Falling Through the Cracks: Pathways For Conserving California's Coastal Ecosystems

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Percos Beach Sand Dunes at The Dangermond Preserve.

Introduction

California is a global biodiversity hotspot[1] (Figure 1), hosting more plant and animal species than the rest of the United States and Canada combined[2]. Along California's iconic coastline, the landscape transitions across biologically rich temperate rainforests, estuaries, and sand dune ecosystems. Coastal California is one of only five Mediterranean ecoregions in the world and is characterized by cool, wet winters and hot, dry summers. Ecosystems within Coastal California are diverse and host both migratory and endemic species, many of which are threatened or endangered and face multiple stressors such as human population growth, coupled with unsustainable water usage, land use changes, sea level rise, extreme flood and drought events, and groundwater depletion. This report will explore three focal areas for preserving California's coastal ecosystems – water management, climate change, and species recovery efforts – and provide case study examples of solutions for each.

This report builds off ongoing science and conservation work at The Nature Conservancy's Jack and Laura Dangermond Preserve, a 24,000-acre property on California's Central Coast within Santa Barbara County. Because the Preserve has been free from significant development over the past 100 years and encompasses nearly the entire 24 square mile Jalama Creek watershed, it provides an unparalleled opportunity to elucidate how groundwater supports and buffers coastal ecosystems against climate change. Intensive scientific monitoring at the Preserve, including 40 groundwater monitoring wells on-site, provides a natural analog that can help support modeling and scalable recovery efforts of critical habitats and species in other coastal regions. Furthermore, this report provides recommendations for actionable conservation strategies, and policy and administrative changes that can be employed at local, regional, and state scales to preserve California's coastal ecosystems.

