CLIMATE CHANGE ASSOCIATED WITH RISING OCEAN LEVELS - A THREAT TO COASTAL AREAS

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Abstract: Even if we were to stop emitting green house gasses this moment, we have already committed to 2m of sea level rise in the future due to the lag of sea level rise response to warming. This means that each year we continue to emit mass amounts of greenhouse gasses, that inevitable number will rise, the average level of the ocean is increasing at an unprecedented rate due to anthropogenic forcing. There are two major uncertainties associated with rise, one is the amount of greenhouse gas emissions (RCPs), and another is the likelihood of the Greenland and Antarctic ice sheets melting. Though scientists are able to make predictions through simulation, it is unknown how fast they will break apart (Velicogna 2018).As communities are threatened by climate change, so are the baylands and their wildlife. Although a few feet of sea level rise may not sound threatening, one meter of rise can affect ecosystems hundreds of meters inland depending on surface slope. Reduced sediment, warmer temperatures, and storm surge will have a detrimental effect on habitat. Restoration practices can be used to increase the Bay's vitality, but rebuilding or protecting development could potentially cost billions of dollars (Velicogna 2018). Many stakeholders are discouraged by short term upfront cost for investment in protection, rather than focusing on long term benefit and avoiding damage expenditure. When choosing a course of action there will be tradeoffs between competing uses, near and long term benefits, and which ecosystems will be protected. Successful implementation will be made possible through adaptive management, the process of learning by doing and utilizing the results to improve tactics. An action strategy for the Bay in the long term will need to focus more on restoring transition zones and realigning levees as well as public outreach (Sea Level Rise Guide, 2018).
Keywords: sea level, climate models, coastal erosion, potential degradation of vulnerable regions, scientific projections

1. ENVIRONMENTAL OVERVIEW

Sea level rise will be an important issue facing California's northern coast in the decades moving forward. Mass infrastructure is at risk, especially in The Bay due to flooding of the delta and sinking of the land. Climate models indicate that sea level could rise by nearly 66 inches by the end of the century, accompanied by storms and high tides (Griggs 2018). This would put homes, energy facilities, contaminated land sites, hazardous material sites, and storm water infrastructure at risk. I am interested in studying the current state of coastal erosion, and potential degradation of vulnerable regions in San Francisco Bay. First I will discuss the scientific projections for local sea level rise in the Bay, then I will explore who and what flora/fauna are most at risk, later I will describe what geographical formations specific to the region may exacerbate the rise, and finally I will explore the plan/methods that can be used to prepare for flooding.

2. INTRODUCTION

Sea level rise is ultimately caused by climate change driven by greenhouse gas emissions. The rate of sea level rise is increasing as the rate of emissions is increasing. As the planet warms, the average sea level rises due to the melting of glaciers/ice sheets, thermal expansion, and the loss of snow pack on land. Glacier/ice sheet melting accounts for over 50% of sea level rise and can be difficult to predict due to different emissions scenarios. The diminishing of the Antarctic and Greenland ice sheets presents massive risk if the trend of warming continues. Thermal expansion accounts for about 40% of rise because as warmer water expands it experiences less density, and thus takes up more volume. Reduced land storage of frozen water accounts for about 10% of rise (Velicogna, 2018).
Global sea level change, the average of all local sea level rise data, can be calculated to the millimeter by satellite, whereas distinct local sea level rise has historically been measured by tide gauges. Regional relative sea level trends are critical for coastal applications such as coastal zone management, infrastructural engineering, habitat protection, and recreation. Hot spots in which rise has more potential for damage occur due to local topography, ocean currents, and development. It is estimated that sea level rise will put about 220,000 people at risk of a 100 year flood in the San Francisco Bay by 2100 (Griggs, 2018).
The San Francisco Bay Area has historically been a populous region, shaped and altered by Native Americans, the Spanish, the Gold Rush, and urban expansion following the 20th century. The concentrated hub of enterprise is important because it accounts for about 30% of California's economy and is home to a large diverse population. The Bay is comprised of nine counties and 100 cities. The region's population is more than 7 million people and its

economy is worth about $750 billion. About 62 billion dollars worth of property is at risk of flooding under moderate 2100 sea level rise scenarios. This means that about 160,000 residents would be affected either at home or work (Bay Area Regional Report, 2018). The disparity between communities' respective abilities to adapt due to socioeconomic differences may lead to a go-it- alone approach. This path would result in ignoring vulnerable populations on the frontline of the impending battle, therefore environmental justice must play a key role in considerations for how to develop adaptation plans. Planning for sea level rise should integrate infrastructure and social system needs in a holistic way to achieve community health.

