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The California Coast and Living Shorelines—A Critical Look

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Abstract: California and most other coastlines around the world are being impacted by both long-term sea-level rise and short-term extreme events. Due to California's long and intensively developed coastline, it is an important area for evaluating responses to these challenges. The predominant historic approach to coastal erosion in California and globally has been the construction of hard coastal armoring such as seawalls and rock revetments. The concept of living shorelines—defined as using natural elements like plants, sand, or rocks to stabilize the coastline—has been widely proposed as a soft or green response to coastal erosion and flooding. However, these approaches have very limited application in high-energy environments such as California's 1100-mile-long outer coast and are not realistic solutions for protection from wave attack at high tides or long-term sea-level rise. Each of the state's coastal communities need to identify their most vulnerable areas, develop adaptation plans, and plan eventual relocation strategies in response to an accelerating sea-level rise.

Keywords: living shorelines; coastal protection; shoreline erosion

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1. Introduction

For virtually the entire history of human civilization, roughly the past 6000 years, global sea level was relatively stable. Many of the earliest human settlements were situated on coasts for well-known reasons including an abundant food supply, a moderate climate, and access to the ocean. Small settlements became villages, which evolved over time into towns and then cities. Some of these eventually grew into the megacities of today (defined as having over ten million people). At present, fourteen of the world's 17 largest cities are on coasts. However, the essentially stable sea level of the past 6000 years was altered beginning about 150 years ago due to the industrial revolution and the increasing use of fossil fuels; first coal, followed by oil and then natural gas [1]. The combustion of these fuels continued to increase the greenhouse gas content in the atmosphere, with the carbon dioxide concentration now about 50% above pre-industrial levels (421 ppm; [2]). Approximately 80 percent of the world's energy is now provided by fossil fuels [3].

The continuing warming of the planet has melted land ice and raised sea water temperature, both contributing to higher global sea levels [2–4]. Countless coastal towns and cities around the world that were built at or very close to the ocean are now experiencing gradually rising seas. These towns and cities are also impacted by short-term extreme events such as hurricanes and cyclones, high tides and storm waves, as well as the occasional tsunami. The impacts of a continuing and accelerating rise in sea level, particularly on low-lying shorelines such as the Atlantic and Gulf coasts of the United State and a number of Pacific Island states, are becoming increasingly clear. Short-term elevated water levels from extreme high tides, as well as storm waves, ENSO (El Niño Southern Oscillation) events on the Pacific coast, and hurricanes along the east and Gulf coasts, have led to increasing coastal storm damage and shoreline erosion in recent decades. While our projections of future sea-level rise are becoming more accurate [5] until at least mid-century, short-term extreme events will be more damaging; although the trends are becoming clearer, there is not yet complete agreement on whether the frequency and magnitude of these extreme events is increasing.

Adaptation options for responding to elevated sea levels and shoreline recession, whether short or long-term, are limited, and many coastal cities around the world are now struggling with future scenarios and risks to oceanfront development, whether public infrastructure or private development. While armor of one type or another (primarily seawalls and rock revetments) or beach nourishment have been the dominant historical approaches for dealing with shoreline recession or coastal erosion, the costs and impacts of these approaches have been questioned in recent years [6,7] with increasing proposals or recommendations for the use of living shorelines. This paper offers a critical assessment of the feasibility of using living shorelines along the high-energy California coast. What are living shorelines? And what do we know about their effectiveness? And where may they actually be appropriate?

2. The California Coast—Responses to Long-Term Sea-Level Rise and Short-Term Extreme Events

California has the second longest shoreline in the United States after Alaska, is the most populous state and also contains many miles of developed coast, which makes it an appropriate place to evaluate the challenge of how to respond or adapt to both long-term sea-level rise and short-term extreme events along the shoreline and take a realistic look at the available options. In recent years, the concept of living shorelines has been advanced in many areas as a response to coastal flooding and shoreline recession [8–10]. Are living shorelines a realistic solution for the coast of California?

While California's population has decreased over the past several years, the state still is the most populous in the nation, being home to about 39 million people in 2023 [11]. Although the state's 19 coastal counties only account for 22 percent of the state's land area, they are home to 68 percent of its population or 26.5 million people. They are not distributed evenly, however, with the three southernmost counties alone (San Diego, Orange, and Los Angeles) home to 41.8% of the state's residents (16.3 million people), and those counties around San Francisco Bay containing another 17.8% of California's population [11].

