Sea level rise impacts on coastal access

By

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ABSTRACT

Climate change and associated sea level rise (SLR) will have substantial impacts on coastlines worldwide, threatening beaches, infrastructure, economies, and communities. In California, communities and individuals rely on the state's public coastal access to physically reach and use the beaches and nearshore waters. Such use constitutes a key component of the state's ocean-dependent coastal tourism and recreation sector, and contributes significantly to state and local economies, coastal culture, and individual's coastal attachment. This study investigates the impacts of SLR on coastal access, first by using geospatial tools to develop a higher resolution database of the location and elevation of coastal access sites (opportunities, amenities, and facilities, including parking) at various coastal access sites statewide. Then, using the Coastal Storm Modeling System (CoSMoS) SLR run-up model, we project the loss of coastal access opportunities due to SLR. We find that impacts to coastal access increase incrementally with SLR and vary widely by access feature type and location, with larger impacts accruing more rapidly in the southern half of the state. We project that access to California's shoreline will drown at the rate of approximately 100 access opportunities per 1 foot of SLR. Losses of coastal access will impact individual communities and groups differently and are sensitive to the effects of different strategies designed to manage coastlines in the face of rising sea levels.

KEYWORDS: Climate change, coastal access, coastal management, sea-level rise.

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One out of every 15 Americans live in one of California's 15 Pacific coast counties, as well as 54% of California's population, and while access to the coast for all Californians is enshrined in the state constitution (Article X, Section 4) and codified in the California Coastal Act of 1972 (CA Public Resource Code [PRC] Sections 30000-30900), disparities in coastal access remain significant (Reineman *et al.* 2016, California Coastal Commission 2019). Distribution of coastal access facilities and amenities are likewise uneven across California's coast, as are users' preferences for them (Christensen and King 2017).[1] Despite these differences, beaches in California remain popular and are a cornerstone of the state's multi-billion-dollar ocean-dependent tourism and recreation economy (Pendleton and Kildow 2006) and the locus of significant personal place attachment for many beachgoers (Reineman and Ardoin 2018).

At the same time, sea-level rise (SLR) presents a substantial threat to California's beaches. For a detailed treatment of SLR scenarios for California, including height projections and timelines, please see the State of California Sea-Level Rise Guidance, 2018 Update, from the CA Ocean Protection Council.[2] As many as two-thirds of southern California's beaches may be completely drowned by 2100 and more than 80% are actively eroding (Vitousek *et al.* 2017, Griggs and Patsch 2019a). These losses pose an existential risk to the attendant ecosystems, ecosystem services, and sociocultural and economic values of California's coast (Heberger *et al.* 2011, Lester and Matella 2016, Patsch *et al.* 2021, Barnard *et al.* 2021). Among these threatened services is the public's access to — and therefore, their ability to use and enjoy — the coast (Caldwell and Segall 2007).

How coastal communities manage threatened beaches has additional and significant implications for the continued existence of both. With options limited to unmanaged/unplanned retreat (i.e., do nothing), beach nourishment, hard armoring structures, living or green shorelines, and managed retreat or relocation, decisions will have a drastic effect on the future usability and accessibility of California's beaches (Caldwell and Segall 2007, Griggs *et al.* 2020, Anderson *et al.* 2020, Lester *et al.* 2022). Hard, shore-parallel armoring structures have been the typical historic response to coastal erosion in California, with 13.9% of the state's and 38% percent of southern California's coastline hardened with structures as of 2018 (Griggs and Patsch 2019b). California beaches — and their associated opportunities, features, facilities, and amenities[3] — are, therefore, caught in the so-called "coastal squeeze" (Lester and Matella 2016) between rising sea level and hardened shoreline development. This squeeze will have uncertain impacts on the distribution of coastal access in California. In this study, we draw upon several sets of public geospatial data to address the question: How will SLR impact the distribution of coastal access sites in California? N.B.: We analyzed

1) See, for example, the Coastal Commission's YourCoast web application, https://www.coastal.ca.gov/YourCoast/#/map (last accessed 18 July 2023) for an overview of the opportunities, features, facilities, and amenities available at coastal access sites throughout California.

2) Available via https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf (last accessed 10 October 2023).

