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Special Issue

Planning for Beach Resilience: A Framework for Understanding Beach Appropriation and the Coastal Squeeze

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Abstract

California is expected to face significant beach loss due to coastal squeeze by 2100 without effective adaptation. Recognizing the importance of beaches to California's social, cultural, economic, and environmental fabric, the state is developing the California Beach Resiliency Plan (CBRP). The CBRP will assess beach vulnerability and guide local adaptation through an interdisciplinary framework that addresses geophysical processes, access and recreation, economic and ecological values, cultural significance, development pressures, justice, and governance. This framing of beaches as complex socio-environmental systems may be useful for supporting efforts to sustain beaches as vital public spaces in the face of sea level rise and increasing coastal constraints.

Keywords: Beach Access; Coastal Squeeze; California Coast; Beach Resilience; Socio-Ecological Systems; Coastal Governance; Climate Adaptation.

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Introduction

Beaches are valued worldwide as places of cultural expression, recreation, commerce, ecological function, storm buffering, beauty, and sustenance. The private appropriation of beaches is also widespread, though its forms and resulting conflicts vary (Low, 2025). Understanding this variation is key for those seeking to preserve beaches as vital public spaces. However, global sea level rise (SLR) and the *coastal squeeze* – the eventual disappearance of beaches trapped between rising seas and fixed human developments, like seawalls and urban infrastructure – may render such understanding and the goal of preserving beaches moot.

To address beach privatization and the coastal squeeze, it is important to understand the physical and social dynamics of beach change. This article focuses on California, where public beach access is highly valued. It outlines the California Beach Resiliency Plan (CBRP), a new interdisciplinary initiative for helping communities address SLR, beach loss, and the often competing social, ecological, and governing factors that determine the resilience of beaches. The CBRP was initiated and funded by the California Ocean Protection Council (OPC) to support the agency's mission to "protect California's coast and ocean by advancing innovative, science-based policy and management, making strategic investments, and catalyzing action through partnerships and collaboration" (California Ocean Protection Council, 2025). The CBRP is being developed by a multidisciplinary research team led by the Ocean and Coastal Policy Center at the Marine Science Institute, University of California, Santa Barbara.

California has a long history of proactive beach management and protection of public shoreline access and recreation. But climate change and global sea level rise now jeopardize both this legacy and the long-term resilience of California's beaches. California's coast is also under stress from an increasingly complicated political landscape, one with a multitude of overlapping regulatory jurisdictions and competing development interests. In response to increasing pressures to balance housing needs, climate adaptation, and economic development, California is seeing a growing call for regulatory streamlining and legislative reforms to facilitate housing solutions in coastal areas.

At the same time, this debate has reinvigorated longstanding private property rights interests that advocate for adaptation solutions that don't require strict regulation or relocation of residential development out of coastal hazard zones (such as managed retreat) (Karlamangla, 2025; Bittle, 2023). Nonetheless, recent polling suggests that California remains largely committed to its legacy of beach protection, with about nine in ten adults saying that "the condition of oceans and beaches is very important or somewhat important to California's future economy and quality of life" (Public Policy Institute of California, 2025). In this context of diverse opinions about coastal management, the CBRP will produce a statewide framework and decision support tools to guide beach adaptation at the local community level.

While the CBRP may support California's statewide commitment to beach resiliency through strategic and interdisciplinary planning, long-term action will depend on funding and collaboration for its implementation. Local communities will need the capacity to navigate trade-offs among often competing uses and values for the beach. In anticipation of such implementation, this article examines the major dimensions of the CBRP framework in relation to the challenge of climate change, beach resiliency, and public beach access.

It suggests that viewing beaches as complex socio-ecological systems (as proposed in the early development of the CBRP) may be a useful shared framework for understanding how private beach appropriation and resilience are linked, the trade-offs between conflicting beach values and functions, and how public beaches may be better sustained in a changing climate. The article authors are members of the CBRP research team, and one is an employee of the funding agency (OPC). However, the conclusions herein are not intended to (nor do they) represent official California policy concerning public beach access and management.

The California Case: from expanding neach access protection to the Coastal Squeeze

California's coast has been inhabited by humans for at least 14,000 years, and evidence suggests significant connections to and use of coastal and marine resources by people. The population of California is estimated to have been around 310,000 at the time of European contact (16th-18th centuries), with tragic and dramatic reductions to perhaps 20,000 by 1900 as colonial populations steadily expanded (from Spain, Mexico, the U.S., and other places). Post-contact coastal population growth was driven primarily by maritime commerce, logging, the California gold rush, and expanding rail transport supporting economic growth. By the late 19th and early 20th century, a coastal leisure economy had also started to contribute to increasing tourism and development from San Diego to San Francisco (ICF *et al.*, 2013).

California experienced accelerating population growth in the early 20th century, with increasing conflict between private development and public interests regarding the use and enjoyment of the shoreline. Though California's 1879 Constitution provided for access to tidelands for any public purpose, expanding governmental grants and sales of tidal areas to private interests for development prompted the California legislature to prohibit such transfers in 1909. Subsequently, the protection of the various public interests in beaches became a key component of a statewide movement to expand public park holdings.

A state bond act to acquire new state parklands overwhelmingly passed in 1927, and in 1929, Fredrick Law Olmsted completed a survey of potential park acquisitions for the state. Concerning the shoreline and beaches, Olmsted was clear-eyed that "the values at stake along a thousand miles of almost unwatched tideland boundary, with many thousands of aggressive private neighbors ready to take an ell where they can get an inch, are too vast to be left longer without vigorous safeguarding" (Olmsted, 1929, p. 23). Olmsted's report focused on the need for acquisition of coastal lands and proactive regulation of private development along the shoreline to avoid the "short-sited and publicly injurious" exploitation of the coast.

On the heels of Olmsted's report, a joint legislative committee recognized that "[t]he future prosperity of the State and the happiness of its citizens in a large measure depends upon the manner in which the waterfront from Oregon to Mexico is developed by both governmental and private agencies (California Legislature, 1931). The committee also recognized that while the state held the land below the mean high tide in trust for the public, most coastal land above the mean high tide line was private. It specifically embraced Olmsted's call for increased public acquisition of coastal uplands for recreational uses as well as acquisition of land between existing public roads and the shoreline to increase public access to tidelands. Perhaps in response to Olmsted's call for more proactive state intervention, the committee observed how increasing public coastal lands might also "protect [...] the private owners of upland beach areas from trespass and from increasingly insistent demands for legislation of a radical character" (*Id*., p. 365).