Large portions of the state's 1100-mile (1760 km) coastline have been intensively developed, with oceanfront property typically being the costliest in California. Sea-level rise and coastal storms, however, do not differentiate between homes or properties of different values, as the El Niño winters of 1982–1983, 1997–1998, and 2015–2016 made abundantly clear. The only difference may be in the armoring that individual coastal property owners may have been able to afford and obtain approval for.

We learned about 25 years ago that the offshore Pacific Ocean of the California coast undergoes an oscillating pattern of climate variability in the ocean–atmosphere system over periods of several decades determined from sea surface temperature anomalies between warmer (or positive) and cooler (or negative) intervals, termed Pacific Decadal Oscillations (Figure 1) [12]. The warmer or positive periods are characterized by higher ocean surface water temperatures with greater evaporation rates and subsequent rainfall, which can generate flooding and landslides in coastal regions. These warmer periods also experience more frequent and severe El Niño events with coastal storms and more energetic and damaging waves along the shoreline, typically approaching from a more westerly or southwesterly direction which have been particularly damaging to south or southwest facing coasts.

The period from about the mid-1920s to the mid-1940s along the California coast was dominated by warmer ocean surface conditions and a generally stormier and more damaging coastal climate (Figure 1). By about 1945, however, the PDO transitioned to a generally cooler and calmer period. This coincided with the end of World War II when California's population rapidly increased. The state's population grew from 9.34 million in 1945 to 22.35 million in 1977, a 240% increase. In order to meet the housing needs of all those new residents, the home construction industry boomed, particularly in southern California. In addition to hundreds of new housing tracts, much of the coast was also subdivided and homes were built on what appeared at the time to be stable and safe cliffs, bluffs, even sand dunes and the beaches themselves. Those ocean view homes and properties became increasingly valuable in subsequent years, but as their owners discovered, also more vulnerable to coastal storm waves and high tides.

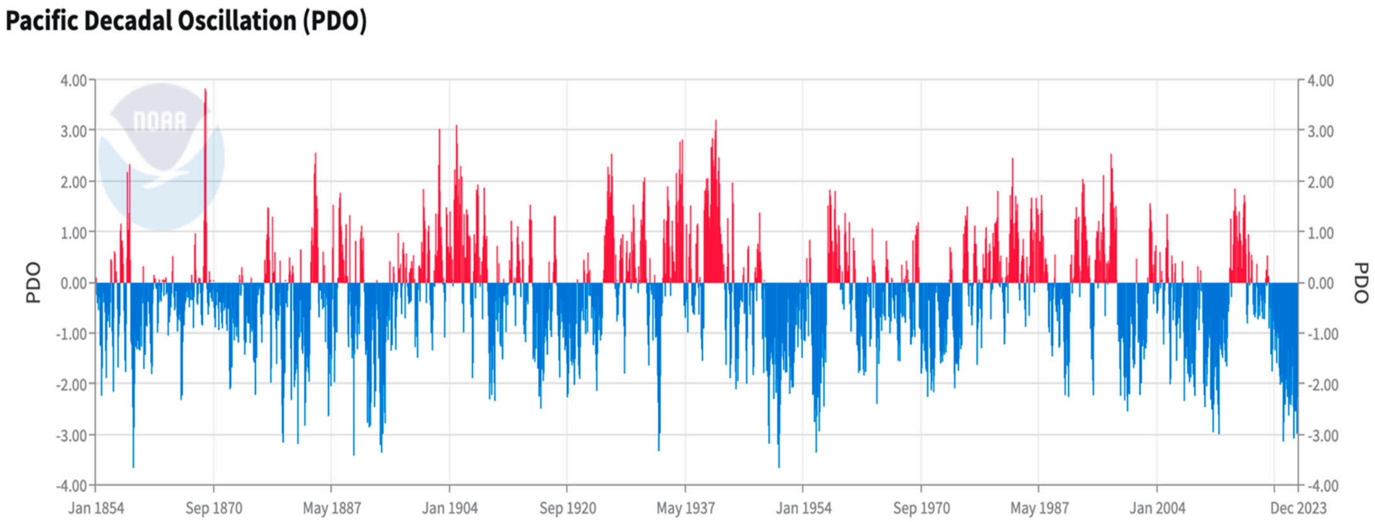

Figure 1. Pacific Decadal Oscillation Index from 1854–2023. Vertical axis is sea surface temperature anomaly in degrees C. Red indicates warm or positive PDO period and blue indicates cool or negative period. (NOAA https://www.ncei.noaa.gov/access/monitoring/pdo/ (accessed on 10 January 2024), 2023).

