Elkhorn Slough National Estuarine Research Reserve

Climate Change Vulnerability Assessment Exercise Summary Information

Contents

Management Context

The Elkhorn Slough National Estuarine Research Reserve (ESNERR), which was designated in 1979, is an ecologically diverse 1,439 acre protected area located on the eastern shore of the Elkhorn Slough, near Monterey Bay in Central California (Figure 1) (ESNERR Management Plan). Elkhorn Slough is a seven-mile arm of the Monterey Bay located half way between the cities of Santa Cruz and Monterey. The Elkhorn Slough NERR is protected for long-term research, water-quality monitoring, and coastal stewardship. As the primary terminus of the Elkhorn Slough watershed, the Reserve is part of a biologically rich system containing a diverse landscape of estuarine habitats, freshwater ponds, and hills containing native upland vegetation.

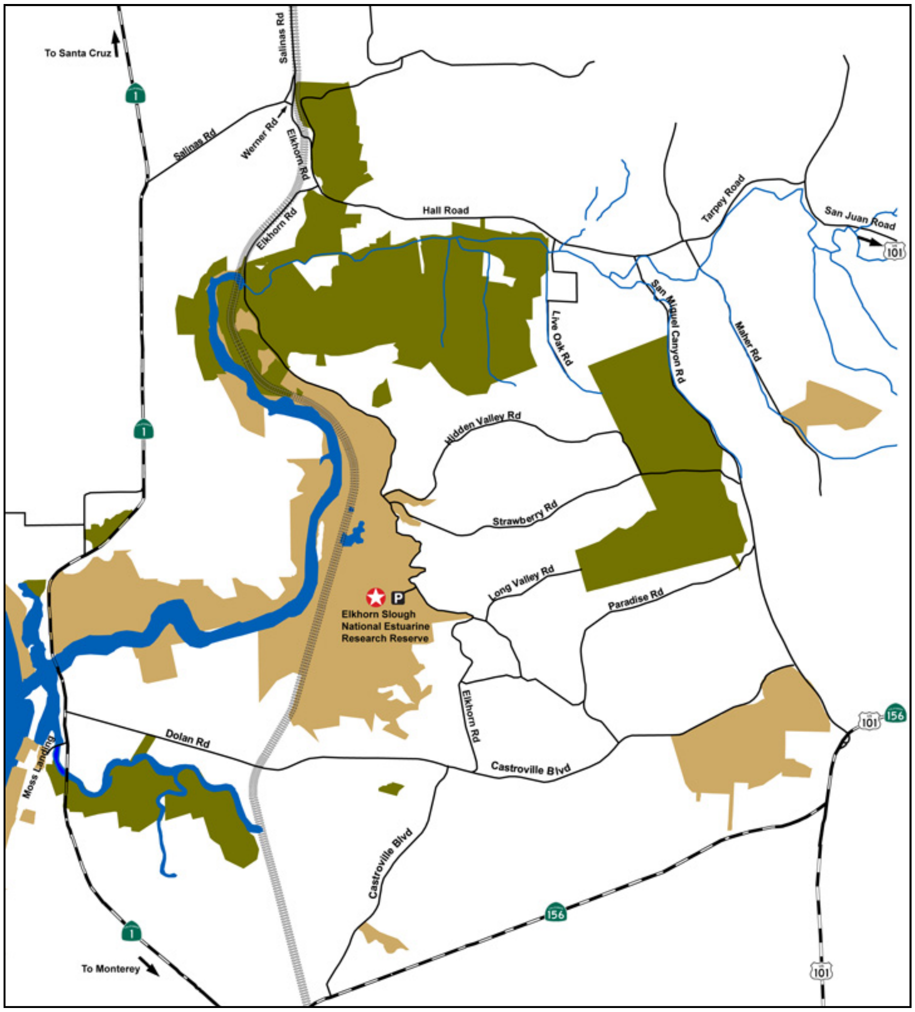


Figure 1

Jurisdictional Context

The Elkhorn Slough NERR is part of the California Department of Fish and Game's (CDFG) Central Region. CDFG is responsible for the direct management of the Reserve's facilities, habitat, and personnel and provides administrative support to the Reserve. The Wildlife Conservation Board (WCB) is the land acquisition arm of CDFG and is responsible for the purchase of properties for the reserve. The ESNERR is part of the broader Elkhorn Slough watershed, which is the focus of conservation and restoration efforts of the Elkhorn Slough Foundation (ESF). ESF serves as an administrative liaison between NOAA and CDFG and administers funds and provides grants for management purposes. NOAA has also designated areas of Elkhorn Slough as part of the Monterey Bay National Marine Sanctuary, and CDFG has designated parts of the slough as a State Ecological Reserve, a Wildlife Management Area, and several marine protected areas: the Elkhorn Slough State Marine Reserve and Conservation Area and the Moro Cojo State Marine Reserve.

Elkhorn Slough hosts a diversity of human uses in a small watershed (www.elkhornslough.org) (see figures at end), including the largest electric power generating plant in California. Moss Landing Harbor, at the entrance to the slough, is one of the most active fishing ports in the State. Elkhorn Slough is flanked by three state highways and the main north-south coastal rail line for the Union Pacific Railroad. One quarter of the land in the Elkhorn watershed is agriculture, with farms in this area producing a significant proportion of the State's strawberry crop. Residential housing is an increasing factor while recreational activities, including boating, kayaking, and birding have increased dramatically over the past decade.

Existing Mission/Goals

The mission of the Elkhorn Slough NERR is to improve the understanding of Elkhorn Slough and its watershed. Vision: The Elkhorn Slough NERR is a hub of substantive research, education, and resource management which models:

— Biodiversity through the protection of existing native habitat and the restoration of disturbed habitat through adaptive management practices.
— Quality, hands-on interaction with watershed habitats without significant negative impact on the environment.
— Inspiration of diverse audiences to make personal commitments to environmental stewardship.
— Objective and responsible information exchange, interaction, and learning.
— Broad-based community involvement.
— Sound, up-to-date, and fiscally responsible infrastructure.
— High professional standards by staff and volunteers.
— Long-term strategic planning.

ENERR has nine specific goals:

- Conservation Goal 1. Protect and Restore Estuarine Habitats in the Watershed. The Reserve will work toward the following objectives over the next five years:
    - *Restore and enhance estuarine habitats with restricted tidal flows.*
    - *Reduce erosion in subtidal habitats and the loss and degradation of intertidal habitats.*
    - *Prevent new biological introductions into estuarine habitats.*
    - *Detect and eradicate new biological introductions into estuarine habitats.*
    - *Develop restoration strategies that help favor dominance by native assemblages*.

- Conservation Goal 2. Protect and Restore the Watershed's Key Freshwater Habitats. The Reserve will work toward the following objectives over the next five years:
    - *Maintain and enhance key freshwater habitats.*
    - *Explore and act upon opportunities for watershed partnerships and outreach.*
    - *Conduct research to improve management strategies for local freshwater habitats.*
    - *Protect Reserve and key neighboring freshwater habitats from selected invaders.*

- Conservation Goal 3. Protect and Restore Maritime Chaparral in the Elkhorn Slough Watershed. The Reserve will work toward the following objectives over the next five years:
    - *Preserve existing maritime chaparral in the Elkhorn Slough watershed.*
    - *Reduce loss of maritime chaparral due to habitat type conversion.*

- Conservation Goal 4. Protect and Restore the Watershed's Coastal Prairie and Coastal Scrub Habitats. The Reserve will work toward the following objectives over the next five years:
    - *Reduce abundance of selected non-native plant and animal species in Reserve coastal prairie and coastal scrub assemblages.*
    - *Help build support for regional Coastal Prairie and Coastal Scrub projects.*
    - *Implement research that informs regional restoration strategies*.

- Conservation Goal 5. Protect and Restore the Watershed's Coast Live Oak Habitats. The Reserve will work toward the following objectives over the next five years.
    - *Protect the watershed's coast live oak habitat from biological invaders.*
    - *Investigate the habitat use of native oak vs. non-native eucalyptus groves.*

- Conservation Goal 6. Reduce Pollution Across the Elkhorn Slough Watershed. The Reserve will work toward the following objectives over the next five years:
    - *Improve understanding of pollution levels, sources, and effects on coastal habitats.*
    - *Generate and disseminate information on estuarine values and how they are affected by pollution.*
    - *Decrease effects of agricultural run-off and erosion on the Reserve*.

- Conservation Goal 7. Monitor Key Indicators of Coastal Ecosystem Health to Enhance Understanding of Spatial and Temporal Variation and Long-term Trends. Reserve monitoring programs fall into three main categories:
    - *Water quality and weather monitoring* to characterize overall ecosystem health.
    - *Habitat and land use change monitoring* to track changes in the context and distribution of different land cover classes.
    - *Biological monitoring* of threatened species and characteristic estuarine and coastal communities.