California increased its coastal state park holdings significantly in the ensuing decades, but rapid growth also continued, particularly in the post-WWII period. By the 1960s, unregulated development was further degrading the coast, steadily reducing public shoreline access, just as Olmsted had foreseen. In the San Francisco Bay Area, uncontrolled filling of the Bay led to the creation of the first state coastal management agency – the San Francisco Bay Conservation and Development Commission (BCDC) – in 1965.

Among other things, BCDC was tasked with protecting the Bay's wetlands and providing public access along the shoreline. BCDC was also inspirational for a statewide political movement to protect the outer coast. Voters passed the 1972 Coastal Initiative, declaring that "the California coastal zone is a distinct and valuable natural resource belonging to all the people." Four years later, the legislature enacted the California Coastal Act to implement this vision. The legislature also created a state Coastal Conservancy to continue coastal land acquisition and provide funding for public access and environmental restoration projects. Meanwhile, the California Department of Parks and Recreation continued to expand the state park system, including along the coast (Lester, 2013).

The Coastal Act created the California Coastal Commission (CCC) to regulate development and protect public shoreline access and other coastal resources. The law affirmed the original 1879 constitutional right-of-way to the navigable waters when required for a public purpose (California Constitution, Article X, § 4) and established a mandate that "maximum access . . . be provided for all the people consistent with public safety needs and the need to protect public rights, rights of private property owners, and natural resource areas from overuse" (California Public Resources Code (PRC), §30210). The Act also required that new development enhance public access and avoid interfering with existing access (California Public Resources Code (PRC), §§ 30211-30212).

To implement these (and other) statewide coastal protection mandates, the Coastal Act required local governments to create land use plans and zoning ordinances (Local Coastal Programs or LCPs), to be approved by the Coastal Commission. Once an LCP was approved, local governments could then assume the Commission's regulatory authority over new development above the mean high tide, with some appellate oversight by the Commission. The Commission retained its authority over development on state tidelands. The Coastal Act thus finally established the comprehensive planning and regulatory program for coastal management that Olmsted and others had called for fifty years earlier.

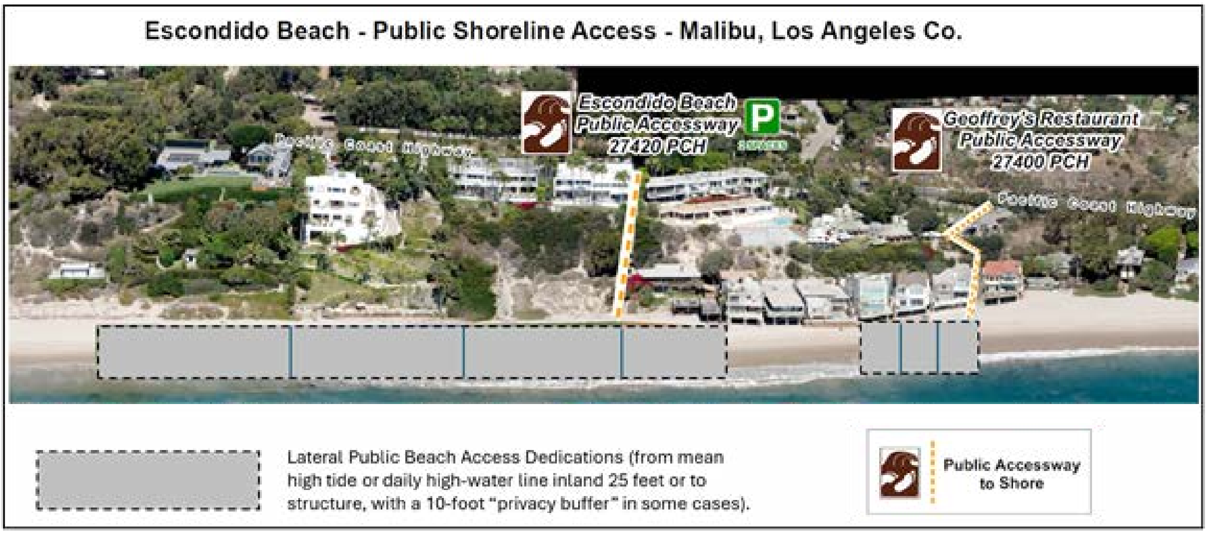
The Coastal Act was born out of the public concern for the increasing degradation of the California coast. However, it was also part of the larger modern environmental movement that saw the creation of many environmental planning and regulation programs, including the Clean Air and Water Acts, protection of sensitive species and wildlife, the regulation of toxic chemicals and dumpsites, and new environmental assessment requirements at the state and national level. The birth of the California coastal program also coincided with the creation and became a part of a national coastal zone management program, managed by the National Oceanic and Atmospheric Administration (NOAA). By the end of the 1970s, comprehensive planning in the coastal zone, including protecting and providing for public shoreline and beach access, was firmly ensconced in California as part of a larger coastal and environmental protection ethic (*Id*.).

The protection of public beach access is one of the great successes of the California coastal program. Since 1977, the CCC has secured over 1,600 public access beach dedications to mitigate development impacts (Lester, 2022). Most of these are "lateral" areas between new or redeveloped private beach homes and the mean high tideline, though nearly 200 are "vertical" accessways from the first inland public road to the shoreline (Figure 1). The CCC has also opened many beach areas that might otherwise be private, blocked by development, or behind locked gates, including stretches of the Malibu coast, luxury hotels, and exclusive resort areas such as the Pebble Beach Golf Course in Monterey (Figure 2).

Not without controversy, beach access litigation is common. In 1987, a CCC decision requiring a private home to dedicate beach access reached the U.S. Supreme Court, where it was overturned in a 5-4 decision that concluded, based on the case facts, that the Commission had an insufficient basis for requiring public access (Nollan, 1987). The case is significant in U.S. property law and may have had a chilling effect on subsequent CCC actions to secure access dedications. Still, the agency has continued to expand public beach access through its planning and regulatory program (*Id.*). These efforts include enforcement of Coastal Act public access requirements, particularly in urban areas where tension between residents and beach visitors is common. In 2020, the CCC fined thirty-three Newport Beach homeowners $1.7 million for public beach encroachments (California Coastal Commission, 2020). That same year, a court upheld another CCC order against a homeowner to remove an illegal seawall and pay a $1-million fine (11 Lagunita, 2020).