In the late-1970s, the PDO switched rather abruptly back to a warm and stormier cycle with more frequent and powerful El Niño events (see Figures 1 and 2). Many of those homes that had been built on the coast or along the shoreline were now threatened by elevated sea levels that accompany the warmer water of an El Niño, as well as larger storm waves, typically arriving from the west and southwest, rather than the more frequent arrival from the northwest. Damaging winters along the shoreline arrived in 1978, 1982–1983, 1997–1998, and 2015–2016, which changed perceptions about the wisdom and risks of living on the edge, although, somewhat surprisingly, have not yet diminished the values of oceanfront homes.

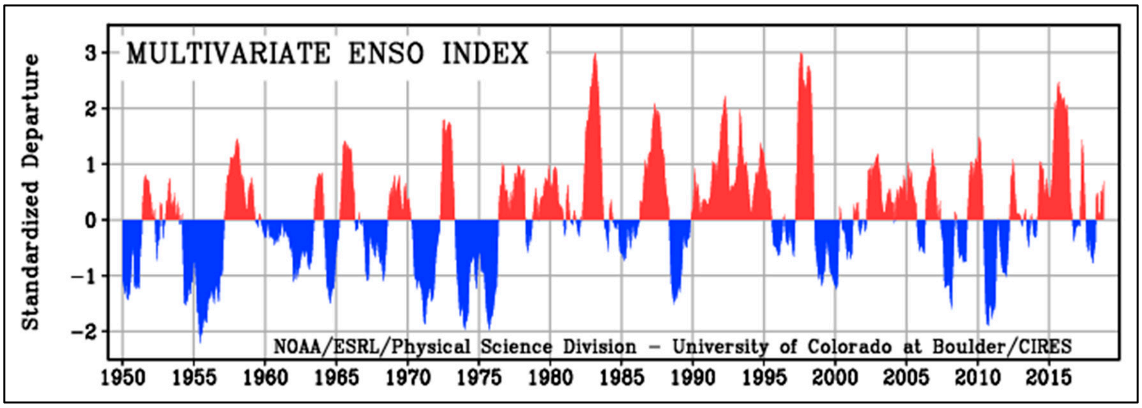

Figure 2. Multivariate ENSO (El Niño-Southern Oscillation) Index plotted as departure from the 1950–2018 mean. The Index (MEI) is based on the six main observed variables over the tropical Pacific, including sea surface pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness of the sky. Red indicates El Niño events (https://www.psl.noaa.gov/enso/mei.old (accessed on 10 January 2024), 2023).

The typical historic response from coastal homeowners, as well as local, state, and federal government agencies in California, when threatened with coastal erosion or flooding has been to protect private property and public infrastructure with some sort of coastal armoring, typically concrete seawalls or rock revetments. While there were a few large coastal armoring projects built early in the last century—the massive O'Shaughnessy seawall constructed in 1928 along San Francisco's Ocean Beach, for example—for the most part, armoring on a large scale did not begin in earnest until the 1970s. Wave attacks on shoreline developments began to present serious threats to public infrastructure and those homes built on cliffs, bluffs, dunes, and beaches following the calm period that persisted along the California coast from the mid-1940s until about 1978. Damages to coastal properties and homes led to a significant increase in the number of permit applications to the California Coastal Commission for some type of protection, followed by the construction of an increasing number of coastal protection structures.

In 1971, only 27.1 miles of the entire state's coast had been armored (2.5%), with 17 miles of that being in the four most densely developed southern California counties (Ventura, Los Angeles, Orange, and San Diego; [7]). By 1998, after two major El Niño winters, this had increased by 400%; 110.3 miles of the state's shoreline, or 10.3%, had been armored. A decade later, as more homes were threatened, armor coverage continued to expand so that by 2018, 148.7 miles had been protected, or 13.8% of the entire 1100 miles of state coastline. For the four most populated and developed southern California counties, these numbers reached 88.1 miles or 37.8%—over a third of the entire 233 miles of shoreline had been protected with some type of structure by 2018 (Table 1; Figure 3) [7].

