Proposal Title: Dunes as nature-based solutions to enhance resilience of California's beaches to climate change
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Proposed Research Activities and Specific Aims

California's sandy beaches are iconic, highly valued spaces that provide many co-benefits to coastal communities, economies and ecosystems. In recent years, the impacts of El Niño events[1-6] and winter storms on beaches across the state have amplified concerns about how to manage the impacts of ongoing climatic variability events superimposed on more insidious, longer-term sea-level rise (SLR)(Fig. 1). The state recognizes the need for viable adaptation strategies, including nature-based solutions (NbS), in many policies (see below). Coastal dunes, both extant and restored, have the potential to buffer and enhance the resilience of adjoined beaches to climate forcing. The goal of this project is to enhance understanding of, and provide actionable information for, the use of coastal dunes as a NbS for enhancing the resilience of sandy beaches in California to climate-change impacts including flooding, erosion and loss of specialized habitats and biodiversity. Specifically, we will identify sites, methods and actions to accelerate implementation and effectiveness of beach-dune restoration as a viable, scientifically informed, accessible adaptation strategy for coastal communities.

Figure 1: *a) Foredune erosion at Humboldt Bay, northern California following the El Niño 2015-16 season.*

b) 'Rebuilding' Goleta Beach near UCSB & Santa Barbara Airport following winter 2022-23 storms and king tides.

c) Winter 2023 storms erode engineered foredune at East Beach, Santa Barbara exposing core stone boulders.

Coastal dunes are highly dynamic systems and their geomorphology is highly dependent on local biology, coastal processes (waves, winds, tides, surges) and exposure to extreme events. Land use constraints, stakeholder interests and management practices make it difficult to achieve dune resilience with a uniform design. Instead, planning and restoration often reflect a compromise between site conditions and constraints, while focus on resilience, or the ability of the dune ecosystem to withstand erosive events and maintain and rebuild itself over time by natural processes, is often secondary or neglected.

The long history of beach-dune restoration on the East and Gulf coasts[7-11] has somewhat limited application to West coast dunes, which are morphodynamically different due to fundamental distinctions in climate, geology and oceanographic forcing. Geographically, California's coastal dunes are also more constrained in location and extent by proximity to their sediment sources (river mouths or bluffs) and by steep inland topography (cliffs, bluffs). Although coastal barrier-dune complexes exist (e.g. San Diego Bay, Morro Bay, Humboldt Bay), continuous linear foredunes like those on barrier islands on the East/Gulf coasts are less common, particularly in central and southern California. Oceanographic forcing is also vastly different, as winter wave forcing exerts greater control on beach-dune erosion on the West coast, compared to episodic storm surges on the East/Gulf coasts.

Dozens of coastal dune restoration projects, varying in extent, design and purpose have been implemented statewide in recent years[12-19], yet many are not fully informed by pilot studies or current science on beach-dune geomorphology, restoration ecology, coastal hazards, or future forecasts. This proposal will fill this need by leveraging results from existing pilot sites and significant expertise from a team of scientists, practitioners and end-users with substantial experience in dune ecosystems and

restoration projects that span California's coast. To improve understanding, facilitation and success of dunes as a NbS for enhancing coastal resilience, our activities will focus on 3 main research objectives:

1) Create a state-wide inventory and vulnerability assessment of coastal dunes in California informed by historical imagery and a recent physically-based coupled model. The inventory will establish a baseline of past and present attributes (e.g., dune types, extent, morphometrics, vegetation, critical habitats) and other ecosystem services. The vulnerability assessment will identify the status of resilience to erosion and SLR of sites based on a cumulative assessment of changes in shoreline positions, habitat distributions, sediment budgets, plant cover, land use and other interventions (e.g., restoration, sand nourishment, armouring)[20-23]. Future SLR impact scenarios will be modeled using 2023 updates for relative sea-level (RSL) trends and the USGS Coastal Storm Modelling System (CoSMoS[24-27]).
2) Assess responses of restored coastal dunes using modeling and observations from pilot sites that state agencies have invested in with our team and collaborating partners. Sites span the geographic range of California's coast, a variety of land tenures, human pressures, management settings and restoration approaches (Table 2). Results and data will be shared with a broad network of >200 end-users engaged in the Coastal Dune Science Network[a] (CDSN) to advance understanding of how dunes can provide NbS to improve coastal resilience via lessons learned and knowledge on effective design, monitoring methods, modeled life-span assessments and adaptive management approaches. Empirical data from pilot sites and the broader inventory will also help refine and extend CoSMoS to better simulate responses of coupled beach-dune systems.
3) Synthesize findings from Obj. 1 & 2 to develop site suitability, restoration and performance assessment frameworks for restoration projects in collaboration with state and local management entities. These frameworks will help identify priority sites and methods for implementing, replicating, scaling and monitoring dune restoration projects to improve coastal resilience and capacity building for underserved communities. This information will help inform eventual development of state-wide guidance and best-practice guidelines for improving coastal resilience using dunes as a NbS.

***Objective 1*: State-wide inventory and vulnerability assessment of coastal dune systems**

Globally, sandy beaches are among the most threatened coastal ecosystems due to increasing anthropogenic pressures and climate-change impacts that are resulting in net erosion, biodiversity losses and increasing hazards from coastal flooding and sea-level rise[2, 28-34]. Linked beach-dune systems can have greater capacity to exchange, accrete and store sand which can make them more resilient to climate variability forcing[35]. Dune systems occupy about 20% of the world's coasts[36] and are integral to many sandy beaches. They form as a result of the interactions between littoral and aeolian (windblown) processes acting on the coastal margin in the presence of vegetation[37]. As such, dunes are dynamic ecosystems that serve as an important sink in the coastal sediment budget that offers protection from erosion and flooding, while also providing a multitude of other ecosystem services with appreciable socio-economic value, including recreation and tourism opportunities, sites of development value, agriculture and forestry, groundwater recharge, specialized habitats for endangered, migratory, or endemic species, nutrient cycling and carbon sequestration[38-48]. Some of these services and other land uses conflict with longer-term sustainability and resilience of beach-dune systems. Coupled with climate change impacts and growing population pressures in the coastal zone, most of the world's sandy beach-dune systems, and the beneficial functions and services they provide, are under increasing threat.

