SAN FRANCISCO BAY SUBTIDAL HABITAT GOALS REPORT

Appendix 2-2: Report on Climate and Other Long-term Changes Likely to Affect the Future of Subtidal Habitats

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Introduction

The Subtidal Habitats Goals Project has a 50-year time horizon for restoration and management of the subtidal habitats of San Francisco Bay. Numerous changes are likely to happen over that time scale and these changes may affect the long-term trajectory of restoration projects. Among these local and regional changes are those that may result, either directly or indirectly, from changes in the global climate. This report summarizes the current understanding of these changes and briefly discusses the potential impacts of changes on subtidal habitats and how restoration and management might need to adapt to these changes. Table 1 lists the changes, with quantitative estimates where available, and some of their potential consequences. A recent report on climate effects in the Gulf of the Farallones and Cordell Banks Marine Sanctuaries provides a more complete and in-depth view of observed and predicted climate effects along the California coast (Largier et al. 2010).

Changes arising through global climate effects

Information on projections of global climate has been obtained from the latest report of the Intergovernmental Panel on Climate Change (IPCC 2007). IPCC casts its projections in terms of ranges of probability or confidence in the projections. These projections are based on alternative scenarios of future emissions that cannot be placed in a probabilistic framework since they depend on the unpredictable response of the world's governments and peoples to reduce emissions. Additional information has been obtained from recent scientific papers, for downscaling from global projections and upscaling from local analyses to regional outcomes.

The basis for projections is the continued growth of greenhouse gases, particularly carbon dioxide. Measurements of the increase in CO_2 are probably the most accurate measurements in the entire climate system. The continuing increase in CO_2 matches the "business as usual" scenario in the IPCC report, indicating that any efforts to reduce emissions have had a negligible effect to date.

Temperature rise Warming in the global climate system is unequivocal, as is now evident from observed increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Eleven of the last 12 years covered by IPCC (1995-2006) were among the twelve warmest years in the instrument record of global surface temperature (since 1850). More recent analysis shows that 1998 and 2001-2009 were the ten warmest years in the record (Hansen et al. in prep). The linear warming trend from 1956 to 2005 was 0.13 (0.10 to 0.16)°C per decade. Most of the earth's excess heat has been stored in the ocean as warmer water down to about 3000-m depth.

Dettinger (2005) analyzed an ensemble of repeated projections using six models and three scenarios (IPCC A2, B2, and IS92a) to forecast California's climate to 2098. He noted that these are not probabilistic projections: the scenarios were selected to explore a range of possibilities. The models were used to forecast joint distributions of temperature and precipitation, which is appropriate since these covary somewhat in the model projections. The most frequently projected temperature increase for California in 2050 is 3°C above the 1951-1980 mean, and about 95% of the predicted increases are within 1 - 5°C. By 2025, model projections that are cooler than the 1951–1980 mean are rare. Seasonal versions of these projections show a larger and more variable temperature change in summer than in winter.

Dettinger (2005) gave equal weight to the three emission scenarios, a reasonable choice given the complete uncertainty about future emissions. However, this may give a misleading impression that the contours in Fig. 1 encompass the actual probability distributions of temperature and precipitation, rather than projections based on the assumption of equal likelihood of each scenario (and no other scenarios).

Increasing overall temperature does not necessarily mean all areas will warm. In California, the warming trend is likely to be most pronounced inland. Available reports conflict on the recent temperature trends along the coast. Temperature records show that low-lying coastal areas have cooled while inland areas have warmed (Lebassi et al. 2009). In contrast, the frequency of coastal fog and stratus has decreased, presumably due to warming in coastal areas (Johnstone and Dawson 2010).

<u>Total precipitation in watershed and timing of runoff</u> Precipitation depends heavily on regional or even local interactions with large-scale weather patterns, including smaller-scale atmospheric and oceanic circulation patterns, latitude, and topography. Therefore, patterns of change in precipitation are more likely to be regional than global (Vörösmarty et al. 2000). The joint projections of temperature and precipitation by Dettinger (2005) are much more confident about an increase in temperature than any change in precipitation, although there is a tendency for the warmer projections to be drier (Fig. 1).

The timing of runoff, however, is more readily predictable (compare Fig. 2 top and bottom). Throughout western North America, including the Central Valley, there has been a measurable shift to an earlier date of median runoff, i.e., the date on which half of the water year's runoff has occurred (Aguado et al. 1992, Stewart et al. 2004, 2005). This is likely due to earlier snowmelt caused by increasing temperatures, since watersheds without substantial snowpack show opposite trends (Stewart et al. 2005). Projections for a sample northern Sierra river (Fig. 2) show the median date of runoff shifting ~20 days earlier by 2050 relative to the historical period, with almost all projections indicating an earlier median date. This effect is less pronounced in the higher-elevation southern Sierra (Knowles and Cayan 2002) but most of the outflow to the bay comes from the north. Knowles and Cayan (2002) investigated the consequences of the shift in runoff peak for salinity in the bay. Since the consequences of an earlier runoff peak depend also on changes in demand and infrastructure, this topic is discussed further below in the context of local and regional influences and water management.