3) Here, we rely on the following definitions for the many confusing terms related to the accessibility of coastal access: Coastal access sites are physical locations where the public can interact with the coast. Sites might include various (or multiple) opportunities (steps, paths, trails, etc.) by which the public can reach the sand, beach, shoreline, or nearshore environment and their various associated features (natural endowments of the coastal environment, including sandy beach, tidepools, surf breaks, etc.), facilities (manufactured elements, including infrastructure and parking), and/or amenities (manufactured elements intended to support visitor experience, including restrooms, picnic tables, showers, sports fields, etc.).

Figure 1. This two-panel figure illustrates a sample (Goleta Beach, Santa Barbara County) of how (top) access sites were virtually ground-truthed to identify exact locations of access opportunities, facilities, and amenities and how (bottom) SLR run-up models, generated by CoSMoS, were overlaid at 0.25 m intervals through 2.0 m and at 5.0 m to identify mapped locations that would be considered inundated. The original Coastal Access Database's single geolocation for Goleta Beach Park is indicated; all other features were created through virtual ground-truthing.

only the southern 10 coastal counties because data for the northernmost counties was unavailable.

METHODS

This analysis relies on the integration of several geospatial data layers, including the Coastal Storm Modeling System (CoSMoS) SLR run-up model polygons[4] (Barnard *et al.* 2019), several Earth surface imagery layers, and the California Coastal Access geodatabase.[5] The lattermost data layer was created and curated by the California Coastal Commission (CCC) and contains information on coastal access sites and their locations throughout the state. Each access site in the CCC database might comprise multiple features (e.g., natural endowments), facilities (e.g., parking), amenities (restrooms, picnic tables, showers, etc.), and access opportunities (e.g., paths, trails, or stairs to the shoreline). Despite this, however, each access site is spatially represented by a single point feature in the California Coastal Access geodatabase. Assessing SLR impacts to coastal access therefore requires accurate, consistent location and elevation information for each element of each site and also a detailed revision of existing data and the creation of new spatial datasets.

Virtual ground-truthing

Using high-resolution aerial imagery within Esri's ArcGIS Pro Software (Esri's World Clarity basemap layer, with occasional validation via other such geospatial exploration tools as Google Earth, Google Maps, and/or Google Street View), we conducted a process, here dubbed "virtual ground-truthing," in which we examined each coastal access site in California (as represented in the CCC dataset) and created for each a new set of distinct geospatial features (points and polygons) and standardized feature placement (i.e. relative to the components of a site) and attribute labeling (Figure 1, top). Additionally, many coastal access sites, rather than providing a single or several opportunities to access the shoreline, consist of a road, path, or trail that parallels the shoreline and along which a visitor could physically access that shoreline at many contiguous places. We term this type of access "parallel access."

Within the original coastal access database, there are more than 1,500 coastal access points digitized in California. Those were filtered to approximately 900 points by selecting the locations within one mile of the coast and labeled as beach access, park, pier, or public access. For each remaining access point, the location of the point was edited to allow for standardization along the entire stretch of California's coastline (e.g., entrance to the parking lot, top of path, bottom of path, beach access). In addition, virtual ground-truthing allowed for the digitization of all amenities and facilities (as points) and parking, including free, fee, and street parking (polygons). Some features were generalized with one point. For example, a picnic area with several tables would have been designated with a single "picnic area" point, and multiple volleyball courts in the same area would have been represented by a single point labeled as "volleyball courts."

For parking, polygons were created around each lot associated with an access point. If parking spaces were visible, they were counted. For street parking or unmarked lots, a 7-m parallel standard and a 3-m width standard were used to calculate the number of parking spaces available in a lot. No-parking zones were

4) These polygons are available for download at https://ourcoastourfuture.org/. Information on downloading data can be found at https://ourcoastourfuture.org/wp-content/uploads/2022/04/OCOF_Downloads-Instructions_Apr2022.pdf.

5) This geodatabase was provided upon request by the California Coastal Commission. The data may be requested using the Commission's Open Data & Public Records Portal https://coastal.ca.gov/open-data/.

