Possible Solutions to California's Changing Coastline from Sea Level Rise

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Abstract

This research paper assesses the effects of climate change and sea level rise on prominent California coastal landforms such as sandy beaches, bluffs, and estuaries. The framework posed by Griggs and Reguero (2021) that includes soft solutions, hard solutions, and managed retreat solutions is utilized to provide insight on conservation options for the three landforms along the California coast. This paper reviews each landform, how the terrain has been impacted by erosion, and how certain communities are responding to sea level rise. For each landform, the paper analyzes what solutions have already been put in place, presents examples of successful California locations, offers several options of solutions for the immediate future, then transitions into a broader discussion about the long-term future of the California coast and its implications among residents. This paper is not meant to take a comprehensive look at every contributing variable, but considers multiple factors when discussing possible solution options. Ultimately, this paper finds that managed retreat is the most ideal solution for sandy beaches, hard solutions are optimal for bluffs, and soft solutions work best for estuaries. However, it argues that managed retreat should still be considered as a fallback solution for each landform when hard and soft solutions fall short.

Introduction

The future of the Earth is uncertain, with rising temperatures, a growing global population, and melting glaciers. These are just a few of the factors of climate change that may indicate what the future holds, along with potential consequences, such as rising sea levels and increased coastline erosion. Although the future of climate change is uncertain, it is undeniable that homes, public infrastructure, and people's livelihoods remain at risk. Climate change is an ongoing and worsening problem facing our planet. According to the United Nations (2024), climate change is defined as the long-term shift in temperatures and weather patterns primarily due to the combustion of fossil fuels such as coal, oil, and gas. Due to these anthropogenic sources of carbon dioxide being released into the atmosphere, warmer atmospheric temperatures are resulting from the greenhouse effect. The greenhouse effect is the entrapment of greenhouse gasses, such as carbon dioxide and methane, within the atmosphere (United Nations, 2024). Greenhouse gasses trap the solar energy emitted from the sun, re-emitting this heat as infrared radiation, leading to warmer atmospheric temperatures (UCAR Center for Science Education, 2021). As temperatures rise, thermal expansion occurs, causing water molecules in the ocean to heat up and expand, which contributes to sea level rise (Griggs & Reguero, 2021). Melting glaciers and ice caps are the second most contributing factor to sea level rise, following thermal expansion (California Coastal Commission, 2024). Due to rising sea levels, California's coastal communities and resources are adversely affected and experience increased flooding, inundation, wave impacts, coastal erosion, changes in sediment dynamics, and saltwater intrusion to groundwater supplies (California Coastal Commission, 2024).

California's coast has faced eight inches of sea level rise over the past century and as early as 2050, a projected 20-inch sea level rise may overwhelm its shorelines (Grenier & Sencan, 2024). As the alarming rate of sea level rise presents an ongoing and worsening problem for the state, the need to protect existing infrastructure has become increasingly important. Nearly 26.3 million Californians live on or near the coastal portions of the state's 1100 miles of shoreline (Lewis, 2023), leaving millions of residents to be potentially at risk. Given California's densely populated coast, the rise in sea level puts existing infrastructure, tourism opportunities, and recreation at risk from flooding and erosion, significantly impacting millions of California residents. The economic costs of the rise in sea levels is drastic, as a staggering $17.9 billion worth of infrastructure may be inundated by the projected 20-inch sea level rise as early as 2050 (Grenier & Sencan, 2024). According to Heady et al. (2018), it is estimated that sea level rise and associated flooding will threaten upwards of $100 billion worth of property along the California coast by the year 2100, displacing millions of Californians. Therefore, it is essential to protect the California Coast and address the ongoing concerns of rising sea levels.

