Human Influences to Clear Lake, California

A 20th Century History

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Clear Lake is a large shallow, eutrophic (nutrient heavy), polymictic (well mixed) lake in the central Coast Range of northern California. Clear Lake is one of California's oldest lakes and the largest natural lake (177 km^2) existing entirely within California. It is also believed to be the oldest natural lake in North America, with continuous lake sediments dating to the early Pleistocene, yielding age estimates of 1.8–3.0 million years old.

As part of a larger effort to collect and document biological and other pertinent information for this unique Lake, it's important to document how 20th century human activity has affected present day Clear Lake. The intent of this paper is not to pass judgment on bygone decisions but to simply provide a history of these actions in context with the many current discussions that deal with water, invasive species and lakebed management.

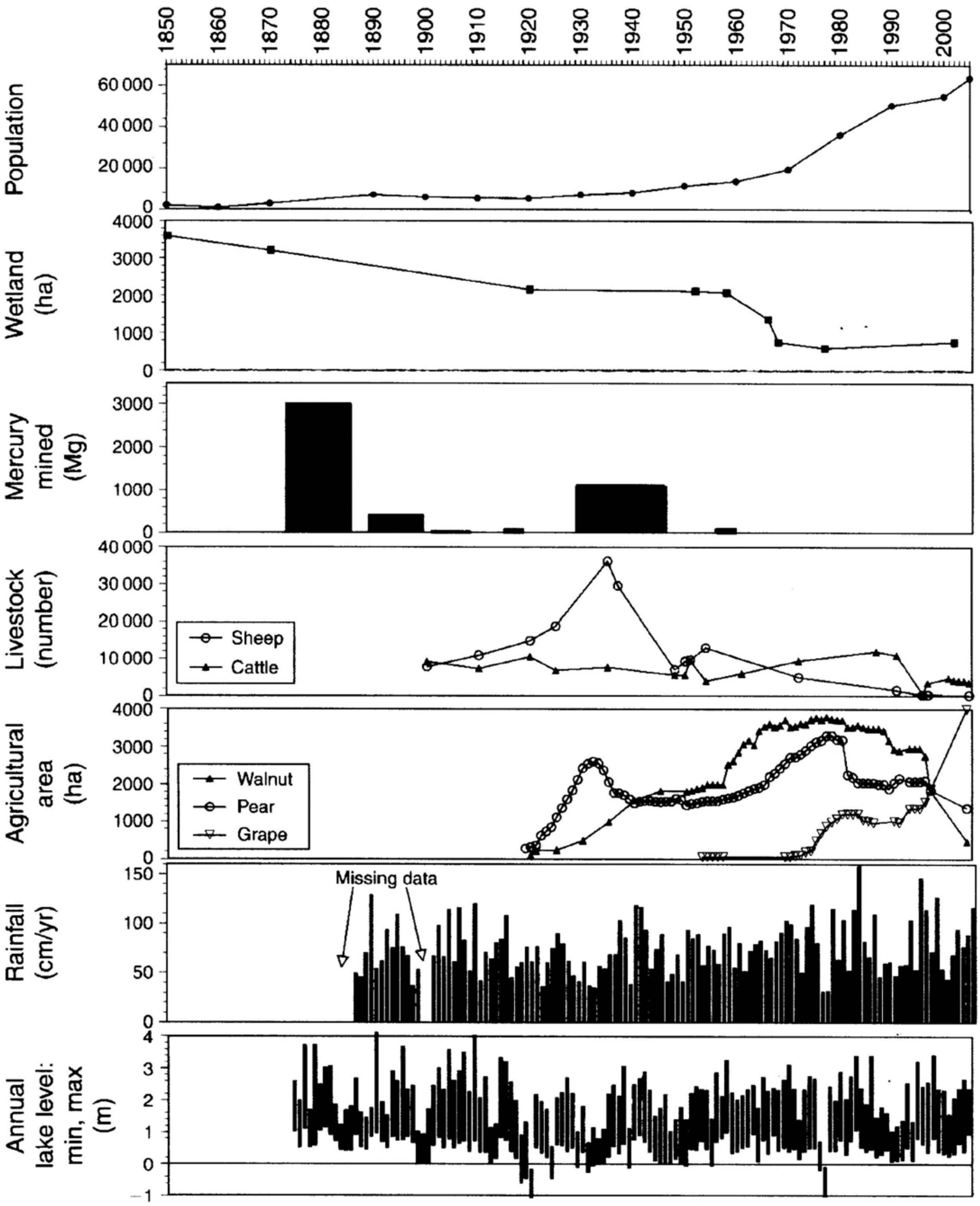
PEOPLE OF THE LAKE

The Clear Lake basin is home to one of the oldest documented North American ''early man'' sites with paleo-Indian occupation going back almost 10,000 years. While the area was occupied by Native Americans since their initial settlement, the Lake, shoreline, and watershed have undergone extensive modification since European settlement in the mid-1800s (Fig. 1). Having lost an estimated 85% of its original natural wetlands, Clear Lake's nutrient balance (nitrogen and phosphorus cycling) has been dramatically altered, resulting in frequent blue-green (cyanobacterial) algal blooms. Natural stressors on this ecosystem have included geologic and tectonic events (some changing the entire flow of the lake), regional and global climate change, fires, droughts, and floods. Human stressors have included water diversion, dam construction, wetland destruction, introduction of non-native plant and animal species, grading and other landscape modification, logging and deforestation, fire, livestock over-grazing, and numerous mining operations, the largest being mercury mining.

USING MUD CORES TO ASSESS HISTORY

