MERCURY IN THE CACHE CREEK WATERSHED – SPATIAL ANALYSIS, ECOSYSTEM SERVICES IMPACTS AND SES FRAMEWORK IMPLEMENTATION

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In

Geography: Resource Management and Environmental Planning

by

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San Francisco, California

May 2018

CERTIFICATION OF APPROVAL

I certify that I have read Title of Culminating Experience by Deseret Margaret Weeks, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirement for the degree Master of Arts in Geography: Resource Management and Environmental Planning at San Francisco State University.

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2018

Mercury bioaccumulation is a local, regional and global-scale problem. The Cache Creek Watershed is one of many in California whose streams, lakes or reservoirs are on the Clean Water Act's 303d list for mercury threshold exceedance due to historic mercury mining and use of mercury for gold mining. It is noted to be the largest contributing source of mercury to the San Francisco Bay Delta. The objective of this thesis was to examine spatial patterns of mercury concentrations in ecosystem indicators in the Cache Creek Watershed, identify ecosystem services impacted and employ a Socio-Ecological Systems conceptual model to reveal environmental management mechanisms that contributed to widespread mercury bioaccumulation, and alternately, remediation. Over 92% of fish monitored from 1974 – 2013 throughout the watershed were above safety thresholds for mercury in fish for subsistence, sport fishing and wildlife. Mercury concentrations were greatest in the vicinity of, or directly downstream from, mine sites in all ecosystem indicators evaluated, including sediment, fish, invertebrates and Cliff Swallow eggs. Individual services within all four ecosystem services categories – supporting, provisioning, regulating and cultural – have been impacted. The General Mining Act of 1872 and lack of regulations were the primary catalysts for widespread mercury bioaccumulation. Support for remediation is being provided by the Clean Water Act and is requiring cooperation between state and federal water quality governing agencies and many other stakeholders at local and regional scales. This thesis presents a framework (Socio-Ecological-Systems) embedded with ecosystem services as part of the framework for evaluating land-use management and resulting ecosystem services impacts, the application of which may be useful for other mercury contamination studies.

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Chair, Thesis Committee

PREFACE AND/OR ACKNOWLEDGEMENTS

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1. Introduction

1.1 Global Perspective and Mercury Background

Mercury (Hg) is a potent neurotoxin that threatens human and ecosystem health, the bioaccumulation of which is a local, regional and global-scale problem with numerous sources (UNEP, 2013). Hg is used for gold mining due to its ability to draw other metals to itself (Domagalski et al., 2004). The Cache Creek Watershed is one of a multitude in California that have been placed on the U.S. Environmental Protection Agency's (EPA) 303d list for contaminated waters due to exceedance of threshold objectives for Hg resulting from a legacy of mercury mining and the use of Hg for gold mining (California Water Boards, 2018). While Hg is no longer used for gold mining in California, remaining mercury and gold mine sites continue to be point sources for Hg bioaccumulation (Alpers et al., 2005). Unfortunately, Hg is still being used for gold mining in many other places globally (UNEP, 2013).

The toxic nature of Hg became widely known following the Hg bioaccumulation catastrophe in the Minamata, Japan area in the 1950's (Harada, 1995). Lacking environmental regulations, the Chisso Chemical Company dumped industrial waste from the production of acetaldehyde, an ingredient in plastics, that used Hg as a catalyst, the byproduct of which was methylmercury (MeHg), directly into the Minamata Bay from 1932 – 1968 (Griesbauer, 2007; Sokol, 2017). The result was bioaccumulation and biomagnification of MeHg in the local food web, but the process by which that happens was not yet understood (Harada, 1995; Griesbauer, 2007). The health impacts were observed throughout the food web and in local residents who were experiencing symptoms of heavy metal poisoning (Sokol, 2017; Minamata Disease Municipal Museum, 2007). Now known as Minamata Disease, it took until 1968 (15 years) for an official cause to be declared – 'methylmercury compound generated by acetaldehyde and acetic acid production at the Chisso Minamata Plant,' which was refuted by the Chisso Chemical Company in 1959 following a university study that pinpointed it as the cause (Minamata Disease Municipal Museum, 2007; Ministry of the Environment, 2013).

There are 2,268 certified Minamata disease patients, 900 of which died from the disease (Minamata Disease Municipal Museum, 2007; Juan, 2007). Figure 1 shows the area that was impacted by this unregulated industrial Hg pollution.

Figure 1: Area of confirmed cases of Minamata Disease which was the result of the Chisso Chemical Company dumping industrial waste into Minamata Bay that had extremely high levels of methylmercury. Modified from Harada, 1995.

The Hg catastrophe in the Minamata area represents an important environmental justice case that played a major role in scientific recognition of Hg as a global pollutant with major implications for both ecosystem and human health. Hg is a global pollutant because it has a global cycle (Figure 2) via transportation through terrestrial-atmospheric-oceanic fluxes and complex biogeochemical processes, all closely linked to the hydrologic cycle (Selin, 2009; Driscoll et al., 2013). The United Nations Environment Program's (UNEP) Chemical Division now has a specialized program to account for localized, regional and global anthropogenic emissions and transport of Hg known as the Global Mercury Assessment (UNEP, 2013). The UNEP's Global Mercury Assessment resulted in the formation of the Minamata Convention on Mercury, which aims to reduce anthropogenic mercury emissions through intergovernmental cooperation to adopt goals and address specific human activities that are contributing to the problem (United Nations, 2013; UNEP, 2013). The UNEP's Global Mercury Assessment released in 2013 contained some alarming findings while also providing important insights into the primary sources of Hg. The assessment showed that anthropogenic Hg emissions and releases have doubled the amount of Hg in the top 100 meters of the oceans and Hg in deeper waters has increased by 10% – 25% (UNEP, 2013). Of the major sources for Hg, artisanal and small-scale gold mining is by far the largest, as shown in Figure 3, which underscores important lessons California and the Cache Creek Watershed has to offer global communities still using Hg for gold mining.

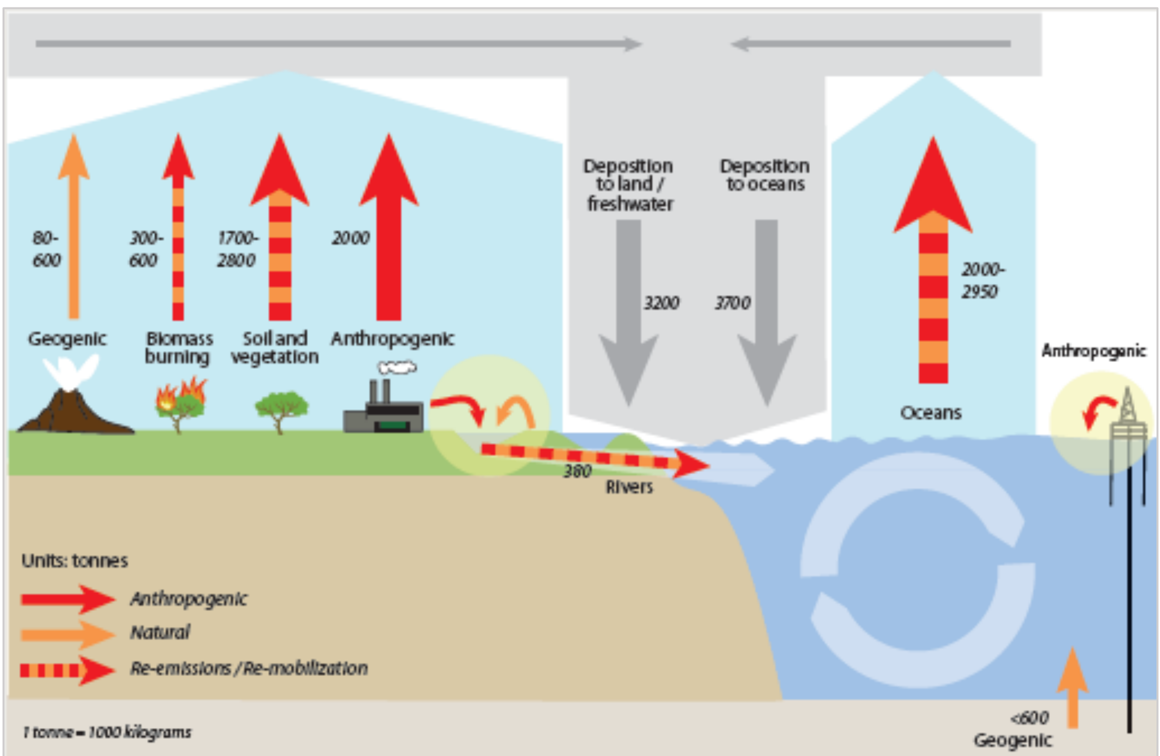

Figure 2: Mercury transport through the global system that includes very broad natural and anthropogenic inputs. Note that re-emission accounts for increases via anthropogenic input to local and global system. Source: UNEP Global Mercury Assessment, 2013

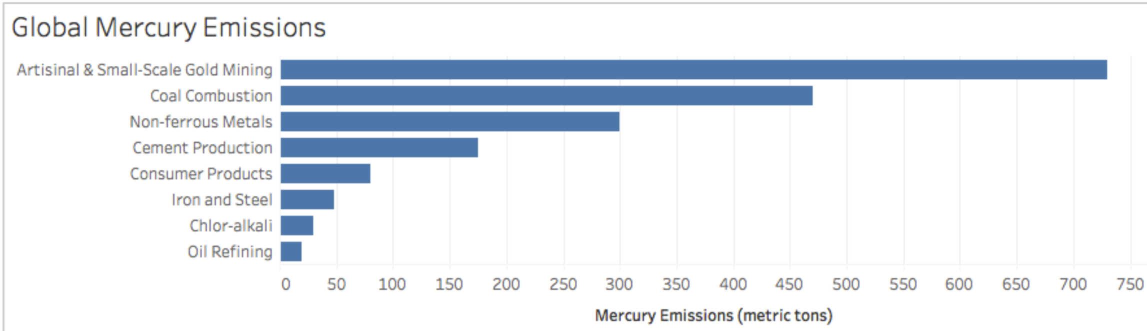

Figure 3: Graph shows categories of global mercury emissions and amount of mercury emitted in metric tons. Data from UNEP, 2013.

The primary source of Hg in the global system attributed to small-scale and artisanal gold mines is due to surface water transport of Hg. In nature, Hg occurs most often in the mineral Cinnabar HgS, which erodes and contributes to the transport of Hg in streams and watersheds (Alpers et al., 2005). This natural process of erosion and transport is the same for areas where mercury is being used for gold mining because Hg is incorporated into the sediment (Alpers et al., 2005). Through this process, Hg accumulates at stream deposition points (Domagalski et al., 2004). This then provides the basis for bioaccumulation in biological organisms in the watershed (Cooke et al., 2004; Alpers et al., 2005).

Hg not only bioaccumulates in ecosystems, it also biomagnifies, presenting a considerable problem for local, regional and global fishers considering the results of the UNEP's Global Mercury Assessment presented above (Domagalski et al., 2004; Alpers at al., 2005). Biogeochemical processes between sulfate-reducing bacteria and Hg result in the transformation of inorganic Hg to its organic form, methylmercury (MeHg), which can then be taken up into the tissues of biological organisms (Domagalski et al., 2004). As MeHg transfers through successive trophic levels it increases in concentration – a process known as biomagnification (Slotten et al., 2004). Biomagnification occurs within a trophic level because those fish eat smaller fish and accumulate a greater concentrations of MeHg (Figure 4). This process of biomagnification also occurs from mother to offspring putting women of child-bearing age and children at increased risk for MeHg contamination through fish consumption (Kim et al., 2006).

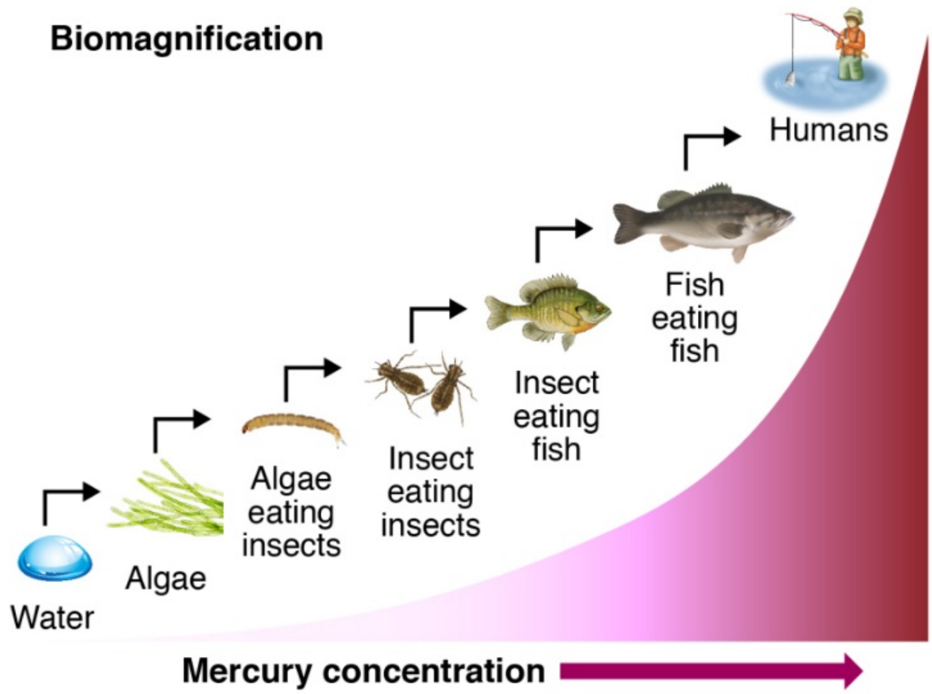

Figure 4: The process by which mercury becomes concentrated as it goes through trophic transfer. Source: https://themercurysite.com/caddo-lake/biomagnification/

1.2 Regional Scale – California

The historical geography of Hg mining and use of Hg for goldmining in California provides an important perspective. The Coast Range of California has a unique geology that contains some of the largest Hg deposits in the world, which have been mined beginning in the 1840's. California did not become a state until 1850, as shown in the timeline (Figure 5), so there were no environmental protection regulations (Krieger, 2015). The Federal Mining Act (Law) of 1872 greatly encouraged the expansion of Hg exploration and mine claims as the law was created to 'foster extractive industry in the western United States' with an underlying goal of gaining control over the land during the westward expansion of colonization of North America (Clark, 2016). Beginning in 1848, throughout the gold rush and well into the 1900s, miners utilized mercury for gold mining as it has the ability to pull other metals to itself through a process known as amalgamation, which increased the demand for mercury (Alpers et al., 2005; Rockwell,

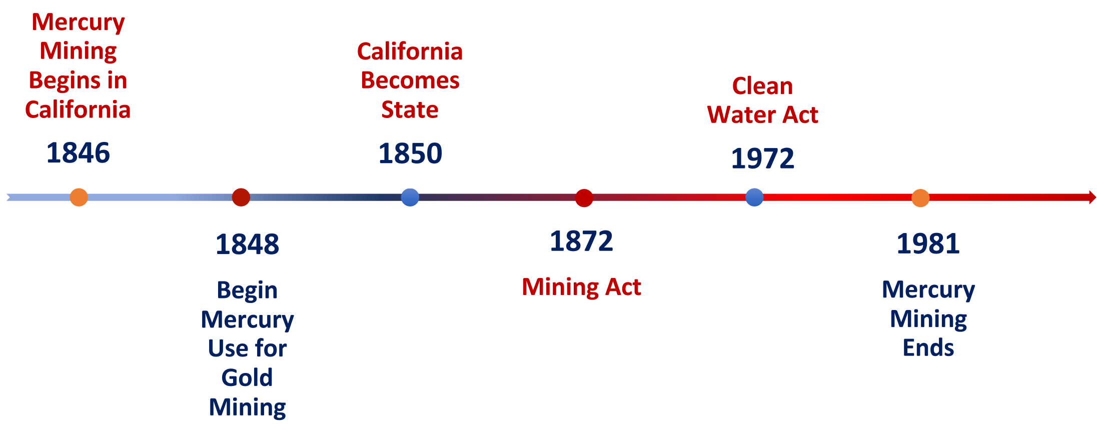

Figure 5: Timeline shows important dates for mercury mining, use of mercury for gold mining, implementation of Clean Water Act (Krieger, 2015; California Department of Toxic Substances Control, 2011; Anderson, 1976).

2008). While Cinnabar was mined and the refined Hg used for gold mining in the Coast Range, the majority was taken to the Sierra Nevada where a common practice known as hydraulic mining was employed in conjunction with the use of Hg (Alpers et al., 2005). Great amounts of sediment were yielded from the blasting away of valley walls with water (Figure 6), which was then pushed through sluices (Figure 7) where liquid Hg was placed to pull the gold in the sediment to the bottom of the sluice (Alpers et al., 2005). An estimated 3 million to 8 million kilograms of mercury was lost to the environment through this mining process; the Hg is transported downstream through seasonal erosional processes in addition to evaporation,

Figure 6: Hydraulic mining was used to access the gold deposits in the Sierra Nevada during the Gold Rush. Photo source: Cali49, 2016

Figure 7: Photo shows sluices that gold miners used to obtain gold flakes from sediment recovered by hydraulic mining by adding mercury to the bottom of the sluice. Photo source: Rawls and Orsi, 1999

atmospheric deposition and transport by species that have accumulated MeHg in their tissues (Alpers et al., 2008; UNEP, 2013).

The losses of Hg to the environment in California are reflected in the extensive areas impacted by mercury (Hg and MeHg) bioaccumulation today, requiring broad-scale remediation efforts (The Sierra Fund, 2008; California Department of Toxic Substances Control, 2011; California Regional Water Quality Control Board Central Valley Region, 2016). A comparison of Figure 8, which shows locations of mercury and gold mines, with Figure 9 that shows California water bodies and streams on the EPA's 303d list for Hg contamination, shows the impacts of mercury mining and the use of Hg for gold mining. This widespread mercury (Hg and MeHg) contamination has prompted the necessity for multi-agency and stakeholder cooperation for remediation. The main environmental management safeguard is delegated by the Clean Water Act to be the US

Figure 8: Watersheds, waterbodies and streams that are on the Clean Water Act 303d list for impaired waters due to exceedance of safety threshold levels of mercury. Map: California Water Boards, 2017

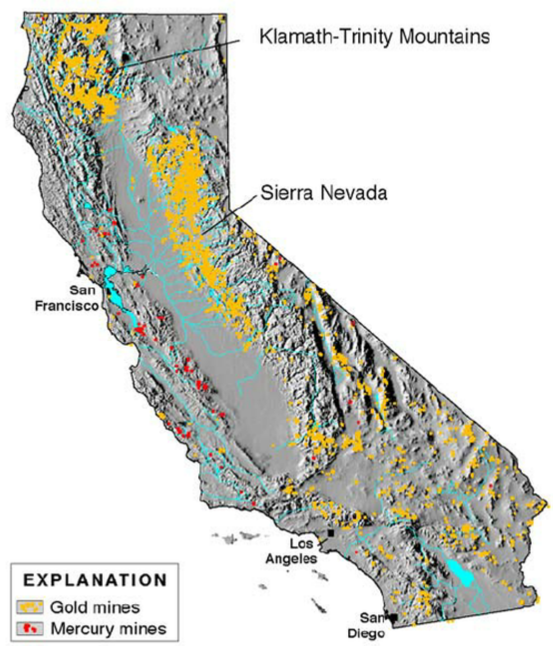

Figure 9: Locations of mercury mines and gold mines. Mercury was used at the gold mine locations. Map: Alpers et al., 2005.

EPA, which works directly with the California Water Quality Control Boards to manage water quality and thus mercury levels in watershed ecosystems (Foe and Bosworth, 2008; California Water Boards, 2017). Remediation of the hundreds of mercury mines and thousands of gold mines where Hg was used is problematic since many of the mines are either abandoned, on federal public lands or have been passed down through many different land owners thus requiring court system litigations and allocation of funds which are limited in most cases (Alpers et al., 2005; California Department of Toxic Substances Control, 2010).

California and its local watersheds demonstrate two important lessons for global communities, which will be explored in this thesis to further understand impacts of mercury bioaccumulation. The first lesson is the result of widespread mercury mining and the use of Hg for gold mining with no regulation. The other lesson is the impacts of mercury bioaccumulation and biomagnification, which underscores the importance of strong environmental regulations, but also requires the cooperation of Federal, state and local agencies as well as non-governmental and grassroots organizations for cooperative remediation.

1.3 Ecosystem Services

Ecosystem services provide an internationally accepted framework for qualitative and quantitative analysis of environmental degradation or anthropogenic impositions on ecosystems and the services they provide including clean water, healthy soils and clean air. Ecosystem services are divided into four broad categories, habitat/supporting, provisioning, regulating and cultural (Figure 10). Habitat/supporting services emphasize the importance of biodiversity maintenance accounting for the availability of food, water and shelter for species – support for the rich biological tapestry that underpins the stability of the other three service categories (Food and Agriculture Organization of the United Nations, 2018; Sukhdev et al., 2008). Provisioning services account for the availability and security of food, raw materials, fresh water and medicinal resources and are closely linked to cultural services, which account for recreation and tourism, such as sport fishing, but also the human spiritual connection to nature. Regulating services represent the environmental science of localized and planetary biogeochemical processes and provide important support for the other three categories and resilience of social-ecological systems and include climate regulation, soil formation processes, erosion prevention, biogeochemistry cycling and extreme event moderation, among others (Sukhdev et al., 2008).