In California, sandy beaches with coastal dunes occupy a similar proportion of the coast (23%[49]) and, according to the Ocean Protection Council's 2022 State of the California Coast & Oceans Annual Report[b], the California Aquatic Resource Inventory (CARI)[c] shows that a significant areal extent of the

[a] https://www.resilientcoastlines.com/
[b] https://www.opc.ca.gov/webmaster/_media_library/2023/01/Annual-State-of-the-Coast-and-Ocean-Report- 2022-508.pdf
[c] https://www.sfei.org/cari

state's coastal landscapes host dunes (~2.7 and 3.4x that of beach and eelgrass habitats, respectively). CARI is a statewide database of wetland extents and classifications, and recently included coastal dune habitats[50]. Historical reports and inspection by our team suggests, however, that this inventory is a considerable underestimate and overlooks most larger dune ecosystems. This is not a trivial issue given the many ecological services and protective functions that beach-dune systems provide, including ecological connectivity between nearshore and inland ecosystems[51-53]. Also, dunes often provide suitable conditions for other valued ecosystems such as wetlands, estuaries, lagoons and dune forests.

Task 1.1: Statewide inventory of coastal dunes

Coastal dunes were once widespread in California as shown in early maps from 1851-1889[97], historic airphotos from the 1920s, Army Corps of Engineers reports[54], geomorphic surveys[49] and many scientific publications and agency reports. Early surveys identified[54] and expanded on[49] 37 sites. For example, dunes at Monterey Bay backed ~18 km of coast and covered ~105 km^2[49]. At Los Angeles, the El Segundo dune complex covered ~100 km^2 between Venice and the Palos Verdes peninsula[49,55] (Fig. 2). Further south, between Long Beach and Huntington Beach, a large dune-marsh complex existed between the mouths of the Los Angeles and San Gabriel Rivers (~24 km)[55]. In San Diego, coastal dunes and salt marshes existed from La Jolla to the Mexico border[49,55]. Although many of these dunes extended inland and stabilized during the Holocene, foredunes and parabolic dunes were common on beaches and many created wetlands. Today, in southern California, 10 sensitive plant taxa are limited to coastal dune habitats[55-56]. As this is typical of the diversity in California's dune ecosystems, it is concerning that relatively little attention has been given to restoring coastal dunes and the many ecosystem services they provide. Many dune landscapes were destroyed or converted to urban, residential or agricultural uses decades ago, well before their roles and importance were recognized. Few surviving examples of intact, functional coastal dune ecosystems exist in developed areas. In the past two decades, however, research on coastal dunes and dynamic restoration has grown, along with public awareness and buy-in, resulting in an increasing number of restoration efforts and opportunities.

Figure 2: *Northern portion of the El Segundo dune & wetland complex near Santa Monica & LAX overlain on USDA 2005 aerial photography. Source ref. 97.*

Many site-specific studies of coastal dunes in California exist[55,57-62], yet a comprehensive account of their extents, attributes and changes does not. To address this, we will develop a GIS inventory of key dune attributes (linear and areal extents, morphologies, landscape setting, vegetation, threatened species, critical habitats, ecosystem services) and observed changes (area, land use/cover, shoreline position) using existing publications, historical maps[97] and aerial photography, low altitude imagery from the California Coastal Records Project[d] (1972 - 2013), recent, frequent satellite imagery using Google Earth Engine, Planet.org's API and CoastSat[13]shoreline change data. A draft inventory will be shared with, and verified by, end-users via regional workshops (Task 3.1) and subsequent field verification campaigns. The

[d] https://www.californiacoastline.org/cgi-bin/lookupform.cgi

updated database will leverage our collective expertise and local knowledge to provide essential, current data to inform ongoing revisions to the CARI database, which is used by federal, state and local agencies in California to coordinate monitoring, status assessments and inform local-scale resilience planning[50].

Task 1.2: Vulnerability assessment

The vulnerability assessment will add value to the updated inventory by identifying the exposure, physical sensitivity and status of resilience to erosion, flooding and SLR for a set of pilot sites (see Table 1, Obj. 2). Regarding site sensitivity and risks, the updated inventory GIS database will provide detailed attributes for the pilot sites including beach/dune form (beach width, dune height, volume, areal extent, accommodation space), function (sediment budgets, aeolian activity, plant cover/communities, vulnerable species, critical habitats, association with wetlands) and ecosystem services (flood control, erosion mitigation, tourism, conservation, etc.). The extent, duration, responses and approaches to restoration at the sites will also be assessed for promoting resilience (recovery from erosive events, plant community responses, required maintenance/interventions) as a proxy for adaptive capacity.

In addition to their protective roles against SLR and erosion, sandy beaches and dunes are vitally important ecosystems that support diverse and unique biota and key ecological functions on many coasts in the world[29,63]. They form a dynamic boundary where the ocean influences terrestrial habitats through wind, waves and energy subsidies like intertidal prey, kelp detritus and animal carcasses[64-65], while the land influences the intertidal beach and nearshore ocean through nutrient and sediment inputs and stabilizing plant species. To maximize the benefits of this land/sea interface, it is important to conserve and maintain a continuum of habitats from the surf zone and intertidal beach to the dunes. Disturbance is a critical driver of habitat diversity and biodiversity for these systems and a resilient beach/dune ecosystem will contain habitat in varying stages of ecological succession. Leveraging the physical vulnerability assessment above, we will also consider the distribution, connectivity and diversity of beach and dune habitats and assess the vulnerability of selected plant and animal species based on habitat requirements. Where data exist on the abundance and distribution of vulnerable species, it will be used to augment the assessment of vulnerable habitats. Beach/dune fauna to be considered include birds, pinnipeds, beach nesting fish and endemic invertebrates. Numerous sensitive plant species, as well as rare plant communities, will also be considered in our vulnerability assessments.

With the use of CoSMoS, the vulnerability assessment will also be able to assess how the updated inventory of coastal dunes might evolve in space and time in response to SLR, increasing vulnerability to flooding, erosion and habitat loss. Specifically, we will develop a cumulative assessment approach that considers both exposure to coastal hazards and sensitivity of dune ecosystems based on their attributes, responses and services at risk. Hazard exposure variables will include current RSL rates, average and extreme total water levels (TWL), high-tide flood elevations and extent, and shoreline change rates. The sensitivity assessment will build on established, physically-based methods[66-67] that rank and aggregate a net exposure index value. Site sensitivity and risks will be assessed using key attributes of dune form, function and ecosystem services identified from the updated inventory, including plant communities, threatened species, wetlands and other critical habitats, sand supply and beach width, beach-dune sediment budgets, aeolian activity, land use, shoreline change, dune extent and accommodation space. As such, this method considers both site exposure to forcing conditions and resulting susceptibility to change, with its inherent ability to resist change or be resilient. Restoration efforts/responses at sites that have sufficient data will also be assessed to characterize site resilience to erosion and SLR as a proxy for their adaptive capacity. For instance, at the Lanphere Dunes in Humboldt Bay, recent research shows that restored foredunes are more resilient to storm impacts than those with invasive beach grass[16].

