California's 2026 Coast and Ocean Assessment

MARCH 2026

Coordinating Authors

Dr. Jill Harris
California Ocean Science Trust

Dr. Tanner Waters
California Ocean Science Trust

Dr. Meghan Zulian
California Ocean Science Trust

Suggested Citation

Harris JL, Waters T, Zulian M (2026) *California's 2026 Coast and Ocean Assessment*. Ocean Science Trust.

Funding

Funding for this work was provided by the California Ocean Protection Council.

About This Report

This report is a product of the work of more than 120 scientists from academic, government, tribal, and nonprofit organizations, convened and supported by the California Ocean Science Trust (OST). It presents novel quantitative evaluations of the status of the coast and ocean and recommendations for strategic investments in monitoring and informs the California Ocean Protection Council's development of the State of the Coast and Ocean Report.

The framework and overall approach to these scientific evaluations, and the operations of many of the working groups, were developed through a collaboration between OST and the Southern California Coastal Water Research Project (SCCWRP) as part of a parallel effort for the West Coast Ocean Health Dashboard. This analysis was framed in the perspective of Western Science. Future evaluations could more fully consider traditional knowledges, such as for establishing longer-term baselines, getting deep understandings of species or places, and taking a less compartmentalized approach.

About California Ocean Science Trust

The California Ocean Science Trust strengthens the bridge between scientific research and sound ocean management. Created by state legislation, we support and bring world-class science and innovation together with state and federal policymakers to accelerate progress toward a healthy and resilient coast and ocean.

Acknowledgements

The findings presented in this report are the result of extensive voluntary collaboration and data sharing from a vast network of dedicated scientists across California and the West Coast. We are particularly grateful for the expertise and datasets provided by federal partners, including NOAA, the USGS, and the USFWS, which were instrumental in developing this state-level assessment. Ultimately, the success of such comprehensive and wide-scale evaluations underscores the vital importance of sustained state and federal investment in the science infrastructure that protects our valuable natural resources.

Key Messages

1. California's coastal ocean moderates our climate, holds potential solutions to climate change, and is directly impacted by a changing climate. California's coast and ocean are also critical natural resources and economic assets, generating $51.3 billion in gross domestic product and supporting more than 500,000 jobs.
2. The public and policymakers can get a broad, state-level understanding of the overall status of the coast and ocean through this synthesis of complex data into single statewide metrics and subsequent aggregation of those evaluations in this report. At the same time, some categories are better understood through downscaled or local evaluations.
3. This coast and ocean assessment is the result of the work of more than 120 scientific experts from academic institutions, state and federal agencies, NGOs, and Tribes. The widespread support that it has garnered exemplifies the value of leveraging buy-in from a broad scientific community that stands poised to continue to support in delivering the best available science to policymakers.
4. State-federal partnerships provide essential infrastructure: evaluations for 13 of the 19 categories leveraged federal data, and the evaluations of five categories were fully reliant on the specialized expertise and in-kind time of federal scientists.
5. Distilling data into single metrics for each category enabled us to flexibly incorporate multiple data types, retain geographic information while providing statewide coverage, and present findings that are both accurate and easily understood. This approach also ensures forward compatibility to incorporate new data as they become available and repeat this analysis in the future.
6. The 2014-2015 marine heatwave was a seminal event that disrupted California's ocean ecosystems, including loss of species and ecosystem services, declining populations, and geographic range shifts. We can expect more warm years like this in the future.
7. The state has a valuable role to play in strengthening the ocean monitoring and evaluation enterprise, such as expanding monitoring in Northern California, coordinating networks and standardizing methods, supporting innovative monitoring technologies to better track cryptic species, and identifying where strategic investments can fill data gaps.

Summary of Findings

Fishes	72% (82 species) of monitored marine fish populations were both abundant and stable/growing. However, this represents only 25% of all fish species in the state; the remaining species (427 out of 571) are unable to be evaluated due to the lack of long-term statewide monitoring data.
Seabirds and Shorebirds	Most species (13 out of 21) have been stable or increasing over the last 30 years. Short-term trends show similar patterns: since 2019, 14 species were stable, increasing, or showed mixed patterns, and 7 species were declining.
Marine Mammals	Marine mammals significantly recovered since the end of commercial whaling in California and implementation of the Marine Mammal Protection Act in the early 1970s. While there is only quality data for about half of California mammal stocks (24 out of 40), nearly all of those populations are stable or increasing. Notable exceptions include the extremely rare and endangered North Pacific Right whale and the declining population of Eastern North Pacific gray whales.
Rocky Intertidal Zone	The loss of functionally important species significantly altered the community composition during the 2013-15 marine heatwave and disease outbreak, but diversity and cover remain high. Parts of the state have seen modest recovery in some species.
Commercial Fisheries	Most (16 out of 18) of the top fisheries were in good economic and ecological condition. Notable exceptions that deserve closer attention include closures and/or disaster declarations for Dungeness crab, the northern red urchin fishery, and Chinook salmon.
Kelp	Following the 2014-15 marine heatwave, more than 75% of kelp canopies are smaller than their pre-heatwave historical median, compared to roughly 50% under normal interannual variability. There is considerable variation at the regional and local scale, and there has been some improvement in parts of the state.
Sandy Beaches	Overall, beaches are returning to average widths after reaching near-record widths a decade ago. Today, 55% of beaches are narrowing, and 45% are widening. Beach width is highly variable at the local scale, with many beaches exhibiting either persistent erosion or persistent stability.

Summary of Findings

Harmful Algal Blooms	In 2024 and 2025, there were major HAB impacts on razor clam harvests in Northern California and marine mammal strandings in Central and Southern California. Over half of coastal counties closed shellfish harvesting due to HABs, but this does not represent a significant departure from the long-term trend.
Ocean Temperature	Despite the long-term global ocean warming trend of approximately 2°F per century, 2024 was a relatively typical year for coastal water temperatures off California. There are early signs that marine species are moving north, likely due to warming temperatures.
Ocean Acidification	Ocean acidification is worsening across the state, and today the volume of seawater that is corrosive to shells is six times larger than before the use of fossil fuels. Conditions tend to be more corrosive in Northern California due to stronger upwelling and shelf processes.
Tidal Wetlands	Over 90% of California's tidal wetlands have been lost since the 1800's, but a precise quantitative evaluation of area lost and quality changes will require coordinated statewide monitoring.
Beach Water Quality	81% of monitored sites met regulatory standards for safe water quality. The remaining sites above the regulatory limit are mostly in known problem areas, like storm drains or beaches with poor circulation.
Coastal Access	55% of the ocean shoreline is within walking distance of a public access point, and this number has been steadily increasing over time. Most (89%) of public coastal access points have at least one amenity (parking, restrooms, accessibility improvements) that improves the quality of how people access the ocean.
Equity	Disadvantaged communities have disproportionately lower access to the ocean: they are 28% of California's total population, but only 3% of the population within 1 mile of the ocean.
Economy	The ocean economy contributes more than $50 billion to the economy and supports over 500,000 jobs, accounting for larger share of GDP and jobs in more rural counties like Del Norte.

Table of Contents

1. Introduction 8

Value of a Holistic Evaluation of the Coast and Ocean 8

How This Report Was Developed 9

Category Selection 9

Metric Development 11

Evaluation 11

2. Coast and Ocean Assessment 14

Species-Based Evaluations 14

2.1. Fishes 14

2.2. Seabirds & Shorebirds 23

2.3. Marine Mammals 36

2.4. Rocky Intertidal Zone 42

2.5. Commercial Fisheries 50

Place-Based Evaluations 58

2.6. Kelp 58

2.7. Sandy Beaches 64

2.8. Harmful Algal Blooms 70

2.9. Ocean Temperature 78

2.10. Ocean Acidification 85

2.11. Tidal Wetlands 95

Target-Based Evaluations 100

2.12. Beach Water Quality 100

2.13. Coastal Access 106

Cross-Cutting Evaluations 111

2.14. Ocean Equity 111

2.15. Ocean Economy 120

Data-Limited Categories 125

2.16. Eelgrass 125
2.17. Coastal Flooding 125
2.18. Marine Debris 126
2.19. Invasive Species 126
3. Data Gaps and Opportunities for Additional Monitoring 128
4. Lessons Learned and Next Steps 131
References 133
Appendix A: Additional Details for Seabirds & Shorebirds Assessment 138
Appendix B: Sea Level Rise Planning Evaluation 141

1.Introduction

Value of a Holistic Evaluation of the Coast and Ocean

California's coastal and ocean waters are critical natural resources and economic assets. They hold intrinsic value and have a profound impact on cultural identity, heritage, and the overall quality of life for all Californians. The coast and ocean are major drivers of the state's economy, contributing $51.3 billion to California's GDP and supporting more than 500,000 jobs.

Given the scale and complexity of the coast and ocean, a comprehensive, holistic, and synthesized understanding of the system is necessary for the public and decision-makers to track changes and identify priority areas for action. In our capacity as Science Advisor to the Ocean Protection Council, the Ocean Science Trust developed a novel framework to evaluate the status of the coast and ocean across physical, biological, and social categories, and to synthesize findings in a transparent, data-driven, and accessible format. This document, *California's 2025 Coast and Ocean Assessment*, presents both the framework and the resulting quantitative evaluations. Our approach relies on informed consent and uses the best available monitoring data from across California and the West Coast. By leveraging the expertise of independent subject-matter working groups, OST has provided an objective synthesis that reflects the currently best available data and collective scientific agreement.

The development of this framework directly supports the Ocean Protection Council's 2026-2030 Strategic Plan, which emphasizes robust monitoring as the foundation for tracking environmental change and prioritizing actions. By aggregating biological, physical, and human dimensions into a single statewide report, this framework allows decision-makers to simultaneously consider multiple dimensions of the coast and ocean. For decision-makers who rely on this information to guide policy and management, a high-level overview of the entire system provides a clear path toward a coherent understanding of overall coastal and ocean conditions across the state.

This integrated perspective makes it easier to identify cross-cutting trends, evaluate tradeoffs, and prioritize management actions. Ultimately, this report identifies where existing monitoring is effective and where strategic investments in monitoring and coordination can support progress toward a healthy, resilient coast.

How This Report Was Developed

This report was developed through a structured and collaborative scientific process. From its inception, OST followed the guidance of the Ocean Protection Council's Science Advisory Team and gathered public input to determine which categories of the ocean and coast should be evaluated in order to provide scientifically rigorous and policy-relevant insight. Simultaneously, a parallel effort led by SCCWRP to develop a similar product at a multi-state scale for the West Coast Ocean Alliance (WCOA) offered an opportunity to leverage resources and expand inclusion. OST and SCCWRP collaborated closely, endeavoring to find opportunities for efficiency, synergy, and alignment. OST convened additional expert working groups to collaboratively develop appropriate methods, identify and evaluate the most relevant data, and produce a quantitative assessment of system conditions using statewide metrics. Working groups are a scientifically rigorous method to build consensus and strengthen the integration of multiple data sources and methodologies, thereby ensuring credibility, relevance, and legitimacy [1]. Working groups met regularly throughout 2024 and 2025. In total, more than 120 experts were involved in working groups, including scientists from academic institutions, state and federal government agencies, non-governmental organizations, and Tribes. Working group members and affiliations are listed in their respective science chapters.

This framework is based on Western Science. Weaving together Western Science and Tribal or Traditional Knowledge, through co-production and other approaches, can improve the collective understanding of the ocean, how society relates to it, and the development of innovative solutions to vexing global environmental challenges [2]. While this work represents some initial steps toward incorporating Traditional Knowledge into the categories and scoring system, the framework was centered on Western Science perspectives on environmental and economically-oriented metrics. In the future, weaving together Traditional Knowledge and Western Science in ocean monitoring and evaluation would ensure approaches to understanding and communicating about the ocean are more comprehensive, accurate, and equitable [3].

CATEGORY SELECTION

The first step was to identify a set of categories that would present a holistic evaluation of the multi-dimensional ocean and coastal system. Given practical constraints to evaluating all aspects of the coast and ocean, the set of categories was selected based on multiple criteria:

- Taken together, would provide a comprehensive look at the biophysical and social system
- Feasible to quantitatively evaluate with currently available statewide data

- Addresses a direct request from OPC based on their strategic priority areas, such as sea level rise planning, commercial fisheries, and coastal access

The initial list of 42 potential categories was proposed by the OPC Science Advisory Team [4]. This broad list was refined in the fall of 2024 through a public input process that included an online survey and a series of public webinars to identify topics of interest to Californians. Details about the public input process and public feedback are available in materials from the March 3, 2025, OPC meeting [5]. As a result of public input, several key changes were made, including:

- Adding a separate category for commercial fisheries, which were previously included in the economy section;
- Adding a sandy beaches category; and
- Refining the approach to sea level rise to focus on sea level rise planning (see Appendix B).

In parallel with the public input process, the list of categories was refined with guidance from OST and OPC staff and partners from WCOA and SCCWRP working with OPC on the West Coast Ocean Health Dashboard.

Following the public input and expert guidance processes, the result was a list of 17 complementary categories that describe species, habitats, stressors, and the human dimensions of the coast and ocean:

- Fishes
- Seabirds & Shorebirds
- Marine Mammals
- Rocky Intertidal
- Commercial Fisheries
- Kelp
- Sandy Beaches
- Harmful Algal Blooms
- Ocean Temperature
- Ocean Acidification
- Tidal Wetlands
- Beach Water Quality
- Coastal Access
- Eelgrass and Seagrass
- Coastal Flooding
- Invasive Species
- Marine Debris and Microplastics

For four of these categories, there was insufficient statewide data to provide a quantitative evaluation: eelgrass, invasive species, marine debris, and coastal flooding. Since those categories are important dimensions of California's coast and ocean, they are still included here with summaries of existing data and suggestions for building statewide monitoring to enable comprehensive evaluation in the future.

Ocean equity and ocean economy were both evaluated quantitatively. However, given the broad and complex nature of these subjects and their pertinence to each of the other categories, they are included as cross-cutting context and not scored like the other categories.

METRIC DEVELOPMENT

Metrics are the units of measurement for categories. For example, the kelp *category* was evaluated using the *metric* of kelp canopy cover. Metrics were selected based on best practices of what makes an effective metric [6]:

- Logically describes the category based on established theory
- Transparently measured; i.e., uses existing, publicly available data
- Covers a large spatial scale, i.e., most of California
- Has a reliable reference value or a long-term dataset
- Is easy to understand
- Relates to a state policy priority

The metrics describe the percentage of species or spatial units, thereby emphasizing species representation or geographic coverage rather than aggregated mean values. For example, rather than reporting the average beach width across the entire state, the sandy beaches category was evaluated based on the percentage of beaches that are eroding or accreting, because beach width is highly variable among locations. Similarly, fishes were evaluated based on the percentage of species with populations at or above targets rather than average biomass or population size.

This approach offers several advantages. First, it retains the flexibility to use different methods across regions (e.g., remote sensing, *in situ* surveys, or local and Traditional Knowledge), provided that each method has sufficient temporal history to establish a baseline for that region. This is particularly useful when variable methods are used in different geographies or for different species, as is the case for indicators like birds and fishes, and it ensures forward compatibility for the addition of new data in the future. Second, a geographically oriented assessment retains regional information while covering the entire state, making this tool useful for decision-makers at the local, regional, state, and tribal levels. Third, it provides a clear path to condense the variable and complex data for each indicator into a single value for the entire state.

EVALUATION

Each category was evaluated according to its current status and trend, providing a snapshot of both immediate conditions and the direction of recent change. Statuses are quantitative values

that reflect how the current conditions of the categories compare to long-term baselines, reference values, or management targets. Trends describe how the metrics have changed over time.

Working groups set baseline time periods, reference values, and trend periods based on what was most appropriate for the nature of the category. For example, kelp coverage is naturally highly dynamic on an annual scale, so the reference value for calculating kelp status was a historical long-term mean, dating to 1984 when widespread satellite coverage began. The time period for evaluating kelp trend was set to include changes since the most recent major disturbance event, the marine heatwave during 2014-2015. In contrast, ocean acidification changes slowly, and the ocean acidification category was explicitly defined to reflect anthropogenic impacts, so the reference value for ocean acidification was set to pre-industrial levels.

Using these baseline and reference values, each category was evaluated using one of three approaches:

1. **Species-based scores** capture how species' populations compare to historical averages. This includes the birds, fishes, commercial fisheries, mammals, and rocky intertidal categories.
2. **Place-based scores** capture how conditions at a specific location compare to that location's historical average. This includes the kelp, sandy beaches, ocean temperature, ocean acidification, and harmful algal blooms categories.
3. **Target-based scores** capture the percentage of units (e.g., sampling sites, area) as they compare to a management goal. This includes the coastal access, beach water quality, and sea-level rise planning categories.

For most of the species-based and place-based scores, each species or location was evaluated individually. Then, each species or location was scored based on where its 2024 value fell within the distribution of historic reference values:

2024 Value	Score
Less than the 10th percentile of the historical distribution	-2
Between the 10th and 25th percentile of the historical distribution	-1
Between the 25th and 75th percentiles of the historical distribution	0
Between the 75th and 90th percentiles of the historical distribution	1
Greater than the 90th percentile of the historical distribution	2

The scoring direction was reversed for categories in which higher values indicate a worse outcome: harmful algal blooms, ocean acidification, and ocean temperature.

Finally, individual scores were averaged to generate a statewide score for each category.

2. Coast and Ocean Assessment

The following sections describe the methods and frameworks, present detailed results from novel analyses, list the working group members and other scientists involved in the evaluations, and include links to data sources for each category.

Species-Based Evaluations

These categories were evaluated based on how current populations of individual species compare to their historical average population sizes. Statewide scores are the averages of individual species scores.