Table 1. Progressive increase in the length and percentage of armoring along the shoreline of California's coastal counties in 1971, 1998, and 2018 [7]. Numbers across the top in parentheses refer to the sources of information listed below the table. * Indicates the four southern California Counties.

Location	**Total Shoreline (1)**	**1971 Armor (2)**	**1998 Armor (3)**	**2018 Armor (4)**	**1971 Armor (2)**	**1998 Armor (3)**	**2018 Armor (4)**
	miles	**miles**	**miles**	**miles**	**Percent**	**Percent**	**Percent**
Del Norte County	45.40	1.20	0	8.06	2.64%	0.00%	17.76%
Humboldt County	121.60	0.00	0	3.67	0.00%	0.00%	3.02%
Mendocino County	122.20	0.00	0	1.18	0.00%	0.00%	0.97%
Sonoma County	62.50	0.00	0.01	0.76	0.00%	0.02%	1.22%
Marin County	70.20	1.00	1.4	3.30	1.42%	1.99%	4.70%
San Francisco County	8.40	1.20	1.4	2.26	14.29%	16.67%	26.85%
San Mateo County	55.90	0.00	6.3	5.11	0.00%	11.27%	9.14%
Santa Cruz County	41.80	2.90	8	10.20	6.94%	19.14%	24.41%
Monterey County	111.30	0.00	0.9	6.48	0.00%	0.81%	5.82%
San Luis Obispo County	92.30	0.30	0.6	6.74	0.33%	0.65%	7.30%
Santa Barbara County	109.80	3.50	14	12.87	3.19%	12.75%	11.72%
Ventura County *	41.20	11.20	18.7	23.55	27.18%	45.39%	57.16%
Los Angeles County *	73.80	2.00	23	22.48	2.71%	31.17%	30.46%
Orange County *	41.90	0.20	12.2	16.28	0.48%	29.12%	38.86%
San Diego County *	76.10	3.60	23.8	25.78	4.73%	31.27%	33.87%
Totals	1074.40	27.10	110.31	148.72	2.52%	10.27%	13.84%
Southern California * Totals	233.00	17.00	77.7	88.09	7.30%	33.35%	37.81%

Key: 1. From Boating and Waterways 1977 Report: Assessment and Atlas of Shoreline Erosion along the California Coast; 2. From 1971 National Shoreline Study California Regional Inventory, US Army Corp of Engineers; 3. From 1998 Aerial Oblique Digital Photography Transferred to GIS (Californiacoastline.org); 4. From 2015–2018 Aerial Oblique Digital Photography Transferred to GIS (Californiacoastline.org and Google Earth).

Figure 3. Continuous seawalls along the back beach in Encinitas, northern San Diego County, where 34% of the entire county shoreline has been armored (Kenneth and Gabrielle Adelman, California Coastal Records Project, Californiacoastline.org).

The California Coastal Act of 1976 established a Coastal Commission of twelve politically appointed individuals to make decisions on coastal land use and permit issues and their consistency with the Coastal Act. The legislation also included policy language regarding coastal erosion and protection [13]. Over time, however, with each new permit request, concerns have been increasingly raised about the impacts of armoring on the coast. The potential impacts of hard structures (seawalls and rock revetments or rip rap) on the shoreline are now well understood and include visual effects, impoundment or placement losses from placing a structure on the beach, reduction of beach access, loss of sand supply from previously eroding bluffs or cliffs, and passive erosion [14]. With nearly 14% of the entire coast of California now armored, including 37.8% of the shoreline of the southern California coast [7], these have become very real concerns to the Coastal Commission.

3. Living Shorelines

The creation of living, organic, or green shorelines has been put forward in recent years as a potentially less impactful response to coastal erosion or recession than hardening the coastline with concrete seawalls or rock revetments. From a global perspective, living shorelines would include creating, protecting, or preserving natural habitats and their ecosystems, coral reefs, mangroves, seagrass, and wetlands, for example. This concept seems to have originated in tropical and subtropical environments where both coral reefs and mangroves are important in stabilizing shorelines and buffering coasts from direct wave attack [15]. Living shoreline, like the word resilient, seems to provide a very appealing answer to the issues of shoreline recession and/or flooding that many coastal communities and cities in California and around the world are facing today.