<u>Sea level rise</u> The IPCC reported a global rise in mean sea level of 1.8mm/year from 1961 to 2003, and a greater increase of 3.1 mm/year from 1993 to 2003, although it was uncertain whether this higher rate indicated a fluctuation or an accelerating trend. About 57% of the long-term increase was from thermal expansion of the ocean, 28% from melting of land ice, and the remainder from melting of polar ice caps. Local or regional rates of rise can differ from the global mean for a variety of reasons (Cayan et al. 2008). Sea level at the Golden Gate has been generally consistent with the global pattern, at about 2 mm/year from 1961 through 2006; at least at this location, the 1993-2003 pattern appears to have been part of a fluctuation and the lower, long-term rate held (Fig. 3).

IPCC model projections interpolated to 2050 indicate a mean sea level rise of 7 – 22 cm relative to present-day levels, although more recent projections were about 3-fold higher (Vermeer and Rahmstorf 2009). However, the height of mean sea level gives only an index of the impact of sea level rise. The height of higher tides in the Bay has increased more rapidly than mean sea level (based on analysis of Fort Point tidal height, not shown). Higher high tides coinciding with storms (low atmospheric pressure, storm surge, strong wind waves, and high freshwater flow) are of the greatest concern for protection of habitat and property. Some of these events can coincide, e.g., during a wet El Niño event (Ryan and Noble 2007). Cayan et al. (2008) analyzed the frequencies of occurrence of high sea-level values in relation to the 99.99% exceedance of hourly historical data from 1960 to 1978 (i.e., the elevation exceeded during only 0.01% of the hours in the historical record, or about 1 hour/year). This frequency was forecast to increase to ~10 hours/year under a scenario in which the rise by 2050 was 12 cm, near the middle of the range forecast by IPCC. If the higher projections of sea level are used (Vermeer and Rahmstorf 2009) the frequency of high-water events would be much greater in 2050 than it is now (Knowles 2010). For example, the 100-year flood area for a 50-cm higher sea level (about year 2050) would include about 35,000 hectares (86,000 acres) of shoreline, about half developed and half in grassland (Knowles 2010). Wetlands can accrete sediment to keep up with some sea-level rise, but the rate of sediment supply from rivers is apparently inadequate to keep up with the rate of rise in most parts of the estuary (Knowles 2010).

<u>Storms and wind</u> In comparison to other manifestations of climate change, evidence for changes in frequency of storms or El Niño/La Niña events is equivocal. The frequency of El Niño/La Niña events during the last century shows no trend toward an increase (Ryan and Noble 2007 Fig. 3). Although globally storms are considered likely to become more intense and frequent, this may not be the case regionally.

The intensity of upwelling is forecasted to increase, with concomitantly stronger alongshore winds during the upwelling season (Snyder et al. 2003). Coupled with higher inland temperature, this may also produce a stronger pressure gradient between the ocean and Central Valley and therefore stronger sea breezes during summer, although this is contradicted by the historical decrease in summer fog (Johnstone and Dawson 2010). Wind waves driven by summer breezes resuspend sediments from shallow areas and are important in the summer winnowing of sediments (see below).

<u>Acidification</u> The pH of the ocean is buffered mainly by the carbonate-bicarbonate system, but the injection of anthropogenic carbon into the ocean has already made the ocean more acidic by 0.1 pH unit since 1750, and projections are for a reduction between 0.14 and 0.35 pH units by 2100. Although much of the attention about acidification has focused on calcifying organisms such as corals, research since the IPCC report was drafted reveals that a wide variety of organisms are likely to suffer negative physiological effects. These effects may be quite difficult to predict; for example, two species of oyster exposed to various levels of atmospheric CO_2 had very different responses in growth and shell formation (Miller et al. 2009). Experiments are continuing on physiological effects of acidification, but ecological effects, perhaps more likely to cause changes in abundance, have not been addressed.

The pH in coastal areas and estuaries is subject to various influences not found in the open ocean, notably inputs of wastewater, freshwater, sediment, acids, and bases, and local biological processes, particularly production and respiration cycles that alter total CO_2 concentrations. Upwelled water is often supersaturated with dissolved CO_2 and low in pH. Large fluctuations in dissolved total CO_2 have occurred in South San Francisco Bay in response to wastewater discharge and phytoplankton productivity cycles (Fuller 2010). Thus, there is no straightforward link between the trend in oceanic pH and changes in the estuary.

Changes due to local or regional influences

In addition to changes caused directly by climate, local and regional patterns of change may influence the outcomes of restoration and management. The most prominent of these, and arguably the least predictable, have to do with freshwater flow into the estuary. From the perspective of subtidal habitats seaward of the Delta (i.e., Suisun Bay to South Bay), the principal effect of changes in flow is a change in the salinity distribution.

