Groins, sand retention, and the future of Southern California's beaches

By

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ABSTRACT

Beaches form a significant component of the economy, history, and culture of southern California. Yet both the construction of dams and debris basins in coastal watersheds and the armoring of eroding coastal cliffs and bluffs have reduced sand supply. Ultimately, most of this beach sand is permanently lost to the submarine canyons that intercept littoral drift moving along this intensively used shoreline. Each decade the volume of lost sand is enough to build a beach 100 feet wide, 10 feet deep and 20 miles long, or a continuous beach extending from Newport Bay to San Clemente. Sea-level rise will negatively impact the beaches of southern California further, specifically those with back beach barriers such as seawalls, revetments, homes, businesses, highways, or railroads.

Over 75% of the beaches in southern California are retained by structures, whether natural or artificial, and groin fields built decades ago have been important for local beach growth and stabilization efforts. While groins have been generally discouraged in recent decades in California, and there are important engineering and environmental considerations involved prior to any groin construction, the potential benefits are quite large for the intensively used beaches and growing population of southern California, particularly in light of predicted sea-level rise and public beach loss. All things considered, in many areas groins or groin fields may well meet the objectives of the California Coastal Act, which governs coastal land-use decisions. There are a number of shoreline areas in southern California where sand is in short supply, beaches are narrow, beach usage is high, and where sand retention structures could be used to widen or stabilize local beaches before sand is funneled offshore by submarine canyons intercepting littoral drift. Stabilizing and widening the beaches would add valuable recreational area, support beach ecology, provide a buffer for back beach infrastructure or development, and slow the impacts of a rising sea level.

KEYWORDS: Groins, sediment transport, coastal structures, beach stabilization.

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California is the nation's most populous state with over two-thirds of its 40 million people living in coastal counties (including those bordering San Francisco Bay). California also has the largest ocean economy of any state, calculated at about $46 billion/year (Eastern Research Group 2015) of which the single biggest contributor is tourism and recreation ($17.6 billion or 38%). The state's beaches are a significant part of the tourism and recreation economy, particularly in southern California with its 18 million residents and millions of annual visitors.

To the degree that we can increase the amount of littoral sand and beach width, we are improving both shoreline protection and enhancing our recreational resources. California has a long history of proactive beach management, including sand replenishment and the construction of groins to increase the size of its beaches. Unfortunately, despite these efforts, climate change-driven sea level rise now threatens to literally drown many of California's sandy beaches. One recent study projects the significant loss of two-thirds of southern California's beaches by 2100, assuming that the developed backshore remains fixed in its current location (Vitousek *et al.* 2017).

In the last five years, dozens of California's coastal communities have started to assess different ways to protect their shorelines, including sandy beaches, supported by a new planning grants program and sea-level rise guidance from the California Coastal Commission. The options being considered in these planning discussions range from more traditional shoreline protection such as shore-parallel structures like seawalls and revetments to beach replenishment strategies and new ideas for managed retreat. On a parallel track, the state Coastal Conservancy has been encouraging shoreline adaptation projects that rely on "natural" or "green" infrastructure, also termed "living shorelines." These might include dune-backed beaches or constructed oyster beds within estuarine or bay environments.

Within this setting of renewed thinking and planning about alternative shoreline management strategies, this article takes a fresh look at groins as a strategy to protect and maintain sandy beaches, with a particular focus on southern California. The article reviews the general history of California's beaches and discusses basic beach dynamics. It also reviews the history of groins in California and considers the prospects for increasing their use as a beach management strategy. The article suggests that depending on the context, groins are deserving of more in-depth consideration as an important beach management and adaptation strategy, particularly in conjunction with beach replenishment.

SOUTHERN CALIFORNIA BEACH TRENDS

Many southern California beaches show historical trends of accretion, or widening, due to large additions of sand from coastal construction and marina

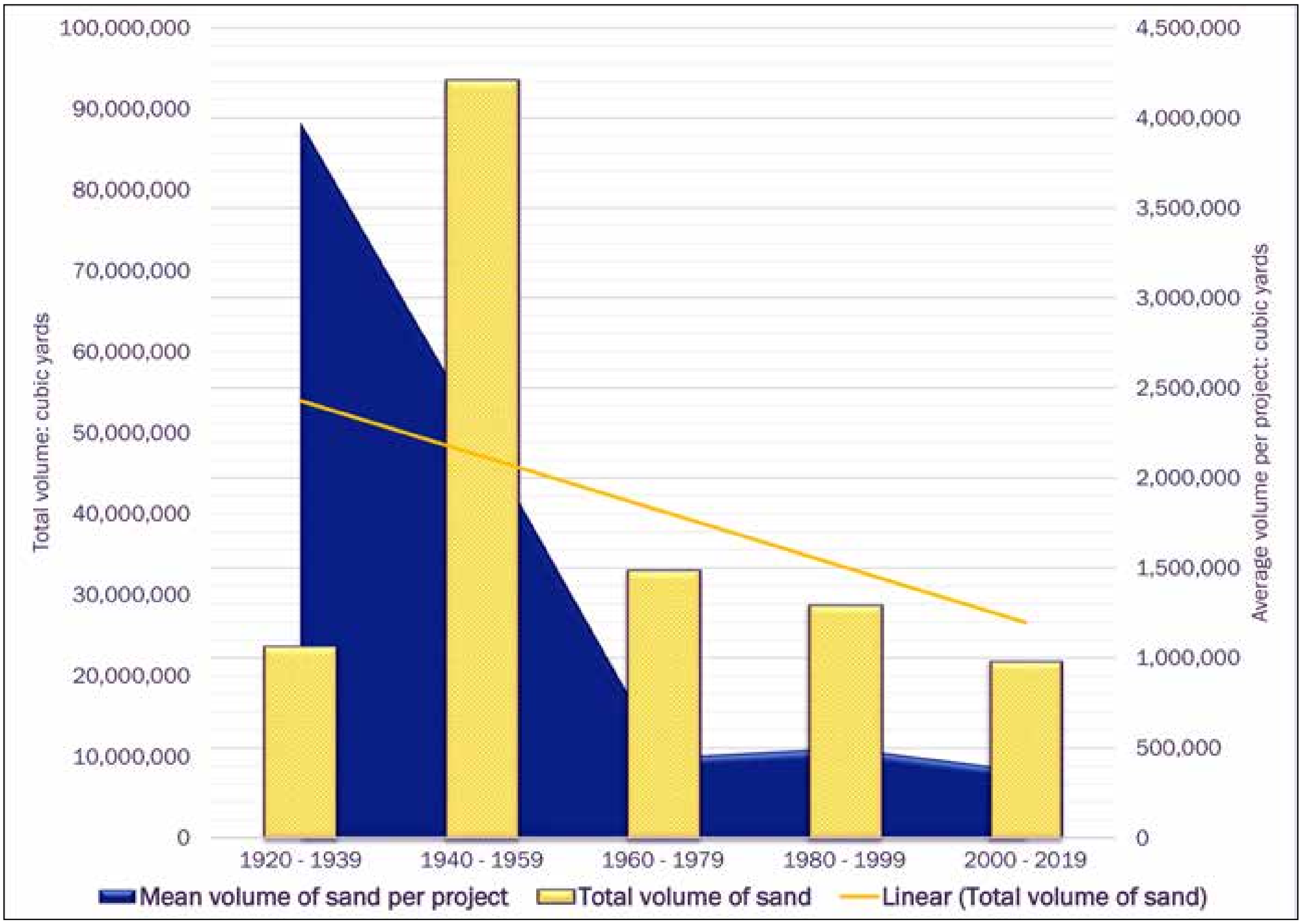


Figure 1. Summary of beach replenishment projects in California (excluding those associated with harbor maintenance dredging and bypassing). Source data: National Beach Restoration Database (ASBPA 2019).

and river channel dredging projects between the 1930s and the 1980s (Flick 1993; Wiegel 1994). These far exceeded the natural sand supply from the heavily altered rivers and streams of the Santa Monica, San Pedro, and Oceanside littoral cells and created wider than natural beaches. As of 1992, over 130 million cubic yards of sand had been added to these beaches from construction projects (Flick 1993).

Sand placement on the beaches from shoreline construction projects in southern California peaked from the 1940s to the 1960s with nearly 100 million cubic yards of sand placed on beaches from 31 different projects with an average project placing over two million cubic yards. During the 1960s and 1970s, 58 projects resulted in the placement of 33 million cubic yards of sand with an average project volume of 460,000 cubic yards. During the 1980s and 1990s, 51 replenishment projects placed 29 million cubic yards with an average project size of 500,000 cubic yards. From 2000 until today (2019), an additional 51 projects with an average volume of 385,000 cubic yards, added 22 million cubic yards (all totals exclude routine harbor maintenance dredging and sediment bypassing at harbors). Over the years, with new construction projects waning, the number of artificial replenishment projects, total volume of sand added to the beaches, and average volume of sand per project has shown a decreasing trend throughout California (Figure 1).