The Bay Area is a biodiversity hotspot characterized by rugged topography and tidal wetlands. Its coastal Mediterranean climate with warm summers and mild wet winters supports a wide range of biological diversity. The abundance of natural capital has resulted in a large population of people who are able to benefit from the plenty. Inhabitants of the Bay have interrupted the natural processes of circulation over the past 200 years, and thus decreased its resilience. The Golden Gate watershed has been "highly modified so that sediment and water flows that reach the estuary are very different from their natural patterns of timing and magnitude" (Goals Project, 2015). The edges of the Bay are heavily lined with mass infrastructure, thus restoring natural habitat is a difficult task. Intertidal habitats have historically been resilient to sea level rise because they accrete sediment and migrate inland over time. This process is unable to function properly in the Bay because of lack of sediment supply, the fast rate of change, and development (Schoellhamer, 2011). Some intertidal habitats such as beaches, eelgrass, and oyster beds have largely been removed, but their presence and restoration help provide a natural barrier. This has lead to the fluvial tidal transition zone being prone to flooding (Bay Area Regional Report, 2018).

The California Ocean Protection Council's Science Advisory Team released an update on California's rising seas in order reach scientific understanding and influence policy. The report found that understanding of rise is advancing at a rapid pace, the rate of ice loss from Greenland and Antartica is increasing, new evidence highlights potential for extreme rise, scientific studies can inform decisions, and local adaptation policy will shape our future. Assessments such as these have an impact on legislation such as Senate Bill 379 which requires local governments to incorporate climate adaptation into their General Plans (Sea Level Rise Guidance, 2018). This guidance helps governments analyze and interpret the risks of sea level rise, as well as provides recommendations for action. The sea level rise guide aids planners in prioritizing social equity, protection of coastal habitat, water dependent infrastructure, preparation for storms, and multi agency/stakeholder collaboration. Tools such as the Surging Seas Risk Zone Map have been developed in order to allow the public and policy makers to spatially visualize rise (Sea Level Rise Guidance, 2018).

Research on vulnerability to sea level rise in northern California became more popular in 2017 through the Bay Area Regional Collaborative and the Association of Bay Area Government's Resilience Program. The analysis pushed the need for preemptive action. Later that year the Plan Bay Area 2040 was adopted in order to compile research, enact planning, and prepare for a more resilient future (Sea Level Rise Guidance 2018). The next step according to the Bayland report will be the Sustainable Communities Strategy which will be an ongoing project until 2021. It integrates land, building, and transportation planning to meet strict environmental standards and increase response to hazards. Local mandates are also important when considering the Bay's future growth and ensuring public safety. Resilience planning is becoming a priority for the Bay Area due to low lying susceptible shorelines and active fault lines (Bay Area Regional Report, 2018). The impact of climate change has decreased the natural ability of the Bay to be resilient. The once adaptable landscape has undergone such fast sharp change that new approaches to shoreline protection are necessary. Resilience is "commonly defined as the ability to recover from setbacks and adapt to change" (Ovans, 2015). Ideally the Bay will be able to respond to physical hazards while protecting vulnerable communities, the natural environment, and critical infrastructure through policy decisions.

Questions:

- ***What are sea level rise projections for The Bay by 2100?***
- ***Who and what flora/fauna are most at risk?***
- ***What infrastructure and geography specific to The Bay may exacerbate effects from sea***
- ***level rise?***
- ***What is the plan/are the methods that can be used to prepare for sea level rise?***