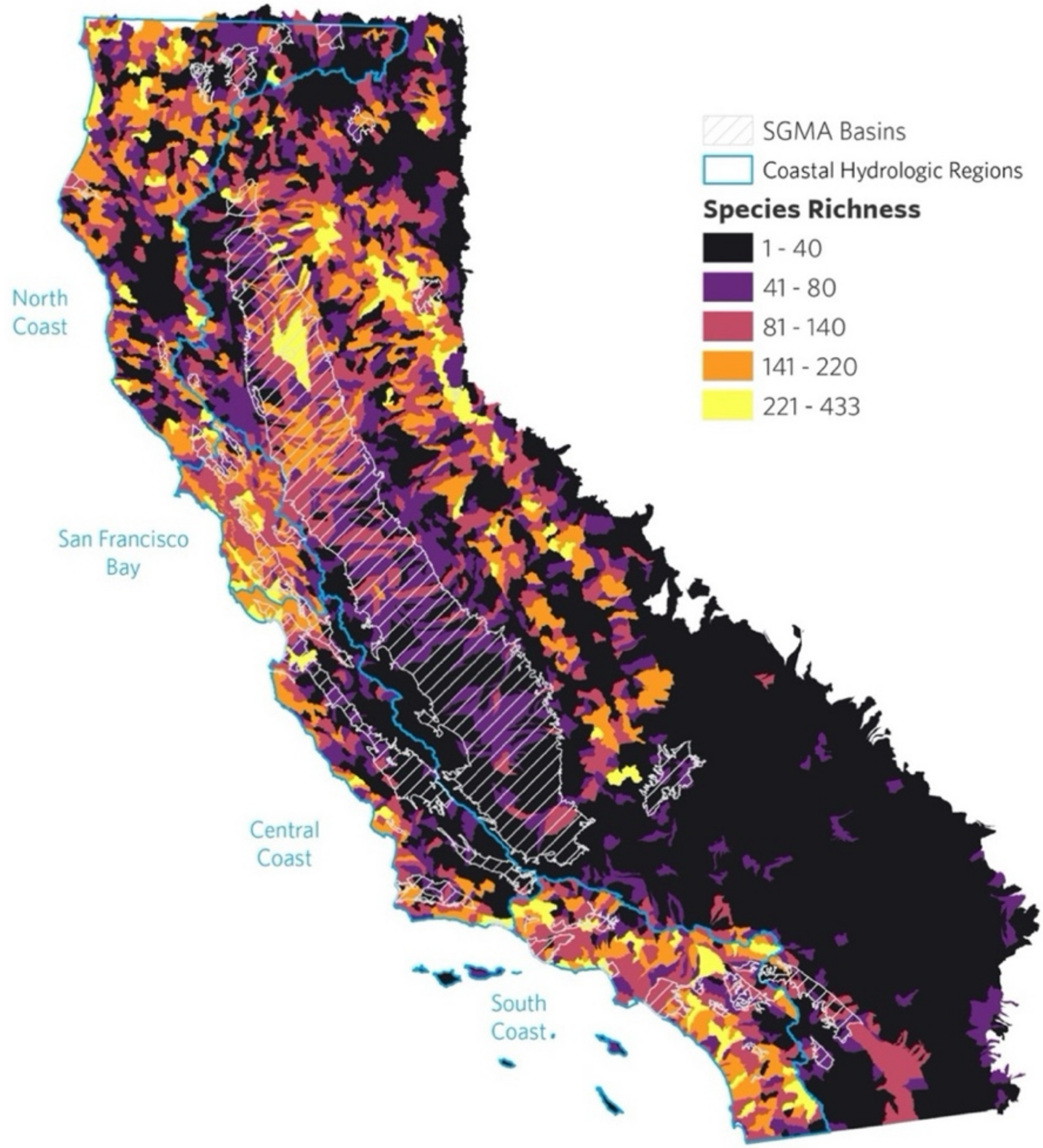

Figure 1. Biological Hotspots in California. Number of species within United States Geological Survey watershed boundaries (HUC-12).

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Jalama Creek at Bucket Bridge looking upstream at the Dangermond Preserve.

Water management

Groundwater is a critical water source for domestic use, irrigation, and ecosystems in Coastal California, and provides a vital buffer against drought. Groundwater is particularly important in Coastal California, often serving as the sole water source, providing more than 90 percent of total water use in some parts such as the Central Coast[3]. Moreover, urbanization and agricultural intensification[4] are projected to increase water demand. Many coastal ecosystems rely on groundwater for some or all their water needs. These groundwater-dependent ecosystems are incredibly diverse, spanning aquatic and terrestrial realms above and below ground, and provide a wide range of ecosystem services[5,6]. Many of these groundwater-dependent ecosystems are vulnerable to groundwater depletion, especially surficial ecosystems since they rely on shallow groundwater levels, but these aquifers and the ecosystems dependent upon them are being threatened by unregulated groundwater pumping and surface water diversions.

Across California's hilly and mountainous coastal terrain, groundwater is stored in underground aquifers within the fractures of hard rocks that were formed in the ancient past by tectonic and volcanic forces, and within alluvial sands deposited on flatter landscapes shaped by rivers and streams. Surficial groundwater-dependent ecosystems rely on groundwater that either emerges on or near the Earth's surface providing a critical seasonal or perennial water source for aquatic ecosystems such as in wetlands and streams, and groundwater access for plant roots. In contrast, subterranean ecosystems exist entirely within aquifer formations such as karsts[7,8]. Ecosystems dependent upon groundwater also depend on the unique chemical quality characteristics that groundwater provides to support unique habitat conditions and are vulnerable to deteriorating groundwater quality due to pollution and groundwater misuse. But, ecosystem groundwater needs are seldom

considered during conservation and water management decisions[9–11], particularly in coastal regions where overlapping policies result in policy gaps for coastal ecosystems due to a lack of interagency coordination and accountability[12]. Additionally, riparian water rights law in California legally entitles landowners to use streamflow without permits, licenses, or government approval. However, the storage of this water for use in the dry season or on land outside the watershed is not permitted. Subsequently, the ecologically rich and diverse ecosystems within Coastal California's fractured hard rock and small alluvial basins remain vulnerable to unfettered groundwater pumping and streamflow diversions in the absence of sufficient groundwater management, well metering, and streamflow regulation.
California was the last Western state to regulate groundwater, enacting the Sustainable Groundwater Management Act (SGMA) in 2014 to halt growing groundwater depletion and prevent undesirable results including groundwater level declines, groundwater storage loss, seawater intrusion, deteriorated groundwater quality, land subsidence, and surface water depletion. Under SGMA, newly formed local groundwater sustainability agencies are required to develop and implement groundwater sustainability plans that will bring high and medium priority groundwater basins into hydrologic balance within a 20-year planning horizon, while balancing the needs of multiple water users, including the environment. SGMA is just one of four legal frameworks globally that requires the identification and consideration of ecological needs into groundwater sustainability metrics[10]. Also, for the first time in California water law, SGMA recognizes surface water and groundwater as an interconnected resource, expanding protections to both systems[13]. Despite this significant progress towards sustainable groundwater management, SGMA only applies to a subset of basins that have been designated as high- or medium-priority[††]. This limitation resulted in SGMA to not be implemented to its fullest extent leaving most of California's groundwater – including Coastal California – vulnerable to groundwater exploitation. While SGMA implementation currently prioritizes regions that are experiencing significant groundwater depletion, it fails to protect and prevent 40% of the state's domestic and agricultural wells and 87% of its groundwater-dependent ecosystems from following the same trajectory of groundwater depletion[14].