However, despite the reduction in artificial replenishment, the impoundment of sand by dams and debris basins, and the channel alterations in coastal watersheds, no littoral cell-wide, long-term, net erosional or depositional beach trends were identified in southern California by Orme *et al.* (2011) from comparisons of long-term aerial photographs. Relatively natural beaches, lacking major human impacts, revealed modest cyclic narrowing and widening related respectively to El Niño and La Niña climate forcing, and longer-term trends weakly related to Pacific Decadal Oscillations. For beaches influenced by shore normal engineering structures (some breakwaters and jetties, for example), no such correlations exist, but net changes over the prior 75 years revealed two interrelated types of variation. First, hard structures predictably disrupt littoral drift within cells with accretion occurring updrift and erosion typically occurring downdrift of jetties and breakwaters. Sand bypassing and other forms of artificial replenishment have usually countered these effects, although the beach widening and sand storage resulting from the construction of engineering structures does become a more permanent change. Second, the longevity of artificial replenishment reflects the volume and grain size of fill introduced and whether or not retention structures are present. In most cases, the effects of replenishment without retention structures are short-lived, with nourished beaches eroding over a few years, leading to repeated and costly cycles of replenishment (Flick 1993; Wiegel 1994; Griggs and Kinsman 2016). Beaches will

Figure 2. Littoral cells and submarine canyon sinks in southern California.

Figure 3. Submarine canyons cutting into the continental shelf along California's coastline.

tend to return quickly to their equilibrium profile in balance with the average sediment supply, grain size, water depth, wave energy, and shoreline orientation (Bruun 1954; Dean *et al.* 2002; Griggs and Kinsman 2016). Climate change and projected sea-level rise will change the water depth and perhaps wave energy, which is why coastal geologists are generally projecting the accelerated retreat or narrowing of sandy beaches where the backshore is unable to retreat inland in response to rising water levels due to armor or back beach development (Vitousek *et al.* 2017).

LITTORAL CELLS AND LITTORAL DRIFT: SAND SOURCES AND SINKS

The shoreline of southern California between Santa Barbara and San Diego can be divided into a series of distinct, essentially self-contained, littoral cells or beach compartments (Figure 2; Inman and Frautschy 1966). These compartments are geographically limited and consist of a series of sand sources (primarily rivers, streams, and eroding coastal bluffs) that provide sand to the beaches, longshore sand transport (which is dominantly to the southeast along the southern California coastline), and sand sinks (such as submarine canyons and coastal dunes) where sand is lost from the shoreline. While historically coastal dunes were a significant sink, today with coastal development and alterations in the sand budgets limiting the extent of dunes along the coast, submarine canyons form the major sink. Sediment within each littoral cell includes the sand on the exposed or dry beach as well as the finer-grained sand that lies just offshore and that moves on and offshore seasonally and alongshore as littoral drift.

Fifteen submarine canyons carve into California's continental shelf, nine of which are located in southern California including Hueneme, Mugu, Dume, Santa Monica, Redondo, Newport, Carlsbad, Scripps, and La Jolla canyons (Figures 2 and 3) with canyon heads close enough to the shoreline (inner edges range from 33 feet to five miles offshore; Figure 4) to interrupt a portion of the alongshore littoral drift and funnel sediment into deep offshore basins (Normark *et al.* 2009). As a function of the proximity of a canyon head to the shoreline, the regional sediment budget, and the location of the canyon within a littoral cell, only five of California's 15 canyons intercept and funnel more than 10,000 cubic yards of sand annually offshore into deep water, essentially removing the sand from the littoral budget; four of these canyons are located in southern California (Hueneme, Mugu, Redondo, and Scripps submarine canyons; Figure 5). The average amount of littoral sand lost permanently into southern California submarine canyons each year is about 1,400,000 yds^3, based on an analysis of California's littoral cell budgets and balancing inputs and outputs (Patsch and Griggs 2006).

A summary of the sand budgets for all of California's major littoral cells was compiled by Patsch and Griggs (2006). This report provides a comprehensive evaluation of the: 1) volumes of sand provided by all sources; 2) littoral drift rates within littoral cells developed using long-term averages of annual harbor dredging volumes as proxies; and 3) sand lost to sinks, as well as how various human activities have altered the natural sand inputs.

In a different study, Everts and Eldon (2005) used a combination of beach sand losses, sand bypass dredging, measurements from diver surveys in submarine canyons and littoral sediment budget analysis to estimate that from 1,250,900 yds^3 to 1,512,000 yds^3 of annual sand is lost to southern California canyons.

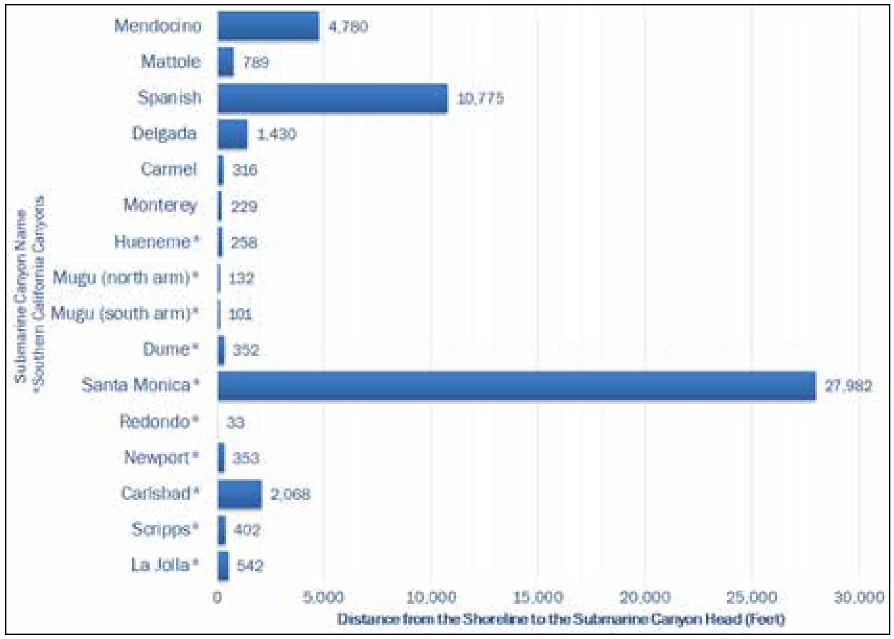
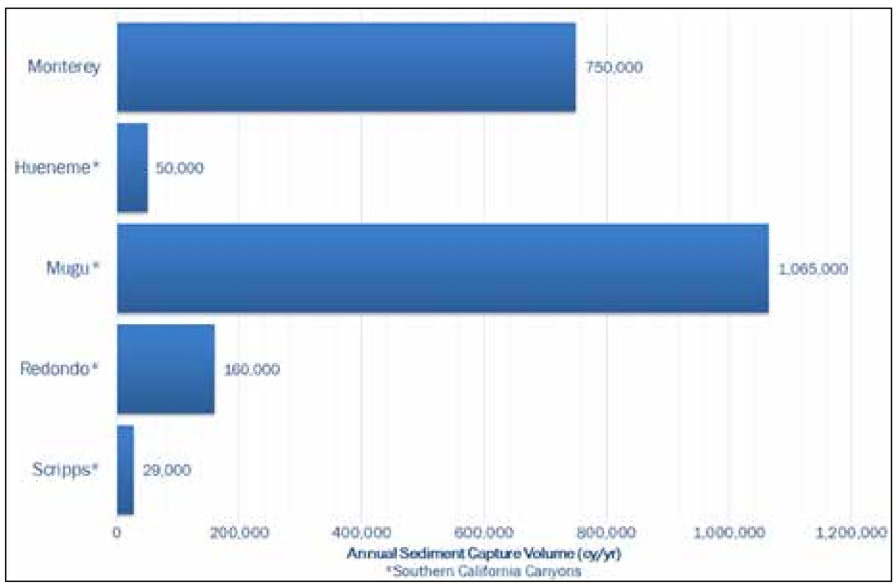


Figure 4 (above). Proximity of the submarine canyon heads to the shoreline.

Figure 5 (below). Approximate annual sand capture for submarine canyons funneling more than 10,000 cubic yards of sand per year offshore (Patsch and Griggs 2005; Moffatt & Nichol and Everts Coastal 2009, Everts Coastal 2002; and Everts and Eldon 2005)



Considering the challenges in obtaining these values or making these measurements, these estimates align well with the assessments of Patsch and Griggs (2006). Assuming a beach profile out to an average depth of closure with a volume to beach area conversion of one cubic yard of sand per square foot of beach, the value (1,400,000 yds^3) obtained by Patsch and Griggs is equivalent to a beach 100 feet wide, 10 feet deep and two miles long lost every year into the submarine canyons along the southern California coast. Thus, each decade, the shoreline extending from Santa Barbara to San Diego loses enough sand to build a beach 100 feet wide, 10 feet deep and 20 miles long, or a beach extending from Newport Bay to San Clemente.