- Conservation Goal 8. Educate the Community About the Watershed and Inspire Them to Consider Environmental Conservation When Making Decisions Affecting Elkhorn Slough and Its Watershed. The Reserve will work toward the following objective in the next five years:
    - *Create and implement environmental education programs for school-aged children, visitors, our watershed neighbors, and decision makers.*

- Conservation Goal 9. Maintain a Viable Base for ESNERR Programs: Organization, Budget, and Facilities. The Reserve will work toward the following objectives in the next five years:

- *Maintain a productive, safe, and efficient ESNERR work environment.*
- *Maintain a viable and positive ESNERR image.*
- *Maintain, repair, and construct ESNERR facilities and infrastructure.*

Ecological Context

Key Habitats

- Tidal Estuary. Estuarine habitats of the Elkhorn Slough include productive salt marshes, rich mudflats, and meandering tidal channels and creeks. Dozens of vascular algae and plant species, over 100 fish species, over 135 bird species, and over 550 invertebrate species have been reported from Elkhorn Slough's estuarine habitats (Caffrey et al. 2002). Many of these are species that have broad aquatic distributions, but some are almost entirely restricted to estuarine or brackish conditions, and therefore of special conservation concern at Elkhorn Slough. These include species such as eelgrass (*Zostera marina L.*), pickleweed (*Sarcocornia pacifica*), the native Olympia oyster (*Ostreola conchaphila*), and the tidewater goby (*Eucyclogobius newberryi*). The relative rarity of estuarine habitats along the Pacific Coast makes Elkhorn Slough's role in supporting species dependent on estuarine habitats all the more essential.

- Salt Marsh. Salt marsh occurs at elevations of approximately 4.6 feet above Mean Low Low Water (MLLW) and high marsh is over 5.3 feet above MLLW (Elkhorn Slough Tidal Wetland Strategic Plan March 2007). The majority of a salt marsh habitat is a flat plain, although some areas near tidal creeks, ponded areas, and upland transitions have more varied topography and greater plant diversity. The salt panne areas are bare patches within the high salt marshes. Salt panes are typically flooded in the winter (with rain and extreme tides) and dry with a salty crust in summer. Tidal brackish marsh occurs where saltwater is diluted by freshwater during much of the year, salinity ranges between 0.5 and 18 parts per thousand (ppt), and it floods extensively (or is in shallow water). The plant and animal species are particularly adapted for a range of saltwater to freshwater conditions. In Elkhorn Slough, most of the tidal brackish habitat currently occurs in sites behind water control structures. Pickleweed (*Sarcocornia pacifica*) is a common, succulent plant of Pacific coast salt marshes (Griffith 2010). It is ecologically important to a variety of other species. Pickleweed marshes are especially well known as important foraging, nesting, and cover habitat for birds (Harvey and Connors 2002). The black rail

(*Laterallus jamaicensis*) in particular requires at least 90-97 percent pickleweed cover, usually located in the upper intertidal for adequate refugia.

- Freshwater Habitats. In the Elkhorn Slough watershed, freshwater habitats occur as riparian corridors, wet meadows, freshwater marshes, and ponds. Riparian habitats are plant assemblages associated with streambanks. Within the watershed, riparian vegetation is dominated by willow (Salix) and is found primarily along Carneros Creek. Wet meadows occur in areas without standing water, but where soils are seasonally saturated and hydric. They sometimes occur as transitional areas between upland grasslands and freshwater marshes, and they commonly include sedge (*Carex*), oatgrass (*Danthonia*), hairgrass (*Deschampsia*), barley (*Hordeum*), rush (*Juncus*), buttercup (*Ranunculus*) and bulrush (*Scirpus*) (Ratliff 1988). Freshwater marsh refers to emergent vegetation growing in at least semi-permanent shallow freshwater. The most frequently dominant freshwater marsh species are bulrush and cattail (*Typha*) (Kramer 1988). Open freshwater ponds also occur in the watershed, and include both natural features, such as Werner Lake and McClusky Slough, artificially created agricultural ponds, and artificial impoundments in former estuarine habitats, including the Reserve's Rookery Pond and Cattail Swail. Also present but not as well documented in the watershed are freshwater seeps and vernal pools.

- Maritime Chaparral. Chaparral is perhaps California's most emblematic vegetation type, forming broad expanses across coastal and inland foothills and constituting about five percent of the state's land cover (Hanes 1988). Ironically, maritime chaparral, a manzanita-dominated association found only in relatively small patches near the coast, is one of our most uncommon and highly threatened vegetation communities.

  Maritime chaparral is naturally uncommon due to its unusual habitat requirements: sand or similar extremely well drained and nutrient deficient soils, and within the zone of frequent fog along the immediate coast. Maritime chaparral stands are dominated by manzanita (*Arctostaphylos*) shrubs, typically a member of the burl-forming woolyleaf manzanita group in association with one or more of 30 rare non-burl-forming manzanita species that are endemic to restricted regions along the coast. In the Elkhorn Slough watershed, locally endemic Pajaro manzanita shares dominance with another central Monterey Bay area endemic, Hookers manzanita, and with the more widely distributed brittleleaf manzanita. Chaparral species exhibit a variety of adaptations to natural disturbances, including burls that resprout and refractory seeds that germinate in the aftermath of fire. Under a moderate fire return cycle, burned chaparral will be replaced by essentially the same mix of species. If fire cycles are frequent, a sufficient seed bank of chaparral shrubs may not accumulate and early successional species will be favored (Davis et al. 1988). Too frequent fire or intense grazing pressure can lead to habitat type conversion, permanently replacing chaparral with coastal scrub vegetation or even annual grassland.

- Coastal Prairie and Coastal Scrub. Coastal prairie and coastal scrub are part of a complex and dynamic mosaic of upland habitats within the Elkhorn Slough watershed. Coastal prairie is a species-rich habitat that occurs within 100 kilometers of the coast. It hosts not only an array of insects, amphibians, reptiles, birds, and mammals, but also a number of endangered annual forbs. The habitat can be defined, in part, by its native grass and forb species (Stromberg et al. 2001). Coastal prairie often coexists with, and frequently has a successional relationship with, northern coastal scrub. Coastal scrub is an assemblage of evergreen shrubs and, within California, ecologists recognize northern and southern divisions. Northern coastal scrub occurs from Santa Barbara County north to the Oregon border. In the Elkhorn Slough watershed, it is dominated by coyote brush (*Baccharis pilularis*). Co-dominants include California sagebrush (*Artemesia californica*), black sage (*Salvia mellifera*), coffeeberry (*Rhamnus californica*), bush monkeyflower (*Mimulus aurantiacus*), California blackberry (*Rubus ursinus*), and poison oak (*Toxicodendron diversilobum*). This habitat is important for a variety of small mammals and birds.

- Coastal Live Oak. Coastal live oak (*Quercus agrifolia*) woodland is common in the Elkhorn Slough watershed and is often found growing on 15 to 50 slopes and loamy sands in the hills east of the Elkhorn Slough NERR. On the Reserve, oak woodlands also frequently appear on the slopes of dissected terraces. Oak woodland can range from dense forests with closed canopies at moderately moist sites, to widely-spaced open woodland or savannah in drier areas. Oak understory vegetation is also variable. Where the canopy is closed, understory vegetation often includes shade-tolerant shrubs, ferns, and forbs. Where trees are scattered, the understory is commonly made up of grassland and occasional shrubs. Coastal oak woodlands provide habitat for a variety of wildlife species, including many mammals and a wide range of birds. Today, residential development threatens to further fragment remaining oak habitat (Scharffenberger 1999) and Sudden Oak Death (caused by the introduced fungus-like pathogen *Phytophthora ramorum* threatens oak throughout coastal California

Key Fish and Wildlife Species

- Fish. Fishes are among the most conspicuous and best-studied inhabitants of Elkhorn Slough. Long a source of food and recreation, they are of special interest to humans and – as both predator and prey – play a critical role in the slough ecosystem. The fish fauna in Elkhorn Slough is abundant, diverse, and dominated by marine and estuarine species. The slough provides critical habitat not only for year-round residents, such as black surfperch (*Embiotoca jacksoni*), Pacific staghorn sculpin (*Leptocottus armatus*), bay goby (*Lepidogobius lepidus*), and bay pipefish (*Syngnathus leptorhynchus*), but also for marine species from nearshore waters that enter sloughs to feed, mate, and spawn. Many marine fishes, including a number of economically important species such as Pacific herring (*Clupea pallasi*), California halibut (*Paralichthys californicus*), and northern anchovy

(*Engraulis mordax*), inhabit the slough's relatively warm, calm water as juveniles before moving to nearshore coastal waters.

- Birds. Elkhorn Slough is recognized as a Globally Important Bird Area by the American Bird Conservancy. More than 265 bird species (73 percent of the California total) have been recorded in the Elkhorn Slough area (Roberson 1991). Most are seasonal visitors, but approximately 40 are year-round residents. Aquatic birds – shorebirds, seabirds, herons, and waterfowl – account for much of the slough's avian diversity. As one of the largest estuaries in California, Elkhorn Slough is a major stopover for birds migrating along the Pacific flyway. More than 20,000 sandpipers (*Scolopacidae* spp.), plovers (*Charadriidae* spp.), and their relatives may be present at the peak of migration. A number of these aquatic species nest in the Elkhorn Slough watershed: great egrets (*Ardea alba*), great blue herons (*Ardea herodias*), and double-crested cormorants (*Phalacrocorax auritus*) nest in a grove of pines and eucalyptus in the ESNERR; Caspian terns nest on man-made islands on the ESNERR; and threatened snowy plovers (*Charadrius alexandrinus*) nest at the salt ponds and beaches.