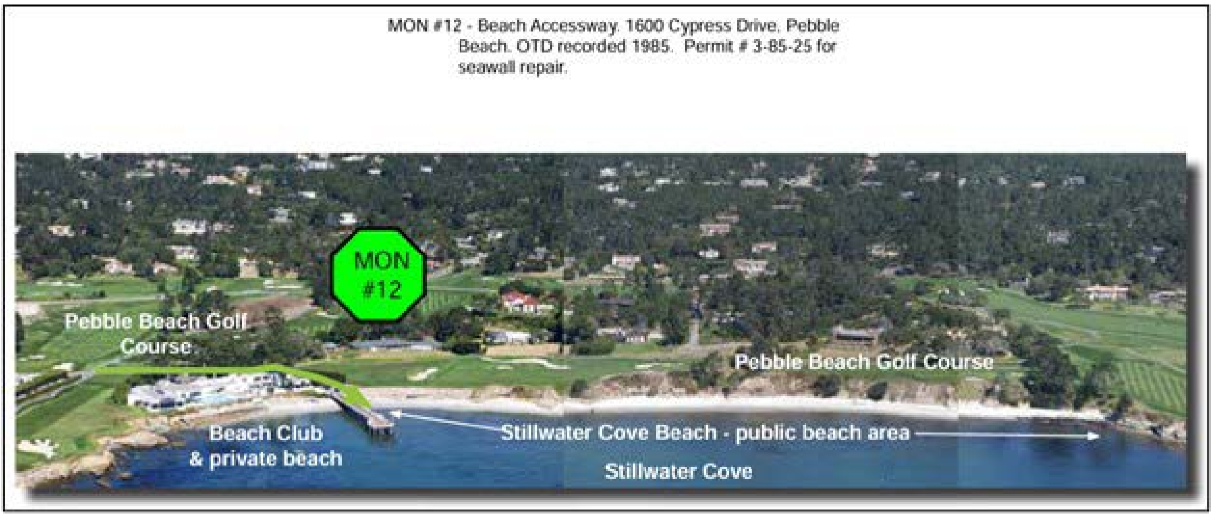
California's success in protecting and expanding public beach access is widely recognized, yet global sea level rise threatens to undue this accomplishment. Sea levels could rise between 1.6 and 3.1 feet by 2100 (California Ocean Protection Council, 2024), perhaps causing the loss of 24% to 75% of southern California sandy beaches by the end of the century. This is largely due to "coastal squeeze" – the gradual inundation and erosion of beaches that are increasingly backed by hardened, non-erodible shorelines (Vitousek *et al.*, 2017). As beaches disappear, so will their ecosystem services, including habitat, storm buffering, and public access. One study estimates that 100 access sites could be lost for every foot of SLR (Patsch and Reineman, 2024). The decreasing supply of public beach access also may be exacerbated by higher demand as people in increasingly hotter inland areas seek relief in the relatively cooler coastal zone (California Coastal Commission, 2024). Meanwhile, California's total population is expected to increase by about 5% or nearly two million people by 2070 (California Department of Finance, 2025).

Figure 1. Example of Beach Access Dedications in Malibu, California.



Source: Adapted from California Coastal Commission, n.d.)

Figure 2. Public Beach Access Dedication at the Pebble Beach Golf Course.



Source: California Coastal Commission, 2016.

The coastal squeeze will also intensify fundamental legal conflict between public and private property interests. As discussed, California has recognized since its inception that tidelands carry inherent public interests, a principle dating back to Justinian's 533 proclamation that the seashore is "common to all" by virtue of natural law (Moyle, 1913). Under the U.S. and California Public Trust Doctrines, only specific public uses, such as commerce, fishing, recreation, and protection of natural resources, are permitted on tidelands. Private residential uses generally are not. California's tidelands (between the mean low and high-water lines) are held in trust for the people for "statewide public purposes" (Lester, 2021). The California State Lands Commission – another important state coastal management agency in California – manages these lands and has authority to remove trespassers or issue leases to use tidelands, provided the use does not cause "substantial impairment" to the public interest (Illinois Central, 1892).

Depending on the slope of a beach, the boundary between public tidelands and private uplands will move as much as 150 feet inland with three feet of SLR – a distinct possibility in the next 50-75 years (Figure 3). This could result in hundreds of private encroachments on public tidelands, prompting disputes over trespass and raising complex property law questions for the State Lands Commission and the courts. The Coastal Commission and local governments may also face challenges implementing the Coastal Act, as the law specifically recognizes the Constitutional requirement to protect public access to tidelands. How these disputes are resolved will shape the future balance between public and private interests along many miles of shoreline (Lester, 2021).

Figure 3. Shoreline Change with 3.3 feet (1 meter) of SLR in Del Mar, CA.

Source: Lester, 2021.

Sea Level Rise And The California Beach Resiliency Plan

The state of California and its coastal management agencies have long recognized the significant threat of climate change and global sea level rise to both shoreline development and important coastal resources, particularly beach access and recreation. Over the last two decades, gubernatorial executive orders have directed California's agencies to plan for sea level rise. Multiple statewide bond measures have directed billions of dollars toward climate change response. Since 2013, the CCC has supported LCP updates to address sea level rise through a grant program to local governments and with comprehensive guidance (2015). More than two-thirds of the 76 communities on the outer coast have completed sea level rise vulnerability assessments, and about a third have completed adaptation plans – many of which address the projected loss of beach resources, including public access (Lester *et al.*, 2023). Most recently, state law was amended to require local governments to prepare sea level rise adaptation plans, and significant funding was given to OPC to support this planning.

OPC has also identified a central concern for beaches in its Strategic Plan, especially the loss of beach habitat due to sea level rise (California Ocean Protection Council, 2020). Accordingly, in December 2023, the OPC approved funding for the completion of the California Beach Resiliency Plan (CBRP) to address future beach loss by assessing the values and functions of California's beaches, evaluating their vulnerability to climate change, and providing a framework to help local jurisdictions prioritize beach adaptation strategies.