Updated projections in the 2022 U.S. Interagency Sea Level Rise Technical Report[e] indicate potential SLR of 0.25-0.30 m by 2050 - an amount roughly equal to that over the last century[68]. RSL rise will vary

[e] https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

regionally due to changes in land and ocean heights and will accelerate at rates much faster than those seen in the last 8000 yrs[69]. In response, the state is updating its SLR projections and plans to publish a new Sea-Level Rise Guidance[f] in June 2023 that will include updated regional SLR scenarios consistent with the 2022 U.S. Interagency Report, updated coastal storm scenarios (1, 20, and 100 yr intervals updated by project partners at USGS) and new high-tide flooding projections[g] [68,70].

These latest projections will be used to evaluate physical exposure and vulnerability of linked beaches and dunes at the pilot sites to habitat loss (intertidal, supratidal, dune), high-tide flooding (frequency and depth), storm-driven total water levels (TWL: waves + runup + surge), observed vs. projected shoreline change and projected SLR. For instance, average or seasonal TWL controls the location of dune vegetation and development[71-73] and can define a threshold for exposure of beach-dune systems to erosion[74-76]. Elevation thresholds can be identified using available LIDAR (e.g., USGS 3DEP LidarExplorer). Observed vs. projected shoreline changes can be examined using CoastSat and CoSMoS, respectively. Annual to multidecadal evolution of sandy beaches to climate variability and SLR scenarios can be reliably predicted and projected using data-assimilated coastal change models[77-79], especially when integrated with satellite-based shoreline observations from CoastSat[27,80]. As part of CoSMoS[24], the USGS has developed coupled projections of beach loss and flooding across California[25-27]. CoSMoS-COAST, the shoreline change component, has been used to understand tipping points of coastal ecosystems[81] and evaluate performance and lifespan of potential beach nourishment projects[82].

Our collaboration with USGS will leverage CoSMoS models and data to characterize the vulnerability and protective benefits of coastal dunes. For example, long-term projections of nearshore wave and TWL conditions, historical shoreline changes and existing model projections of erosion/accretion (at 100-200 m alongshore transects) will help identify sites that are most vulnerable to erosion. CoSMoS-COAST only simulates beach evolution, so our study adds value by providing empirical data from pilot sites and a postdoc to work with USGS to adapt the model to include a dune erosion model, building on prior developments[83-86]. The coupled beach-dune model will be capable of simulating bi-directional sediment transport and feedbacks between sandy beaches and dunes and model their long-term fate with SLR. In turn, this refined model could be applied to assess existing and/or restored dune lifespans.

***Objective 2*: Assess responses and effectiveness of restored dunes using existing and new observations**

Dune response and recovery to restoration and storm impacts in California are significant knowledge gaps that limit our ability to assess the effectiveness of dunes as a NbS for climate change adaptation. Our study will yield new information on where and how various dune restoration methods can improve coastal resilience. Current performance monitoring of dune restoration projects is mostly permit-related and limited to 3-5 years as required by the CA Coastal Commission. Protocols to document ecosystem responses differ, but variables often include plant cover/composition and geomorphic attributes (e.g. cross-shore profiles). More detailed monitoring and data, including plant quadrat or line-intercept counts, digital elevation models (DEMs), aerial imagery, sediment budget estimates, etc. occur for some projects. To date, however, these datasets have not been integrated or analyzed synthetically to identify attributes, successes or challenges of existing projects.

Task 2.1: Leverage existing results and observational data from pilot dune restoration sites

The project will assess beach-dune system response and project performance by leveraging observations from 7 restoration pilot sites (Table 1) that span the geographic diversity of California's coast and include various land tenures, management settings, restoration approaches and disadvantaged communities (Fig. 3). Many are previous state investments for which longer term behavior and responses to disturbance have not been assessed. Others have several years to decades of restoration phases and observations. All sites involve end-user collaborations on restoration implementation and/or monitoring, and our study will

[f] https://www.oceansciencetrust.org/projects/slr-update2023/
[g] https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding?

facilitate expansion of monitoring and partnerships. While some sites have monitoring reports, few have assessed project performance, particularly in response to storms. We will source and compile existing data and assess site performance in response to restoration treatments and erosive events, such as the winter 2023 storm season. From this, we will identify key metrics and measurements for tracking beach-dune restoration responses that can be used to develop a performance assessment framework (Obj. 3).

Task 2.2: Continue & expand monitoring at pilot sites and beyond

The relatively short window of required monitoring for coastal dune restoration projects in California is insufficient to assess ecosystem (re)establishment, dune development, performance and resilience to extreme events. To address this, we will facilitate a 2-year extension of monitoring at pilot sites. Mature projects with long-term (decadal) observations on fully (re)developed dunes are rare, yet provide key insights on responses that reflect climatic variability change impacts. Our pilot sites include some of the most extensive and oldest in the state, along with other recent, innovative projects.

Figure 3: *a) Native species replanting following invasive plant removal, Lanphere Dunes pilot site Humboldt Bay, CA.*

b) Wood shim roughness array dune initiation experiment, Border Fields pilot site, southern CA.

c) Dune restoration pilot site on highly groomed, urban beach in Santa Monica, southern CA.

We will also leverage monitoring data from another 10 beach-dune sites recently funded by the Ocean Protection Council to Co-PI Emery (site, county): 1) Tolowa Dunes/Del Norte; 2) MacKerricher State Beach, Mendocino; 3) Manchester State Beach, Mendocino; 4) Sunset State Beach, Santa Cruz; 5) Sand City, Monterey; 6) Asilomar State Beach, Monterey; 7) Guadalupe Dunes, Santa Barbara; 8) Ellwood, Santa Barbara; 9) Carpinteria State Beach, Santa Barbara; 10) San Onofre State Beach, San Diego. Two of these sites have planned restoration projects and 8 are in disadvantaged communities. Collectively, with the 7 pilot sites, we will monitor and examine 17 beach-dune sites spanning the state, from Crescent City to Imperial Beach, including those in undeveloped to highly urbanized areas and in 11 disadvantaged communities. From these sites, and others identified by the CDSN network, we will co-develop cost-effective monitoring protocols, assessment metrics, and project performance evaluations via end-user workshops (Tasks 3.1, 3.2).

Standardized data collection will occur biannually (spring, fall) at pilot sites to expand/extend existing monitoring using GPS cross-shore transects, uncrewed aerial system (UAS) surveys and frequent satellite data (Tasks 1.1, 1.2) to examine changes in beach and dune habitat zones, geomorphic features and plant cover. As possible, opportunistic surveys will also occur before/after storm events and king tides to measure impacts and as SLR proxy conditions. UAS surveys will provide visual and multispectral imagery to create high-resolution (1-5 cm) photomosaics and DEMs using Structure-from-Motion photogrammetry for geomorphic and habitat mapping, and estimating plant cover. DEMs will allow quantification of sediment budgets and morphodynamics using statistical change detection[17,92] and modeled TWL and SLR impact scenarios to

analyze site responses at the landscape scale. On ground GPS transect surveys will measure ecogeomorphic data, including vegetation cover, species abundance and diversity, wrack cover, beach and dune morphometrics (toe location/elevation, dune height, zone widths) and recent tide strandlines (TWLs). Long-term monitoring and community engagement in site changes will be facilitated through establishment of citizen science CoastSnap photo stations[93].