- Other Notable Species. The Elkhorn Slough is home to California's greatest concentration of sea otters (*Enhydra lutris*), as well as populations of endangered Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*) and the threatened California red-legged frog (*Rana draytonii*). The population of sea otters living in Elkhorn Slough reflects that the species is well-adapted for estuarine habitat, and may be a model for the historical sea otter populations now extinct in San Francisco Bay.

Key Ecosystem Processes

- Tidal Hydrology. Elkhorn Slough is a partially-mixed estuary, characterized by a weak stratification that is mixed during spring ebb tides (Elkhorn Slough Tidal Wetland Strategic Plan 2007). The tides in Elkhorn Slough are mixed semi-diurnal with a mean daily tide range of 5.6 feet and a low-low tide that follows a high-high tide. The spring tide range is 8.2 feet and the neap tide range is 3 feet (Broenkow and Breaker 2005). The tide range is the difference in the level between successive high and low tides. Tidal currents in Elkhorn Slough are ebb-dominated, so ebb tides have stronger velocities and are shorter in duration than flood tides. The resulting potential for sediment erosion and transport is thus greater on ebb (outgoing) tides than flood (incoming) tides and partially contributes to the net expert of sediment from the estuary.

- Water Chemistry. The salinity in the main channel of Elkhorn Slough ranges from 0.5 to 37 ppt. Evaporation exceeds the rate of freshwater input during the dry summer and fall, resulting in hypersaline conditions in the upper third of Elkhorn Slough until the first winter rainfall. Recent hydrodynamic and nutrient analyses demonstrate that waters from the Old Salinas River Channel can be carried up the estuary as far as Kirby Park by tidal currents. Freshwater inputs also enter Elkhorn Slough from Carneros Creek at the head of the estuary with discharge rates between 7 and 1,300 cubic feet per second from December to April.

- Coastal Upwelling. The California Current system consists of a wind-driven surface current that flows southward along the coast (Snyder et al. 2003). This current brings cool water from the Gulf of Alaska, which mixes with warmer tropical waters off the coast of southern California. One of the features of this system is the occurrence of wind-driven upwelling during the spring through fall seasons north of Point Conception and to the south in all seasons. The upwelling process brings cold, nutrient rich water to the surface in coastal areas. These waters in turn support a diverse marine fauna. Changes in upwelling can have a profound effect on a variety of ecosystems, and variations in upwelling can result in large and significant changes in productivity.

- Geomorphic Processes. The geomorphology, or shape and elevation of the landscape, can particularly be affected in California by long-term tectonic movements as well as seismic events. Three major earthquakes (magnitude 7.0 to 7.9) have occurred in the region in the past 150 years (Elkhorn Slough Tidal Wetland Strategic Plan 2007). Reportedly, subsidence at the Moss Landing pier changed the water depth from 6 feet deep before the great earthquake of 1906 to 18 or 20 feet after the earthquake, and caused nearby land subsidence of 2 feet. There has also been subsidence in Elkhorn Slough habitats, which could be due to a number of factors such as groundwater withdrawal, diking, and tectonic events. However, the relative importance of groundwater withdrawal compared with tectonic events in causing subsidence needs further research.

- Marsh Processes. Since the 1930s, cover of salt marsh vegetation within Elkhorn Slough has declined from an average of 90 percent to an average of 46 percent in 2003 (Van Dyke and Wasson 2005; Watson 2008). While this marsh degradation is normally attributed to the 1947 construction of an artificial channel at the mouth of Elkhorn Slough, and associated increases in tidal prism and velocity within the slough, the exact mechanism triggering marsh degradation is still unclear. Two other major stressors over include a shift in the mouth of major tributary to Elkhorn Slough, the Salinas River, during winter storms in 1909-1910. Since then, tide gates have been constructed

to prevent the river from re-occupying the old channel. Thus, Elkhorn Slough has been unnaturally isolated from its largest potential sediment source. Scattered reports of subsidence due to groundwater overdraft in the vicinity suggest that Elkhorn Slough may be experiencing accelerated sea level rise. While in many wetlands accumulation is linked to primary productivity, wetlands in Elkhorn Slough are composed of primarily mineral sediment derived from fluvial and littoral sources. In terms of marsh composition, the biomass of pickleweed is mostly affected by salinity, flooding, and nutrients (Griffith 2010). Although many salt marsh plants grow faster and attain a higher biomass when freshwater is available, pickleweed requires some salt for optimum growth. Regardless of the salinity of flooded water, inundation itself can have negative effects on pickleweed growth. More frequent tidal immersion at lower elevations is likely the direct cause of lateral branching inhibition as well as the inhibition of vegetative propagation by re-rooting along the sediment.

Existing Threats/Stressors

While Elkhorn Slough today still hosts extensive estuarine habitats and diverse species, there is strong evidence that local biodiversity is threatened, and has already undergone significant changes in the past centuries (Caffrey et al. 2002). Over the past 150 years, human actions have altered the tidal, freshwater, and sediment processes which are essential to support and sustain Elkhorn Slough's estuarine habitats.

- Bank and Chanel Erosion. Major threats to estuarine habitats result from increased rates of tidal erosion, marsh drowning, and dikes. The accelerated rate of bank and channel erosion in Elkhorn Slough is causing tidal creeks to deepen and widen reducing functions for estuarine fish, salt marshes to collapse into the channel and die, and soft sediments that provide important habitat for invertebrates to be eroded from channel and mudflat habitats. Increases in the flooding of tidal waters on marshes are causing plants to "drown" in central areas of the marsh. Based on current knowledge, the accelerated rates of tidal erosion and marsh drowning are primarily due to the estuarine mouth modifications. Since the 1870s, approximately 30 percent of the salt marsh has been lost due to the construction of levees to drain wetlands for cattle grazing, railroad and road construction, and the creation of freshwater impoundments for duck hunting (Van Dyke and Wasson 2005). After a harbor was constructed at the mouth of Elkhorn Slough in 1947, 50 percent of the salt marsh was lost due to the marsh drowning and bank erosion and continues today at dramatic rates.

- Invasive Species. About 60 non-native invertebrates have been documented at Elkhorn Slough, and they include some of the most common species encountered, such as the European green crab (*Carcinus maenas*) and the Japanese mud snail (*Batillaria attramentaria*) (Wasson et al. 2001). There are also common algal, plant, and fish invaders in Slough estuarine habitats. Marine and estuarine invasions have been shown to cause local extinction of native competitors and prey organisms, alteration of flow of energy and materials through whole ecosystems (Grosholz 2002).

- Agriculture and Other Development. A network of shallow lakes and freshwater marshes that once extended south of the city of Salinas to the north of the city of Watsonville was drained in the late 1800s and early 1900s for agricultural use (Gordon 1996). Freshwater springs and seeps that were once common along the edges of Elkhorn Slough have been lost since the 1940s, presumably due to lowered groundwater levels resulting from agricultural and domestic pumping (Van Dyke and Wasson 2005). Development has also contributed to declines in important habitats such as coastal prairie, scrub, and live oak systems across the region.

- Pollution. In some areas, ponds, marshes, and meadows are affected by excessive agricultural runoff which results in sediment accumulation, increased turbidity, and other pollutants. Remarkably high nutrient and pesticide concentrations have been documented in the Slough's estuarine habitats. Few studies have directly addressed the ecological impacts of pollution at Elkhorn Slough, but based on published studies elsewhere, it is possible that changes in water quality have increased the abundance of nutrient-limited producers (e.g., macroalgae such as sea lettuce) and pollution-tolerant animals, while decreasing the abundance of pollution-intolerant species.

Climate Change Context

The following scenarios are from multiple sources, as indicated. There are notable inconsistencies across various studies.

Air Temperature

- Recent Changes. Statewide average temperatures increased by 1.7º F from 1895 to 2011, and warming has been greatest in the Sierra Nevada (California Climate Change Center 2012).

- Projections. Temperatures in California will rise significantly during this (California Climate Change Center 2012). Springtime warming – a critical influence on snowmelt – will be particularly pronounced. Summer temperatures will rise more than winter temperatures, and the increases will be greater inland compared to the coast. Heat waves will be more frequent, hotter, and longer. There will be fewer extreme cold nights.