One of the challenges with managing groundwater in these unregulated areas is that monitoring and modeling groundwater within fractured hard rock terrain is more difficult than in larger alluvial basins, requiring more costly geophysical surveys and *in situ* instrumentation to characterize the complex subsurface. When considering that these places are also coincident with public lands and privately-owned rural areas with insufficient financial and technical capacity, significant support from state and federal agencies would be necessary to manage groundwater in these areas. Nevertheless, deferring groundwater management in these regions will only increase the social, environmental, and economic costs. Taking a proactive approach to avoiding groundwater depletion is of critical importance, whereas a reactive approach is likely to be more resource intensive in the future as communities are put into a position of grappling with conditions that may be impossible to reverse.

California's coastal areas are important groundwater discharge areas, receiving groundwater from local (from days to decades) and regional (from hundreds to thousands of years) pathways. In general, groundwater flows in fractured hard rock aquifers along the

[††] According to the California Water Code 10933(b), the prioritization of basins is based on the following eight criteria in each basin, to the extent at which data are available: population, rate of current and projected population growth, number of public supply wells, total number of wells, irrigated acreage, the degree to which groundwater is the primary source of water in the basin, documented impacts (such as overdraft, subsidence, saline intrusion, water quality degradation), and other relevant information determined by the California Department of Water Resources, including adverse impacts on local habitat and local streamflow.

topographic gradient, supporting forest ecosystems in upland areas, streamflow, brackish environments in estuarine and coastal wetland ecosystems, and even marine environments[15–17]. Recent research conducted at the Dangermond Preserve has revealed that groundwater in this coastal environment is ancient (10,000-30,000 years old based on radiocarbon age dating) and that stream water is more than 70 years in age[18]. This suggests that groundwater discharge in these streams are predominantly receiving groundwater from longer regional flow pathways and may be more resilient to drought than ecosystems reliant on younger groundwater that is more meteorologically sensitive[19]. However, this may not be the case if groundwater or streamflow pumping is outcompeting ecosystem water needs by pulling groundwater out of reach from plant roots and streambeds, regardless of its age. Even rural clusters of residential wells in coastal aquifers that extract relatively small quantities of water can cumulatively pull significant quantities of water away from streams and adversely impact critical habitat for imperiled species such as salmon and steelhead[20], which have cultural and economic significance. In the absence of groundwater and streamflow regulation, water mismanagement and climate change threaten to exacerbate streamflow depletion and seawater intrusion in Coastal California, creating challenges for both ecosystems and human settlements.

Box 1. Well permitting and the Public Trust Doctrine

Resources providing broad public benefit and not easily managed under private ownership (e.g., air, rivers, oceans) have long been understood as public trust resources. California's public trust resources – including lands and waters that support fisheries, wildlife, aesthetics, and navigation – are protected for the public's benefit under the Public Trust Doctrine. In California, the Public Trust Doctrine is entrusted to both the federal and state governments, but court decisions play a critical role in ensuring that public trust resources are being managed for the public's benefit.

In 2018, California Court of Appeals *Environmental Law Foundation v. State Water Resources Control Board* decision ruled that the state has the obligation to manage groundwater extractions that might negatively impact the environment of navigable surface water. As a result, county-led efforts have emerged in Sonoma, Siskiyou, and Santa Cruz Counties to address public trust impacts during the well permitting process. However, because the California Court of Appeals decision did not provide technical and policy guidance on how public trust resource impact analysis should occur during a county's well permitting process, these decisions are being locally determined. Nevertheless, this ruling provides an additional opportunity for protecting coastal ecosystems located outside SGMA basins (i.e., groundwater stored in fractured rock aquifers but not delineated into groundwater basins, and groundwater stored in small alluvial basins designated as low and very low priority basins under SGMA). However, local governments would benefit from state-supported technical and policy guidance on how to assess, monitor, and mitigate public trust impacts caused by groundwater pumping.


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Monitoring streamflow at the Dangermond.

Climate Change

Extreme flood and drought events are intensifying globally due to climate change[21,22]. California has always oscillated between dry and wet cycles, but in recent years, flood and drought events are intensifying. These extreme climatic events are creating flood damage and evacuations, fueling record-breaking wildfires, accelerating groundwater depletion that causes lands to sink, seawater to intrude along coastlines, and wells and ecosystems to dry up[23–25].