Griggs and Reguero (2021) present a variety of possible conservation solutions which can be categorized into three main types: soft (natural) solutions, hard (built) solutions, and managed retreat. Soft solutions focus on restoring natural processes and mitigating erosion, including beach nourishment, dune restoration, and the implementation of marshes, oyster, and coral reefs. Hard solutions entail the construction of man-made infrastructure including seawalls, levees, and bulkheads (Sutton-Grier et al., 2015). Managed retreat requires large initial financial investment but would eliminate the "coastal squeeze," or the narrowing of the remaining habitat, by returning regularly flooding land back to its natural state, reducing further damage (California Coastal Commission, 2024). Managed retreat is a response strategy to receding shorelines that typically requires the abandonment or relocation of people's assets, including their homes, personal properties/land, or other publicly-owned buildings. This is accomplished through methods such as planning and the creation of setback zones for properties at risk, the relocation of buildings, buy-back and buy-out programs for properties, and buy-out and rental programs for houses (Griggs & Reguero, 2021). This research paper evaluates the benefits and drawbacks of various solutions to address coastal erosion along the diverse landforms and geographies of the California Coast. Feasible solutions are categorized into three main types: hard solutions, soft solutions, and managed retreat. While not every landform type may have an exact or ideal solution, this analysis aims to identify the most effective strategies for different coastal environments.

Methods

This research paper utilizes the literature review methodology by analyzing primary research and other online studies. Published online sources were found from Google Scholar, California Coastal Commission, National Academies Press, National Geographic, NOAA, United Nations, and the US National Park Service. These sources were incorporated into the following analysis. Based on the various sources used as evidence or references, this paper draws conclusions about the efficacy and potential of proposal conservation solutions. This approach allows me to build upon and uniquely contribute to the topic in accordance with other scholars' work on the matter.

Results

Sandy beaches

Figure 1

A sandy beach in Laguna Beach, CA

Note. From Strauss, 2022.

Sandy beaches (see Figure 1 above) extend more than one-third of the global coastline and hold important socioeconomic values in terms of recreation, tourism, and ecosystem services (Vousdoukas et al., 2020). Population density tends to be higher near the coast and current projections indicate that trends of coastward migration, population growth, and urbanization will continue (Vousdoukas et al., 2020). Increased shoreline erosion and flooding in low-lying areas from rising sea levels may threaten natural resources and human infrastructure (Heady et al., 2018).

Due to the risk posed by rising sea levels to sandy beaches, their vulnerability remains a concern as sea level rise may worsen in future years. In an assessment conducted by the California State Coastal Conservancy and The Nature Conservancy, the Vulnerability Index is utilized to describe a relative index of nature's ability to respond and adapt to sea level rise (Heady et al., 2018). This assessment found that at least half of the sandy beaches with facilities had high vulnerability in 9 out of the 15 outer-coastal counties, including all of the heavily populated counties (Los Angeles, San Diego, San Francisco, San Mateo, Orange & Ventura). Los Angeles County tops the list with 88% of its sandy beaches with facilities having high vulnerability (Heady et al., 2018). Numerous California coastal counties are categorized as having high vulnerability, demonstrating the need to consider more comprehensive solutions.

To start, hard solutions are not an appropriate solution for responding to and managing sea level rise on sandy beaches. The implementation of hard solutions, such as seawalls or levees, will not be efficient in mitigating sea level rise because the armoring structures can interrupt the migration of beaches over the long-term and accelerate the loss of the remaining beach left (California Coastal Commission, 2018). This is because the wave energy is reflected and not absorbed by the seawalls, leading to increased erosion. Armoring structures negatively impact the state of sandy beaches and adjacent areas, proving to be an inefficient solution. Further, according to Lewis (2023), armoring structures can take up beach space and reduce beach access, which minimizes the full potential sandy beaches provide to patrons, the community, and the economy. As sandy beaches provide a space for tourism and outdoor recreational activities, both of which are prevalent on the California Coast, armored structures may inhibit the function of the beaches and what resources provide. Due to the multiple drawbacks posed by implementing hard solutions on California's sandy beaches, they are not an effective solution for mitigating risk.

Soft solutions may also not be a viable option to cope with the effects of sea level rise for sandy beaches. Soft solutions focus on restoration and mitigating erosion, such as beach nourishment. Beach nourishment, or sand nourishment, on beaches is often used to restore, build up elevation, or expand beach width (Martin & Adams, 2020) using imported sand from other locations. According to Martin & Adams (2020), beach replenishment is now the preferred option for short-term stabilization of eroding coastlines in the United States. In fact, projects in Oceanside, a city in Southern California, found that frequent repetition of sand nourishment and harbor dredging (removal of sediment below the water) may degrade the habitat by not allowing sufficient time for the ecosystem to recover. There have been dozens of sand replenishment projects along the coast of California over the past decades (Martin & Adams, 2020), which have all remained temporary solutions. Lewis (2023) finds that the replacement sand can be washed away in a single storm, causing serious environmental concerns. In considering the negative effects that sand replenishment, a soft solution, brings about on the environment, a more permanent solution is needed to address sea level rise on sandy beaches.