Climate impacts discussed above imply a shift toward an earlier peak in snowmelt and possibly a reduction in total runoff into the watershed. However, the link between the runoff in the watershed and outflow into the estuary is influenced by several human activities. To understand this requires an understanding of the role of the major water projects of the Central Valley.

Operation of the water projects The purpose of the major water projects, notably the Central Valley Project and State Water Project, is to capture water where and when it is abundant and deliver it where and when it is scarce (see DWR 2006 for a discussion of project operations and climate impacts). Water is more abundant to the north and in winter, and demand is higher to the south and in summer. Dams and reservoirs store the runoff captured during the wet season for use in the dry season. To move the water from the area of supply to the area of demand requires an extensive system of diversions and canals, and the use of river beds as conveyances during the dry season.

The two major water projects store water in large reservoirs mainly in the northern Sierra and Cascade foothills with a capacity of about one year's average runoff. These reservoirs are operated for flood control during the high-flow season, and then as the risk of flooding diminishes into spring, they are allowed to fill by capturing snowmelt through spring to provide water through the dry season. This process involves a difficult risk assessment: too little storage results in a water shortage in summer; too much storage increases the risk of flooding downstream of the dam. During the high-flow season, then, much of the flow passes through the reservoirs, resulting in high flows into the estuary.

During the dry season water is released from the major reservoirs to flow down the Sacramento River to the Sacramento-San Joaquin Delta, where it is diverted south by large pumping plants to cities and farms in central and southern California. When operators decide to increase pumping from the South Delta, they coordinate with dam operators to increase the flow into the Delta. Delta outflow, essentially the difference between inflow and export (diversion) flow, is controlled by the combination of dam releases and export pumping to meet several overlapping standards. These include salinity standards for ecosystem protection in spring, drinking water standards, and limits on the ratio of export flow to inflow. The net effect of all these regulations is that Delta outflow to the Bay is weakly related to export flow, and strongly related to inflow to the Delta because of the influence of high, uncontrolled winter flows (Kimmerer 2002).

The future of water projects in California Four key factors point to future changes in how water is captured and delivered in the Central Valley. First, a key element of the entire Central Valley water delivery system is its reliance on snowpack at high elevations for water storage from winter through spring and into early summer. The large amount of water stored in snow allows for relatively modest storage capacity in reservoirs to supply the water needs of the state through summer. However, as the snowpack diminishes with continuing warming and the peak in runoff occurs progressively earlier, much of this natural storage capacity will be lost. Furthermore, to protect against larger, earlier floods, dam operators will release more water earlier and the reservoirs will likely end up with reduced storage in late spring. Together these factors imply a reduction in supply; a logical response of the water agencies would be to construct more reservoir capacity. This would be most valuable south of the Delta because large amounts of water can be pumped south during high-flow periods, when environmental regulations are least restrictive.

The second change is an increase in demand. The Department of Water Resources forecasts an increase in demand for water in the Central Valley of about 2 km^3/year over the next 30 years (DWR 2009a). Some of this forecasted increase is due to population growth, and some is due to responses to a drier, warmer climate. This increase is about 7% of the total flow into all of the Central Valley reservoirs, based on average historical conditions. Although the DWR water plan explores alternative scenarios about growth in demand, it does not provide a probabilistic analysis of the trend.

The third change is due to likely alterations in the plumbing of the Delta to reduce conflicts over diverting water from the south Delta. The most prominent proposal is for a "peripheral canal" or similar large structure to carry water from north to south bypassing the Delta. If this project were to be constructed in conjunction with south-of-Delta storage, it would facilitate the movement of water during the wet season, and reduce the amount of water transferred in the dry season.

Fourth is the strong possibility that the plumbing of the Delta will be rearranged through a catastrophic failure of multiple levees surrounding Delta islands due to flooding or earthquake. Because many of these islands are deeply subsided, a large amount of "accommodation space" (Mount and Twiss 2005) will fill with water when the levees fail. The DWR Delta Risk Management Strategy report (DWR 2009b) calculated the likelihood of a 20-island failure by 2030 at about 50% (around 70% by 2050 neglecting the increasing probability of seismic activity with time since the last earthquake). A failure of this size would require roughly 0.5 km^3 of water to fill, a volume about equal to that of Suisun Bay. Most of this volume would come from seaward, resulting in a massive shift of the salinity field to the east. An immediate response of the water agencies would be to terminate export pumping and possibly to increase reservoir releases, over time restoring the Delta to a freshwater condition and moving the salinity field seaward. Subsequent actions, and the potential for cascading failures, remain uncertain (DWR 2009b).

Note that a similar analysis to DWR (2009b) has not been done for levees outside the Delta, e.g., either along rivers or around the Bay. These areas are presumably at less risk because they are not subsided, but there may be some vulnerable locations, particularly with higher sea level.