Ecosystem services are an important consideration for mercury (Hg and MeHg) bioaccumulation and biomagnification since it can impact the entire ecology of a watershed (Domagalski et al., 2004; Suchanek et al., 2008). Impacts on the watershed ecology via biomagnification can directly impact human and wildlife livelihood. Importantly, application of Ecosystem Services to show holistic impacts of pollutants such as mercury reveals and underscores the importance of protecting ecosystems as a whole as well as the importance of water quality and species protection measures such as those provided by the Clean Water Act. In the current political climate of deregulation, Ecosystem Services provides the ability to understand how human actions directly impact the ecosystems they depend on for life support services such as clean water, clean air and food.

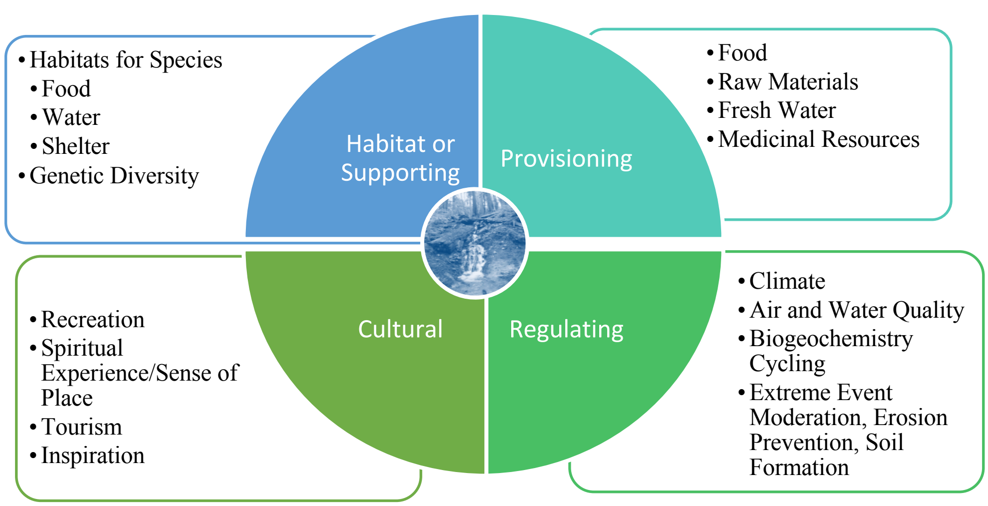

Figure 10: Ecosystem Services framework. Source of information: Sukhdev at al., 2008.

1.4 Socio-Ecological Systems Framework

Cause and effect relationships resulting from anthropogenic impacts on ecosystems, are causing broad-scale environmental degradation in this new age of the Anthropocene (Crutzen, 2006). Mercury mining and the use of Hg for gold mining resulting in widespread mercury bioaccumulation is a prime example of this problem as exemplified by Figure 9. Global change includes biodiversity loss, climate change, nitrogen cycle overburden, and chemical pollution such as heavy metals, including mercury, and is the result of the multitude of anthropogenic impositions that are directly impacting ecosystem services (Polce et al., 2016; Rockström et al., 2009). Global Change impacts on ecosystem services are providing the necessity for humans to recognize their existential connectivity to ecosystems and to bring that understanding into environmental management measures (Ostrom, 2009). Socio-ecological-systems (SES) is a framework for analyzing cause and effect relationships between human systems and ecological systems with an underlying goal of fostering sustainability (McGinnis and Ostrom, 2014; Ostrom, 2009). The SES Framework allows for analysis that accounts for sub-systems that may be multilayered with feedbacks, the internal variables of which may vary depending on the situation (Ostrom, 2009). SES analysis provides the ability to integrate social and physical sciences and foster sustainable land use management (Lund, 2015;Ostrom, 2009). The employment of the SES framework can provide a working example of how human behavior, including mercury mining and the use of mercury for gold mining, has directly impacted the ecosystem services that support the health of humans and wildlife alike and alternately, what is required for support for remediation and thus ecosystem services health.

1.5 Cache Creek Watershed

1.5.1 Description and Background

The Cache Creek Watershed is located north of San Francisco in California's Coast Range and Sacramento Valley (Figure 11). The watershed is 2950 km^2 and drains from west to east with western basin divide elevations in the Coast Range exceeding

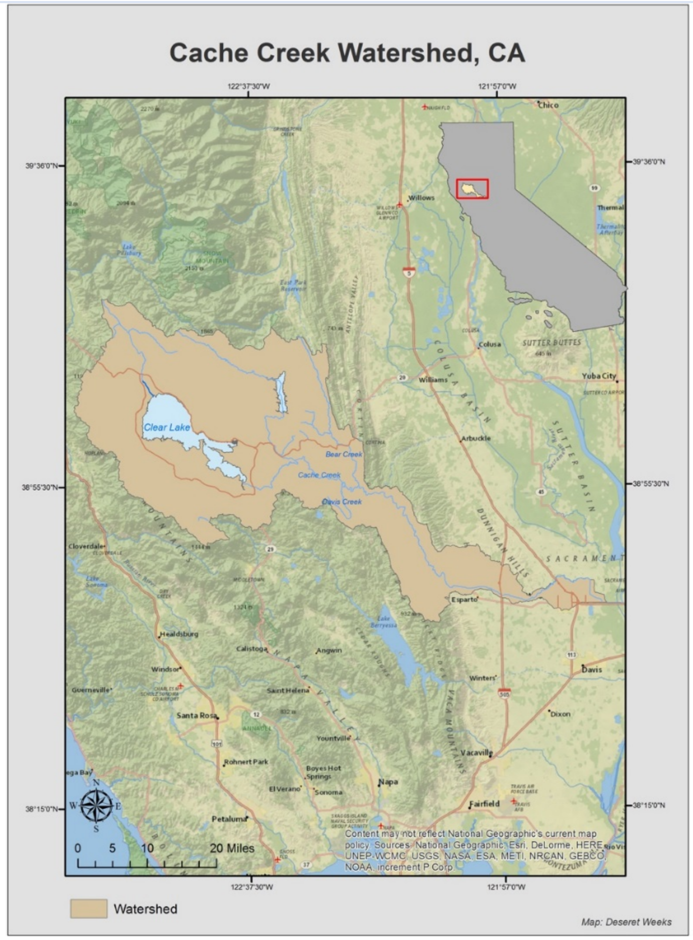

Figure 11: The Cache Creek Watershed, northeast of San Francisco.

1219 meters (Kamman Hydrology and Engineering, 2010). The headwaters of the Cache Creek is Clear Lake, which is a warm (~7° C in winter and ~27° C in summer) shallow lake (< 18 meters). Clear Lake is the largest natural lake entirely within California and one of the oldest lakes in North America, estimated to be between 1.8 - 3 million years old (Giusti, 2009; Sacramento River Watershed Program, 2017; Winder et al., 2010). The Watershed has three main sub watersheds – North Fork Cache Creek, Cache Creek (main fork) and Bear Creek, which flows year-round (Foe and Bosworth, 2008). The North Fork Cache Creek is divided by the Indian Valley Reservoir, the controlled flow releases provide for continuous flow of the North Fork Cache Creek to the Cache Creek throughout the summer (Macedo, 1988).

The Cache Creek Watershed has a Mediterranean climate, which equates to very dry, warm summers and cool, wet winters (Kamman Hydrology & Engineering, Inc., 2010) (Gasith and Resh, 2009). The rainy season varies but is generally November through March (Domagalski et al., 2004; Winder et al., 2010). Winter rains come with storms from the west with orographic precipitation being a strong influential factor due to topography, which causes great variability in precipitation patterns throughout the basin (Kamman Hydrology & Engineering, Inc., 2010). Lowlands of the Cache Creek Watershed may receive an annual average of 43 centimeters of rain, while the highlands might exceed 127 centimeters and mountains above 914-meters may receive snow (Cooke et al., 2004; Kamman Hydrology & Engineering, Inc., 2010).

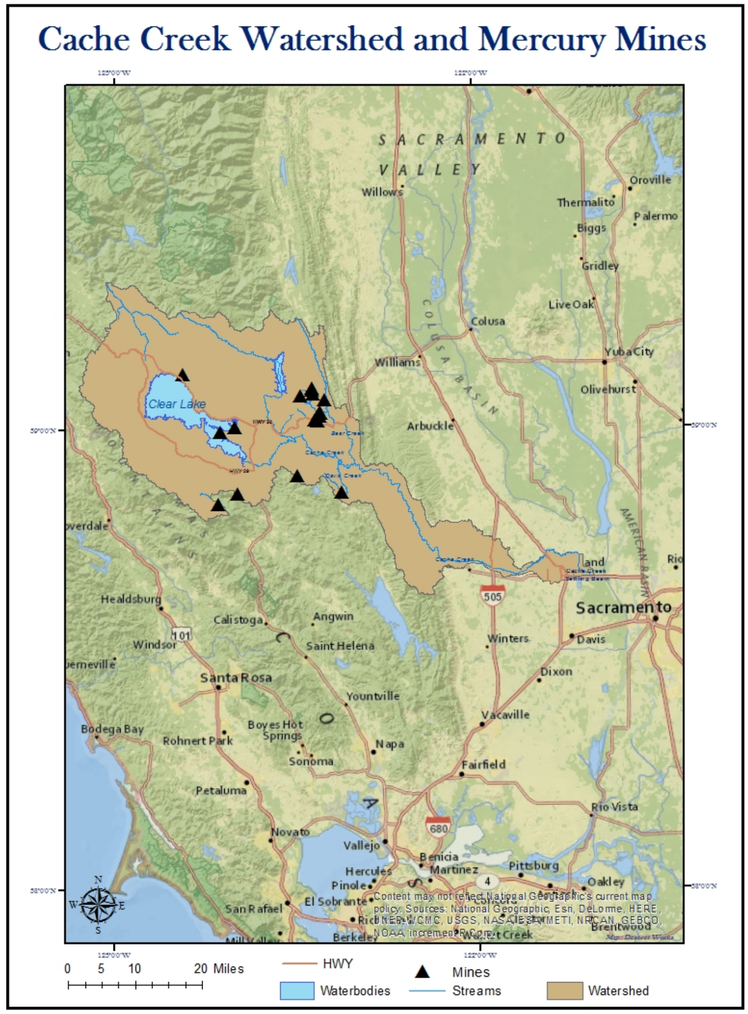

Figure 12: Locations of mercury mines in the Cache Creek Watershed. Mine locations data source: California Department of Toxic Substances Control., 2011.

Precipitation patterns play an important role in the movement of water and sediment transport and thus Hg in this watershed, as well as geology and mine locations that are also important controls (Figure 12) (Churchill and Clinkenbeard, 2003; Alpers et al., 2005). While the Franciscan Complex is prevalent in the western areas of the watershed, which also has fewer mines and is more resistant to erosion due to geological properties and presence of vegetation, the Bear Creek drainage with the majority of Hg mines is generally made up of the Great Valley Sequence, which is highly erodible (Kamman Hydrology & Engineering, Inc. 2010; UC Davis Natural Reserve System 2007). The Great Valley Sequence is a major source for Hg in this watershed due to the presence of cinnabar that occurs in the silica-carbonate rock that was formed from detrital serpentinite (Smith et al 2008; Holloway et al. 2009; Tingley and Bonham, 1986). The cinnabar however is resistant to weathering and is in the form of mining waste at the many mines in the Sulphur Creek area that drains to Bear Creek providing an important resilient source of Hg in sediment that is transported by surface water to the Cache Creek, the Sacramento River and San Joaquin/San Francisco Bay Delta Estuary (Kamman Hydrology & Engineering, Inc. 2010; Holloway et al. 2009; Domagalski et a., 2004, Alpers et al., 2008; Foe and Bosworth, 2008). Hg in sediment provides the basis for the biomagnification of MeHg (Domagalski et al., 2004; Slotten et al., 2004). A badland topography also exists in the area of the watershed (Sulphur Creek) with mines that are upstream of Bear Creek and are extremely prone to erosion, yielding high amounts of sediment (Lustig and Busch, 1967; Kamman Hydrology & Engineering, Inc. 2010).

The Cache Creek Watershed provides critical habitats including unique and endangered species, particularly aquatic and riparian zone species. Native aquatic species include the Sacramento sucker, Threespine stickleback, California roach, Clear Lake Spittail, Clear Lake hitch, Prickly sculpin, Sacramento blackfish, Sacramento pike minnow and Sacramento perch (Department of Fish and Wildlife, 2017; Thompson et al., 2013). Table 1 shows fish that are native or endemic to Clear Lake including those that are endangered or now extinct from the lake. The fish populations of Clear Lake and the Cache Creek Watershed have changed “drastically” over the last 150 years with decreases in native populations and increases in non-natives such as channel catfish, largemouth bass, brown bullhead, Mississippi silversides, common carp and smallmouth bass, among others (Thompson et al., 2013). These changes are attributed to changes in land use such as agriculture and resulting water drawdown as well as increased fluxes of sediment and pollutants, water diversion such as dams and the weir at the settling basin, the application of dichloro-diphenyl-dichloroethane (DDD), introduction of non-native fish, and mining (Thompson et al., 2013). Other species of concern in these critical habitats include the Southern Bald Eagle and Golden eagle, which are protected under the Bald Eagle and Golden Eagle Protection Act, the Yellow-billed cuckoo and the Peregrine falcon (Department of Fish and Wildlife, 2017).

Table 1: Table shows fish that are native to Clear Lake (Thompson et al. 2013) (Department of Fish and Wildlife 2017).

Sacramento sucker *Catostomus occidentalis* 	**thicktail chub** *Gila crassicauda* **Extinct 1957 – no photo**	**threespine stickleback** *Gasterosteus aculeatus* 	**California roach** *Lavinia symmetricus* 
Clear Lake Spittail **(extinct from Clear Lake)** *Pogonichthys ciscoides* 	**Clear Lake Hitch (Threatened)** *Lavinia exilicauda chi* 	**Pacific lamprey (extinct from Clear Lake)** *Lampetra tridentata* 	
prickly sculpin *Cottus asper* 	**rainbow trout/steelhead** *Oncorhynchus mykiss* 	**Sacramento blackfish** *Orthodon microlepidotus* 	
Sacramento pikeminnow *Ptychocheilus grandis* 	**Sacramento perch** *Archoplites interruptus* 		

1.5.2 Land Use

The Cache Creek Watershed has a long history of land use by humans dating back more than 10,000 years to the Patwan, Miwok and Pomo Native American tribes, but it was the more recent arrival of the colonizers of North America and modern developments that have had major negative impacts on the watershed (UC Davis Natural Reserve System 2007). Major land use development in this watershed began in the 1800's and included livestock grazing, mining then agriculture with towns developing as these land uses developed (Capay Valley Vision, 2017). The watershed extends across three counties, Lake, Colusa and Yolo. The current land uses of the watershed include subsistence (fish as food), agriculture, tourism and recreation that emphasizes fishing, boating and whitewater rafting, gravel mining, urban land use, national forests and Bureau of Land Management (BLM) lands (Planning and Public Works Department, 2009; Matrix Design Group, 2008; De Novo Planning Group, 2012). Some BLM lands have abandoned mercury and gold mines on them (Sacramento River Watershed Program, 2010).

Mercury mining in the Cache Creek Watershed started in the 1860's and continued through the 1980's (Suchanek et al., 2010; Jago, 1995; Central Valley Water Board, 2009). It is estimated that there are about 40 mercury mines in the watershed. The locations of 17 mercury mines are shown in Figure 12 (Data for Figure 12: California Department of Toxic Substances Control, 2011). Imbalances due to mercury and gold mining have materialized as impaired water quality and an overabundance of mercury (Hg and MeHg) in the system, resulting in bioaccumulation and biomagnification (Domagalski et al., 2004). Every major water body and stream in the Cache Creek Watershed is on the Clean Water Act's 303 (d) list for impaired waters due to dangerous mercury levels in fish including Clear Lake, Cache Creek, Bear Creek and Sulphur Creek (California Water Boards, 2017). The Cache Creek Watershed is noted to be the greatest contributing source for mercury in the San Francisco Bay Estuary, which is also on the 303d list for mercury threshold exceedance in fish (Foe and Bosworth, 2008) (Domagalski et al, 2004). As stated above, mine sites are point sources for high concentrations of Hg in stream sediment, which provides the basis for ongoing mercury bioaccumulation and biomagnification (Domagalski et al., 2004; Alpers et al., 2005).

1.6 Research Questions

Global-scale environmental problems call for analysis and management methods that are cross-disciplinary and can be applied and understood at local, regional and global scales to increase environmental management success rates (Ostrom, 2009). Important lessons can be gained from California and the Cache Creek Watershed's experience with mercury bioaccumulation.

Key research questions include:

1. What are the spatial patterns and temporal trends of mercury in sediment, invertebrates and fish in the Cache Creek Watershed?
2. Are there spatial patterns between mercury levels in biological indicators and point sources, if so, where are the major point sources?
3. What are the ecosystem services impacts in the Cache Creek Watershed and what are the extent of those impacts?
4. What does implementation of Ostrom's SES Framework reveal from a land use management perspective?

The Cache Creek Watershed provides an ideal basin to further understand Hg bioaccumulation and remediation implementation and ecosystem effects. Geographic information systems (GISystems) are employed to represent ecological indicators of bioaccumulation, biomagnification and hot spots associated with point sources of Hg. Two globally accepted conceptual frameworks, ecosystem services and Socio-Ecological Systems, are also used to reveal particular aspects of ecosystem burden and environmental management strategies at play that allow for widespread Hg bioaccumulation and alternately, environmental management strategies that are providing support for remediation. Ecosystem services and Socio-Ecological Systems are referred to as conceptual frameworks here as each provide the ability to show relationships, feedbacks and impacts within the watershed system (including consideration of connectivity to downstream watersheds) emphasizing the intrinsic connectivity of humans with the ecosystems in which they live (Sinclair, 2007).

2. Methods

2.1 Historical Data and Statistical Analysis

External archival data from the California Environmental Data Exchange Network (http://www.ceden.org/) and literature review of mercury concentrations in stream sediment, invertebrates, fish and cliff swallow eggs in the Cache Creek Watershed of California were compiled into a database. Fish were separated into trophic levels 3 and 4 for analysis of temporal trends, spatial patterns and differences in total Hg concentrations in various fish of each trophic level (Table 2) (fish types in each trophic level in appendix). Statistical analysis was performed using the JMP software package version 13.0 (SAS Institute, Cary, NC). Hg concentrations for each trophic level were tested for normality using the Shapiro-Wilk W test with a null hypothesis of normal distribution and alpha (α) level of 0.05. Non-parametric statistical testing methods were employed due to rejection of the null hypothesis. Regression analysis was employed to determine if Hg in fish for each trophic level is decreasing over time. ANOVA, Wilcoxon and Tukey statistical tests were used to test for statistical differences of Hg in fish types for each trophic level.

Table 2: New (2018) US and California EPA thresholds for mercury in fish for California Inland Waters (Torres, 2018)

Mercury Thresholds for Subsistence, Sport Fishing and Wildlife	
Sport Fishing	0.2 ppm
Subsistence – Trophic Level 3 Fish	0.03 ppm
Subsistence – Trophic Level 4 Fish	0.06 ppm
Wildlife	0.05 ppm

Hg concentrations in sediment, invertebrates, fish and Cliff swallow eggs are reported as either total mercury or methylmercury (MeHg) as indicated, and are reported here in parts per million (ppm), units were converted where necessary. Stream sediment mercury (total Hg) data was retrieved from available mercury inventories (CEDEN) that measured Hg at stream deposition points in silt, sand and gravel, those of which were averaged for each location for cartographic representation (Foe and Bosworth, 2008; Little and Foe, 2011). Invertebrate MeHg concentrations were included for a variety of invertebrates throughout the watershed reported with geographic locations by the U.S. Geological Survey (USGS) (Domagalski et al, 2004). Fish mercury concentrations are reported as total mercury, however, this thesis follows the Office of Environmental

Health and Hazards and 'assumes that all mercury detected in fish is methylmercury since nearly all total mercury in fish is in that form' (Bloom, 1992;Gassel and Brodberg, 2014). MeHg measurements in Cliff swallow eggs throughout the watershed were obtained from a report by Hothem et al. (2008) that also included geographic locations for those measurements, which was used to make the Cliff Swallow eggs indicator map.

2.2 Spatial Analysis

Maps of Hg concentrations in ecological indicators were created using ArcGIS. Data tables were created for each indicator, sediment, invertebrates, fish (trophic levels three and four) and cliff swallow eggs that included geographic locations and concentrations of total Hg and MeHg (ppm). Data tables were imported into ArcGIS. Hg concentrations in stream sediment were mapped (Data source: Foe and Bosworth, 2008) using normal background levels of mercury in soil for the Cache Creek Watershed (0.2 – 0.4 ppm) as a reference for concentration levels (Foe and Bosworth, 2008). MeHg symbology levels for invertebrates and cliff swallow eggs were set according to past research that revealed sub-lethal effects of Hg in wildlife to be 0.03 – 0.1 ppm and lethal effects that may occur at > 0.1 ppm (Eisler, 1987). Hg symbology levels for fish were set using the California EPA's safety thresholds for Hg in trophic levels 3 and 4 fish for tribal subsistence and sport fishing (0.03 and 0.2 ppm, respectively) (Table 3) as well as the US EPA's national threshold of 0.3 ppm (Torres, 2017;US EPA, 2009). The data tables for the indicators are located at the end of this thesis in Appendix (A and B).