Among the three proposed solutions, managed retreat offers the best, long-term solution for managing sea level rise on sandy beaches. The purpose of managed retreat is to protect coastal assets and people through abandonment or relocation (Griggs & Reguero, 2021). Although managed retreat may seem expensive initially, as it involves the cooperation of property owners, the government, planners, and politicians (Lewis, 2023), Bragg et al. may suggest otherwise. Managed retreat, in the long term, is likely to be less costly than the maintenance of hard infrastructure or the eventual deconstruction of eroded property. As hard solutions can provide a false sense of security, increased property development may occur along the coast, inducing future problems (Bragg et al., 2021). By relocating infrastructure away from vulnerable coastal areas, managed retreat reduces potential risk to impacted communities in the future. In addition, relocation of infrastructure allows for tourism and recreational activities to continue and flourish.

Managed retreat has been successful in many projects on California beaches. For example, the Surfers' Point Managed Shoreline Retreat project in Ventura moved a parking lot inland,

restoring the beach area (California Coastal Commission, 2024). The project was successful in reducing erosion, improving habitat, and supporting recreational opportunities in the area. Another example of managed retreat success was the Pacifica State Beach project in 2005 which resulted in a reduction of flood hazards, an increase in functioning wetland habitat, and expanded recreational opportunities (Kershner, 2024). As proven through these examples, managed retreat has been successful in addressing sea level rise for sandy beaches in the past, and will be successful in providing a long-term solution for sandy beaches.

Bluffs

Another prominent landform along the California coast are bluffs. According to the National Academies Press (2012), 72 percent of the California coastline is characterized by these steep, actively eroding sea cliffs. This research paper will focus on bluffs; however, it is important to first distinguish differences between bluffs and cliffs. National Geographic (2024a) defines a bluff (see Figure 2 below) as a wide, rounded cliff, usually bordering rivers, beaches, or other coastal areas. On the other hand, a cliff (see Figure 3 below) is defined as a mass of rock that rises high (National Geographic, 2024b). According to these definitions, all bluffs are cliffs, but not all cliffs are bluffs.

Figure 2

A bluff in Southern California

Note. From Skibba, 2021.

Figure 3

A cliff in San Mateo County, California

Note. From UC San Diego Today, 2022.

Bluffs are extremely susceptible to weathering and erosion from factors such as wind, water, and ice (US National Park Service, n.d.). Overtime, the bluffs are broken down into particles including clay, silt, and fine sand (US National Park Service, n.d.), demonstrating the vulnerability bluffs have to these natural forces. Bluffs are formed into sediment from loose materials like clay, sand, and gravel, while cliffs are vertical masses of rock. As a result, bluffs are more subject to erosion and the dangers of sea level rise. For example, when oceanfront bluffs are exposed to violent waves and high tides, they become more susceptible to erosion. This erosion can lead to landslides and the geologic instability of the bluffs, impacting homes, infrastructure, Highway 1, and other roads and public utilities (California Coastal Commission, 2024).

Soft solutions are less effective in combating sea level rise and erosion to the coastal bluffs in California. Research has shown that beach nourishment, a soft solution, is not a sustainable strategy to mitigate sea level rise and erosion in California, as there are significant negative ecological consequences of beach nourishment (Griggs & Patsch, 2019). There have been several instances where beach nourishment has been attempted to reduce erosion and wave energy, but these have proven to be unsuccessful for coastal bluffs in California. One example is the San Diego County Projects 1 and 2, also known as the Regional Beach Sand Projects (RBSP) I and II, which were implemented in various San Diego beaches (Griggs & Patsch, 2019). During the RBSP I and II, sand was placed in front of bluffs in an attempt to reduce wave energy and erosion (Griggs & Patsch, 2019). In these instances, 2.6 million cubic meters of sand was added to the county's beaches, most of which was eroded during the first year after nourishment (Griggs & Patsch, 2019). Especially in areas with high wave energy, bluffs are constantly being undercut by the waves, increasing their susceptibility to collapse due to the erosion at the base of the bluffs. The RBSP supports the idea that beach nourishment is only a temporary solution, which was largely unsuccessful in preventing the bluffs from eroding. During RBSP II, the beach nourishment at Solana, Moonlight, and Batiquitos beaches did not protect the bluffs from sea level rise and erosion, as much of the sand from the beach was gone within the initial 6 months (Griggs & Patsch, 2019). Therefore, as these projects show, soft solutions