Groundwater is a critical resource for buffering against drought events, providing a reliable water source for ecosystems and rural residential wells[23,26]. During drought, ecosystems exhibit a greater reliance on groundwater when surface water is less available. Coastal fog also serves as a crucial water source for ecosystems, particularly during the dry summer months. This marine fog layer reduces water stress by providing cool moisture to reduce evapotranspiration and can mitigate plant drought stress by up to 40 percent, since fog drip can contribute significantly to local hydrology by infiltrating soils and contributing to streamflow[27,28]. Heat waves create higher evapotranspiration demands for natural vegetation and crops, which must also be met. When groundwater access is inhibited within ecosystems, widespread tree die-off has been observed[29–33]. Groundwater supports important drought refugia by providing a reliable water source for vegetation within riparian corridors that support nesting habitats for birds, and shade cool, groundwater-fed streams that protect invertebrates and fishes when streams become intermittent and disconnected[17,34] (Figure 2). As a result, these groundwater-dependent ecosystems have been shown to be more resistant to drought and wildfire with quicker recovery[34,35].

However, when groundwater depletion occurs due to higher water demands during drought, groundwater pumping consequentially increases and further exacerbates water stress on ecosystems. Drought-induced vegetation die-back and mortality increases wildfire susceptibility and the release of carbon stored in woody biomass back into the atmosphere, further exacerbating climate change. On an annual basis, groundwater supports woody vegetation that accounts for over 50% of California’s aboveground carbon stocks in the state[16]. This is a critical ecosystem service that is largely unaccounted for and unacknowledged in state climate goals[5].

Groundwater also serves as an essential buffer during atmospheric river events that bring heavy precipitation and flashy streamflow. When managed, floodwaters can be converted from a flood risk to an essential water supply that replenishes depleted groundwater reserves by reconnecting floodplains and directing excess flows to agricultural land or recharge facilities[36–39]. Groundwater recharge is highly variable across the coastal landscape, with rates ranging between 3% to 45% of the ~15 inches of total precipitation at the Dangermond Preserve. The Point Conception Institute at the Dangermond Preserve has been working with partners at the University of California, Santa Barbara to develop a ‘digital twin’ of the Jalama watershed at Point Conception supported by a sensor network for rainfall, streamflow, and groundwater. From this network, an average of 29.7 inches of precipitation was measured at nine weather stations over 31 storm events during the 2022/2023 winter. We were also able to detect the effect of these precipitation events on groundwater recharge, resulting in an average of 5.25 feet of groundwater level rise in four wells measured. This is the most extensive network of watershed sensors in the region, leading to new insights on the implications of extreme events on freshwater ecosystems.

Box 2. Wildfire risk and prevention

Across California, wildfire frequency and intensity are escalating due to the prohibition of cultural burns, a history of fire suppression, recent land management practices, and changing climatic conditions. Under warming conditions, increased vapor pressure deficit (VPD) – a measure of the drying power in the atmosphere – is an important wildfire risk factor as it augments fire-danger conditions by drying out vegetation and reducing water availability[40–42]. The increase in VPD linked to emissions from fossil fuel corporations and major carbon polluters contributed to about 37% of the total area burned by forest fires between 1986 and 2021 in the Western United States and Canada. To quantify wildfire risk more accurately, there is a need to better understand how groundwater, surface water, and soil water interactions are affecting wildfire susceptibility in plants. Currently, wildfire risk and vulnerability assessments are conducted by field and remotely sensed measurements, but freshwater resources are not incorporated into these assessments. To help fill this gap, The Nature Conservancy is leveraging freshwater data collected at the Dangermond Preserve to improve decision-making frameworks for community wildfire protection and prescribed burn planning. This work is being done in partnership with NASA, state and federal resource agencies, and academia.