2.1. FISHES

72% (82 species) of monitored marine finfish populations were both abundant and stable/growing. However, this represents only 25% of all fish species in the state; the remaining species (427 out of 571) are unable to be assessed due to the lack of long-term monitoring data.

Lead Author
Christopher M. Free, University of California, Santa Barbara

Working Group Members
Larry G. Allen, California State University, Northridge
Lyall Bellquist, Scripps Institution of Oceanography
Katie Cieri, California Ocean Protection Council
Jeremy T. Claisse, Cal Poly Pomona
John C. Field, National Oceanic and Atmospheric Administration, National Marine Fisheries Service
Scott L. Hamilton, San José State University and Moss Landing Marine Lab
Andrew Leising, National Oceanic and Atmospheric Administration, National Marine Fisheries Service
Erin V. Satterthwaite, California Sea Grant and California Cooperative Oceanic Fisheries Investigations (CalCOFI) and Scripps Institution of Oceanography
Javier Silva, Sherwood Valley Band of Pomo Indians / North Coast Resource Partnership

Executive Summary

The status of marine fishes was evaluated based on populations of individual species. In 2024, 72% (82/114) of California's well-monitored marine finfish species had high abundance and either a

stable or growing population over the last five years. This evaluation includes all well-monitored California finfish that live in the ocean, including sharks, rays, and salmon, but does not include invertebrates (such as lobsters and shrimp) or marine mammals (such as dolphins and whales). Fishes were evaluated using the species-based approach, so each individual fish species was compared to an established management target from a stock assessment, if available, and otherwise to its long-term population size. The state score is the average score of all 144 fish species with reliable long-term monitoring data, which constitutes 25% of the 571 known species.

Species that are more heavily managed, particularly those that are commercially harvested, generally had higher abundance and positive trends, confirming that the majority of marine fishes in California that are formally assessed for management also have healthy populations. Only two species for which we have stock assessments, quillback rockfish and shortspine thornyhead, had low abundance and decreasing population trends. Species that are unassessed, vulnerable to overfishing, and/or impacted by climate change should be prioritized for monitoring and management. For example, Pacific herring is one of the California fishes most vulnerable to climate change impacts [7].

Basis of Evaluation

The working group used the species-based approach to describe the status of marine fishes, evaluating each individual species based on its population status using either stock assessments or long-term monitoring surveys. Stock assessments are the mathematical models used to estimate population size and fishing pressure relative to management reference points. Because stock assessments integrate multiple data types (e.g., indices of relative abundance, length and age composition, catch), they represent our best understanding of trends in population abundance and provide the most objective method for assessing the status of finfish populations. However, stock assessments are resource-intensive and tend to be conducted for only the most commercially and recreationally important species. Stock assessments exist for 38 species (6%) of California fishes.

The remaining California marine fish species without stock assessments were evaluated based on long-term, fisheries-independent monitoring surveys. The working group reviewed monitoring programs in the California Current [8] and selected five surveys that each span ≥10 years and collectively cover a wide portion of California waters (Figure 1.1).

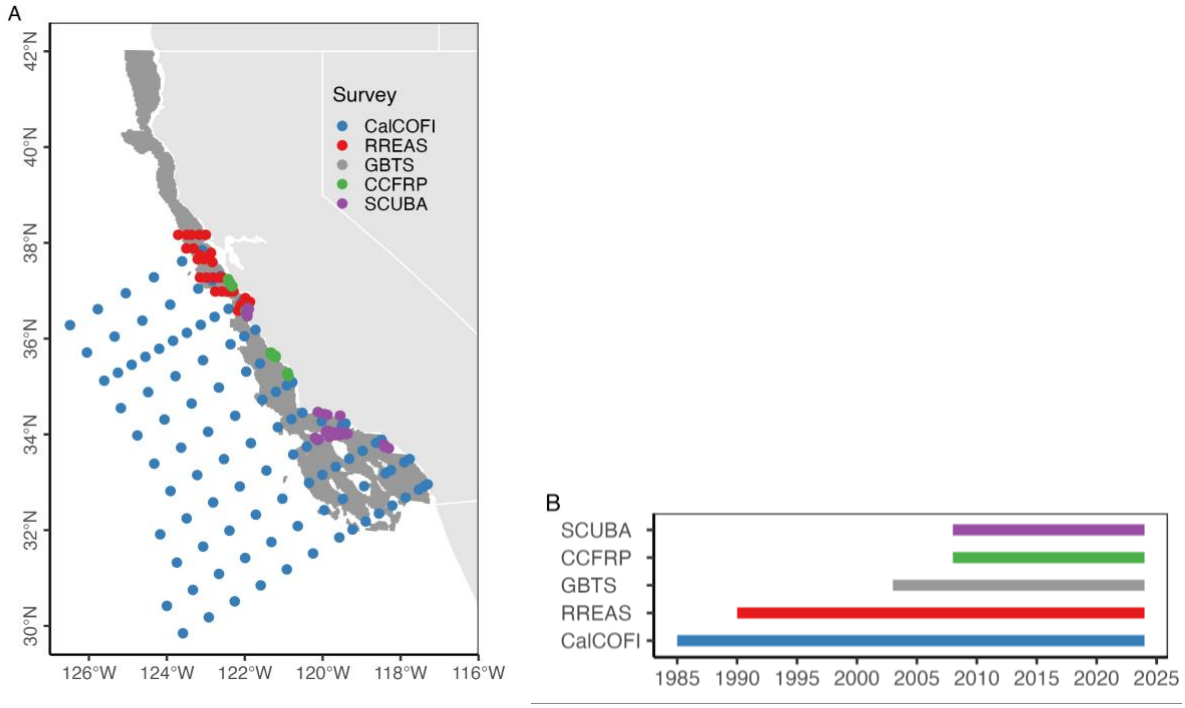

Figure 1.1. Spatial (A) and temporal (B) coverage of the five monitoring surveys used for this analysis.

The five surveys included in the analysis are:

- California Cooperative Oceanic Fisheries Investigations (CalCOFI) has been conducting regular oceanographic and biological sampling in southern California since 1951, including sampling of fish eggs and larvae, which approximates size of the spawning population [9–11]. The survey has been widely used to assess regional ecosystem processes [12]. Counts are measured as mean abundance per $10m^2$ of area sampled, based on an oblique bongo tow to 210m. The working group used data from recent years (1985–2022) with consistent stations and evaluated the 38 species occurring in ≥30 of the 38 years and in ≥300 tows, following the criteria used in a recent similar analysis [13].
- Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) has been conducted in Central California since 1983 and throughout southern and northern California waters since 2004 [14,15]. This annual survey uses a midwater trawl to sample pelagic juvenile stages of groundfish and other forage species, such as krill and market squid. Relative abundance is measured as count per tow. The working group used data from all stations from 2004-2024 and evaluated the 19 species occurring in ≥20 of 24 years and in ≥300 tows.
- West Coast Groundfish Bottom Trawl Survey (GBTS), a long-term, standardized bottom trawl survey conducted by the National Oceanic and Atmospheric Administration's (NOAA) Northwest Fisheries Science Center [16]. Since 2003, the annual GBTS has used consistent

sampling gear, spatial sampling protocols, and methods to assess species abundance using a random stratified design. Relative abundance for each species is measured as kg per km^2 of area swept by the survey gear. The working group evaluated the 59 species occurring in ≥18 of the 22 years and in ≥5% of tows.

- The California Collaborative Fisheries Research Program (CCFRP), a partnership between scientists and recreational anglers, uses hook-and-line surveys in a stratified random sampling design to monitor nearshore fishes in MPAs and adjacent reference sites. Each fish is measured for length prior to release, and those lengths are converted to weights using species-specific length-weight equations. Biomass is calculated as kg per angler per hour of fishing. Surveys have been conducted in Central California since 2007 and in other regions since 2017. Data were evaluated for the 20 species occurring in ≥14 of 17 years and at least 100 surveys.
- SCUBA surveys for MPA monitoring: A consortium of California academic institutions uses SCUBA to survey fishes on nearshore rocky reefs throughout California as part of statewide long-term monitoring of MPA and reference sites following standardized CRANE [17] and PISCO [18] protocols. The working group used data from sites consistently sampled since 2008 (excluding the north coast sites monitored by Humboldt State University scientists, where monitoring began in 2013) and removed surveys conducted before July 1 due to their limited frequency. Data were evaluated for 45 species occurring in ≥14 of 16 years and ≥2.5% of surveys.

The working group considered and excluded several other surveys due to insufficient spatial or temporal coverage. For example, the Southern California Coastal Water Research Project (SCCWRP) Bight Regional Monitoring and NOAA Shelf Rockfish Hook and Line Surveys were excluded because they are limited to southern California, and that region was sufficiently covered by other monitoring. Although the RREAS, CCFRP, and SCUBA programs have recently expanded to the North Coast, the northern surveys of these programs were not included due to short temporal coverage. However, as monitoring continues in these areas, these observations will have sufficient temporal coverage to be included in future analyses.

Methods

Status

The metric for marine fishes is based on current population relative to a defined management target (for species with stock assessments) or a long-term average (for all other species). This evaluation uses a species-based approach, where each species is evaluated separately, and the overall state score is an average of all species.

First, the group identified all marine finfish in California's waters, defined here as the portion of the 200-mile U.S. Exclusive Economic Zone occurring off the California coast. This list of all California finfish was created by combining species identified in the *Guide To The Coastal Marine Fishes of California* [19], *The Ecology of Marine Fishes: California and Adjacent Waters* [20], and the long-term monitoring surveys described above.

To evaluate current status and abundance trends from stock assessments, the working group used model output collated in the NOAA StockSMART database, as it captures up-to-date abundance time series and estimates of the ratio of observed biomass to the biomass that would provide maximum sustainable yield (terminal B/B_{MSY}). To assess changes in status through time, the working group used model output collated in the RAM Legacy Database [21], because time series of biomass (B/B_{MSY}) and fishing pressure (F/F_{MSY}) are not included in StockSMART. The stock assessment output collated in the RAM Legacy Database is likely a few months to years out of date, but it represents the best available information.

To estimate model-based indices of relative abundance for each species-survey combination, the working group used a spatiotemporal generalized linear mixed effects modelling framework fit using the *sdmTMB* package [22]. This approach explicitly accounts for interannual variability in the timing and location of sampling efforts by using spatiotemporal random effects.

To evaluate individual species, two approaches were used: one for species with stock assessments and another for those without. Each species with a stock assessment was assigned a "high abundance" status if the population was above the target reference point in the most recent year of the assessment, and a "low abundance" status if it was below it. This means that stocks in the precautionary zone below the target reference point but above the limit reference point ($0.5 < B/B_{MSY} < 1.0$) were given an "low" status, even though they are not overfished in legal terms.

Most species without stock assessments appeared in data sets from more than one long-term monitoring program. These species were evaluated using the most reliable index of relative abundance, ranking available indices according to the duration and spatial coverage of the long-term monitoring surveys: (1) GBTS; (2) CalCOFI; (3) RREAS; (4) CCFRP; and (5) SCUBA surveys. Each species was evaluated by comparing recent abundance (mean of the most recent 5 years) to the long-term mean abundance (all years available). A species was classified as "low abundance" if the recent population was significantly lower based on a t-test, and "high abundance" if the recent population was either significantly greater than or indistinguishable from the long-term average abundance.

Trend

Trend over the most recent five years was assessed using Thiel-Sen regression, a form of robust regression that is insensitive to end points and outliers [23]. Each species was evaluated as "stable/increasing" if it exhibited either a significantly positive trend or a non-significant/stable trend, and a "decreasing" trend if it exhibited a significantly negative trend.

The overall score for marine fishes was a combination of status and trend, where each species was deemed: (1) high abundance and stable/increasing; (2) high abundance but decreasing; (3) low abundance but stable/increasing; and (4) low abundance and decreasing. Note that "high" abundance includes average abundance.

Thus, the statewide status score is reported as the percentage of species with both high abundance and increasing trends. The overall statewide trend reflects how the average population relative to the target population B/B_{MSY}) has changed over time for 38 managed species.

Results

By combining species lists from the two reference books and taxa lists compiled from five monitoring programs, this analysis identified 571 known species of marine fishes in California waters. The stock assessments and surveys detected 417 species, of which 144 (25%) had sufficient population data for this analysis. Thus, this evaluation reflects only the 144 species, spanning 21 orders, 51 families, and 95 genera (Figure 1.2).

None of the surveys detected species from six orders known to occur in California: Albuliformes, Cypriniformes, Cyprinodontiformes, Orectolobiformes, Siluriformes, and Zeiformes. An additional 17 orders known to occur in California were detected but did not have sufficient data to support this evaluation: Acipenseriformes, Atheriniformes, Beloniformes, Elopiformes, Gobiesociformes, Hexanchiformes, Lamniformes, Lampriformes, Lophiiformes, Mugiliformes, Ophidiiformes, Petromyzontiformes, Squatiniformes, Stephanoberyciformes, Syngnathiformes, Tetraodontiformes, and Torpediniformes (Figure 1.2).

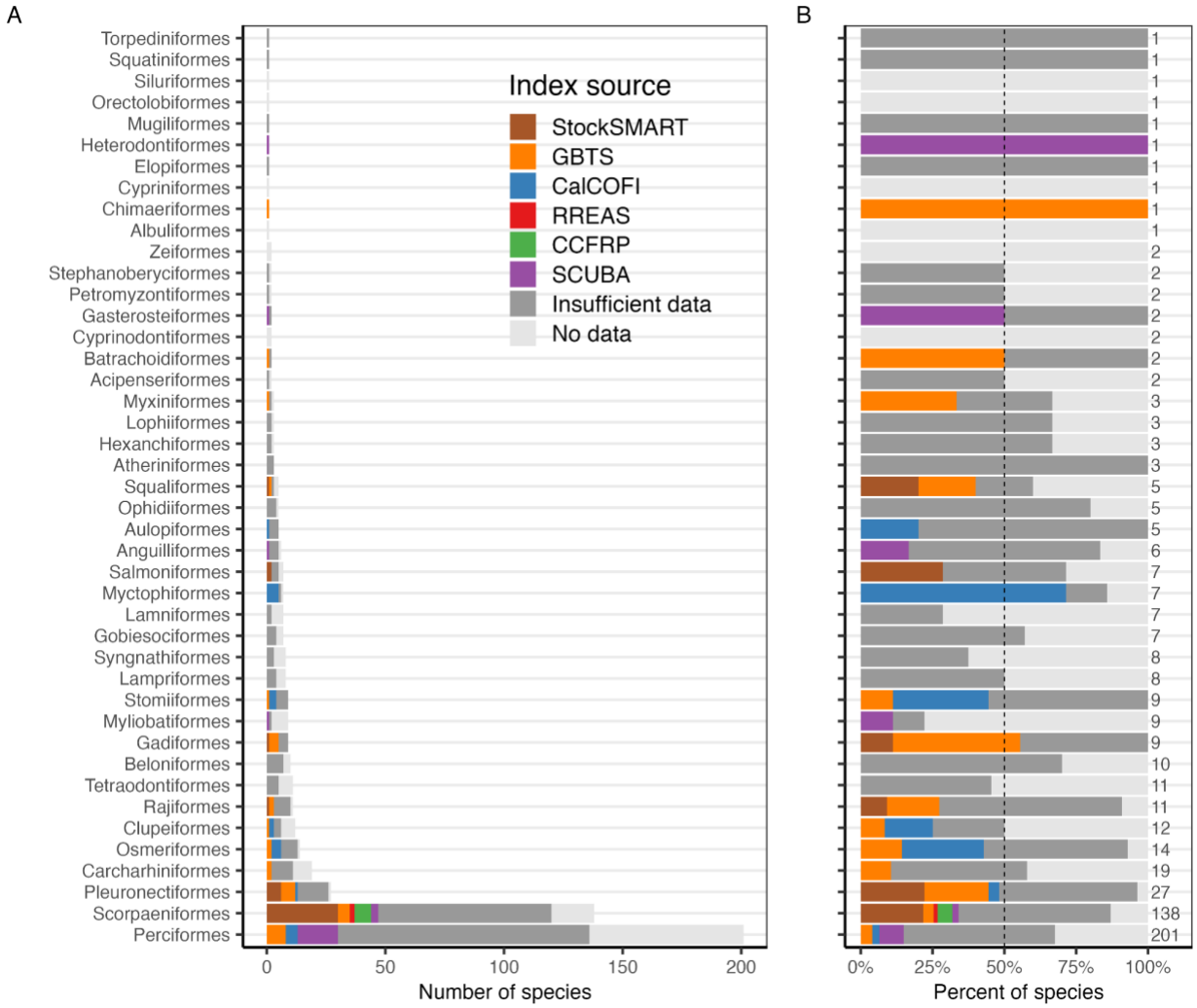

Figure 1.2. The representation of California marine fish species in the long-term monitoring surveys evaluated in this analysis by taxonomic order. Colored bars indicate species found within long-term monitoring programs; brown indicates species evaluated based on management evaluations in StockSmart; dark grey indicates species observed in the survey data but with insufficient data to support the evaluation of status and trend; light grey indicates orders known to occur in California but that were not observed in these surveys. The total number of species within each order is printed on the far right of the right panel.

Status and Trend

The majority of assessed species (72%) had both high abundance and increasing population trends (Figure 1.3, green box). Nearly all assessed species (93%) had stable or increasing abundance trends (Figure 1.3, green + orange boxes). Only two species, quillback rockfish (*Sebastes maliger*) and shortspine thornyhead (*Sebastolobus alascanus*), had both low abundance and decreasing trends (Figure 1.3, red box).