Sediment cores are commonly used to trace historical impacts on water bodies since they reflect changes in the deposition of both pollen and other elements that accumulate in mud over time. A study by University of California Davis used core samples to catalog stresses that have impacted Clear Lake since the arrival of Europeans. The study's objective was to describe the pattern of human-induced stresses on Clear Lake in order to better understand the connections between stressors and effects.

FIG. 1. A REVIEW OF DATA SETS PRESENTING FOR POPULATION GROWTH; WETLAND ACREAGE; HG MINED; LIVESTOCK NUMBERS; CULTIVATED ACRES; ANNUAL RAINFALL; AND LAKELEVEL.



Data were collected from several Clear Lake sediment cores in 1996 and 2000 as part of a larger ecosystem level study that traced the origin and pathways of mercury (Hg) from the ore body of an abandoned mercury mine. These pathways trace mineral movements through the sediment, water and the food chain (including invertebrates, plankton, fish, birds and mammals). Historic (1800s to present) and prehistoric (to 3000 years) core data were used to define the variability of mercury loading and other stressors to Clear Lake before and after European settlement in the watershed. One of the most prominent stressors has been mercury contamination from an abandoned mine along its shoreline. The Clear Lake ecosystem has been dramatically impacted by pesticides, accelerated eutrophication (nutrient loading), and alien species introductions.

MERCURY AND CLEAR LAKE

The Sulphur Bank Mercury Mine, along the eastern shore of Clear Lake, began as a sulfur mine in 1865 and converted to a mercury mine in 1873 after cinnabar deposits were found beneath the surface's sulfur deposit. Mining operations began using shaft mining and shallow cuts that had relatively minor impacts on the lake and landscape, but gave way to large-scale open-pit mining operations in 1927. This year has become widely recognized as a watershed event and set the lake and its water's quality on a path of increased stress. Open-pit practices included bulldozing mine tailings and waste rock directly into Clear Lake. Mining continued intermittently into the 1950s, with the final mine closure in 1957. Mercury contaminated mine wastes continued to erode into Clear Lake over the next 35 years.

Fig. 2. An aerial view of the Sulphur Bank Mine and the "Herman Pit" the source of mercury contamination.