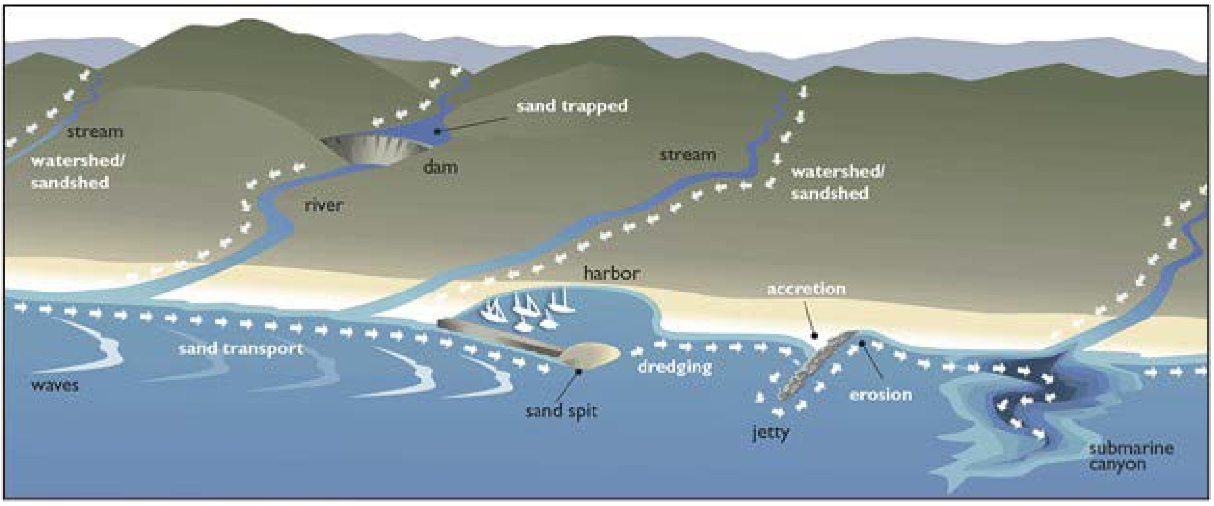
The CBRP will also offer recommendations to address beach resiliency statewide (California Ocean Protection Council, 2023). The plan will include modeling linking beach behavior with cliff retreat to better project beach change and support evaluation of beach values vulnerable to SLR, including ecology, risk mitigation, public access, cultural and tribal significance, economics, and social equity. The goal is to help communities identify key strategies to prioritize specific beaches and adaptation approaches to achieve their resilience goals. The following sections briefly describe the core dimensions of the CBRP currently being developed by a multidisciplinary research team.

Geophysical Drivers of Beaches and Resiliency

Beaches are shaped by sediment transport, wave energy, tides, and sea level. Understanding these processes is essential to predicting how beaches will respond to human activities and environmental change, like SLR. Coastal watersheds collect and channel surface water – and sediment – toward common outlets like rivers or oceans. California's rivers historically supplied the sand that nourished beaches. But dams, urbanization, and channel modifications have disrupted these flows, leaving many beaches sand-starved. Coastal cliffs, especially those made of soft material, provide supplemental sand to the beaches, if not armored with a seawall.

Sandsheds – also called littoral cells or beach compartments – are semi-enclosed zones where sediment sources (rivers, cliff and dune erosion, onshore transport) and sinks (losses to submarine canyons offshore and dune formation) interact (Figure 4). Headlands and submarine canyons often define their upcoast and downcoast boundaries. Longshore drift, driven by wave angles and nearshore currents, moves sand along the California coast, primarily southward in winter and northward in summer, reshaping beaches seasonally. Disruptions of sediment supplies to a sandshed, like a river dam, sand mining, or cliff armoring, may increase beach erosion. Regional sediment management strategies aim to restore sand supply by removing barriers or bringing sediment to the shoreline.

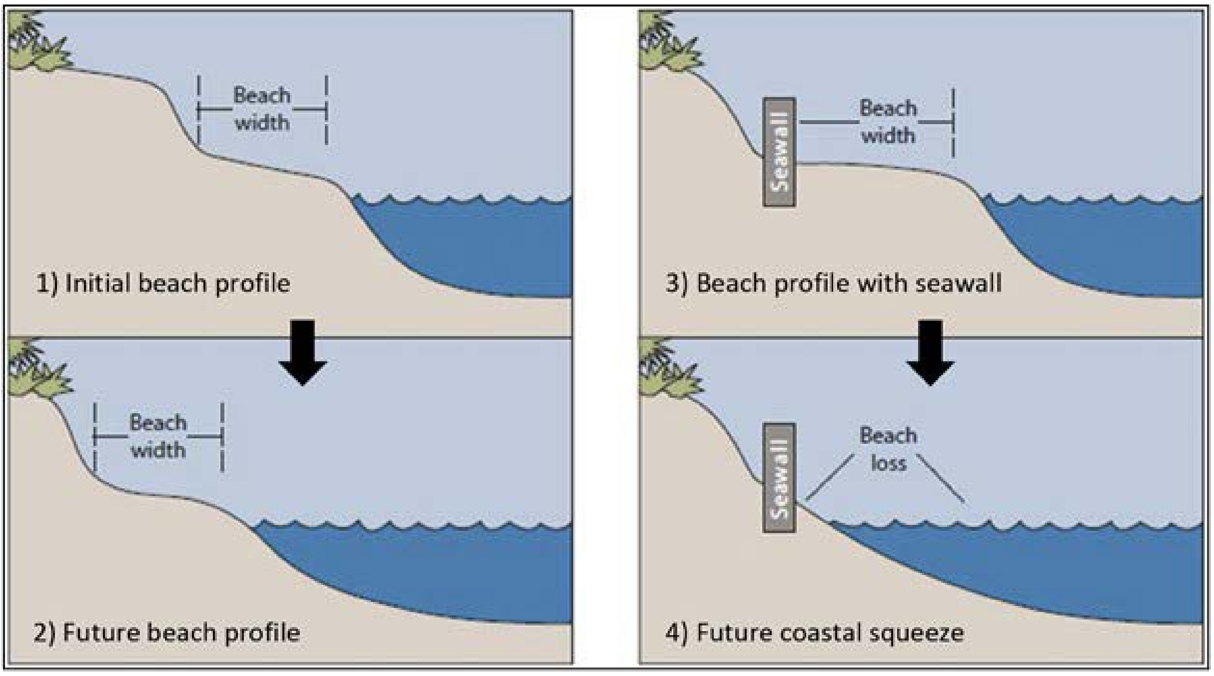
Figure 4. The Sand Shed.



Source: Explore Beaches, 2025. Available on: https://explorebeaches.msi.ucsb.edu/sandy-beach-life/sand-movement. Access on: 08 nov. 2025.

SLR drives long-term beach change through shoreline migration or transgression. The ability of a beach to persist under rising seas depends largely on *accommodation space*, or the landward area available for natural retreat and sediment deposition. Where bluffs, seawalls, or urban infrastructure block this space, coastal squeeze causes beaches to narrow or disappear (Figure 5). Beaches with ample sediment and accommodation space, such as those backed by dune fields, may maintain their width and buffering functions. California's urban beaches are facing severe constraints, and some say sustained investment in large-scale beach nourishment increasingly may be needed to offset the coastal squeeze.