The ecological indicators selected for this thesis represent important steps and evidence for bioaccumulation and/or biomagnification of Hg in the Cache Creek watershed. Collectively, these indicators contribute to the understanding of the impacts of mercury mining on the watershed ecosystem and the services it provides wildlife and humans. For example, since Hg in sediment provides the basis for biomagnification, identifying the location of point sources of Hg or areas where Hg concentrations are greatest, such as stream deposition points, can inform land use managers where remediation should be applied (Delta Tributaries Mercury Council and Sacramento River

Watershed Program, 2002; Wentz et al., 2014). Similarly, cartographic representation of Hg levels in biological indicators such as invertebrates, fish and birds, compared with locations where Hg concentrations are elevated in sediment provides evidence for transformation of Hg to MeHg and biomagnification in specific areas thus providing scientific evidence of the impacts of mining and the need for remediation as well as support for science-based policy (Delta Tributaries Mercury Council and Sacramento River Watershed Program, 2002). Trophic levels 3 and 4 fish are important for inclusion since Native American populations prefer eating trophic level 3 fish (native fish) and sport fishermen/women prefer trophic level 4 fish such as Largemouth bass and Crappie (Torres, 2017; Wolff et al., 2016). Cartographic representation of the areas with species, especially fish, with high levels of Hg reveal risk for certain populations and/or economics (Wolff et al., 2016; Wentz et al., 2014). Surface water Hg concentrations were not included in this study due to a lack of available data.

2.3 Ecosystem Services

The ecosystem services impacts analysis was done taking into account the four categories of Ecosystem Services as well as consideration of specific population demographics for the Cache Creek Watershed, those dependent on fish as protein, sport fishing as recreation and wildlife risk (critical habitats). US EPA and California EPA thresholds for mercury in fish (Table 2) for subsistence, sport fishing and wildlife in addition to information from the literature review that provided evidence for safety thresholds or dangerous levels of Hg in wildlife were used to reveal impacts on regulating, supporting, provisioning and cultural services. Comparisons were made between mercury (Hg and MeHg) concentrations in the sediment, invertebrate, fish and cliff swallow eggs indicators, as represented by the indicator maps, and Hg concentration safety thresholds to reveal areas where Hg and MeHg are highest in concentration thus implying impacts to ecosystem services and increased risk for humans and wildlife living in and visiting those areas of the watershed.

2.4 SES Framework implementation

Ostrom's SES framework (Figure 13) was employed to reveal underlying mechanisms of human impositions on, and degradation of, ecosystem services associated with Hg mining and the use of Hg for gold mining as well as mechanisms providing support for watershed remediation of Hg bioaccumulation. The main components of the framework allow for input of variables specific to the situation. For this thesis, the framework represents two time periods, one for the time period during Hg mining and the use of Hg for gold mining and the other for the time period when Hg mining ceased to the present whereby water quality and remediation is a major goal of the governing system. The resource units (RU) represent ecosystem services. The governance system (GS) simply represents the prevailing governance system or laws imposed that are specific to Hg mining and remediation. The resource system (RS) represents the entire watershed. The users (U) are the users of the watershed (wildlife and humans). The outcomes of the framework are important as they reveal impacts on ecosystem services and thus impacts on coupled human-environmental systems within the watershed and downstream.

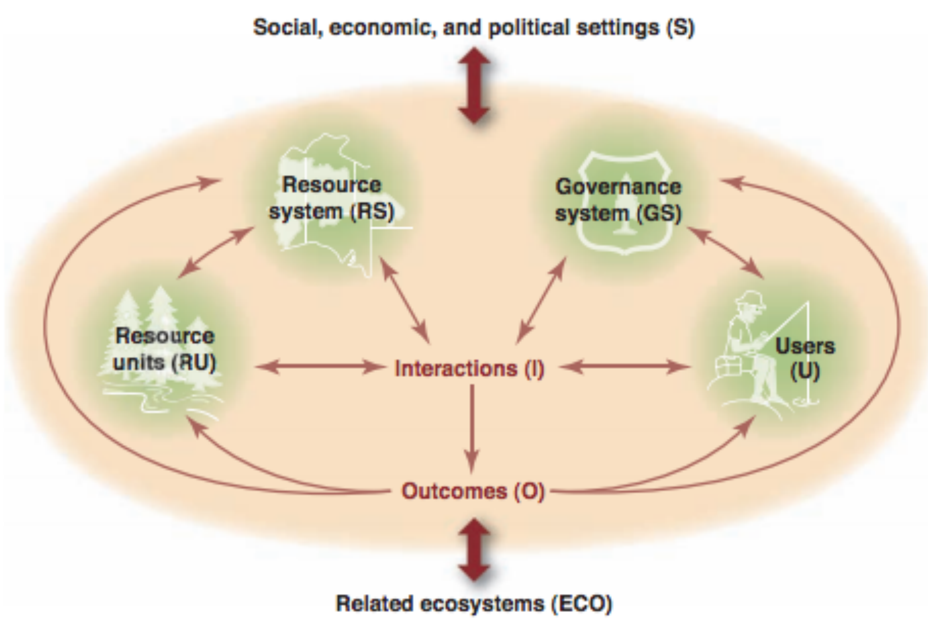

Figure 13: Socio-Ecological-Systems framework for environmental management (Ostrom, 2009).

The SES framework accounts for sub-systems that may be multilayered with feedbacks, the internal variables may vary depending on the situation (Ostrom, 2009). Since a SES is dynamic and adaptable, changing over time with differences in variables, the framework provides a comprehensive or integrated way to understand interactions of human-environment systems (Schlüter et al., 2014). Understanding connectivity of processes and human influence at various scales, local, regional and global, is fostered by the employment of the framework, which is important for watershed management, including water quality and Hg transport. Sub-systems within the framework can become quite complex (i.e. Ecosystem Services as the Resource Units) and are important considerations for environmental management strategies. The incorporation of Ecosystem Services in the SES Framework as sub-systems within the Resource Units further increases the ability to understand burdens of human systems on ecological systems and the vital services they provide via feedbacks within the entire SES.

3. Results

3.1 Spatial Distribution of Mercury in Different Ecosystem Indicators

The spatial extent of sites sampled between 1974-2013 with available data on Hg and MeHg in fish, sediment, invertebrates, and cliff swallow eggs in the watershed are included in this analysis. These indicators were chosen because they represent important steps in biomagnification, are sensitive to Hg contamination and cover the greatest spatial extent in the Cache Creek Watershed. As explained in the introduction, Hg in Sediment provides the basis for methylation so accounting for and mapping levels of Hg in sediment provide needed insights into the first basic step in trophic transfer (Domagalski et al., 2004; Alpers et al., 2005). Invertebrates are low on the food chain; identification of contamination will help to identify point sources as well as proof of methylation of Hg and trophic transfer (Domagalski et al., 2004). Trophic levels 3 and 4 fish represent separate steps in biomagnification as discussed in the introduction. Cliff swallows eat invertebrates making them an important bioindicators of biomagnification. The indicators chosen provides insights for the Ecosystem Services impacts analysis as they represent important members of the food web.

The utilization of GIS for visualization of Hg and MeHg concentrations throughout the watershed facilitates spatial analysis and proximity to point sources of Hg contamination. It can also be used to identify evidence of biomagnification and provides insights into ecosystem services impacts. Specific geographic locations where stream sediment and biological indicators have high concentrations of Hg are referred to in this thesis as hot spots as there is evidence of methylation of mercury and biomagnification in those specific areas (Viega and Baker, 2004). People and wildlife living in the direct vicinity of Hg hot spots are at an increased risk of negative impacts due to the neurotoxic nature of mercury (Park and Zheng, 2012; Harada, 1995; Griesbauer, 2007). Hot spots also provide the ability to identify the need for remediation of point sources of Hg contamination upstream. Maps were developed to evaluate spatial patterns of Hg and MeHg concentrations in multiple ecosystem indicators including sediment, invertebrates, fish and Cliff Swallow eggs. Results are discussed in the following sections.

3.1.1 Sediment

Hg in its mineral form, most commonly cinnabar, in stream sediment provides the basis for biomagnification as it is this form of Hg that sulfate-reducing bacteria transform to methylmercury (Domagalski et al., 2004; Foe and Bosworth, 2008). Total Hg concentrations in stream sediment (silt, sand and gravel) for 2008 range in concentration from 0.03 ppm to 51.2 ppm. Maps were developed in ArcGIS to evaluate spatial patterns in total Hg concentrations in sediment using averages of mercury in silt, sand and gravel for each location. Figure 14 map shows those averages of total Hg concentrations in silt, sand and gravel at locations along Cache Creek and Bear Creek and identifies mine locations as point sources of contamination. Background levels for total Hg in sediment in this watershed are 0.2 – 0.4 ppm (Foe and Bosworth, 2008). In general, stream sediment located directly downstream from mine sites have the highest concentrations of total Hg. Bear Creek has the highest concentrations of total Hg in stream sediment

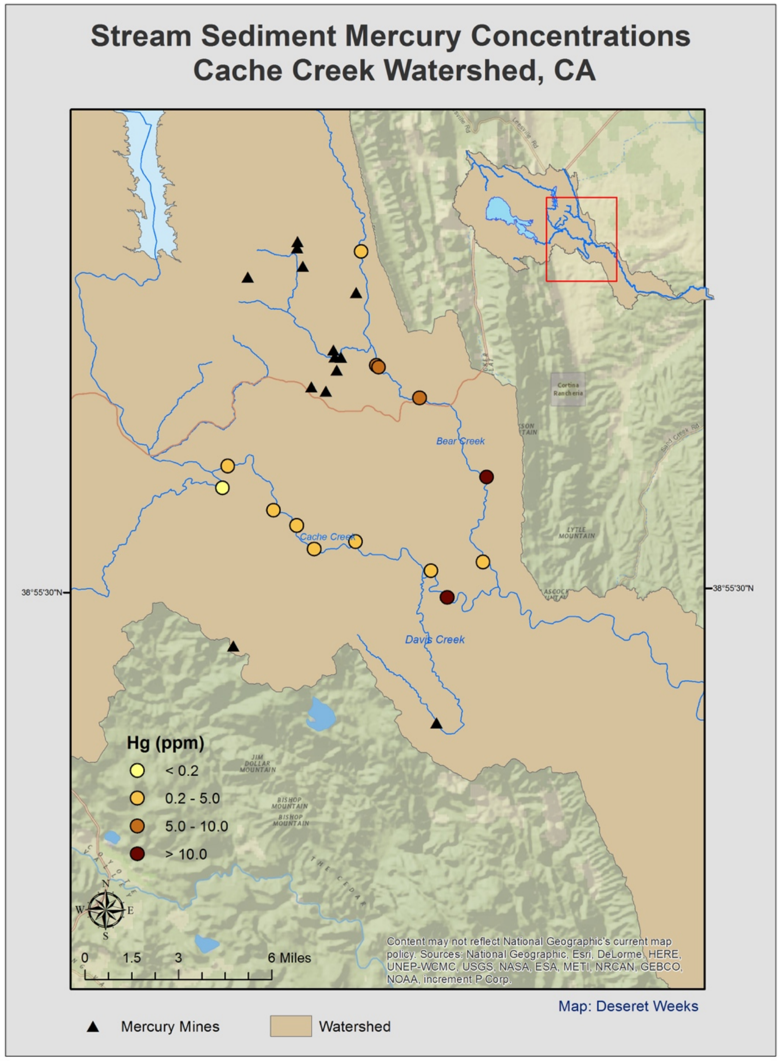

Figure 14: Mercury concentrations in stream sediment at deposition points along Cache Creek and Bear Creek. The background level of mercury in sediment in the Cache Creek Watershed is 0.2-0.4 ppm, which was used for the classification (< 0.2 ppm). Data source: Foe and Bosworth, 2008.

ranging from 0.05 ppm to 51.2 ppm, and receives water from the Sulphur Creek tributary which has multiple mine sites (Figure 14). Cache Creek east of its confluence with Davis Creek also has very high total Hg concentrations in sediment (> 10 ppm) as shown in Figure 14. Cache Creek receives sediment via erosional processes and water from the Davis Creek Reservoir and mine tailings pond located on Davis Creek, which serves as a point source for Hg contamination (Domagalski et al., 2004; Regents of the University of California, 2009). The Davis Creek Reservoir drainage contains two Hg mines known as Reed and Harrison Mines, which are point sources for Davis Creek Reservoir and mine tailings pond (Regents of the University of California, 2009). A dam located just downstream (approximately 2.4 km) from Clear Lake on the Cache Creek retains sediment and thus inputs of Hg from the mines located on Clear Lake, which may explain the lower Hg concentrations along the Cache Creek (Lake County, 2017) (Figure 12).

3.1.2. Invertebrates

Invertebrates represent an important step in biomagnification of MeHg in the food web due to their low trophic level position (Le Jeune et al., 2012). MeHg concentrations in invertebrates throughout the Cache Creek Watershed range from 0.006 ppm to 0.937 ppm (Figure 15). Similar to the spatial patterns of Hg concentrations in stream sediment, MeHg concentrations in invertebrates are the highest near or downstream from mine sites (Figure 15). The greatest levels of MeHg in invertebrates (>0.3 ppm) were measured near the Turkey-

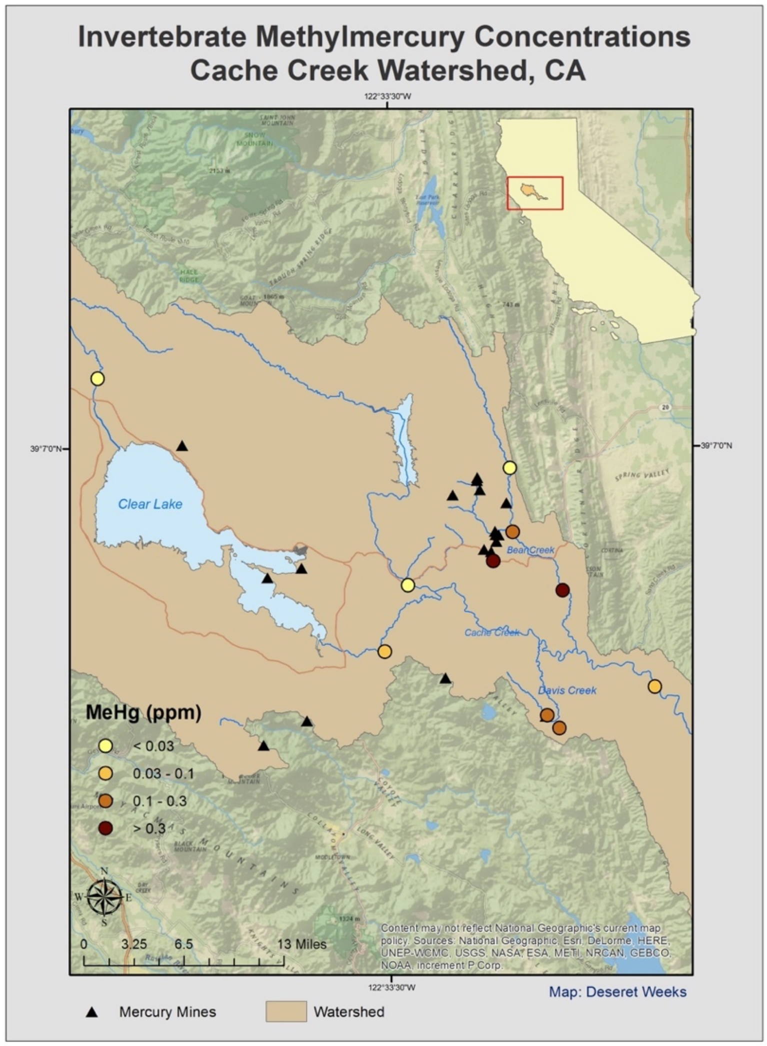

Figure 15: Methylmercury concentrations in invertebrates throughout the Cache Creek Watershed. Data source: Slotten et al., 2004

Abbot Mines, which were recently remediated and drain to Bear Creek, as well as along Bear Creek (Domagalski, 2004). Invertebrates also have extremely high levels of MeHg (>0.3 ppm) near the Reed Mine and Davis Creek Reservoir, Davis Creek. The similarity of spatial patterns of levels of Hg in sediment and MeHg in invertebrates indicates the urgent need for remediation of the mine point sources to control the methylation of Hg by sulfate-reducing bacteria.

3.1.3 Fish

To evaluate spatial patterns in total Hg concentrations in fish with consideration of impacts to specific ecosystem services and related populations of humans and wildlife in the Cache Creek Watershed, maps were developed for trophic level 3 fish and trophic level 4 fish (Figures 16 and 17). Total Hg was detected in all fish with available data in the Cache Creek Watershed from 1974-2013, ranging in

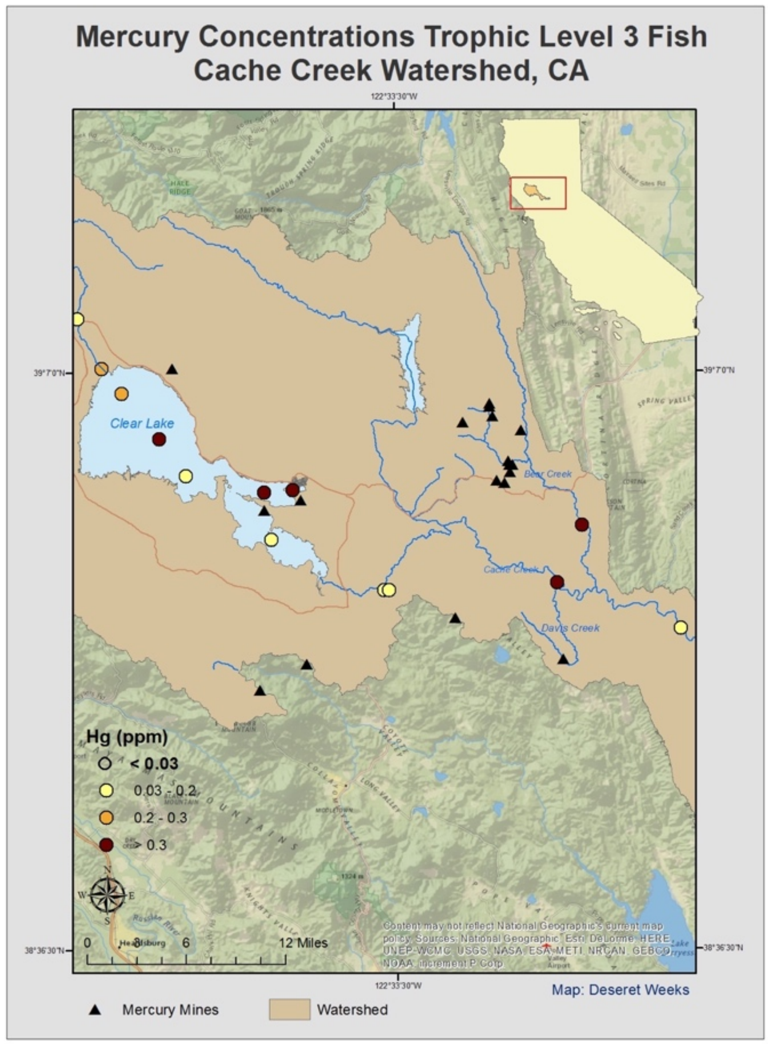

Figure 16: Average total Hg concentrations (per location) in trophic level 3 fish 1974-2013. Data source: California Environmental Data Exchange Network - http://www.ceden.org/.

concentration from 0.02 ppm to 1.91 ppm. In general, concentrations of total Hg in fish were higher downstream from (or in the vicinity of – Sulphur Bank Mine at Clear Lake) mercury mines representing point sources of contamination (Figure 16 and 17). There were a total of 85 fish in streams and 575 fish in Clear Lake with available measured Hg concentrations that were included in this analysis. Separation of trophic levels 3 and 4 fish in streams and Clear Lake provided percentages above thresholds for subsistence (0.03 ppm) and sport fishing (0.2 ppm) as shown in table 3. Of the total fish that were sampled in streams, 70% were trophic level 3 fish and 30% were trophic level 4 fish. Of the total fish that were sampled in Clear Lake, 24% were trophic level 3 fish and 76% were trophic level 4 fish.