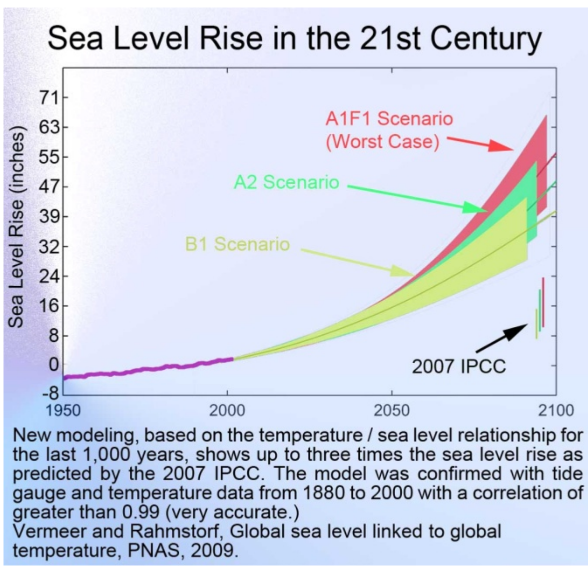
Precipitation

- Recent Changes. Throughout the past century, precipitation (rain and snow) has followed the expected pattern of a largely Mediterranean climate with wet winters and dry summers, and considerable variability from year to year (California Climate Change Center 2012). No consistent trend in overall amount of precipitation has been detected, except that a larger proportion of total precipitation is falling as rain instead of snow.

- Projections. Model projections of precipitation over California continue to show the Mediterranean pattern of wet winters and dry summers with seasonal, year-to-year and decade-to-decade variability (California Climate Change Center 2012). Even in projections with relatively small or no declines in precipitation, central and southern parts of the state can be expected to be drier from the warming effects alone. Studies also indicate the potential for an increase in the frequency of heavy precipitation events in Northern California, even if overall precipitation does not change.

Sea-level Rise

- Recent Changes. Climate change is contributing to an increase in the rate of sea-level rise due to the thermal expansion of ocean waters and melting glaciers and ice fields. The average global (eustatic) sea level rise 6.7 inches over the 20th century, at an average rate of 0.07 inches (1.7 mm) per year. This was 10-times faster than the average rate of sea-level rise during the last 3,000 years (IPCC 2007). Importantly, eustatic sea-level rise is not uniform across the globe – it can vary based on a range of factors, such as ocean circulation patterns, variations in temperature and salinity, and the earth's rotation and shape. In the coming decades, the average rate of sea-level rise is expected to accelerate, even under the most aggressive scenarios for reducing global emissions of greenhouse gases. For coastal management purposes, it is important to also understand the potential changes in relative sea level, which includes the eustatic rate as well as localized factors that determine changes in vertical land elevation, such as land subsidence, sedimentation, and marsh accretion. Vertical land motions caused by plate tectonics and the ongoing response of the Earth to the disappearance of North American ice sheets have a significant impact on sea-level rise along the Washington, Oregon, and California coasts (NRC 2012).



New modeling, based on the temperature / sea level relationship for the last 1,000 years, shows up to three times the sea level rise as predicted by the 2007 IPCC. The model was confirmed with tide gauge and temperature data from 1880 to 2000 with a correlation of greater than 0.99 (very accurate.)
Vermeer and Rahmstorf, Global sea level linked to global temperature, PNAS, 2009.

Figure 2

- Projections. The most recent estimates from the 2007 IPCC assessment show an additional 18 to 59 cm (7- to 23-inch) rise in global average sea level by the 2090s, with an additional 10 to 20 cm possible by taking into consideration the current rate of ice flow from Greenland and Antarctica. There is compelling new evidence, however, that because these figures ignored the recent dynamic changes in Greenland and Antarctica ice flow, it is likely to that they significantly underestimate the rate of global sea-level rise we will experience in the coming decades (Jevrejeva et al. 2010; Otto-Bliesner et al.

2006; Overpeck et al. 2006; Overpeck and Weiss 2009; Rahmstorf 2007; Rignot and Kanagaratnam 2006; Vermeer and Rahmstorf 2009) (Figure 3). While future projections vary, Rahmstorf (2007) proposes that, taking into account possible model error, a feasible range by 2100 is a rise of 50-140 cm. More recently, this work was updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf 2009). Sea level along the California coast south of Cape Mendocino is projected to rise 2-12 inches by 2030, relative to 2000 levels, 5-24 inches by 2050, and 17-66 inches by 2100 (NRC 2012).

Coastal Storms

- Recent Changes. Evidence suggests that the frequency and intensity of extreme cyclones in the North Pacific has increased markedly over the past 50 years (Graham and Diaz 2001). Some observational studies report that largest waves are getting higher and winds are getting stronger (NRC 2012). While storm systems in the Pacific are complex due to factors such as El Niño/Southern Oscillation cycles, scientists believe this trend may be attributed in part to increasing sea surface temperatures (SST) in the western tropical Pacific Ocean (Graham and Diaz 2001). Importantly, most coastal damage is caused by the confluence of large waves, storm surges, and high astronomical tides during a strong El Niño (NRC 2012).

- Projections. Even if storminess does not increase in the future, sea-level rise will magnify the adverse impact of storm surges and high waves on the coast.

Sea Surface Temperature and Chemistry

- Recent Changes. While factors that affect sea surface temperatures in the Pacific Ocean are highly complex due to factors such as El Niño/Southern Oscillation, evidence suggests that there has been a trend toward higher average sea surface temperatures in the North Pacific Ocean (Overland and Wang 2007). Increases in water temperature off the coast of California have already led to a shift in the geographic range of species (California Climate Adaptation Strategy 2009). In addition, as oceanic carbon dioxide has increased in recent decades, the world's oceans have become more acidic, with pH decreasing by 0.1 standard units since 1750 (Archer 2005). This represents a 30 percent increase in ocean acidity.

- Projections. Ocean water temperatures are projected to continue to rise as air temperatures rise. Overland and Wang (2007) suggest that the trend of warming ocean temperatures will begin to dominate natural variations within the next 30-50 years. This is likely to cause changes in marine and coastal species behavior and distribution (California Climate Adaptation Strategy 2009). Other research suggests that there will be an increased gradient between temperatures over land and those over the oceans, with the former likely to trend towards higher increases (Snyder et al. 2003). This could enhance alongshore winds that drive upwelling. The average pH of the world's oceans may decrease by as much as 0,1 to 0.4 pH units over the next 90 years, due to increasing absorption and solution of carbon dioxide into warmer ocean waters (Royal Society 2005; Kuffner et al. 2008; Ishimatsu et al. 2005).

References

Archer, D. 2005. The fate of fossil fuel CO2 in geologic time. Journal of Geophysical Research 110, c09s95.

Broenkow, W.W. and L.C. Breaker. 2005. A 30-year history of tide and current measurements in Elkhorn Slough, California. Scripps Institution of Oceanography Library Paper 8. http://repositories.cdlib.org/sio/lib.e.

Caffrey, J., M. Brown, W.B. Tyler, and M. Silberstein. 2002. Changes in a California Slough: A Profile of Elkhorn Slough. Elkhorn Slough Foundation.

California Climate Adaptation Strategy. 2009. A Report to the Governor of the State of California In Response to the Executive Order S-13-2008.

California Climate Change Center. 2012. Our Changing Climate 2012. Vulnerability & Adaptation to the Increasing Risks from Climate Change in California. A Summary Report of the Third Assessment from the California Change Center.

Davis, F.W., D.E. Hickson, and D.C. Odion. 1988. Composition of maritime chaparral related to fire history and soil, Burton Mesa, Santa Barbara County, California. Madroño 35: 169-195.

Gordon, B.L. 1996. Monterey Bay Area: Natural History and Cultural Imprints. Pacific Grove, CA: Boxwood Press.

Graham, N.E. and H.F. Diaz. 2001. Evidence for intensification of North Pacific winter cyclones since 1948. Bulletin of the American Meteorological Society 82: 1869-1893.

Griffith, K.A. 2010. Pickleweed: Factors that control distribution and abundance in Pacific Coast estuaries and a case study of Elkhorn Slough, California. Elkhorn Slough Technical Report Series 2010:9. ESNERR and ESF.

Grosholz, E. 2002. Ecological and evolutionary consequences of coastal invasions. Trends in Ecology and Evolution 17: 22-26.

Hanes, T. L. 1988. *California chaparral*. Pp. 418-469 in M. G. Barbour and J. Major (eds.), Terrestrial Vegetation of California. California Native Plant Society, Sacramento, CA.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (S. Solomon, S.D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, eds.). Cambridge, U.K. and New York: Cambridge University Press.

Ishimatsu, A., M. Hayashi, K.-S. Lee, T. Kikkawa, and J. Kita. 2005. Physiological effects on fishes in a high-CO2 world. Journal of Geophysical Research 110: http://www.agu.org/pubs/dcrossref/2005/2004JC002564.shtmlpress.

Jevrejeva, S., J.C. Moore, and A. Grinsted. 2010. Howe will sea level respond to changes in natural and anthropogenic forcings by 2100? Geophysical Research Letters 37, L07703, doi:10.1029/2010GL042947.

Kuffner, I.B., A.J. Andersson, P.L. Jokiel, K.S. Rodgers, and F.T. Mackenzie. 2008. Decreased abundance of crustose coralline algae due to ocean acidification. Nature Geoscience 1: 114-117.