LAND USE AND CLEAR LAKE

During the last half of the 19th century, land clearance for farmland, road building, livestock grazing, mining, logging, and firewood cutting potentially increased erosion and eutrophication rates, similar to what occurred in the eastern United States. Past histories written of settlement in the Clear Lake basin discuss the prevailing intensity of grazing and logging. As a result, native bunchgrasses were almost completely replaced by alien Mediterranean grasses and forbs in the 19th century. This vegetation shift is evident in pollen profiles that have been dissected from mud cores taken in the Upper Arm of Clear Lake. The only distinctive European plant recognized in the pollen record was the relatively late appearance of walnut cultivation. It is generally understood that the overall vegetation pattern within the basin has changed little, apart from cultivated areas. The pollen record confirms this impression. Early reports show a peak of cultivated agricultural acreage in 1880, when total cultivated land reached about 19,500 acres (7900 ha) in the whole county, about 2.4% of Lake County's total area. Clear Lake's drainage basin is about 338,500 acres (137, 000 ha), so even if all the agriculture occurred in the Lake's catchment (which it did not), only a little more than 5% of the basin would have been disturbed by agriculture. Agriculture today is dominated by vineyards and pears, but walnuts were important throughout most of the 20th century. These three crops together reached a peak of about 19,200 acres (7800 ha) in 1980, falling to 14,300 acres (5800 ha) in 2000. Thus, cultivated agricultural land remains a small portion of the total watershed area. Most of the basin is composed of steep slopes with thin soil. The oak woodland, conifer forest, and chaparral plant communities that cover these slopes are relatively undisturbed.

ALGAE AND THE LAKE

Past studies that looked at causes of Clear Lake's algal blooms concluded that nutrient loading, particularly phosphorus, increased substantially between 1925 and 1938 due to heavy earthmoving activities that occurred beginning in the 1920s. After 1927, the year that is widely recognized as one in which heavy machinery became prevalent in the basin, sedimentation rates going into the lake increased 10 fold from pre-1927 rates. By 1938, when a series of water transparency measurements were made, the Lake had become too turbid for rooted aquatic vegetation to flourish, and blue-green algae scums had become a perennial problem.

Road-building and lake-filling activities increased significantly after 1925, including the open-pit operations at the mine. In 1928, a 2,000 acre (810-ha) wetland reclamation project was constructed using heavy equipment. It eliminated most of a large wetland at the northwest end of the lake. This project created Rodman Slough, a narrowly confined waterway/wetland complex that conveys flood flows directly into the lake, thus removing a major sink (filter) for nutrients and sediment. Adding to the flow of nutrients was the fact that, until 1987, in-stream gravel mining was still common.

When assembled in a timeline, the degree and extent of 20th century impacts and alterations, and their impact to water quality become self evident. For some of these historic practices, their legacies continue to influence the Lake today (Fig. 3).

FIG. 3. TIMELINE FOR MAJOR ENVIRONMENTAL EVENTS IN LAKE COUNTY THAT HAVE IMPACTED CLEAR LAKE, CALIFORNIA, USA.

1. Tule Lake wetland reclamation (destruction), early 1900s;
2. Clear Lake dam completion, 1914;
3. Cache Creek straightened above Grigsby Riffle, 1919;
4. Gopcevic Water Decree, 1920;
5. Middle Creek wetland reclamation, 1927;
6. Grigsby Riffle deepened, 1938;
7. Bemmerly Water Decree, 1939;
8. Rodman Slough wetland reclamation, 1959;
9. Adobe Creek Reservoir completed, 1962;
10. Highland Springs Reservoir completed, 1963;
11. Kelsey Creek dredged, 1955;
12. Scott's Creek gravel mining for road construction, 1969;
13. Solano Water Decree, 1978.

PEST CONTROL AND CLEAR LAKE

Nuisance animal and plant species management and eradication efforts have been undertaken during the past 60 years. The mid-century applications of insecticides were curtailed and replaced with the introduction of a non-native fish species as a tool for abating nuisance insects. Most other fish introductions were done to improve recreational fishing. It now appears that non-native fish are limiting Clear Lake's gnat population, perhaps to the detriment of native species. Applications of herbicides continue to be applied for native and non-native nuisance aquatic vegetation (Fig. 4). The shift from a blue-green algae-dominated lake to one dominated by summer aquatic weeds has been dramatic since the early 21st century as water clarity has improved significantly during this time.