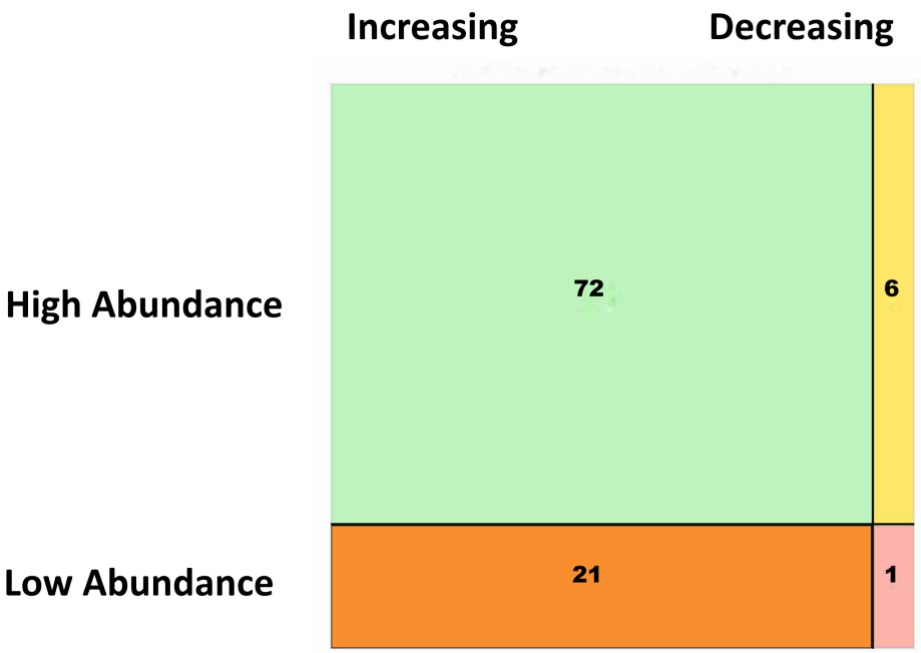

Figure 1.3. Proportion of 144 fish species that had high vs. low abundance (vertical axis) and stable/increasing vs. decreasing trends (horizontal axis).

Species that are more heavily managed generally had higher relative abundances and increasing trends. Species that are commercially harvested, which receive the majority of management attention, had significantly better statuses and trends than unharvested species. Managed species, which are a subset of harvested species, had generally better statuses and trends than unmanaged species and had even more favorable status and trends than the broader list of harvested species.

There was some variation in status and trend by biological characteristics. In general, longer-lived species and species at higher trophic levels had better statuses and trends than shorter-lived and lower-trophic-level species. Status and trend were not strongly correlated with either body size or habitat. Quillback rockfish and shortspine thornyhead, the only two species with "low and decreasing" scores, are both long-lived, carnivorous demersal groundfish species, but are also commercially harvested and subjected to high management intensity.

Discussion

Overall, in 2024 most assessed marine fish species had robust populations, meaning they were at or above reference levels and exhibited either long-term stability or increasing abundance trends. In general, stable or growing fish populations are the goal in California because fish and other marine wildlife are managed for long-term sustainability under both state and federal regulations.

However, there are circumstances under which decreasing fish populations are not cause for concern. For example, fish populations naturally fluctuate over time, so a species near its ecological carrying capacity would fluctuate in size. For example, sardines and anchovies can exhibit extreme population variability related to changes in oceanographic conditions along the California coast. Thus, more stable fish populations are generally, but not always, a positive indication of the overall status of marine fishes.

Notably, this evaluation only applies to the approximately one-quarter of species (144/571) for which we have sufficient data. Most of the other 427 species that make up California's diverse marine fish community are rare and/or not well-studied, and scientists have a very limited understanding of their status. One notable exception is the Barred Sand Bass, which is a heavily targeted, data-rich, and highly studied species that was recreationally overfished on spawning aggregations and subsequently collapsed. While this species was unassessed while this evaluation was conducted, as of 2026, CDFW is assessing its status in partnership with the recreational fleet, and results could be incorporated into future evaluations. Advanced tools, targeted long-term monitoring, and prioritization of uniquely vulnerable (e.g., aggregating) species will provide scientists with a more complete picture of the status of California's entire diverse fish community.

This assessment took a broad stroke by including all finfish species with sufficient data. Future evaluations could highlight, or assign weighting to, individual species with particular value, such as those that are commercially or recreationally important, have cultural value to California Native Americans, or are highly vulnerable to overfishing and/or climate change impacts.

Source Data

- GBTS data are available from https://www.webapps.nwfsc.noaa.gov/data/map and https://www.fisheries.noaa.gov/inport/item/18418
- CalCOFI data are available from https://calcofi.org/data/ and NOAA Coastwatch ERDDAP at https://coastwatch.pfeg.noaa.gov/erddap/index.html
- RREAS data are available from NOAA OceanView ERDDAP at https://oceanview.pfeg.noaa.gov/erddap/index.html
- CCFRP data are available from the California Open Data Portal at https://data.ca.gov/
- MPA SCUBA survey data are available from Data One at https://opc.dataone.org/view/doi%3A10.25494%2FP6%2FMLPA_kelpforest.9
- NOAA Fisheries StockSMART data are available from apps-st.fisheries.noaa.gov/stocksmart. 09/16/2025

Appendix

All analyses were done in R (R Core Team, 2025), and all data and code are available on GitHub: https://github.com/cfree14/ca_stock_status. The fishes evaluation is supported by a scientific publication that is currently in preparation.

2.2.SEABIRDS & SHOREBIRDS

Most species (13 out of 21) have been stable or increasing over the long term. Short-term trends show similar patterns: since 2019, 14 species were stable, increasing, or showed mixed patterns, and 7 species were declining.

Authors

Nadav Nur, Mike Johns, Julie Howar, and Jaime Jahncke, Point Blue Conservation Science

Working Group Members

Josh Adams, USGS Western Ecological Research Center
Dan Robinette, Point Blue Conservation Science
Scott Shaffer, San Jose State University
Javier Silva, Sherwood Valley Band of Pomo Indians
Pike Spector, Ocean Protection Council
William Sydeman, Farallon Institute
Pete Warzybok, Point Blue Conservation Science
Jeannette Zamon, NOAA Fisheries

Executive Summary

The status of seabirds and shorebirds was evaluated based on the populations of twenty-one species that represent a diversity of habitats, feeding strategies, and food sources. In 2024, California's seabirds and shorebirds showed a mixed picture: populations were generally stable, but more populations were decreasing than increasing. Over the long term (1997-2024), there was stability among offshore and nearshore fish-feeding birds, such as Common Murres and Brandt's Cormorants, but there was a consistent decline among shorebirds and estuarine waterfowl, such as Dowitchers, Scoters, and Scaup. This pattern suggests ongoing anthropogenic impacts in nearshore coastal and estuarine habitats.

Over the short term (2019-2024), more than one-third of species were stable, two species showed significant increases (Brown Pelicans and Snowy Plovers), and five species showed significant declines (Cassin's Auklets, Ashy Storm-petrels, Least Terns, Bufflehead, and Canvasback). Thus,

while long-term trends are relatively stable across the broad community of seabirds and shorebirds, recent ocean conditions and coastal pressures are creating new vulnerabilities.

Basis of Evaluation

The working group used a species-based approach to assess the status of seabirds and shorebirds, evaluating 21 indicator species individually using data from long-term monitoring programs, and then combining the statuses to produce an overall evaluation for California seabirds and shorebirds.

California has a diverse community of marine birds, ranging from shorebirds and waterfowl to seabirds that spend most of their lives far offshore. Seabirds and shorebirds are long-lived, wide-ranging, and sensitive to environmental variability, so they serve as useful indicators of ocean conditions, climate variability, and human pressures. This evaluation is broadly inclusive of all bird species that depend in any way on ocean or coastal resources, including seabirds, shorebirds, and waterfowl. Seabirds are species that spend nearly all their lives in the open ocean, such as albatrosses. Shorebirds are species that use nearshore and mainland habitats for feeding and nesting, and therefore live closer to the coastline, such as gulls and pelicans. Waterfowl are birds that live in coastal estuaries, such as buffleheads. The working group selected 21 indicator species to represent a range of habitats (offshore, nearshore, coastal), prey types, ecological roles, and taxonomic diversity across multiple orders (Table 2.1). The set of indicator species includes both migratory and locally-breeding species, as well as a mix of listed species of conservation concern and species not at conservation risk.

Species were evaluated by combining population data from multiple sources: at-sea surveys, conducted from vessels, and land-based surveys, which included colony counts, wintering shorebird surveys, and waterfowl surveys (some of which also used aerial methods), totalling twelve long-term monitoring programs across the state. While some species were represented by only one category, five species had sufficient data from both. For these, data from each survey type were evaluated separately and then combined for that species before reporting, ensuring that species represented by multiple datasets did not contribute with greater weight than species represented by a single dataset.

Standardized at-sea shipboard surveys in California began in the 1980's, the Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) in 1983, and extensive statewide coverage started in 1997 and has continued through the present. Accordingly, the primary time series analyzed for most species was 1997–2024. When possible, the same time series was used across species; however, some began later (e.g., shorebirds from 2011–2024). All data sets except the shorebird series span at least 20 years. Three datasets were reviewed but excluded: (1) Black Oystercatcher

data lacked coverage for the most recent three years, (2) San Francisco Bay bridge surveys were too sparse to support trend analysis, and (3) colony counts of California Gulls in San Francisco Bay were heavily influenced by local management and habitat changes (e.g., salt pond restoration to tidal marsh), limiting their relevance to statewide trends.

Table 2.1. Time series (N=25) for bird species included in this analysis, indicating whether data were derived from land-based or aerial counts (colony) or at-sea surveys, acronyms of monitoring programs, each species' primary habitat and prey, long- and short-term trends, mean percentiles for status assessment, and species- and survey-specific weighted scores (see Appendix A for details).

Data Type	Bird Species	Survey Program	Main Habitat	Main Prey	Long-term trends percent/yr	Short-term trends percent/yr	Percentile	Weighted Score
Colony	Ashy Storm-Petrel	SEFI CPUE	Offshore	Invert	0.38	-10.64	23	-0.36
Colony	Brandt's Cormorant	SEFI, ANI, VAN	Nearshore	Fish	5.85	-0.57	73	0.00
Colony	Bufflehead	MWS	Coastal	Invert	1.67	-24.71	63	0.00
Colony	Canvasback	MWS	Coastal	Invert	1.40	-22.46	75	0.00
Colony	Cassin's Auklet	SEFI	Offshore	Invert	0.14	-7.09	20	-0.67
Colony	Common Murre	SEFI	Offshore	Fish	6.33	7.29	91	1.24
Colony	Double-crested Cormorant	SFBBO	Coastal	Fish	-3.42	-7.88	9	-0.86
Colony	Dowitcher (two spp.)	PFSS	Coastal	Invert	-5.84	-1.37	24	-0.27
Colony	Least Tern	CDFW	Nearshore	Fish	-2.87	-7.46	5	-1.74
Colony	Marbled Godwit	PFSS	Coastal	Invert	-1.36	-1.77	42	0.00
Colony	Pigeon Guillemot	SEFI, VAN	Nearshore	Fish	1.29	-1.46	48	0.00
Colony	Sandpiper spp.	PFSS	Coastal	Invert	-4.08	0.73	39	0.00
Colony	Scaup (two spp.)	MWS	Coastal	Invert	-3.06	-9.72	52	0.00
Colony	Scoter (three spp.)	MWS	Coastal	Invert	-4.77	-7.38	19	-0.23
Colony	Snowy Plover	USFWS	Coastal	Invert	2.16	2.03	92	2.27
Colony	Western Gull	SEFI, ANI, VAN	Nearshore	Fish	-0.10	6.01	68	0.00
At-Sea	Black-footed Albatross	CalCOFI, RREAS	Offshore	Fish	-1.10	-9.45	7	-3.00
At-Sea	Brandt's Cormorant	CalCOFI, RREAS	Nearshore	Fish	3.18	-8.29	85	1.22
At-Sea	Brown Pelican	CalCOFI, RREAS	Nearshore	Fish	-0.23	13.33	84	1.30
At-Sea	California Gull	CalCOFI, RREAS	Nearshore	Fish	-2.93	9.27	39	0.00
At-Sea	Cassin's Auklet	CalCOFI, RREAS	Offshore	Invert	-1.80	-10.56	27	0.00
At-Sea	Common Murre	CalCOFI, RREAS	Offshore	Fish	5.48	2.94	79	2.03
At-Sea	Marbled Murrelet	USFWS	Nearshore	Fish	3.41	-3.85	59	0.00

Data Type	Bird Species	Survey Program	Main Habitat	Main Prey	Long-term trends percent/yr	Short-term trends percent/yr	Percentile	Weighted Score
At-Sea	Sooty Shearwater	CalCOFI, RREAS	Offshore	Fish	2.08	-0.51	88	3.00
At-Sea	Western Gull	CalCOFI, RREAS	Nearshore	Fish	-2.08	-6.35	9	-3.00

Methods

Status

Status of each species was determined by comparing relative population estimates during the most recent three years (2022–2024) against the distribution of population estimates for the years 1997-2021, derived from model-predicted annual values while controlling for relevant covariates (Appendix A). For most datasets, the only additional covariate was spatial location of the survey (see Appendix A). For at-sea surveys, day of year (Julian day) and survey bin area (in km^2) were also included to account for seasonal and sampling variation. Species percentiles were calculated separately for each survey type (at-sea or colony), then each species was assigned a score of [-2, 1, 0, 1, 2] based on how its most recent population compared to historical population percentiles, in line with the scoring approach described in the introduction.

For species represented by only one survey type, this score was used directly. For the five species with both at-sea and colony data, scores were combined using a weighted mean, where weights were based on the inverse of the standard error to reflect degree of uncertainty. This ensured that more precise datasets contributed proportionally more to the score. For example, a dataset with a standard error of 0.01 (approximately 1% variation per year) received twice the weight of one with a standard error of 0.02 (approximately 2% variation per year). Because weighting was based on proportional rather than absolute abundance, highly numerous species did not automatically dominate the results. To avoid extreme influence from any single dataset, weighted scores were capped between -3 and +3.

Overall bird status, the statewide score, was evaluated as the mean score for all species, incorporating the weighting adjustment described above. Apart from the weighting adjustment, each species contributed equally to the overall score, regardless of whether it was represented by one or two survey types.

Trend

Both long-term (full time series since 1997) and short-term trends (2019–2024) were examined to provide complementary contexts for interpretation. The datasets used in this assessment were diverse, requiring a tailored analytical approach. In some cases, annual densities were provided based on models developed by the data analysts. In most cases, however, raw count data (e.g., the number of individuals per survey at a given location) were provided, along with relevant contextual information such as survey location or timing. Analytical methods were selected to match the structure and quality of each dataset. Simpler datasets were analyzed using linear models, while more complex datasets—particularly those with multiple locations—were analyzed using mixed-

effects models, with location treated as a random effect. Depending on the distribution of the data, either linear mixed-effects models or negative binomial mixed-effects models were applied.

Additional Analyses: Ecological and regional comparisons

Seabirds and shorebirds are highly diverse, so the working group examined whether statuses and trends varied among ecological and regional groupings. First, we classified species into three primary habitat categories: offshore, nearshore, and coastal/estuarine (hereafter referred to as "coastal"; see Table 2.1), while acknowledging that many species occupy multiple habitats. Second, we grouped species by dietary guild— those that primarily consume fish versus those that feed mainly on invertebrates and plant matter (Table 2.1). Finally, we compared trends by region, separating Southern California from Central and Northern California at Point Conception. We tested for differences in trend between the two regions. Appendix A provides information on data inclusion, covariates, and other model specifications for each species–survey combination analyzed.

Additional analysis: Model-predicted annual values and overall change over time

In addition to estimating species-specific linear trends, we calculated model-predicted annual values for each species and survey type on a natural-log scale. These values represent the marginal effect of year while controlling for relevant covariates. Location was included as either a fixed or random effect, as appropriate. The model-predicted annual values were converted to percentile scores as described above. To illustrate change over time across all 21 species, we fit a linear model to the predicted annual values for each species–survey type combination, treating species–survey type as a main effect. Each species was weighted equally; however, for species represented in both at-sea and colony datasets, we applied the weighting scheme described above (Status) to incorporate both survey types without giving those species disproportionate influence.

Results

Status

The overall mean weighted score across all species was 0.02, on a scale of -3 to 3, indicating stability in bird populations. Results were broadly consistent across ecological groups: by habitat, offshore species averaged +0.19, nearshore species –0.19, and coastal/estuarine species +0.10. By feeding guild, fish consumers averaged –0.05, while invertebrate consumers averaged +0.11 (Table 2.2).

Table 2.2. Scores for individual species, along with their primary habitat and prey.

Species	Habitat	Prey	Weighted Score
Ashy Storm-Petrel	Offshore	Invertebrate	-0.36
Black-footed Albatross	Offshore	Fish	-3.00
Brandt's Cormorant	Nearshore	Fish	0.61
Brown Pelican	Nearshore	Fish	1.30
Bufflehead	Coastal/Estuarine	Invertebrate	0.00
California Gull	Nearshore	Fish	0.00
Canvasback	Coastal/Estuarine	Invertebrate	0.00
Cassin's Auklet	Offshore	Invertebrate	-0.33
Common Murre	Offshore	Fish	1.63
Double-crested Cormorant	Coastal/Estuarine	Fish	-0.86
Dowitcher (two spp.)	Coastal/Estuarine	Invertebrate	-0.27
Least Tern	Nearshore	Fish	-1.74
Marbled Godwit	Coastal/Estuarine	Invertebrate	0.00
Marbled Murrelet	Nearshore	Fish	0.00
Pigeon Guillemot	Nearshore	Fish	0.00
Sandpiper spp.	Coastal/Estuarine	Invertebrate	0.00
Scaup (two spp.)	Coastal/Estuarine	Invertebrate	0.00
Scoter (three spp.)	Coastal/Estuarine	Invertebrate	-0.23
Snowy Plover	Coastal/Estuarine	Invertebrate	2.27
Sooty Shearwater	Offshore	Fish	3.00
Western Gull	Nearshore	Fish	-1.50
Average			**0.024**

Trend

Offshore species showed mixed long-term trends (Table 2.1). Common Murres and Sooty Shearwaters increased strongly, indicating stable or improving offshore conditions for these fish-eating seabirds. Black-footed Albatross and Cassin's Auklets declined, reflecting vulnerability of wide-ranging species to climate variability and changing prey fields. Ashy Storm-petrels increased slightly at colonies but were near stable at sea.