Table 1: *Pilot sites, restoration approaches (caps), motivations or methods (lower case). DR=dune ecosystem restoration (cr=coastal resilience to SLR, es=endangered species habitat, fc=fencing, rs=replanting/seeding native species, tc=topographic contouring, s=stop beach grooming), IR=invasive species removal (he=heavy equipment, ml=manual, hb=herbicide), BR=beach-dune rebuilding (ec=erosion control, mr=managed retreat). DAC= dis-advantaged community per 2016-20 American Community Survey Median Household Income, Census Place scale.*

Location	**Land Tenure [*Indigenous Tribes*]**	**Restoration approach/ motivation**	**Restoration timeline**	**Setting & [DAC status]**	**Existing data & *publications/reports***
1) Little River State Beach, Humboldt County, north CA	CA State Parks [*Wiyot*]	IR(he) DR(es)	7 years: 2009 vegetation removal, monitoring to 2016	Undeveloped park backed by Hwy. 101. [DAC]	LiDAR, GPS profile surveys *Refs 87-88*
2) Lanphere & Ma-le'l Dunes, Humboldt County, north CA	US Fish & Wildlife Service [*Wiyot*]	IR(ml, hb) DR(rs, es, cr)	30 years: 1992-97, 2005-09, 2016-23, monitoring to present	Undeveloped federal National Natural Landmark [DAC]	TLS, UAS, GPS profile surveys, sediment budgets, shoreline changes, plant cover. *Refs: 14, 16, 89, 90 Multiple FWS reports*
3) Morro Bay, San Luis Obispo County, central CA	CA State Parks, Montana Del Oro District [*Chumash*]	IR(he, ml) DR(es, cr)	5 years: 2018-23, monitoring to present	Undeveloped state park	UAS surveys, plant cover, saltwater intrusion, sensitive species surveys *CDFW Final Report*
4) Vandenberg Space Force Base, Santa Barbara County, central CA	US Dept. of Defense [*Chumash*]	IR(he, tc) DR(es, tc)	5 years: removal 2009-11, contouring 2014-15, herbicides & contouring in 2023	Military base, railway	Shorebird/seabird surveys, endangered bird nesting, wrack, cross-shore profiles, plant cover. *Refs: 91*
5) Surfers Point, Ventura County, southern CA	City of Ventura [*Chumash*]	BR(ec, mr) DR(fc, rs)	9 years: 2012 restoration, 2013-21 monitoring	Urbanized	Elevation profiles, plant cover, UAS surveys *ESA project reports*
6) Santa Monica Beach, Los Angeles County, southern CA	City of Santa Monica [*Tongva*]	DR (cr, fc, rs, sg)	7 years: 2016 restoration, monitoring to present	Heavily urbanized	6 years plant and topography data, multiple UAS surveys *Annual technical reports*
7) Border Field State Park, San Diego County, southern CA	CA State Parks, Tijuana River Reserve [*Kumeyaay*]	DR (cr, fc, rs)	3.5 years: 2019-2020 restoration, monitoring 2020-present	Undeveloped, urban/military lands, research reserve. [DAC]	Plant cover, GPS surveys & elevation profiles, UAS surveys, seeding & shim experiments *Annual consulting reports*

***Objective 3*: Co-develop site suitability, restoration and performance assessment frameworks**

Results from Obj. 1 and 2 will inform development of several planning and assessment frameworks for advancing coastal dune restoration NbS across California. Frameworks will be developed in collaboration with community partners and federal, state and local end-users to help identify priority sites and methods for implementing, replicating and expanding dune restoration projects to improve coastal resilience. These will lay groundwork for developing common monitoring protocols and science-based metrics for comparing site conditions and tracking performance over time. Currently, a lack of common protocols for monitoring, reporting, site suitability and restoration are key challenges for dune restoration project permitting, feasibility and performance as a NbS for building coastal resilience.

Task 3.1: Develop a framework for evaluating site suitability and appropriate dune restoration methods

No framework exists for assessing the suitability of, and prioritization of sites for, coastal dune restoration in California and the applicability of frameworks developed on other coasts (e.g. ReDune[9]) is limited given distinctly different climatic, geological, ecological, and oceanographic controls. Outputs from the comprehensive inventory (Task 1.1) and vulnerability assessment (Task 1.2), coupled with scientific expertise and local knowledge of end-users (Task 2.1), will provide the foundation for identifying sites where dune restoration could be implemented to improve ecosystem services and coastal resilience. This will also help recognize constraints for other sites (e.g. accommodation space, sand supply, wind climate) and limiting management practices (e.g. winter berm building, beach grooming, vehicle use). The resulting framework will provide a roadmap to identify sites, feasibility constraints and suitable restoration methods. A key goal of the framework is to help indicate where conditions and processes are capable of maintaining dunes that can persist and improve coastal resilience with limited intervention post-restoration, as well as sites where dune restoration could occur but might require more involved adaptive management (e.g., sand nourishment, supplemental planting). The site suitability framework will be informed by end-user workshops via the CDSN, as well as specifically engaging California's Tribes via the Indigenous Coastal Stewardship Initiative of the Climate Science Alliance[h], to collectively solicit ideas and feedback on the dune inventory, vulnerability assessment and suitability framework drafts. The research team will also test this framework in each of the three geographic regions with support from community partners and end-users.

Task 3.2 Develop a performance assessment framework for resilience of dune restoration projects

Using monitoring results from Obj. 2, an interdisciplinary framework for evaluating performance of dune restoration approaches will be created. Team members have already developed preliminary concepts for evaluating resilience through geomorphic and plant community responses from site-specific research[17,94]. Team members also led a scoping workshop in November 2022 with the CDSN that explored biophysical resilience indicators that would be leveraged to develop this framework[18](Fig. 4). The vulnerability assessment (Task 1.2) will help outline how performance indicators can indicate resilience and adaptive capacity (e.g. resistance to, and recovery from erosion, restoration potential, inland migration). The framework will also identify common monitoring protocols for evaluating project performance and resilience and for comparative evaluation across sites and restoration

Figure 4: *Dune resilience indicators scoping workshop, UCSB, Nov. 2023 hosted by the Coastal Dune Science Network (CDSN).*

[h] https://www.climatesciencealliance.org/

methods (see Task 2.2). Per Task 3.1, this framework will be co-developed with community partners and end-users through workshops that share results from Obj. 2, discuss monitoring plans and identify information needs on dune response to restoration and resilience over time. This task also will recognize and promote pathways for improving the leadership and engagement of underserved communities and Tribes in undertaking restoration, stewardship and implementation of coastal beach-dune NbS efforts.