Sand losses to submarine canyons are permanent. Once sand moves into the steeper slope of a submarine canyon head, it doesn't return to the littoral zone (Everts and Eldon 2005). The former littoral sand will move downslope, either through slow creep/sand flow or through periodic and more rapid turbidity currents, and ultimately will be deposited in a deep-sea fan thousands of feet below

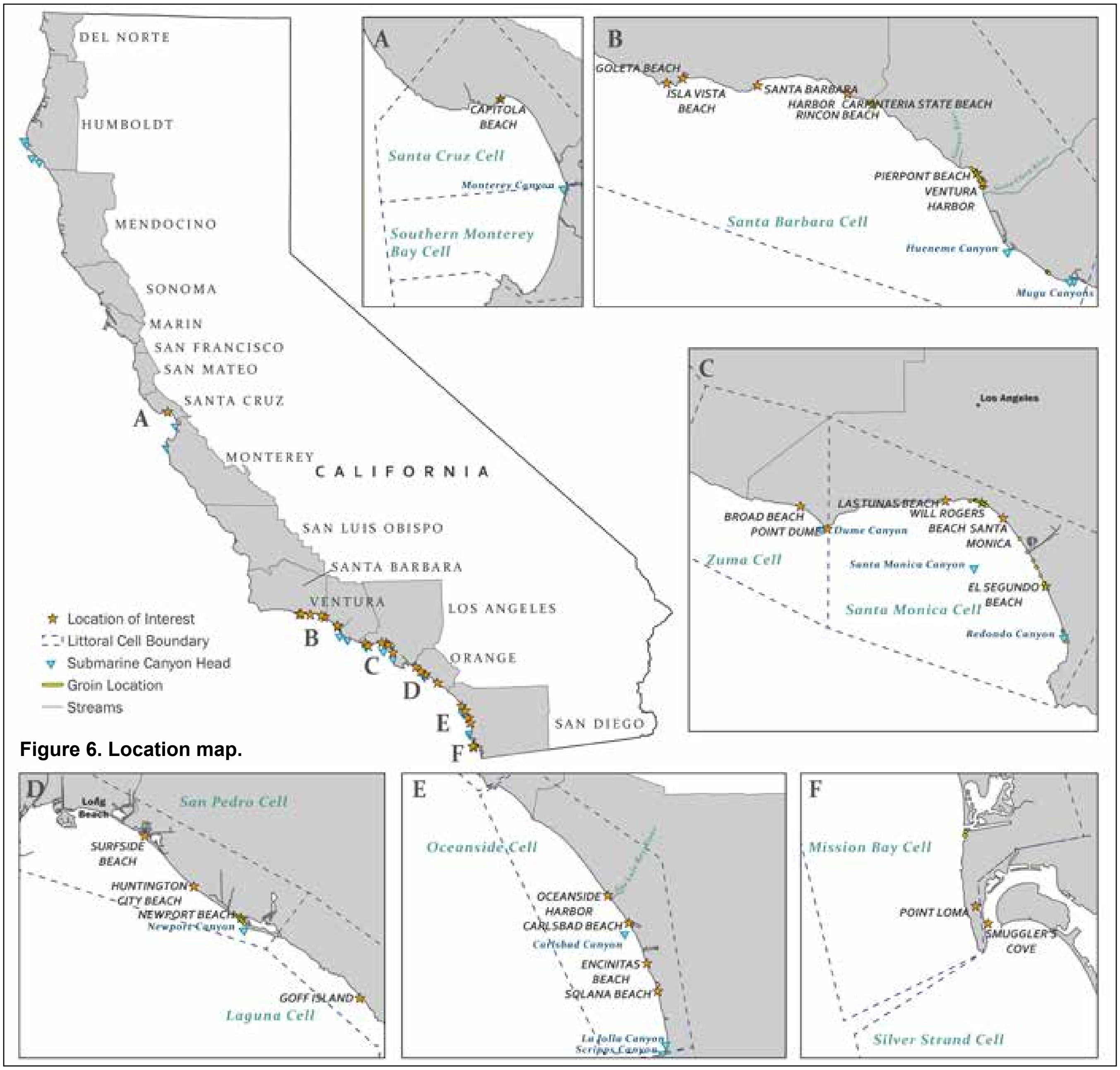


Figure 6. Location map.

sea level. These fans can be very large and contain hundreds of millions to billions of cubic yards of sand (Everts and Eldon 2005; Emery 1960), which attests to the enormous quantities of beach sand that have been permanently lost to the deep sea, and to the tens of thousands of years over which these processes have been operating.

While there are sections of the southern California coast where the beaches are very wide and stable (the low-lying, originally dune-backed shoreline of Santa Monica Bay is a good example; Figures 6 and 7), there are other areas where, for a variety of reasons, beaches are narrow or virtually nonexistent, including Isla Vista in western Santa Barbara County (Figures 6 and 8), the Rincon coast of Ventura County (Figure 6), Broad Beach in western Los Angeles County (Figures 6 and 9), and extensive reaches of northern San Diego County. There are multiple reasons for these differences along the southern California coastline, which include shoreline orientation and lack of littoral drift barriers, rates of littoral drift, human impacts on sand input, and shoreline processes, to name some of the most significant (Flick 1993; Wiegel 1994; Everts and Eldon 2000; Everts Coastal 2002; Patsch and Griggs 2006; Orme *et al.* 2011; Griggs and Kinsman 2016; Griggs and Patsch 2018).

HISTORIC RESPONSES TO COASTAL RETREAT AND NARROW BEACHES

To provide some long-term perspective on the retreat of the southern California coastline, at the end of the last ice age about 18,000 years ago, sea level was 350-400 feet lower and the coast of southern California was at the edge of the continental shelf, anywhere between one mile and 12 miles west of the present shoreline. As glaciers retreated and ice melted, and ocean water warmed and expanded, sea level rose relatively rapidly (about one-half an inch/year or four feet per century) between 18,000 years ago and 8,000 years ago. This led to the retreat of the southern California coastline,

Figure 7. The low-lying shoreline and broad beach of Santa Monica in Los Angeles County, California.

along with its fronting beaches, at average rates in the range of six inches to six feet per year. About 8,000 years ago the rate of sea-level rise slowed to perhaps one mm/year and shoreline retreat significantly slowed, although winter wave attack, particularly during high tides, continued to erode the cliffs and bluffs along the coast. With the shoreline development of the past century, erosion began to threaten both coastal infrastructure and private development.

Armoring the coast, usually with either riprap revetments or seawalls, has been the most common approach to dealing with coastal erosion in California. By 2018, 148.7 miles (or 13.8% of the state's entire 1,100-mile coastline) had been armored, and 88.1 miles or 38% of the more intensively developed coast of southern California had been protected by some form of armor (Griggs and Patsch 2019a). However, seawalls and revetments are built to protect cliffs, bluffs, backshore development or infrastructure, and not to protect beaches. In fact, armoring structures can have significant negative impacts on beaches, including placement losses, reduction of sand supply from eroding bluffs (Runyan and Griggs 2003), and passive erosion (flooding the beaches where they are backed by armor or other development) with continuing sea-level rise (Griggs 2005).

The California Coastal Commission (CCC) has been regulating proposed shoreline protection for nearly 50 years, and has been specifically concerned with mitigating the negative impacts of armoring structures for at least the last three decades (Lester and Matella 2016; California Coastal Commission 1997). With increasing attention on the impacts of global sea-level rise, including the possibility of accelerated erosion of California's sandy beaches, the CCC has heightened its review of new proposals for additional armoring. This includes renewed focus on the original language in the Coastal Act of 1976, which sought to allow only shoreline protection for structures that were in existence at that time (California Coastal Commission 2018a; Lester 2005). Given this heightened regulatory concern, it may become increasingly difficult to get new armoring approved along the state's coastline (Griggs and Patsch 2019b). Additionally, with a continuing rise in sea level, the process of passive erosion will lead to progressive loss of sandy beaches in armored settings (Vitousek *et al.* 2017) with resultant reduction of beach visitation and the associated economic losses (Pendleton *et al.* 2012).

There are essentially two ways to increase the extent or width of beaches: 1) increase the amount of sand reaching the shoreline or on the beach naturally or artificially, or 2) reduce littoral transport or retain the sand such that more of it remains on the beach. While beach replenishment has been used extensively for decades along the sandy shorelines of the Atlantic and Gulf coasts of the U.S., this has not been the case in California. With several recent exceptions, adding sand artificially to California beaches has been primarily opportunistic where sand from new marina construction or maintenance dredging of existing harbors or stream channels, or from large construction projects in coastal dunes where sand has been placed on adjacent or nearby beaches as a convenient location to dispose of the sand (Flick 1993; Wiegel 1994).

The major exception to this opportunistic disposal has been two recent San Diego County replenishment projects where collectively 3.5 million cubic yards

Figure 8. The narrow cliff-backed beach of Isla Vista in Santa Barbara County, California.

of sand were dredged from offshore sites and pumped onto a number of San Diego County beaches at a total cost of $46 million (Regional Beach Sand Projects — RBSP I and II; Griggs and Kinsman 2016). Without any structures to retain the sand, however, most of this sand was eroded from the subaerial beach during the first or second year following placement. Without either regular or repeated replenishment, or the construction of retention structures such as a groin or series of groins, there is no reason why in an area with naturally narrow beaches and a high littoral drift rate that any artificially added sand should remain on the exposed beach or widen it for any extended period of time.

Considerable time, effort, and expense has been invested along the southern California shoreline in both 1) searching for and then recovering, transporting, and distributing new sources of sand from offshore or onshore to nourish beaches, and 2) efforts to return the natural transport of sand to the shoreline through dam removal. While the latter is an important objective with clear benefits, long and complicated environmental analysis, exhaustive government agency review and approvals, and rising costs, have made dam removal projects nearly an endless process. The Carmel River San Clemente Dam was successfully removed after two decades of assessment and planning. Dedicated and continuing efforts to remove the Matilija Dam on the Ventura River, which is essentially full of sediment (about 3 million cubic yards of sand), began in the mid-1990s and the hope now is for removal by 2025 — 30 years later — and at a cost now estimated in excess of $100 million. Dam removal is without question a worthwhile goal that we need to continue to pursue, but experience in California and elsewhere has made it clear that such projects will never be quick, easy, or inexpensive to accomplish.