Figure 5. Sea Level Rise, Coastal Squeeze, and Beach Loss.



Source: California Coastal Commission, 2018. https://documents.coastal.ca.gov/assets/climate/slr/vulnerability/residential/RevisedDraftResidentialAdaptationGuidance.pdf. Access on: 08 nov. 2025.

2. Ecology of Beaches

Sandy beach ecosystems are part of a larger system that connects the surf zone, beach, and backshore. To a casual visitor, California's beaches may appear relatively empty of life. No plant life can persist on the shifting sand of open beaches, and most of the characteristic intertidal animals are small, highly mobile, and difficult to see. Yet, beaches support diverse communities of resident and transient species, including those that forage, nest, or overwinter along the coast.

Beach ecosystems perform vital functions. They absorb wave energy, filter seawater, and recycle nutrients. Fueled by cool, phytoplankton-rich upwelled waters and connected to productive kelp forests, California's beaches support some of the most diverse intertidal invertebrate beach communities ever documented. These invertebrates, in turn, support fish like surfperch and corbina, which are important for human shore fishing and wintering shorebirds. Beaches also provide critical habitat for wildlife, such as pinnipeds, declining and endangered bird species, and beach-nesting fish, like California grunion and surf smelt.

The upper shore zones of the beach are expected to suffer the greatest ecological impacts from the coastal squeeze (Barnard *et al.*, 2021; Jaramillo *et al.*, 2021). These dynamic zones offer refuge for mobile animals during storms and provide nesting areas for species like the western snowy plover and grunion. At their landward edge, these upper zones can also support pioneering plants that trap sand and help build dunes, enhancing resilience to SLR. However, these also are often the most intensively modified by infrastructure, residential development, beach grooming, and recreational activity.

Upper zones of armored beaches tend to be narrow and truncated (Figure 6) but are typically wide yet ecologically degraded on groomed beaches (Dugan *et al.*, 2008; Dugan and Hubbard, 2010). Armoring and grooming both reduce ecosystem function and biodiversity (Dugan and Hubbard, 2010; Jaramillo *et al.*, 2021; Schooler *et al.*, 2019). Implementing management practices that shape the extent and condition of upper beach zones, such as dune restoration (Figure 7, Johnston *et al.*, 2023; Emery *et al.*, 2024) and managed retreat, can provide opportunities to increase beach ecosystem condition and resilience to SLR.

Figure 6. Loss of the upper beach zone at low tide on an armored beach.

Source: (Dugan et al., 2018 ; photo credit: E. Jaramillo, 2009).

Figure 7. Dune restoration on a groomed urban beach.

Source: (Johnston et al., 2023, Photo credit K. Emery, 2022).

3. Beach Access and Recreation

Beaches are essential public spaces offering diverse access and recreational experiences. Access is more than physical entry points; it includes informal paths, adjacent neighborhood routes, and transportation systems for visitors' movement. *Meaningful* access ensures that people with varied backgrounds, abilities, and interests can reach and enjoy the beach. An access experience may depend on amenities, safety, water quality, and crowding. Understanding beach access involves key questions such as:

- Are there well-maintained paths, boardwalks, and infrastructure, including for those with mobility challenges?
- Is access affordable, with free or low-cost parking, lodging, and transit options?
- Are signs, amenities, and programming culturally and linguistically inclusive?
- Are there adequate facilities such as restrooms, picnic areas, and lifeguards?
- Do available recreational opportunities support diverse interests?

Balancing public access with beach quality raises complex questions, especially in a state that mandates "maximum access." Should *all* beaches be maximized for visitation? How would that affect user experience or ecological function? In some cases, preserving more remote or undeveloped beaches may be appropriate.

California's coast offers a diversity of access opportunities that serve different geographic areas and patterns of visitation. Most beachgoers are residents, with people frequenting beaches closer to them (Christensen and King, 2017). Nonetheless, some may travel farther based on parking availability, facilities, or specific coastal conditions they seek (Patsch and Reineman, 2024). Some beaches, such as Venice or La Jolla, may attract national and international visitors. Understanding beach visitation patterns helps identify access disparities, especially for inland or lower-income communities facing higher travel costs and other barriers (Reineman *et al.*, 2016). Access-shed analyses utilize tools, including geospatial models and cell-phone mobility data, to map visitation patterns and identify communities that may depend on specific beaches (Reineman and Patsch, in review). This information can support the provision of more equitable access by showing who benefits or may be excluded from existing access opportunities.

4 Economics

Beaches are vital public assets that generate significant economic value through tourism, recreation, and local commerce. Economists assess both market and "non-market" beach value – the worth people assign to goods and services not directly priced. Studies suggest that, adjusted for inflation, the non-market value of an average beach day in California in 2025 is $62, summed to billions annually across the state, including $2 billion in San Diego County alone (Pendleton and Kildow, 2006). Beaches also have "existence value" – the non-market valuation of beaches by people, even if they never visit them.

Visitors' spending varies by beach location, amenities, and lodging types. Urban beaches typically generate more spending per visitor because they are near restaurants, shopping, and entertainment. Overnight visitors, particularly those staying in hotels or short-term rentals, contribute substantially more to local economies than day-trippers. In contrast, campers or those staying with friends or family spend less, though lower-cost options improve access equity. The specific types of beach recreation and amenities, from sunbathing to surfing, hiking, volleyball, camping, and bonfires, also influence the economic value of certain beaches.

Lodging near beaches generates a crucial part of the revenue for local governments through Transient Occupancy Taxes (TOT), typically ranging from 10 to 15%. Urban beaches with more hotels or rentals often generate several times more TOT revenue than rural beaches with limited accommodations. TOT funds support public safety, infrastructure, and beach management. Visitors' spending also generates sales tax revenue through purchases at restaurants, retail shops, and recreational businesses. While the state collects a base sales tax of 6%, local jurisdictions often add between 1.25% and 3.25%, sometimes for specific projects such as transportation.

Beach spending varies significantly depending on the socioeconomics of beach visitors as well as the availability of restaurants, hotels, and other places where they typically spend money. Wealthy communities such as Manhattan Beach or Santa Barbara in southern California receive significantly higher spending per visitor than do many less urban beaches or beaches adjacent to less advantaged communities. This disparity in revenue can create a "have and have not" impact on local communities, raising the question of whether State and Federal authorities should actively address these disparities by subsidizing beaches that serve disadvantaged communities. On the cost side of community finances, SLR and beach erosion pose growing financial risks. One study projected hundreds of millions in lost tourism and tax revenue due to 4.6 feet of SLR by 2100, including:

- Ocean Beach (San Francisco): $82 million
- Venice Beach (Los Angeles): $439.6 million.
- Zuma & Broad Beach (Malibu): $498.7 million.
- Carpinteria City and State Beach (Santa Barbara): $164.7 million.
- Torrey Pines City and State Beach (San Diego): $99 million (King *et al.*, 2011).