are ineffective for responding to sea level rise and bluff erosion. To add on, managed retreat also proves not to be the best solution for California's vulnerable bluffs because it has the potential for more community resistance, operational challenges, and regulatory government issues due to the upfront investment (Griggs & Patsch, 2019).

In order to protect this valuable infrastructure, implementing a solution is necessary. Out of the options of soft solutions, hard solutions, and managed retreat, hard solutions are the most effective solution for bluffs in responding to sea level rise and erosion. Hard solutions have been implemented successfully in several locations along the California coast, protecting vulnerable infrastructure atop bluffs. For example, at Goleta Beach in Santa Barbara County (see Figure 4 below), rock revetments, or sloping structures made up of boulders along the coastline, have been installed to protect the park from future damage, such as the storm season and high-wave energy events, proving to be an effective solution (Martinez-Pogue, 2021).

Figure 4

Goleta Beach rock revetments

Note. From Dressler, 2021.

This placement of the revetments not only protect the bluffs from violent wave action, but also from further erosion, as the large rocks reduce the impact of the energy from the waves. Another instance where hard solutions have been utilized is in Pacifica, CA. Replacing rock revetments with vertical seawalls increased public access to sandy beach areas, where public access was made limited by the rock revetments (Duff, 2022). Additionally, the project will improve resiliency to sea level rise and protect critical city infrastructure, with the seawall projected to last for at least 30 years (Duff, 2022). In this situation, the seawalls would decrease the oncoming wave energy to the underlying cliffs, further reducing erosion. Overall, hard solutions prove to be an efficient solution to mitigate the effects of sea level rise.

Estuaries

Figure 5

The San Diego River Estuary in California

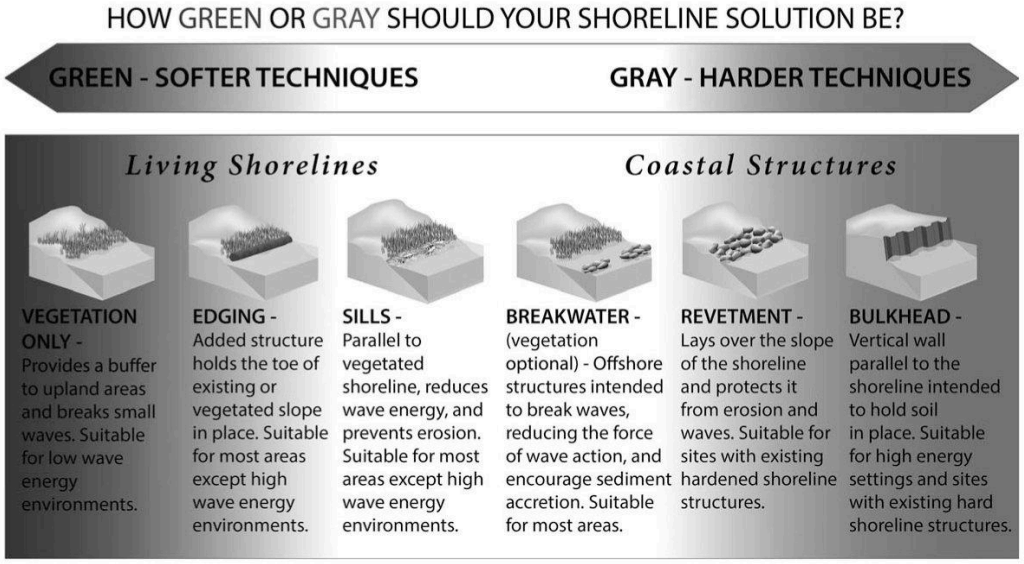
Note. From Labrador, 2022.