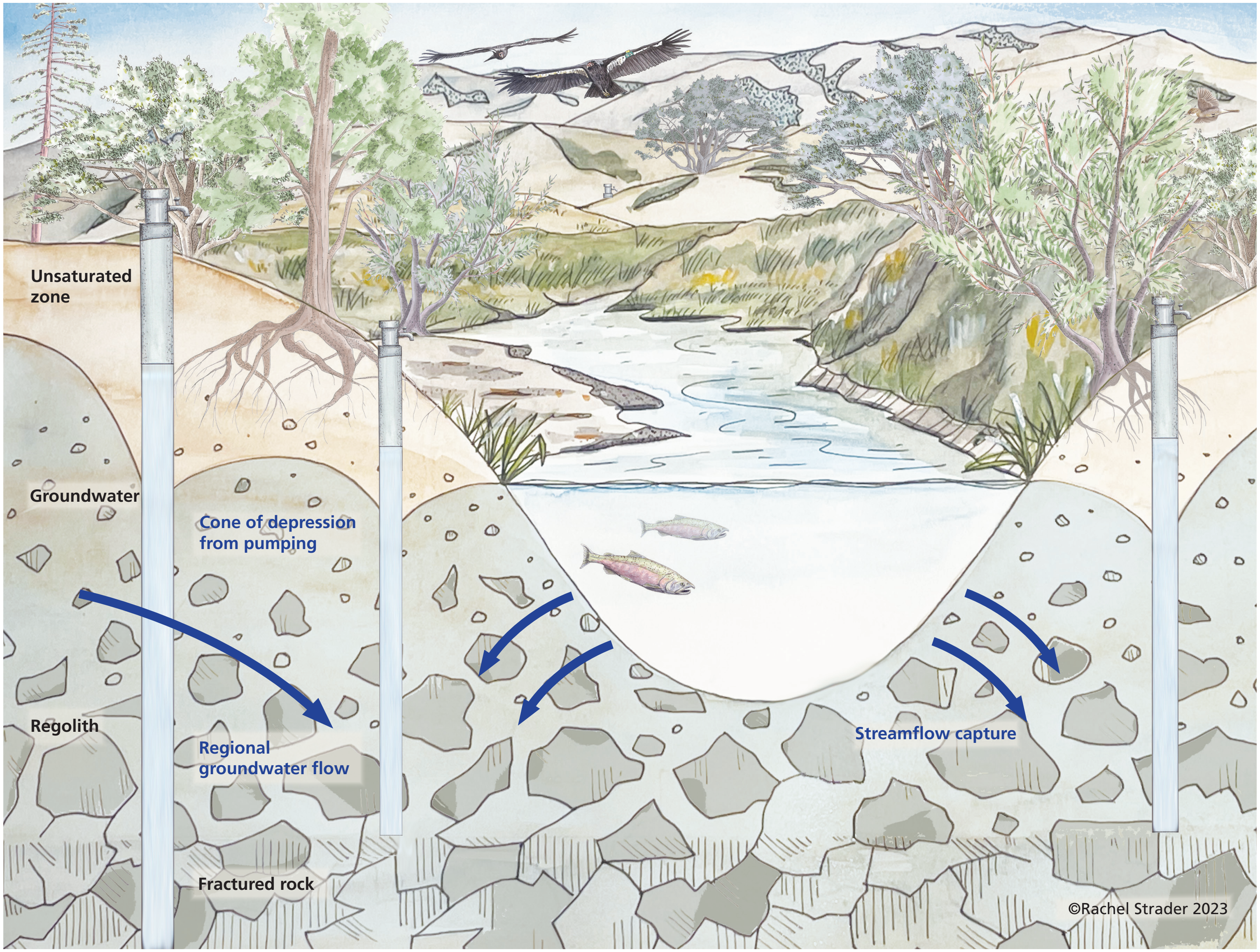

Figure 2. Conceptual diagram depicting hydrological dynamics in coastal environments.

Critical Species Recovery

Coastal California is biologically diverse with a high incidence of endemism, providing critical habitat for many rare, endangered, and threatened species, including the iconic coast redwoods (*Sequoia sempervirens*), California Condor (*Gymnogyps californianus*), and Pacific salmon and steelhead (*Oncorhynchus* spp.). Despite groundwater providing a critical water source for many California species and habitats, their groundwater needs are often not considered or addressed in species recovery efforts[43] or sustainable groundwater management planning[11]. If the connection between groundwater and the ecosystems they support are lost due to drought or unsustainable pumping practices, then streams, wetlands and springs can run dry and put them at greater risk of extirpation or extinction.

Species recovery efforts are often undertaken by multiple federal, state, and local agencies, as well as non-governmental groups and private landowners, and because of the multiple stressors on listed species and the many partners involved, coordination can be difficult. For example, Pacific salmon and steelhead that span across marine and freshwater habitats face numerous varied threats, such as climate effects on sea surface temperatures, migration barriers along rivers, higher stream temperatures due to decreased groundwater baseflow and reduced vegetation cover, fish hatchery impacts, and habitat degradation[44,45]. With more than 90 percent of all native freshwater species endemic to California vulnerable to extinction within the next 100 years[46,47], accounting for ecosystem water needs will be critical during future recovery efforts. Importantly, inter-agency coordination is critical given the interdisciplinary nature of stressor impacts. Box 3 provides an example of where inter-agency coordination has worked well with Southern California Steelhead recovery.