The net result of these changes is a trend toward lower outflow from the Delta in summer, higher flow in winter (although all but the highest flows may be cut off by export pumping), and a high probability of one or more catastrophic failure scenarios in the Delta. It does not seem possible to quantify these trends, mainly because of uncertainties about how society will respond to future water shortages.

Salinity responses Salinity at any point in the estuary responds mainly to tides over time scales of hours to weeks, and freshwater flow over time scales of weeks to years. The relationship of salinity at any point to freshwater flow is sigmoid and depends on the sampling location. The distance of salinity penetration into the estuary is modeled as inversely proportional to the logarithm of flow (Jassby et al. 1995). For example, a doubling of flow results in an 8-km seaward movement of the salinity field, a distance roughly equal to the tidal excursion. Thus, substantial seaward movement of the salt field requires massive amounts of water and is seen only during very wet winters (Kimmerer 2002). During summer the surface salinity throughout San Pablo to South Bay is generally high, above 20 psu except in the northern end of San Pablo Bay during very wet years (Figure 4). During winter it is lower and more variable.

Since salinity responds inversely to outflow from the Delta, the forecast changes in flow should result in generally higher salinity throughout the estuary except during winter flow pulses. The largest effect of climate and the human response to water shortages is likely to be in springs, particularly of wet years (Knowles and Cayan 2002). The greatest effects will be on areas of intermediate salinity, e.g., Suisun Bay.

Organisms respond to salinity in two fundamentally different ways. Pelagic organisms (plankton, some fish) remain within a particular range of salinity and are therefore most abundant wherever that range occurs. Benthic organisms such as clams cannot move very far and therefore must either adjust physiologically to a change in salinity or die. Thus over time scales of months, movements in the salinity field result in changes in the distribution of benthic organisms.

Sediment supply Sediment input to the estuary comes predominantly from the rivers, and the supply has been decreasing due to a winnowing out of sediments released during hydraulic mining and to trapping of river-borne sediments behind dams (Wright and Schoellhamer 2005). Hydraulic mining released enough sediment to cause shoaling in most basins of the estuary, which reversed after the cessation of large-scale mining in 1884 (Jaffe et al. 2007). In particular, the area of mudflats is predicted to continue to erode because of sediment starvation (Jaffe et al. 2007). In an unreviewed article, Schoellhamer (2009) reported a decrease in suspended sediment concentrations around 1999 and speculated that the pool of erodible sediment, originally due to hydraulic mining, had been depleted.

Likely consequences of the decrease in sediment supply for subtidal habitats include a loss of mudflats and an increase in water clarity. Increasing near-surface water clarity has been noted in the Delta (Kimmerer 2004), although some of that increase may be due to trapping of sediments by an increasing extent of submerged freshwater weed. Changes in near-surface clarity in the lower estuary have not been reported. Although a moderate increase in water clarity would benefit eelgrass and attached algae, phytoplankton blooms may also become more frequent and shade out the submerged plants. At present, phytoplankton growth is limited by light and, in some parts of the bay, grazing by clams limits accumulation of phytoplankton biomass. If the light limitation were reduced, the abundant nutrients in the bay would allow for explosive phytoplankton growth. The consequences of that for subtidal habitats are difficult to predict.

A sediment budget would allow for the effects of reduced sediment loading to be calculated. However, such budgets are very difficult to construct, and various attempts have yielded widely different net values (Cohen 2008).

Introduced species The high proportion of introduced species in San Francisco Bay is well known, as is the potential for more colonizations. It is impossible to predict what additional species might arrive in the estuary or, more importantly, which will have major impacts on the ecosystem. Zebra and quagga mussels are likely candidates for introductions, with likely harmful effects in freshwater.

A reasonable response to this situation is continued vigilance, public awareness, and the development of rapid response plans for eradication.

Effects of a changed climate on subtidal habitats

Several effects of climate change may seem obvious, e.g., physiological effects of higher temperature and greater depth due to sea level rise. However, it is critical to avoid such a simplistic view of the likely changes. The multiple simultaneous trends described above may work together, either in synergy or antagonism, to make the outcomes far more subtle than such as simple reading would imply.

Increased temperature is known to affect metabolic rates of organisms that do not regulate their temperature. Thus, we might expect, for example, increased growth of epiphytes on eelgrass. However, there are two factors that might alter the way these responses play out. First, an increase in upwelling frequency is projected by some studies; in addition, the atmospheric pressure gradient between the cool ocean and the hot central valleymay increase with warming. Both of these factors would result in cooler ocean waters, stronger wind, and locally more fog in summer. Thus the net effect of climate change may be cooler water during summer near the coast and to some distance into the bay, at least in years of persistent upwelling, and warmer water in the rivers and upper estuary.

The second factor is that physiological effects are only the first and most apparent response of marine organisms to changing temperature. These effects result in changes in growth and development rate, size at maturity, feeding rate, and fecundity, each with strong ecological ramifications. For example, decreased size at maturity may alter the vulnerability of an organism to predation, a powerful force for ecological change. Furthermore, different species have different setpoints for temperature effects, so one consequence of a change in temperature is likely to be a shift in the assemblage of species in the bay.