An estuary is a body of brackish water where freshwater, such as a river, meets the sea (NOAA, 2008). Sea level rise leads estuaries to become inundated, causing erosion and the displacement of wildlife. Out of the three solutions to sea level rise—hard solutions, soft solutions, and managed retreat—the best solution for estuaries are soft solutions. For example, one of the biggest estuaries in the United States is California's Bay Delta estuary, which has bays and channels connecting the San Francisco Bay to the Sacramento-San Joaquin River Delta (National Academies Press, 2012). As soft solutions focus on restoring natural processes and reducing erosion (Sutton-Grier et al., 2015), this includes the rehabilitation of oyster reefs and eelgrass beds as soft solutions. With climate change and rising sea levels, the vulnerability of estuaries increases, illustrating the need for soft solutions.

Living shorelines are protected and stabilized shorelines that are made up of natural materials such as plants, sand, or rock (NOAA, 2019). These shorelines would be classified as soft solutions. These shorelines may also include vegetation, edging, and sills (NCCOS, 2018). They are suitable for most areas except high wave energy environments. Estuaries, such as the California Bay Delta Estuary in Northern California, do not fall into the high wave energy category due to their geographical location. The NCCOS (2018) encourages that living shorelines be implemented in sheltered areas to preserve habitats and improve ecosystems, which is consistent with estuarine characteristics and location.

Figure 6

Living shorelines versus coastal structure



Note. From Griggs & Patsch, 2019.

One instance where these soft solutions have been implemented is The San Francisco Living Shorelines Project, which began in the California Bay Delta estuary in 2012 (Judge et al., 2017). This project examined how oyster reefs and eelgrass beds can reduce erosion, protect the shoreline, and maintain natural coastal ecosystems (Judge et al., 2017). It revealed that oyster reefs and eelgrass beds can substantially increase food resources and biodiversity, as well as reduce wave energy by 30% (Judge et al., 2017). As demonstrated by the implementation of these soft solutions in California's Bay Delta estuary, these approaches offer natural protection against erosion and increase the shoreline's resilience. Additional examples of soft solutions successfully being put in place in California estuaries include the Bolsa Chica Lowlands Restoration Project (CA State Lands Commission, n.d.), the Humboldt Bay Living Shorelines (Humboldt County, CA, n.d.), and the Tijuana River Estuary Sediment Management (Tijuana River Sediment Management Work Plan TRNERR Advisory Committee, 2023). These all have restored the natural environment and habitat through restoration projects and adaptive management. This shows that soft solutions have been successful in improving the estuarine habitats in spite of sea level rise and erosion.

In addressing these climate problems, managed retreat still needs to be considered when sea level rise and erosion become irreversible to estuaries. When worse comes to worse, there would be no other options other than to retreat inland. However, living shorelines remain effective in combating sea level rise at the current moment, illustrating that soft solutions are the best solution in addressing sea level rise for estuaries.

Discussion

This paper proposes a single, most logical solution for each of the three landforms: sandy beaches, bluffs, and estuaries. These solutions have been determined based on the review of recent literature and case studies from around California, which were used for analysis and discussion. This paper focuses on the most pertinent factors for each landform and its proposed solution, rather than providing comprehensive analysis at every contributing element. Given that hard and soft solutions are temporary, managed retreat would still remain the most reliable mainstay in the long term. Additional research could still be done on this topic to address the limitations in the current review. This paper did not address factors such as cost, politics, the economy, policymaking, and public opinion. It is still unclear whether or not future greenhouse gas levels are projected to remain constant or change, which highlights the complexity of the climate change issue and the difficulty of determining an encompassing solution for each landform.

Conclusion

Seeing that sea level rise impacts various environments and landforms, the solutions provided for each should involve a targeted approach. This review paper has illustrated three different landforms above—sandy beaches, bluffs, and estuaries—each with their own proposed solution that works for each area's unique characteristics. Ultimately, this paper finds that managed retreat is the most ideal solution for sandy beaches, hard solutions the most optimal for bluffs, and soft solutions the most effective for estuaries. Looking towards the future, the hope is that researchers continue to refine and expand solutions as they study the environment more and more. In addition, finding ways of preventing and slowing the source of the problem in the first place is necessary, which is the growing rate of climate change and its adverse effects.

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