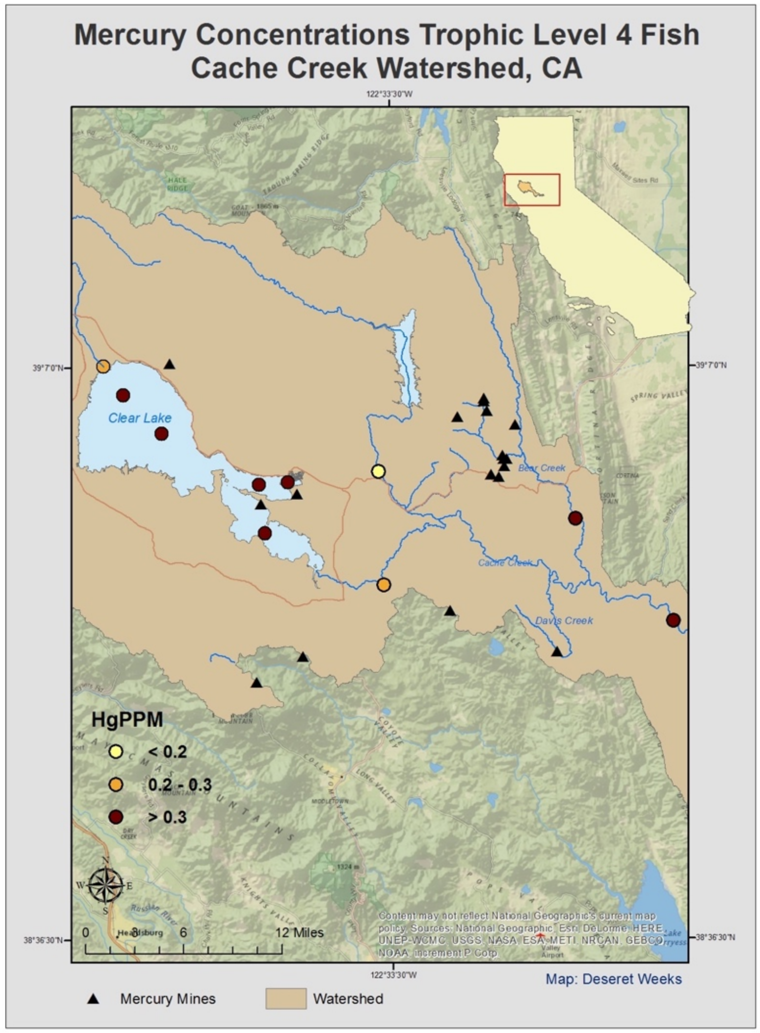

Figure 17: Average total mercury concentrations (per location) in trophic level 4 fish 1974-2013. Data source: California Environmental Data Exchange Network - http://www.ceden.org/.

The range in total Hg concentrations for trophic level 3 fish was 0.027 - 0.94 ppm, while the range in total Hg concentration for trophic level 4 fish was 0.07 – 1.91 ppm. For the trophic level 3 fish, 98.7% in streams were above the safety threshold of 0.03 ppm and 99.2% in Clear Lake. While 94.5% of trophic level 4 fish sampled in Clear Lake were above the safety threshold for Sport Fishing (0.2 ppm), 46% of those fish from the same trophic level sampled in streams were above that threshold. 98.5% of all fish sampled in the Cache Creek Watershed from 1974-2013 were above the safety threshold for wildlife – species that eat fish.

Table 3: Percentages of fish total mercury concentrations that were above the newly accepted threshold for mercury in fish for subsistence, sport fishing and wildlife.

Percentages of Fish Above Safety Thresholds (table 3)	
Trophic Level 3 Fish – Streams	98.7% > 0.03 ppm
Trophic Level 3 Fish – Clear Lake	99.2% > 0.03 ppm
Trophic Level 4 Fish – Streams	46% > 0.2 ppm
Trophic Level 4 Fish – Clear Lake	94.5% > 0.2 ppm
Wildlife Threshold	98.5% > 0.05 ppm

Averages of total Hg concentrations at specific locations from 1974-2013 in trophic levels 3 and 4 fish are shown in Figures 16 and 17. Importantly, it is assumed that nearly all of total Hg in fish is MeHg following the Office of Environmental Health Hazard Assessment assuming all mercury measured in fish to be MeHg (Bloom, 1992; Gassel and Brodberg, 2014). For trophic level 3, symbol colors correspond to health thresholds: above the US EPA's national threshold > 0.3 ppm; at or below the US EPA's and California EPA's subsistence threshold of 0.03 ppm for trophic level 3 fish (US EPA, 2017; Torres, 2017). For trophic level 4, symbol colors correspond to health thresholds above the US EPA's national threshold level (US EPA, 2017), > 0.3 ppm; at or below the threshold for sport fishing > 0.2ppm (Torres, 2017). Hg concentrations in fish for each location are long-term averages for that location.

While no fish in trophic level 3 had Hg concentrations below the recommended threshold for subsistence diets in Clear Lake (< 0.03 ppm), the map reveals that fish with the highest concentrations were collected in areas near or directly downstream from mine sites (Figure 16). Figure 17 map shows there were very few trophic level 4 fish below the Hg threshold for sport fishing (0.2 ppm). All but one location in Clear Lake had long-term averages for each location 1974-2013 of total Hg concentrations for trophic level 4 that were above the nationally accepted threshold of 0.3 ppm, which is above the sport fishing threshold of 0.2 ppm. The one location in Clear Lake where total Hg concentration was just below the EPA's nationally accepted threshold of 0.3 ppm was located at the far western shore (Figure 17), which is the opposite end of the lake as Sulphur Bank Mercury Mine, bearing in mind also that streams in this watershed flow from west to east. There was however one location on the North Fork of the Cache Creek where trophic level 4 fish average Hg concentration was below the safety threshold for sport fishing (Figure 21). For comparison, trophic level 3 map shows 5 locations where Hg in fish were below the sport fishing threshold but those fish are smaller and not usually sought by sport fishermen/women (Figure 16). This underscores the significance of classification of trophic levels of fish for Hg biomagnification and ecosystem services impacts analyses (discussed further in the following sections) since specific populations of wildlife and/or humans prefer certain types and sizes of fish. Trophic level 4 fish are larger and eat smaller fish so they have greater concentrations of Hg.

3.1.4 Cliff Swallow Eggs

Further insights into bioaccumulation and biomagnification of Hg in the Cache Creek Watershed via Hg concentrations in Cliff swallow eggs were also evaluated (Hothem et al., 2008). Available data from Hothem et al. (2008) was used to develop a bio-indicator map to reveal spatial patterns and identify impacts on ecosystem services (Figure 18). Cliff swallows are an important indicator of biomagnification of Hg because their diet consists primarily of invertebrates (Link, 2005). Cliff swallows eggs at 9

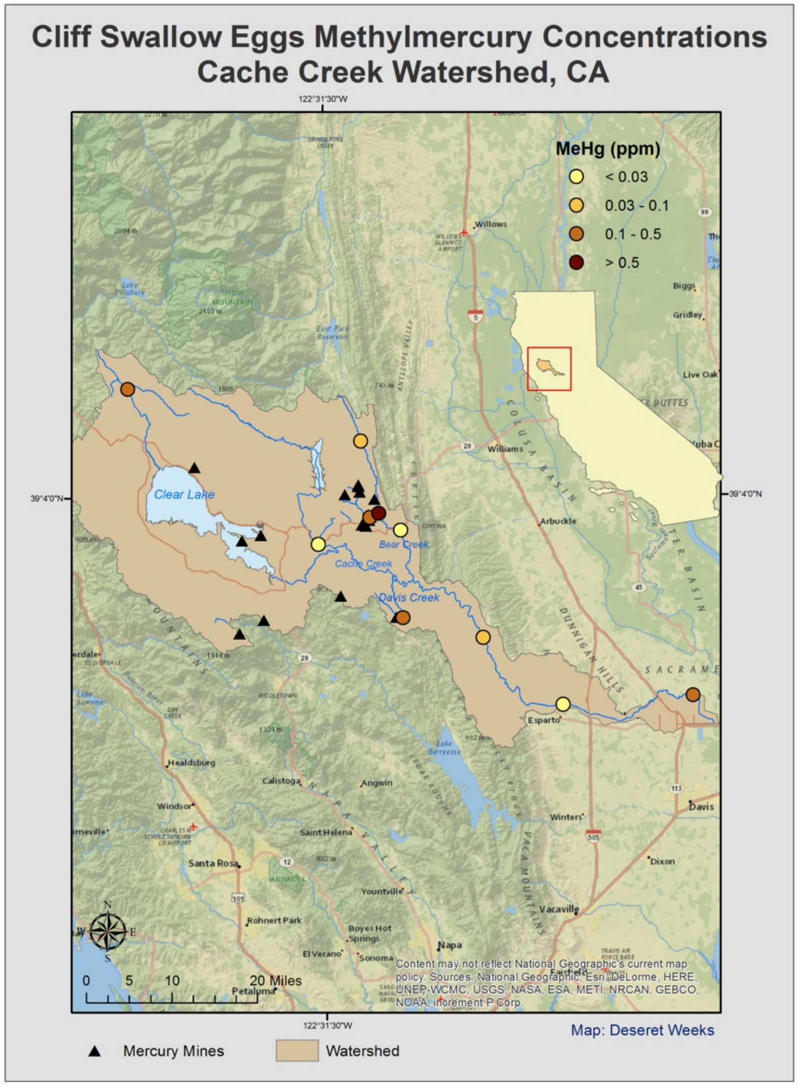

Figure 18: Methylmercury concentrations in Cliff swallow eggs. Data source: Hothem et al., 2008.

locations in the Cache Creek Watershed with MeHg concentrations (Figure 18) ranged from 0.027 - 0.54 ppm (Hothem et al., 2008). Importantly, lethal amounts of Hg in wildlife have been found to be 0.1 to 1 ppm while sub-lethal adverse effects have been found to be in the range of .03 - 0.1 (Eisler, 1987), which are the levels used for classification on the map (Figure 18). Similar to all of the other indicator maps, spatial patterns of mercury in Cliff swallow eggs were such that concentrations were greatest near or downstream from mine sites, reiterating the need for remediation of mine sites to control Hg bioaccumulation and biomagnification.

3.2 Statistical Analysis

Statistical analysis was performed on the fish data for Clear Lake to evaluate differences in total Hg concentrations for each trophic level. Results of the ANOVA and Wilcoxon statistical tests were significant and showed there were statistical differences in the mean concentrations of Hg in different fish types for trophic levels 3 and 4 for fish in Clear Lake (p-value < 0.0001) (Figures 19 and 20). For trophic level 3 fish, Sacramento blackfish and White catfish had the highest total Hg concentrations (0.08 - 0.86 ppm and

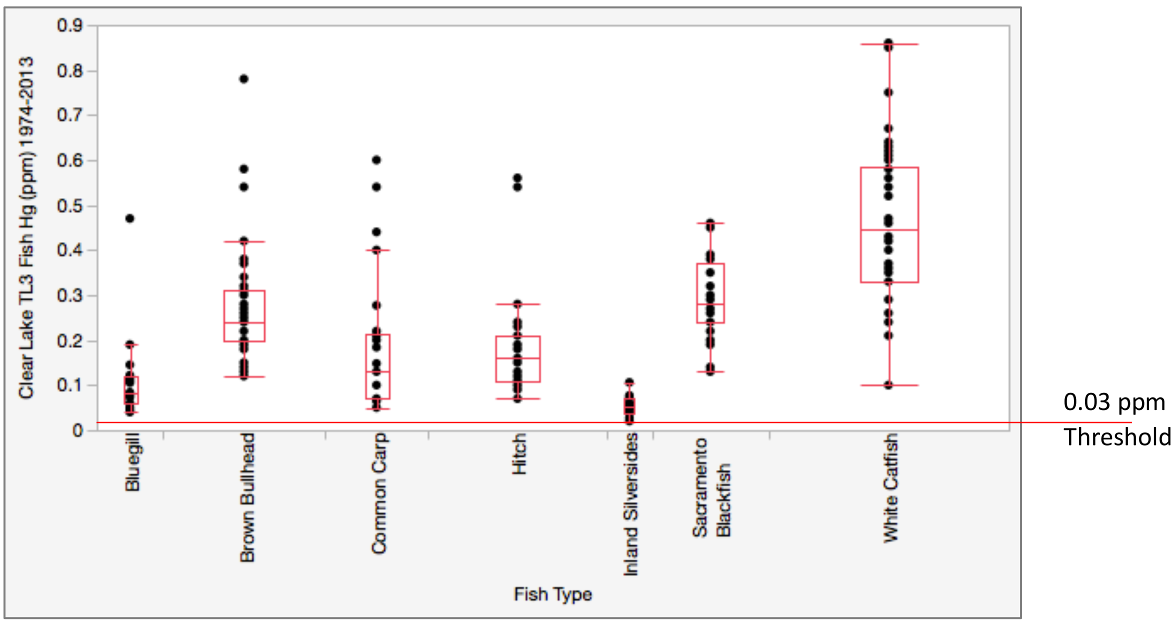

Figure 19: Differences in total mercury concentrations by fish type within trophic level 3 fish 1974-2013, Clear Lake, CA.

0.10 - 0.38 ppm respectively) while Inland silversides and Bluegill had the lowest (0.02 - 0.106 ppm and 0.04 - 0.47 ppm, respectively). A comparison of total Hg concentrations in trophic level 3 fish to the safety threshold of 0.03 ppm shows that Inland silversides are the only fish with total Hg concentrations below the threshold limits for subsistence diets but the mean total Hg concentration, 0.05 ppm, is above that threshold (Figure 20). For trophic level 4 fish, Largemouth bass had the highest total Hg concentrations, ranging from 0.097 – 1.91 ppm. All trophic 4 fish had mean concentrations above the safety threshold for sport fishing (> 0.2 ppm) (Figure 20). The mean total Hg concentrations for all trophic level 4 fish in Clear Lake were above the EPA's national threshold of 0.3 ppm indicating those fish are not safe for human consumption.

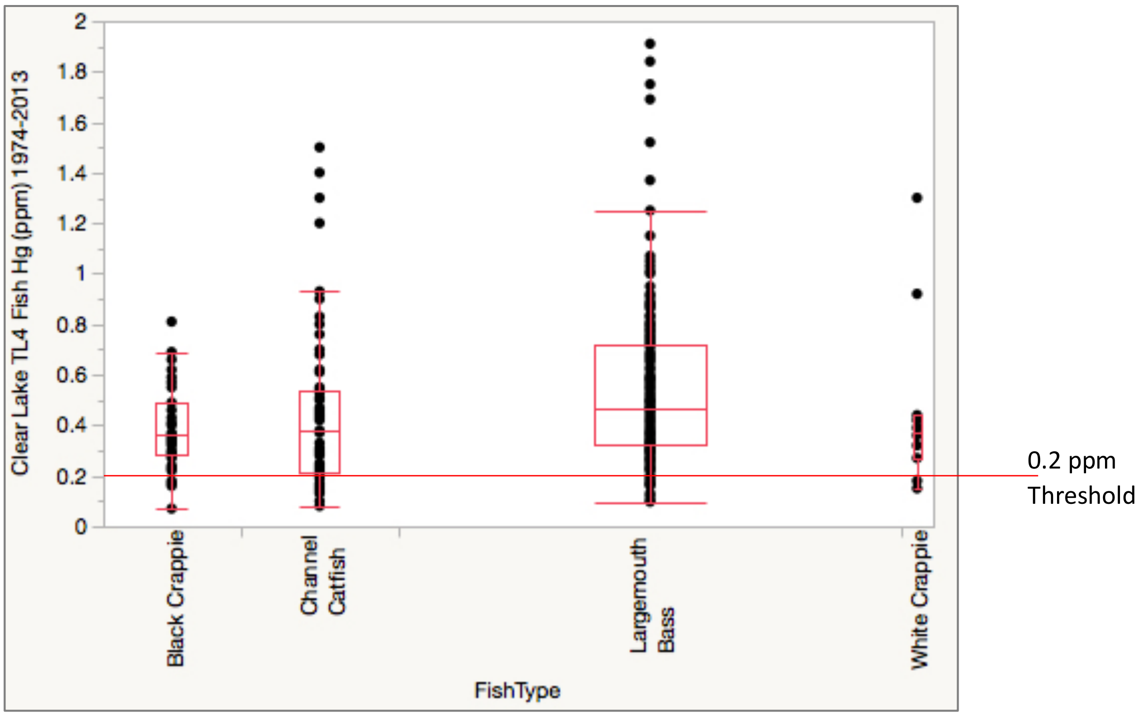

Figure 20: Differences in mercury concentrations by fish type within trophic level 4 fish 1974-2013, Clear Lake, CA..

Regression analysis suggests total Hg concentrations in both trophic levels 3 and 4 fish in Clear Lake are decreasing over the time period from 1974-2013 (Figures 21 and 22) and that they are statistically significant ($\alpha = 0.05$; p-value < 0.0001). Likewise, the slope coefficient for dates for each model was negative indicating an inverse relation between total Hg concentrations and time, such that total mercury concentrations are decreasing over time. While only 11% ($R^2 = 0.11$) of the variance in total Hg for trophic level 3 fish can be explained by time, trophic level 4 fish was even lower at 0.5% ($R^2 = 0.005$). Comparatively, the standard error for trophic level 3 was 2.4 while it was 3.2 for trophic level 4 suggesting that total Hg is reducing over time for trophic level 4 fish at a lower rate than trophic level 3 fish.

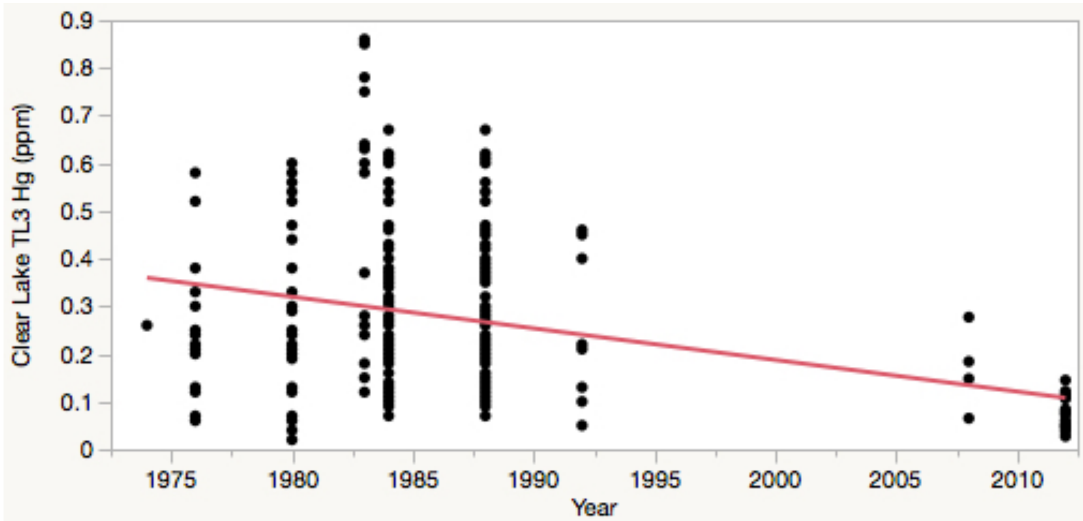

Figure 21: Total mercury concentrations in trophic level 3 fish in Clear Lake, CA, 1974-2013. While results showed mercury is decreasing over time, the levels are still well above the safety threshold for subsistence diets (0.03 ppm) and just 1.1% of the variance (R^2 = 0.11) in mercury is explained by time.

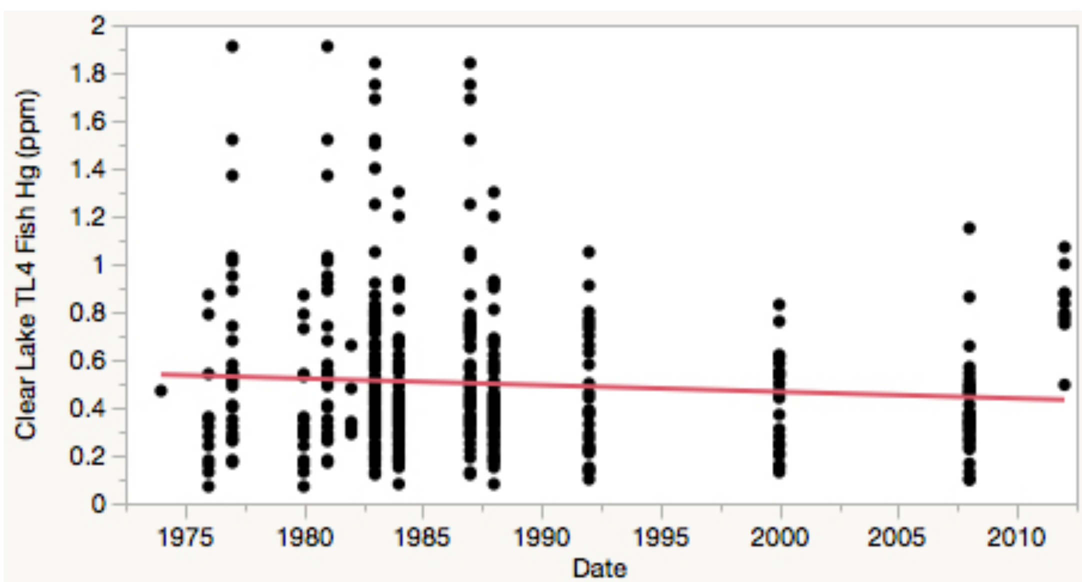

Figure 22: Total mercury concentrations in trophic level 4 fish in Clear Lake, CA, 1974-201. While results showed mercury is decreasing over time, the levels are still well above the safety threshold for sport fishing (0.2 ppm) and just 0.05% of the variance (R^2 = 0.005) in mercury is explained by time.