Higher mean sea level will place extant habitats in deeper water and move the subtidal/intertidal boundary shoreward. Eelgrass beds in deeper water may die back because of a lack of light, although they may also be protected from grazing by geese. However, none of the habitats of greatest concern are static. In places where the bottom slopes gradually into the high intertidal zone, sediment movement and eelgrass growth might be expected to shift mudflat and eelgrass habitats shoreward. The key, however, is the availability and movement of sediment. The apparent shortage of sediment in the bay may mean that this shoreward transgression of these habitats cannot take place without human intervention. Furthermore, the interaction among water depth profiles, wind waves, and tidal currents that produce today's sediment distributions are difficult to predict in a future bay of higher sea level and possibly stronger wind. Without explicit, detailed modeling of sediment budgets and movement in the bay, the overall outcome is very uncertain. The USGS CASCaDE project is investigating these effects as well as other outcomes of climate change in the bay.

The effects of sea level rise and decrease of sediment supply on ecological functions may not be predictable given our rudimentary knowledge of the ecological limits on species in the bay. For example, we do not understand why eelgrass beds are so patchy and temporally variable, or why they occur in some places but not other places that appear suitable. Responses of phytoplankton to a deeper but clearer bay might include higher productivity, but the overwhelming influence of benthic grazing must be taken into account. Low salinity due to high flow can have a negative effect on oysters, which cannot tolerate freshwater for very long and can die back during periods of low salinity (Zabin et al. 2009). Likewise, eelgrass communities are more likely to suffer ill effects from prolonged low salinity than high salinity, since eelgrass beds are most abundant in high-salinity waters. Effects of prolonged high salinity may be more subtle and also difficult to predict; for example, species that are currently excluded from the estuary by occasional low-salinity pulses may be able to move into the estuary if the salinity is persistently close to oceanic values. As with temperature, it is necessary to consider the ecological as well as physiological consequences of these changes, and ecological consequences are difficult to predict.

Consequences for restoration and management of subtidal habitats

Based on the above discussion, several features of the future estuary stand out for consideration in planning for subtidal habitats. It is important to focus on highly likely changes (e.g., sea level rise), changes involving multiple causes or interactions (e.g., erosion due to the combination of lower sediment availability, higher sea level, and larger wind waves), and changes that carry high risk but for which confidence in future magnitude, time, or place is low (e.g., seismic risk to levees).

First, the combination of higher sea level, more frequent high-level events, and a reduced sediment supply means that it will be increasingly difficult to maintain habitats that require a continual supply of sediment. This means that intertidal mudflats, which may exist largely as a relic of hydraulic mining, may be unsustainable over the time frame of this project. Research is therefore needed to determine the feasibility of stabilizing existing mudflats through various engineering methods such as adding dredged sediments near a mudflat to provide a sediment source to balance losses due to erosion.

The second trend of concern is temperature. A northward regional shift in species distributions with increasing temperature has already been noted in both marine and terrestrial environments. If this occurs in the Bay area the result may be the loss of cold-adapted species from the bay and the increase or introduction of more species from warmer waters. Some of these species are almost certain to have undesirable impacts, but both extirpations and natural introductions would be difficult to predict or control.

The third trend is species introductions more broadly. Although there is no reason to believe the rate of introductions is increasing, it is very likely that additional undesirable alien species will be introduced some time in the future. Mechanisms for early detection and, if feasible, eradication would be a valuable adjunct to any management scheme.

Fourth, the expected increase in average salinity, particularly in the dry season or following a levee failure in the Delta, may allow species such as oysters to establish populations farther into the estuary, but may also encourage the penetration of marine species into the estuary. This should be investigated, although perhaps little can be done about it.

The other long-term trends are either too small or uncertain to warrant action until the trends and their consequences become clearer.

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Table 1. Long-term changes projected or likely to occur in the estuary relative to present-day conditions, with projections for change described in the text and some potential consequences for the more seaward reaches of the estuary. Causes in bold are those with a high probability of occurrence, or that are already observed. Other causes are either weakly or inconsistently supported by models.