Nearshore species generally did well. Brandt's Cormorants and Marbled Murrelets both increased, suggesting resilience in nearshore fish consumers. Western Gulls were stable at colonies but declined at sea. California Gulls declined more strongly, consistent with management and habitat changes. Pigeon Guillemots increased modestly.

Coastal and estuarine species showed the strongest declines. Dowitchers, Sandpipers, and Scoters all declined, while Scaup and Double-crested Cormorants also trended downward. Marbled Godwits declined modestly. In contrast, Snowy Plovers, Bufflehead, and Canvasback increased.

By prey group, fish-eating species such as murres, cormorants, and murrelets generally showed positive long-term trends, while many invertebrate-feeding shorebirds and waterfowl declined.

Short-term trends for offshore species have diverged in recent years (Table 2.1). Common Murres continued to increase strongly, while Brown Pelicans rebounded sharply. In contrast, Black-footed Albatross, Cassin's Auklets, and Ashy Storm-petrels all declined steeply, highlighting short-term sensitivity to recent ocean conditions.

Nearshore species were variable. Western Gull colonies increased, and California Gulls at sea rose despite long-term declines. However, Brandt's Cormorants fell sharply at sea, though colonies were stable.

Coastal species showed mixed signals, but mostly declined in the short term. Snowy Plovers and Sandpipers improved slightly. However, most other taxa declined, including Bufflehead, Canvasback, Double-crested Cormorants, Least Terns, and Scaup. Dowitchers, Scoters, and Marbled Godwits also decreased.

By prey group, fish-feeding species such as murres and pelicans are improving, while many invertebrate feeders (particularly waterfowl and shorebirds) show sharp recent declines.

Regional Comparisons

Where data permitted, the working group compared long- and short-term trends between Southern California and Central/Northern California. Four species had clear and significant regional differences, with some species showing resilience in one part of the state while declining in another:

- Least Tern: Southern California populations experienced strong long-term and short-term declines, while no decline was evident in Central/Northern California.
- California Gull: Southern California populations showed a strong short-term increase and only a slight long-term decline. In contrast, Central/Northern California populations exhibited little recent increase but a strong long-term decline.
- Brown Pelican: Northern California populations increased strongly over the long term but declined in Southern California. Short-term trends were significantly positive in both regions.
- Dowitcher spp.: Southern California populations declined significantly over the available time series (2011–2024), while no decline was observed in Central/Northern California.

Discussion

Seabirds are generally considered good sentinels of global climate change and ecosystem status because they are long-lived, wide-ranging, and sensitive to environmental variability [24]. Along with this, changes in their observed populations in California reflect not only conditions in our state waters but also pressures and trends elsewhere in the Pacific. This analysis showed that overall, and when considered collectively as a community at the statewide level, California's seabird and shorebird populations have generally been stable over the last 25 years. However, this analysis represents a diverse group of species with a wide range of life histories and habitats, and the species statuses are similarly mixed. Over the short-term, there have been notable increases in populations of Brown Pelicans, Scoters, and Snowy Plovers, though more populations decreased than increased (8 species versus 5 species). Over the long-term, there were more declines among coastal and estuarine birds, suggesting ongoing pressures in those nearshore habitats. There were further regional differences across the state, such as some species declining in Southern California while remaining stable or increasing in Central and Northern California. Thus, bird populations and conservation challenges are not uniform across the state. This multi-species, state-level analysis is a good high-level perspective on the status of seabirds and shorebirds, but targeted, evidence-based action would require more focused evaluations.

This working group's process of synthesizing multiple data sources to develop a multi-species, statewide evaluation underscores that decentralized monitoring is a significant challenge for the State. A total of twelve individual researchers representing diverse research programs contributed data to this process. Further complicating the scientific landscape, the seabird science community is unique compared to other fields of ocean monitoring in that independent nonprofit science organizations play major roles in seabird science and monitoring in California. This highlights the importance of continued collaboration, coordination, and state and federal support to make these data available and useful.

The working group considered several other types of information that would support future analyses of seabird and shorebird status. First, an important caveat is that increases in at-sea survey counts do not always reflect increases in the underlying populations. For some species, higher observations at sea could simply reflect changes in distribution, for example if seabirds are spending more time near shore due to changes in prey availability. Second, future work should include changes in productivity, that is, the number of chicks that successfully fledge from well-known breeding colonies as this demographic parameter is well-measured and relatively easy to interpret, both in terms of ecosystem dynamics and seabird populations and conservation. Finally, this bird evaluation is a prime opportunity to weave in traditional knowledge, potentially through

including indicator species with cultural value or broadening the sources of information used to inform species status.

Acknowledgements

We gratefully acknowledge the many data providers who not only shared their datasets but also invested in building and maintaining the long-term monitoring programs that make this assessment possible (see Appendix C for a full list of individuals and contributing programs). In particular, we thank Blake Barbaree (Point Blue Conservation Science), Craig Strong (Crescent Coastal Research), Dan Robinette (Point Blue Conservation Science), Laura Van Vranken and Hans Sin (California Department of Fish and Wildlife); Micah Ashford (U.S. Fish and Wildlife Service), Michelle Hester and Parker Forman (Oikonos Ecosystem Knowledge), Nathan Van Schmidt (San Francisco Bay Bird Observatory), Pete Warzybok (Point Blue Conservation Science), Susan De La Cruz and Laurie Hall (U.S. Geological Survey), William McIver (U.S. Fish and Wildlife Service), and William Sydeman (Farallon Institute). We thank the working group members for their guidance, expertise, and constructive feedback. Finally, we recognize the field biologists, volunteers, and community partners who conducted surveys, maintained monitoring sites, and ensured the continuity of the time series. Their sustained efforts enable tracking trends in California's bird populations and inform conservation and management decisions for the benefit of ecosystems and communities alike.

Farallon Institute: This analysis uses data collected by the Farallon Institute, U.S. National Oceanic and Atmospheric Association's (NOAA) Integrated Ocean Observing System (IOOS) with funding distributed to the Southern California Coastal Ocean Observing System (SCCOOS), and the U.S. National Science Foundation's (NSF) California Current Ecosystem Long Term Ecological Research (CCE LTER) site under Grant No. OCE 2142918 (and earlier awards). Earlier financial and organizational support for these seabird observations was also provided through generous gifts from the National Fish and Wildlife Foundation, Moore Family Foundation, Packard Foundation, and Point Blue Conservation Science. For use of the CalCOFI dataset, we acknowledge data originators and PIs Richard R. Veit, K. David Hyrenbach, and William J. Sydeman. For use of the RREAS dataset, we acknowledge data originator and PI William J. Sydeman, and NOAA NMFS Santa Cruz Laboratory for collaboration.

Point Blue Conservation Science: This analysis uses data collected and/or compiled by Point Blue Conservation Science (1) on the Farallon Islands; (2) on Vandenberg Space Force Base; (3) as part of the Pacific Flyway Shorebird Survey. Monitoring on the Farallon Islands was conducted under cooperative agreement with the U.S. Fish and Wildlife Service (USFWS) at the Farallon Islands National Wildlife Refuge, and funded in part by the USFWS, private foundations, and individual

donors. Monitoring at Vandenberg Space Force Base was conducted under cooperative agreement with the Army Corps of Engineers.

USGS Midwinter Waterfowl Survey: We thank U.S. Fish and Wildlife Service, Ducks Unlimited, and Citizens Committee to Complete the Refuge for funding and logistical support during one or more years of the Midwinter Waterfowl Survey (MWS) and Ducks Unlimited, the California Wildlife Foundation, U.S. Fish and Wildlife Service, the California State Coastal Conservancy, and Valley Water for funding ground surveys within the North and South San Francisco Bay pond complexes. Additional funding was provided by the USGS Ecosystems Mission Area. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government

Source Data

- Pacific Flyway Shorebird Survey data available upon request from Blake Barbaree, Point Blue Conservation Science, bbarbaree@pointblue.org
- Vandenberg Space Force Base, Seabird data available upon request from Dan Robinette, Point Blue Conservation Science, drobinette@pointblue.org
- Black Oystercatcher data (not included in this analysis) available upon request from Daniel Orr, Audubon California, Daniel.Orr@audubon.org
- Sea Ranch Monitoring Program data (not included in this analysis) available upon request from Frankie Moitoza, California State Polytechnic University, Humboldt, fdm6@humboldt.edu
- Least Tern colony survey data available upon request from Laura Van Vranken and Hans Sin, California Department of Fish and Wildlife, Laura.Vanvranken@wildlife.ca.gov, or from https://map.dfg.ca.gov/metadata/DS3146.html
- Snowy Plover Window Survey data available upon request from Micah Ashford, USFWS, micah_ashford@fws.gov
- Ano Nuevo Island data available upon request from Michelle Hester, Oikonos Ecosystem Knowledge, michelle@oikonos.org
- Double-crested Cormorant and California Gull colony data available upon request from Nathan Van Schmidt, San Francisco Bay Bird Observatory, nvanschmidt@sfbbo.org
- Farallon Islands Program data available upon request from Pete Warzybok, Point Blue Conservation Science, pwarzybok@pointblue.org
- Midwinter Waterfowl Survey subtidal data available at U.S. Fish and Wildlife Service Catalog, ServCat https://iris.fws.gov/APPS/ServCat; or upon request from Susan De La Cruz and

Laurie Hall, USGS, sdelacruz@usgs.gov. South Bay Salt Pond Data available upon request from Nathan Van Schmidt, nvanschmidt@sfbbo.org.

- Marbled Murrelet survey data available upon request from William McIver, USFWS, bill_mciver@fws.gov, or from published reports at https://www.fs.usda.gov/r6/reo/monitoring/marbled-murrelet.php
- CalCOFI and RREAS cruise data available upon request from William Sydeman, Farallon Institute, wsydeman@faralloninstitute.org, or from ERDDAP at https://oceanview.pfeg.noaa.gov/erddap/search/index.html

This analysis used data collected by the Farallon Institute, U.S. National Oceanic and Atmospheric Association's (NOAA) Integrated Ocean Observing System (IOOS) with funding distributed to the Southern California Coastal Ocean Observing System (SCCOOS), and the U.S. National Science Foundation's (NSF) California Current Ecosystem Long Term Ecological Research (CCE LTER) site under Grant No. OCE 2142918 (and earlier awards). Earlier financial and organizational support for these seabird observations was also provided through generous gifts from the National Fish and Wildlife Foundation, Moore Family Foundation, Packard Foundation, and Point Blue Conservation Science. For use of the CalCOFI dataset, we acknowledge data originators and PIs Richard R. Veit, K. David Hyrenbach, and William J. Sydeman. For use of the RREAS dataset, we acknowledge data originator and PI William J. Sydeman, and NOAA NMFS Santa Cruz Laboratory for collaboration.

This analysis used data collected by the Point Blue Conservation Science on the (1) Farallon Islands; (2) Vandenberg Space Force Base; and along (3) Pacific Flyway Shorebird Survey. Monitoring on the Farallon Islands was conducted under cooperative agreements with the U.S. Fish and Wildlife Service (USFWS) at the Farallon Islands National Wildlife Refuge, and funded in part by the USFWS, private foundation, and individual donors. Monitoring at Vandenberg Space Force Base was conducted under cooperative agreements with the Army Corps of Engineers.

2.3. MARINE MAMMALS

Marine mammals significantly recovered since the end of commercial whaling in California and implementation of the Marine Mammal Protection Act in the early 1970s. While there is only quality data for about half of California mammal stocks (24 out of 40), nearly all of those populations are stable or increasing. Notable exceptions include the extremely rare and endangered North Pacific Right whale and the declining population of Eastern North Pacific gray whales.

Author

Jill Harris, *California Ocean Science Trust*

Working Group Members

Karin Forney, National Oceanic and Atmospheric Administration

Frances Gulland, University of California, Davis

Sue Ellen Moore, University of Washington

Sarah Wilkin, National Oceanic and Atmospheric Administration

Alexandra Curtis, National Oceanic and Atmospheric Administration

Kerri Danil, National Oceanic and Atmospheric Administration

Clarissa Anderson, Southern California Coastal Ocean Observing System (SCCOOS) and Scripps Institution of Oceanography

Henry Ruhl, Central & Northern California Ocean Observing System (CeNCOOS) and Monterey Bay Aquarium Research Institute

Thomas Farrugia, Alaska Ocean Observing System (AOOS)

Jan Newton, University of Washington and Northwest Association of Networked Ocean Observing Systems (NANOOS)

Jacquelyn Shaff, Marine Mammal Commission

Alissa Deming, Pacific Marine Mammal Center

Lian Hortensius, The Marine Mammal Center

Jessie Huggins, Cascadia Research

Jim Rice, Oregon State University

Justin Greenman, National Oceanic and Atmospheric Administration

Terra Kelly, University of California, Davis

Jayme Smith, Southern California Coastal Water Research Project

Executive Summary

The status of marine mammals was evaluated based on population trends for all marine mammal stocks in California, including whales and cetaceans, otters, and pinnipeds (seals and sea lions). There are 40 marine mammal stocks in California. In 2024, 9 stocks increased, 2 were stable, 13

had no overarching trend, and 2 decreased. The two decreasing stocks were the gray whale (Eastern North Pacific stock) and the killer whale (Southern resident). The remaining 14 stocks had insufficient data to determine a trend, either because the most recent stock assessments were outdated or because the animals were observed too infrequently to detect a population trend.

Broadly speaking, populations of whales and other marine mammals in California have increased since commercial whaling ended. However, one-third of mammal stocks are data deficient, and many data-deficient stocks are critically endangered, such as the North Pacific right whale. Marine mammal experts continue to develop methods to incorporate additional data types, like strandings and population structure, to improve this coast and ocean assessment.

Basis of Evaluation

The working group used the species-based approach to describe the status of marine mammals, evaluating each stock individually and then combining the statuses to produce an overall evaluation for California marine mammals. Population trend is the most widely accepted metric for describing status of marine mammal stocks, used in evaluations such as NOAA's Stock Assessment Reports and the IUCN Red List, a global inventory of extinction risk. Data on total population size do not exist for most marine mammal species due to the expense and logistical challenges of at sea and aerial surveys, and the fact that marine mammals are difficult to observe directly because of animal behavior and large home ranges. Typically, each species in California is assessed only once every few years. Some of the rarer species are rarely observed during visual surveys. Marine mammal scientists are beginning to use alternative methods, such as acoustic monitoring and satellite imagery, to estimate population sizes, but these techniques are newer and not widely available.

Therefore, the working group used population trends to evaluate marine mammals. An increasing population is generally considered a healthy population. The many species that are recovering or have recovered from historical exploitation, such as commercial whaling, are nowhere near their ecological carrying capacity, so, for most stocks, an increasing population is the ultimate metric of population health.

Methods

Each of the 40 stocks of marine mammals in California waters was evaluated using the data and conclusions reported in the most recent federal stock assessment reports. Stock assessment reports are published by NOAA and the U.S. Fish and Wildlife Service. For species for which stock assessment reports were not available, other technical memoranda were used (e.g., Becker *et al.* 2020 for Risso's dolphin). These stock assessment reports and technical memoranda provide long-term population data from observations and/or models and include conclusions on whether a stock

is increasing, decreasing, stable, or has no trend. For estimated trends, the mean was used regardless of uncertainty. Stocks were deemed stable if a formal trend analysis determined a stable trend. Stocks were deemed no trend if they had highly variable populations or limited data. Stocks were deemed data deficient if the most recent survey was more than 8 years old (2015 or earlier).

Group trend was calculated as the total population over time for each of the three major groups of marine mammals: large whales, small cetaceans, and pinnipeds. Otter population data lacked sufficient time series and were excluded from the trend analysis. The trend was reported as the linear change over the last 10 years.

Results

Out of a total of 40 marine mammal stocks, 9 were increasing, 13 had no trend, 2 were stable, and 2 stocks were decreasing: the gray whale (Eastern North Pacific) and the killer whale (Eastern North Pacific Southern resident). 14 stocks were deemed data deficient (Table 3.1).

California has 14 marine mammal stocks that are listed as Threatened or Endangered. Of these, 6 are increasing, 4 data deficient, and 3 are stable or have no trend. The population of one Endangered stock, the Eastern North Pacific Southern Resident Killer Whale, is decreasing.

Table 3.1. List of all marine mammal stocks in California, their group for trend analysis, endangered or threatened status, year of most recent survey, and population trend used to determine a score.