California climate action priorities and related broader impacts

The project's research outcomes will provide actionable information for state leaders and coastal adaptation practitioners including: 1) a statewide inventory and vulnerability assessment of coastal dunes useful for the Pathways to 30x30 Strategy[i] and the California Climate Adaptation Strategy[j] ; 2) frameworks for informing and facilitating coastal dune NbS planning and permitting; 3) new insights for project siting, prioritization and feasibility; 4) improved understanding of, and recommendations for, adaptive management of beach-dune restoration projects across the state; and 5) informing broad dune restoration guidance and lessons learned for public audiences and policy development/refinement.

Specifically, this study addresses the Pathways to 30x30 Strategy (*Actions 6.12, 6.17*) that prioritizes coastal habitats for restoration using science-based assessment to enhance resilience to SLR and storm impacts. It also targets several priorities in the California Climate Adaptation Strategy and offers notable broader impacts. For Priority 1 (Strengthen Protections for Climate Vulnerable Communities), we include pilot sites adjacent to, or historically used by, underserved communities and Tribes (Table 1). The project will integrate socio-economic, cultural and Tribal knowledge and stewardship experience into the dune inventory, vulnerability assessment and site suitability framework. For example, co-PI Engeman's CA Sea Grant/UCSD team will facilitate knowledge exchange and input from the Indigenous Coastal Stewardship Initiative (see Task 3.1). Team members will share the dune inventory and assessments and explore these with Tribal site priorities, indigenous knowledge and stewardship, restoration experiences, and perspectives on leadership for the Tribes in coastal NbS. This also addresses Priority 6 (*Goal B, Action 6*) by helping increase protection of cultural heritage resources from climate impacts with a science-based approach that integrates tribal expertise and traditional knowledge. CA Sea Grant is also leading a binational project (2023-24) to identify, develop and fund cross-border research-community partnerships to support coastal resilience in the San Diego-Baja Norte region. The Border Field pilot site is a high priority for this project.

Figure 5: *a) Winter berm built as temporary mitigation against king tide flooding, Dec. 2023, Carpinteria City Beach, CA.*

b) Complete erosion of beach & winter berm at Santa Barbara Yacht Club during winter 2022-23 storms and king tides.

For Priority 4 (Accelerate nature-based solutions and strengthen climate resilience of natural systems), the project will support research and monitoring of a range of dune restoration pilots so as to increase the pace and scale of NbS for coastal

[i] https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/30-by-30/Final_Pathwaysto30x30_042022_508.pdf
[j] https://climateresilience.ca.gov/

protection and resilience (*Goal A, Actions 7, 4*). The inventory will document sites where protective dunes exist(ed) and develop suitability criteria to identify and prioritize future sites for feasible restoration investments (*Goal C, Action 3*). Per Priority 5, we will also provide actionable climate science to inform decision making using best available data, expanded monitoring, and a collaborative state-wide network of researchers, practitioners and end-users to help advance expertise and implementation of beach-dune restoration NbS as an effective adaptation strategy (*Goal A, Action 7; Priority 6; Goal B, Action 6*).

The project also supports the State Agency SLR Action Plan[k] (*Actions 1.7,2.5,2.7,6.2,6.3,6.9*) by providing inventory, monitoring and performance evaluation of pilot projects and helping develop guidance for future projects. Further, the 2022 State of the California Coast & Oceans Report says that most jurisdictions have not completed SLR adaptation plans. To address *Goal 1, Obj. 1.1*, we will provide actionable outcomes to build resilience of coastal ecosystems and communities to SLR, storms, flooding, and erosion via restoring dunes as a feasible strategy or stage in a longer-term adaptation pathway.

Goals, milestones, short- and long-term climate action outcomes

The goal of this project is to identify sites, methods and actions to accelerate implementation and effectiveness of beach-dune restoration as a viable, scientifically informed adaptation strategy. Details on milestones and timeframes are provided in Tables 2 and 3 in the following section. *Actionable, short-term outcomes linked to California's climate action priorities and the needs of end-users include:*

1) Scientific observations, results and models to address the California Climate Adaptation Strategy (*Priority 4*), Pathways to 30x30 Strategy (*Actions 6.2, 6.7*) and the State Agency Sea Level Rise Action Plan (*Actions 1.7, 2.5, 2.7, 6.2, 6.3, 6.9*) including a complete and accurate inventory of the state's coastal dune resources and current conditions, an evaluation of site vulnerabilities and a site suitability framework to help agencies and communities prioritize and optimize investments in beach-dune restoration. These outputs are also data resources for the Ocean Protection Council's State of the California Ocean & Coast annual report and the CARI database.
2) Expanded monitoring of state investments in dune restoration and a resilience assessment framework to determine how sites have performed and whether they are suitable or effective to be replicated or scaled elsewhere in California. This also directly informs state climate action policies listed above.
3) Strengthened and leveraged partnerships among scientists, practitioners and end-users who study and manage dune sites. This project will facilitate productive exchange and development of NbS expertise through collaborative monitoring and assessment and co-production of the dune inventory, vulnerability assessment and site suitability and resilience performance assessment frameworks.
4) Enhanced training and research opportunities for undergraduate and graduate students and postdocs, including those from underrepresented groups (e.g., BIPOC, LGBTQIA+, Veterans) and Tribes to engage and prepare them for careers in coastal science and climate change adaptation.
5) Support for disadvantaged, BICPOC and non-english speaking community partners, residents and visitors through education, outreach and restoration opportunities that expand capacity to monitor and assess sites, prioritize and optimize limited resources, and engage in science and climate change adaptation outreach. Many partners and end-users (see letters) such as Coastal Conservancy, Climate Science Alliance and Guadalupe-Nipomo Dunes Center benefit underserved communities. These groups and others will be engaged in workshops and provide input to the research products.

Long-term outcomes for the project include:

1) Improved planning and permitting for coastal dune restoration NbS. Information on site suitability, monitoring protocols, and performance indicators is intended to increase the pace and scale of dune restoration and eventual development of best practices and guidelines for dunes as NbS in California.