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Dangermond Preserve Survey – Juvenile Western Pond

Box 3. Steelhead Reintroduction and Recovery

The Southern California steelhead (*Oncorhynchus mykiss*) is a federally listed endangered species on the brink of extinction that has lost 90 percent of its historic habitat (Figure 3). To restore Southern California steelhead populations, the primary recovery actions are: 1) remove fish passage barriers, and 2) ensure there is sufficient water in streams for habitat and migration. Because many watersheds in Southern California are highly developed and experience significant groundwater depletion that impairs streamflow and riparian habitat conditions, recovery efforts at the relatively undeveloped Dangermond Preserve can offer an important stronghold for steelhead recovery efforts.

To help in the recovery of the Southern California steelhead population, The Nature Conservancy is working in collaboration with the Santa Ynez Band of Chumash Indians tribe, National Oceanic and Atmospheric Administration, and California Department of Fish and Wildlife to reintroduce steelhead to Jalama Creek within the Dangermond Preserve. Reintroduction efforts will be supported through the removal of two fish passage impediments in Jalama Creek, which are impeding movement of juvenile and adult steelhead. This project will open up 12.3 miles of steelhead spawning and rearing habitat, and restore 21 miles of connectivity from the ocean into headwater tributaries. In addition to benefitting steelhead, the project will further the recovery of other state and federally listed species, such as the tidewater goby (*Eucyclogobius newberryi*), California red-legged frog (*Rana draytonii*), and the western pond turtle (*Emys marmorata*).

Figure 3. Southern California Coast Steelhead recovery planning area. Boundaries of the recovery planning area extend beyond the current distribution of the listed species (source: National Marine Fisheries Service, Southern California Steelhead Recovery Plan, 2012).

Pathways Forward

California's coastal ecosystems face serious challenges related to water mismanagement, climate change, and species recovery efforts. However, preserving these ecosystems is possible if we take concerted action across local, regional, and state scales. Below, we provide recommendations for improving conservation strategies and policy and administrative changes to enhance protections for California's coastal ecosystems.

Delineate all of California into Groundwater Management Units.

SGMA provides California with the opportunity to halt groundwater depletion and safeguard this critical resource for current and future uses and build resilience to extreme climate events. However, a vast majority of California's groundwater, and the wells and ecosystems dependent upon it, remains unprotected by SGMA because of how groundwater basins are delineated by the California Department of Water Resources (DWR)[14]. In 2014, the United States Geological Survey (USGS) released a statewide map of groundwater units that includes: 1) DWR's alluvial groundwater basins, 2) highland areas that are adjacent to and topographically upgradient of groundwater basins, and 3) highland areas not associated with a groundwater basin (Figure 4)[48]. This resulted in 938 Groundwater Units, in contrast to the 515 alluvial groundwater basins delineated by DWR[3]. By coordinating with the USGS to incorporate these 938 groundwater units into California's Groundwater (formally referred to as "Bulletin 118"), DWR would be setting the foundation necessary to sustainably manage groundwater

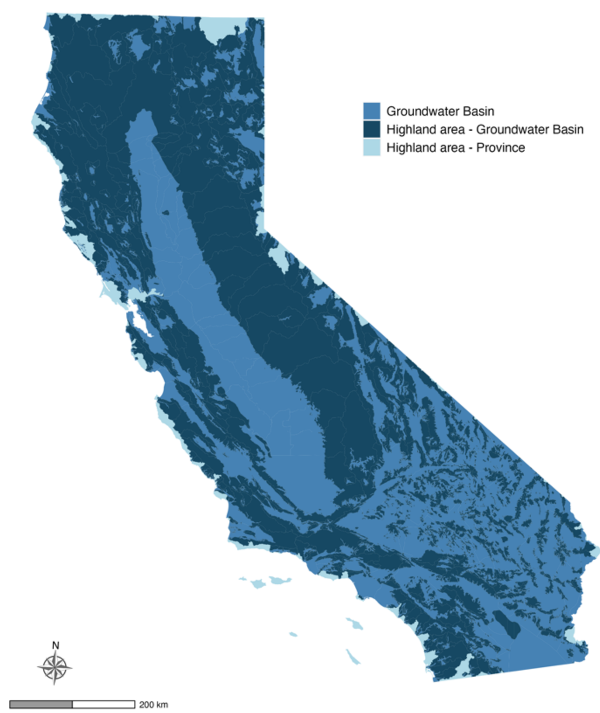

Figure 4. California Groundwater Units.

statewide. This would subsequently trigger the new groundwater basins to be prioritized into critical, high, medium, low, or very low basins[49]. Because many of these additional groundwater units are not as populated and agriculturally intensive as the other alluvial basins, they would most likely fall under low and very low priority status. While low and very low priority basins are not required to form a groundwater sustainability agency or submit groundwater sustainability plans, it would provide the foundation necessary for local agencies to voluntarily comply with SGMA regulations. Another benefit is that groundwater basins that are hydrologically connected to highland groundwater management units could better coordinate groundwater monitoring and land use decisions to better manage groundwater recharge in the headwaters.