An important starting point in any discussion of this potential solution or approach is to be clear on just what is meant by this term, as different definitions or interpretations seem to be used. A sampling of several of these definitions include the following:

- National Oceanic and Atmospheric Administration (NOAA)—A living shoreline is a shoreline management practice that provides erosion control benefits; protects, restores, or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural organic materials [16]
- NOAA Fisheries—A living shoreline is a protected, stabilized coastal edge made of natural materials such as plants, sand, or rock. Unlike a concrete seawall or other hard structure, which impede the growth of plants and animals, living shorelines grow over time. Natural infrastructure solutions like living shorelines provide wildlife habitat, as well as natural resilience to communities near the waterfront. Living shorelines are sometimes referred to as nature-based, green, or soft shorelines [10].
- Virginia Institute of Marine Sciences (VIMS)—Living shorelines are nature-based approaches for shoreline protection. These stabilization techniques not only protect shorelines and infrastructure, but they also conserve, create or restore natural shoreline habitats and ecosystem services [17].
- National Geographic—A living shoreline is a way of managing coastal areas to protect, restore, or enhance the habitat. This is done through the placement of plants, stone, sand, and other materials [18].

We now also have the power of ChatGPT-3.5 that can do searches of vast amounts of on-line information and produce summaries or definitions within seconds. The following is just one of several that were instantly generated, with each being slightly different:

- "Living shorelines are coastal management approaches designed to protect and stabilize shorelines using natural and nature-based elements, in contrast to traditional "hard" or engineered structures such as seawalls and bulkheads. These approaches aim to create resilient and sustainable shoreline protection while promoting the health of the environment and natural ecosystems. Living shorelines work with the natural processes of erosion and sediment movement to reduce wave energy and erosion while maintaining or enhancing the ecological function of the shoreline."

Commonalities in these definitions include the objectives of erosion control and protecting, restoring, or enhancing habitat. In addition, most of these definitions also include the use of plants, sand, or rock. Sand and rocks seem to significantly expand the definition beyond what many might perceive as a living or green shoreline. Do these definitions mean that rip rap or a rock revetment is considered a living shoreline (Figure 4)? Does sand and rock actually "grow over time"? This is an important element to be clear on when living shorelines are being proposed or discussed.

Where protected and preserved, coral reefs and mangroves have provided important natural or living shoreline protection, although there are also many locations where reefs and mangroves have been either removed or destroyed, often for aquaculture, shoreline access, marinas and harbors, and a variety of tourist-serving facilities. There have now been a number of landmark studies on the importance of these naturally occurring living shorelines that have also calculated their economic benefits, which has led them to be considered or recommended for coastlines well outside of the tropical or subtropical ranges of coral reefs and mangrove forests [19–21].

What does not always seem to be appreciated or understood, however, is that these prime examples of the importance and effectiveness of living shorelines are their geographic restrictions and the energy conditions that they can withstand. Mangroves, for example, only grow in sheltered tropical and subtropical coastal areas, which in general are between latitudes of 25 degrees north and south of the equator, although these can vary somewhat depending upon local ocean climate and water temperatures (Smithsonian). The closest mangroves to California, for example, are distributed from the southern tip to the center of the Gulf of California, mostly in small bays, estuaries, and isolated pockets.

Figure 4. About half of the three miles of West Cliff Drive in the city of Santa Cruz has been armored with rip rap. Does this rock constitute a living shoreline (Kenneth and Gabrielle Adelman, California Coastal Records Project, Californiacoastline.org)?

Reef building corals have similar temperature constraints and grow optimally in water temperatures between 73° and 84 °F (23–29 °C) and cannot tolerate temperatures below 64 °F (18 °C), which generally means between 30 degrees north and south of the equator [22]. For reference, the southernmost part of California is at 32.5 degrees north, but because of the cool offshore California current, historical ocean water temperatures off the southern end of the state (San Diego) get as cold as 57 °F (14 °C) in the winter months. The closest recognized coral reef to the south is at the tip of the Baja California peninsula, about 800 miles south of the border with California. Mangroves and reef building corals do not grow along the California coast because water temperatures are too low.