Future sea-level rise will pose additional problems and eventually further limit the effectiveness of both coastal armoring and beach replenishment. A recent synthesis of future sea-level rise for California (Griggs *et al.* 2017), requested by the state's former governor and based on new research on the potential for ice sheet collapse in Antarctica, included sea-level projections for 2030, 2050, and 2100. These projections were also given probabilities based on different future greenhouse gas emission scenarios. This report was followed by a sea-level rise guidance document (California Ocean Protection Council 2018), which used the same future projections, but took them one step further and designated different probabilities as *Low Risk Aversion*, *Medium-High Risk Aversion*, and *Extreme Risk Aversion* in order to provide a risk perspective for each sea-level rise value as a guide for both state agencies and local governments. Analysis from

Figure 9. King-tide, nonexistent beach at Broad Beach in Los Angeles County, California, December 2018.

the U.S. Geological Survey (USGS) show that perhaps two-thirds of southern California's beaches will disappear by 2100 from the effects of projected sea-level rise (Vitousek *et al.* 2017).

THE HISTORY OF GROINS ALONG THE SOUTHERN CALIFORNIA COAST

An approach used in the past, but which has created down-drift impacts or other side effects at some locations, has been the emplacement of groins. Several groin fields were built years ago in southern California where beaches were narrow, and these have proven effective in either stabilizing or widening beaches at Ventura, Malibu, Santa Monica, and Newport Beach. While there are a number of critically important design considerations and precautions (height, length, location, material, spacing, and orientation of groins, location within a littoral cell, as well as the sand volumes needed to fully charge or initially fill the area upcoast of groins following construction), these structures basically mimic natural littoral drift obstructions or barriers and have the potential to significantly widen or stabilize beaches with the benefits that wider beaches provide (Griggs 2003; Everts Coastal 2002). Currently, there are 49 groins in California (Figure 10), 84% of which are located in the state's southern counties (Table 1) with an average length of approximately 300 feet (Figure 11).

Table 1.
Number of groins by county in California.

County	Number of groins
Marin County	6
Santa Cruz County	1
Santa Barbara County*	1
Ventura County*	11
Los Angeles County*	16
Orange County*	8
San Diego County*	6
Total number of groins in CA	49
* Total number of groins in SoCal	42 (84%)

Groins have been successfully used at a limited number of locations in southern California, but have often been lumped with the much larger breakwaters and jetties as coastal engineering structures that have had major secondary or negative downdrift effects. The words "groin" and "jetty" have also been used interchangeably by many without understanding their inherently different purposes. This may be due to a lack of familiarity with groins specifically, particularly among coastal residents and users. Kinsman and Griggs (2016) found that nearly 20% of users surveyed between 2008 and 2010 were not familiar with the term "groin." In southern California, it is common for many users to refer to all rock structures that are perpendicular to shore as jetties. The Newport groin field, which is known among the local surf population as the "Newport Jetties," is a case in point.

There are important differences between groins and jetties, however. Jetties are nearly always built in pairs with the intended purpose of stabilizing entrance channels to ports, harbors, or marinas or to maintain inlets. They are usually many hundreds to thousands of feet long, and while they often trap or retain littoral sand, their primary goal is to prevent sand from entering an entrance channel or inlet. Groins, on the other hand, are concerns about the potential impacts of groins on beach aesthetics, surfing, and other resources, groins have not usually been looked upon favorably by many as an approach to building or stabilizing beaches.

Figure 10. Location of groins in California.

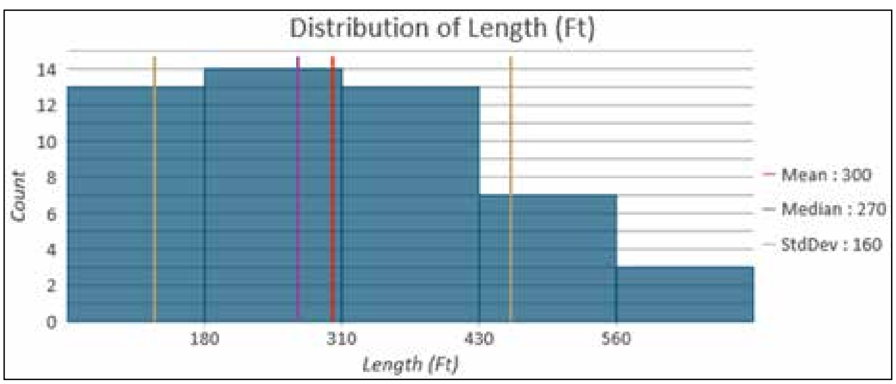


Figure 11. Distribution of groin lengths in California. The average length of groins in California is approximately 300 ft.

usually considerably shorter and have a primary purpose of trapping or retaining littoral drift in order to build, stabilize, or widen a beach. Single groins can be constructed or a groin field consisting of a number of groins can be built along a stretch of shoreline. Without question, jetties and breakwaters that have created many of California's ports and harbors have had major impacts on littoral drift (Figure 12). While groins also have a direct impact on sand movement, these impacts tend to be smaller relative to those of jetties and breakwaters, as well as shorter in duration, starving down-coast beaches only for as long as the groin is not fully charged, or filled to capacity. Once charged, sediment will migrate around the tip of the structure (Figure 13). Still, perhaps as a result of the perceived similarities of groins with jetties and breakwaters, as well as other

Ventura Pierpont Groins

Pierpont or San Buenaventura State Beach, one of the main beaches in the City of Ventura (Figure 6), is partially supplied by sand from the immediately upcoast Ventura River, as well as littoral drift from streams at least as far west as Point Conception and possibly beyond (Patsch and Griggs 2006). However, like many southern California watersheds, rainfall and therefore sand discharge are very intermittent (Brownlie and Taylor 1981). In addition, two large dams, Matilija and Casitas, impound about 47% of the entire Ventura River watershed and form major sand traps for fluvial sand transport. As a result, during major flood years, large volumes of sand are delivered to the coast, but these years are interspersed with years of low flow and minimal sand discharge. Significant shoreline damage occurred in about 1936, followed by the very large 1938 floods, which brought over 650,000 yds^3 of sand to the shoreline (Brownlie and Taylor 1981). Reduced sediment yields from the Ventura River during the dry interlude between 1948 and 1959, which also happened to follow the construction of the Matilija Dam, were largely responsible for causing the shoreline between the Ventura and Santa Clara rivers to erode 300 feet landward over that time period. To offset this, an erosion control project was completed between 1962 and 1967 at San Buenaventura State Beach, comprising seven rock groins (400-540 feet long; Figure 14) and placement of 880,000 cubic yards of sand on a beach 120-260 feet wide and two miles long (Orme 2005). This beach has been maintained in part with sand dredged from the downcoast Ventura Marina.

Las Tunas Groins

One of the oldest groin fields in California was placed in 1929 along the Las Tunas shoreline, a strip of eastern Malibu next to Topanga Canyon. Thirteen groins, from 80 to 455 feet long consisting of steel sheet-piles capped with concrete were constructed (Figure 15) in order to widen the beach to partially protect the homes built along the shoreline as well as the Pacific Coast

Figure 12. A breakwater at Santa Barbara trapped millions of cubic yards of sand following construction in 1928-1930 Courtesy: Bruce Perry, California State University Long Beach.

Highway. There was no Coastal Commission, no California Environmental Quality Act (CEQA) or environmental review process at that time. The groins did work effectively for a number of years along a stretch of shoreline that has only a very modest littoral drift rate due to the general lack of upcoast sand supply, a supply which has now virtually disappeared (Griggs and Patsch 2018). Over the subsequent 90 years, however, the concrete deteriorated, along with parts of the steel sheet-piles, leaving a jagged and dangerous set of metal projections extending across the shoreline (Figure 16), which led to safety concerns, lawsuits, and proposals for removal and the construction of new groins. Some remnants of the original sheet-piles still exist, however. In 2003, the CCC approved a State Lands Commission proposal to remove five of the groins. Ultimately, over 900 feet of dilapidated groin material was excavated and removed from the beach, with an average sheet-pile height of five feet. In addition, divers removed 265 feet of sheet-pile from the surf area to increase the safety of the beach. One groin was capped and restored (Figure 17).

Groins of Santa Monica

What may have been the first groins built along the southern California coastline were those constructed at the northern end of Santa Monica Bay near Will Rogers State Beach in about 1925, although not without some controversy (Figure 6). Wilkie Woodard, chief engineer for the Santa Monica Mountain Park Company (a property development firm), performed some pioneer work on groins and the attributes that determine their effectiveness. With the observation that some bedrock reefs extending out from the shoreline could collect sand and thereby widen the beach Woodard, who was described by William Herron (1986; who was himself a pioneer coastal engineer) as "a real estate agent turned engineer," realized that this was a good way to build valuable coastal real estate for his employer. He actually built some steel sheet-pile and timber structures that he could adjust with boards to block sand, or let sand through, and also change the crest level and observe what happened. This ultimately led to a lawsuit by the City of Santa Monica based on the adverse effects the groins were having on sand transport along the Santa Monica coast and marked the end of Woodard's experiments and engineering career.

There is also a separate set of groins known as the Bel Air Club groins in the far northern corner of Santa Monica Bay where the shoreline makes a turn from the east-west trending Malibu coast to the SSE trending curve of Santa Monica Bay. Beaches were narrow here initially, but there were concrete groins constructed that took advantage of rock reefs and simply extended them (Herron 1986). These proved very effective in providing a stable and wider beach than originally existed, although it is not clear who built these groins or when. Today, however, there are six rock groins in this area that have effectively widened and stabilized this section of shoreline (Figure 18). Downcoast, as the Santa Monica Bay shoreline gradually comes into equilibrium with the dominant direction of wave approach, the beaches become much wider and stable, such that there is no apparent impact of the groins on the down drift beaches. It is not known when these groins were built, but they were in place by at least 1972 (Figure 19).