Cause	2050 Projections	Consequences
Temperature rise	+2.5 (1.5-4.5)°C	Change in phenology, biogeography of estuarine and marine species.
		Species introductions and local extinctions.
		Reduced survival, reproduction, and growth of eelgrass and native oysters.
Total precipitation	~0 (±25) cm/y	More total flow and lower salinity with increase.
Timing of runoff	20 (5-25) d earlier	Higher winter, lower spring/summer flow (salinity opposite).
Sea level rise	+7 to 22 cm	Habitats will be in deeper water, less suitable because of turbidity; landward shift limited by shoreline conditions.
		Higher tide and tidal range may increase erosion and alter shorelines, mudflats, and marsh boundaries.
		Increase in tidal range may increase intertidal area; depends on sediment characteristics and sediment supply rate.
		Increased salt penetration due to enhanced estuarine circulation.
		Increase in tidal range and depth will increase strength of tidal currents, possibly erosion.
Wind speed	Uncertain	Increased resuspension from shoals with increased wind speed.
Storm Frequency	Equivocal	Increased erosion with increased storm frequency.
Acidification	+0.14 to 0.35 pH units	Impaired calcification of native oysters, possible impacts on other species.
Interactions	--	Higher sea level with stronger currents coinciding with storms accelerates erosion.
		Higher erosion and lower sediment supply depletes mudflats and marshes
		Reduced runoff, increased demand, levee failures result in higher salinity.
Levee failures in Delta	20 islands: ~70% prob.	Short term, rapid rise in salinity (if in wet season); long term, chronically higher salinity.
Change Delta configuration	--	Depending on operating criteria, potential increase in salinity.
Population growth	--	Increased demand for all ecosystem services; increased urbanization, impacts from transportation and infrastructure.
Water demand	+2 km^3/y	Decreased outflow and increased salinity.
Reduction in sediments	--	Continued shortage of sediments to build and maintain marshes, mudflats. Increase in water clarity possibly leading to eutrophication.
Introduced species	--	Impossible to predict; depends on what species and where.

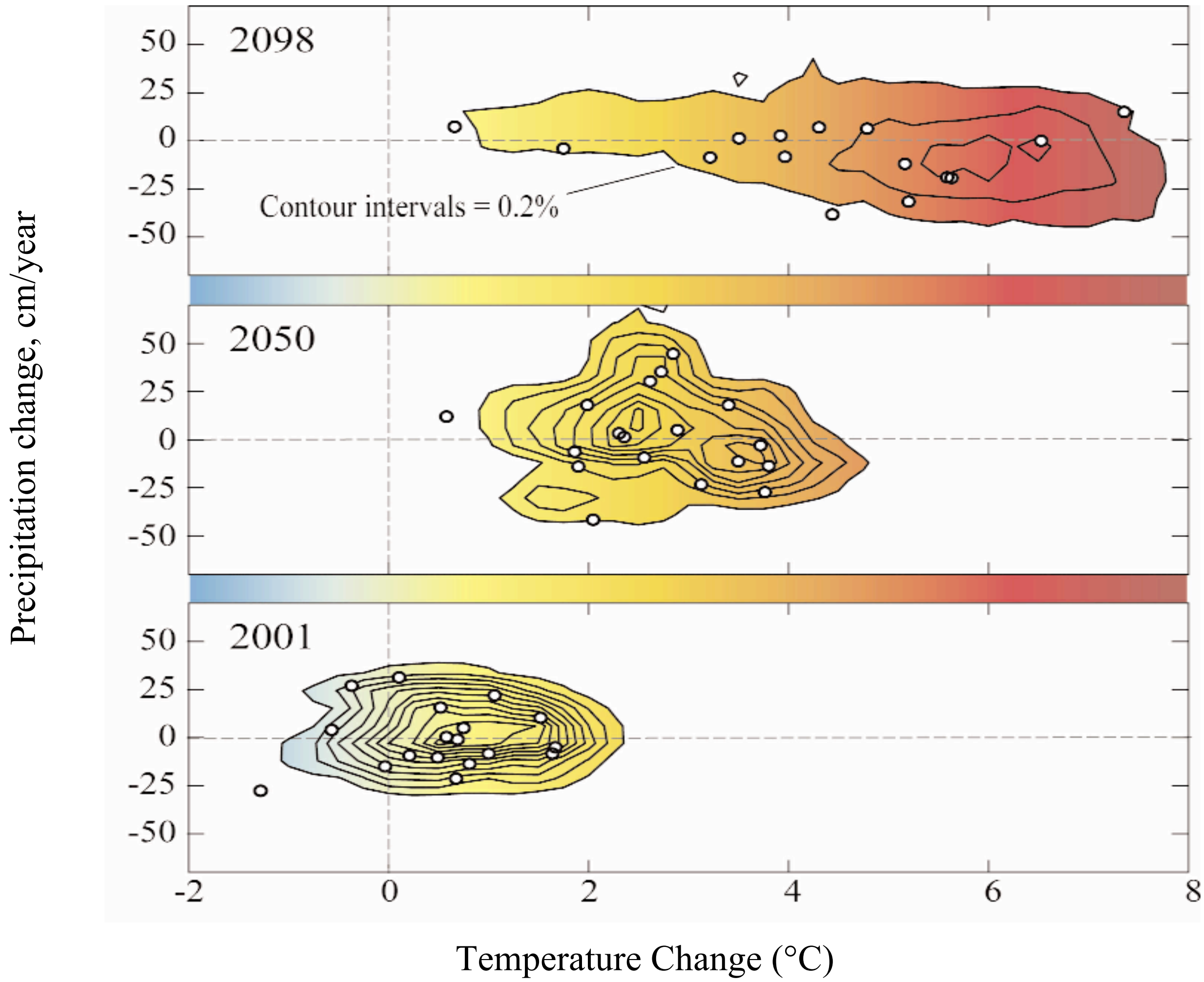

Figure 1 (Figure 5 in Dettinger 2005). Time slices of the joint temperature-precipitation distributions of resampled ensemble of model projections. Circles indicate values in the original 18-member ensemble of projections. See Dettinger (2005) for details.