Enhance funding and technical support for hydrologic monitoring.


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Stream monitoring at the Dangermond Preserve.

Massive data gaps in groundwater, streamflow, and ecosystems currently hinder conservation and water resource management efforts statewide. Even in SGMA regulated basins, gaps in shallow groundwater and streamflow monitoring data has contributed to ineffective ecosystem protection in groundwater sustainability plans[11]. California's Statewide Groundwater Elevation Monitoring (CASGEM) program, which provides a standardized data sharing platform for local and state agencies, could be enhanced by providing financial and technical support for groundwater monitoring in unregulated areas. This could be accomplished through enhanced coordination with federal agencies, in addition to providing technical assistance and financial incentives to private well owners to voluntarily provide data to CASGEM. In addition, local governments could also strengthen well permitting rules for new and existing wells to meter pumping and install pressure transducers that can monitor groundwater levels (Box 1). Intensive monitoring networks on public and private protected lands, such as at The Nature Conservancy's Dangermond Preserve, also offer an opportunity to better inform our ecohydrologic understanding of ecosystem water needs in watersheds with limited human disturbance, which can serve as 'reference' sites for unimpaired hydrology. Prioritizing monitoring sites through geospatial analyses and employing indirect modeling methods such as machine learning[50] such as The Nature Conservancy's Shallow Groundwater Estimation Tool[‡‡], can help reduce logistical and financial burdens associated with monitoring. To optimize monitoring efforts for conservation outcomes, monitoring wells, stream gauges, and meteorologic sensors should be prioritized around: 1) streams, 2) sensitive habitats and critical species recovery areas,

‡‡ The Nature Conservancy's Shallow Groundwater Estimation Tool is available at https://igde-work.earthengine.app/view/sage.

3) rural residential well clusters, and 4) existing monitoring efforts (e.g., species-level monitoring). In addition, forecasts of atmospheric rivers and the associated effects (e.g., flooding, aquifer recharge) could be improved if additional meteorological observations were available.

Develop state-supported tools and models.

Conservation and water management efforts throughout much of the state could be improved by the development of state-supported tools and modeling platforms. Currently, state-supported modeling platforms are primarily designed for large alluvial aquifers and are not applicable in fractured rock aquifers typically underlying coastal regions. In the absence of numerical models, alternative modeling platforms such as analytical modeling tools and streamflow vulnerability mapping could aid interested parties in evaluating impacts to public trust resources during California Environmental Quality Act (CEQA) evaluations, local government well permitting processes (Box 1), and conservation efforts at preserves or species recovery efforts (Box 3). Other useful state-wide tools to help improve hydrologic models include expanding geophysical surveys to map depth to bedrock in fractured hard rock aquifers and subsurface geologic heterogeneity, such as ongoing airborne electromagnetic surveys in SGMA regulated basins[51]. In addition, the adoption of state-wide ecosystem health monitoring tool that uses either Landsat or Sentinel satellite imagery, such as The Nature Conservancy's GDE Pulse tool[§§52], could help conservation and water practitioners prioritize monitoring and management efforts.

[§§] The Nature Conservancy's GDE Pulse Tool is available at https://gde.codefornature.org.

Establish ecologically protective environmental streamflow criteria across California.

Streamflow depletion caused by groundwater pumping can cause reductions in streamflow that are harmful to ecosystems. Streamflow depletion modeling is typically used in groundwater management, since streamflow gauging data alone is insufficient to detect groundwater pumping impacts due to multiple drivers on streamflow (e.g., weather variations, lagged pumping times and cumulative effects of groundwater pumping). However, it is almost impossible to validate streamflow depletion models in real-world settings because it needs to be compared with information on what streamflow would be in the absence of groundwater pumping. Streamflow analyses conducted without groundwater pumping considerations are generally carried out via model simulations; however, the generated model output typically does not translate back to meaningful ecological impacts. By establishing consistent state-wide ecologically relevant streamflow criteria, such as The Nature Conservancy's Natural Flows Database[***][53], modeling efforts can use these streamflow criteria data to develop meaningful conclusions on how water management and usage is impacting ecosystems so that trade-offs and protections can be evaluated and planned. The California Environmental Flows Framework (CEFF) provides a consistent, science-based, multi-agency approach for evaluating environmental flow needs across the state[54]. By implementing CEFF across California, streamflow criteria established at the stream-reach scale would fill a critical data gap experienced by groundwater sustainability agencies tasked with evaluating streamflow depletion impacts caused by groundwater pumping. The CEFF process could also benefit SGMA implementation, local government well permitting evaluations on public trust resources (Box 1), California Coastal Commission permitting decisions, and consultants tasked with evaluating project impacts during CEQA evaluations.