3. WHAT ARE SEA LEVEL RISE PROJECTIONS FOR THE BAY BY 2100?

Sea level rise is not an issue of the distant future, the Bay Area has already been impacted. The region has experienced about 20 centimeters rise over the past 100 years. Global sea level was rising at a rate of about 1-2mm/year prior to 1990, but the rate has doubled to about 3mm/year (Bay Area Regional Report, 2018). Regional historical data for the rise along The Bay is easily accessible thanks to the Ft. Point tide gauge near the Golden Gate which holds the oldest tide record in North America. All of the gauges that surround the Bay Area have shown

significant acceleration of the rate of rise since 2011 (Griggs, 2018).
The projections used in this paper for rise were primarily provided by the National Research Council study conducted in 2012. It incorporated ocean current components, glacier and ice sheet loss, and vertical land motion in order to come to the Bay projection of 92 centimeters by 2100. The study projects median sea level rise between .74m (RCP 4.5) and 1.37m (RPC 8.5) for 2100 (NRC, 2012). This is a conservative estimate though, because recent studies using ice sheet observation and advanced modeling suggest that sea level could rise about 3m. This catastrophe would be due to the possibility of extensive loss of either the Antarctic or Greenland ice sheets (Sea Level Rise Guidance, 2018).
California's Fourth Climate Change Assessment projects a "0.1% and 5% chance of sea level rise reaching 2.87 m and 2.41 m by 2100, respectively" (Pierce et al., 2018). Another primary concern for water penetration into the Central Bay and along the open coast is the potential change in long period wave energy, especially during southwest swell events. More frequent and intense storms will amplify damage from tides simultaneously. The powerful 2016 El Nino resulted in a 50% increase of wave energy in the winter, leading to unprecedented beach erosion. Periodic El Nino events create a coastal hazard in which seasonal flooding can be 30 centimeters above normal (Pierce et al., 2018). The frequency and magnitude of these events in the future will be an important component of coastal vulnerability. Research on possible future El Nino patterns is largely inconclusive, so it is best to be prepared.

4. WHO AND WHAT FLORA/FAUNA ARE MOST AT RISK?

Because the Bay is not homogeneous topographically or socioeconomically, not all regions will be affected by sea level rise equally. There are high levels of socioeconomic inequity in the region that affect the ability of some communities to prepare and recover from "natural" disasters. Financial resources may not be adequate, especially for low income communities. This poses an environmental justice threat because effects associated with greenhouse gas emissions disproportionately affect those who are least able to respond. The Bay Area Climate Report defines vulnerable populations as low income individuals, people of color, elderly, people with disabilities, people with health issues, and people with limited English proficiency. These groups are already feeling the impact of climate change, and are less able to adapt to its effects such as sea level rise. For example, low income communities have a lower rate of car ownership which means it is harder to escape flooding and save possessions (Bay Area Regional Report, 2018). Vulnerable populations are heavily reliant on public transportation which may be damaged during extreme weather as well.
The lack of affordable housing is forcing families into less desirable locations with higher vulnerability to environmental risks such as flooding. Sudden inundation in the Bay may result from levee system failures, especially considering many are seismically poor structures. Subsidence of bay front lands has resulted in some communities being below mean high water levels (Giwargis, 2017). Examples are Alviso and Bethel Island which are already susceptible to levee failure induced flood. Lower watersheds in urban areas that surround San Francisco Bay are at current risk of inundation as was seen at Coyote Creek in San Jose 2017 (Giwargis, 2017). There are a few public health risks associated with sea level rise that should concern all residents. There are dozens of hazardous waste sites at risk of flooding, and the mobilization of the contaminants could pose direct health risk due to exposure to metals and petrochemicals. Our drinking water supply is at risk due to saltwater intrusion into groundwater and into the San Joaquin Delta. Disruption of the transportation network due to flooding would be hazardous because individuals may have difficulty reaching hospitals and emergency responders etc. (Bay Area Regional Report, 2018).
The ability of flora and fauna to respond to the rapidly changing conditions in the upcoming decades is poorly understood. Nearly all of the Delta ecosystems will be affected by rising sea level and the shore will either need to adapt or transform. Perhaps the most threatening aspect of climate change to the Bay's wildlife is rising seas on wetlands because of their limited ability to move inland and become established (Baylands and Climate Change, 2015). The Bay is home to about 3000 native plant taxa and a diverse range of terrestrial, freshwater, estuarine, and marine habitats. Climate change has led to shifts in vegetation, but as I will discuss later, wetlands can serve an important role in combating the effects of sea level rise. Restoration efforts need to take rising seas into account (Baylands and Climate Change, 2015).
Bay wildlife is threatened by habitat loss, barriers such as infrastructure, and higher rates of change. The alteration in the distribution of plant communities due to inundation and salinity will have far reaching effects on the ecosystem. Two types of impacts from change will affect flora and fauna: long term trends, and episodic events such as storms. Long term trends will affect population and habitat, whereas short term amplifications create extinction risk in isolated populations (Baylands and Climate Change, 2015). Salinity, a long term trend, often determines the plant composition and habitat quality for animals. Delta outflow is "positively correlated with the abundance of