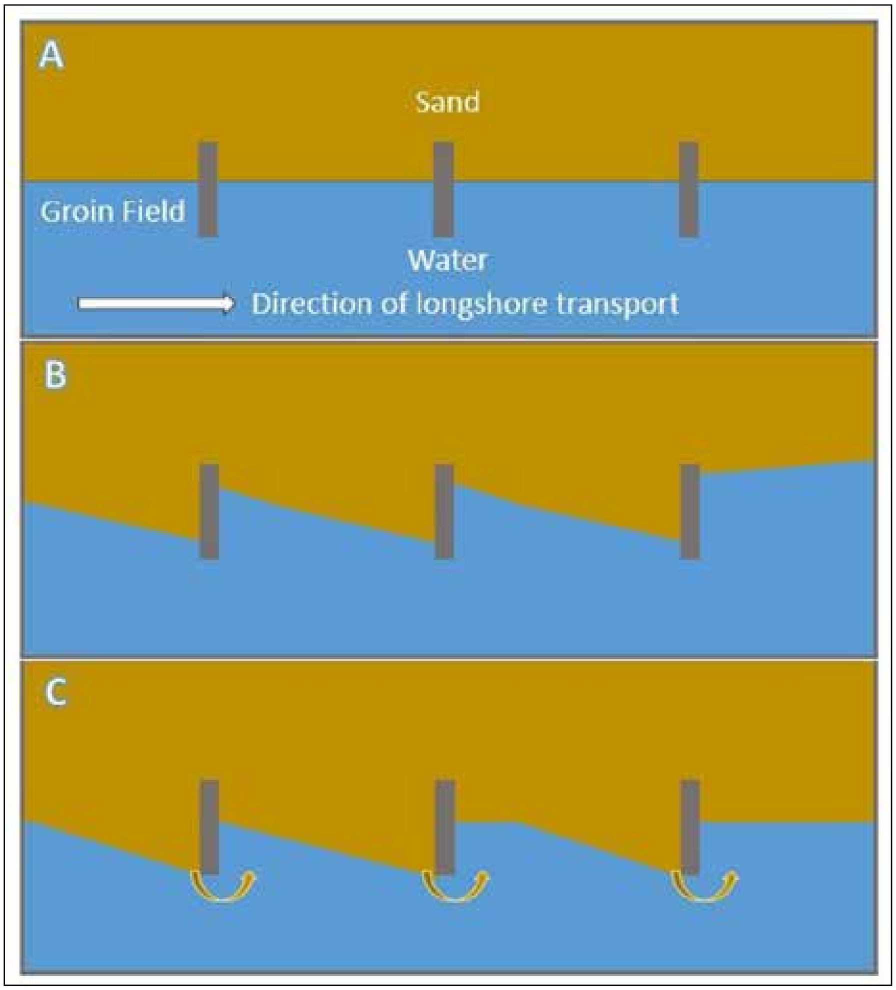


Figure 13. A. Groin field constructed perpendicular to the beach with the intention to retain sand. B. With a net littoral drift direction to the right in the diagram, sand accumulates on the updrift side of the structure causing the beach to accrete, and may erode the beach on the downdrift side of the structure depending upon groin width and spacing. C. Once the groin is charged, or reaches its capacity to interrupt littoral drift, sand will bypass the groin and once again provide sand to the downdrift beaches.

Flick (2013) in a report to the City of Los Angeles on coastal issues related to future sea-level rise describes the groins at the western half of Will Rogers State Beach as built prior to the 1960s, but that the groins were dilapidated and were slated for removal. He also states: "*This segment of shoreline is highly instructive in that it illustrates successful and relatively unobtrusive groin beach width stabilization structures that will almost certainly become increasingly and widely necessary if area beaches are to be preserved in the future.*"

Surfside Timber Groins

An aerial photograph from the UCLA Spence Collection taken in 1935 (Figure 20) shows extensive beach development backing a narrow beach with at least 45 wooden groins along the coast of Surfside, south of Long Beach. These groins are quite close together and this is the largest groin field anywhere in southern California that the authors have discovered. We have, however, been unable to uncover any history on this groin field beyond the two photographs in Figures 20 and 21.

Newport Beach Groins

The fluvial sand supply to the urbanized southern California coastline has been significantly reduced by the construction of flood control dams and debris basins in the contributing watersheds, as well as the lining of most of river channels with concrete for stabilization (Brownlie and Taylor 1981; Orme *et al.* 2011; Sherman and Pipkin 2005). Beaches also undergo changes over time in response to sediment reduction, as well as storm occurrence and intensity, and also significant El Niño events (Young *et al.* 2018).

Much of Newport Beach in Orange County was built on a barrier spit and is significantly affected by large waves generated by southern hemisphere storms and also tropical storms off Baja California, in large part because the Newport Beach coast is south facing and lacks protection from the offshore Channel Islands. Shoreline erosion is often most serious in summer as a result. In the summer of 1965, for example, the beach eroded 165 feet before being stabilized by sandbags just five feet from property lines. Similarly, severe erosion occurred again in 1968. The greatest threat has been at West Newport Beach; this area has been the site of numerous beach protection and restoration efforts, mainly Corps of Engineers regional projects. Eight rubble mound and sheet pile groins were installed in the 1960s and 1970s (Figure 22), and several replenishment projects have added more than 1.5 million yds^3 of sand to this beach. In 1991, another 1.3 million yds^3 of sand, dredged from the Santa Ana River, were used to build an offshore sand mound to feed the beaches (Sherman and Pipkin 2005). These groins have proven effective in stabilizing the beach along the barrier spit for 50 years. The eight groins at West Newport Beach were built immediately updrift of the head of Newport Submarine Canyon. As a result of these groins as well as other upcoast engineering structures, very little sand is now presumed lost to Newport Canyon. Regardless of the amount of sand transported into the canyon, the groins and beach nourishment have so far been effective in maintaining a wider beach with both structural and recreational benefits.

Oceanside Groins

The coastline and sand supply in Oceanside (Figure 6) has been impacted by multiple structures that have been built throughout the 20th century. One key event was the damming of Lake Henshaw in 1922, which severely reduced the sand supply to the city's beaches (Kuhn and Shepard 1984). In the 1940s, the federal government constructed a breakwater and boat basin for Camp Pendleton, located just north of the city. In the early 1960s, the City of Oceanside constructed a small boat harbor. Combined, these structures have contributed to severe downcoast erosion and beach sand loss (Kuhn and Shepard 1984; Flick 2005; USACE 1991). In order to help control

Figure 14. Pierpont Beach, 1926 (left), and Pierpont Beach, today (right).

sediment flow near the harbor, the city installed a groin alongside the San Luis Rey River mouth in 1961, in addition to a submerged groin in 1962 (Perdomo 2004). The San Luis Rey River groin, which was extended to 915 feet in 1968, has played an important role in helping to retain sand on the popular beach in front of Oceanside Harbor for decades.

Overall, Oceanside has experienced considerable beach sand loss throughout the 20th and 21st centuries (Orme *et al.* 2011; Young *et al.* 2018; Flick 2005). Today, many of the beaches south of Oceanside pier are experiencing high rates of erosion with narrower beaches during high tides and storm events (Figure 24). A substantial portion of Oceanside's coast is lined with riprap, and many sections have little to no beach during much of the year (Orme *et al.* 2011). Since the late 1970s, the city has explored options for beach sand stabilization, ranging from rock revetments to seawalls and groin systems (Hales 1978; Kuhn and Shepard 1984; Moffatt and Nichol 2001). In the early 1980s, consultants proposed several potential groin-based options for sand retention along the city's southern shores. To date, the City of Oceanside has not constructed any new groins.

Figure 15. Original Las Tunas groin field along the eastern Malibu shoreline (in background).