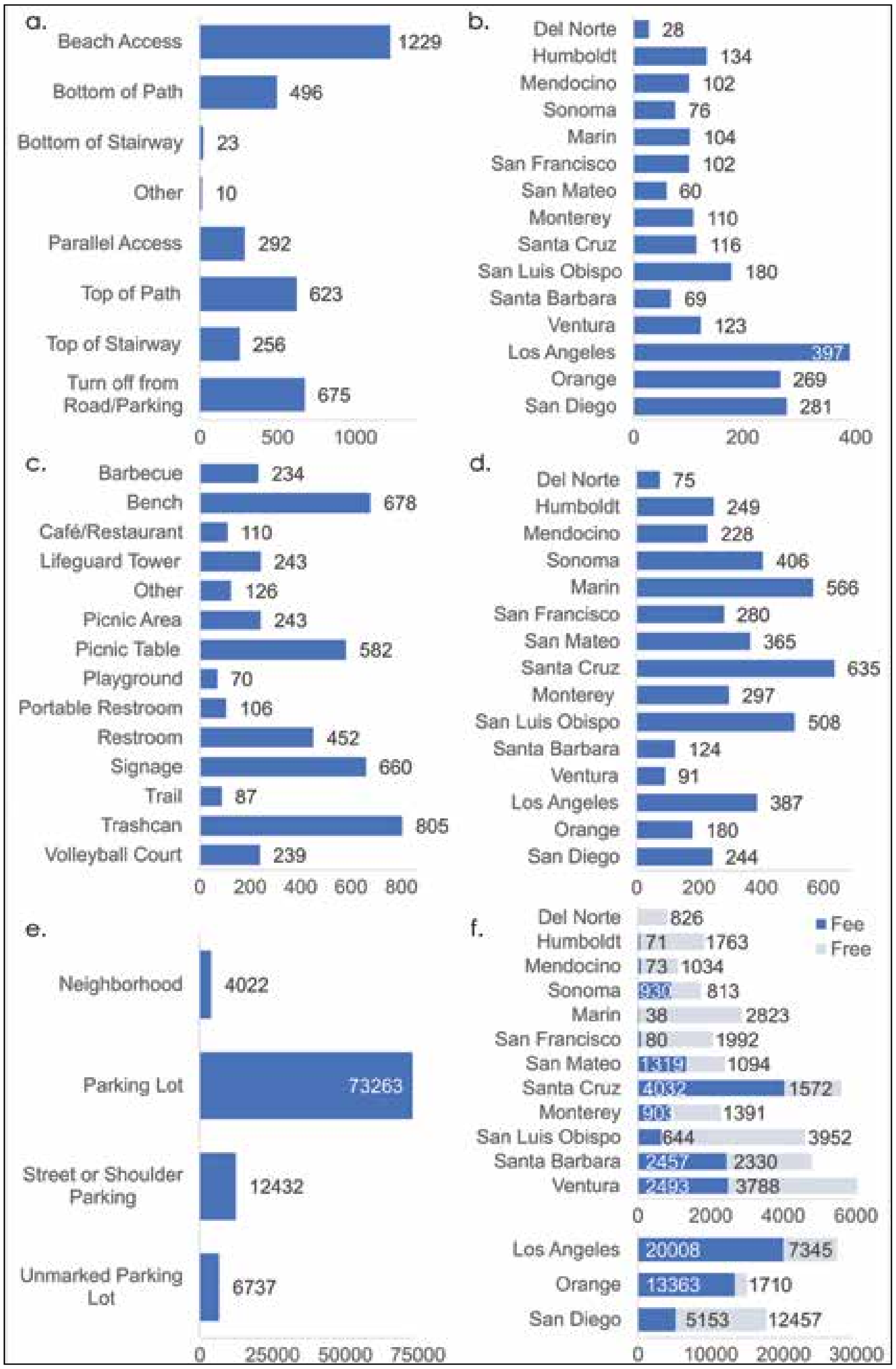

Figure 2. Counts of coastal access opportunities, amenities, and facilities mapped reveal differences across type and county. Top: coastal access opportunities by type (a) and by county (b); Middle: coastal access amenities by type (c) and by county (d). Bottom: parking space availability by type (e) and by county (f); note separate horizontal scales due to proportional differences between southern three and northern 12 counties).

accounted for when assessing opportunities; however, it should be noted that street parking regulations may change (as they did for many stretches of the Pacific Coast Highway in Los Angeles County during this project). For access opportunities near neighborhoods, the street areas within a range of 100 m from the main access point in every direction were assessed. In some cases, when the beach access stretches for several kilometers or there were many access points along the stretch of coast, more than 100 m of parking were digitized.