Common Name	Group	ESA Status	Most Recent Survey	Rating
Blue whale	Large Whales	Endangered	2018	No Trend
Bryde's whale	Large Whales	Endangered	n/a	Data deficient
Fin whale	Large Whales	Endangered	2018	Increasing
Gray whale - Eastern N Pacific	Large Whales	Not Listed	2025	Decreasing
Gray whale - Western N Pacific	Large Whales	Endangered	2016	Increasing
Humpback whale Central America / Southern Mexico - CA/OR/WA	Large Whales	Endangered	2021	Increasing

Common Name	Group	ESA Status	Most Recent Survey	Rating
Humpback whale Mainland Mexico – CA/OR/WA	Large Whales	Threatened	2018	Increasing
Minke whale	Large Whales	Not Listed	2018	No Trend
Sei whale	Large Whales	Endangered	2014	Data deficient
Sperm whale	Large Whales	Endangered	2018	No Trend
North Pacific Right Whale	Large Whales	Endangered	2008	Data deficient
Baird's beaked whale	Small Cetaceans	Not Listed	2018	No Trend
Bottlenose dolphin - California Coastal	Small Cetaceans	Not Listed	2011	Data deficient
Bottlenose dolphin - Offshore	Small Cetaceans	Not Listed	2018	No Trend
Cuvier's beaked whale	Small Cetaceans	Not Listed	2016	No Trend
Dall's porpoise	Small Cetaceans	Not Listed	2018	Stable
Dwarf sperm whale	Small Cetaceans	Not Listed	2014	Data deficient
Harbor porpoise - Monterey Bay	Small Cetaceans	Not Listed	2013	Data deficient
Harbor porpoise - Morro Bay	Small Cetaceans	Not Listed	2012	Data deficient
Harbor porpoise - Northern CA / Southern OR	Small Cetaceans	Not Listed	2022	No Trend
Harbor porpoise - San Francisco-Russian River	Small Cetaceans	Not Listed	2017	No Trend
Killer whale Eastern N Pacific Offshore	Small Cetaceans	Not Listed	2012	Data deficient
Killer whale -	Small Cetaceans	Endangered	2023	Decreasing

Common Name	Group	ESA Status	Most Recent Survey	Rating
Eastern N Pacific Southern Resident				
Killer whale - West Coast Transient	Small Cetaceans	Endangered	1997	Data deficient
Long-beaked common dolphin	Small Cetaceans	Not Listed	2018	No Trend
Mesoplodont beaked whales	Small Cetaceans	Not Listed	2014	Data deficient
Northern right whale dolphin	Small Cetaceans	Not Listed	2018	No Trend
Pacific white-sided dolphin	Small Cetaceans	Not Listed	2018	No Trend
Pygmy sperm whale	Small Cetaceans	Not Listed	2014	Data deficient
Risso's dolphin	Small Cetaceans	Not Listed	2018	No Trend
Short-beaked common dolphin	Small Cetaceans	Not Listed	2018	Increasing
Short-finned pilot whale	Small Cetaceans	Not Listed	2014	Data deficient
Striped dolphin	Small Cetaceans	Not Listed	2018	No Trend
Southern Sea otter	Otters	Threatened	2019	Stable
California sea lion	Pinnipeds	Not Listed	2014	Data deficient
Guadalupe fur seal	Pinnipeds	Threatened	2019	Increasing
Harbor seal	Pinnipeds	Not Listed	2012	Data deficient
Northern elephant seal	Pinnipeds	Not Listed	2023	Increasing
Northern fur seal	Pinnipeds	Not Listed	2022	Increasing
Steller Sea Lion	Pinnipeds	Endangered	2022	Increasing

Discussion

While most of the evaluated marine mammal stocks were stable/no trend or increasing, these results may overestimate the overall status of marine mammals in California. There were 14 stocks deemed data deficient, and many of those are critically endangered species with populations too small to be surveyed with traditional survey methods. For example, the North Pacific right whale is considered the most endangered whale species in California waters and one of the rarest whale species in the world [25], and this species is currently estimated to have around 30 individuals.

One interesting case study is the gray whale, the California State Marine Mammal. Gray whales comprise two separate stocks: Eastern North Pacific and Western North Pacific. The Western stock is listed as Endangered, with a small but increasing population. The Eastern stock has a much larger population, but it experienced an unusual mortality event from 2019 to 2023, with high numbers of strandings and a decline in calf production. The population has continued to decline, raising concerns about the status of this population. The most recent estimate is the third-lowest since gray whale surveys began in 1967. The comparison between these two stocks of gray whales illustrates the limitations of relying on population trends alone, where it becomes difficult to compare a small, increasing population with a large, rapidly decreasing population.

To address such data limitations, the working group explored the possibility of incorporating additional data types, such as strandings. The NOAA West Coast Marine Mammal Stranding Network responds to and tracks mammal strandings in California, Oregon, and Washington, publishing data on the types and locations of stranded animals. Stranding data can be an early warning sign of threats to marine mammal populations. In addition, stranding data reflects current ocean conditions such as the spread of infectious diseases, prey availability, and toxin prevalence. Scientists are developing models to combine stranding and population survey data to produce more accurate estimates of marine mammal population health as well as early warning flags changing environmental conditions.

Source Data

- Mammal stock assessments for most stocks from: Carretta, J.V., Oleson, E.M., Forney, K.A., Bradford, A.L., Yano, K., Weller, D.W., Lang, A.R., Baker, J., Orr, A.J., Hanson, B., Moore, J.E., Wallen, M., & Brownell, Jr., R.L. (2024). Draft U.S. Pacific Marine Mammal Stock Assessments: 2024. https://www.fisheries.noaa.gov/s3/2025-03/Draft-2024-Pacific-SARs.pdf
- Risso's dolphin assessment from: Becker, E. A., Forney, K. A., Miller, D. L., Fiedler, P. C., Barlow, J., & Moore, J. E. (2020). Habitat-based density estimates for cetaceans in the California Current Ecosystem based on 1991-2018 survey data. https://repository.library.noaa.gov/view/noaa/27826/noaa_27826_DS1.pdf

- Northern Pacific gray whale assessment from: Eguchi, Tomo, Aimée Lang, and David Weller. 2025. Abundance of Eastern North Pacific gray whales 2024/2025. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-SWFSC-724. https://doi.org/10.25923/jqea-s505

2.4. ROCKY INTERTIDAL ZONE

The loss of functionally important species significantly altered the community composition during the 2013-15 marine heatwave and disease outbreak, but diversity and cover remain high. Parts of the state have seen modest recovery in some species.

Lead Authors

Rich Ambrose, University of California, Los Angeles

Jennifer Burnaford, California State University, Fullerton

C. Melissa Miner, University of California, Santa Cruz

Jayson Smith, California State Polytechnic University, Pomona

Lead Analyst

David Gillett, *Southern California Coastal Water Research Project*

Coordinating Author

Jill Harris, California Ocean Science Trust

Working Group Members / Contributors

Lisa Gilbane, Bureau of Ocean Energy Management

Adriana Le Compte-Santiago, Southern California Coastal Water Research Project

Pike Spector, California Ocean Protection Council

Stephen B. Weisberg, Southern California Coastal Water Research Project

Executive Summary

The status of the rocky intertidal zone was evaluated based on the abundance and stability of four key taxa: ochre sea stars (*Pisaster*), rockweeds (Fucoids), mussels (*Mytilus*), and surfgrass (*Phyllospadix*). Between 2013 and 2023, the most recent year for which complete data were available, the rocky intertidal zone had fundamentally changed, largely due to the widespread loss of sea stars and rockweed. The rocky intertidal zone was evaluated using the species-based approach, in which each of the four key taxa was scored relative to its baseline abundance, and the

statewide score was calculated as the average of these four scores. The statewide trend was reported as the change over the last decade.

Statewide, rocky intertidal communities underwent a major shift from 2013- 2016 due to a combination of an outbreak of sea star wasting disease, a heatwave, and an El Niño event. These events caused the decline of key taxa like sea stars and rockweeds, but other species have increased to such an extent that biological cover and diversity remain high. Since this major shift, there has been a modest recovery in key groups in some parts of the state.

Basis of Evaluation

The working group used a species-based approach to assess the status of the rocky intertidal zone, evaluating each group based on abundance and stability. The rocky intertidal community was fundamentally altered a decade ago by intense stress from a combination of the 2013-15 marine heatwave and several outbreaks of diseases affecting intertidal invertebrates. Stability over time is a key indicator of rocky intertidal ecosystem health [26]. Thus, the working group used the species-based approach to evaluate how the site-specific abundance of four key groups has changed over time.

This evaluation focuses on the population dynamics of three ecologically important "foundation" taxa and an ecosystem engineer that create habitat or modify environmental conditions that facilitate the success of other species : 1) mussels (*Mytilus*), a main food source in the intertidal and ecosystem engineers because they provide physical habitat and food for many other species; 2) rockweeds (Fucoid seaweeds) and 3) surfgrass (*Phyllospadix* spp.) which both provide habitat for other species, and a keystone predator: 4) ochre sea stars (*Pisaster ochraceus*), which can drive the composition of rocky intertidal zones through predation. These four groups have outsized roles in shaping overall community composition in the rocky intertidal zone. Changes in their abundances do not precisely mirror changes in overall rocky intertidal community composition and biodiversity, because there are highly site-specific patterns of change in the greater than 250 species in California's rocky intertidal zone. However, the working group consensus was that the patterns of these four indicator taxa are representative of the health of the rocky intertidal zone as a whole.

The rocky intertidal zone was evaluated using data from the Multi-Agency Rocky Intertidal Network (MARINe), which conducts a standardized long-term monitoring program. Scientists from MARINe have been monitoring rocky intertidal communities at over 200 sites across the West Coast from Mexico to Alaska since the 1980s.

Methods

The metric for the rocky intertidal zone is based on a comparison of abundances of the four indicator taxa between recent years, 2013-2023, and the baseline reference period, 2004-2012. This evaluation uses a species-based approach, where each species was evaluated separately, and the overall state score is an average across the four taxa. The period of 2004-2012 was designated as the baseline years against which subsequent comparisons could be made, because 2004 is the year that routine statewide monitoring began, and 2012 is the year immediately preceding the heatwave, El Niño event, and disease outbreaks that fundamentally altered rocky intertidal species.

Abundance data for each of the four key taxa were obtained from the MARINe long-term permanent photo plots (mussels, rockweeds), transect surveys (surfgrass), or irregular plots (ochre stars). For photo plots, photographs and field observations were taken of the flora and fauna, including key species, within permanent 50 x 75cm plots distributed across the intertidal zone at each site. For transect surveys, the cover of surfgrass and macroalgae was measured along permanent 10m transects at each site. Irregular plots were used to delineate fixed areas within which sea stars were counted. Abundance for each key taxon was summarized as the mean percent cover (photoplots and transects), or total count (sea stars) at a given site for each year the site was monitored.

A total of 66 sites across California were sampled from 2004 to 2024. Nearly all sites were sampled annually, but most 2024 data were not entered in time for this analysis and were thus omitted. The condition of the rocky intertidal zone was evaluated at the statewide level and within four geographic regions commonly used to discuss rocky intertidal biota: Northern California, Central California, Northern Channel Islands, and Southern California (Figure 4.1).

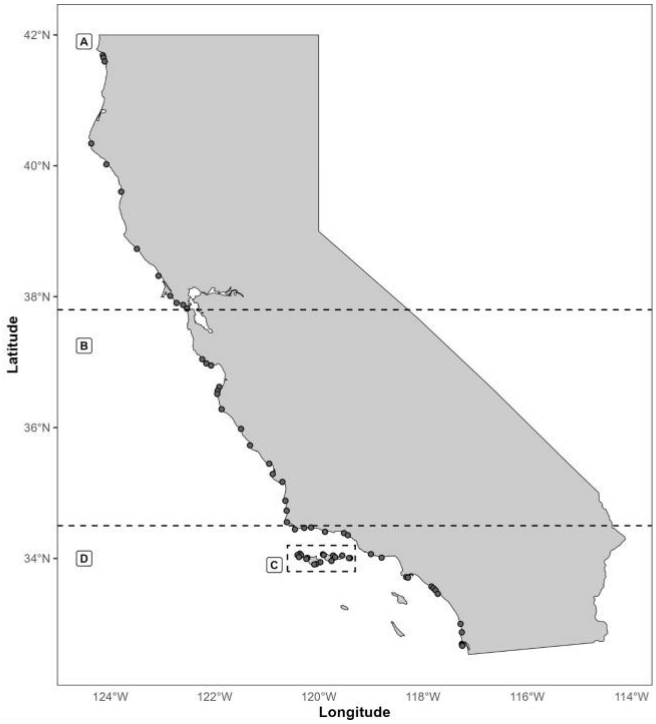

Figure 4.1. Rocky intertidal sampling sites across the state. The letters and dashed lines represent the four different regional zones used in this analysis: A - Northern California, B - Central California, C - Northern Channel Islands, and D - Southern California

Rocky intertidal status was scored [-2, -1, 0, 1, 2] based on the abundance of each taxon at a given site and in a given year compared to the distribution of its abundances at that site during the 2004-12 baseline period, following the scoring approach described in the introduction. There is substantial site-to-site variability in rocky intertidal communities, so all comparisons were made within each site and then summarized at the state and regional scales.

Individual scores for each key taxon were averaged to produce a score for each site and each year. These site scores were then averaged across all sites to provide annual statewide scores and scores for each of the four geographic regions described in Figure 4.1.

The trend in rocky intertidal zone condition was calculated as the linear change over time in the annual statewide scores.

Results

Status

In 2023, the statewide rocky intertidal zone score was -0.46, out of a possible range of -2 to 2 (Figure 4.2). Scores for the four key taxa were: mussels = 0.58, surfgrass = 0.18, rockweed = -1.08, and sea stars = -1.51 (Figure 4.2B). Scores for the four regions were: Northern California = 0.13,

Central California = -0.83, the Northern Channel Islands = -0.17, and Southern California = -0.52 (Figure 4.3).

Trend

During the baseline period, there was some variability in the statewide score, with a decline from the 2008 El Niño and subsequent recovery to previous conditions in 2012. This type of community change and recovery is typical of a healthy, resilient ecosystem. However, there was a sharp decline in condition after 2012, and since then, the rocky intertidal community has not recovered and has remained different from the baseline community.

Among individual taxa, mussels and surfgrass remained relatively stable across the baseline and current time periods, though both had declined in abundance in 2008 and again in 2013. In contrast, rockweeds and sea stars both showed large differences between the baseline and more recent periods. In particular, sea stars declined markedly in 2013-14 and have not yet recovered (Figure 4.2). The regional patterns largely mirror the statewide patterns, including declines in 2008, recovery in 2012, and a muted decline following 2013-14 with some recovery in the most recent years (Figure 4.3).

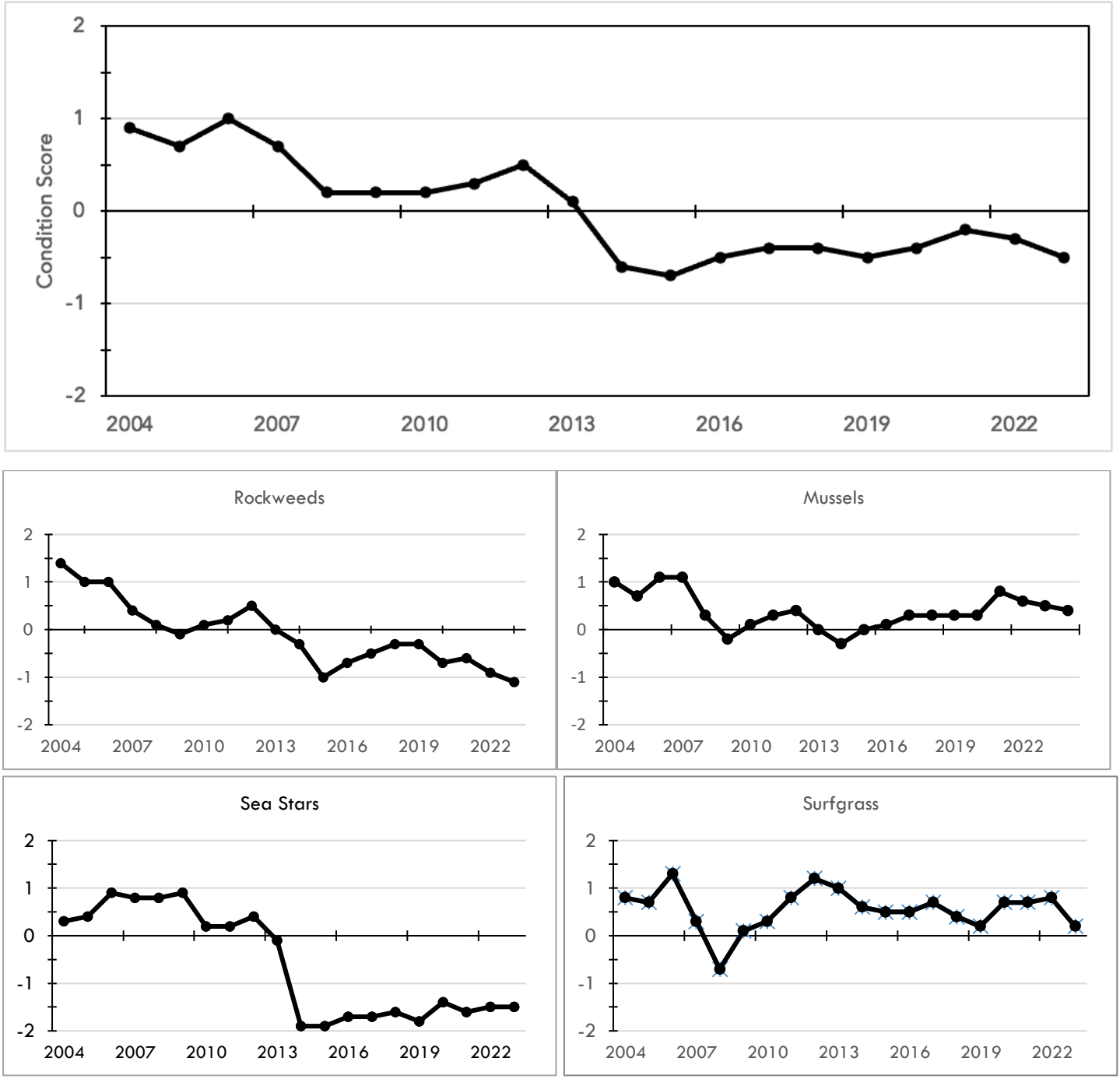

Figure 4.2. Temporal trends in overall rocky intertidal zone condition (upper) and the four key taxa (lower) from 2004-23. Each point represents the average score for all sites within a year.