Enhance recharge and water conservation efforts.

Over the past several years, California has been making good progress to enhance groundwater recharge to replenish depleted aquifers during wet periods. State-supported infrastructure investments, pilot projects, and streamlined permitting processes have made it easier for local entities to divert excess flood flows from rivers for recharge during atmospheric events, but most of these efforts are occurring outside of Coastal California in California's Central Valley. While there is certainly a potential to capture flood flows for recharge in Coastal California, the steep and undulating terrain necessitates distributed recharge across the landscape. This could be done using the Recharge Net Metering (ReNeM) concept developed at the University of California, which utilizes financial incentives (pumping offsets) to private landowners to replenish groundwater on their land using existing water rights[38,39]. However, another untapped opportunity would be to enhance groundwater recharge on agricultural lands through conservation agriculture practices[†††] that build soil health and increase the water holding capacity and infiltration of soils. This is essentially what is referred to as "indirect recharge" and has the added potential of distributed recharge to occur during all rain events without having to be in close proximity to a stream or wait until flood flows occur. Other benefits of indirect recharge may include atmospheric carbon drawdown into agricultural soils, wildlife benefits, and reduced water demand for crops.

[***] The Nature Conservancy's Natural Flows Database is available at https://rivers.codefornature.org.
[†††] Conservation agriculture practices that build soil health include no-till, cover cropping, no synthetic chemical applications (e.g., pesticides, herbicides, fertilizers), crop diversification.

Advance scientific research and inter-agency collaboration.

Inter-agency collaboration between indigenous groups and government agencies at the federal, state, and local level is needed to integrate traditional knowledge from indigenous groups into western scientific practices and enhance cooperation across government agencies. The following areas of research are needed to support the preservation of California's Coastal ecosystems.

Coastal fog | How it supports coastal ecohydrology, and how it is being affected by climate change?

Atmospheric river events and impacts | Forecast modeling, impact assessments, flood mitigation efforts, and real-time groundwater recharge opportunities.

Drought refugia | Which habitats are less affected by drought, what are the enabling conditions (e.g., groundwater levels, fog drip, ecosystem water-stress adaptations), and which critical status species are benefiting so that conservation efforts can be prioritized? How does groundwater support ecosystems during drought?

Wildfire and groundwater nexus | Are higher evapotranspiration rates in forests inducing streamflow depletion or increasing wildfire susceptibility?

Multi-stressor science | Advance modeling and statistical approaches for isolating impacts.

Water stress indicators and thresholds | What groundwater levels and streamflow levels are necessary to prevent ecological thresholds from being surpassed?

New technologies for watershed monitoring & capturing extreme events | How can we leverage sensor networks, unmanned aerial vehicles, and remote sensing technologies to quantify groundwater recharge, availability, and ecosystem responses? How can technology be effectively utilized to assess groundwater movement in fractured rock?

Nature-based solutions | How can restoration efforts or conservation agriculture practices (e.g., soil health improvements via regenerative agriculture) improve groundwater availability and regulate streamflow?

Scalable and transferable solutions | How can we enhance the transparency and accessibility of data, sensor networks, and tools?

Establish and support a network of reference watersheds | The research and study of reference watersheds with intact ecosystems, unimpaired flows, and limited consumptive water use, like the Dangermond Preserve's Jalama Creek watershed, can provide invaluable insights for understanding groundwater and dependent ecosystems, providing a valuable knowledge basis for evaluating ecological responses to management and climate change.

Conclusion

The preservation of California's coastal ecosystems requires synergistic efforts carried out by multiple levels of government, non-profit organizations, tribes, and private landowners. As we outline in our recommendations above, much of the regulatory authority to better protect coastal ecosystems exists under the public trust doctrine, Sustainable Groundwater Management Act, state and federal Endangered Species Acts, and the California Environmental Quality Act. However, their effectiveness depends upon improved implementation, administrative changes, inter-agency coordination, and additional research. To secure a resilient water future and halt biodiversity loss under a warming climate, we must act now.

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Coast Redwood Forest

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