several key populations of fish and crustaceans." Fish that rely on freshwater, such as delta smelt, will be increasingly replaced by marine fish, especially in Suisun Marsh due to saltwater intrusion (Baylands and Climate Change, 2015). Salinity limits the ability for many brackish plants, such as the endemic water hemlock, to thrive and reproduce in the winter and spring germination periods. Marsh birds such as wrens and yellowthroats depend on these plants for breeding sites and thus and extensive food chain is negatively affected (Baylands and Climate Change, 2015).

Inundation, which can be an episodic event, can lead to a greater risk of predation because wildlife is forced to move landward and cling to vegetation in small concentrated areas. This generates mortality pressure and increased competition for less space. The lowering and loss of mudflats relative to sea level may result in the decline of several waterbird species. Deeper water reduces foraging habitat and alters prey location for shore birds which are energetically limited during winter migration. They rely on easy access in the estuary to complete their energy budgets (Baylands and Climate Change, 2015).

5. WHAT INFRASTRUCTURE AND GEOGRAPHY SPECIFIC TO THE BAY MAY EXACERBATE EFFECTS FROM SEA LEVEL RISE?

The relationship between land use, transportation infrastructure, and energy systems is important in the Bay Area, especially in relation to the economic growth and prosperity of the region. This interdependent system is highly vulnerable to the impacts of sea level rise. Much of the transportation system is concentrated along the coastline which is susceptible to flooding and storm surges (Sea Level Rise Guidance, 2018). The Bay's electrical grid is vulnerable to power outages, while the natural gas transmission system rests along waterways that will feel the impact of inundation. Wastewater treatment plants that have historically been placed along the shoreline for convenience are now susceptible to rising water. This calls for improved management to avoid disastrous effluent mishaps. Levee failures can lead to the contamination of the Delta water supply through salinity intrusion (Sea Level Rise Guidance, 2018).

Over 7 million people live in the Bay which encompasses about 1,000 miles of shore line where ports, roads, aiports, and electrical grids are concentrated. Flooding could result in hundreds of millions of dollars in damage. The model below using data from Lidar visualizes risk of combined sea level rise and storm surge for the Port of Oakland which is an important shipping center linked to the terrestrial transportation network. The transportation systems at risk of being flooded are critical junctions such as highways serving the port of Oakland (Sea Level Rise Guidance, 2018). The risk shows need for increased stormwater management and one water systems that integrate water treatment, discharging wastewater, and handling storm water.

Hummel states that wastewater treatment plants in the South Bay are most immediately in danger from sea level rise, and that rising groundwater tables will affect inundation. If saline groundwater enters sewer systems, wastewater recycling treatment will become exponentially more expensive (Hummel et al., 2018). San Francisco is unique because wastewater and stormwater is collected and treated through the same infrastructure. During wet storms the influent volume has been up to seven times greater which can overwhelm the treatment process and lead to ocean discharge. Contaminated land sites that hold hazardous substances are also vulnerable. This includes landfills and brownfields, some of which require clean up. Often multiple agencies share oversight of monitoring, so addressing impending problems can be a convoluted process. Many of these sites were historically Bay fill but have been converted into shoreline recreation areas, some are former industrial areas adjacent to disadvantaged communities (Adapting to Rising Tides, 2018). The release of hazardous substances would have significant negative effects on public health, but most remediation practices are not designed to address sea level rise or changes in groundwater conditions.