Kramer, Gary. 1988. Fresh Emergent Wetland *in* Mayer, Kenneth E., and William F. Laudenslayer, Jr. (eds.). A Guide to Wildlife Habitats of California. State of California, Resources Agency, Department of Fish and Game. Sacramento, CA

NRC (National Research Council). 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, D.C.: The National Academies Press 2012.

Overland, J.E. and M. Wang. 2007. Future climate of the North Pacific Ocean. Eos 88: 178-182.

Otto-Bliesner, B.L., S.J. Marshall, J.T. Overpeck, G.H. Miller, A. Hu, and CAPE Last Inerglacial Project members. 2006. Simulating Arctic climate warmth and icefield retreat in the Last Interglaciation. Science 311: 1751-1753.

Overpeck, J.T., B.L. Otto-Bliesner, G.H. Miller, D.R. Muhs, R.B. Alley, and J.T. Kiehl. 2006. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. Science 311: 1747-1750.

Overpeck, J.T. and J.L. Weiss. 2009. Projections of future sea level becoming more dire. Proceedings of the National Academy of Sciences 106: 21461-21462.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. Science 315: 368-370.

Ratliff, R.D. 1988. Wet Meadow, in Mayer, K.E. and W.F. Laudenslayer, Jr. (eds.). A Guide to Wildlife Habitats of California. Sacramento, CA: State of California, Resources Agency, Department of Fish and Game.

Rignot, E. and P. Kanagaratnam. 2006. Changes in the velocity structure of the Greenland ice sheet. Science 311: 986-990.

Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. Policy document 12/05. London, England. http://royalsociety.org/displaypagedoc.asp?id=13314.

Snyder, M.A., L.C. Sloan, N.S. Diffenbaugh, and J.L. Bell. 2003. Future climate change and upwelling in the California Current. Geophysical Research Letters 30. Doi:10.1029/2003GL017647.

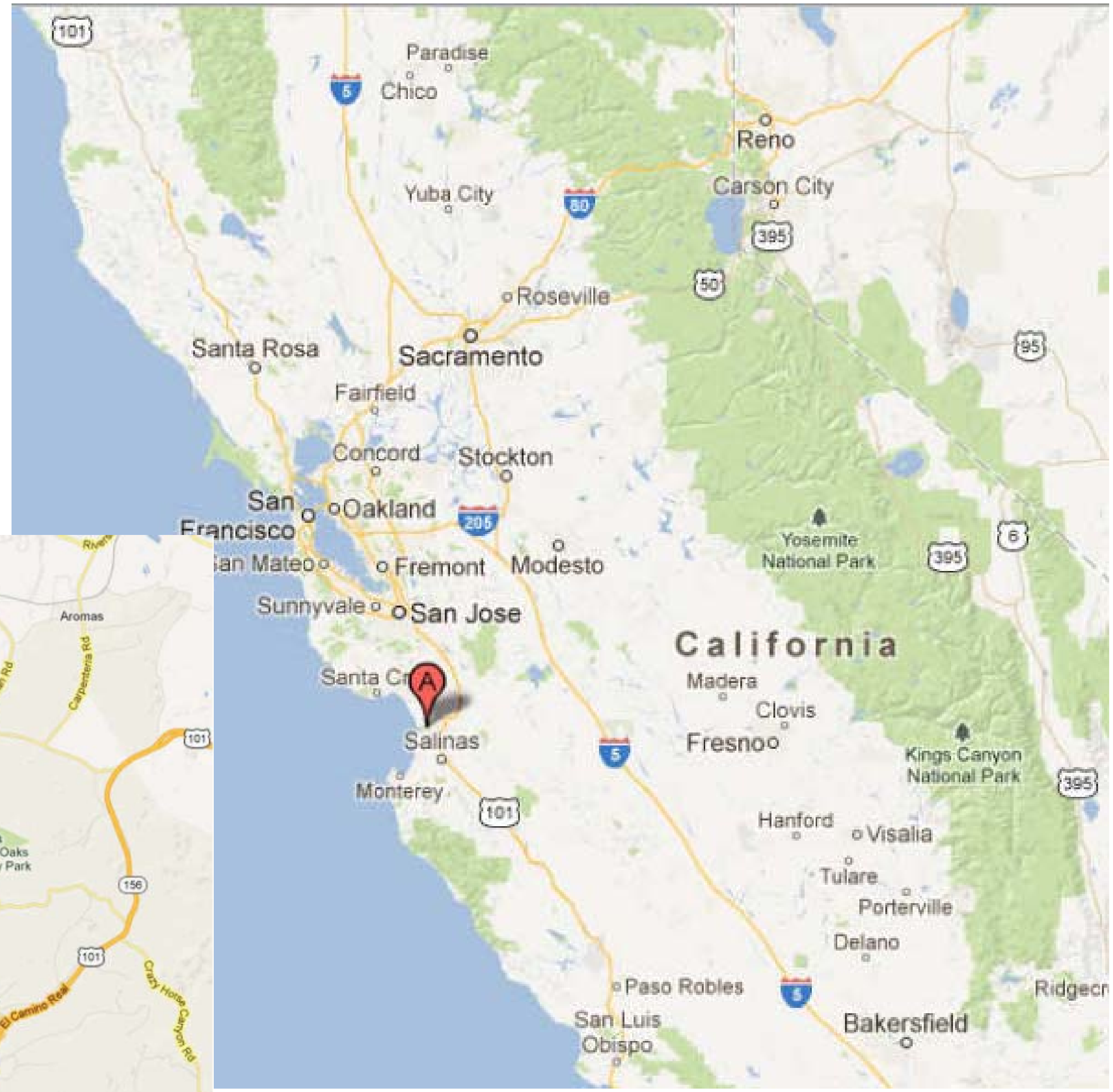
Stromberg, M.R., P. Kephart, and V. Yadon. 2001. Composition, invasibility, and diversity in coastal California grasslands. Madroñ 48: 236-252.

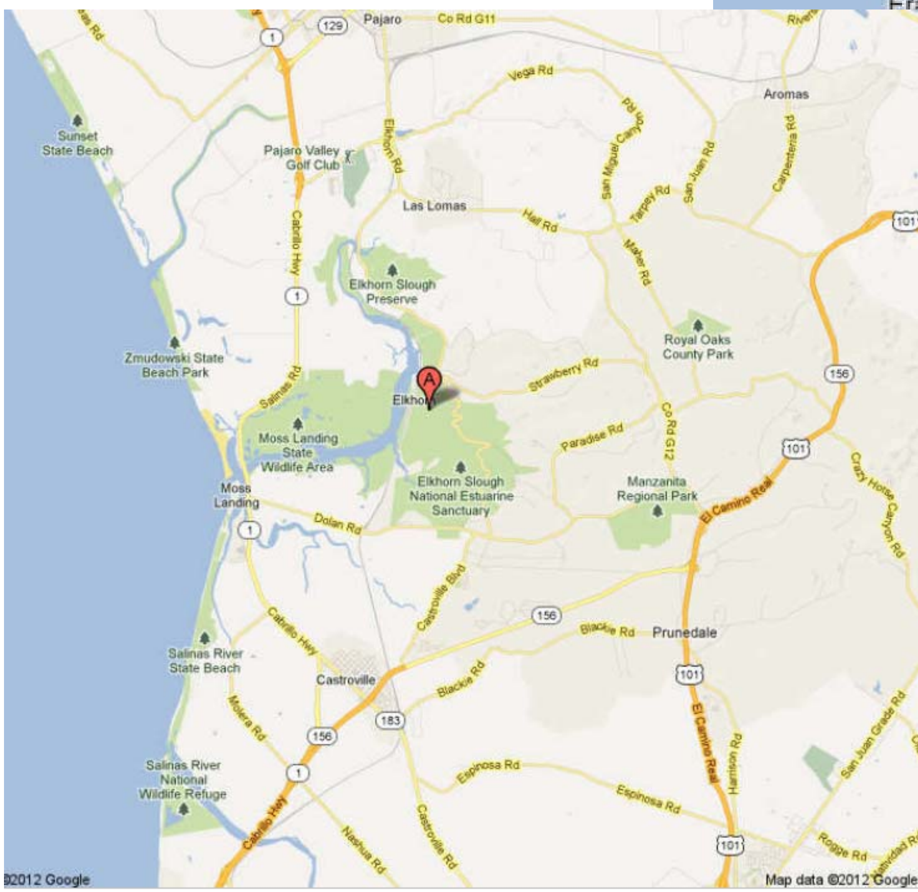
Van Dyke, E. and K. Wasson. 2005. Historical Ecology of a Central California Estuary: 150 Years of Habitat Change. Estuaries 28(2):173-189.