[k] https://www.opc.ca.gov/webmaster/_media_library/2022/02/Item-7_Exhibit-A_SLR-Action-Plan-Final.pdf

2) Informed project siting, prioritization, feasibility and funding needs. The suitability assessment and performance indicator framework will help identify opportunities for existing and future project siting, investments, and adaptive management to improve coastal resilience.
3) Climate "smart" and cost-effective implementation of NbS beach-dune restoration projects spanning the geographic range of the state. Project frameworks, coupled with end-user workshops, extended monitoring of pilot sites and lessons from many other existing projects statewide are intended to advance the eventual development of statewide guidance and best practices including transferability and scalability of various dune enhancement approaches to improve coastal resilience.
4) Broaden outreach and engagement in beach-dune ecosystem services and restoration approaches with public audiences through engagement with underserved communities, established beach science and management networks, and other end-users and community partners (see letters of support). The network of CoastSnap stations at the pilot sites will also engage community members and the general public in monitoring and citizen-science efforts at their local beaches.

Building on prior research and pilot projects

This project builds on a wealth of research, collaboration and practical experience in beach-dune restoration ecology, geomorphology, management and monitoring across the state. Our comprehensive inventory (Task 1.1) will leverage the existing CARI database and develop an updated GIS database that could be used to inform ongoing updates to coastal dune habitats. We will also build on California's investment in the CoSMoS model[95] by leveraging it for our vulnerability assessment (Task 1.2) and partnering with USGS to help refine CoSMoS-COAST to include a dune component. We also plan to use the new updated California Sea-Level Rise guidance (expected Sept 2023) to assess coastal dune risks based on new projections[96]. The project also leverages the state's 4th Climate Change Assessment Report, "Toward Natural Shoreline Infrastructure to Manage Coastal Change in California", which provides guidance on how to design natural infrastructure. We will expand on this for coastal dunes through our site suitability framework and synthesis of effective restoration methods derived from our network of pilot sites. We will also leverage monitoring funded from other grants (see Leveraging Plan) and end-user partnerships in underserved communities (e.g. Coastal Ecosystems Institute of Northern California (CEINC) in northern CA, Guadalupe-Nipomo Dunes Center in central CA, Tijuana River National Estuarine Research Reserve in southern CA) and will build on our engagement in state-wide management and research networks (e.g. CDSN, Beach Erosion Authority for Clean Oceans & Nourishment (BEACON), American Shore & Beach Preservation Association (ASBPA), Beach Ecology Coalition (BEC)). Collectively, these networks represent the most robust knowledge base in dune restoration and experimental design, and their members will assist the project team in synthesizing and incorporating data and experiences from a broad range of sites beyond our pilot network. For instance, CDSN has compiled information on restoration projects, related monitoring reports and hosted a virtual workshop with 135 participants to discuss dune resilience approaches and science from 20 dune sites across California. CDSN leadership also provided briefings and training to state agencies to inform policies and investments in NbS and will continue providing these types of engagement via this project.

Timeframe, Milestones, and Evaluation Metrics

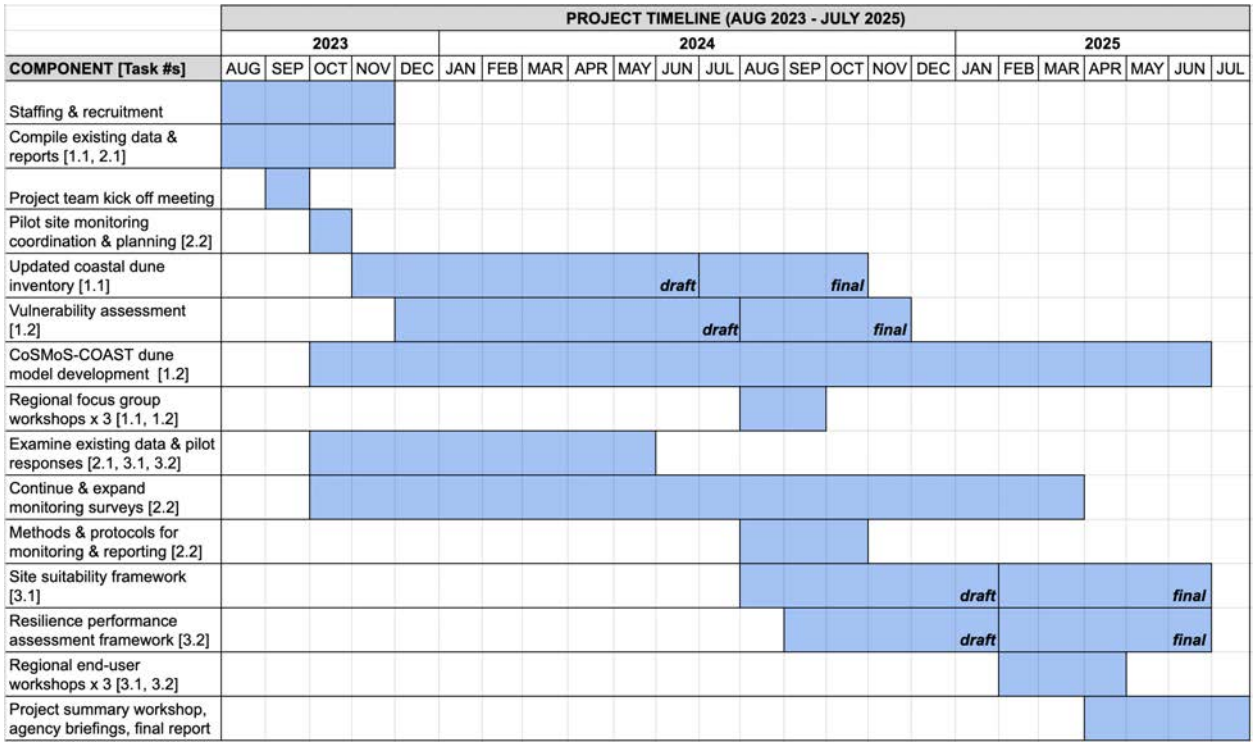
Table 2: *Milestones and evaluation metrics for this study.*

Milestones [Task #s]	• **Benchmarks** • ***Evaluation metrics (short-or long-term)***
Staffing & recruitment of postdocs (PDS), grad students (GSR), undergrad RAs (UGRAs)	• Hire staff, PDSs, GSRs, UGRAs. Assign supervisors, tasks/deliverables, reporting intervals. • *Time to hire, # hired* • *JEDI representation achieved*
Compile existing data, maps, reports, publications	• Summary of existing information & gaps • CDSN survey to ensure comprehensiveness & identify other knowledge gaps or data/info needs