The pesticide, dichlorodiphenyldichloroethane (DDD), was applied in increasing quantities to Clear Lake in the late 1940s to mid-1950s (with the largest and last application in

1957) in an attempt to control the Clear Lake gnat (*Chaoborus astictopus*), a noxious non-biting insect that was a serious nuisance to people living and recreating along the lake. This resulted in an ecosystem-wide contamination that decimated Western Grebe populations. Clear Lake was one of the first ecosystems in which the phenomena of chlorinated hydrocarbon “bioaccumulation” in food webs and of the delayed expression of contamination due to the “bioconcentration” of pesticides were observed. These studies at Clear Lake were popularized in Rachel Carson’s book “Silent Spring”.

FIG. 4. HISTORIC AND CONTEMPORARY CHEMICAL APPLICATIONS TO CLEAR LAKE:

- Dichlorodiphenyldichloroethane (DDD) applications for gnat control, 1949, 1954, 1957;
- methyl parathion applications for gnat control, 1962–1975;
- during the mid- to late-1990s, large quantities of the aquatic weed control agents Komeen and Sonar were used in the *Hydrilla* eradication program; applications post-2000 were orders of magnitude smaller and used in strategic amounts and at strategic locations.
- Komeen (copper-ethylenediamine complex and copper sulfate), 1994–2006 and later;
- Sonar (fluridone), 1996–2006 and later;
- glyphosate, 2002–2006 and later;
- diquat dibromate, 2002–2006 and later;
- copper carbonate, 2002–2006 and later;
- potassium salts of endothall, 2004–2006 and later;
- triclopyr, 2005–2006 and later.

Current pesticide applications must adhere to all pertinent regional, state and federal guidelines and policies affecting water, fish, wildlife and people. Clearly, these safeguards were not in place throughout the history of Clear Lake management.

HUMAN IMPACTS ON CLEAR LAKE FISHERY

Taken in the context of modern awareness of environmental protection, the 20th century history of human decisions and actions focusing on fish management have ranged from comical to absurd to outright disastrous. For instance, when carp become so abundant in Clear Lake, a suggestion was forwarded to the California Fish Commission (1896-97) to introduce California sea lions into the lake. The idea generated from a similar situation in Lake Merced, San Francisco, where sea lions were introduced to control carp. The sea lions remained in Lake Merced until the fish supply became exhausted and they simply walked back to the ocean. The idea was finally abandoned because “It was thought, however, that the swamp and tule land surrounding [Clear Lake] would harbor the carp and furnish them with areas that the sea lions would not reach (California Fish Commission Report for 1897–98, p. 33).

Unfortunately, not all accounts are so nonsensical. Historical accounts tell us “Clear Lake once swarmed with countless thousands of native minnows. Not only did these fish cause Livingston Stone difficulty in fording some of its tributary streams by horse when they ran upstream to spawn, but in more recent years they died in such quantities that the stench was almost intolerable to the lakeshore residents. Every year large quantities of dead fish had to be buried, but according to Capt. J.D. Dondero of the Division of Fish and Game, the establishment of white catfish in Clear Lake, which he said occurred in the 1920s, "... solved this problem." The population of non-game fish diminished, and the windrows of dead fish were a thing of the past (pers. comm.)”. [Source: Fish Bulletin 178]

Fish have and continue to play an important economic and social role for Clear Lake residents and visitors. Commercial, sport and recreational utilization of fish have long been important aspects of the natural system. Clear Lake’s pre-settlement fish fauna was dominated by species found naturally occurring in both the Russian and Sacramento River systems; as a result of the Lake’s connection to both systems over geologic times. Native fish include: Pacific lamprey* (*Lampetra tridentate),* Sacramento perch* *(Archoplites interruptus)*, hitch (*Lavinia exilicauda),* Clear Lake split tail* *(Pogonichthys ciscoides),* Sacramento blackfish (*Orthodon microleptidotus),* Sacramento pikeminnow (*Ptychocheilus grandis),* Sacramento sucker (*Catostomus cocidentlis)*, prickly sculpin (*Cottus gulosus)*, tule perch (*Hysterocarpus traski)*, rainbow trout (*Oncorhyrnchus mykis)*, three-spined stickleback (*Gasterosteeus aculeatus)*, and thick-tailed chub* (*Gila crassicauda*). Those fish marked with an asterisk are considered extirpated from the Lake.