Energy companies such as PG&E with infrastructure in the line of fire have conducted their own climate assessments. FEMA's flood risk report shows PG&E's assets are at risk of flooding by the end of the century. The company has responded by elevating structures in San Mateo, Napa, and Richmond in order to ensure the reliability of the grid. They have deployed portable generation systems and integrated advanced control technologies as well (PG&E 2016). Both the Oakland and SFO airports, which contribute billions of dollars and hundreds of thousands of jobs to the Bay, are currently at risk from storm events and inundation. They are are projected to be flooded within 1 meter of sea level rise which is likely by 2100. The Coastal Conservancy and SFO partnered to produce a resilience study and found that roads and the BART airport connecter that provide access to the airport are vulnerable to inundation that is "equivalent to todays 50 year extreme tide level" (Adapting to Rising Tides, 2018). Even temporary disruption of airport operations would have international consequences. The massive cost of protecting and possibly relocating the critical infrastructure should be considered in capital investment plans for the facilities (Hummel et al., 2018).

The main aspect of the Bay's geography that will exacerbate sea level rise is subsidence. The vertical land movement is due to seismic effects, groundwater fluctuations, sediment compaction, and marsh accretion. The extensive pumping of groundwater in the Santa Clara Valley in the early to mid 1900s has resulted in as much as 1 meter of land subsidence along the South San Francisco Bay. Some of the land that was submerged has been able to be recovered at a rate of about 1-2mm/year due to more responsible pumping practices (Shirzaei & Burgmann, 2018). Another reason the land is sinking which is not related to plate tectonics is compaction. The artificial and mud filling that was used to create a large portion of the Bay's shoreline is subsiding. For example, the northwestern tip of Treasure Island "dropped about 20mm/year from 1992-2000 and subsidence of up to 10 mm/yr occurred along mud-dominated shoreline areas, such as the San Francisco waterfront, San Francisco International Airport, and Foster City, though most subsidence rates in the Bay Area are less than 2 mm/yr" (Shirzaei & Burgmann, 2018). Subsidence matters because infusion of seawater into groundwater creates a potable water crisis.

6. WHAT IS THE PLAN/ARE THE METHODS THAT CAN BE USED TO PREPARE FOR SEA LEVEL RISE?

Projects such as vulnerability assessments, new government structure, and infrastructure improvements are underway. A vulnerability assessment for the Bay has been periodically released, as well as regional assessments for Marin, San Mateo, Alameda, and Contra Costa counties (Riordan, 2018). The research provides extremely important insight for moving forward with potential solutions. Cities such as San Francisco and Berkeley are investing in green infrastructure such as bioswales to help manage stormwater at a small scale which can dampen flood overflow risk. The lack of sediment deposition in the Bay could be increased by updates to infrastructure such as dams, changes in reservoir management, and alterations in creek
alignments (Bay Area Regional Report, 2018). Management of freshwater resources is important because tidal marshes are able to increase in elevation rapidly by creating peat. Modeling shows that these marsh barriers may be able to be sustained at the lower end of the sea level rise productions, but they ultimately will lack longevity if the rate continues to rise (Riordan, 2018).

Though the Bay does not have a cohesive strategy to adapt underway, examples of regional adaptation plans include Resilient by Design, RISeR SF Bay, and C-SMART. The Resilient by Design Challenge, modeled after New York City's post Superstorm Sandy Resiliency Design competition, was established in order to develop potential solutions to sea level rise in the Bay. The year long collaborative challenge financed by the Rockefeller Foundation incorporated local and international experts in conjunction with regional resident input. Nine innovative plans created by teams of designers, urban planners, architects, engineers, and experts were chosen in order to strengthen the Bay's resilience (Resilient by Design 2018). For example one of the plans is centered around State Route 37 in the North Bay which is prone to flooding because it slices through wetlands. In order to protect the region's ecological health the design lifts the route 25 feet higher and allows it to follow a scenic path. Bike paths would also be incorporated to encourage less consumptive modes of travel. Another design is called the South Bay Sponge which uses natural systems as the primary tool for resiliency. The plan includes restoring the historic salt ponds and wetlands that have absorptive and filtering qualities. The layout includes floodable parks and green spaces at higher elevations alongside existing and new development (Resilient by Design 2018). The catch is that not all of the amazing designs are likely to be financed and implemented.