[1.1, 2.1]	• Synthesis report of available data/information resources • *# information sources compiled, broad geographic coverage of sites/info, % respondents to CDSN survey, gaps/needs identified* • *Distribution of synthesis report; Training of PDS, GSRs, UGRAs & staff*
Project team kick off meeting	• Meeting agenda, summary, workplan • *# attendees, completeness of work plan with assigned action items toward all tasks*
Pilot site monitoring coordination & planning meeting [2.2]	• Monitoring & permitting plan for field work, data sharing, access constraints, etc. • *Plans for all regions that accommodate site partners & access constraints, action items assigned including training & logistics with regional POCs, Co-Is, PDS/GSR/UGRAs*
Develop statewide coastal dune inventory [1.1, 3.1]	• GIS inventory database developed, verified with end-user workshops/feedback • ID site characteristics & conditions at existing dune sites to inform site suitability framework • Final database to SFEI for potential updating of the CARI database (long-term) • *Completeness of GIS database, uptake by SFEI for CARI updates* • *# of useful suitability indicators identified from the database* • *Peer-reviewed publication & conference presentations; Training of PDS, GSRs, UGRAs*
Conduct vulnerability assessment, CoSMoS-COAST dune model development [1.2]	• Draft vulnerability assessment, to be revised with end-user workshops/feedback • CoSMoS-COAST dune model development/verification. Final coupled model (long-term). • *Uptake of vulnerability assessment to inform site restoration, adaptive management, adaptation/resilience decision making* • *Progress toward final coupled CoSMoS-COAST beach-dune model* • *Peer-reviewed publication & conference presentations; Training of PDS, GSRs, UGRAs*
Regional focus group workshops with POCs and end-users x 3 [1.1, 1.2]	• Presentations on draft dune inventory & vulnerability assessment with end-users in all 3 regions. Revisions with participant feedback. Synthesis report/s to summarize findings. • *# participants, # regional projects represented beyond pilot site network* • *Distribution of synthesis report/s; Training of PDS, GSRs, UGRAs*
Examine existing data & pilot project methods & responses [2.1, 3.1, 3.2]	• Analysis of monitoring data & pilot site responses to restoration & erosive events. Summary of restoration methods used. ID key metrics for interpreting site responses to inform resilience performance framework. • *# sites with available data, temporal extent of data, range of monitoring variables* • *# sites where some level of performance assessment can be conducted using existing methods* • *# sites with demonstrated improvement and/or resilience in system response to erosive events* • *Distribution of synthesis report; Training of PDS, GSRs, UGRAs*
Continue & expand monitoring [2.2]	• Implement & expand biannual (fall, spring) monitoring across pilot site network, conduct field surveys. Synthesize pilot site end-user monitoring needs & metrics. • Year 1 synthesis report monitoring data/results with prior data and new OPC sites, as available. Repeat for Year 2. • Future funding & collaborative opportunities identified to leverage project efforts (long-term) • *# sites with data, results/reports; # sites with expanded scope &/or timeline for monitoring* • *# end-users & Tribes providing information; # funding & collaborative opportunities* • *Distribution of synthesis report; Training of PDS, GSRs, UGRAs*
Methods & protocols for monitoring & reporting [2.2]	• Review existing monitoring methods, protocols & reporting across pilot sites and with input/surveys from broader end-user network • White paper/publication with recommendations for common & cost-effective monitoring methods & protocols that can be used at a variety of sites • Integration of protocols into state-local monitoring policies for beach-dune sites (long-term) • *# sites for which monitoring protocols are established &/or expanded* • *# and diversity of monitoring methods & variables, future expansion of these* • *Synthesis report; Peer-reviewed paper with management focus (e.g., ASBPA's Shore & Beach)* • *Consideration of monitoring protocols/plans/reporting with state-local agencies* • *Distribution of publication &/or synthesis report; Training of PDS, GSRs, UGRAs*
Site suitability assessment framework [3.1] Resilience performance assessment framework [3.2]	• Draft suitability & resilience performance assessment frameworks to be revised with end-user workshops/feedback • Verification testing of suitability framework on existing pilot sites & new sites in each region • Verification of assessment framework on pilot sites & others in broader end-user network • State-wide application of both frameworks & integration into state-local planning (long-term) • *Positive outcomes of framework testing/verification at sub-set of existing pilot & new sites*

	• *Synthesis reports; Paper submissions to peer-reviewed journal* • *Distribution of publications &/or synthesis reports; Training of PDS, GSRs, UGRAs*
Regional end-user workshops x 3 [3.1, 3.2]	• End-user workshops to co-develop cost-effective monitoring protocols and verify site suitability assessment & performance evaluation frameworks • *# end-users, projects, Tribes & underserved communities engaged in review & workshops* • *Amount & utility of feedback/recommendations received* • *Distribution of synthesis report/s; Training of PDS, GSRs, UGRAs*
Project summary workshop, agency briefings/webinars & final report	• Final project workshop with research team, end-users, community/Tribal members, CDSN & other interest groups. Final round of feedback on all project results & frameworks. Integrated into final project report. Briefings & webinars with state-local planning agencies. • *# participants/projects, # underserved communities, # Tribes represented, #agencies engaged* • *Utility of feedback/suggestions for refining project outcomes & report* • *# new collaborations, projects & funding opportunities resulting from project outcomes* • *Distribution of publications &/or synthesis reports; Training/graduation of PDS, GSRs, UGRAs*

Table 3: *Gantt chart of proposed timeline of key milestones for this study.*



Organizational Structure – Research Team, Collaboration, and Mutual Benefit

Our team represents an established network of scientists, practitioners and end-users with expertise in coastal ecology, geomorphology, oceanography and adaptation planning who are engaged in the design, monitoring and assessment of NbS projects from Humboldt Bay to San Diego. Our extensive 17-site network of pilot sites leverages significant research, monitoring, and partnerships with multiple end-user partners, underserved communities and indigenous Tribes who will all benefit extended and enhanced monitoring and an integrated synthesis of coastal dune systems, their vulnerabilities to storms and SLR, and assessment frameworks for restoration suitability and resilience performance. These sites include some of the most extensive and oldest publicly-funded projects, which provides a rich empirical dataset for CoSMoS model application and refinement with our USGS partners.

Project personnel will be structured regionally, each with a researcher Co-I who is familiar with projects and end-users in the region, plus an end-user point of contact (POC) to facilitate exchanges with regional

projects/end-users, help synthesize existing reports and monitoring data, and participate in workshops. Each region will also have a dedicated student/postdoc researcher to assist the Co-I and end-user POC.

- North: Co-I Pickart (USFWS) + POC: Coastal Ecosystems Institute of Northern California (CEINC)
- Central: Co-I Dugan (UCSB) + POC: Morro Bay National Estuary Program (MBNEP)
- South: Co-PI Engeman (CA Sea Grant/UCSD) + POC: K. Johnston (UCSB), a PhD student with extensive professional experience managing & implementing coastal dune pilot sites in southern CA.