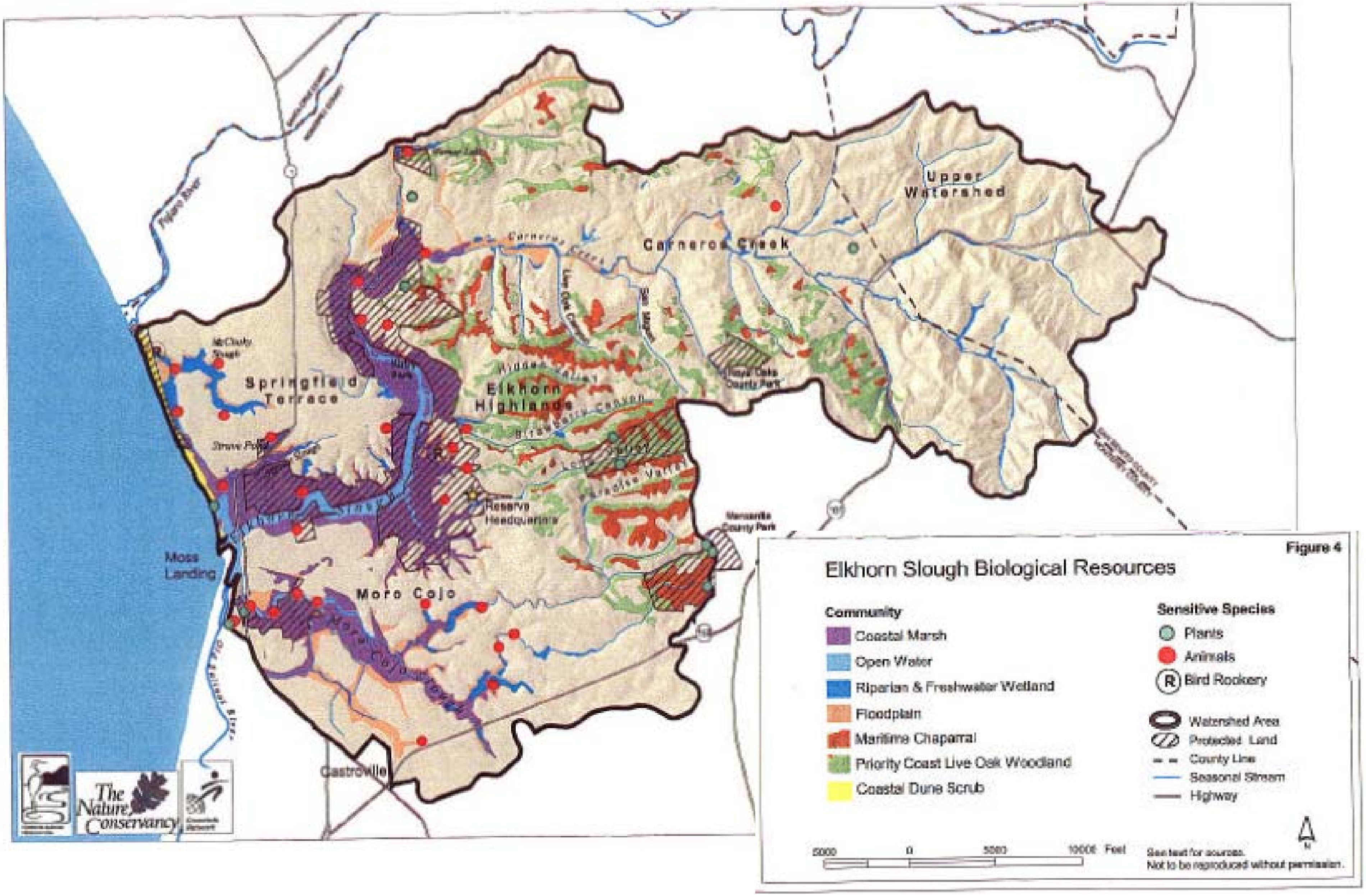
Vermeer, M. and S. Rahmstorf. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences 106: 21527.

Wasson K, Zabin CJ, Bedinger L, Diaz MC, Pearse JS (2001) Biological invasions of estuaries without international shipping: the importance of intraregional transport. Biological Conservation 102:143-153.

Watson, E.B., 2008. Dating recent sedimentation rates in healthy marsh at Elkhorn Slough using Pb-210 and Cs-137 dating methods. Land, Air, and Water Resources, University of California, Davis.


Paradise
Chico
Reno
Carson City
Yuba City
Roseville
Santa Rosa
Sacramento
Fairfield
Concord
Stockton
San Francisco
Oakland
San Mateo
Fremont
Modesto
Yosemite National Park
Sunnyvale
San Jose
California
Madera
Clovis
Fresno
Santa Cruz
Salinas
Monterey
Kings Canyon National Park
Hanford
Visalia
Tulare
Porterville
Delano
Paso Robles
San Luis Obispo
Bakersfield
Ridgecr


Pajaro
Aromas
Sunset State Beach
Pajaro Valley Golf Club
Las Lomas
Elkhorn Slough Preserve
Zmudowski State Beach Park
Royal Oaks County Park
Elkhorn
Moss Landing State Wildlife Area
Moss Landing
Elkhorn Slough National Estuarine Sanctuary
Manzanita Regional Park
Prunedale
Salinas River State Beach
Castroville
Salinas River National Wildlife Refuge
©2012 Google
Map data ©2012 Google



Upper Watershed
Carneros Creek
Springfield Terrace
Elkhorn Highlands
Reserve Headquarters
Moss Landing
Moro Cojo
Castroville
The Nature Conservancy
Figure 4
Elkhorn Slough Biological Resources
Community
Coastal Marsh
Open Water
Riparian & Freshwater Wetland
Floodplain
Maritime Chaparral
Priority Coast Live Oak Woodland
Coastal Dune Scrub
Sensitive Species
Plants
Animals
R Bird Rookery
Watershed Area
Protected Land
County Line
Seasonal Stream
Highway
5000 0 5000 10000 Feet
See text for sources.
Not to be reproduced without permission.