Commercial fishing for live-fish export to San Francisco’s Asian markets continued from the early part of the 20th century until the first decade of the 21st century.

The possibility of continued commercial exploitation of the Lake's fish is still possible and may continue in the future (Fig. 5).

The commercial catfish catch of the Delta generally ranged from 200,000 to 700,000 lbs. a year with catches exceeding 1 million pounds in 1908 and 1929. It was centered in the Sacramento-San Joaquin Delta area and at Clear Lake, Lake County. The commercial fishery on Clear Lake for catfish closed in 1941.

Fig. 5. Seining was a commonly used technique for commercial fishing on Clear Lake.

Because of the economic potential associated with freshwater fish markets, coupled with recreational opportunities for a thriving tourism economy, many species of fish where intentionally introduced as sport fish or prey fish to support the sport fishery. One species, the Inland Silverside, was introduced in 1967 as a biological control agent for the Clear Lake gnat. Another fish species, a member of the herring family, the Threadfin Shad was introduced into Clear Lake can dramatically limit food supplies of other fish during times of unusually high population numbers.

Unfortunately, a particularly undesirable and invasive plant, *Hydrilla veritcillata,* has also become established through illegal introductions late in the 20th century, resulting in quarantine and eradication efforts. A list of introduced non-native species and the year of their introduction is presented in Fig. 6.

FIG. 6. NON-NATIVE SPECIES INTRODUCTIONS TO CLEAR LAKE:

- whitefish (*Coregonus clupeaformis*), 1875, failed;
- brown bullhead (*Ameiurus nebulosus*), 1875;
- white catfish (*Ameiurus catus*), 1875;
- smallmouth bass (*Micropterus dolomieu*), 1875;
- common carp (*Cyprinus carpio*), 1880;
- grass pickerel (*Esox americanus*), 1896, failed;
- golden shiner (*Notemigonnus crysolencus*), 1896 & 1950, failed;
- northern largemouth bass (*Micropterus salmoides*), 1897;
- bluegill (*Lepomis macrochirus*), 1906;
- black crappie (*Pomoxis nigromaculatus*), 1906;
- channel catfish (*Ictalurus punctatus*), 1908;
- lake trout (*Salvelinus namaycush*), 1923 & 1924, failed;
- pumpkinseed (*Lepomis gibbosus*), 1942;
- white crappie (*Pomoxis annularis*), 1945;
- inland silversides (*Menidia beryllina*), 1962;
- Florida-strain largemouth bass (*Micropterus salmoides*), 1967;
- Florida-strain black crappie (*Pomoxis nigromaculatus*), 1984;
- threadfin shad (*Dorosoma petenense*), 1985;
- *Hydrilla veritcillata*, 1994.

The threat of more invasive species becoming established in Clear Lake persists to the present time. Recent concerns over Dressenid mussels (quagga and zebra), New Zealand mud snails, and other commercially sold aquarium fish species pose a constant threat of adding more stress to the lake's system.

SUMMARY

Early 20th century exploitation of mined resources has left a prolonged and costly legacy on Clear Lake. The resultant mercury contamination continues to exercise its influence through health advisory warnings on fish consumption and persistent evidence of its existence within the Lake's food web.

Water and land management influenced the "algae problem" that plagued residents and visitors alike for decades until the county's aggressive approach to erosion control efforts have limited the entry of phosphorous and other nutrients into the lake, finally abating the chronic nuisance algae.

Decisions and water agreements with other counties continues to challenge county administrators and decision makers as they try to address 21st century domestic and commercial water needs.

Fish, an ever present and valued resource of the lake, have been shaped by various land-practices, introductions and markets. With contemporary interest and protections afforded native species, past decisions will continue to shape and affect the sustainability of native fish populations.

Contemporary demographic shifts and modern modes of transportation increase the likelihood that future introductions of undesirable species will add costs and further restrict lake activities currently enjoyed.

Human influence on Clear Lake has a long and varied history with both legacy and contemporary influences affecting the lake and its processes. This document has attempted to compile a brief synopsis of what history teaches us about California's largest natural lake.

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