PI Walker (UCSB) will oversee all research activities, coordinate with Co-I leads in all regions, and co-supervise all students/postdocs. Co-PI Engeman (UCSD) will supervise a research associate to provide project support and coordination and leverage her role as lead of the CDSN to develop, facilitate and synthesize all meetings/workshops. Co-I Hubbard (UCSB) will coordinate all field monitoring for the project with assistance from Co-PI Emery (UCLA) and Co-I Dugan (UCSB). Emery will also provide support/training for monitoring field work with Hubbard, assist in monitoring data synthesis and results, and provide data and access to the 10 OPC-funded sites. Co-I Robinette (Point Blue) will oversee all ecological research/monitoring and data compilation for the project with Co-Is Dugan, Hubbard and Pickart. They will provide synthesis of specialized habitats, species at risk and other ecological ecosystem services for Tasks 1.1 & 1.2. The team also includes Co-Is from two federal agencies: Pickart (US Fish & Wildlife) and Vitousek & Hayden (USGS). USGS will provide CoSMoS products to inform the vulnerability assessment and work with PI Walker and a postdoc to refine CoSMoS-COAST. Pickart will support north coast field work and engagement with end-users at several sites. All team members are active in established beach science/management networks (CDSN, BEACON, Beach Ecology Coalition, ASBPA) and will leverage these links to expand site data and engagement with a larger audience. We also have experience working with, and providing outreach and training to, state agencies and will engage them through briefings/workshops to inform NbS investments, policy and site prioritizations.

Community/End-User Engagement Plan (Optional for Seed Grants)

One of the most important contributions of this project is the co-development and sharing of results with end-users to inform policy and beach-dune restoration decision making. Our team has extensive experience communicating scientific information to the public and translating relevant data and concepts to inform adaptation efforts. We obtained 15 Letters of Commitment from end-users confirming their participation, including federal agencies (US Fish & Wildlife, US Geological Survey), state agencies (CA State Coastal Conservancy, CA Coastal Commission, CA Ocean Protection Council, CA State Parks), regional government agencies (e.g. BEACON, LA County Dept. of Beaches & Harbors, Resource Conservation District of Santa Monica Mountains, CA), local governments (City of Santa Monica) and non-profit organizations (Beach Ecology Coalition, Morro Bay National Estuary Program, Tijuana River National Estuarine Research Reserve, Climate Science Alliance, Guadalupe Nipomo Dunes Center). Many of these entities represent or work with disadvantaged communities, underrepresented groups, indigenous Tribes, and several have strategic goals relating to engagement of, and building resilience for, underserved communities. Our plan for engagement of includes the following activities:

1) Input to, and verification of, the coastal dune inventory and risk assessment components. The draft inventory will be shared with and verified by community partners/end-users via virtual and in-person focus group sessions (Task 3.1) supported by Engeman/CA Sea Grant staff and Sea Grant fellows via the CDSN. Drafts will also be vetted through beach end-user networks (e.g., Beach Ecology Coalition, BEACON). Socio-cultural considerations on vulnerability will also be integrated via input from state agencies, community partners and Tribal groups (CA Coastal Conservancy, Tijuana River NERR, Climate Science Alliance, Guadalupe Nipomo Dunes Center).
2) Collaboration for expanding and leveraging dune site observations and assessments. End-user partners (e.g. Morro Bay NEP, Tijuana River NERR, USFWS, City of Santa Monica, State Parks) and others will help facilitate permitting, site access, data collection and compilation for site monitoring and assessments. Task 2 monitoring results and protocol development will be shared with a broad network

of over 200 end-users engaged in the CDSN through workshops and their website, which serves as an online educational hub for California coastal dune literature and project information.

3) Co-production and testing of site suitability and resilience performance frameworks. Regional end-user workshops will be used to co-develop the site suitability criteria and performance frameworks. The latter will be tested with partners at several of the pilot sites (e.g. Lanphere Dunes, Morro Bay, Santa Monica, Border Field). Participants will also comment on outcomes of the site monitoring assessments (Task 2.1) and help identify common measurement protocols and indicators of resilience to be integrated into the performance assessment framework. We will also provide more direct opportunities for engagement with underserved and Tribal communities through smaller focus groups discussions via the community partners that serve these groups.
4) Ongoing peer learning with community partners and end-users. Project results will be shared with the extensive 200+ member CDSN as described in item 2 above. Since 2019, CDSN has advanced expertise and collaboration on coastal dunes and their role in beach resilience and, in 2021, hosted a virtual workshop showcasing case studies of dune restoration science and resilience projects with 135 participants. CDSN will be a primary outlet for our results by providing webinars, technical expertise, publications, outreach, training and guidance for stakeholders throughout the project. CDSN's engagement with state agencies will also ensure our deliverables are readily accessible for informing state priorities and investments in coastal dunes.

Leveraging Plan

Several follow-on funding ideas are envisioned that will stem from our project. Some will expand on our research to refine monitoring, models and projections, while others will use project products to help community partners plan and develop funding and strategies for dune restoration projects to enhance resilience of their beaches. The team intends to pursue non-state grant funding to match and expand this seed grant, which include, but are not limited to:

- National Fish & Wildlife Foundation Coastal Resilience Funds: USFWS and non-profit agency Friends of the Dunes in Humboldt Bay received $2M in 2022 to restore and build resilience at Wadulh Dunes. The project will benefit and learn from the nearby Lanphere/Ma-le'l pilot sites and assessments. Partners will apply for Wildlife Conservation Board funding to continue work. Project partner Point Blue will also submit a proposal for up to $250K for 2023 NFWF funds to support/expand work on dune habitat and endangered species vulnerabilities and restoration performance with partners from the Dept of Defense.
- NOAA-Effects of Sea Level Rise (ESLR) Program: USGS plans to collaborate with UCSB to submit a proposal to extend CoSMoS-COAST model development, seeded by this project, to improve simulation and feedbacks between sandy beach shoreline change and coastal dunes.
- US Environmental Protection Agency: Morro Bay NEP and others plan to apply for EPA and other federal funds for expansion of dune restoration, monitoring and research activities.
- Additional funds will be sought through Graduate Student Fellowships, a California Sea Grant proposal (up to $25,000 from NOAA Sea Grant) and NSF. UCSB Co-Is have applied for additional support for students conducting field work and research at the pilot sites. Partners will also explore opportunities with end-user groups to support local planning/adaptation projects leveraging our research products.

We also leverage support and collaboration from 15 federal and state agencies, regional and local government agencies, and NGOs (see Letters of Commitment). All include in-kind commitments from staff to attend workshops, support project objectives, review/disseminate results, fieldwork/permitting support, technical review, and data/report provision. CA Sea Grant and Climate Science Alliance will also provide in kind support through their Indigenous Coastal Initiative, which will allow for further Tribal communication and coordination. USFWS also committed .25 FTE for two years as in-kind support.

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