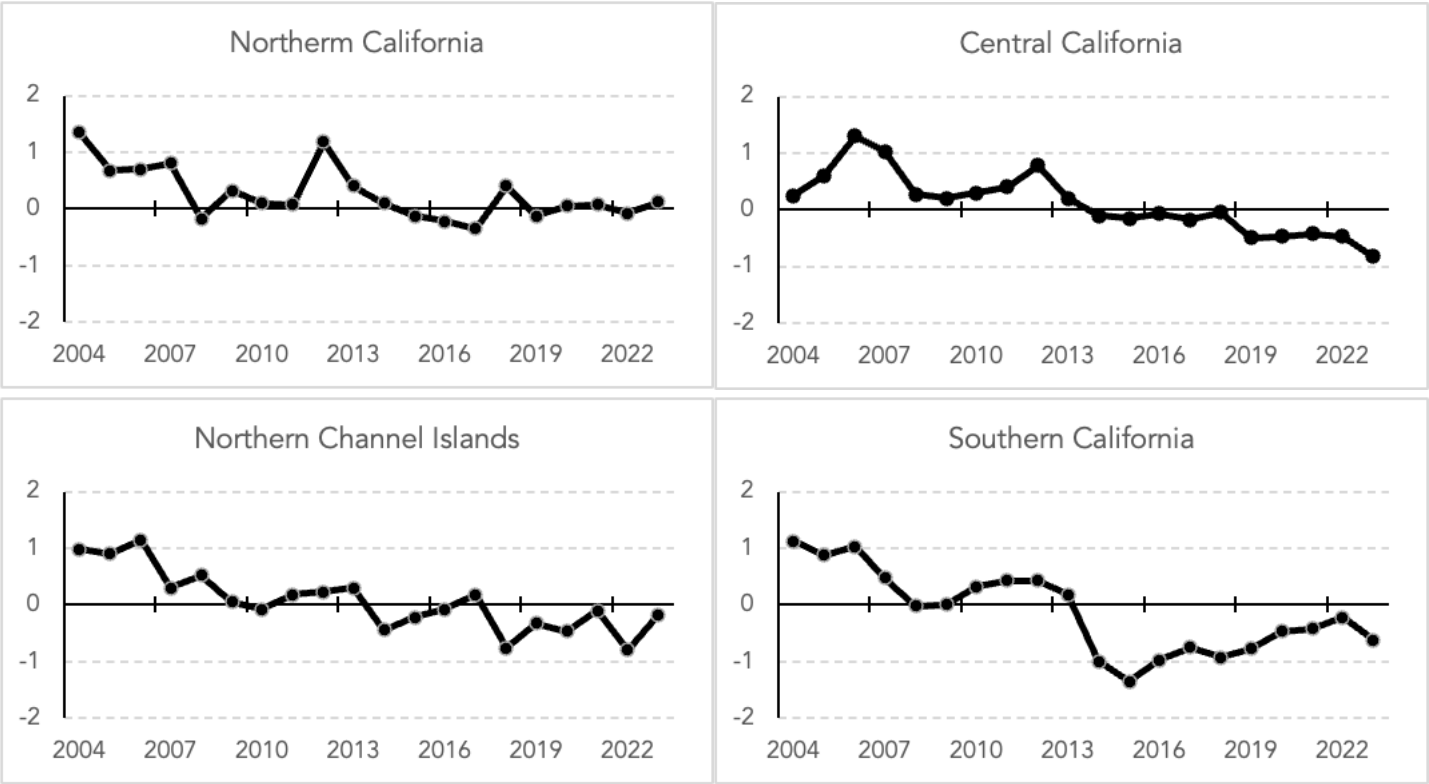

Figure 4.3. Temporal trends in rocky intertidal scores for the four geographic regions from 2004-2023. Each point represents the average score for all sites within a region for a given year.

Discussion

Statewide, the rocky intertidal zone has seen a decline of many functionally important taxa, and their decline has significantly changed the community compared to 20 years ago. A major change occurred from 2013 to 2016, when rocky intertidal communities experienced multiple, overlapping, major disturbance events: an outbreak of star wasting disease, a marine heatwave, and an El Niño event. These events caused the decline of sea stars and rockweeds, but other species have increased to such an extent that biological cover and diversity remain high. Over the last decade, there has been a modest recovery in some parts of the state. In the future, additional significant shifts in the rocky intertidal zone are likely as the frequency and severity of disturbance events, such as marine heatwaves, increases due to climate change [27].

There are regional differences in rocky intertidal community resilience and in the impacts from human uses, which can exacerbate other stressors. Scores were lower in Southern and Central California, which are the more populated areas of the state. In these highly populated areas, rocky intertidal communities and other coastal ecosystems are subject to direct human impacts, including pollution and trampling from visitors. Marine protected areas and other regulations can reduce

some of these impacts, but without strict enforcement, regulations alone do not entirely eliminate these impacts [28]. To thoroughly evaluate how MPAs impact rocky intertidal communities and influence resilience, the working group highlighted the value of expanding statewide monitoring to include more paired sites within and outside of protected areas.

Overall, this category is a model example of good data availability for statewide evaluation. The statewide MARINe program, an organized network of individual research groups across the state, uses standardized methods, repeated surveys at long-term sites over a large geographic span, and a centralized database. In addition, MARINe data are publicly available for assessment and management purposes. The result is an invaluable dataset that makes it straightforward for scientists and state agencies to monitor and evaluate the status of rocky intertidal communities. Financial support to continue and expand this type of monitoring program will ensure that the state can continue to have reliable scientific information to inform management decisions.

Source Data

All data are available from MARINe at https://marine.ucsc.edu/explore-the-data/data-requests/

The MARINe website and associated data summaries and graphs were developed by Pete Raimondi and the rocky intertidal research group at the University of California, Santa Cruz. Data are provided by numerous MARINe members and funding sources, including the Bureau of Ocean Energy Management, the Ocean Protection Council, and the National Park Service.

2.5. COMMERCIAL FISHERIES

Most (16 out of 18) of the top fisheries were in good economic and ecological condition. Notable exceptions that deserve closer attention include closures and/or disaster declarations for the Dungeness crab, the northern red urchin, and Chinook salmon fisheries.

Author

Jill Harris, California Ocean Science Trust

Contributors

Chris Free, University of California, Santa Barbara

Katie Cieri, California Ocean Protection Council

Staci Lewis, California Ocean Protection Council

Lyall Bellquist, Scripps Institution of Oceanography

Executive Summary

The status of California's commercial fisheries was evaluated based on ecological and economic attributes using data provided by the California Department of Fish and Wildlife and the National Oceanic and Atmospheric Administration. In 2024, 16 out of 18 of the most economically valuable fisheries had robust populations and were providing stable or increasing economic value over the last 40 years. The evaluation applies to the top 18 species, which accounted for 99% of total commercial fishery value over the last 20 years (2005-2024). Commercial fisheries were scored using a modified species-based approach, in which each fishery was assessed based on fish population status, economic benefit (landings revenue), and ecosystem impacts (e.g., entanglement or bycatch). The state score is the average combined ratings for each species, weighted by landings value. Trend is the linear change in total landings revenue, total landings volume, and participation (number of vessels or people) over the last ten years (2015-2024) based on data collected by CDFW.

While most fisheries scored highly, a few, notably Chinook salmon and Pacific sardine, are significantly declining in both population and economic benefits. There are also negative ecosystem impacts, like whale entanglement, from some fisheries, including the Dungeness crab and sablefish trap fisheries. In 2024, several major fisheries were closed: the Dungeness crab fishery, the northern red urchin fishery, and the Chinook salmon fishery, which was also declared a federal fisheries disaster. The evaluation presented here considers only ecological and economic components of fisheries, so adding social and community-level factors is a prime area for future improvement.

Basis of Evaluation

Commercial fisheries are complex systems shaped by ecological, economic, and social factors. A healthy fishery could be defined by robust fish populations, high profit provided to those employed, low bycatch, reliable or numerous jobs, or some combination of these factors. Several frameworks exist to evaluate fisheries, including:

- The social-ecological evaluation of fisheries as part of NOAA's California Current integrated ecosystem assessment, which includes 11 indicators such as commercial and recreational catch, commercial and recreational revenue, recreational effort, catch diversity, and earnings for employees [29].
- The fisheries dimension of the Environmental Performance Index, which is designed to summarize sustainability, includes metrics such as mean trophic level targeted, bycatch and discard volume, status of fish stocks, and percent of fish caught by bottom trawling or dredging [30].
- The Fisheries Performance Index, supported by the World Bank and used globally to measure the triple bottom line of sustainable economies, communities, and ecology, measures 68 separate metrics [31].

While these frameworks provide a comprehensive evaluation of the many dimensions of commercial fisheries, they were not suitable for this assessment because the required data are not available for all fisheries and all geographies in California. Therefore, this evaluation was based on these frameworks to cover the primary dimensions of ecology and economy, and then simplified to be feasible within the constraints of available data.

This evaluation does not thoroughly include social factors or community data, which is a prime area for improvement in future iterations.

All data were provided by state and federal agencies, primarily through CDFW's Marine Fisheries Data Explorer (MFDE), which provides summarized landings data from the nearly 50,000 landing receipts submitted to the state annually. Additional data sources are listed below.

Methods

The commercial fisheries that cumulatively accounted for 99% of total landings value over the past 20 years (2005-2024) were evaluated based on ecological status (fish populations), economic benefits (landings revenue), and ecosystem impacts (e.g., bycatch). Each of these

components was rated separately, and the statewide score was the average of the combined ratings, weighted by economic value.

To determine the species that make up 99% of the commercial fishing value in the state, the total landing revenue of all commercial fisheries from 2005-2024 was calculated from the MFDE as $3.32 billion. For each commercial fishery included in the MDFE data, the total and cumulative value for the time period was calculated (Table 5.1).

Ecological status for each fishery was rated 1-3 based on the robustness of the population. A rating of 1 indicates the current population is widely considered collapsed, is more than one standard deviation lower than the mean over the last 40 years, is well below management targets, and/or has been declared overfished. A rating of 2 indicates species of some concern, such as mixed conclusions from management reports or a population that is beginning to decline. A rating of 3 indicates species whose populations are widely considered robust, with current populations greater than one standard deviation above the mean over the last 40 years, and with no concerns and no signs of overfishing.

Economic benefits for each fishery were evaluated with the explicit judgment that economic benefits should be stable or growing over time. The economic benefit of each fishery was rated 1-3 based on how the current landings revenue compares to the average revenue over the last 40 years. Values were adjusted for inflation to 2024 dollars using the general producer price index for all commodities. A rating of 1 indicates the current value is more than 1 standard deviation below the mean for the last 40 years; a rating of 2 indicates the current value is within 1 SD above or below the mean; a rating of 3 indicates the current value is more than 1 SD above the mean.

The ecosystem impact of each fishery was based on any known widespread impacts or benefits of the fishery. Each fishery received a default rating of 0.5, which was adjusted up to 1 for ecosystem benefits and down to 0 for negative ecosystem impacts, such as bycatch and entanglement.

Individual fishery scores were the sum of ecological, economic, and ecosystem ratings. The statewide score was the average of each fishery's individual score, weighted by the percent of economic value from 2005 to 2024. The range of possible scores was 2-7.

Results

18 species comprised 99% of the commercial fishing value over the last 20 years. Value was dominated by Dungeness crab and market squid, which each make up about 30% of the total commercial fishing value in the state (Table 5.1).

Most species received high ecological scores, and the unweighted mean ecological score was 2.6, indicating generally robust fish populations for commercially fished species in California. 13 out of 18 species received a rating of 3, three species received ratings of 2, and 2 species, Chinook salmon and Pacific sardine, received ratings of 1 (Table 5.1). Most fisheries also received high economic scores, indicating that, in general, the value of commercial fisheries has increased over the last 40 years. 12 out of 18 fisheries received a rating of 3, 5 received a rating of 2, and only one, Chinook salmon, received a rating of 1 (Table 5.1). For the ecosystem adjustment, most fisheries had a neutral impact on the environment and retained the default rating of 0.5. No fisheries were adjusted up for positive impacts, and four fisheries were adjusted down to a rating of zero:

- Dungeness crab due to whale entanglement in trap lines
- Red sea urchin due to diminished urchin roe quality available to the fishery in Northern California
- Sablefish due to whale entanglement in trap lines
- Swordfish due to bycatch in drift gillnets, which are being phased out

The red urchin fishery shows a sharp geographic divide between the northern and southern parts of the state. Overall, the fishery was rated a 2 for fish population, because urchin quality is declining in the northern part of the state, and several studies suggest decreasing density. The overall fishery was rated a 3 for economic benefits because, despite the recent fishery disasters and continued economic challenges in the northern fishery, largely out of Fort Bragg, the fishery volume and value in the southern part of the state, largely out of Santa Barbara, remain high. In 2024, the total landed value of red sea urchins was $7.5 million for 2.1 million pounds, or $3.51/lb, which is much higher than average over the last 40 years (average of $9.5 million for 8 million lbs, or $1.14/lb). These numbers describe a clear picture in which, statewide, a smaller volume of urchins is being landed, but the value is increasing more than enough to offset the reduction in landings.

Chinook salmon stands out as the lowest-scoring fishery, and the only fishery rated a 1 for both ecology and economic benefit. Commercial fishing for Chinook has been declared a federal fishery disaster and closed since 2023 and has an extensive history of prior disaster declarations. This fishery has been marked by prolonged decline over the last half-century, though there have been some short-lived periods of ecological recovery and economic growth. In 2024, California released a strategy to recover salmon populations across the

state by removing barriers to migration, restoring habitat, and helping populations adapt to climate variability [32].

Discussion

Overall, this evaluation provides a general picture of California's commercial fisheries as relatively strong in terms of economic benefits and ecological sustainability, as reflected in steady or growing fish populations. While this conclusion is accurate, it also points to the importance of providing this whole state-level perspective alongside more focused analyses, because in California, there are salient examples of fisheries that are neither economically nor ecologically healthy: the salmon, urchin, and Dungeness crab examples described above. Thus, this evaluation can be interpreted to mean that while many commercial fisheries are sustainably managed and provide economic benefit, there are notable exceptions that require more effective management interventions. Much of this work is underway: for example, whale entanglement is a priority topic for policy and research.

This evaluation is founded on several assumptions that significantly influence the main findings. First, the economic rating is based on the explicit judgment that economic benefits should be stable or growing over time. However, this raises the question: what is the purpose of a commercial fishery? It could be to contribute to gross domestic product, in which case, it would be appropriate to evaluate based on total landed value. However, if the purpose is to catch fish efficiently, then a better metric would be catch per unit effort; to provide jobs, a metric of employment numbers; or to provide food, a metric of total volume regardless of economic value. Second, the statewide score was weighted by landed value over the last 20 years. Weighting by this more recent landed value means that fisheries that were historically major parts of the state's fishing industry prior to 2005, but that are less dominant today, had less influence in the statewide score. For example, anchovy, white sea bass, and highly migratory species like tuna and swordfish were major fisheries in the early and mid-20th century, but today, these fisheries are a fraction of their former size. Finally, weighting by economic value at all is based on the principle that commercial fisheries are primarily economic engines, and the ecological or social factors are less useful to evaluate. This evaluation did not include social factors, such as employment, downstream income to industries like processing, or distribution of income among fishing and port communities. Data from the MFDE show the common pattern that participation, as measured by fishing licenses and vessel registration, is declining, even as catch and landed value are steady or increasing. Overall, this evaluation of California's commercial fisheries was driven by assumptions that prioritized recent and stable economic value. Future versions could consider more holistic measures that include employment and other social impacts.

Acknowledgements

The approach to this evaluation was developed with additional input from Elliott Hazen and Jameal Samhouri (National Oceanic and Atmospheric Administration Fisheries).

Source Data

- Fish population data are available from:
  - NOAA Stock SMART for federally managed species
  - NOAA stock assessments
  - Enhanced Status Reports available from the CDFW Marine Species Portal
  - The Pacific Groundfish Fishery Management Plan for Sablefish, Shortspine Thornyhead, Dover sole, Petrale sole
- Economic benefit data are available from:
  - CDFW Marine Fisheries Data Explorer
  - General producer price index for inflation adjustment from FRED (Federal Reserve Economic Data, available from https://fred.stlouisfed.org)
- Economic score derived from confidential landings data since 1980, provided by Chris Free, UCSB.

Table 5.1. Landed value and individual scores for species used in this analysis because they make up 99% of the total commercial fishery value in California, 2005-2024.

Fishery	Total Value 2005-2024	% of Value of All Commercial Fisheries 2005-2024, and Weight	Economic Score	Ecological Score	Ecosystem Adjustment	Total Score (unweighted)
Dungeness Crab	$1,026,957,587	30.9	2	3	0	5
Market Squid	$1,015,984,351	30.6	3	3	0.5	6.5
California Spiny Lobster	$275,675,817	8.3	3	3	0.5	6.5
Chinook Salmon	$200,425,808	6.0	1	1	0.5	2.5
Red Sea Urchin	$161,007,590	4.8	3	2	0	5
Sablefish	$155,965,105	4.7	2	3	0	5
Pacific Sardine	$71,986,344	2.2	2	1	0.5	3.5
California Halibut	$68,354,426	2.1	3	2	0.5	5.5
Swordfish	$63,388,253	1.9	3	3	0	6
Shortspine Thornyhead	$42,526,103	1.3	3	3	0.5	6.5
Dover Sole	$38,824,274	1.2	3	3	0.5	6.5
Pink Shrimp	$35,567,062	1.1	2	3	0.5	5.5
Petrale Sole	$32,103,325	1.0	3	3	0.5	6.5
Albacore Tuna	$24,629,049	0.7	3	3	0.5	6.5
Northern Anchovy	$21,604,827	0.7	2	3	0.5	5.5
Pacific Mackerel	$16,398,605	0.5	3	3	0.5	6.5

Fishery	Total Value 2005-2024	% of Value of All Commercial Fisheries 2005-2024, and Weight	Economic Score	Ecological Score	Ecosystem Adjustment	Total Score (unweighted)
Yellowfin Tuna	$15,279,516	0.5	3	3	0.5	6.5
Hagfishes	$14,642,507	0.4	3	2	0.5	5.5
TOTAL	**$3,281,320,549**	**98.8**				

Place-Based Evaluations

These categories were evaluated based on how current conditions at a specific location compared to that location's historical average conditions. Statewide scores are the averages of individual location scores.