RISeR SF Bay is a project that strives to tackle sea level rise by studying hydrodynamics, governance, transportation, and economy. The team includes "engineers from UC Berkeley, transportation experts from NYU, political scientists from UC Davis, and ocean experts from the U.S. Geological Survey" (Riser SF Bay, 2018). A public advisory group from the Bay Area provides input and feedback on the project. The advanced modeling system can show the effect of sea level rise at different levels from county to county. It proves that regional collaboration, rather than separation, will be important concerning adaptation. The team is able to showcase how the inundation of one local freeway can result in far reaching traffic impacts on other Bay transport sectors. RISeR also recommends ways to improve policy utilizing public polls to gage public knowledge and viewpoints (Riser SF Bay, 2018).

C-SMART is the collaborative sea level Marin adaptation response team which includes stakeholders and technical advisory committees in Marin county. Their action plan focuses on identifying exposure, sensitivity, adaptive capacity, and potential impact. Their goal is to educate the public so that floodable development and managed retreat are options eventually accepted by the community (County of Marin 2018). The residents are heavily involved, and the group has created adaptation reports for Stinson beach and Tomales Bay, as well as a home owners guide to preparing for sea level rise which encourages altering private infrastructure in order to increase resilience. Their platform includes a "sea level rise library" which is a compendium of journal articles and media reports on sea level rise in the area in order to increase awareness (County of Marin, 2018).

Discussion

The Bay Area is woefully unprepared for the rise that is to come. Our response to rising seas will be fundamental in determining the fate of the wildlife population, the price tag on damaged infrastructure, and the safety of residents. If we do not act, projections show that the Baylands will shrink due to loss of wetlands and erosion. Either we can respond with cost effective more natural infrastructure now so that we can expand and alter as the years pass, or we can wait until we are forced to put up a blockade with hardened edges and little vegetation. This would result in the region being obliged to construct and maintain sea walls and levees, prompting poorer water quality because wetlands could not serve their purpose of absorbing excess nutrients from wastewater and filtering contaminants (Baylands and Climate Change, 2015). The biodiversity of the habitat would be decimated and millions of birds could loose critical feeding grounds.

In order for a united response to take place, increased regional coordination is necessary. Communities along the Bay are at high risk of flooding, but they may have limited resources to pursue an adaptation strategy. The disparities in political and economic power may leave regions acting independently rather than together. This would result in highly variable results for community health and resilience. Agencies and stakeholders should collaborate on methods to achieve a healthy shore for the entire region. Bay Area residents have proved their strong interest in saving the Bay by making the historic decision to levee a tax upon themselves. Measure AA is a parcel tax that will raise about 25 million dollars annually (500 million over 20 years) to fund flood control, habitat restoration, and shoreline access. It passed with a whopping 70% approval rate across nine counties and was put into effect in 2017. Governor Brown catalyzed research on preparation for sea level rise in California because “waiting for scientific certainty is neither safe nor prudent” (Sea Level Rise Guide, 2018).

Ultimately mitigating greenhouse gas emissions is the solution, buffers are a band aid for a systemic global issue. A cultural shift towards renewable energy and the development of scaleable, economically viable ways to sequester atmospheric carbon back into the ground will reduce future impact. There has been a lag between scientific understanding and government action, and a lack of funding for environmental preparation. This is important to note because although unabated warming will raise sea level by multiple meters, slow reaction can be frustrating for stakeholders. The general benchmark for California is to revert carbon dioxide levels in the atmosphere back to pre 1980s levels (Velicogna, 2018).

Because international mitigation will take time and may not occur fast enough, adaptation at the local level can be implemented. Natural infrastructure can serve as a form of adaptation to sea level rise, the Bay is home to marsh and wetland habitats which protect against flooding. When addressing sea level rise in the region there are multiple threats such as sea level variability plus tidal forcing, groundwater flooding, and watershed or stormwater fooding.

Protective infrastructure must respond to all of these. The value of natural elements as protection comes from their inherent ability to create a more resilient shoreline. They also serve as habitat for native species, support ecosystem diversity, and place for recreation (Baylands and Climate Change, 2015).