Sustaining the economic benefits of California's beaches will require proactive investment. Coastal cities must evaluate the long-term costs and benefits of adaptation strategies. Comparing options such as nourishment, living shorelines, hard armoring, or managed retreat can help decision-makers develop fiscally responsible and environmentally sound plans. Land use decisions, such as building a new hotel or retiring oceanfront development, may also influence the balance between beach revenue generation and preservation of coastal character and access.

5 Tribal Communities

California's beaches are ecological and recreational spaces, but they also belong to the cultural landscapes of Indigenous peoples. For millennia, coastal tribes such as the Chumash, Yurok, Amah Mutsun, Coast Miwok, and Ohlone have relied on beach and nearshore ecosystems for ceremony, subsistence, trade, and social life. Beaches supply them with fish, shellfish, seaweed, and medicinal plants. They were connected to inland villages through seasonal migration, and coastal tribes managed shoreline zones through systems of tenure and sustainable harvesting practices (Lightfoot and Parrish, 2009).

Shoreline adaptation efforts in California are increasingly recognizing tribal relationships to the shoreline (Lester *et al.*, 2024). While tribal ownership of coastal lands remains limited due to historical dispossession, several tribes, such as the Yurok and Elk Valley Rancheria, are actively engaged in vulnerability assessments and climate adaptation planning. The designation of the Chumash Heritage National Marine Sanctuary in 2024 exemplifies a co-management approach to institutionalize tribal leadership in ocean and shoreline governance. These actions reflect an important evolution in California's adaptation planning framework: one that seeks to incorporate Tribal values, ecological knowledge, and sovereignty into future-oriented strategies.

Beach resilience is often defined by its geomorphic stability, ecological function, and capacity for hazard mitigation. However, resilience should also include the ability of coastal places to support cultural survival, spiritual renewal, and intergenerational knowledge. This broader understanding of resilience, grounded in social relations and reciprocity, enriches prevailing adaptation frameworks by emphasizing relationships with place rather than just physical assets. This understanding may be deepened through such questions as:

- How do tribal communities value and use sandy beaches today, and how are these relationships changing in response to climate change and SLR?
- What does "beach resilience" mean from a Tribal perspective, and how might these views inform adaptation strategies?
- How can co-management and "land back" initiatives be incorporated into adaptation strategies?
- Where are tribal perspectives currently absent in beach planning, management, or climate adaptation programs?
- How can traditional ecological knowledge and Western science engage in fruitful and reciprocal dialogue?

These questions point toward a more inclusive and relational approach to beach resilience, which acknowledges historical exclusion, supports tribal sovereignty, and centers long-standing cultural practices in the face of accelerating coastal change.

6 Environmental Justice

Beaches are spaces where power, access, ownership, and ecological vulnerability intersect. Power is exercised both structurally, as elites reshape coastal spaces and consolidate control (Bruno and Salle, 2017; 2018), and relationally, through social networks that influence policy and planning decisions (Clarke, Tually, and Scott, 2016). These dynamics play out through development, tourism, and industrial expansion, which have intensified pressures on coastal environments, contributing to habitat destruction, erosion, and pollution while also deepening racial and economic inequalities.

Scholars have called for a closer, deeper examination of coastal planning, particularly how the racialized history of coastal development informs present and future adaptation strategies (Hardy *et al.*, 2017; Jefferson, 2020; Kahrl, 2012). Recent efforts in California have advanced equity in coastal governance. In 2019, the California Coastal Commission adopted environmental justice principles into policy, affirming the coast as a public good rather than a privilege of the wealthy (California Coastal Commission, 2019).

Environmental justice (EJ) encompasses distributive, procedural, and recognition forms of justice. *Distributive justice* concerns the unequal distribution of environmental harms and benefits, including unequal access to coastal resources themselves. Marginalized communities often disproportionately bear the burdens of pollution, coastal erosion, flooding, gentrification, and climate risks. On the other hand, wealthier communities may enjoy more access to coastal resources and protections from harm.

Studies of Miami (Montgomery *et al.*, 2015) and South Korea (Kim, Lyu, and Song, 2019) show how inequities in beach access reflect broader environmental justice concerns, situating California's challenges within a wider global context of distributive exclusion. *Procedural justice* asks who has a voice in shaping shoreline adaptation, whose knowledge informs coastal decision-making, and whether it is fair. It refers to "how regulatory and participatory processes that contribute to EJ outcomes are structured to include or exclude particular concerns, amplify or silence certain voices, and create or deny opportunities for participation" (Johnson *et al.*, 2022, p. 66). At the same time, EJ must also grapple with the multispecies dimensions of coastal vulnerability and account for those who cannot speak for themselves. Scholars recognize that coastal disruption affects more-than-human communities with whom we inhabit and shape these environments (Gesing, 2021).

Recognition justice insists on "the necessity of centering the cultures, knowledges, and values of communities affected by environmental decisions[; it] demands respect for and adherence to affected communities' values, traditions, and epistemologies" (Johnson *et al.*, 2022, pp. 65, 70). This necessitates attention to situated ecocultural identities and the role of positionality in knowledge production (Castro-Sotomayor and Minoia, 2024; Milstein and Castro-Sotomayor, 2020).

Coastal conflicts are not only political and distributive, but also intrinsically moral: disputes often turn on competing visions of what a beach is and should be, whether as a space of leisure, commerce, cultural ritual, or ecological care. These moral contestations illustrate how exclusion can persist even in the absence of overt discrimination. For example, multiple intersecting obstacles continue to shape meaningful beach access. These include limited infrastructure and amenities for low-income and disabled communities, such as (according to Fingal (2019)):

- digital reservation systems that presume access to technology, digital literacy, and English-language fluency;
- cultural representations that perpetuate a coastal aesthetics of exclusion and privilege.