2.6.KELP

Following the 2014-15 marine heatwave, more than 75% of kelp canopies are smaller than their pre-heatwave historical median, compared to roughly 50% under normal interannual variability. There is considerable variation at the regional and local scale, and there has been some improvement in parts of the state.

Author

Christina Frieder, Southern California Coastal Water Research Project

Working Group Members

Tom Bell, Woods Hole Oceanographic Institution
Helen Berry, Washington State Department of Natural Resources
Kyle Cavanaugh, University of California, Los Angeles
Danielle Claar, Washington State Department of Natural Resources
Jan Friewald, Reef Check
Benjamin Grime, The Nature Conservancy
Sara Hamilton, Oregon Kelp Alliance
Henry Houskeeper, Woods Hole Oceanographic Institution
Scott Marion, Oregon Department of Fish and Wildlife
Tristin McHugh, The Nature Conservancy
Gray McKenna, Washington State Department of Natural Resources
Ed Parnell, Scripps Institution of Oceanography
Pike Spector, California Ocean Protection Council

Executive Summary

The status of kelp was evaluated based on the extent of kelp canopy cover. In 2024, more than 75% of California's kelp forests had canopy cover below their long-term average. This is a slight improvement from 2023, which marked one of the lowest canopy years since the beginning of the time series in 1984, but still a higher percentage than would be expected under natural interannual variability (roughly 50%). Kelp forests statewide and along the entire west coast have been

struggling since the 2014-2015 marine heatwave, which triggered widespread losses, particularly in Northern California, where recovery has yet to occur. Central California kelp has seen a general decline since 2019, while kelp in Southern California shows a more mixed picture. These regional contrasts highlight the range in vulnerability and resilience of kelp forests and underscore the importance of continued monitoring to track recovery and inform management of one of California's most ecologically and culturally significant marine ecosystems.

Basis of Evaluation

The working group used the place-based approach to describe the status of kelp, evaluating how the size of the canopy at individual kelp beds compared to that location's historical average kelp canopy extent. This metric includes both species of canopy-forming kelp in California, giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*).

Kelp canopy extent was evaluated using Landsat satellite imagery, which measures the extent of emergent kelp canopy on the ocean surface. Landsat satellites offer the longest historical perspective on California's coastal oceans with the greatest temporal frequency relative to other satellite platforms or aerial survey programs. Landsat imagery has demonstrated validations from southern, central, and northern California.

Methods

The metric for kelp is based on current kelp canopy cover relative to a long-term average. This evaluation uses a place-based approach, where each location is evaluated separately and the overall state score is an average of all locations.

Status

Kelp canopy coverage was measured using the Santa Barbara Coastal Long Term Ecological Research (SBC LTER) project's kelp canopy dynamics dataset derived from Landsat imagery. This dataset provides quarterly (3-month) estimates of kelp canopy area from 30-m resolution Landsat imagery from 1984 to present and is updated seasonally. Pixels containing kelp canopy are identified using a random forest classifier from band-normalized, atmospherically corrected imagery from the Landsat 5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper +, Landsat 8 Operational Land Imager, and Landsat 9 Operational Land Imager 2.

The spatial units of assessment for kelp canopy coverage were semi-regularly spaced coastal segments approximately 10 km in length. Coastlines included California's mainland and Channel Islands. For all segments, boundaries began at the coastline and encompassed state waters, which also encompassed kelp habitat. The length along the coast of each segment was approximately 10

km, with minor manual adjustments made to alongshore boundaries based on coastal geomorphology or to ensure the cores of kelp forests were not split among segments.

Coastal segments were categorized as either "No Historical Kelp," "Ephemeral Kelp," or "Contains Kelp" (Table 6.1). Segments with < 0.02% of its area with kelp-containing pixels were categorized as having "No Historical Kelp." These included areas known to be devoid of kelp, e.g., sandy beaches. Segments with either < 0.15% of its area with kelp-containing pixels or where kelp is inconsistently present (specifically, canopy present in less than half the years of available observations) were categorized as having "Ephemeral Kelp;" otherwise, the segment was categorized as "Contains Kelp." The kelp assessment reflects only those segments that are defined as "Contains Kelp."

Table 6.1. Number of coastal segments that contain kelp, have ephemeral kelp, or have no historical kelp by region.

	Contains Kelp	Ephemeral Kelp	No Historical Kelp
Northern California	15	4	30
Central California	30	1	14
Southern California	26	0	12
Channel Islands	42	3	1
TOTAL	113	8	57

From the quarterly Landsat dataset, the sum of kelp-containing pixels within each segment was converted to total canopy area by multiplying this sum by the size of an individual pixel (900 m^2). Because giant kelp and bull kelp vary in timing and magnitude of seasonality, the value for each segment was set to the maximum quarter of coverage for each year for each segment. The result was an annual time-series of kelp canopy area since 1984 for each coastal segment.

Kelp status was assessed by comparing kelp canopy size during the most recent year to the distribution of canopy sizes during the reference period (all years prior to 2014):

$$S_{i,T} = \frac{C_{i,T}}{med(C_{i,Tref})} \times 100 \qquad \text{Eq. 1}$$

Status, S, of segment i in the year T is assessed as the maximum annual canopy coverage, C, for that segment relative to the reference period (Equation 1). Reference coverage, C_{Tref}, is the canopy coverage for all years for which data is available prior to 2014, which demarcates the onset of the 2014-2015 marine heatwave. The heatwave was a recent major disturbance event for most kelp

forests along the U.S. West Coast. The median, med, was used because many of the segment-level time series were non-normally distributed.

To derive a statewide score, each segment was assigned a score of [-2,-1,0,1,2] based on how its 2024 coverage fell within that segment's reference period percentiles, in line with the scoring approach outlined in the introduction.

Trend

Kelp trend evaluated changes in kelp canopy coverage during the most recent five-year time period (2019-2024). The researchers evaluated multiple time periods and selected the 5-yr time period to evaluate changes after the most recent coast-wide disturbance event to kelp. The researchers did not employ linear-model fitting, nor model fitting more generally, given the shortcomings of a limited sample size. Rather, it was evaluated whether the cumulative year-on-year changes are positive or negative. To do this, the cumulative annual change in absolute coverage over the last five years was calculated and normalized to the cumulative canopy coverage over the same time period (Equation 2).

$$\delta_i = \frac{\sum_{t=T-5}^{T} [\![(C]\!]_{i,t} - C_{i,t-1})}{\sum_{s=T-5}^{T} C_{i,s}} \qquad \text{Eq. 2}$$

where T is the latest year and $C_{i,t}$ is the absolute canopy coverage at year t for segment *i*. δ_i is then the segment-level five-year cumulative change normalized to the cumulative canopy coverage over those five years. To derive a coast-wide estimate of 5-year changes, researchers took the weighted average from the segment-level values, using the 5-year cumulative canopy coverages per segment as weights.

Results

Status

In 2024, the statewide kelp score was -0.63, meaning that kelp coverage in 2024 was slightly worse than the typical reference year prior to 2014. This translates to a statewide median coverage of 44%. Statewide, there was a broad range and sharp geographic pattern of kelp coverage, with values ranging from 0 – 791% relative to the reference baseline (Figure 6.1). Average kelp canopy cover among segments along northern, central, and southern California was 4%, 47%, and 36%, respectively, relative to their historical baseline. The Channel Islands had the highest coverage, 84%.

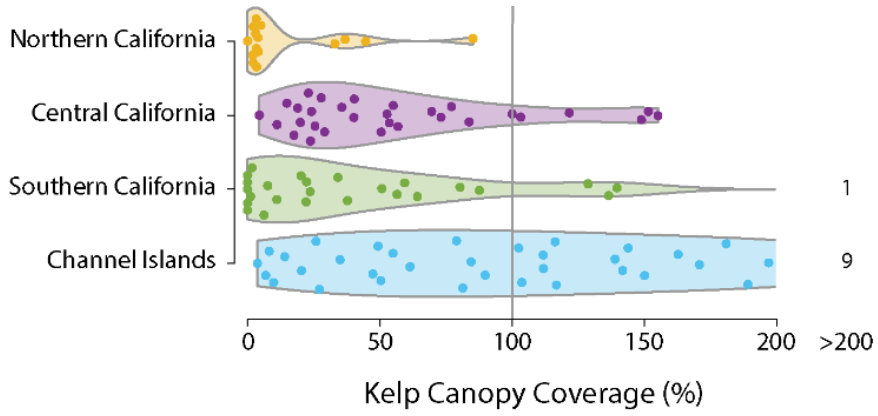

Figure 6.1. Kelp canopy coverage by segment in 2024 (circles) as a percent of the historical baseline grouped by region.

Trends

Among segments, the 2024 recent 5-year cumulative change varied from -50% to 30% with a strong geographic pattern (Figure 6.2). The northern California kelp segments were more varied as nine segments had recent increases, and five segments had recent losses with an overall average of -3%. All but five segments in central California had recent losses with regional average change of -18%, while southern California and the Channel Islands off southern California had seen a more varied response, with averages of -26% and -11%, respectively.

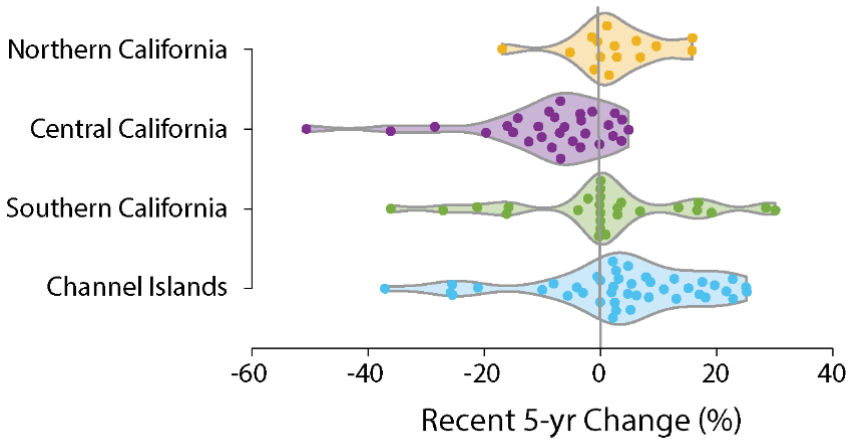

Figure 6.2. Segment-level recent 5-year change (%) grouped by geographic region. Individual points represent the cumulative five-year change as a percentage of the kelp canopy coverage. Shaded region is a violin plot inclusive of all segments.

Discussion

This analysis illustrates how multi-decadal, high-resolution data is essential for transforming local observations into a comprehensive statewide analysis of ecological change. Leveraging a 40-year dataset, this evaluation spans timescales of contemporary ocean-climate cycles, captures the full range of natural variability across the coastline, and significantly improves our ability to distinguish between seasonal fluctuations and the long-term declines facing global kelp forests compared to other shorter-term or more localized studies. While this 40-year dataset provides robust evidence, kelp have supported human populations for at least 16,000 years, probably longer. Off Santa Cruz, California, there is evidence that a century ago kelp canopy existed at 12-fold its current extent. Incorporating this type of local ecological knowledge from California Native American Tribal experts could help contextualize the current evaluation of kelp status.

Kelp canopy cover data are available across the entire California coastline, and canopy cover is a reliable, widely recognized metric to estimate kelp presence. However, using kelp canopy cover alone neglects understory kelp species and communities, which are captured by diver surveys that have much more limited spatial and temporal coverage. Future evaluations could investigate ways to merge these two data sources, thus providing both breadth and depth of coverage.

This analysis robustly detected the marine heatwave of 2014-2016, referred to as "The Blob", which was the major disturbance event for marine ecosystems in California and the entire U.S. West Coast. As a result of the heatwave, kelp coverage declined to varying degrees across all regions of California, with particularly sharp and persistent declines in Northern California. Marine heatwaves are expected to become more frequent and more severe with climate change. Early investments in kelp research, monitoring, pilot restoration efforts, and activities to reintroduce sunflower sea stars show promise for improving kelp forest ecosystem health.

Source Data

Bell, T., K. Cavanaugh, and D. Siegel. 2025. SBC LTER: Time series of quarterly NetCDF files of kelp biomass in the canopy from Landsat 5, 7 and 8, since 1984 (ongoing) ver 28. Environmental Data Initiative. https://doi.org/10.6073/pasta/d33bd376547863acffc675a611b40289

Time series of kelp canopy by segment are available at:
https://experience.arcgis.com/experience/4a4ea925a1cd49aab42b1b03ad8686e4/

The evaluation is supported by the following publication:

Frieder, C.A., Bell, T.W., Berry, H., Cavanaugh, K., Claar, D.C., Freiwald, J., Grime, B., Hamilton, S., Houskeeper, H.F., Lombardo, N. and Marion, S., 2025. Developing a Status and Trends

Assessment for Floating Kelp Canopies across Large Geographic Areas. *Environmental Science & Technology* 59 (46), pp. 24745-24754. https://pubs.acs.org/doi/full/10.1021/acs.est.5c07501

All code to make calculations is available as an R package:
https://github.com/SCCWRP/KelpAreaIndicator

2.7.SANDY BEACHES

Overall, beaches are returning to average widths after reaching near-record widths a decade ago. Today, 55% of beaches are narrowing, and 45% are widening. Beach width is highly variable at the local scale, with many beaches exhibiting either persistent erosion or persistent stability.

Lead Analyst and Author

Jon Warrick, U.S. Geological Survey

Working Group Members

Gabby Alampay, Washington State Department of Ecology
Timothy Baxter, University of California, Santa Barbara
Kyle Emery, University of California, Santa Barbara
Douglas George, National Oceanic and Atmospheric Administration
Karina Johnston, Heal the Ocean
George Kaminsky, Washington State Department of Ecology
Joshua Kelly, California State University, Los Angeles
Ella McDougall, California Ocean Protection Council
Bill O'Reilly, Scripps Institution of Oceanography
Peter Ruggiero, Oregon State University
Brett Sanders, University of California, Irvine
Eric Stein, Southern California Coastal Water Research Project
Heather Weiner, Washington State Department of Ecology

Executive Summary

Beaches were evaluated based on beach width, which is a strong indicator of erosion and ecosystem benefits, including habitat availability and space for recreation. In 2024, the statewide average indicated a mildly erosional year. Beaches statewide have been mildly erosional over the last four years as beaches return to average width after reaching near record widths during 2013-

2015. Beach width and change, i.e., erosion or accretion, were derived from satellite imagery using the open-source CoastSat technique, which uses Landsat and Sentinel-2 imagery to map beach area. Patterns are highly variable across the state, with more eroding beaches in Central and Northern California than in Southern California. Though this analysis permitted the development of a statewide score for beaches, it ultimately emphasized the importance of reporting beach width status at the local level, including identifying locations where beaches are consistently eroding.

Basis of Evaluation

The working group used a place-based approach to describe the status of sandy beaches, evaluating each beach based on its current width relative to a long-term average. The working group selected beach width as a metric of beach status because width is considered a good indicator of erosion and is broadly associated with a variety of ecosystem benefits provided by sandy beaches [33]. Broader beaches provide more habitat, better coastal protection, and more space for recreation and access. The working group also considered evaluating the extent of beaches backed by dune ecosystems, because dunes provide valuable habitat and a natural buffer against erosion and sea level rise. Dune extent would be an informative addition to this metric as statewide data on dune extent become available [34].

One way to measure beach width and erosion/accretion rates is with LIDAR, which is considered the gold standard for high-resolution data and used to produce the annual San Diego Beach Report. However, this method is resource-intensive and not available statewide. Thus, for this evaluation, the working group used satellite-derived shoreline measurements from the open-source CoastSat technique, which combines imagery from the Landsat and Sentinel-2 satellites, machine learning enhanced radiometric analyses, and tidal models. This method measures shoreline change by identifying the boundary between water and land in each satellite image, accounting for tides and beach slope to ensure the measurements are accurate. The data used for this evaluation came from a recent study of shoreline change across the Pacific Ocean [35, 36] and are the most recent release of these measurements [37; version 1.5].

Methods

Using the CoastSat data, the working group calculated monthly mean shoreline positions and beach area changes. Signal processing techniques were used to produce regular interval time series of shoreline positions over continuous beach segments, reduce the uncertainty in satellite-derived shoreline positions, and characterize the patterns, behaviors, and causes of beach change [36]. The annual mean shoreline positions were calculated for 329 beach segments of the California coast, where each segment represents a unique geographical setting defined by features including headlands, breakwaters and groins, harbors, river mouths, piers, changes in shoreline orientation,

or changes in shoreline change trends. Beach segments were excluded if they included irregularities caused by land-cast shadows, offshore rocks, coastal structures, and the opening and closing of river mouth inlets.

Beaches naturally get wider and narrower throughout the year due to seasonal changes in wave energy. To remove seasonal effects and make long-term trends clearer, the researchers used statistical techniques to remove the effects of season while preserving annual and multi-annual trends [36]. Finally, each beach segment was averaged over the "wave year" of November 1 to October 31, keeping all storms in a single winter season together in a single year. Shoreline position is relative, so the first three years of the dataset (1984-1986) were used as the anchoring point for evaluating subsequent change (i.e., erosion or accretion), and thus the mean shoreline position of 1984-1986 for each beach segment was subtracted from the mean annual shoreline positions.

