcystin benthic cyanobacteria linked to cattle deaths on alpine pastures in Switzerland. Eur. J. Phycol. 32:111-117.

Mez K., Habselmann K and Preisig H. R. 1998. Environmental conditions in high mountain lakes containing toxic benthic cyanobacteria. Hydrobiologia 368:1-15.

Moore, J. G. 2000. Exploring the highest Sierra. Stanford University Press: 1-86.

Moore S.K., Trainer V.L., Mantua N.J. 2008. Impacts of Climate variability and future climate change on harmful algal blooms and human health. Environmental Health. 7 (S2):S4

Ohio State University. 2006. Ohio livestock manure management guide. Bulletin: 604-06:1-9.Ohio State University, Columbus, Ohio.

Roth H. 1965: Pathway in the Sky. Howell-North Books, Berkeley, CA: 9-41.

Samet J., Bignam G.S., Feldman R. et al. 2001. Pfiesteria: Review of the Science. Environ Health Prospect 109 (S5);639-659.

Shoemaker R.C. Lawson W. Pfiesteria in Estuarine Waters: The Question of Health Risks. Environ Health Prospect 2007.115; A126

Ursem C, Evans S, Ger KA, et al. 2009. Journal of High Altitude Medicine and Biology 2009: In Press.

USDA National Agricultural Statistics Service. 2007. Livestock County Estimates California.

.

Winder M, Reuter J.E., Schladow S.G. 2008. Lake warming favors small sized planktonic diatom species. Proc R Soc B: doi:10.1098/rspb.2008.1200 published online.

Yers, H. L., Cabrera, M. L., Matthews, M. K., et al. 2005. Environmental Management. Phosphorus, sediment and Escherichia coli.

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