Another consideration for the feasibility of utilizing living (or green) shorelines along California's outer coast is the typical energy conditions. The 1100-mile California coast is frequently exposed to very high wave energy, which does vary seasonally, as well as from north to south, and also as a function of the orientation of the coastline and any offshore barriers, such as the Channel Islands.

The issue or question of appropriate energy conditions suitable for living shorelines is described in a NOAA report [23] and illustrated in a NOAA graphic (Figure 5), which depicts a range of shoreline protection approaches ranging from green to gray. This is a useful and simplified way to frame the issue of where living shorelines may be appropriate to consider or encourage and where they would be inappropriate.

Figure 5. Conditions suitable for Green vs. Gray shoreline solutions [18].

What is clear but not always acknowledged when living shorelines are proposed or considered in any alternative analysis for shoreline protection is the distinction spelled out in this graphic between Living Shorelines (Green—Softer Techniques) and Coastal Structures (Gray—Harder Techniques). The living or green shorelines are "suitable only for low wave energy environments" [23]. The increasingly gray or harder techniques are the options proposed for those locations exposed to high wave forces. The entire 1100 miles of California's exposed outer coastline is, at least seasonally if not year-round, a high wave energy environment.

There are certainly low-energy estuarine and lagoonal environments along the state's coastline, including Humboldt Bay, San Francisco Bay, Elkhorn Slough, Morro Bay, Agua Hedionda, Batiquitos Lagoon, and San Diego Bay, to name a few of the larger ones. These are locations where living shorelines have or can be restored and protected as defense measures against sea-level rise, for at least the near-term future. However, many of our southern California estuaries and bays, such as San Diego Bay, Newport Bay, Ballona Wetlands, and others, as well as San Francisco Bay on the central coast, are surrounded or backed by development or infrastructure, so there is a limit to how much future sea level can be accommodated (Figure 6).

Another factor in the consideration of the appropriateness of a living shoreline is the shoreline topography or landforms. As a result of the state's active tectonic setting, the great majority (72 percent, or about 790 miles) of the California coast consists of eroding bluffs or sea cliffs [24]. Of these 790 miles, about 650 miles (~59%) consists of relatively low-relief bluffs typically eroded into uplifted marine terraces (Figure 7); the other 140 miles (~13%) consists of high-relief cliffs and coastal mountains (Figure 8). The remaining 310 miles or 28 percent of the coastline is of low relief and relatively flat. These include the wide beaches, sand dunes, bays, estuaries, lagoons, and wetlands, which form many of the state's coastal recreational environments and parkland (Figure 9).

Figure 6. West side of San Francisco Bay showing Foster City and end of San Mateo Bridge with little room for shoreline migration (Google Earth image, 2023).

Figure 7. Eroding coastal bluff fronting the lowest marine terrace at Solana Beach, northern San Diego County (Kenneth and Gabrielle Adelman, California Coastal Records Project, Californiacoastline.org).

Figure 8. Steep mountainous coast in the Big Sur area of Central California with Mud Creek landslide (May 2017- Jon Warrick, U.S. Geological Survey).

Figure 9. Beach front development backed by wetlands at Imperial Beach (Kenneth and Gabrielle Adelman, California Coastal Records Project, Californiacoastline.org).

4. Coastal Dunes and Living Shorelines

If rock revetments are considered as living shorelines, which seems somewhat questionable as they are certainly not alive and growing, there are already many miles of these structures along the state's coast. In terms of actual living vegetation, however, the main efforts along California's outer coast have been focused on planting to stabilize existing coastal dunes [25]. There are a number of large, well-known dune fields along the state's outer coast, but they have some specific requirements in order to form [19]. These include the following: (1) a large supply of fine-grained sand; (2) a dominant onshore wind direction; (3) a wide flat beach so that sand can dry out between tides and can be moved by the wind; and (4) low relief topography inland of the beach where sand can be transported and accumulate.

Field studies have shown that the roots of dune vegetation tend to bind the sand together which helps to keep sand grains from blowing or washing away. The exposed portions of vegetation also act to reduce the wind velocity near the ground surface, thereby diminishing the potential for the wind to transport or move the sand. These are the reasons why efforts to restore degraded sandy shorelines and stabilize coastal dunes have often turned to planting dune vegetation or the construction of dune fences as solutions.