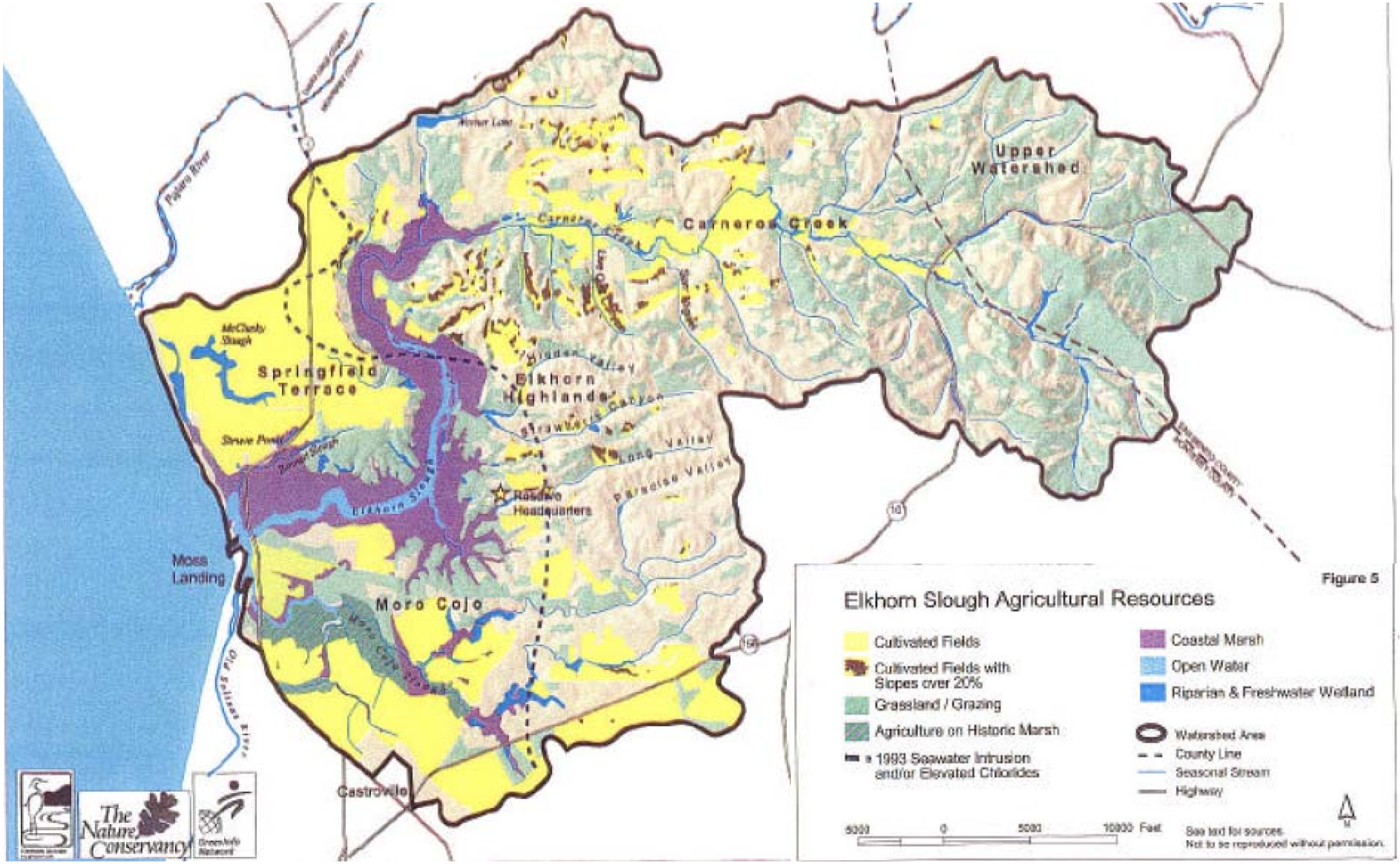
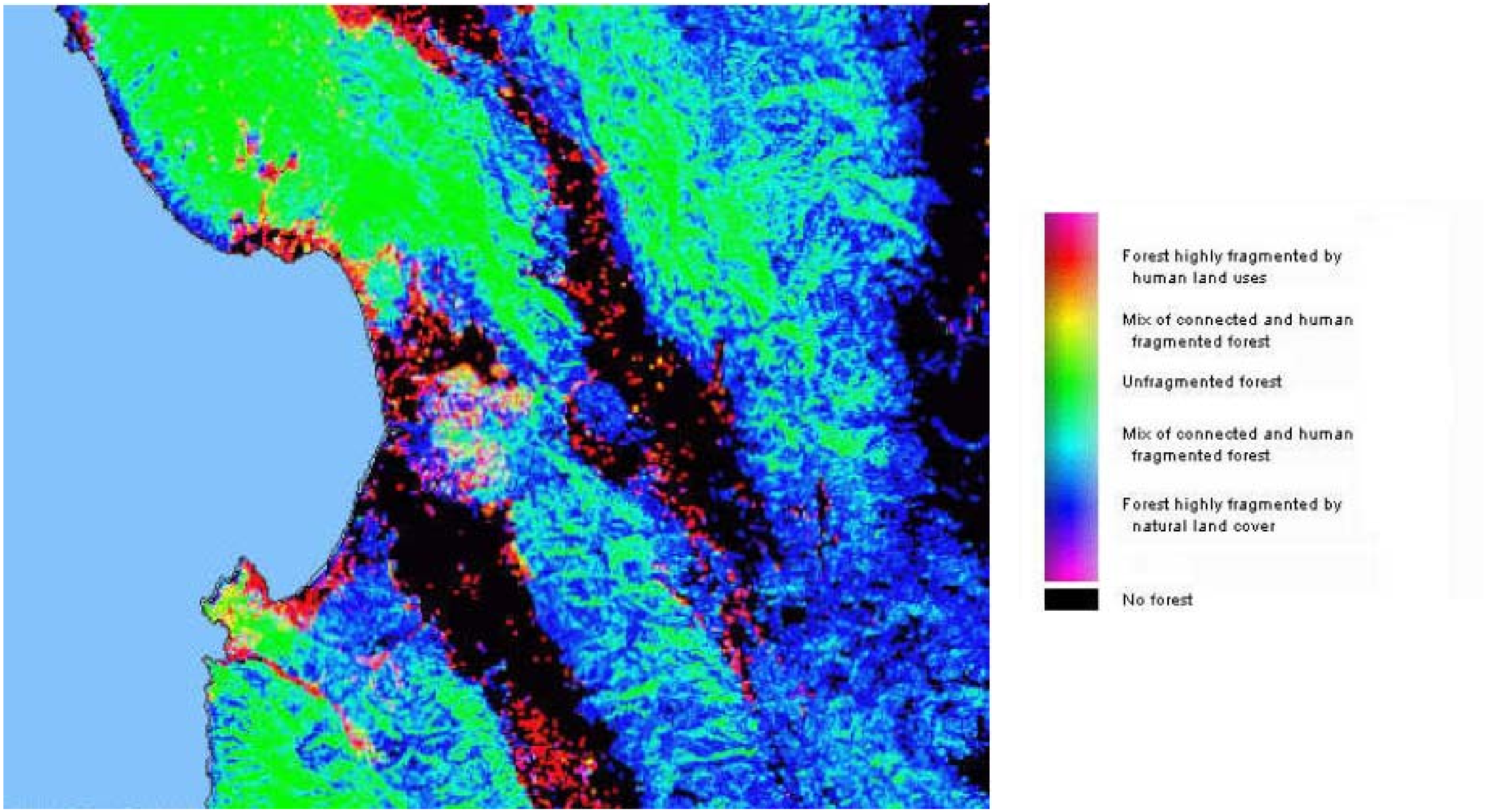
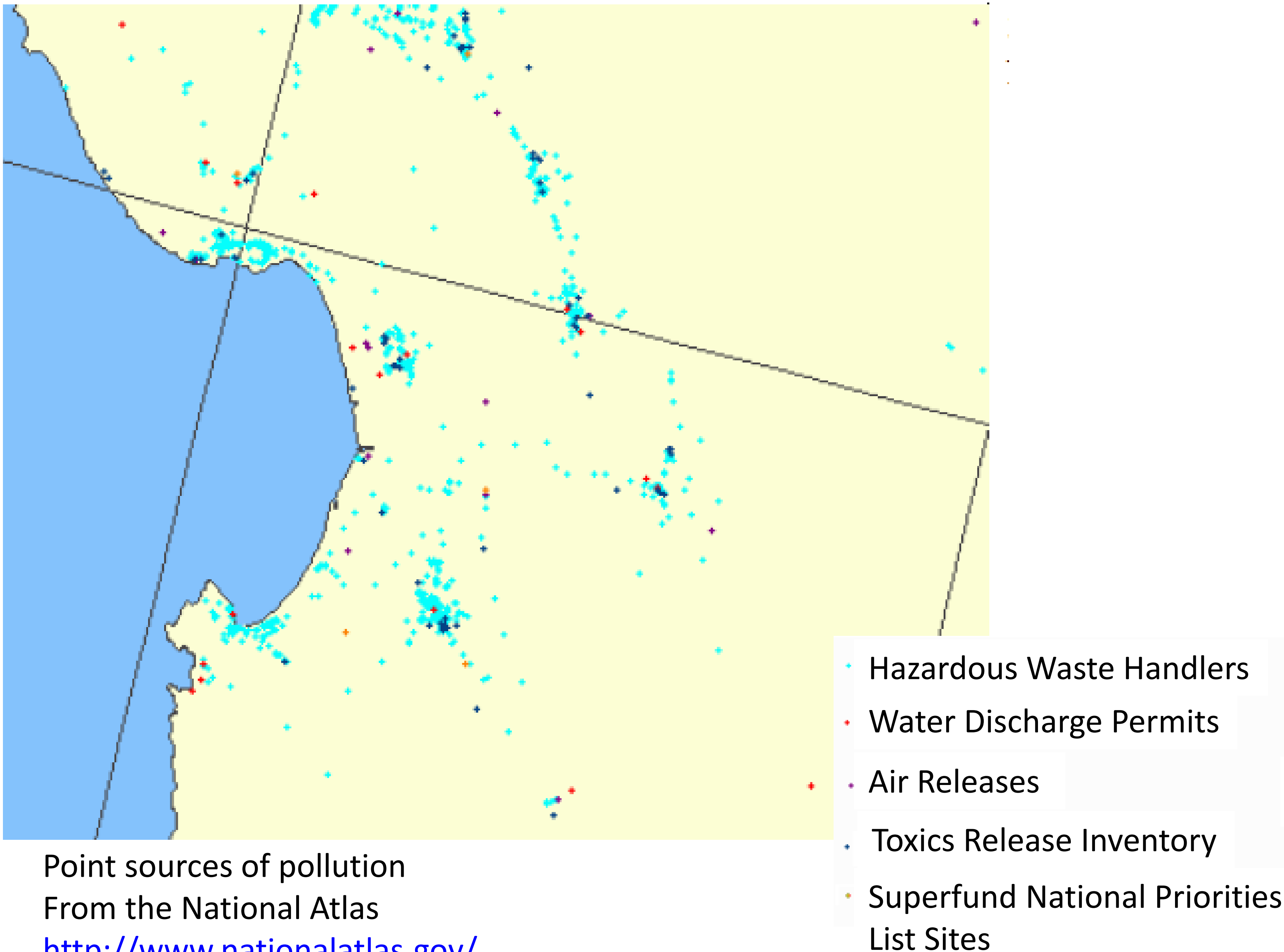


Figure 5
Elkhorn Slough Agricultural Resources
Cultivated Fields
Cultivated Fields with Slopes over 20%
Grassland / Grazing
Agriculture on Historic Marsh
= 1993 Seawater Intrusion and/or Elevated Chlorides
Coastal Marsh
Open Water
Riparian & Freshwater Wetland
Watershed Area
County Line
Seasonal Stream
Highway
5000 0 5000 10000 Feet
See text for sources.
Not to be reproduced without permission.
Upper Watershed
Carneros Creek
Springfield Terrace
Elkhorn Highlands
Hidden Valley
Long Valley
Paradise Valley
Reserve Headquarters
Elkhorn Slough
Moss Landing
Moro Cojo
Castroville
Pajaro River
Old Salinas River
The Nature Conservancy