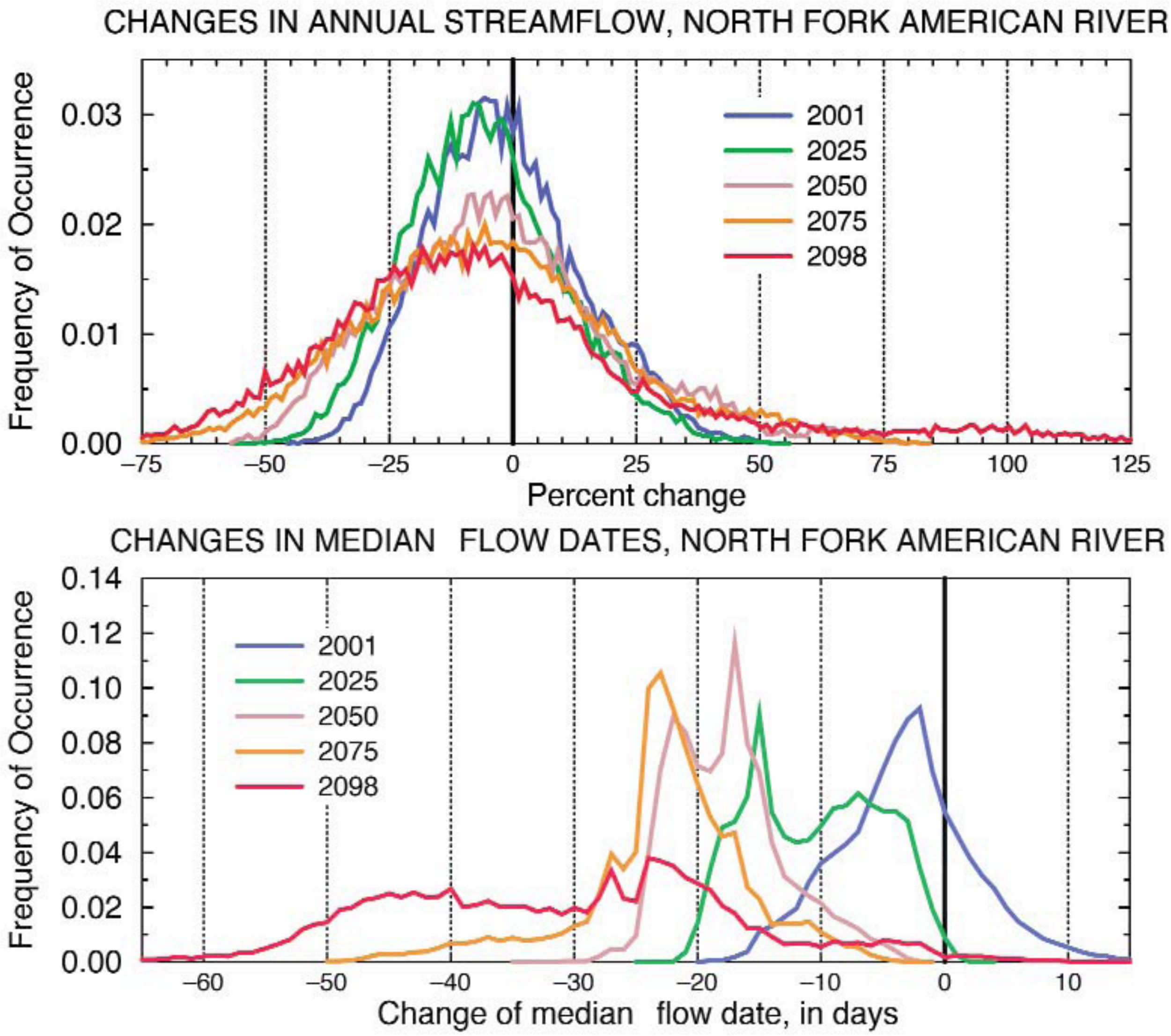

Figure 2 (Figure 6 in Dettinger 2005). Forecasts for changes in annual streamflow (top) and median flow date (i.e., date in the water year by which half of the year's runoff has occurred, bottom) for the North Fork of the American River. The water year begins on October 1 to encompass the entire wet season within one year.