Sea-level rise impact assessment

With these new, more spatially specific and accurate data, the intersection of coastal access opportunities with SLR flood polygons were assessed with more confidence. Coastal access opportunities, as well as facilities and parking, were intersected with flood polygons generated by CoSMoS for SLR scenarios at 0.25 m increments up to 2.0 m and at 5.0 m to assess the loss of access, or total inundations, of all the access features (Figure 1, bottom). A point location (access opportunities and amenities) is considered drowned by the first inundation increment that overlaps it. For parking polygons, aggregate counts of parking spaces were divided by total parking polygon area to calculate an average area per parking space; inundation of polygons could then be assessed proportionally, and a loss of parking spaces calculated for each increment of SLR. At the time of these analyses, CoSMoS flooding models had not yet been published for California's five northernmost counties (out of the 15 total Pacific coast counties): Del Norte, Humboldt, Mendocino, Sonoma, and Marin. As a result, sequential inundations for coastal access opportunities were not assessed for these counties.

RESULTS

The initial California Coastal Access geodatabase obtained from the CCC contained coastal sites referenced by 1,500 points — each with an associated latitude and longitude. Each access site was reviewed using our virtual ground-truthing methodology, and additional points and polygons were digitized to account for the actual, accurate locations of the various opportunities, amenities, features, and facilities (including parking) associated with each coastal access site's original point feature. Here, we first present the results describing the current distribution of access at statewide and county levels, followed by results showing how this distribution might change as sea levels rise.

Current distribution of access opportunities

Our revised coastal access geodatabase contains a total of 3,815 digitized points marking the various coastal access opportunities, including turnoffs from roads or entrances to parking lots, the tops and bottom of paths/trails/stairways to the beach, parallel access, piers, and the specific locations where a visitor would step directly onto the sand. These totals are displayed in Figure 2a. Figure 2b totals them by county. Of these coastal access opportunities, 1,694 provide direct access to the shoreline. Likewise, a total of 4,635