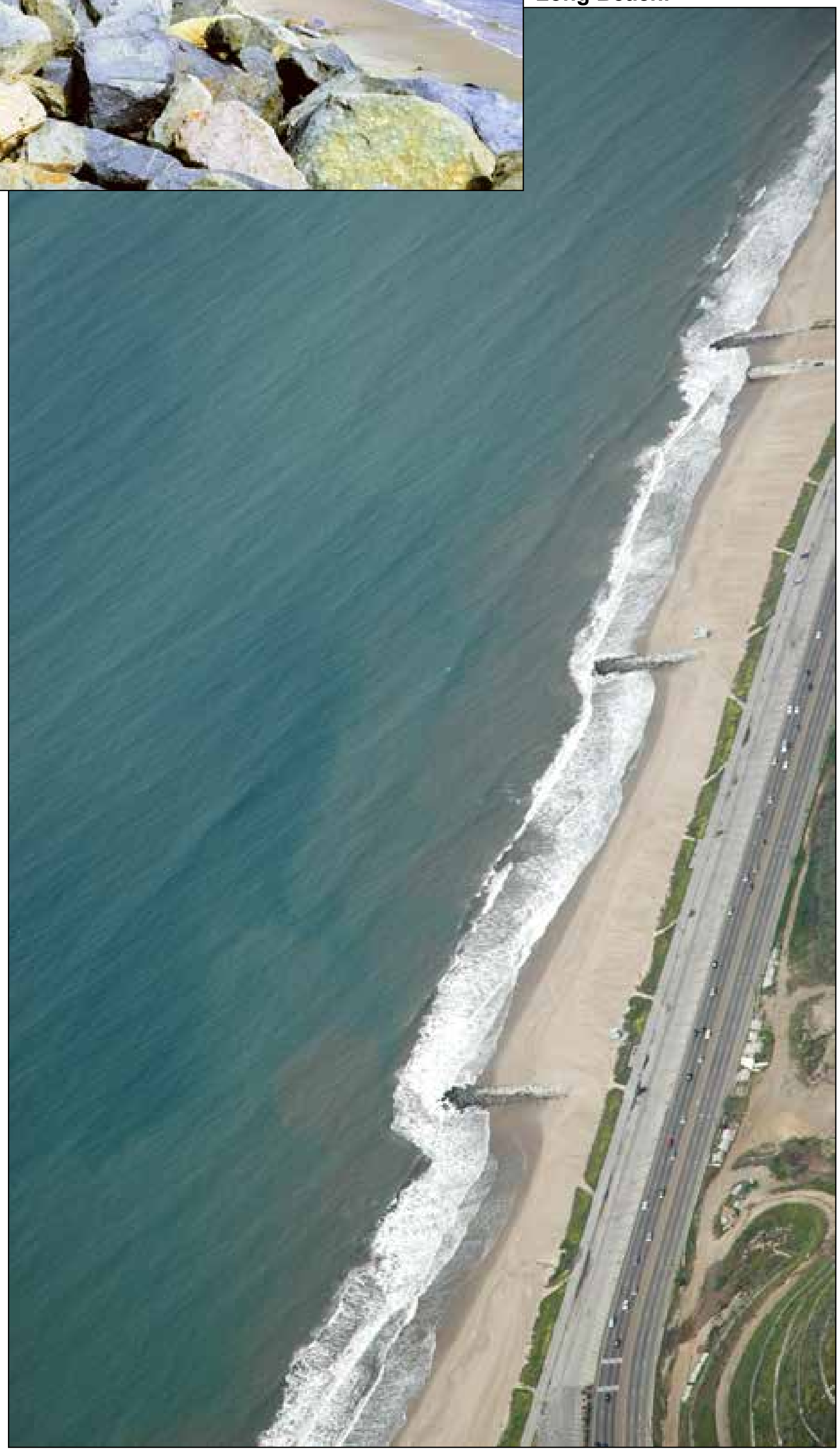
Figure 16. Dilapidated sheet-pile groins left hazards along the shoreline at Las Tunas Beach, Los Angeles County, California

IMPORTANCE OF LITTORAL DRIFT BARRIERS TO SOUTHERN CALIFORNIA BEACHES

Many of California's beaches exist because of natural littoral drift barriers such as headlands and points (Figure 25). Over 75% of the beaches in southern California are retained by structures, whether natural or artificial:

Figure 17 (left). Repaired groin, Las Tunas Beach, Los Angeles County, California. Photo: Kiki Patsch.

Figure 18 (below). Groins along the northern end of the Santa Monica shoreline. Courtesy: Bruce Perry, California State University Long Beach.



> *Two-thirds of those structures are headlands, surface-piercing or submerged reefs, near-coast submarine canyons, rock stream deltas, and various types of irregular bathymetry. The remaining third are jetties, groins, and shore-parallel and shore-normal breakwaters. By regulating the breaking wave height, the angle waves make with the shoreline, and the path sediment takes as it moves along the coast, beach-retention structures promote wider and more stable beaches than would otherwise exist. Performance and adverse impacts vary from place to place depending upon a complex interdependence of the type and size of the retention structure, the way in which it regulates the longshore component of energy flux, and local orientation of the coast* (Everts and Eldon 2000).

In addition to continuing efforts to remove dams that no longer serve their intended purpose by virtue of being filled with sediment, the use of sand retention structures along the southern California shoreline needs to receive a fresh look as a possible management option when planning for sea-level rise. It will be important to consider littoral drift rates and location with a littoral cell, the local orientation of the shoreline, sand supply (both natural and artificial), as well as the engineering specifications of the retention structures in order to reduce the impact on the downdrift shoreline.

GROINS AND THE CALIFORNIA COASTAL COMMISSION

When the original California Coastal Act was written and then passed by the

Figure 19. Groins at the northern end of Santa Monica shoreline in 1972. Courtesy: California Coastal Records Project.

Legislature in 1976, California had been in a cool or negative phase of what we now understand as the Pacific Decadal Oscillation (PDO). That cool era began in the mid- to late-1940s and continued until about 1977-1978. These three decades were characterized by relatively calm coastal conditions with few large El Niño events and storms with little shoreline wave damage (Griggs *et al.* 2005). This same roughly three-decade long period was precisely the era when California's population grew rapidly and many coastal communities were developed. The state's population grew from 9.3 million in 1945 to 22.8 million in 1978, or a 240% increase.

In 1978, however, the climate over the North Pacific and along California's coast transitioned rather abruptly to a warm, or positive, PDO period characterized by larger and more frequent El Niño events. The elevated sea levels and more damaging coastal storms took their toll on coastal development and infrastructure (Griggs *et al.* 2005; Griggs and Patsch 2019a; Griggs and Patsch 2019b); Bromirski *et al.* 2011).

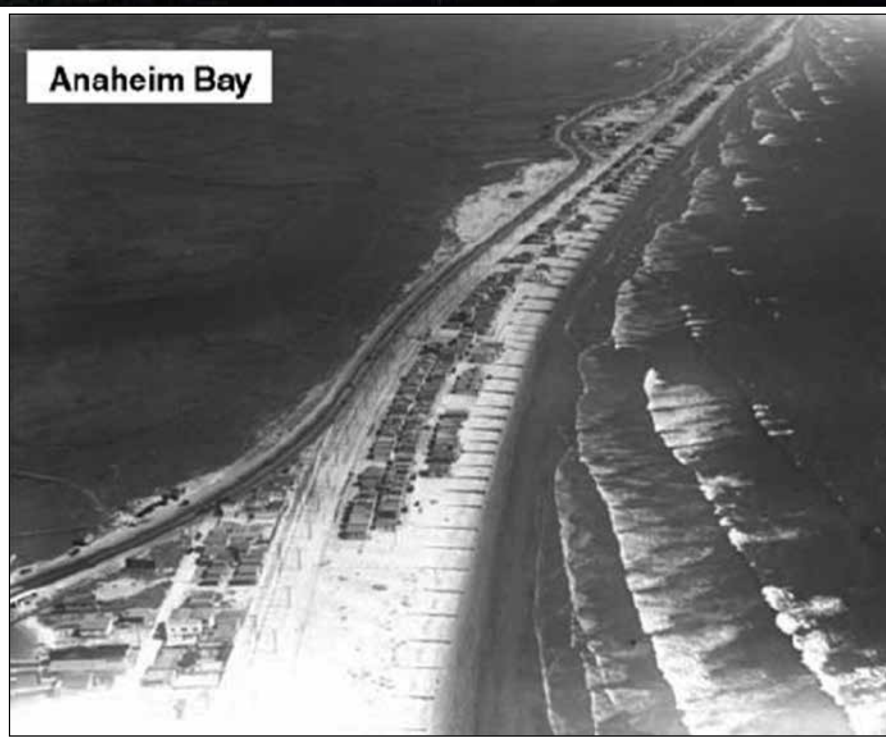


Figure 20. Residential development at Surfside in 1935, looking southward. The beach is very narrow and broken up by wooden groins. Spence Collections. Reproduced courtesy: Dept. of Geography, University of California Los Angeles.

Figure 21. Surfside ~late 1940s. This is the same area as shown in Figure 20, but the groins have been destroyed or removed except for some residual pilings in the foreground that presumably supported the timber groins.

The Coastal Act is a comprehensive law covering coastal management concerns ranging from public access and habitat protection to growth management and protection of rural agricultural landscapes (Lester 2013). With respect to coastal hazard issues, the planning leading up to the Coastal Act was also comprehensive, and it included discussion of both "sand movement and shoreline structures" and "development in hazardous areas" that supported eight very detailed proposed policies (Lester and Matella 2016; CCZCC 1975). When it came time to draft the Coastal Act, these policies were distilled down into two broad coastal hazard policies. One policy, Coastal Act Section 30253, stated a goal that new development minimize coastal hazard risks to life and property and avoid new shoreline armoring (Lester 2005). The second policy, Coastal Act Section 30235, attempted to address the circumstances under which any engineered structure that interfered with shoreline processes could be approved. It states in part:

> *"Revetments, breakwaters, groins, harbor channels, seawalls, cliff retaining walls, and other such construction that alters shoreline*

Figure 22. Groins along the Newport Beach shoreline Courtesy: California Coastal Records Project.

Figure 23. Oceanside groin, which was built in 1961 and extended in 1968. Photo: Ryan Anderson

Figure 24. South Oceanside, showing riprap and narrow to nonexistent beaches. Image taken from just south of Wisconsin Street in July 2019. Photo: Ryan Anderson.

processes shall be permitted when required to serve coastal-dependent uses or to protect existing structures or public beaches in danger from erosion, and when designed to eliminate or mitigate adverse impacts on local shoreline sand supply."

This policy states that a coastal structure such as a seawall, jetty, or groin may be approved if the purpose of the structure is to protect either a "coastal-dependent" development such as a boat harbor, or an existing development or public beach endangered by erosion, as long as the structure is the necessary alternative and adverse impacts of the structure on local sand supply are avoided or otherwise mitigated.