3.3 Ecosystem Services Impacts

The four categories of ecosystem services, including supporting, provisioning, regulating and cultural, provides a framework for identification of the impacts of Hg bioaccumulation and biomagnification in multiple ecosystem services from a holistic perspective. Using this framework, ecosystem services were evaluated to determine whether Hg mining and the use of Hg for gold mining have impacted the watershed ecosystem and the services it provides, such as fish and the ability to consume fish safely. ecosystem services is included in this study as a framework; in that regard Provisioning

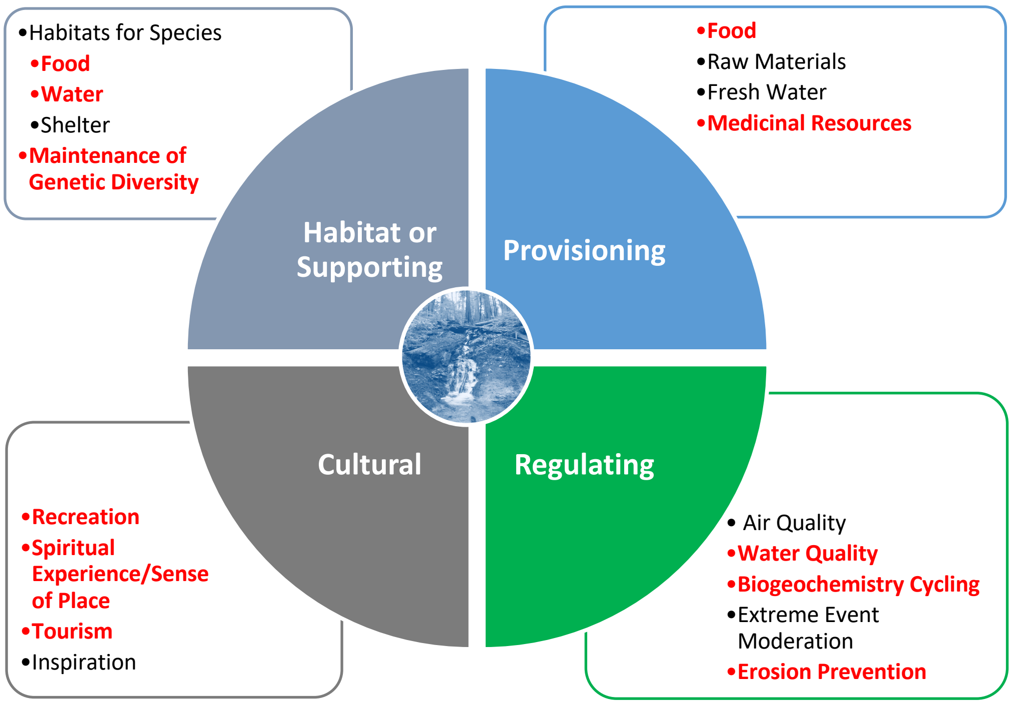

Figure 23: Ecosystem Services framework and individual services that have been or may be impacted (in red) by mercury mining and the use of mercury for gold mining in the Cache Creek Watershed.

and cultural services can be viewed as being dependent on Regulating and Supporting services. For example, the greater than background detection of Hg concentrations in stream sediment in the Cache Creek watershed has contaminated food sources for individuals in the food web. Algae, invertebrates, and small fish that are unsafe for individuals in the food web who consume those species due to Hg biomagnification provide the "Supporting" Services for species (i.e. Fish) that humans eat, which is a "Provisioning" service provided to humans by the watershed ecosystem. In this way, if Supporting Services are contaminated, those contaminants pass on to food in the Provisioning Services category, as they have in the Cache Creek Watershed. This underscores the importance of stewardship of regulating services via environmental regulations such as the Clean Water Act and the existential connectivity of humans to the entire food web. Implementation of the Ecosystem Services framework into landuse management decision processes would be extremely helpful for preventing localized and broad-scale environmental dilemmas such as the case with Hg bioaccumulation in watersheds and the global system (Vlachopoulou, et al., 2014). The framework also then increases our ability to protect wildlife and human health as well as local economies considering the importance of fisheries. Results indicate that all four categories of ecosystem services have been impacted as discussed below (Figure 23).

It is important to note that the ecosystem services impacts analysis in this thesis does not include an economic quantification, such as funds lost due to impacts to fisheries. The impacts revealed here are primarily connected to the health of humans, wildlife and the food web.

Fish are an important Ecosystem Service (food) for wildlife and humans and are considered both Supporting and Provisioning Ecosystem Services. The category of Ecosystem Services that provides support for wildlife is Supporting Services and includes food free from toxic substances, such as Hg contamination, for the food web including algae, invertebrates and fish (La Notte et al., 2017). The category for Ecosystem Services that accounts for fish as food for humans is Provisioning Services, which includes subsistence. Native Americans and low-income communities live in the watershed and rely on fish as an important protein source. Supporting and provisioning services have been impacted as shown by the fish indicator maps and in the comparison of total Hg concentrations in fish to safety thresholds provided by the US EPA and California EPA. Greater than 90% of all fish sampled from 1974-2013 were above safety thresholds. Wildlife and humans are at risk considering the neurotoxicity of Hg (Park and Zheng, 2012). Hg reduces motor functions, which is particularly harmful for wildlife as they depend on their motor functions to forage for food and fend for themselves and their offspring (Park and Zheng, 2012). Additionally, biodiversity, part of the supporting services category of ecosystem services, is also at risk as the survival rate, ability to mate and produce offspring, may be reduced. It is also important to consider the critical habitats in the Cache Creek Watershed that support the American Bald Eagle, Golden Eagle and Peregrine falcon, all of which are at the top of the food chain and eat fish (Cooke et al., 2004; US Environmental Protections Agency, 2017).

For provisioning services, the statistical results and indicator maps for fish provide evidence that humans consuming fish (an important ecosystem service), including both trophic levels 3 and trophic level 4, from the Cache Creek Watershed, particularly from Clear Lake and Bear Creek, are at an increased risk of adverse health effects. For fish with available Hg concentration data from 1974 -2013, > 98% were above safety health thresholds set by the US EPA and California EPA for subsistence (> 0.03 ppm) (California Water Boards, 2018) and sport fishing (> 0.2 ppm) (California Water Boards, 2018) and the indicator maps revealed that nearly all fish sampled in the watershed were above the national mercury threshold of 0.3 ppm (US Environmental Protections Agency, 2017; California Water Boards, 2018). Women of childbearing age and children are at an increased risk of adverse health effects due to congenital biomagnification of mercury (Kim et al., 2006; Ministry of the Environment, 2013; Minamata Disease Municipal Museum, 2007). When total Hg concentrations in fish exceed the subsistence threshold and fish become critically contaminated, a major staple food for subsistence and low income populations in this watershed is no longer reliable. Moreover, from a holistic health perspective, food (nutrition) as medicine, which is an ecosystem service within the provisioning category, has been impacted and is particularly harmful for those whose diets traditionally rely on fish as their major protein source. These results indicate that the fish in the watershed are found to have unsafe levels of Hg for human consumption. Provisioning services have been seriously impacted.

Cultural services of recreation and tourism are at risk of being impacted due to elevated Hg levels, which may be a threat to local economies. Sport fishing is large part of the economy in the Cache Creek Watershed especially at Clear Lake, which is referred to as the Bass Capital of the West (Kukura, 2016). It is possible that fishermen/women will choose a different location for fishing especially considering the signage warning against the ingestion of certain species of fish and the ingestion of fish by women of child-bearing age and children throughout the watershed (figure 24). The local economy could suffer if those sport fishermen/women choose other locations to fish. Those who enjoy whitewater rafting may choose a different river for rafting due to fears of Hg exposure which may also reduce the annual income and impact local businesses. There is no direct proof that all aspects of cultural services have been impacted, since there were no interviews conducted, however, sense of place and/or "cultural experience" could be impacted since the watershed and its ecosystem is damaged from mining and fish have unsafe Hg concentrations. Spiritual connectivity to nature is found by many through the act of fishing and preparing the fish for loved ones as a meal to share (Khakza and Griffith, 2016). This is an important link between ecosystem services and human well-being particularly for Native American populations in the Cache Creek Watershed.

Figure 24: Sign located in the Cache Creek Watershed warning about methylmercury in fish, types and amounts to be eaten safely and gender and age of people who should limit their intake according to types of fish

Regulating services, particularly biogeochemical cycling, water quality and erosion prevention, have been impacted due to the large concentrations of total Hg that are being supplied from point sources (mines), as revealed by the ecosystem indicator maps (Figures 14 ,15, 16, 17 and 18) of mercury concentrations at stream sediment deposition points (as compared to normal background levels) downstream from those point sources and biomagnification in the same areas – hot spots. The stream sediment deposition points are secondary point sources since the mercury concentrations there are high (0.05 - 51.2 ppm; background mercury in sediment in this watershed is 0.2 - 0.4 ppm) thus providing sources for mercury transport to locations further downstream and the possibility of methylation of Hg by sulfate-reducing bacteria (Foe and Bosworth, 2008; Bosworth and Morris, 2009; Suchanek et al., 2010). Erosion potential is high and erosion prevention at mine sites and stream deposition point locations does not exist due to the presence of waste rock, accumulation of stream sediment with high levels of mercury and lack of vegetation. Additionally, this watershed has a Mediterranean climate, which contributes to erosion particularly in the vicinity of the mines in the Sulphur Creek Watershed draining to Bear Creek (Lustig and Busch, 1967). Furthermore, the lack of vegetation contributes to increased rates of erosion as roots are not present to provide stability.

3.4 SES Framework implementation

3.4.1 SES Framework 1

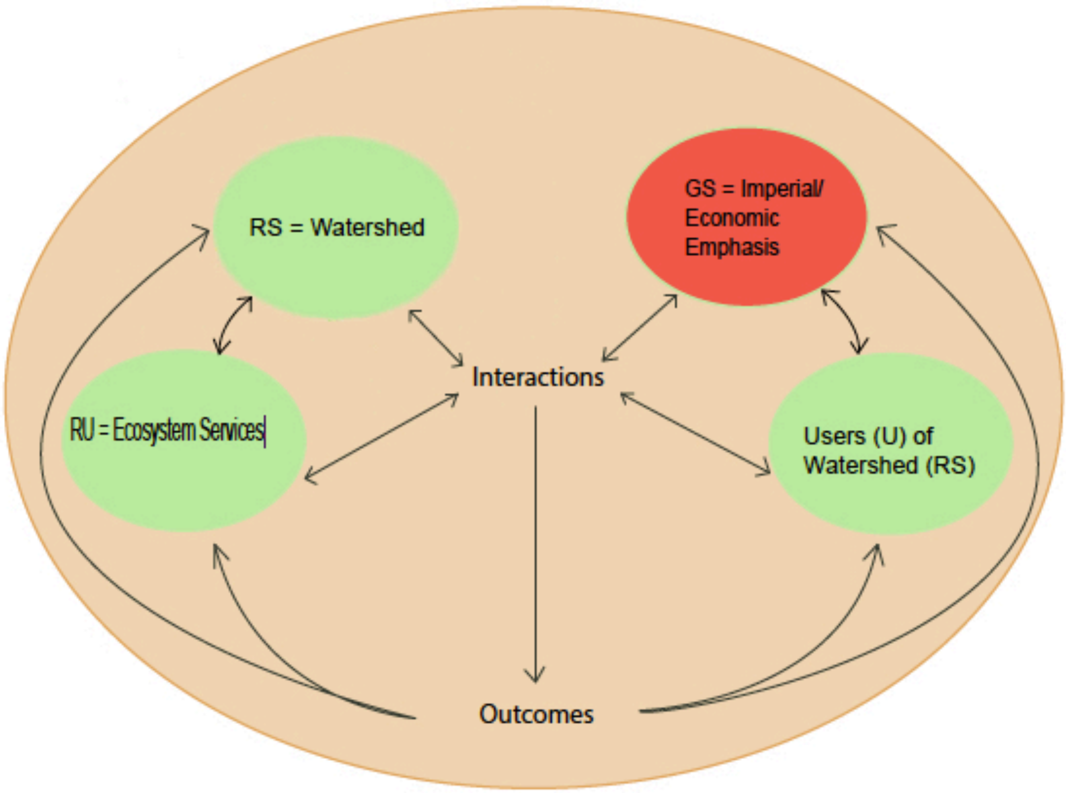

Figure 25: Implementation of Ostroms's SES Framework for the time period when mercury was being mined and mercury was being used for gold mining which was greatly expanded due to the General Mining Act of 1872. GS = Governing System which, during this time period, was the period of colonial expansion of the United States westward into Native American-occupied zones.

Implementation of Ostrom's SES Framework for the time period from 1846 to 1981 when Hg was being mined and used for gold mining provides vital insight into causal factors that brought about the extensive Ecosystem Services impacts, threats to Ecosystem services and the vitality of the entire SES (Figure 25). The governance system (GS) at the time emphasized imperial power expansion (colonial expansion) and capitalistic gain (Anderson, 1976; Rinke, 2000). The General Mining Act of 1872, signed into law by Ulysses S Grant, made it legal for individuals and corporations to stake mining claims on "public domain lands" (Anderson, 1976). The law had two main intentions, development and "settlement" (gaining control over land – colonization) of the North American west (Rinke, 2000). Mining in the Cache Creek Watershed, and California, did not last long but the potential environmental damage is long-lasting and far-reaching into watershed ecosystems and the services (Ecosystem Services = RU) they provide. The number of individuals who benefitted from the law are far outnumbered by those negatively impacted which includes all members of the food web, residents, Native American tribes and recreational visitors, as shown in the ecosystem services results section above.

Ecosystem services impacts embedded in this SES framework as the resource units (RU) provides the ability to understand the long-lasting impacts the General Mining Act of 1872 had on the SES as a whole. The statistical results, spatial patterns of Hg concentrations in ecological indicators in relation to point sources and provisioning services (fish) represent major environmental justice issues in the watershed as users (U) of the watershed receive major feedbacks from the resource units (RU). The Pomo Native American Tribe members living at the Elem Colony have raised concerns for many years about the impacts Hg in fish is having on them such as 'blurred vision, slurred speech, emotional instability and kidney failure' and blood tests revealed elevated levels of mercury in the tribe's members, supporting those concerns (Glen, 1995). The Elem Colony is located directly adjacent to the Sulphur Bank Mercury Mine, which is an EPA Superfund Site and point source for mercury (Swiderski, 2008; Domagalski et al. 2004). This emphasizes the outcomes as a direct impact on the users (U) of the watershed today as well as the resource system (RS = Watershed). The Cache Creek Watershed is made up of a majority of low-income residents (average per-capita income = $21,000/year), many of which have relied on fish from Clear Lake as a major protein source (Mason, 2017; US Census Bureau, 2016). Similarly, tourism and recreation stand to be seriously impacted, which are a major source of income for the Cache Creek Watershed (City of Clear Lake, 2017). Impacts on ecosystem services such as fisheries and local economies are serious underlying reasons for changes in the governing system represented by the arrows in the framework.

3.4.2 SES Framework 2

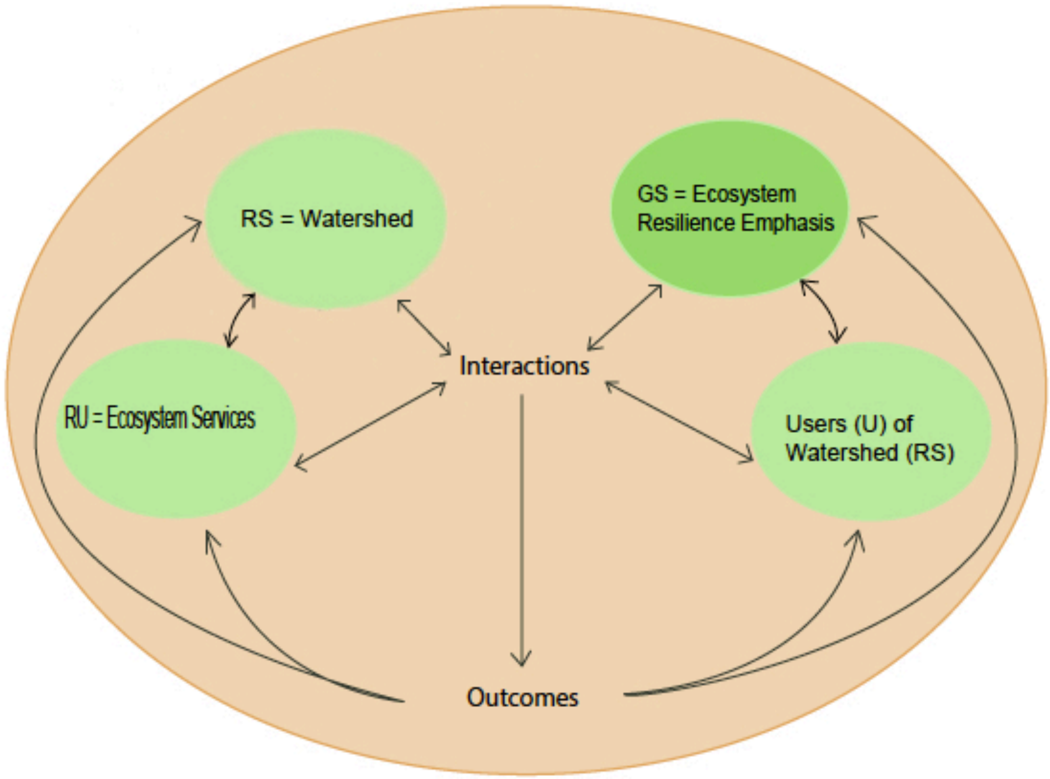

Figure 26: Implementation of Ostroms's SES Framework for the current time period of water quality protection and mercury remediation in California and the Cache Creek Watershed. The Governing System (GS) for this time period provides greater Ecosystem Services protection via the Clean Water Act, US EPA, California EPA, California Water boards, among others..

Implementation of the SES framework for the time period after the Clean Water Act was passed and Hg mining and the use of Hg for gold mining ended to the present time (SES Framework 2) provides insight into what is necessary, or providing support, for remediation and recovery of the holistic health of the watershed ecosystem and the services it provides (Figure 26). The governing system (GS) in the framework has important goals and structures for protection of water quality, which are supported by the Clean Water Act (Glicksman and Zellmer, 2013). The goals of the Clean Water Act emphasize restoration of biological integrity and include pollution standards and programs to enforce standards, the management of which is assigned to the US EPA (Glicksman and Zellmer, 2013). Under section 402 of the Clean Water Act, the US EPA works with the state water resources control boards to uphold water pollution standards (US EPA, 1989). Within the Clean Water Act is a section (40 C.F.R. § 130.7) – Total Maximum Daily Loads (TMDL) – that requires periodic water quality testing and data analysis for compliance and remediation (Cornell Law School, 2001). The TMDL section of the Clean Water Act, as well as the US EPA and California Water Quality Control Boards, provided the safety threshold standards for mercury in fish for wildlife, subsistence and sport fishing (table 2).

Another component of the governing system are regional and local networks that have been playing a pivotal role of support for mercury remediation in California and the Cache Creek Watershed. The near collapse of San Francisco Bay Delta Smelt and Chinook salmon in 1992 and a six-year drought brought about the formation of the CALFED Bay Delta Program, which began with grass-roots activism and is now a network of local, state and national stakeholders and agencies working to increase the health and integrity of watersheds draining to the San Francisco Bay through ecosystem restoration (State of California, 2007; Sommer et al., 2007). The CALFED Bay Delta Program includes 13 state and federal agencies (authorized by congress) and a science program to support its goals along with funding (State of California, 2007). A primary focus of the program has become the widespread bioaccumulation and biomagnification, and thus remediation of mercury, resulting from mercury mining and the use of mercury for gold mining in California (Domagalski et al., 2004). The CALFED Bay Delta Program is providing financial support for scientific research and working closely with academic institutions and the USGS, among others, which has resulted in a multitude of reports, many of which provided the available data for this thesis (State of California, 2007).

4.0 Discussion

4.1 Significance of Spatial Analysis

Spatial patterns of Hg bioaccumulation and biomagnification in the Cache Creek Watershed provide important insights into the long-lasting impacts of mercury mining and the use of mercury for gold mining. The ecosystem indicator maps (Figures 14, 15, 16, 17 and 18) revealed that where Hg in stream sediment is accumulating most, there is also biomagnification occurring. This is also true for Clear Lake, particularly in the vicinity of Sulphur Bank Mercury Mine where total mercury concentrations in fish were highest (Figures 16 and 17). Maps of ecological indicators that represent important steps in biomagnification (trophic transfer of mercury) such as invertebrates, trophic level 3 fish and trophic level 4 fish, as well as the Cliff swallows who consume invertebrates as fish do, not only support trophic transfer of Hg occurring throughout the Cache Creek Watershed but also provide the ability to identify areas where those processes are most severe – hot spots. This provides valuable information for land use managers and may also provide justification for obtaining support for remediation and long-term monitoring. The findings of this thesis may be useful for land use managers and stakeholders in other watersheds faced with Hg contamination of multiple ecosystem indicators and the need for Hg remediation.

The ecosystem indicator maps underscore the importance of rapid and effective remediation of Hg mine sites as well as gold mining areas where Hg has been used. Identifying Hg point sources of contamination for remediation is critical since point sources are the main source for the transformation of Hg to MeHg and then trophic transfer. The spatial patterns of Hg bioaccumulation and biomagnification in the Cache Creek Watershed can be attributed to the General Mining Act of 1872 which made it legal for individuals to stake mining claims on “federal” lands. Fortunately, some of the mercury mines in the Cache Creek Watershed are in the litigation process to start remediation which can be attributed to the Clean Water Act and its requirements, the California Water Boards water quality control plans, associated Total Maximum Daily Loads regulations and ongoing support from other local and regional (state and federal) community stakeholder groups highlighted in this thesis (California Regional Water Quality Control Board, 2016; Torres, 2017; California Water Boards, 2017).