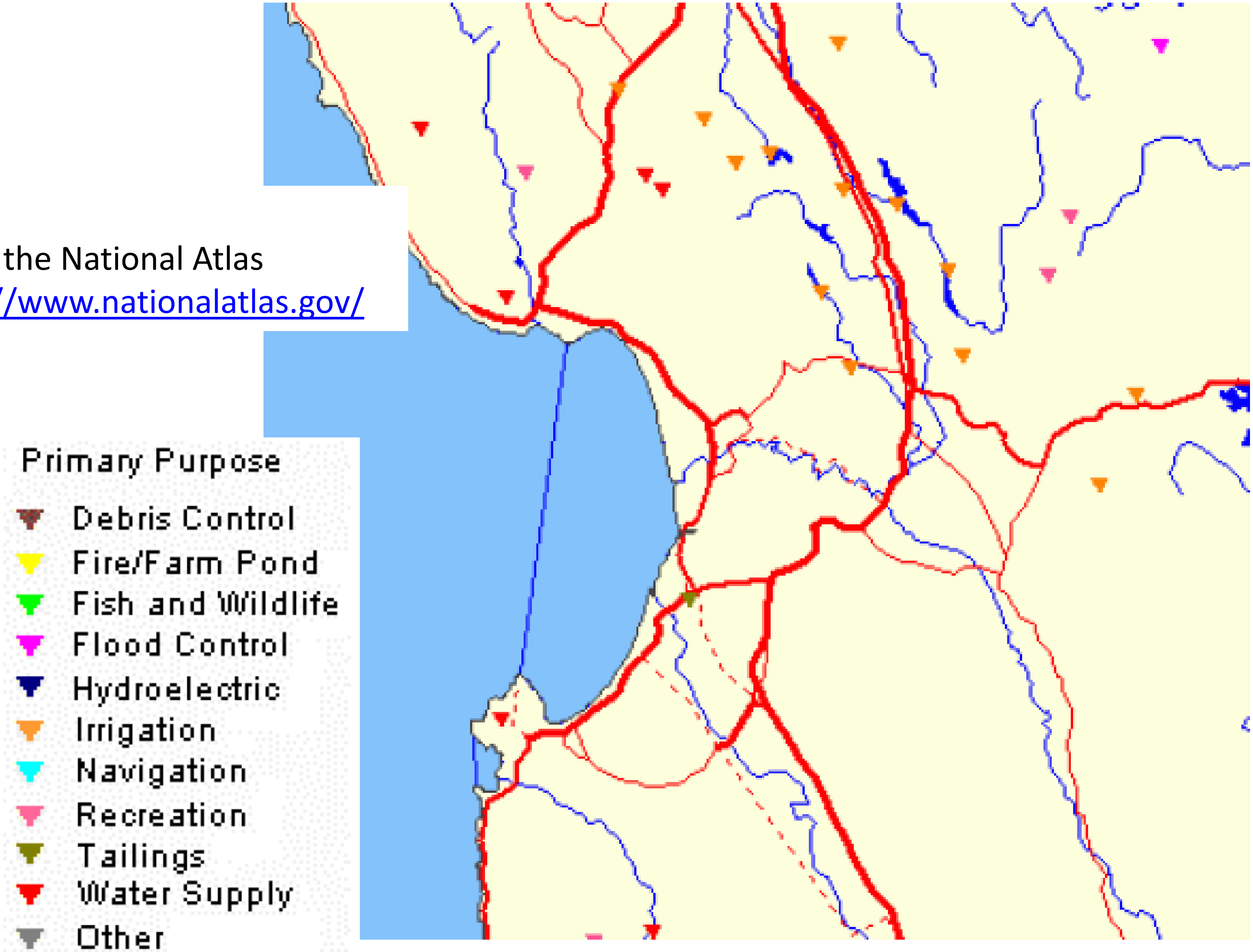


Forest cover
From the National Atlas
http://www.nationalatlas.gov/

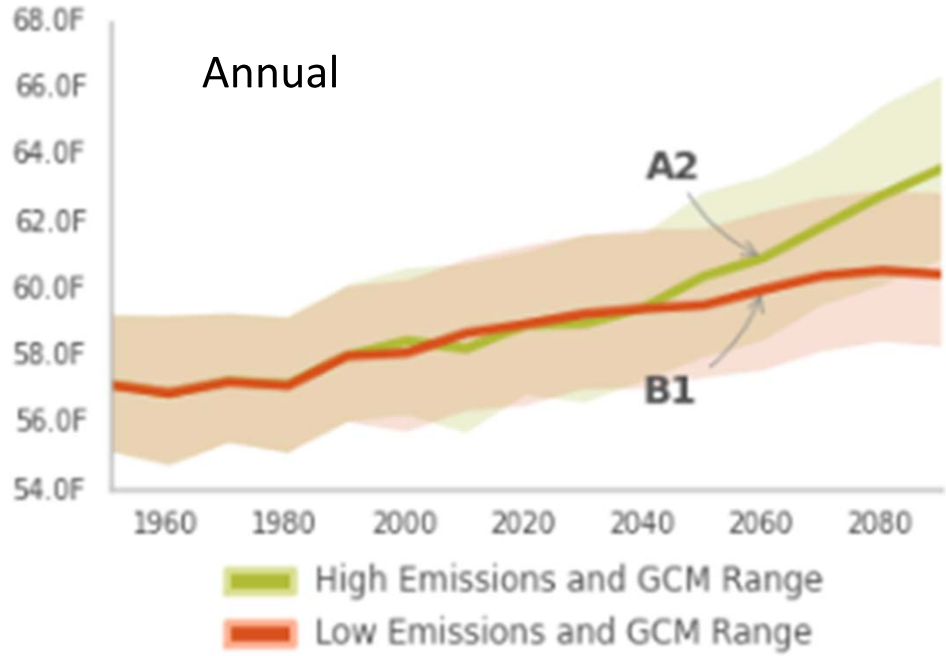


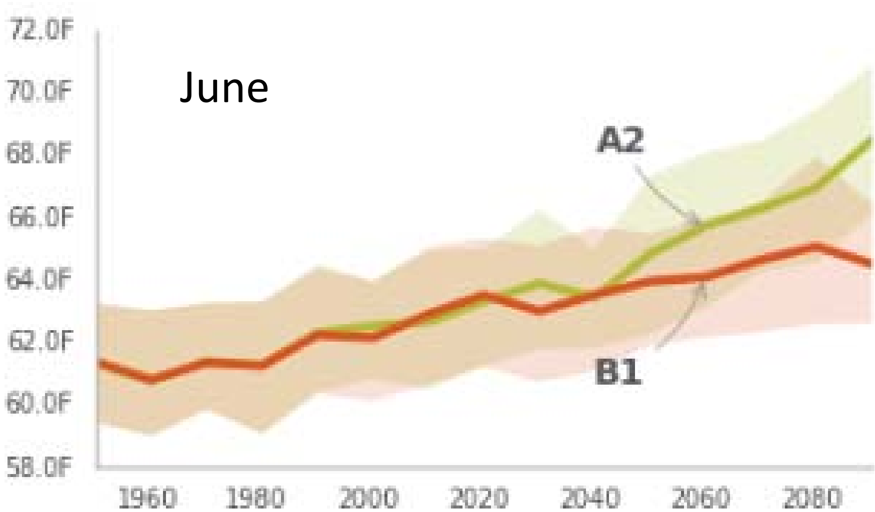
Point sources of pollution
From the National Atlas
http://www.nationalatlas.gov/

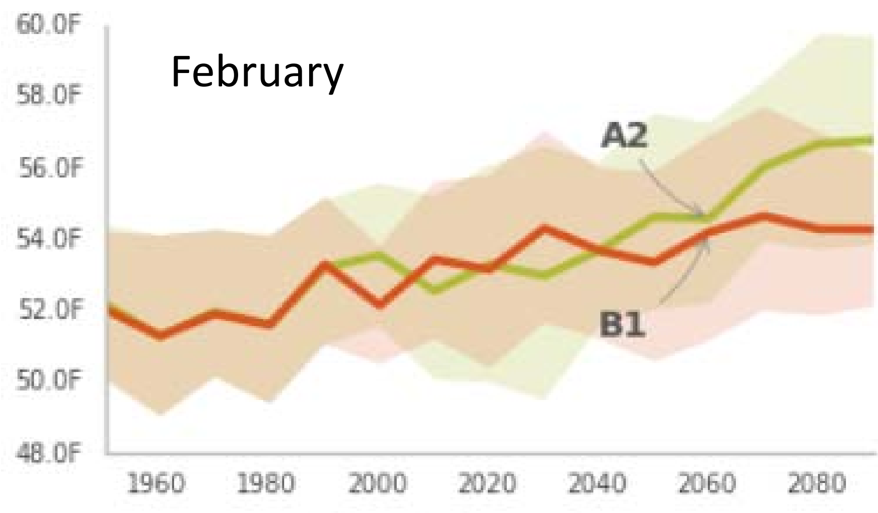
Dams
From the National Atlas
http://www.nationalatlas.gov/



Elkhorn Slough
Temperature projections
Mutlimodel ensemble
Taken from http://cal-adapt.org/







Elkhorn Slough
Precipitation projections
Mutlimodel ensemble
Taken from http://cal-adapt.org/

Annual