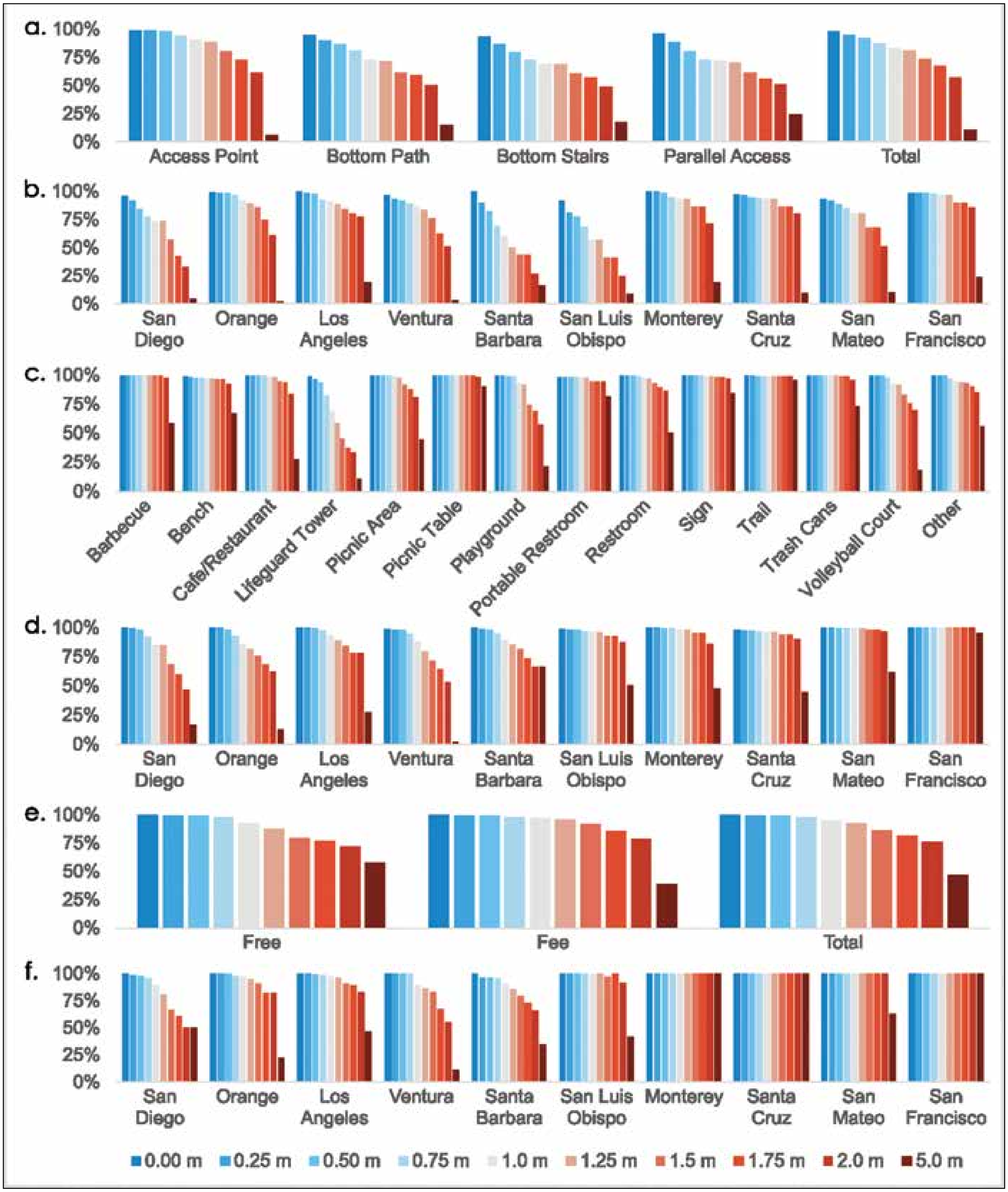

Figure 3. Projected impacts of incremental inundation from SLR on coastal access opportunities, amenities, and facilities vary across types and counties. Proportion of coastal access opportunities lost by type (a) and by county (b); proportion of coastal access amenities lost by type (c) and by county (d); and proportion of parking space availability lost by type (e) and by county (f).

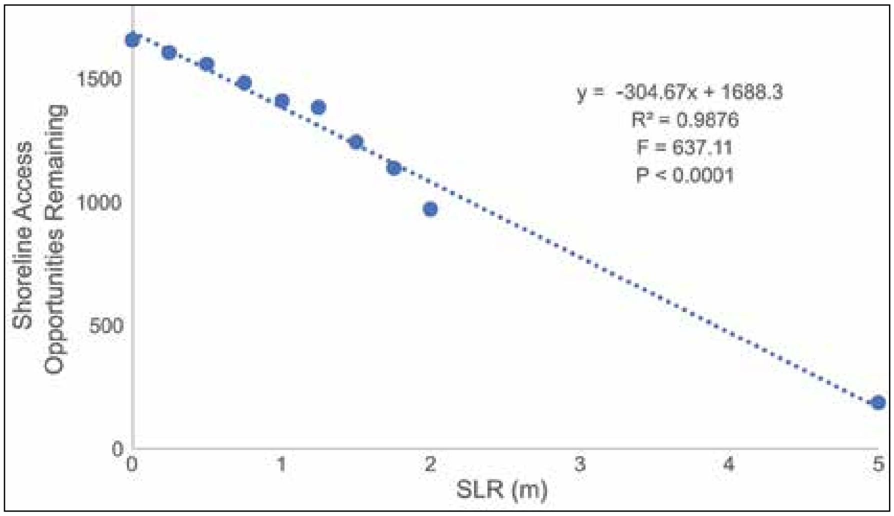

Figure 4. Sequential loss of coastal access opportunities with rising sea levels equates to approximately 304 access opportunities drowned per 1.0 m of SLR (approximately 100 access opportunities per 1 ft of SLR). Linear regression reveals this trend is significant with and without the data point at 5.0 m.

facilities and amenities were digitized statewide: a breakdown of the number of facilities/amenities by type and by county, respectively, are shown in Figure 2c and Figure 2d.