Identifying point sources of Hg is also relevant for downstream watersheds including the Sacramento River Basin and the San Francisco Bay Delta, both of which have high levels of Hg in sediment and are on the 303d list for mercury contamination (California Water Boards, 2018). While it is true that downstream areas may have biogeochemical processes that differ or vary from those of the Cache Creek Watershed, such as the presence of wetlands and/or anoxic conditions that have been shown to be precursors to methylation of Hg, bioaccumulation and transport to other areas where these processes may occur needs to be considered by land use managers (Suchanek et al., 2008). The connectivity of watersheds is important for the holistic health of watersheds and the communities (wildlife and humans) they support. Communication among local and regional land use planners should be frequent and common goals should be identified that consider connectivity of watersheds and the whole Earth system.

4.2 Significance of the Statistical Analysis

The statistical analysis revealed there are differences in Hg among fish types. This is valuable information for those who provide communication to those living in or visiting the watershed who consume fish either by choice or by need, such as low-income residents. Those fish that have the highest amounts of Hg, such as Largemouth bass, should not be consumed due to increased health risks. Unfortunately wildlife are also at risk for exposure to the neurotoxic and holistic health impacts of Hg. This further underscores the importance of remediation of point sources.

While Hg was shown to be reducing over time from 1974 to 2013, the reduction is occurring at a slow rate and the thresholds may not be met in the immediate future. This is especially true for trophic level 4 fish, which further points to the need for remediation. The area of Sulphur Bank Mercury Mine is of particular concern since the greatest levels of total Hg concentrations in fish were observed there. Support for the remediation of Sulphur Bank Mine by community members and land use managers is warranted.

4.3 Significance of Ecosystem Services Impacts

The spatial patterns and statistical results underscore the relevance, and importance, of utilization of the ecosystem services framework for environmental impacts analyses. The spatial analysis provided the ability to identify mercury hot spots in the watershed in relation to point sources. This is also where ecosystem services are most impacted. For example, invertebrates, fish, cliff swallows and their eggs are part of the food web so their Hg contamination in those hot spot areas may be passed on as supporting and provisioning services to wildlife and humans alike. Furthermore, the statistical analysis revelation of greater concentrations in certain fish types can be communicated to humans as warnings throughout the watershed by signage, by media (such as the internet) or educational programs but wildlife cannot read the signs and are vulnerable. Birds of prey, including threatened, endangered and/or protected species such as the Bald Eagle, Golden Eagle, Peregrine Falcon as well as bears, all of which are present in the Cache Creek Watershed, are at major risk as well since supporting services are impacted by mercury contamination (Sacramento River Watershed Program, 2011). Supporting services include healthy, reliable habitat, food and water for wildlife. As shown by this thesis, ecosystem services provide the ability to gauge our level of stewardship and evaluate whether the stewardship that is occurring is sufficient.

Ecosystem services applied as a conceptual framework provides a greater ability for the information to be shared with the global community since it is a globally accepted management framework (Ostrom, 2009). Further, this information can contribute to developing practical solutions for environmental challenges such as Hg contamination that are occurring at local, regional and global scales. The utilization of ecosystem services in this Master’s thesis is a valuable step towards that goal.

4.4 Relevance of the SES Framework

While ecosystem services as a framework provides the ability to identify holistic impacts of mercury mining and the use of mercury for gold mining, it is also important to consider sustainable land use management. The implementation of the SES framework helps to provide insights for communities where Hg is being used for gold mining as well as those seeking remediation. The embedding of ecosystem services within the SES framework as the resource units (RU) provides for increased understanding, flexibility and support for environmental management decision processes and sustainability of socio-ecological-systems.

The complexity and adaptive capacity is an important aspect of the SES framework and its applicability to environmental management. The framework can be scaled up or down while providing insights into connectivity as well as flows, feedbacks and outcomes at various scales. For example, the resource system (RS) being the Cache Creek Watershed in this case could be scaled down to a sub-watershed such as the Bear Creek tributary which had the highest Hg concentrations in multiple ecosystem indicators due to point sources directly upstream. The governing system (GS) for the Bear Creek sub-watershed would be more specific in localized terms since that area is primarily National Public Lands. This presents different dynamics from a land-use management and mercury remediation perspective as it may be necessary to focus on a smaller sub-watershed due to remediation constraints including resources and priorities. Alternately, the framework could be scaled up and the resource system (Watershed) could include the Sacramento River Basin which is downstream of the Cache Creek Watershed and discharges to the San Francisco Bay.

The “Outcomes” of the SES framework as a system – a socio-ecological-system – for both time periods (1846-1981; 1981- current) signify the weight of the governing system (GS) as well as the influence of the ecosystem services via flows and feedbacks. The governing system provided for changes in ecosystem services in the Cache Creek Watershed first by allowing users of the watershed to mine with a lack of regulations and the General Mining Act which impacted the whole resource system (watershed) as well as the broader-scale resource systems such as regional watersheds. This point reiterates the intention of the SES framework to provide the ability to organize findings and cumulate knowledge to increase the sustainability of human society within the planetary system (Ostrom, 2009).

4.5 Local, Regional and Global Insights and Connections

Management and remediation of Hg bioaccumulation from its many sources requires methods that are applicable at local, regional and global scales (Ostrom, 2009). The SES Framework applied in this thesis provides a working example of a governing system that emphasizes ecosystem resilience, one that could be adapted in other regions to increase sustainability and relieve pressures of Global Change, of which mercury bioaccumulation is a key aspect. Compliance with water quality control plans and cooperative efforts of local, state and federal agencies as well as global treaties for remediation is key for making truly holistic impacts. Global compliance through the United Nations Environment Program's Minamata Convention (a global treaty on mercury) (UNEP, 2013), similar to the Intergovernmental Panel on Climate Change from a cooperative standpoint, represents a global governing system that strives for ecosystem resilience and supports cross-disciplinary scientific networks with open access to data such as the database (California Environmental Data Exchange Network, http://www.ceden.org/) that provided the majority of data for this thesis. The outcomes of what the Cache Creek Watershed and California is striving for in terms of the current governing system are in line with those of the Minamata Convention. Getting all global regions on board with these efforts may be aided through the example of the SES framework in this thesis for the earlier time period that lacked regulation resulting in the widespread mercury bioaccumulation being dealt with today.

Important parallel lessons can be drawn from the Cache Creek Watershed and Minamata, Japan, such as the influence of a governing system that emphasizes economic growth (over ecosystem resilience) and the connectivity of human health to the health of ecosystems and the services they provide. The Chisso Chemical Company was a powerful influence over the Resource System as it provided the majority of income in the area of Japan that was impacted by Minamata Disease (Juan, 2006; Squillace, 1988). That influence was required to change after many years of scientific research and Minamata Disease cases which provided evidence that the governing system needed adjustment and implementation of environmental regulations. Attributed largely to the General Mining

Act of 1872, California is now grappling with the remediation of thousands of abandoned mercury mines and gold mining areas where mercury was used and is also implementing controls for mercury biomagnification (The Sierra Fund, 2008; Delta Tributaries Mercury Council, 2002). These lessons are important to share with communities that are currently engaging in the use of mercury for gold mining around the world.

The short-term profits currently being made in developing nations and other areas through the use of mercury for gold mining is similar to California's history with mercury and resulting impacts on ecosystems and those dependent on the services those ecosystems provide. It is estimated that 20 tons of soil and rock are required to produce just one gold ring that may be worth about $300.00 on the American market (Bland, 2014). This clearly shows an error in valuation considering the resources required for remediation in California (estimated > $2 million to remediate the Sulphur Bank Mercury Mine alone with > 30,000 mine sites to remediate in California) (Wood, 2003; The Sierra Fund, 2008). The EPA estimates that remediation of the contaminated sediment in Clear Lake may cost up to $949 million (Wood, 2003). These costs don't account for the loss of quality of life for wildlife and humans due to the neurotoxic nature of mercury (Eisler, 1967; Park and Zheng, 2012; Sokol, 2017). About 1400 metric tons of mercury is estimated to be used annually for artisanal and small scale gold mining, one third of which is released directly into the atmosphere as vapor, the other two thirds is transported into local watersheds, spreading regionally and globally (Schmidt, 2012; UNEP, 2013). Developing countries and/or poor communities may not have the necessary resources for remediation such as environmental regulatory laws protecting water quality, strong scientific networks and funding for scientific research and millions of dollars (if not more) in remediation costs posing a future challenge to society and local, regional and global governing systems.

4.6 Political Ecology of the Governing System

Political ecology, or political dynamics interacting with and providing controls over humans and ecological systems, as an underlying mechanism of the use of mercury for gold mining is an important aspect of the problem, one that is woven throughout modern human society and the current economic system of capitalism and even more broadly, imperialism. This point reflects the relevance of the two SES Frameworks in this thesis via comparison of the outcomes. The employment of the SES Framework with a governing system that emphasizes environmental regulations and funding for science to protect ecosystems and the services they provide, would increase the adaptive capacity of watersheds, residents and visitors of those watersheds. As natural resources decrease under the infinite growth model of capitalism, protection for water quality and ecosystems will be fought against by those whose main objectives are monetary gain supported by natural resource extraction. This is an important point if deregulatory efforts were to increase. This underscores the importance of open source education resources and scientific networks to protect ecosystem resilience. The more people understand environmental science, the impacts of mining and industry and existential connectivity of humans to the ecosystems in which they live, the more likely they are to make more informed decisions.

There are many agencies and individuals working towards finding solutions for the challenges of mercury bioaccumulation linkages to gold mining (State of California, 2007; Domagalski et al., 2004; Slotten et al., 2004). Grassroots organizations, scientists, global communities and governments are coming together to reduce the inputs of mercury form local sources to the global system. The United Nation’s Chemical Waste sub-program on Mercury has created a Global Mercury Partnership in conjunction with the Minamata Convention to support communities and countries to reduce dependence on and use of mercury for small scale artisanal gold mining and more broadly, mercury emissions and releases from the sources such as coal combustion, non-ferrous metals and cement production, among others (figure 3) (UNEP, 2013; UNEP, 2015). The Global Mercury Partnership has developed a guidance document for nations to adopt mercury reduction plans that include implementation strategies as well as legal guidance (UNEP, 2015). The Minamata Convention is a global treaty many countries have signed onto as well as an action plan with periodic meetings to review scientific findings and progress (http://www.mercuryconvention.org/). This cooperative is an example of the SES Framework at the broadest scale. Complicating though, are the inputs from the governing system which is complex at this scale, hence the importance of the United Nation's global cooperative programs on mercury (UNEP, 2013). Illegal use of mercury for gold mining further underscores the importance of community education and open source scientific data.

4.7 Broader Impacts

This thesis provides an important novel perspective of the impacts of Hg bioaccumulation and biomagnification on watershed ecosystems and the services they provide wildlife and humans as well as the ability to understand the influence humans have over Earth's ecosystems (at local, regional and global scales) and inadvertently themselves through land use management decisions. The synthesis of decades of research on Hg in the Cache Creek Watershed provided available data on a variety of ecological indicators for identification of spatial patterns of Hg bioaccumulation and biomagnification as well as statistical analysis to identify temporal trends and differences in levels of Hg in various fish types. The spatial analysis and statistical results provided the ability to recognize holistic impacts to distinct services within the four broad categories of ecosystem services (supporting, regulating, provisioning and cultural) – a framework recognized globally by major organizations (such as the United Nations Environment Program and the Kyoto Protocol, among others) and scientists working on issues of Global Change such as chemical pollution. The employment the SES's framework provided the ability to bring all of the elements of the thesis together to better understand how human governing of ecosystems can have extremely deep impacts that are far-reaching and long-lasting as well as the ability to understand actions and feedbacks between players and systems within the system and outcomes that have regional and global impacts such as with Hg cycling, bioaccumulation and biomagnification.

The Cache Creek Watershed is the greatest contributing source of mercury to the San Francisco Bay Delta (Domagalski et al., 2004; Cooke et al, 2003). Consideration of the size of the watershed in comparison to all of the watersheds that drain to the San Francisco Bay that are also on the 303d list for mercury contamination underscores the urgency for remediation of all of the mine sites within the watershed (Bosworth and Morris, 2009). It also highlights the importance of watershed and water quality management that considers and incorporates local, regional and global scale connectivity.

While a major vector for mercury transport is surface water, species at different trophic levels in the food web are also major vectors, as discussed in this thesis. For example, the cliff swallow eggs indicator map provides insight into impacts of mercury bioaccumulation and biomagnification on birds. Cliff swallows, which are migratory birds, in the Cache Creek watershed, are not restricted to a small geographical area and thus serve as a vector for mercury transport over longer distances (Link, 2005). Moreover, Cliff swallows are known to move their eggs to the nests of other birds (Link, 2005).

Another major route for inorganic mercury transport is fire, acknowledged as being the greatest source for re-release of mercury to the atmosphere (Eagles-Smith et al., 2016). The Cache Creek Watershed is not only prone to fire due to the Mediterranean climate, large areas of the watershed have been impacted by the invasive species Tamarisk (Robertson, 2012). Tamarisk increases the risk of fire as it is not only highly flammable, it reduces the ability of native species to germinate as it deposits salt from its leaves when they fall to the ground which forms salt crystals on the soil (Baranco 2001; Sacramento River Watershed Program 2017; Brice 1997). Additionally, Tamarisk depletes groundwater due high its rates of drawdown thus depleting water resources for native species which then increases the risk for fire (Baranco 2001; Sacramento River Watershed Program 2017; Brice 1997).

While the Cache Creek watershed has a weir at its outlet to retain mercury in stream sediment from entering the Sacramento River and eventually the San Francisco

Bay, only 50% of the mercury load is retained in the Settling Basin (Foe and Bosworth, 2008). Considering the connectivity of mercury transport to the global system, there are evaporative losses as well as mercury accumulation in sediment and fish that may be transported into the Pacific Ocean thus adding to the problem of mercury in the ocean and areas receiving atmospheric deposition of mercury (Sundseth et al., 2017).

4.8 Limitations

Insights into Hg bioaccumulation, biomagnification and variations over time in the Cache Creek watershed were limited by the available Hg data in terms of frequency, timing and species monitored. Available data on Hg concentrations in fish were irregular, such as every two years. There were data gaps between years for fish, particularly trophic level 3. The same fish species were not measured consistently over time most likely due to the fact that different agencies or scientists were conducting the monitoring. This sheds light on the need for greater communication and cooperative research between the scientists and agencies conducting the research. While the archived data repository is extremely valuable for sharing available historical data, the data could be improved upon with better communication between scientists and organizations to provide consistency in monitoring and species sampled.

There was limited long-term data available for species other than fish, limiting insights into changes over time in different trophic levels of the food web. Evaluating spatial patterns of Hg contamination in the Cache Creek watershed is also limited due to the fact that some important areas of the watershed did not have available Hg data. Measurements of Hg in invertebrates and cliff swallows at or near Clear Lake where total Hg concentrations in fish were found to be above subsistence health thresholds, such as the shoreline near Sulphur Bank Mine and the adjacent Native American reservation would have provided valuable information. This further emphasizes the need for greater cooperative research.

Seasonal variability in mercury concentrations were not included in this thesis due to a lack of available data which may have had an impact on the results of the statistical analysis particularly considering averages in total Hg concentrations of stream sediment at deposition points. Total Hg concentrations in stream sediment are greatly increased during periods of increased precipitation and erosion (Domagalski et al., 2004). El Niño, and alternately, La Niña, years may also represent variability in Hg concentration due to changes in precipitation patterns and erosion associated with wet and dry years, which was not evaluated in this study.

There was very limited data available for water quality related to the presence of mercury. Most mercury concentration measurements in water were suspended sediment. There was nearly a complete lack of dissolved mercury water quality data available for the Cache Creek Watershed. This may have added to the understanding of influence on mercury speciation, particular locations for those influences and contribution to trophic transfer.

Another limitation of this study is the lack of personal interviews with local communities. To understand Provisioning and Cultural Ecosystem Services impacts, interviews with tribal members (particularly elders) would provide first-hand knowledge about changes in access to fish as protein, views on risk associated with mercury consumption of fish and the food web, instances of illness that fit the symptoms of mercury contamination in humans and insights into impacts on spiritual connectivity to the watershed. Like interviews with tribal members, interviews with residents living around Clear Lake would have provided greater insights into changes the local community has had to make, such as switching to processed foods in place of fresh fish, and whether they plan on staying in the area under the current circumstances. Interviews with sport fishermen/women would have provided insight to ascertain the amount of fish (if any) are being ingested by those people and their families that are catching them.

4.6 Future Research

Monitoring of additional ecosystem indicators would provide greater insight into impacts on the food web as well as changes over time as mine sites are remediated and biogeochemical equilibrium of mercury in the watershed system is restored. Long-term monitoring would also be beneficial for the multitude of watersheds in California, the Western United States, and globally, that are faced with mercury contamination, bioaccumulation and/or remediation.

Long term monitoring and accounting for mercury in the food web, particularly, fish, in the San Francisco Bay is needed. Considering the number of watersheds draining to the San Francisco Bay that are on the 303d list for mercury, Ecosystem Services impacts from mercury bioaccumulation and biomagnification may occur well into the future even after watersheds upstream are restored into equilibrium. Wetlands are also an important consideration since conversion of mercury to methylmercury occurs in those areas (Davis et al., 2003).

Regional and global accounting for watersheds that have an overabundance of mercury due to mercury mining and the use of mercury for gold mining as well as other sources is needed. While fisheries represent a major food source as well as income for developed and developing countries alike, maintenance of the integrity of the food web underpins the capability of provisioning of ecosystem services (Notte et al., 2017; European Commission, 2015). Regional and global accounting and cartographic representation is an important aspect of treaties to reduce mercury emissions and releases (UNEP, 2013). Furthermore, mercury is a heavy metal and part of the chemical pollution threshold needing quantification for the Planetary Boundaries for human sustainability within Earth’s system (Rockström et al., 2009). Communication and collaboration at local, regional and global scales between scientists, communities, governmental organizations and non-governmental organizations is needed, as shown throughout this thesis. The Minamata Convention is providing a support network but more cooperation is needed for holistic positive results in less time.

5.0 Conclusions

The Cache Creek Watershed has provided an important case study for a global problem – Hg bioaccumulation – the biggest source of which is the use of mercury for gold mining (UNEP, 2013). There are two major lessons that that can be viewed as outcomes of this thesis for communities and individuals still using mercury for gold mining. The first is the result of mercury mining and the use of mercury for gold mining which result in long-term impacts on Ecosystem Services, particularly fisheries. Changes over time in aquatic species including fish extinctions in the Cache Creek Watershed may be partly attributed to Hg contamination, as discussed in this thesis. Other communities using Hg for mining may face similar circumstances for their local and regional watersheds and the services they provide wildlife and humans. The second lesson has been underscored throughout this thesis which is the importance of environmental regulations as well as the requirement of cooperation of federal, state and local agencies, non-governmental and grassroots organizations for remediation. It is important to consider if these resources will be available to those communities in the future. Developing countries may not have the economic, regulatory and scientific network support required to bring their watersheds back into balance.

Spatial patterns and temporal trends of Hg in sediment, invertebrates, fish and Cliff Swallows provided evidence of Hg bioaccumulation and biomagnification. Hot spots associated with point sources of Hg throughout the Cache Creek Watershed were revealed as well. Spatial analysis revealed mine sites to be primary point sources for Hg with stream sediment deposition points downstream from mine sites to be secondary point sources for bioaccumulation and biomagnification. A recurring finding throughout this thesis is the urgent need for remediation of all mine sites in the Cache Creek Watershed. Connectivity to downstream watersheds is linked to this point particularly considering the Cache Creek Watershed being the biggest contributing source of Hg to the San Francisco Bay Delta which discharges into the Pacific Ocean thus adding to the problem of Hg in ocean fisheries (Domagalski et al., 2004; Little and Foe, 2011; Cooke et al., 2004).

The employment of ecosystem services embedded in the socio-ecological-systems conceptual model revealed systemic burden and environmental management strategies (General Mining Act of 1872) at play that allowed for widespread mercury bioaccumulation and alternately, environmental management strategies that are providing support for remediation such as, broadly, the Clean Water Act. All four categories of ecosystem services had services within them that were shown to be impacted due to the governing system during the time period of colonial expansion that lacked environmental regulations. Food and water for wildlife within the supporting services category have been impacted by Hg and MeHg due to biomagnification throughout the food web while maintenance of genetic diversity may be impacted. Within the Provisioning services category food (fish) has been impacted as mercury levels in fish are above safety health

thresholds. Erosion prevention, biogeochemistry cycling and water quality within the regulating services category have been impacted due to overabundance of mercury in stream sediment and lack of vegetation coupled with mine waste at mines sites as well as high levels of mercury at stream sediment deposition points. Within the cultural services category, spiritual experience/sense of place has been impacted as fish are no longer safe to eat which is a traditional part of the communities who reside in the Cache Creek Watershed. Tourism and recreation may also be impacted within the cultural services category. The SES is applied as a conceptual framework as it reveals impositions of the governing system on the watershed system which then feeds back to impact users of the watershed.

The employment of the ecosystem services and SES Frameworks reveal that humans are not separate from the ecosystems in which they live. We can only be as healthy as the ecosystems we manage. Ecosystem services and socio-ecological systems as conceptual frameworks have provided the ability to show relationships, feedbacks and impacts of Hg bioaccumulation and biomagnification within the watershed emphasizing the intrinsic and existential connectivity of humans with the ecosystems in which they live. In this new age of the Anthropocene, environmental regulations, such as the Clean Water Act, are more important than ever as well as science-based policy. Creating strong networks that are cross-disciplinary that understand and employ common socio-ecological systems frameworks for environmental management will increase environmental stewardship capabilities at local, regional and global scales.