The Section 30235 allowance for new structures that "protect... public beaches" was likely a direct effort to potentially provide for groins or other structures that may serve this purpose given that it was generally understood that revetments, seawalls and retaining walls didn't protect beaches from erosion. Although also concerned with the potential negative impacts of groins, the Coastal Act's precursor Coastal Plan explained how groins were one method for decreasing sand loss from beaches by "reducing the long-

Figure 25. Zuma Beach in western Los Angeles County has been created by the large natural littoral barrier formed by Point Dume. Courtesy: Bruce Perry, California State University Long Beach.

shore movement of sand." The Plan thus proposed to allow shoreline structures, including groins, if they would protect a "public recreation area," such as a beach, and if they were the least environmentally damaging alternative (CCZCC, 1975). This proposal set the stage for the Coastal Act's allowance for the approval of groins if they would protect an eroding public beach.

The Coastal Plan and ensuing Coastal Act policies also required a more comprehensive analysis of the impacts of different types of structures on other coastal resources, including public beach access, marine habitats, water quality, and scenic resources. This is important because different structures raise different concerns, and are highly dependent on context. For example, in contrast to jetties and breakwaters — which may be many hundreds or thousands of feet in length, can trap millions of cubic yards of sand, and which often necessitate expensive annual dredging to maintain the littoral drift system and keep harbor entrance channels open (Griggs 1986) — groins can be of variable length and height and do not require annual maintenance or dredging. Groins have inherently different purposes, and unlike seawalls or revetments, are not designed to protect backshore development or infrastructure (except perhaps indirectly); they are typically designed to retain sand.

There are important considerations to account for with the placement of any engineered coastal structure, groins included. The ecological impacts of groin construction, including potential habitat loss and connectivity, are one primary concern. As Dugan *et al.* (2011) argue, there has been relatively little research on how armored shorelines affect coastal ecosystems (see Dong *et al.* 2016 and Tatematsu *et al.* 2014 for two recent case studies). Groins, and particularly groin *fields*, can "create barriers to the longshore movement of mobile benthic animals and propagules" (Dugan *et al.* 2011). They can also trap higher volumes of macrophyte wrack (macroalgae and seagrasses) and terrestrial detritus where accretion is taking place, while reducing such accumulations where erosion is taking place (Dugan *et al.* 2011). Groins and other hard structures can clearly affect physical processes and ecological communities, but they also have the potential to create new habitat (Dugan *et al.* 2011; Tatematsu 2014). Wrack accumulations can be beneficial to shorebirds and other beach consumers, for example, but can also result in ecological changes that disrupt or alter existing systems. Such considerations should be addressed with the construction of any coastal engineering structure. In addition, there are numerous marine protected areas along California's coast with regulations that may restrict the placement of materials in beach, tidal and subtidal habitat areas (CDFW 2019).

A second concern with the installation of groins is how they can potentially affect coastal recreation activities. One common impact of groins is the interruption of lateral access along beaches, though the extent of this impact will vary with

Figure 26. Groin at Capitola along the northern Monterey Bay shoreline that was built in 1969 to restore and stabilize the beach lost when the upcoast Santa Cruz Small Craft Harbor was built. Courtesy: California Coastal Records Project.

conditions and design alternatives. The effect of groins on surf breaks is another such example. There is an ongoing debate about the effects of coastal structures on surf breaks (Corne 2009; Nelsen 2009). One case study focused on the negative effects of the "Chevron groin" in El Segundo (Nelsen 1996). In that case, groin construction for an oil loading terminal resulted in the deterioration of surfing conditions. At the same time, however, other cases, such as the groin field in West Newport, have resulted in the creation of new, consistent surf breaks. In addition, some of the most popular surf breaks in northern San Diego County are the result of coastal structures such as jetties, piers, and groins (e.g. Oceanside Harbor, Oceanside Pier, and the Warm Water Jetty in Carlsbad).

While there are a number of important design considerations and precautions associated with groins, they basically mimic natural littoral drift barriers and become artificial headlands. As such, they trap sand and either create beaches where they previously did not exist or stabilize or widen existing beaches. In either case, they have the potential to reduce the problems or impacts of either seasonal beach erosion or slow long-term shoreline erosion (Griggs 2003). The strategic and carefully planned use of groins, particularly when used in conjunction with an artificial replenishment or sand disposal project or just updrift of a submarine canyon, would: 1) provide more stable and wider beaches for both recreational use and back shore protection; 2) potentially eliminate or greatly reduce the need for additional shoreline armoring; 3) potentially provide the opportunity for selective removal or reduction of existing armor; 4) retain sand on beaches before it is lost permanently down submarine canyons; and 5) either eliminate the proposals for future artificial replenishment and/or retain the sand added by replenishment projects. These are all very significant potential benefits for the shoreline of southern California. In terms of a short-term management strategy, groins may stabilize the beaches along some stretches of California's coast while the logistics of restoring the natural sand supply to the beaches through the time-intensive planning for the removal of dams and potentially the removal of seawalls at the base of cliffs and bluffs can be achieved, or long-term managed retreat solutions can be initiated (Griggs and Patsch 2019b).

Considering that one purpose of Coastal Act Section 30235 is to protect public beaches, the placement of well-planned and engineered groins, and if deemed necessary, the initial filling of the upcoast void behind each groin to its full capacity (Figure 13), may be consistent with the Coastal Act depending on other resource impacts and assuming other Coastal Act policies can be met. Depending on the context, groins may protect a public beach, and serve one of the most important coastal-dependent activities — use of beaches for recreational purposes. By building, widening, or stabilizing beaches, they would, in many places along the southern California shoreline, protect existing structures and public beaches from erosion and would have positive effects on local shoreline sand supply by trapping some of the ~1.4 million cubic yards of sand that ends up in the submarine canyons and then is per-

Figure 27. Visual simulation of proposed permeable groin at Goleta Pier/Beach (CCC 2009).

manently lost to the deep-sea floor every year. Essentially, groins trap a natural supply of sand before it is funneled offshore by the submarine canyons and lost to the littoral system. As sea level rises, compatible sand for beach replenishment projects, which often has to be a match in grain size and color, is going to become an increasingly expensive limited resource; groins may be an effective way of storing naturally compatible sand for future use before it is lost permanently.

Groins have perhaps been in disfavor in recent decades, but the Coastal Commission has found that groins are consistent with the Coastal Act if the purpose is to protect a public beach or coastal dependent development and if other policy requirements are met. There are a handful of cases where *new* groins have been approved by the Commission. For example, in 1983 the Commission approved the 900-foot Chevron groin (discussed above) to protect the coastal-dependent El Segundo marine terminal, consistent with Section 30235 (CCC 1983), despite the possibility that it might adversely affect a surf break, which it eventually did. Similarly, in 1989, the Commission approved the approximate 600-foot South Beach groin as part of the Ventura harbor navigational improvements project (CCC 1989). More recently, the Commission approved an "underwater groin" for the Navy at Smuggler's Cove at Point Loma (Figure 6) to create intertidal and subtidal habitat and restore a small recreational beach (CCC 2019a).

The more common Coastal Commission action has been to approve the repair, maintenance, or replacement of already-existing groins (built before the Coastal Act), such as the Capitola "jetty" (Figure 26), which maintains Capitola's main beach. In approving the project, the Commission recognized that despite occupying some public beach space, the project's greater benefit was building and stabilizing the beach in the first place:

> *...the jetty [groin] itself serves to help form and maintain Capitola Beach, which would be in danger of disappearing if the jetty were not present. ...Thus, the jetty serves to protect a public beach in danger from erosion, consistent with the allowed uses in Section 30235* (CCC 2019b).

Similarly, the Commission recently recognized how groins can help maintain beaches when it approved the addition of rock and repair of two groins at the Bel Air Bay Club on Santa Monica Bay back to their original 1947 footprint and design:

> *The groins are experiencing scouring and loss of stones within the core, leading to an ineffective structure that will cause the public beach to narrow. Groins are effective at retaining sand within the Santa Monica Bay littoral zone, which experiences a high rate of sand drift, and may aid in advancing the shoreline and public beach along this portion of the bay* (CCC 2018b).

The Coastal Commission's actions show that it will approve both new and significant rebuilds of existing groins to protect coastal-dependent development or public beaches in danger from erosion, just as the Coastal Act contemplates. However, the Commission still exercises case-by-case review, and depending on the circumstances, the agency may not approve a groin project (CCC 1999; CCC 2016). One of the best examples of this is the Commission's denial of the so-called "permeable groin" at Goleta Beach in Santa Barbara County — a very popular recreational park facing long-term beach and bluff erosion. The project consisted of a series of alternating piles placed adjacent to the base of Goleta Pier in a manner that the applicants anticipated would promote beach building up- and downcoast of the pier, yet also allow sand transport to continue downcoast (Figure 27). The project also included initial sand replenishment upcoast of the "groin," and extension of pier decking over the new pilings to create more public recreational pier space. The Coastal Commission staff recommended approval of the project, concluding that it was both consistent with Section 30235 and that it enhanced public access on the pier. However, there was significant opposition to the project, including battling expert opinions as to whether the project would work as designed and concern about increased downcoast erosion. Many people advocated for the managed retreat of the park over any engineered structural approach. Ultimately, after a long public hearing, the Commission did not agree with the staff recommendation and denied the project (CCC 2009).