Parking was digitized along the entire coast of California with attributes describing the type of parking (marked lot, unmarked lot, street/shoulder parking, or neighborhood), whether the lot was a pay/fee lot or free, and the approximate number of vehicle spaces. In total, ~1,800 parking areas were delineated providing spaces for ~96,500 vehicles. In total there were 431 fee lots with a total of ~51,500 spaces available (53%), and 1,352 free parking areas with ~45,000 spots available (47%). The breakdown of beach parking available by type and county are shown in Figures 2e and 2f, respectively.

SLR impacts on coastal access

The impacts of SLR based on CoSMoS runup models (for all but the five northernmost Pacific coast counties) on coastal access are displayed in Figure 3 as follows: opportunities (panels a and b), amenities (panels c and d), and parking (panels e and f). Of the total 1,694 points marking direct shoreline access, 16.8% will drown with 1.0 m, and 42.8% with 2.0 m of SLR (Figure 3a). These impacts vary widely by county, with the most immediate and significant losses occurring in San Diego, Santa Barbara, and San Luis Obispo counties (Figure 3b). Likewise, of the 4,635 amenities mapped, 3.6% and 11.8% will be lost at, respectively, 1.0 and 2.0 m of SLR. This proportion rises to 36.3% at 5.0 m and, again, varies widely by county (Figure 3c and d). Approximately 47% of all parking will drown with 5.0 m of SLR but is variable by type and county (Figure 3e and f).

At the statewide level, this impact equates to 304 access opportunities being drowned per 1.0 m of SLR (Figure 4; approximately 100 access opportunities per 1 ft of SLR). Linear regression suggests that this decrease is statistically significant ($R^2 = 0.9876$; $F = 637.11$; $P < 0.0001$. Note that the result is statistically robust when the outlying 5-m SLR point is removed: $m = -324.93$ opportunities/m; $R^2 = 0.9537$; $F = 144.25$; $P < 0.0001$).

DISCUSSION

These analyses of the effect of SLR on coastal access sites, including opportunities for reaching the shoreline, amenities, and critical facilities like parking, confirm concerns that SLR is a major threat to public access to the coast in California (Caldwell and Segall 2007, California Coastal Commission 2015, Melius and Caldwell 2015, Reineman *et al.* 2016). Beach access for large populations of coastal residents and visitors will be directly impacted. Our results further reveal that the degree of this threat varies widely according to the type and location of coastal access opportunity. With 0.5 m of SLR, for example, 14% and 20% of coastal access paths and stairs (respectively) will terminate underwater, as will 20% of parallel access sites (Figure 3a); this impact aligns with projections for the loss of beaches themselves (Vitousek et al. 2017). However, the pattern varies widely across the state with some counties (e.g. San Diego, Santa Barbara, and San Luis Obispo) facing rapid incremental loss while others remain more robust in the face of higher SLR (e.g. Orange and San Francisco; Figure 3b). By contrast, amenities are typically situated at higher elevations and are therefore not generally as susceptible to higher levels of future SLR. A single meter of SLR, for example, threatens fewer than 4% of total amenities – and nearly half of those are lifeguard towers, which are typically movable (Figure 3c). Amenities involving more investment, such as restrooms and playgrounds, are not threatened until higher levels of SLR: only 14% of restrooms will be lost after 2.0 m of SLR and 26% of playgrounds after 1.5 m (Figure 3c).

These impacts likewise vary widely across the state, with a general trend that southern California counties (San Diego through Santa Barbara) will suffer more rapid, incremental loss of amenities compared with north central coast counties (north of San Luis Obispo; Figure 3d). This trend is comparable for parking as well, with San Diego through Santa Barbara counties each to experience fairly rapid drowning of both free and fee parking spaces while more northerly counties, starting at San Luis Obispo, will experience almost no drowning and no losses, except for some at 5.0 m of inundation (Figure 3e and f).

These impacts also underscore the importance of obtaining accurate geospatial data on threatened resources, places, or development for the purposes of assessing vulnerability to spatially specific threats like SLR. Faced with SLR and attendant coastal erosion and risks to infrastructure and access opportunities, coastal managers will be forced to make hard choices about where and what kind of coastal access should be prioritized (Melius and Caldwell 2015). These analyses constitute a simple examination of California's coast. Subsequent analyses could focus on a suite of related impacts and could employ more nuanced examination of, for example, population, demographic, and equity impacts; travel times and population impacts in urban cores; specific coastal amenities, such as sports fields; and other recreational amenities, such as area of open sand, surfing sites, tidepool opportunities, etc.