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Appendix A

This appendix contains a table that has the ecological indicators, their mercury ranges, dates of measurements and locations as well as a table with fish types in trophic levels 3 and 4.

Indicator	Location	Date Range	Number of Samples	Analyte	Mercury Range (ppm)
Trophic 3 Fish	Cache Creek Watershed Various Stream Locations	1996-2000	60	Hg	0.027 - 0.94
Trophic 3 Fish	Clear Lake	1974 - 2012	141	Hg	0.02 - 0.86
Trophic 4 Fish	Cache Creek Watershed Various Stream Locations	2000	25	Hg	0.07 – 0.665
Trophic Level 4 Fish	Clear Lake	1974-2012	434	Hg	0.07 – 1.91
Stream Sediment	Cache Creek	2008	105	Hg	0.02 - 23.6
Stream Sediment	Bear Creek	2009	40	Hg	0.05 - 51.2
Invertebrates	Various Watershed Locations	2000	1845	MeHg	0.006 - .937
Cliff Swallow Eggs	Seven Watershed Locations	1997 - 1998	27	MeHg	0.087 - 0.54

Fish Types by Trophic Level (US EPA, 2007)	
Trophic Level 3	Bluegill, Brown Bullhead, Common Carp, Hitch, Inland Silversides, Sacramento Blackfish and White Catfish
Trophic Level 4	Clack Crappie, Channel Catfish, Largemouth Bass, Smallmouth Bass and White Crappie

Appendix B

This appendix contains the data tables used for importation into ArcGIS to create the maps in this thesis.

Mercury Mine Sites in the Cache Creek Watershed. Data Source: California Department of Toxic Substances Control, 2011.

Mine Location Data for ArcGIS			
Mine Site Name	**Latitude**	**Longitude**	**County**
Abbot Mine	39.0206	-122.4439	Lake
Baker Mine	38.88768	-122.5296	Lake
Central Mine	39.037722	-122.430604	Colusa
Cherry Hill Mine	39.032825	-122.432332	Colusa
Clyde Mine	39.07208	-122.4816	Colusa
Elgin Mine	39.05596	-122.47222	Colusa
Empire Mine	39.034249	-122.426021	Colusa
Konocti Mine	38.99481	-122.7056	Lake
Manzanita Mine	39.034544	-122.429844	Colusa
Petray Mine	39.085641	-122.451797	Colusa
Rathburn-Petray Mine	39.07694	-122.4486	Colusa
Reddington (Knoxville)	38.8246	-122.3389	Napa
Reed Mine	38.86319	-122.37056	Yolo
Sulphur Bank	39.003888	-122.664722	Lake
Turkey Run	39.0186	-122.4353	Lake
Utopia	39.11972	-122.8088	Lake
Weiper Mine	38.88961	-122.5239	Lake
West End Mine	39.034919	-122.435147	Colusa
Wide Awake	39.028273	-122.428757	Colusa
Wilbur Springs-Abbot Mine	39.06457	-122.41667	Colusa

Bear Creek Deposition Point Sediment Mercury. Bosworth, David, and Patrick Morris. 2009. "BEAR CREEK MERCURY INVENTORY." Staff Report.

Sediment Mercury Measurements and Geographic Locations Bear Creek						
Bear Creek Deposition Point Sediment Hg			**Mercury concentration (ppm)**			
Station Code	**Latitude**	**Longitude**	**Silt**	**Sand**	**Gravel**	**Average of Hg in Silt, Sand and Gravel**
BC01	39.09906	-122.41249	0.54	0.06	0.06	0.22
BC03	39.06912	-122.41045	2.3	1.15	0.1	1.18
BC04	39.07081	-122.41085	1.29	2.01	0.56	1.29
BC06	39.08003	-122.41302	2	0.59	0.13	0.9
BC08	39.05665	-122.41169	3.11	4.51	0.12	2.58
BC11	39.04226	-122.40949	2.3	0.08	0.05	0.81
BC13	39.03866	-122.40705	51.2	24.7	0.66	25.52
BC14	39.0211	-122.39115	15.6	12.2	0.4	9.4
BC16	39.01178	-122.36121	7.88	1.49	1.76	3.71
BC17	39.01178	-122.36121	12.1	5.77	0.43	6.1
BC20	38.99508	-122.35517	1.7	1.86	0.32	1.3
BC23	38.97495	-122.33929	28.2	1.65	2.74	10.86
BC24	38.96638	-122.34048	14	1.13	0.14	5.1
BC26	38.92972	-122.33388	2.67	0.59	0.15	1.13

Mercury Amounts in Silt, Sand and Gravel. Data Source: Foe, Chris, and David Bosworth. 2008. "MERCURY INVENTORY IN THE CACHE CREEK CANYON."

Sediment Mercury Measurements and Geographic Locations Cache Creek						
Cache Creek Mercury per Grain Size			**Mercury Concentration ppm**			
Cache Creek Location	**Latitude**	**Longitude**	**Silt**	**Sand**	**Gravel**	**Average of silt, sand and gravel**
Cache Creek above N Fork	38.97346	-122.49733	0.06	0.04		0.05
Cache Creek above N Fork	38.97658	-122.49657	0.08	0.06	0.07	0.07
Cache Creek above N Fork	38.97996	-122.5035	0.1	0.08	0.21	0.13
North Fork Cache Creek	38.98097	-122.50511	0.08	0.13	0.13	0.11
North Fork Cache Creek	38.98447	-122.51469	0.03	0.02	0.13	0.06

North Fork Cache Creek	38.98767	-122.53883	0.03	0.07	0.09	0.06
North Fork Cache Creek	39.06953	-122.58406	0.08	0.13	0.13	0.11
North Fork-Stemple	38.98372	-122.49419	0.04	0.58	0.05	0.22
North Fork-Stemple	38.98531	-122.48386	0.04	0.03	0.03	0.04
Stemple-Harley	38.988	-122.48361	0.05	0.04	0.06	0.05
Harley-Rocky	38.9844	-122.47911	0.55	0.04	0.13	0.24
Harley-Rocky	38.98155	-122.47916	0.92	0.07	1.1	0.69
Rocky-Jack	38.97892	-122.47556	0.24	0.05	0.04	0.04
Rocky-Jack	38.97793	-122.47269	1.68	0.07	0.12	0.61
Rocky-Jack	38.97612	-122.46973	0.23	3.02	0.09	1.11
Jack-Judge	38.97219	-122.46763	1.42	0.07	0.08	0.52
Jack-Judge	38.96725	-122.46559	0.63	0.09		0.36
Jack-Judge	38.96289	-122.467	0.45	1.43	0.4	0.76
Jack-Judge	38.96143	-122.46083	0.23	0.66	0.26	0.38
Brushy-Petrified	38.95848	-122.45587	0.09	0.12	0.07	0.09
Petrified-Trout	38.95584	-122.45328	0.06	0.07	0.04	0.06
Trout-Crack	38.94464	-122.44292	1.31	1.56	1.77	1.55
Trout-Crack	38.94258	-122.43896	0.16	0.24	0.27	0.22
Trout-Crack	38.94445	-122.43497	0.47	1.23	4.75	2.15
Trout-Crack	38.94515	-122.42945	0.58	0.62	1.2	0.8
Trout-Crack	38.94795	-122.41965	0.34	0.74	0.41	0.49
Trout-Crack	38.94807	-122.41814	1.07	1.07	0.54	0.89
Trout-Crack	38.94541	-122.4156	3.58	0.76	0.93	5.27
Trout-Crack	38.94266	-122.41513	1.68	1.48	0.57	1.24
Crack-Davis	38.94101	-122.40026	1.67	0.06		0.86
Crack-Davis	38.93992	-122.3931	0.88	0.45		0.47
Crack-Davis	38.94395	-122.39084	0.25	0.41	0.3	0.32
Crack-Davis	38.93959	-122.38425	0.68	0.7	0.46	0.61
Davis-Bear	38.93426	-122.37315	0.39	1.35	1.43	1.06
Davis-Bear	38.92743	-122.37019	0.42	0.08	0.06	0.19
Davis-Bear	38.9261	-122.37391	0.92	1.27	3.76	1.98
Davis-Bear	38.92455	-122.3704	0.33	2.16		1.25
Davis-Bear	38.92168	-122.36372	11.2	1.28	2.21	4.9

Davis-Bear	38.92291	-122.357	1.67	0.06		0.87
Davis-Bear	38.9193	-122.35362	0.32	2.2	1.69	1.4
Davis-Bear	38.91754	-122.35429	0.48	0.06		0.27
Davis-Bear	38.91584	-122.35121	1.56	1.43	4.08	2.36
Davis-Bear	38.91845	-122.34826	1.73	2.79	4.2	2.9
Davis-Bear	38.92386	-122.34142	1.11	9.95	0.06	3.7
Davis-Bear	38.92321	-122.33832	0.12	0.14	0.11	0.12
Davis-Bear	38.92597	-122.33509	1.93	0.08	0.14	2.15
CC Settling Basin	38.68292	-121.67314	0.23	0.22	0.25	0.7
CC Settling Basin	38.68708	-121.67383	0.34	0.35	0.33	0.34
CC Settling Basin	38.684	-121.67669	0.42	0.32	0.29	0.34
CC Settling Basin	38.67858	-121.67325	0.29	0.38	0.39	0.35

Invertebrate mercury measurements throughout the Cache Creek Watershed. Data Source: Slotten et al., 2004.

Invertebrate Methylmercury Measurements, Locations and Conversions					
Sample Site	Latitude	Longitude	Insect Family	MeHg WW ng/g	Conversion of ng/g to ppm
Cache Ck. bel. Clear Lake	38.93	121.4255556	Hydropsyche	74	.074
North Fork Cache Creek	38.98972222	121.4619444	Baetis	7	.007
North Fork Cache Creek	38.98972222	121.4619444	Hydropsyche	16	.016
North Fork Cache Creek	38.98972222	121.4619444	Perlodidae	16	.016
North Fork Cache Creek	38.98972222	121.4619444	Tipulidae	15	.015
Cache Creek at Rumsey	38.89472222	121.7575	Hydropsyche	35	.035
Cache Creek at Rumsey	38.89472222	121.7575	Perlodidae	37	.037
Cache Creek at Rumsey	38.89472222	121.7575	Corydalidae	41	.041
Cache Ck. bel. Hwy 505	38.69638889	120.0722222	Calopterygidae	14	.014

Cache Ck. bel. Hwy 505	38.69638889	120.0722222	Hydropsyche	32	.032
Cache Ck. bel. Hwy 505	38.69638889	120.0722222	Libellulidae	29	.029
Cache Ck. below Yolo	38.735	120.2116667	Calopterygidae	16	.016
Cache Ck. below Yolo	38.735	120.2116667	Hydropsyche	43	.043
Cache Ck. below Yolo	38.735	120.2116667	Coenagrionidae	48	.048
Middle Creek	39.19333333	121.0822222	Ephemerellidae	6	.006
Middle Creek	39.19333333	121.0822222	Hydropsyche	14	.014
Middle Creek	39.19333333	121.0822222	Naucoridae	20	.02
Middle Creek	39.19333333	121.0822222	Corydalidae	15	.015
Harley Gulch	39.01611111	121.5558333	Hydropsyche	274	.274
Harley Gulch	39.01611111	121.5558333	Coenagrionidae	296	.296
Harley Gulch	39.01611111	121.5558333	Naucoridae	937	.937
Harley Gulch	39.01611111	121.5558333	Corydalidae	582	.582
Davis Creek abv. DCR	38.87277778	121.6294444	Perlidae	96	.096
Davis Creek abv. DCR	38.87277778	121.6294444	Libellulidae	143	.143
Davis Creek abv. DCR	38.87277778	121.6294444	Naucoridae	131	.131
Davis Creek abv. DCR	38.87277778	121.6294444	Corydalidae	107	.107
Davis Ck. bel. DCR	38.85277778	121.6427778	Hydropsyche	291	.291
Davis Ck. bel. DCR	38.85277778	121.6427778	Naucoridae	243	.243
Davis Ck. bel. DCR	38.85277778	121.6427778	Corydalidae	238	.238
Upper Bear Creek	39.10638889	121.5802778	Hydropsyche	31	.031
Upper Bear Creek	39.10638889	121.5802778	Libellulidae	30	.03
Upper Bear Creek	39.10638889	121.5802778	Naucoridae	33	.033
Upper Bear Creek	39.10638889	121.5802778	Tipulidae	18	.018
Sulfur Creek	39.03916667	121.5844444	Ephemerellidae	32	.032
Sulfur Creek	39.03916667	121.5844444	Coenagrionidae	290	.29
Sulfur Creek	39.03916667	121.5844444	Naucoridae	139	.139

Mid Bear Creek	38.99111111	121.6405556	Elmidae	297	.297
Mid Bear Creek	38.99111111	121.6405556	Hydropsyche	359	.359
Mid Bear Creek	38.99111111	121.6405556	Coenagrionidae	138	.138
Mid Bear Creek	38.99111111	121.6405556	Libellulidae	286	.286
Mid Bear Creek	38.99111111	121.6405556	Naucoridae	306	.306

Mercury measurements in Cliff Swallow eggs. Data Source: Hothem et al., 2008.

Cliff Swallow Eggs Methylmercury Measurements and Locations				
Location	**Latitude**	**Longitude**	**Egg Tot Hg (dry weight ug/g) (ppm)**	**Egg MeHg (dry weight ug/g) (ppm)**
W. Fork Middle Cr.	39.252	122.954	0.085	0.113
Mill Cr. at Brim Rd.	39.163	122.446	0.1	0.098
Davis Cr. Reservoir	38.862	122.357	0.422	0.402
Sulfur Cr. Barn	39.033	122.427	0.393	0.406
Bear Cr. at Sulfur Cr.	39.04	122.408	0.47	0.535
Cache Cr. at Guinda Bridge	38.828	122.183	0.064	0.027
Cache Cr. at Rd. 102 Bridge	38.726	121.729	0.293	0.282

Trophic level 3 fish streams, Data Source: California Data Exchange Network
http://www.ceden.org/

Trophic Level 3 Fish Mercury Measurements for Streams and Locations							
Year	White Catfish	Speckled Dace	California Roach	Sacramento Sucker	Bluegill	Lat.	Long.
1996				0.3		38.9243	-122.565
1996				0.069		38.9243	-122.565
1996				0.21		38.9243	-122.565
1996				0.049		38.9243	-122.565
1996		0.48	0.37	0.385		39.024	-122.572

1996		0.107	0.084	0.079		39.024	-122.572
1996		0.26	0.34	0.255		39.024	-122.572
1996		0.063	0.082	0.051		39.024	-122.572
1996			0.375	0.18		39.024	-122.572
1996			0.09	0.035		39.024	-122.572
1996				0.225		39.024	-122.572
1996				0.051		39.024	-122.572
1996				0.165		39.024	-122.572
1996				0.041		39.024	-122.572
1996			0.185	0.12		39.1634	-122.915
1996			0.044	0.027		39.1634	-122.915
1996			0.145			39.1634	-122.915
1996			0.036			39.1634	-122.915
1997		0.27	0.325	0.195		39.024	-122.572
1997		0.056	0.079	0.04		39.024	-122.572
1997		0.345	0.325	0.275		39.024	-122.572
1997		0.08	0.061	0.063		39.024	-122.572
1997		0.37		0.26		39.024	-122.572
1997		0.084		0.059		39.024	-122.572
1997		0.355				39.024	-122.572
1997		0.082				39.024	-122.572
1997		0.59				39.024	-122.572
1997		0.149				39.024	-122.572
1997		0.58	0.42			38.93	-122.377
1997		0.146	0.099			38.93	-122.377
1997		0.62	0.425			38.93	-122.377
1997		0.153	0.109			38.93	-122.377
1997		0.54	0.94			38.93	-122.377
1997		0.132	0.235			38.93	-122.377
2000	0.1			0.35	0.055	38.9243	-122.565
2000				0.09	0.06	38.9243	-122.565
2000				0.095	0.07	38.9243	-122.565
2000				0.11	0.075	38.9243	-122.565
2000				0.105	0.095	38.9243	-122.565
2000				0.105	0.095	38.9243	-122.565
2000				0.19		38.9243	-122.565
2000				0.275		38.9243	-122.565
2000				0.36		38.9243	-122.565
2000				0.32		38.9243	-122.565
2000				0.345		39.024	-122.572
2000				0.19		39.024	-122.572
2000				0.19		39.024	-122.572
2000				0.47		39.024	-122.572
2000				0.37		39.024	-122.572
2000				0.12		39.024	-122.572

Trophic Level 3 Fish Clear Lake mercury measurements 1974-2013. Data Source: California Data Exchange Network http://www.ceden.org/

Trophic Level 3 Fish Mercury Measurements Clear Lake and Geographic Locations									
Year	Sac. Blackfish	White Catfish	Brown Bullhead	Common Carp	Hitch	Inland Silverside	Bluegill	Lat.	Long.
1974		0.26						39.0547	-122.821
1976	0.38	0.24	0.12	0.07				39.0091	-122.709
1976	0.3	0.24	0.2	0.2				39.0091	-122.709
1976		0.24	0.25	0.13				39.0091	-122.709
1976		0.52	0.58					39.0091	-122.709
1976			0.2					39.0091	-122.709
1980	0.3	0.52	0.25	0.07			0.04	39.0091	-122.709
1980	0.38		0.58	0.13			0.19	39.0091	-122.709
1980				0.2		0.02	0.47	39.0091	-122.709
1980		0.21	0.22					39.0894	-122.861
1980		0.33					0.06	39.0894	-122.861
1980		0.21						39.1194	-122.886
1980		0.29						38.943	-122.639
1983		0.26						38.943	-122.639
1983		0.58	0.37					39.1194	-122.886
1983			0.12					39.1194	-122.886
1983			0.24					39.1194	-122.886
1983		0.64						39.0128	-122.676
1983		0.6						39.0128	-122.676
1983		0.63						39.0128	-122.676
1983		0.75						39.0128	-122.676
1983		0.86						39.0128	-122.676
1983		0.85						39.0128	-122.676
1983		0.78						39.0128	-122.676
1984		0.43	0.19					39.0091	-122.709
1984		0.62	0.24					39.0091	-122.709
1984		0.56	0.31					39.0091	-122.709
1984		0.56	0.24					39.0091	-122.709
1984		0.4	0.26					39.0091	-122.709
1984		0.6	0.26					39.0091	-122.709
1984		0.36	0.22					39.0091	-122.709
1984		0.52	0.26					39.0091	-122.709
1984		0.47	0.24					39.0091	-122.709
1984		0.61	0.14					39.0091	-122.709
1984		0.35	0.24					39.0091	-122.709
1984		0.37	0.27					39.0091	-122.709
1984		0.46	0.2					39.0091	-122.709
1984			0.42					39.0091	-122.709
1984			0.38					39.0091	-122.709
1984	0.2	0.37			0.21			39.0894	-122.861
1984	0.24	0.67			0.24			39.0894	-122.861
1984	0.26	0.54			0.11			39.0894	-122.861
1984	0.29				0.12			39.0894	-122.861
1984	0.27				0.09			39.0894	-122.861
1984	0.35				0.09			39.0894	-122.861
1984	0.29				0.19			39.0894	-122.861
1984	0.26				0.13			39.0894	-122.861
1984	0.45				0.09			39.0894	-122.861
1984	0.18				0.24			39.0894	-122.861

1984	0.18				0.16			39.0894	-122.861
1984	0.08				0.28			39.0894	-122.861
1984	0.19				0.18			39.0894	-122.861
1984	0.3				0.16			39.0894	-122.861
1984	0.17				0.07			39.0894	-122.861
1984	0.27				0.1			39.0894	-122.861
1984	0.18				0.23			39.0894	-122.861
1984	0.32				0.12			39.0894	-122.861
1984	0.39				0.12			39.0894	-122.861
1984	0.38				0.21			39.0894	-122.861
1988	0.13	0.35			0.15			39.0091	-122.709
1988	0.19	0.37						39.0091	-122.709
1988	0.2	0.4						39.0091	-122.709
1988	0.22	0.42						39.0091	-122.709
1988	0.24	0.43						39.0091	-122.709
1988	0.24	0.46						39.0091	-122.709
1988	0.24	0.47						39.0091	-122.709
1988	0.24	0.52						39.0091	-122.709
1988	0.26	0.56						39.0091	-122.709
1988	0.26	0.56						39.0091	-122.709
1988	0.26	0.6						39.0091	-122.709
1988	0.27	0.61						39.0091	-122.709
1988	0.3	0.62						39.0091	-122.709
1988	0.31							39.0091	-122.709
1988	0.32							39.0091	-122.709
1988	0.34							39.0091	-122.709
1988	0.38							39.0091	-122.709
1988	0.42							39.0091	-122.709
1988	0.54							39.0091	-122.709
1988	0.08	0.37			0.07			39.0894	-122.861
1988	0.17	0.54			0.09			39.0894	-122.861
1988	0.18	0.67			0.09			39.0894	-122.861
1988	0.18				0.09			39.0894	-122.861
1988	0.18				0.1			39.0894	-122.861
1988	0.19				0.11			39.0894	-122.861
1988	0.2				0.12			39.0894	-122.861
1988	0.24				0.12			39.0894	-122.861
1988	0.26				0.12			39.0894	-122.861
1988	0.26				0.13			39.0894	-122.861
1988	0.27				0.16			39.0894	-122.861
1988	0.27				0.16			39.0894	-122.861
1988	0.29				0.18			39.0894	-122.861
1988	0.29				0.19			39.0894	-122.861
1988	0.3				0.21			39.0894	-122.861
1988	0.32				0.21			39.0894	-122.861
1988	0.35				0.23			39.0894	-122.861
1988	0.38				0.24			39.0894	-122.861
1988	0.39				0.24			39.0894	-122.861
1988	0.45				0.28			39.0894	-122.861
1992	0.45	0.1		0.22				38.9709	-122.701
1992				0.1				38.9709	-122.701
1992				0.05				38.9709	-122.701
1992				0.05				38.9709	-122.701
1992	0.46			0.05				39.0091	-122.709
1992				0.05				39.0091	-122.709