DISCUSSION AND CONCLUSIONS

Beaches are a huge economic engine for the coastal cities and counties of southern California between Santa Barbara and Imperial Beach and are also a significant component of the history and culture of the region; yet sand supply to beaches has been reduced by the construction of dams and debris basins in coastal watersheds and the armoring of eroding coastal cliffs and bluffs. Additionally, about 1,400,000 yds^3 of sand is lost annually on average to the submarine canyons that intercept littoral drift moving south and east along this intensively used shoreline. Over just one decade, this volume of sand is enough to build a beach 100 feet wide, 10 feet deep and 20 miles long, or a continuous beach extending from Newport Bay to San Clemente.

Over 75% of the beaches in southern California are retained by structures, whether natural or artificial, and several groins fields built decades ago have been important components of local beach growth and stabilization efforts. While groins have been generally discouraged in recent decades in California, and there are important engineering and environmental considerations involved prior to any groin construction, the potential benefits are very large for the intensively used beaches and growing population of southern California. Sea-level rise will negatively impact the beaches further, specifically those with back beach barriers such as seawalls, revetments, homes, businesses, highways, or railroads (Griggs and Patsch 2019b; Vitousek *et al.* 2017).

The strategic placement of groin fields where beaches are narrow or nonexistent, where recreational opportunities are limited, and where backshore coastal development, whether public infrastructure or private development, is threatened can provide important opportunities for retaining littoral sand before it is lost permanently to a submarine canyon. The benefits of groins in many cases may also be consistent with the broad objectives of the California Coastal Act, and depending on the overall environmental circumstances, may be consistent with the specific requirements of Coastal Act Section 30235 and other provisions of the Act.

The benefits of groins may be particularly compelling in the context of increasing adaptation planning in response to sea-level rise. In recent years, multiple community plans have specifically analyzed groins as a way to protect shorelines and beach resources. For example, in Imperial Beach, a 2016 Sea-Level Rise Assessment evaluated multiple adaptation strategies, including the use of five groins (by building out an original U.S. Army Corps of Engineers concept that was never completed). Among other things, the analysis concludes that in the short term, groins coupled with beach replenishment may be slightly better than other options, such as seawalls or managed retreat; that in the medium term (through 2069), managed retreat and groins have similar net benefits; and that over the long-term, managed retreat (first) and groins (second) yielded the highest net benefits in terms of maintaining a wide beach (City of Imperial Beach 2016).

In the City of Pacifica, the Sea-Level Rise Adaptation Plan proposed the consideration of "sand retention structures," including the concept of a "series of engineered rock headland units with submerged reefs and a jetty (or stem) connecting the headlands to the backshore (different than smaller structures known as groins)" (City of Pacifica 2018a) (Figure 28 — while designated as jetties in their plan, these by definition would be considered as groins). The City of Pacifica also considered draft policies for its Local Coastal Program (LCP) that would direct the evaluation of "the feasibility of using beach nourishment, in conjunction with sand retention structures (artificial headlands) to reduce shoreline structure maintenance requirements and maintain beaches of at least 100 feet in width on average" (City of Pacifica 2018b).

Further south, the City of Carpinteria (City of Carpinteria 2019) and Ventura County (Ventura County 2019) have published documents that include the concept of sand retention through "cobble-based berms" shaped like groins. As the Ventura County draft strategies report concludes for Ventura's North Coast:

> The nearly unidirectional longshore sediment transport along the North Coast makes sand retention relatively feasible and effective. It's believed this could be done using traditional techniques such as groins, or by using more innovative, nature-based approaches such as erodible cross-shore cobble berms. Boulder-size groins are generally aesthetically unappealing, impede access, and permanently alter the configuration of the shoreline... cobble berms that are shaped like groins may be the only short-to-midterm nature-based adaptation strategy suitable for this area. Though feasibility studies from technical experts would be needed prior to moving forward with the untested, more progressive, nature-based approaches like erodible cross-shore cobble berms. The report suggests that such cobble berms may be effective on a 2-5 year timescale, depending on annual storm activity.

Clearly the strategy of sand retention by means of groins or groin-like structures is receiving significant attention in current sea-level rise adaptation assessments, particularly as a short or medium-term option for protecting beaches and developed shorelines. A logical next step is to identify specific stretches of shoreline in southern California where groins may offer a feasible and more environmentally sound solution to stabilizing the shoreline. Potential pilot projects could be constructed where the benefits of retaining littoral sand before it is funneled offshore to a submarine canyon are evident. These projects can be monitored to determine the efficacy of this management solution on a broader scale.

The case of Broad Beach in Malibu is interesting to consider in this light. Homeowners there have been struggling to implement a beach erosion management strategy since at least 2010, when an approximately 4,150-foot-long emergency revetment was constructed to protect beachfront homes and septic systems. The homeowners subsequently formed a Geological Hazard Abatement District

Figure 28. Artificial headlands concept, City of Pacifica Sea Level Rise Adaptation plan (Source: City of Pacifica 2018a) .

(GHAD) to finance a long-term plan, and in 2015 the Coastal Commission approved a project to periodically replenish the beach and cover the revetment with constructed dunes (CCC 2015). However, there is considerable uncertainty about whether the project will be successful at maintaining Broad Beach over the long term without frequent replenishment efforts. In addition, the project has encountered many challenges, including difficulties meeting the Commission's permit conditions, trouble finding suitable sand, opposition and litigation from inland communities affected by the proposed trucking of sand, and in-fighting among the GHAD members over the public access conditions and assessment fees (e.g. Malibu Times 2019; Broad Beach GHAD 2019). In the meantime, the beach and public access have yet to be restored (there has been very little beach to speak of except at low tides for almost 10 years; Figure 9), the project costs are now estimated to be over $50 million, and it is unclear if and when the project will begin.

Interestingly, the construction of five groins along Broad Beach at approximately 1,000-foot intervals was considered early in the environmental review process, but was eliminated through preliminary screening based on feedback from regulators that it would "not be a viable option moving forward" (Moffatt & Nichol 2010). The review concluded that such an alternative had "the potential to substantially extend the life of a renourished Broad Beach and may reduce the frequency of future needed renourishment events." However, the review also concluded that the project would interfere with lateral public access and longshore sand transport:

Exposed rock groins would tend to interrupt access along the low tide beach and berm face causing beach walkers, joggers and other users to have to detour inland around elevated portions of the groins. This effect would become more pronounced over time as sand is gradually lost down-coast, particularly after cessation of nourishment activities, eventually even obstructing such access over the long term. In addition, this alternative has the potential to materially impact down-coast beaches by interrupting or reducing longshore transport of sand, particularly during times of erosion on Broad Beach when the groins would retain a greater proportion of sand from longshore transport. This effect would become more pronounced after cessation of nourishment by the BBGHAD when the groins would interrupt an ever increasing proportion of the limited amount of sand moving downcoast across Broad Beach. Further, preliminary interactions with the regulatory agencies by the applicant's team indicate that a groin field may be found inconsistent with adopted plans and policies and would thus not be a viable option moving forward (CSLC 2014).

In addition to this review, the California Department of Fish and Wildlife had raised concerns about the potential impacts of the project on the marine habitats of the adjacent Point Dume State Marine Conservation Area (SMCA) and Point Dume Marine Reserve. The placement of groins, therefore, may not be supported by the Department of Fish and Wildlife, though the regulations of the Point Dume SMCA, where the groins would be placed, do allow exceptions to regulatory restrictions for "beach nourishment and other sediment management activities" if properly permitted (CDFW 2019).

It has been five years since the environmental review of alternatives at Broad Beach, and nearly 10 years since the emergency revetment was placed in response to erosion. Given this delay, the potential sand retention benefits of a groin alternative at Broad Beach, and the uncertainty of both whether the project will eventually get underway and if so, whether it will work, it may be worth reconsidering a groin strategy, at least as an interim, short- to mid-term adaptation strategy.

As the case of Broad Beach suggests, in California, beach replenishment is an expensive and perhaps short-lived approach to managing the shoreline in the face of sea-level rise. The construction of groins, in conjunction with a replenishment project, may offer a solution that will stabilize the shoreline while larger dam removal projects and other adaptation strategies come to fruition, and may also allow for rock revetments and seawalls to be removed, thus restoring the natural supply of sand to the beach. These groins must be well thought out and engineered within the broader scope of regional sand management, with particular attention to the sand budget of downdrift beaches.

Groins can be constructed using a variety of materials and dimensions, each with their own effect on littoral drift. It is time to be creative in our thinking and manage our sand with a regional scope and forward thought. Varying groin height, length, and material will retain

different volumes of sand and create a variety of beach widths depending on sand supply and littoral drift rates. With a pilot project or two, groins could be lengthened over time and additional groins could be built either up- or downcoast depending upon the specific shoreline conditions and the local objectives. They can also be built of timber, rock, or concrete so as to mimic natural rock outcrops.

There are a number of individual areas in southern California where sand is in short supply, beaches are narrow, and retention could be used to widen or stabilize local beaches, thereby adding valuable recreational area and providing a buffer for back beach infrastructure or development. A few specific areas to consider would include: Isla Vista in Santa Barbara County (Figure 8), Broad Beach in Los Angeles County (Figure 9), and Oceanside, Encinitas, and Solana beaches in northern San Diego County (Figure 6). In addition, a groin or groin field may be used up-coast from Mugu Submarine Canyon to capture the more than 1 million cubic yards of sand that is funneled offshore. This sand may be used as a source of compatible sand for downcoast beaches such as Broad Beach.

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