Dashboards

- **Access points:** https://www.arcgis.com/apps/dashboards/85c6e1094ccf40ceaf65bcbce2517c0c
- **Sea level rise flooding:** https://www.arcgis.com/apps/dashboards/19ac80fe57e747ac9caaf966b29cb9c4

The database is available to view and download in two data dashboards via these QR codes.

ACCESS POINTS

SLR FLOODING

Equity and environmental justice in particular bear further examination. As of 2010, proportionally fewer Hispanic and Latino, Black, and Native American residents lived within 1 km of a coastal access site in California as compared to white residents (Reineman *et al.* 2016). Furthermore, different preferences for the different opportunities, features, facilities, and amenities of coastal access sites occur among these different groups (Christensen and King 2017). The degree, type, and location of SLR impacts to coastal access will therefore have varying impacts upon different groups of people and different types of beachgoers. For example, loss of restroom amenities will likely be more impactful for visitors who must travel farther to reach the beach; loss of playgrounds will likely affect visitors with families; loss of lifeguard towers will likely deter individuals — especially from historically marginalized communities (e.g., Wiltse 2014) — with less confidence as swimmers. Given the need for further research, the complete geodatabases of access locations and run-up impacts created in this study are available through an online portal for viewing and download. The authors invite suggestions and corrections to the current so that it can be continually revised and improved.[6]

Associated with this study — and the published geodatabases — we must address several limitations. Foremost among these is that virtual ground-truthing is not likely to be as effective as physical, in-person ground-truthing. For example, parking lots adjacent to coastal access points could be public but could also be private and not actually available to visitors — a distinction obfuscated in aerial imagery; or perhaps a picnic area has been removed or added during the time elapsed between the present day and when the aerial imagery used in this study was recorded. Additionally, not all opportunities and amenities are clearly visible in aerial imagery. Barbecues and showers, for example, typically have small physical footprints, or may be covered or obscured such that the total statewide counts of 234 and 11, respectively, are likely considerably undercounted. Therefore, the database and associated results, while vastly improved over prior analytical opportunities, should be considered as interim until such time as trained surveyors can visit each of California's thousands of coastal access sites to create new and more accurate geospatial data.

Another key limitation is that, at the time of these analyses, SLR run-up scenarios for the CoSMoS model were not available for Del Norte, Humboldt, Mendocino, Sonoma, or Marin counties — California's five northernmost ones — so impacts to coastal access in these counties could not be presented here.[7]

CONCLUSIONS

This study illuminates trends, revealed elsewhere, that the impacts of climate change are likely to be increasingly significant and that they will not be evenly distributed. Also, the relatively steady loss of beach access opportunities statewide resulting from rising sea levels — approximately 100 per 0.30 m (1 ft) of SLR — represents a significant impact from climate change to a key aesthetic, recreational, and economic asset in California (Pendleton and Kildow 2006, Heberger *et al.* 2011, Pendleton *et al.* 2012). This result also complements other research efforts to directly assess SLR impacts to beaches themselves (Vitousek *et al.* 2017). Given its simpler approach, it may be of interest to other geographies and communities where beaches and their associated social and economic benefits are valued and where stakeholders may wish to consider these effects on their own coasts and endeavor to replicate these analyses. Sustaining beaches — and meaningful access to them — requires coordinated efforts by managers and stakeholders combined with both knowledge of beach resilience and data on how beach management affects beach value and vulnerability and beach access and visitation. Geospatial studies of this nature can support such efforts (Lester and Matella 2016), as can tools, such as the Beach Sustainability Assessment (Patsch *et al.* 2021). All together, these can lead to both better understanding of and more successful management of coastal access in the face of the existential threat of rising sea level.

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6) Database is available to view in a map-based format and/or download via Esri Storymaps using the web addresses or QR codes shown on this page.

7) Data on SLR impacts to these five northernmost counties will be incorporated into the online database referenced at fn 6.

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