Protective shoreline is not an option for the entire Bay, its placement is critical. The containment strategy allows some of the flooding to proceed but this is often not possible in highly populated urban areas. It would require managed retreat inland or a new internal infrastructure. Specific communities need to take into account individual geography and protection needs in order to receive benefit. Because San Francisco Bay is not, for the most part, characterized by open coast with steep slopes there is little opportunity for truly natural shorelines. If the communities were to decide upon allowing the shoreline to evolve in response to environmental variability and serve its role as a natural barrier, retreat and restoration would be necessary (Baylands and Climate Change 2015). This is an unlikely scenario so it is almost certain that artificial elements will be required, therefor hybrid approaches may be a solution.

Natural elements can be integrated into engineered structures, for example a horizontal levee. Marshes or other vegetation serve as the first line of defense on the bayside of the structure to reduce wave energy. This ultimately reduces the amount of energy the structure must endure. Low crested berms made from material such as oyster shell or coarse gravel can serve as alternatives to conventional armor. Sediment accretion is paramount to saving the Bay with a more natural approach. Mineral sediment deposition is highest bordering tidal channels and breaches which can lead to natural levees (Baylands and Climate Change, 2015). Filling the marsh or using dikes does not allow these channel networks to fully evolve, and thus there is insufficient tidal prism and poor habitat. Presently tidal marshes are keeping up with sea level rise, but the demand for sediment is increasing. Direct placement of sediment in subsided areas has been successfully implemented in several regions of the Bay. It has allowed for the recharging of the water column and mudflats but has the potential to have detrimental impacts on habitat so its use is cautionary. The Bayland Report notes that significant amounts of local sediment are trapped behind dams, so moving the resource to the bay could be incorporated into watershed management. Sediment transport can also be improved by reconnecting waterways such as creeks and rivers to the landward side of marsh (Baylands and Climate Change, 2015).

Restoration and conservation efforts often focus on mud flat slope because it is the most frequent determiner of the balance between erosion and progradation. The elevation and slope of a mudflat is determined by sediment supply and wave energy, but when the accumulation cannot keep up with sea level rise the marsh habitat is lost. The Baylands report recommends the establishment of tidal marsh corridors along the saltwater and freshwater gradient in order to succeed in conservation efforts. This is because their is a "strong feedback loop" between the inundation and plant productivity which drives the organic matter accumulation. Corridors can give marshes a leg up, also known as elevation capital, on sea level rise so that they can grow as high into the tidal frame as possible (Baylands and Climate Change 2015). For alluvial fan transition zones the protected increase in riverine flooding could be used to increase sediment supply through the valleys, fans, and marsh bushing the transition zone bayward and enlarging migration space. This approach is effective where fluvial fans have not been redeveloped yet. Flood control designs may not be able to suffice, the difficult task of infrastructure realignment and planned retreat may be needed by 2100 to ensure safety (Baylands and Climate Change 2015). But, the retreat strategy may lead to gentrification and community displacement, so socioeconomic and disparities and equity should be taken into account.

As sea level rises, the estuary in the Bay becomes more saline causing the habitat to shift from fresh, to brackish, to salt water. This poses a major problem for the fresh water supply in the Delta. If the gradient of salt to freshwater moves further inland, planning for water allocation will need to be done. Sea level rise planning does not just occur at the shoreline, management of creeks, rivers, reservoirs, and stormwater is critical because sediment and land water build estuarine habitat. Shoreline adaptation will require policy shifts, coordination, the inclusion of local people, and money allocation (Baylands and Climate Change, 2015).

California has proven itself a leader when it comes to addressing climate change, but adapting to sea level rise is a daunting task. Innovation for resilience is on the rise but the pace of change is swift. A deadline for change and necessary response is quickly approaching in order to avoid flooding. For adaptation strategies to be carried out, scientists, policy makers, experts, and the public need to work together. Individuals have the power to make a difference through their vote. Electing regional officials who care about responding to changing climate and its effects will be paramount in the coming decades. Adaptation does not happen overnight, we need to start preparing now. The ultimate objective of a broad range of diverse stakeholders is a resilient future for the Bay Area.

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Bruce Riordan - program director of UC Berkeley's Climate Readiness Institute and one of four lead authors of the Bay Area report 8/15/18
Roland Burgmann - UC Berkeley professor of earth and planetary science currently researching Bay area subsidence and sea level rise 9/1/18
Isabella Velicogna - UC Irvine Cancellor's fellow and professor of physical sciences, equity, and inclusion 11/8/18