However, recent research using the very large flume at Oregon State University (230-feet long) produced results that were somewhat contrary to conventional thinking [26]. The researchers compared 19 h of wave impacts on a dune that had been vegetated for six months with those on a bare dune. As wave heights in the flume were increased to 3.3 feet (one meter), both vegetated and bare dunes formed near-vertical scarps, although the scarp on the vegetated dune formed several hours earlier, moved farther inland, and was twice as high as the scarp on the bare dune. From observations and measurements during the experiments, wave energy periodically deposited sand on the dune and then eroded it again. Without any vegetation, larger waves could deposit sand on top of the bare dune. Where plants were present, however, waves could not runup as much, so the water percolated into the sand. This pore water made the sand more prone to erosion when subsequent waves washed up the dune. On the unvegetated dune, the wave runup infiltrated over a larger area, so had less of an effect.

While planting may help to stabilize dunes and reduce sand transport during moderate weather, during severe wave conditions (hurricanes along the Atlantic or Gulf Coast, or when large waves occur at high tides along the California coast), dunes, whether vegetated or not, can erode quickly. Vegetated dunes along the central and southern Monterey Bay shoreline have been repeatedly eroded back during large El Niño events, threatening coastal homes and historically leading to the construction of coastal armoring (Figures 10 and 11).

Even along the low-relief, usually less energetic Atlantic coast of the U.S., vegetated dunes can be eroded quickly during periods of large waves, whether tropical storms, hurricanes, or nor'easters (Figure 12). Dunes are wind-blown piles of unconsolidated sand and are highly susceptible to recession when impacted by large waves, and as sea levels continue to rise, waves will reach coastal dunes more frequently, accelerating the erosion. There is a limit to what dunes, whether vegetated or not, can withstand and how much sea level rise they can resist.

Figure 10. Erosion of a vegetated dune at the Pajaro Dunes development along the central Monterey Bay shoreline during the severe El Niño of January 1983.

Figure 11. Rip rap revetment placed against eroded dune face at Pajaro Dunes (Photo April 2006).

Figure 12. Erosion of vegetated dunes at Sea Isle along the New Jersey coastline during Tropical Storm Ophelia 24 September 2023 (Courtesy of Sea Isle News-Donald Wittowski).

5. Discussion

The reality is that California's coastal communities face a challenge of increasing magnitude—and we have no clear agreed-upon or simple solutions. There is some vegetation that can thrive and stabilize or trap sediment in the state's low-energy coastal environments such as estuaries, lagoons, marshes, and sloughs. With much of the shoreline of these marginal marine environments backed by development or infrastructure along the central and south coast of California, however, there is only so much sea-level rise they can tolerate before being permanently inundated.

For the 1100 miles of the state's exposed, high-energy outer coast, with 72 percent consisting of coastal bluffs or high cliffs, a living shoreline is not a realistic solution for protection from wave attack or for adapting to long-term sea-level rise. Some of the state's shoreline communities and neighborhoods are already experiencing coastal flooding during king tides and periods of large waves (Figures 13 and 14), and many intensively developed coastal bluff and cliff areas are suffering or threatened by continuing retreat or recession.

Figure 13. Flooding of East Cliff Drive in Santa Cruz during high tide and large waves in early January 2023 (Photo: Michael Beck).

Figure 14. Flooding of Beach Drive in Rio Del Mar along the northern Monterey Bay shoreline during the 1983 El Niño.

6. Conclusions

Every coastal community, city, and county in California needs to determine its most vulnerable areas and assets and develop response and adaptation plans with thresholds for relocation or beginning the process of moving back from the shoreline [27]. Thresholds could include when sea level reaches a specific elevation, or when a street, neighborhood, or home is flooded or damaged a certain number of times during a given time period, or when the bluff edge gets to within some agreed-upon distance of a home or some public infrastructure. These will need to be community-specific decisions, and it's not too early to start these discussions with the rate of sea level rise accelerating. Even if we do not know exactly how high the sea level will be at a specific point in the future, the Pacific Ocean is rising, and we are in the way. And for the high-energy outer coast of California, there are no living shoreline solutions that are going to hold back the Pacific Ocean. The only long-term response will be to relocate those threatened structures and facilities further inland away from the shoreline.

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