As beach loss intensifies, it threatens to exacerbate distributive, procedural, and recognitional inequalities. Too often, low-income communities and communities of color are excluded from coastal decision-making, even as they face the highest risks from SLR. To address procedural injustices, we must question whether official and institutionalized decision-making models truly foster meaningful participation. How do these models shape coastal policy in California? Do they reinforce existing power imbalances or allow agency and influence to emerge? Research suggests that coastal policy, as "a cultural artifact" demands building models of participation in coastal policy that value the knowledge and experiences of those who have the most to lose in decision-making (Foxwell-Norton, 2017, p. 5). Then, how can we design participatory frameworks that build community and institutional capacity while centering the knowledge and experiences of those most at risk, including both marginalized human communities and more--than-human life?

By analyzing the social decision-making infrastructure in place, an EJ approach seeks to build governmental and community capacity for diversifying representation, fostering engagement, expanding agency, and improving outreach. This entails recognizing "that vulnerability may be more complex than the mapping of economically-disadvantaged areas defined by census data" (Lester *et al.*, 2023, p. 98). The emphasis on procedural justice, community building, and grounded, place-based resiliency planning allows us to go beyond mapping social vulnerability withGeographic Informations Systems (GIS)and demographic information, to encompassing impacts on distributive and recognition justice.

7 Built Environment, Governance, and Adaptive Capacity

Despite the well-documented role of coastal squeeze in reducing the adaptive capacity of beaches, coastal armoring continues to expand along urbanized stretches of the California coast. Ensuring beach resiliency will require strategies that preserve natural processes and increase adaptive capacity for beaches to move inland. These include sediment management, dune restoration, nature-based shoreline protection, and managed retreat. This highlights the importance of California's governance system in guiding shoreline adaptation.

As discussed, the Coastal Act provides legal mandates for protecting resources, ensuring public access, and managing development. Local governments implement these through Local Coastal Programs (LCPs), which incorporate site-specific land-use and adaptation policies. Many cities and counties are now engaging in adaptation planning vulnerability assessments, which frequently identify beaches as highly exposed to long-term SLR. However, turning these assessments into meaningful policies and actions has proven more difficult. Fewer than one-third have adopted formal adaptation strategies, and less than a quarter have updated their LCPs to address SLR and beach-specific responses (Lester *et al.*, 2023).

Where planning has progressed, local strategies increasingly move away from reliance on hard infrastructure, identifying strategies such as sediment management, nourishment, dune restoration, adaptive setbacks, and phased retreat. These are tailored to local conditions and often follow a model that adjusts strategies over time in response to observed changes in shoreline vulnerability – so-called "adaptation pathways." This planning shows a growing willingness to address hard questions about beach loss, access, and equity.

Pragmatically, the persistence of beaches may increasingly serve as indicators of a region's adaptive capacity and readiness to govern through actionable policy. Still, moving from assessment to action is difficult, and a tension remains between near-term protection of property and long-term preservation of public beach space and function (*Id.*). The statewide California Beach Resiliency Plan intends to support the movement to meaningful local action by offering a shared science-based framework and decision tools to help address the competing values and functions inherent in the physical and social dimensions of beaches.

Conclusion: Beach Resiliency Planning – A Shared Framework For Understanding Beach Appropriation And The Coastal Squeeze?

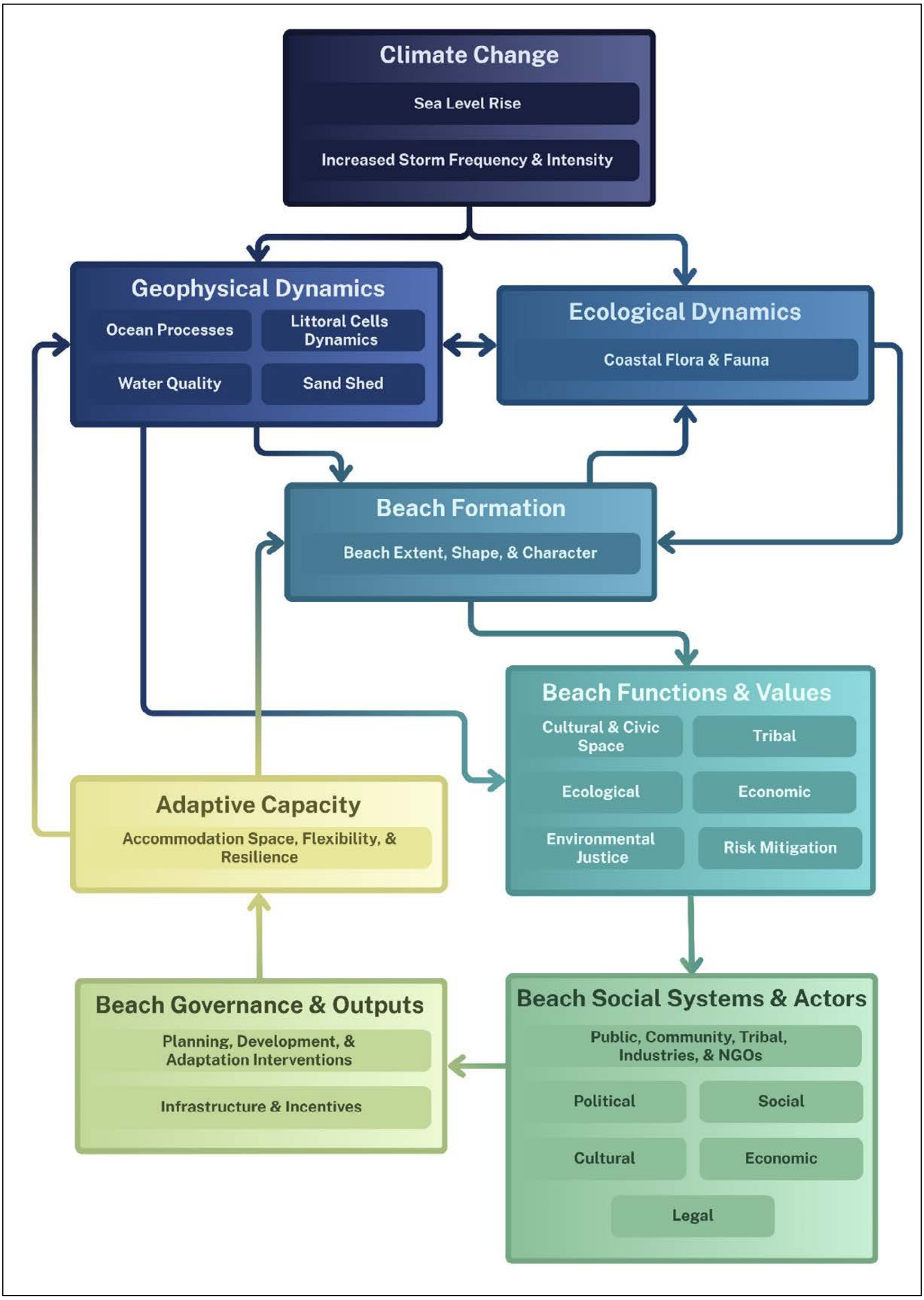
Sandy beaches are increasingly recognized as integrated socio-ecological systems (SES), shaped by interactions between ecological, socio-cultural, and economic values and functions (Defeo *et al.*, 2021; James, 2000; Rodil *et al.*, 2022). Beaches are dynamic environments affected by multiple stressors, including sea-level rise and extreme storms, as well as human impacts from urbanization, tourism, and armoring. These pressures can interact in feedback loops, moving systems toward thresholds and leading to shifts that threaten beach resilience (Berry *et al.*, 2014; Fanini *et al.*, 2020; Bianco and García-Ayllón, 2021; Schlacher *et al.*, 2008). The SES perspective refocuses attention away from single-purpose beach management frames (e.g., providing recreation or protecting ecology alone) to more comprehensive and multi-dimensional adaptive strategies that address ecological, socio-cultural, and economic vulnerabilities in relation to each other.