1992				0.1				39.0091	-122.709
1992				0.13				39.0091	-122.709
1992				0.21				39.0091	-122.709
1992				0.4				39.0091	-122.709
1992				0.13				39.0894	-122.861
1992				0.1				39.0894	-122.861
2008				0.184				39.025	-122.791
2008				0.148				39.025	-122.791
2008				0.277				39.025	-122.791
2008				0.065				39.025	-122.791
2012						0.027	0.078	39.025	-122.791
2012						0.037	0.122	39.025	-122.791
2012						0.047	0.073	39.025	-122.791
2012						0.049	0.084	39.025	-122.791
2012						0.061	0.145	39.025	-122.791
2012						0.106	0.105	39.025	-122.791
2012						0.077	0.115	39.025	-122.791
2012						0.073	0.11	39.025	-122.791
2012						0.053	0.045	39.025	-122.791
2012						0.053	0.051	39.025	-122.791

Trophic level 4 fish streams. CEDEN and Slotten et al., 2004

Trophic Level 4 Fish Mercury Measurements and Locations – Streams						
Year	Smallmouth Bass	Sacramento Pikeminnow	Largemouth Bass	Sacramento Sucker	Latitude	Longitude
2000			0.295		38.9243	-122.565
2000			0.295		38.9243	-122.565
2000			0.45		38.9243	-122.565
2000			0.665		38.9243	-122.565
2000			0.09		38.9243	-122.565
2000			0.625		38.9243	-122.565
2000			0.08		38.9243	-122.565
2000			0.095		38.9243	-122.565
2000			0.09		38.9243	-122.565
2000			0.07		38.9243	-122.565
2000			0.16		38.9243	-122.565
2000			0.11		38.9243	-122.565
2000			0.14		38.9243	-122.565
2000			0.27		38.9243	-122.565
2000	0.335	0.23			39.024	-122.572
2000		0.15			39.024	-122.572
2000		0.185			39.024	-122.572
2000		0.11			39.024	-122.572
2000		0.25			39.024	-122.572
2000		0.125			39.024	-122.572
2000		0.235			39.024	-122.572
2000		0.115			39.024	-122.572

2000		0.26			39.024	-122.572
2000		0.18			39.024	-122.572
2004			0.8	0.11	38.93	-121.4255556
2004		0.21		0.065	38.98972222	-121.4619444
2004	0.41	0.425		0.15	38.89472222	-121.7575
2004	0.44	0.48		0.18	38.69638889	-120.0722222
2004		0.7		0.29	39.10638889	-121.5802778

Mercury measurements in trophic level 4 fish, Clear Lake, CA, 1974-2013. Data Source: California Data Exchange Network http://www.ceden.org/

Trophic Level 4 Fish Mercury Measurements and Locations – Clear Lake						
Year	Black Crappie	White Crappie	Channel Catfish	Largemouth Bass	Latitude	Longitude
1974				0.47	39.0547	-122.821
1976	0.07			0.13	39.0091	-122.709
1976	0.28			0.79	39.0091	-122.709
1976	0.16			0.87	39.0091	-122.709
1976	0.24				39.0091	-122.709
1976	0.18			0.35	39.0894	-122.861
1976				0.54	39.0894	-122.861
1976				0.32	39.0894	-122.861
1976				0.36	39.0894	-122.861
1977				0.17	39.0547	-122.821
1977				0.18	39.0547	-122.821
1977				0.26	39.0547	-122.821
1977				0.27	39.0547	-122.821
1977				0.29	39.0547	-122.821
1977				0.32	39.0547	-122.821
1977				0.35	39.0547	-122.821
1977				0.4	39.0547	-122.821
1977				0.41	39.0547	-122.821
1977				0.49	39.0547	-122.821

1977				0.51	39.0547	-122.821
1977				0.53	39.0547	-122.821
1977				0.54	39.0547	-122.821
1977				0.54	39.0547	-122.821
1977				0.55	39.0547	-122.821
1977				0.58	39.0547	-122.821
1977				0.68	39.0547	-122.821
1977				0.74	39.0547	-122.821
1977				0.89	39.0547	-122.821
1977				0.95	39.0547	-122.821
1977				1.01	39.0547	-122.821
1977				1.03	39.0547	-122.821
1977				1.37	39.0547	-122.821
1977				1.52	39.0547	-122.821
1977				1.91	39.0547	-122.821
1980	0.07			0.13	39.0091	-122.709
1980	0.16			0.79	39.0091	-122.709
1980	0.24			0.87	39.0091	-122.709
1980	0.28				39.0091	-122.709
1980	0.18			0.32	39.0894	-122.861
1980				0.35	39.0894	-122.861
1980				0.36	39.0894	-122.861
1980				0.54	39.0894	-122.861
1980				0.53	38.943	-122.639
1980				0.73	39.0128	-122.676
1980				0.3	39.1194	-122.886
1981				0.17	39.0547	-122.821
1981				0.18	39.0547	-122.821
1981				0.26	39.0547	-122.821
1981				0.27	39.0547	-122.821
1981				0.29	39.0547	-122.821
1981				0.32	39.0547	-122.821
1981				0.35	39.0547	-122.821
1981				0.4	39.0547	-122.821
1981				0.41	39.0547	-122.821
1981				0.49	39.0547	-122.821

1981				0.51	39.0547	-122.821
1981				0.53	39.0547	-122.821
1981				0.54	39.0547	-122.821
1981				0.54	39.0547	-122.821
1981				0.55	39.0547	-122.821
1981				0.58	39.0547	-122.821
1981				0.68	39.0547	-122.821
1981				0.74	39.0547	-122.821
1981				0.89	39.0547	-122.821
1981				0.95	39.0547	-122.821
1981				1.01	39.0547	-122.821
1981				1.03	39.0547	-122.821
1981				1.37	39.0547	-122.821
1981				1.52	39.0547	-122.821
1981				1.91	39.0547	-122.821
1981				0.92	39.0128	-122.676
1982				0.34	39.0128	-122.676
1982				0.31	39.0128	-122.676
1982				0.34	39.0128	-122.676
1982				0.48	39.0128	-122.676
1982				0.66	39.0128	-122.676
1982				0.33	39.0128	-122.676
1982				0.29	39.0128	-122.676
1983				0.39	38.943	-122.639
1983				0.81	38.943	-122.639
1983				0.92	38.943	-122.639
1983				0.51	38.943	-122.639
1983				0.37	38.943	-122.639
1983				0.42	38.943	-122.639
1983	0.16			0.13	39.1194	-122.886
1983	0.23			0.12	39.1194	-122.886
1983	0.28			0.32	39.1194	-122.886
1983				0.16	39.1194	-122.886
1983				0.23	39.1194	-122.886
1983				0.2	39.1194	-122.886
1983				0.28	39.1194	-122.886

1983				0.2	39.1194	-122.886
1983				0.34	39.1194	-122.886
1983				0.46	39.1194	-122.886
1983				0.2	39.1194	-122.886
1983				0.28	39.1194	-122.886
1983				0.31	39.1194	-122.886
1983				0.36	39.1194	-122.886
1983				0.51	39.1194	-122.886
1983				0.38	39.1194	-122.886
1983				0.32	39.1194	-122.886
1983				0.38	39.1194	-122.886
1983			0.8	0.62	39.0128	-122.676
1983			1.4	0.25	39.0128	-122.676
1983			1.4	0.47	39.0128	-122.676
1983			1.5	0.45	39.0128	-122.676
1983				0.36	39.0128	-122.676
1983				0.24	39.0128	-122.676
1983				0.5	39.0128	-122.676
1983				0.22	39.0128	-122.676
1983				0.18	39.0128	-122.676
1983				0.41	39.0128	-122.676
1983				0.37	39.0128	-122.676
1983				0.33	39.0128	-122.676
1983				0.83	39.0128	-122.676
1983				0.57	39.0128	-122.676
1983				0.44	39.0128	-122.676
1983				0.67	39.0128	-122.676
1983				0.42	39.0128	-122.676
1983				0.58	39.0128	-122.676
1983				0.6	39.0128	-122.676
1983				0.72	39.0128	-122.676
1983				0.59	39.0128	-122.676
1983				0.58	39.0128	-122.676
1983				0.59	39.0128	-122.676
1983				0.65	39.0128	-122.676
1983				0.43	39.0128	-122.676

1983				0.76	39.0128	-122.676
1983				0.13	38.9709	-122.701
1983				0.12	38.9709	-122.701
1983				0.5	38.9709	-122.701
1983				0.34	38.9709	-122.701
1983				0.19	38.9709	-122.701
1983				0.3	38.9709	-122.701
1983				0.49	38.9709	-122.701
1983				0.22	38.9709	-122.701
1983				0.46	38.9709	-122.701
1983				0.35	38.9709	-122.701
1983				0.22	38.9709	-122.701
1983				0.34	38.9709	-122.701
1983				0.28	38.9709	-122.701
1983				0.44	38.9709	-122.701
1983				0.25	38.9709	-122.701
1983				0.53	38.9709	-122.701
1983				0.29	38.9709	-122.701
1983				0.36	38.9709	-122.701
1983				0.35	38.9709	-122.701
1983				0.56	38.9709	-122.701
1983				0.35	38.9709	-122.701
1983				0.71	38.9709	-122.701
1983				0.33	38.9709	-122.701
1983				0.44	38.9709	-122.701
1983				0.53	38.9709	-122.701
1983				0.73	39.0091	-122.709
1983				0.57	39.0091	-122.709
1983				0.75	39.0091	-122.709
1983				0.72	39.0091	-122.709
1983				0.66	39.0091	-122.709
1983				0.52	39.0091	-122.709
1983				0.78	39.0091	-122.709
1983				1.52	39.0091	-122.709
1983				0.79	39.0091	-122.709
1983				0.76	39.0091	-122.709

1983				0.79	39.0091	-122.709
1983				1.69	39.0091	-122.709
1983				1.84	39.0091	-122.709
1983				0.74	39.0091	-122.709
1983				0.78	39.0091	-122.709
1983				1.05	39.0091	-122.709
1983				0.87	39.0091	-122.709
1983				1.25	39.0091	-122.709
1983				1.75	39.0091	-122.709
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
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1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1983					39.0894	-122.861
1984	0.66		0.08		39.0091	-122.709
1984	0.29		0.25		39.0091	-122.709
1984	0.37		0.19		39.0091	-122.709
1984	0.46		0.19		39.0091	-122.709
1984	0.33		0.3		39.0091	-122.709
1984	0.35		0.17		39.0091	-122.709
1984	0.41		0.19		39.0091	-122.709

1984	0.36		0.29		39.0091	-122.709
1984	0.62		0.51		39.0091	-122.709
1984	0.57		0.46		39.0091	-122.709
1984	0.55	0.44	0.38		39.0091	-122.709
1984	0.43	0.39	0.93		39.0091	-122.709
1984	0.28	0.15	1.2		39.0091	-122.709
1984	0.33	0.36	0.28		39.0091	-122.709
1984	0.17	0.92			39.0091	-122.709
1984	0.22	0.27			39.0091	-122.709
1984		0.32			39.0091	-122.709
1984		0.18			39.0091	-122.709
1984		1.3			39.0091	-122.709
1984					39.0091	-122.709
1984					39.0091	-122.709
1984	0.27	0.42	0.2		39.0894	-122.861
1984	0.36		0.38		39.0894	-122.861
1984	0.34		0.24		39.0894	-122.861
1984	0.32		0.42		39.0894	-122.861
1984	0.46		0.68		39.0894	-122.861
1984	0.3		0.38		39.0894	-122.861
1984	0.49		0.43		39.0894	-122.861
1984	0.46		0.45		39.0894	-122.861
1984	0.34		1.3		39.0894	-122.861
1984	0.69		0.9		39.0894	-122.861
1984	0.29				39.0894	-122.861
1984	0.4				39.0894	-122.861
1984	0.4				39.0894	-122.861
1984	0.49				39.0894	-122.861
1984	0.3				39.0894	-122.861
1984	0.81				39.0894	-122.861
1984	0.66				39.0894	-122.861
1984	0.43				39.0894	-122.861
1984	0.57				39.0894	-122.861
1984	0.59				39.0894	-122.861
1987				0.41	39.0091	-122.709
1987				0.12	38.9709	-122.701

1987				0.13	38.9709	-122.701
1987				0.19	38.9709	-122.701
1987				0.22	38.9709	-122.701
1987				0.22	38.9709	-122.701
1987				0.25	38.9709	-122.701
1987				0.28	38.9709	-122.701
1987				0.29	38.9709	-122.701
1987				0.3	38.9709	-122.701
1987				0.33	38.9709	-122.701
1987				0.34	38.9709	-122.701
1987				0.34	38.9709	-122.701
1987				0.35	38.9709	-122.701
1987				0.35	38.9709	-122.701
1987				0.35	38.9709	-122.701
1987				0.36	38.9709	-122.701
1987				0.37	38.9709	-122.701
1987				0.44	38.9709	-122.701
1987				0.44	38.9709	-122.701
1987				0.46	38.9709	-122.701
1987				0.49	38.9709	-122.701
1987				0.5	38.9709	-122.701
1987				0.53	38.9709	-122.701
1987				0.53	38.9709	-122.701
1987				0.56	38.9709	-122.701
1987				0.71	38.9709	-122.701
1987				0.41	39.0091	-122.709
1987				0.52	39.0091	-122.709
1987				0.57	39.0091	-122.709
1987				0.66	39.0091	-122.709
1987				0.72	39.0091	-122.709
1987				0.73	39.0091	-122.709
1987				0.74	39.0091	-122.709
1987				0.75	39.0091	-122.709
1987				0.76	39.0091	-122.709
1987				0.78	39.0091	-122.709
1987				0.78	39.0091	-122.709

1987				0.79	39.0091	-122.709
1987				0.79	39.0091	-122.709
1987				0.87	39.0091	-122.709
1987				1.05	39.0091	-122.709
1987				1.25	39.0091	-122.709
1987				1.52	39.0091	-122.709
1987				1.69	39.0091	-122.709
1987				1.75	39.0091	-122.709
1987				1.84	39.0091	-122.709
1987				0.28	39.0894	-122.861
1987				0.28	39.0894	-122.861
1987				0.3	39.0894	-122.861
1987				0.32	39.0894	-122.861
1987				0.34	39.0894	-122.861
1987				0.4	39.0894	-122.861
1987				0.42	39.0894	-122.861
1987				0.43	39.0894	-122.861
1987				0.45	39.0894	-122.861
1987				0.45	39.0894	-122.861
1987				0.45	39.0894	-122.861
1987				0.48	39.0894	-122.861
1987				0.48	39.0894	-122.861
1987				0.48	39.0894	-122.861
1987				0.51	39.0894	-122.861
1987				0.52	39.0894	-122.861
1987				0.58	39.0894	-122.861
1987				0.65	39.0894	-122.861
1987				0.69	39.0894	-122.861
1987				0.73	39.0894	-122.861
1987				0.76	39.0894	-122.861
1987				1.03	39.0894	-122.861
1988	0.17	0.15	0.08		39.0091	-122.709
1988	0.22	0.18	0.17		39.0091	-122.709
1988	0.28	0.27	0.19		39.0091	-122.709
1988	0.29	0.32	0.19		39.0091	-122.709
1988	0.33	0.36	0.19		39.0091	-122.709

1988	0.33	0.39	0.25		39.0091	-122.709
1988	0.35	0.44	0.28		39.0091	-122.709
1988	0.36	0.92	0.29		39.0091	-122.709
1988	0.37	1.3	0.3		39.0091	-122.709
1988	0.41		0.38		39.0091	-122.709
1988	0.43		0.46		39.0091	-122.709
1988	0.46		0.51		39.0091	-122.709
1988	0.55		0.93		39.0091	-122.709
1988	0.57		1.2		39.0091	-122.709
1988	0.62				39.0091	-122.709
1988	0.66				39.0091	-122.709
1988	0.27	0.42	0.2		39.0894	-122.861
1988	0.29		0.24		39.0894	-122.861
1988	0.3		0.38		39.0894	-122.861
1988	0.3		0.38		39.0894	-122.861
1988	0.32		0.42		39.0894	-122.861
1988	0.34		0.43		39.0894	-122.861
1988	0.34		0.45		39.0894	-122.861
1988	0.36		0.68		39.0894	-122.861
1988	0.4		0.9		39.0894	-122.861
1988	0.4		1.3		39.0894	-122.861
1988	0.43				39.0894	-122.861
1988	0.46				39.0894	-122.861
1988	0.46				39.0894	-122.861
1988	0.49				39.0894	-122.861
1988	0.49				39.0894	-122.861
1988	0.57				39.0894	-122.861
1988	0.59				39.0894	-122.861
1988	0.66				39.0894	-122.861
1988	0.69				39.0894	-122.861
1988	0.81				39.0894	-122.861
1992			0.15	0.13	38.9709	-122.701
1992			0.22	0.1	38.9709	-122.701
1992			0.24	0.39	38.9709	-122.701
1992			0.21	0.58	38.9709	-122.701
1992			0.1	0.29	39.0091	-122.709

1992			0.1	0.63	39.0091	-122.709
1992			0.14	0.77	39.0091	-122.709
1992			0.1	0.5	39.0091	-122.709
1992			0.23	0.8	39.0091	-122.709
1992			0.38	0.44	39.0091	-122.709
1992			0.46	0.73	39.0091	-122.709
1992			0.33	0.91	39.0091	-122.709
1992			0.7	0.66	39.0091	-122.709
1992			0.38	0.27	39.0894	-122.861
1992				0.37	39.0894	-122.861
1992				0.75	39.0894	-122.861
1992				0.77	39.0894	-122.861
1992				1.05	39.0894	-122.861
2000				0.585	39.1156	-122.829
2000			0.25		39.0866	-122.843
2000			0.54		39.0866	-122.843
2000			0.46		39.0866	-122.843
2000			0.16		39.0866	-122.843
2000			0.62		39.0866	-122.843
2000			0.21		39.0866	-122.843
2000			0.13		39.0866	-122.843
2000			0.15		39.0866	-122.843
2000			0.2		39.0866	-122.843
2000			0.5		39.0866	-122.843
2000			0.55		39.0866	-122.843
2000			0.28		39.0866	-122.843
2000			0.55		39.0866	-122.843
2000			0.44		39.0866	-122.843
2000			0.83		39.0866	-122.843
2000			0.76		39.0866	-122.843
2000			0.21		39.0866	-122.843
2000			0.61		39.0866	-122.843
2000			0.47		39.0866	-122.843
2000			0.37		39.0866	-122.843
2000			0.24		39.0866	-122.843
2000			0.53		39.0866	-122.843

2000			0.31		39.0866	-122.843
2008				0.226	39.025	-122.791
2008				0.166	39.025	-122.791
2008				0.226	39.025	-122.791
2008				0.318	39.025	-122.791
2008				0.329	39.025	-122.791
2008				0.266	39.025	-122.791
2008				0.367	39.025	-122.791
2008				0.26	39.025	-122.791
2008				0.307	39.025	-122.791
2008				0.33	39.025	-122.791
2008				0.372	39.025	-122.791
2008				0.279	39.025	-122.791
2008				0.478	39.025	-122.791
2008				0.239	39.025	-122.791
2008				0.343	39.025	-122.791
2008				0.496	39.025	-122.791
2008				0.336	39.025	-122.791
2008				0.38	39.025	-122.791
2008				0.452	39.025	-122.791
2008				0.491	39.025	-122.791
2008				0.461	39.025	-122.791
2008				0.466	39.025	-122.791
2008				0.517	39.025	-122.791
2008				0.131	39.025	-122.791
2008				0.657	39.025	-122.791
2008				0.332	39.025	-122.791
2008				0.379	39.025	-122.791
2008				0.296	39.025	-122.791
2008				0.412	39.025	-122.791
2008				0.351	39.025	-122.791
2008				1.15	39.025	-122.791
2008				0.862	39.025	-122.791
2008				0.543	39.025	-122.791
2008				0.103	39.025	-122.791
2008				0.097	39.025	-122.791

2008				0.3	39.025	-122.791
2008				0.318	39.025	-122.791
2008				0.542	39.025	-122.791
2008				0.281	39.025	-122.791
2008				0.306	39.025	-122.791
2008				0.326	39.025	-122.791
2008				0.33	39.025	-122.791
2008				0.569	39.025	-122.791
2008				0.349	39.025	-122.791
2012				0.749	39.025	-122.791
2012				1	39.025	-122.791
2012				0.872	39.025	-122.791
2012				1.07	39.025	-122.791
2012				0.88	39.025	-122.791
2012				0.495	39.025	-122.791
2012				0.835	39.025	-122.791
2012				0.835	39.025	-122.791
2012				0.793	39.025	-122.791
2012				0.773	39.025	-122.791