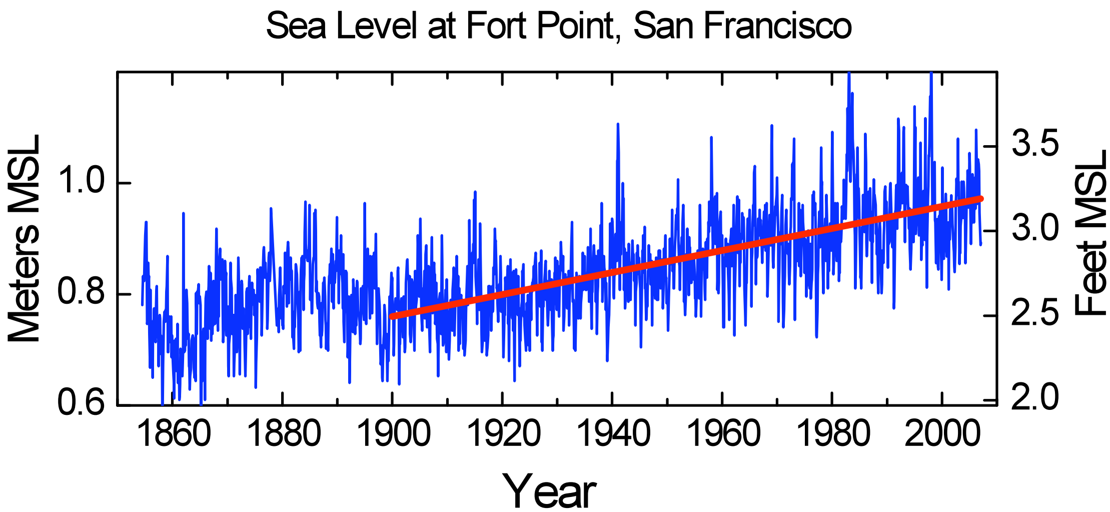

Figure 3. Monthly mean sea level at Fort Point, San Francisco. The line is a linear regression fit to the data from 1900 to 2006, with a slope of 2 ± 0.2 mm/year. The total change since 1900 was 21 cm. Data from NOAA at http://tidesandcurrents.noaa.gov/ Station ID 9414290.

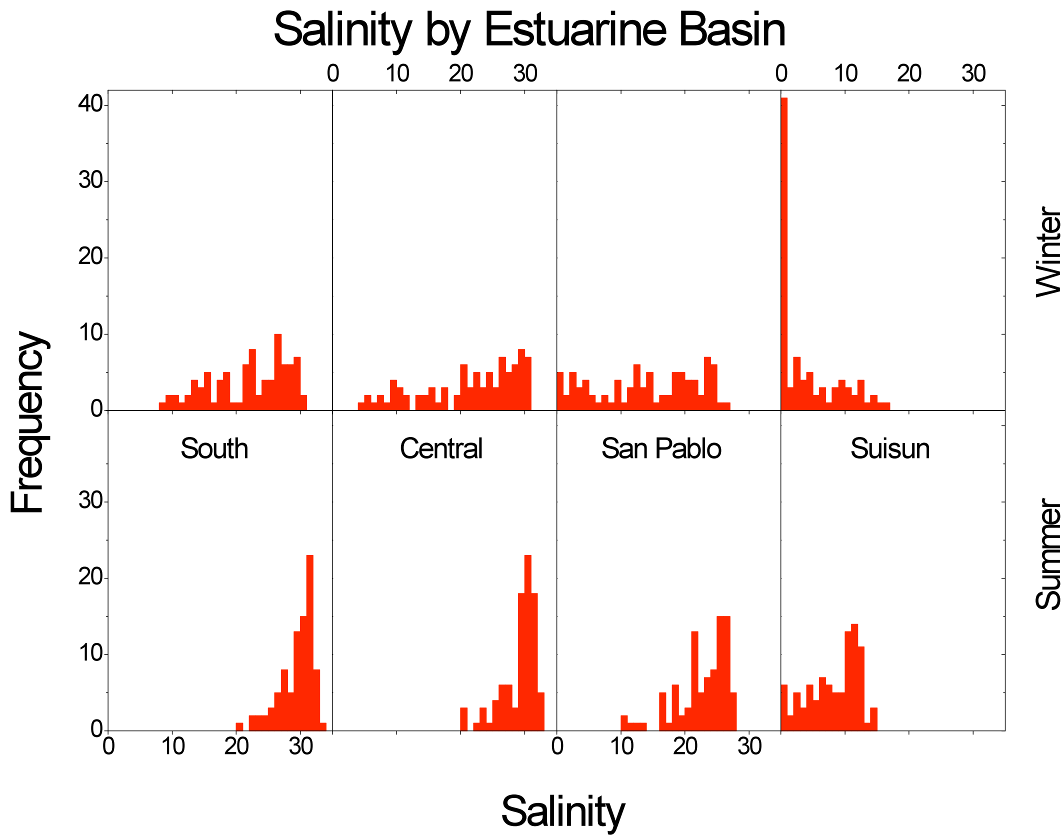

Figure 4. Frequency distribution of salinity in 1-psu increments by region and for summer (June – November) and winter (January-April). Data are medians of each station in each basin for each month in the record from the San Francisco Bay Study (K. Hieb, CDFG, pers. comm.) from 1980 through 2006.