Several studies have applied this systems approach to practical tools, including resilience indices, assessment frameworks, and vulnerability metrics (Lucrezi *et al.*, 2016; McLachlan *et al.*, 2013; Bianco and García-Ayllón, 2021). Effective beach or coastal governance depends on adaptive, interdisciplinary methods, supported by ongoing monitoring and inclusive engagement with diverse stakeholders. Participatory methods such as citizen science are also emphasized as tools for improving environmental awareness and justice, deepening public involvement in the long-term stewardship of beaches (Fanini *et al.*, 2021).

Beach resiliency planning grounded in SES thinking offers a lens for analyzing how beach access, appropriation, and adaptation unfold across diverse settings. It highlights the dynamic interplay between geophysical processes, ecological functions, and social systems, including public access, economics, cultural expression, equity, and governance (Figure 8). Hence, beach resiliency concerns the *system's capacity* to maintain and enhance the core values and function of beaches in the face of environmental and social change. To what extent is the beach SES, confronted with the coastal squeeze, able to *resist*, *recover*, *adapt*, or even *transform* to provide its core values (Folke *et al.* 2016; The Intergovernmental Panel on Climate Change – IPCC, 2022)?

The SES approach allows comparisons across settings where beach ownership may range from more public to more privatized or commodified, as well as comparisons between legal and policy statements about public shoreline access versus the implementation practice of providing public access. These contrasts can reveal how legal frameworks, cultural norms, and environmental risks affect beaches and influence who benefits from coastal spaces. The framework also deepens understanding of the public law aspects of the coastal squeeze as a global trend accelerated by the privatization of the beach backshore. In California, shoreline armoring tied to private property entitlements is limiting beach migration and reducing public access, despite the Coastal Act's commitment to public coastal rights. But in places like Hawai'i, a more expansive legal definition of the public trust may enable more effective adaptations such as managed retreat (Hawai'i, 2025).

Figure 8. The Beach Socio-Ecological System.



Source: Prepared by the authors

The SES framework also highlights where strategies align or diverge in balancing ecological resilience and social equity. The inclusion of cultural, political, and legal context, including histories, highlights the role of structural inequities in shaping patterns of beach appropriation (Gray, 2023). In the U.S., *red-lining* – a discriminatory practice denying housing loans and investments in specific neighborhoods resulting in racial segregation – led to enduring patterns of inequitable land ownership, including closer to the coast and beaches (Rothstein, 2017).

This was a central reason why the original vision of the California Coastal Act presumed that "maximum access" included "opportunities for people of all incomes to live near the ocean" (California Coastal Zone Conservation, 1975, p. 10) – a recognition that economic power was central to realizing meaningful beach access. A half-century later, another (long overdue) recognition of California's tribal communities and their deep relationships with the coast further underscores how social, political, and cultural dynamics necessarily shape beach resilience. An SES perspective brings these relationships to the fore, supporting the possibility for more inclusive and thus transformative coastal adaptation (The Intergovernmental Panel on Climate Change, 2022; Ziervogel et al., 2016). By providing a common frame of reference for understanding beach appropriation and the coastal squeeze across diverse social settings, it may also help scholars and practitioners better realize their shared interests in protecting sandy beaches as vital public spaces.

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Planejamento para a resiliência das praias: uma estrutura para compreender a apropriação das praias e a compressão costeira

Resumo

A Califórnia enfrenta uma perda significativa de praias devido à compressão costeira até 2100, sem uma adaptação eficaz. Reconhecendo a importância das praias para o tecido social, cultural, econômico e ambiental da Califórnia, o estado está desenvolvendo o Plano de Resiliência das Praias da Califórnia (CBRP). O CBRP avaliará a vulnerabilidade das praias e orientará a adaptação local por meio de uma estrutura interdisciplinar que aborda processos geofísicos, acesso e recreação, valores econômicos e ecológicos, significado cultural, pressões de desenvolvimento, justiça e governança. Essa abordagem das praias como sistemas socioambientais complexos pode ser útil para apoiar esforços de manutenção das praias como espaços públicos vitais diante da elevação do nível do mar e do aumento das restrições costeiras.

Palavras-chave: Acesso à Praia; Compressão Costeira; Costa da Califórnia; Resiliência da Praia; Sistemas Socioecológicos; Governança Costeira; Adaptação Climática.

Planificación para la resiliencia de las playas: un marco para comprender la apropiación de las playas y la compresión costera

Resumen

California se enfrenta a una pérdida significativa de playas debido a la compresión costera para el año 2100 si no se implementa una adaptación efectiva. Reconociendo la importancia de las playas para el tejido social, cultural, económico y ambiental de California, el Estado está desarrollando el Plan de Resiliencia de Playas de California (CBRP). El CBRP evaluará la vulnerabilidad de las playas y guiará la adaptación local mediante un marco interdisciplinario que aborda los procesos geofísicos, el acceso y la recreación, los valores económicos y ecológicos, la importancia cultural, las presiones del desarrollo, la justicia y la gobernanza. Esta visión de las playas como sistemas socioambientales complejos puede ser útil para apoyar los esfuerzos por mantenerlas como espacios públicos vitales ante el aumento del nivel del mar y las crecientes restricciones costeras.

Palabras clave: Acceso a la Playa; Compresión Costera; Costa de California; Resiliencia de las Playas; Sistemas Socioecológicos; Gobernanza Costera; Adaptación Climática.

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