Shoreline changes in linear units of change in shoreline position (m) were converted to units of change in beach area (m^2) by multiplying the shoreline position measurements by the length of the beach segment.

To check the accuracy of the satellite-derived data, the researchers compared it to data from field surveys conducted by scientists at Scripps Institution of Oceanography at three beaches in San Diego County: Cardiff, Solana Beach, and southern Torrey Pines. These comparisons revealed that the linear regression slopes between the satellite-derived and field-collected data ranged between 0.96 and 1.37 (average = 1.18), confirming that the satellite measurements are reliable for studying long-term changes.

Status

Each of the 329 coastal segments was scored [-2,-1,0,1,2] based on how that segment's width in 2024 compared to the distribution of widths during the historical baseline period, using the scoring approach outlined in the introduction. The baseline period was defined as 1984-2020, because 1984 is the earliest year for which LandSat data are available, and 2020 is the latest year that wasn't included in this trend analysis. Thus, lower scores indicate beaches that are net eroding and higher scores indicate beaches that are net accreting.

Statewide score was the mean score for all beach segments. These summary scores were highly correlated with other metrics of beach state, including the percent of beaches wider than the baseline condition and the overall total integrated beach area (Figure 7.1).

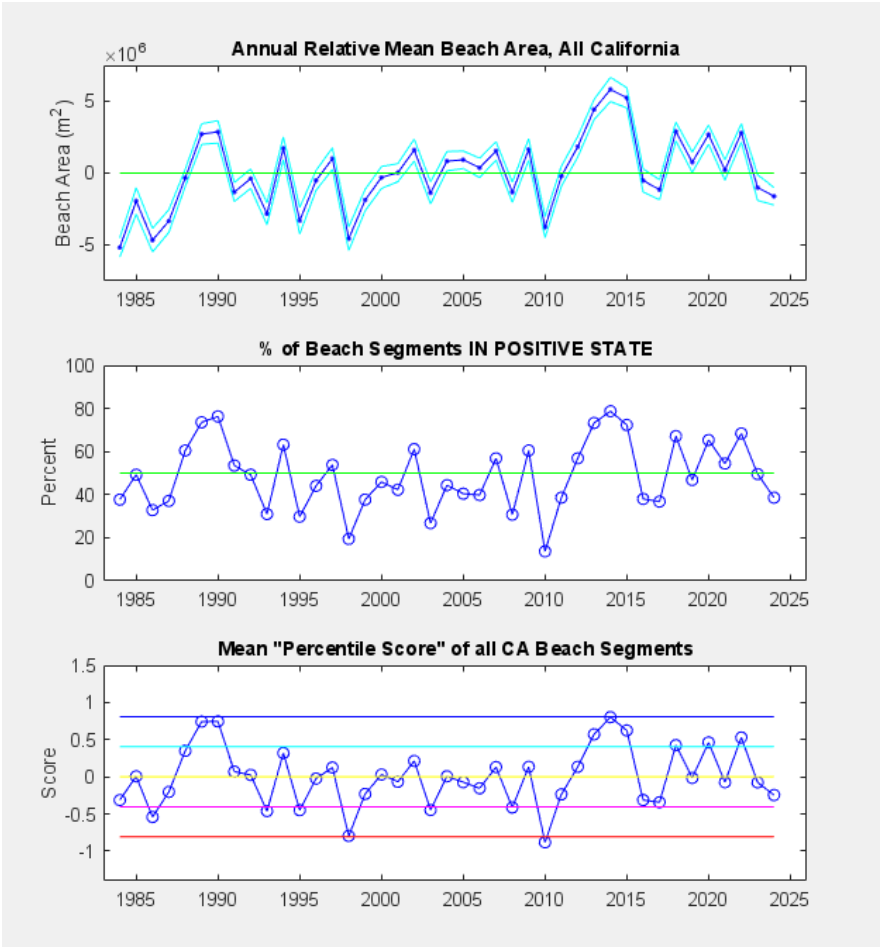

Figure 7.1. Comparisons of three different metrics of beach width. *Top:* total beach area (dark blue line) relative to the 1984-2024 mean (horizontal green line at 0) along with the 1-σ uncertainty in the annual values (light blue lines). *Center:* percent of beach segments that are wider than their 1984-2020 average values. *Bottom:* annual mean statewide beach score based on beach width relative to the distribution of widths from 1984 to 2020.

Regional scores were calculated as the mean of all segments in Northern California (north of the Golden Gate Bridge), Central California (Golden Gate Bridge to Point Conception), and Southern California (south of Point Conception).

Trend

Trend was calculated as the slope in the linear regression of total beach area in the state, and for each of the three geographic regions, over the last four years, 2021-2024. The working group examined trends at several different intervals and concluded that a 4-year trend best captured the

erosion-recovery cycles inherent in California beaches while not being overly sensitive to natural variability. Annual relative mean beach area is shown from 1984 to 2024 (Figure 7.1).

Results

Status

The statewide score for 2024 was -0.25. There were more eroding beaches in Northern California and Central California than in Southern California (Table 7.2). However, these regional differences were relatively small, and each region fell within one standard deviation of the mean. This highlights 2024 as a mild year for beach erosion and accretion strength.

Table 7.2. Percentage of eroding and accreting beaches, and corresponding scores, for each region.

	% of beaches eroding	% of beaches accreting	Score
Northern California	59%	41%	-0.39
Central California	70%	30%	-0.43
Southern California	45%	55%	0.01

Trend

The trend over the last four years was a moderate erosional trend. Following considerable erosion in 2010, California beaches recovered to near record widths during 2013-2015. Since then, those wide beaches have been getting narrower, but the recent slight erosion trend puts the stateside score near the long-term average. Trends are highly variable from beach to beach. In some places with persistent erosion, like Surfside and San Clemente, beaches are consistently getting narrower.

Discussion

Though this analysis permitted the development of a statewide score for beaches, it ultimately emphasized the importance of local dynamics and interannual storm variability. The statewide analysis found 2024 to be a slightly erosional year, with a statewide score close to the long-term average. However, trends are highly variable from beach to beach, with some locations like Surfside and San Clemente consistently narrowing. Given that erosion is a concern and is managed at a local scale, regional management may be better informed by analyses that identify specific areas in need of shoreline management, including sediment nourishment or other adaptation

interventions that may sustain wider beaches. Alternatively, future iterations of this work may use a cost-benefit analysis to explore how adaptation measures, including sediment management, affects beach width.

Beach width was used as the metric of beach status because width is considered a good indicator of beach volume and shoreline position, including erosion and accretion patterns, and is broadly associated with a variety of ecosystem benefits provided by sandy beaches. However, other metrics could be considered for future evaluations. The working group considered evaluating the extent of beaches backed by dune ecosystems, because dunes provide valuable habitat and a natural buffer against erosion and sea level rise. However, this data was not used because it is not yet available statewide [33]. Given that more data is becoming available, and local analyses may actually prove more impactful, researchers should revisit this metric for future analyses. Other metrics that could be considered include sandy beach ecology, dune extent, and net width, in addition to directional change of beach width [33].

The evaluation is supported by the following publications:

Warrick, J.A., Vos, K., Buscombe, D.D. *et al*., 2026. Net Widening of Southern California Beaches. *Nature Communications*. https://doi.org/10.1038/s41467-026-68880-9

O'Reilly, W.C., Merrifield, M.A., Cagigal, L., Yoon, D., Leslie-Bole, H., Adusumilli, S., Young, A.P., Vos, K. and Guza, R.T., 2025. Interannual wave-driven shoreline change on the California coast. *Nature Communications*, 16(1), p.9967. https://www.nature.com/articles/s41467-025-65944-0

2.8. HARMFUL ALGAL BLOOMS

In 2024 and 2025, there were major HAB impacts on razor clam harvests in Northern California and marine mammal strandings in Central and Southern California. Over half of coastal counties closed shellfish harvesting due to HABs, but this does not represent a significant departure from the long-term trend.

Authors

Jayme Smith, Southern California Coastal Water Research Project

Working Group Members

Clarissa Anderson, Southern California Coastal Ocean Observing System

Maggie Broadwater, National Oceanic and Atmospheric Administration

David Caron, University of Southern California

Alex Harper, Central & Northern California Ocean Observing System

Stephanie Moore, National Oceanic and Atmospheric Administration

Misty Peacock, Northwest Indian College

Data Analysis Contributors

Kyla Kelly, California Ocean Protection Council

Kate Robinson, California Ocean Protection Council

Nick Lombardo, Southern California Coastal Water Research Project

Christina Frieder, Southern California Coastal Water Research Project

Executive Summary

The status of harmful algal blooms (HABs) was evaluated based on the percent of shellfish harvesting days lost due to HABs. In 2024, HABs led to shellfish harvesting closures in 8 of 15 coastal counties. Northern California has been most strongly impacted by HABs, with harvesting opportunity loss increasing since 2009, largely due to persistent toxin levels in razor clams. However, for 13 of 15 coastal counties, there was no change in the long-term trend harvest closures. Beyond the impacts to fisheries, in Central and Southern California there have been unusually high numbers of marine mammal strandings linked to suspected HAB poisoning in recent years. Taken together, these patterns show how HABs disrupt coastal ecosystems, pose risk to public health, and affect local economies and cultural practices.

Basis of Evaluation

The working group used the place-based approach to describe the status of harmful algal blooms (HABs) by evaluating advisories and closures for recreational and commercial bivalve harvesting. Bivalves can accumulate HABs-related toxins, and when those toxins reach unsafe levels, the state issues harvest advisories and/or closures. Thus, this analysis evaluates the extent to which HABs impact commercial and recreational shellfish harvesting.

The U.S. Food and Drug Administration has established "safe to eat" levels of multiple HAB toxins that guide states in issuing consumption advisories and harvesting closures for shellfish and other seafood. In California, shellfish monitoring and management is conducted collaboratively by the California Department of Public Health, the California Department of Fish and Wildlife, and the Office of Health Hazard Assessment. This analysis used agency records of HABs biotoxin-related bivalve health advisories and closures to calculate lost bivalve harvesting opportunities.

Methods

Status

The metric for HABs is based on the percent of commercial and recreational shellfish harvesting days lost due to HABs. This evaluation uses a place-based approach, where each coastal county was evaluated separately and the overall state score is an average of all counties. The metric of "impaired bivalve harvest opportunity" was defined as the number of days for which an advisory (recommending against) or closure (prohibiting) due to HAB toxins was in place for commercial and/or recreational harvesting.

The species used in this analysis are described in Table 8.1. The duration of advisories and/or closures for each recreational and commercial bivalve fishery was calculated for each of California's 15 coastal counties. When an advisory and closure overlapped for the county, days lost were not double-counted. Similarly, closures issued during existing quarantines or closed fishing seasons were excluded from the calculation.

Table 8.1. Bivalve species, toxins, and sectors considered in the HAB-impaired shellfish harvest opportunity analysis. DA = domoic acid; PSP = paralytic shellfish poisoning; DSP = diarrhetic shellfish poisoning.

Species	Toxin	Sector
Razor clams	DA	Recreational
Mussels	DA, PSP, DSP	Recreational, Commercial

Species	Toxin	Sector
Other bivalves (oysters, scallops, and species of clam besides razor clam)	DA, PSP, DSP	Recreational, Commercial

Data are reported at the county level, so harvest opportunity loss was calculated at the county level. Therefore, any advisory or closure that was issued for specific stretches of a coastal county or zone applied to the county as a whole even if there were stretches of coast that were still open for harvest within that county. Annual harvest loss per county was calculated as the ratio of days closed to total harvest days available in a year.

Status was calculated as current harvest loss relative to historical average harvest losses. Using the scoring approach outlined in the introduction, each county was assigned a score of [-2,-1,0,1,2] based on how its 2024 harvest lost percentage compared to the distribution of harvest losses during all prior years for which data were available, beginning in 2009 when digital record-keeping became more reliable and robust. Thus, the baseline period for historical average comparisons was 2009-2023. For counties with both recreational and commercial bivalve data, the score was the average of the two scores.

Trend

Trend was calculated as the linear change over time for only recreational harvest, because recreational harvest occurs in all coastal counties, while commercial harvests only occur in 5 counties.

Results

Status

For many counties, there was no loss of harvest days for most years during the baseline period. As an example, both San Diego and Orange counties had zero bivalve harvest loss in all years but one. In those cases, no loss was assigned a score of 2, and any loss was assigned a score of -2.

The statewide HABs score was 0.47 on a scale of -2 to 2, meaning that in 2024, HABs had a slightly higher impact compared to the typical impact over the 15 years. This translates to a statewide loss of 14% of recreational harvest opportunity and 5.5% of commercial harvest opportunity (Table 8.2). These losses were distributed very unevenly throughout the state, with much greater loss in Northern than in Southern California, and higher losses for recreational than for commercial harvest. Del Norte and Humboldt Counties lost 96% and 60% of their recreational harvest days,

respectively. In contrast, Ventura, Los Angeles, Orange, and San Diego Counties had no recreational advisories or closures in 2024 (Table 8.2).

Table 8.2. County-level percentages of recreational and commercial bivalve harvest days lost due to closure in 2024 as a percent of the total available harvest days for that year. The 10th, 25th, 75th, and 90th percentiles for the county-level baseline are provided. Cells with "-" are for counties that have no commercial harvest of bivalves.

County	Rec Bivalve Harvest Loss (%)	Rec Baseline Percentiles	Rec Score	Comm Bivalve Harvest Loss (%)	Comm Baseline Percentiles	Comm Score	Combined Score
Del Norte	95.9	[2.7, 10, 43.4, 56]	-2	-	-	-	-2
Humboldt	59.9	[4.2, 7, 42.4, 48.9]	-2	0	[0,0,0,0]	2	0
Mendocino	0	[0, 0, 6.4, 11.4]	2	-	-	-	2
Sonoma	8.9	[0, 0, 4.3, 8.4]	-2	-	-	-	-2
Marin	12	[0, 0, 8.7, 14.9]	-1	8.5	[0,0,1.8,4.2]	-2	-1.5
San Francisco	0	[0, 0, 0, 7.1]	2	-	-	-	2
San Mateo	0	[0, 0, 7, 14.7]	2	-	-	-	2
Santa Cruz	10.6	[0, 0, 8.6, 16.5]	-1	-	-	-	-1
Monterey	12.8	[0, 0, 12.6, 19.2]	-1	-	-	-	-1
San Luis Obispo	0	[0, 0, 8.5, 14.9]	2	9.6	[0,0,0,0]	-2	0
Santa Barbara	9.7	[0, 0, 10.3, 20.9]	0	5.9	[0,0,14.4,22.3]	0	0
Ventura	0	[0, 0, 12.1, 18.8]	2	-	-	-	2
Los Angeles	0	[0, 0, 2.2, 15.6]	2	-	-	-	2
Orange	0	[0, 0, 0, 0]	2	-	-	-	2
San Diego	0	[0, 0, 0, 0]	2	3.7	[0,0,0,0]	-2	0
Statewide	**14.0**		**0.47**	**5.5**		**-0.8**	**0.3**

Trend

The working group analyzed trends at the county and statewide scale (Table 8.3). Linear trends were assessed for the full extent of the data (2009-2024). Data were visually inspected for other

types of trends (nonlinear; step change; etc) in the chance that a linear trend would not capture important changes; linear trends were deemed sufficient for this exercise.

Table 8.3. Summary of trends by county.

Trend	No. of Counties	Counties (change in harvest loss per year)
No trend	13	Mendocino, Sonoma, Marin, San Francisco, San Mateo, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange, San Diego
Increasing	2	Del Norte (4.6 %/yr), Humboldt (3.4 %/yr)
Decreasing	0	None

Statewide approach (Figure 8.1): Average bivalve harvest loss across all counties and then evaluate the change over time. The result was a statistically significant increase in bivalve harvest loss at a rate of 0.72% per year.

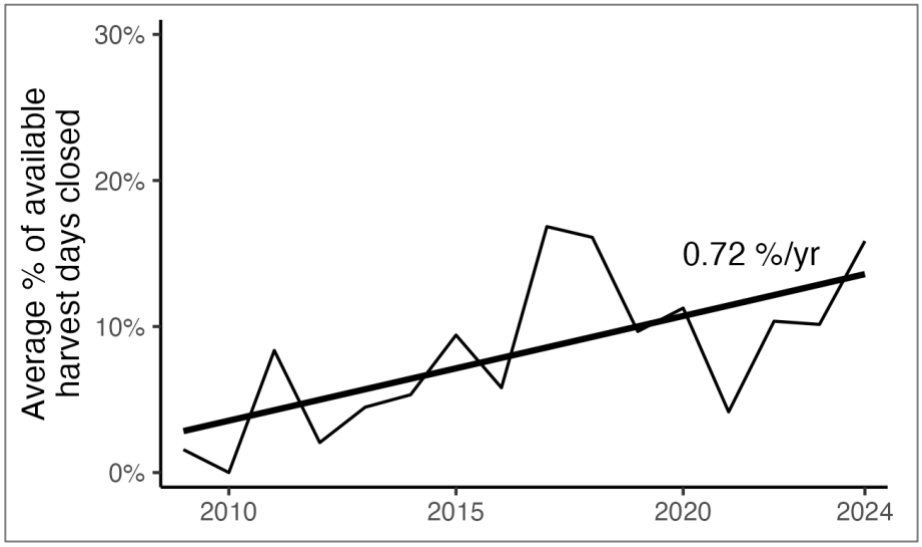

Figure 8.1. The average percent of closure days for recreational bivalves among the 15 counties has increased by 0.72% per year.

County approach (Figure 8.2): Evaluate the trend per county and average the trends across counties. The result shows no significantly different average slope from zero.

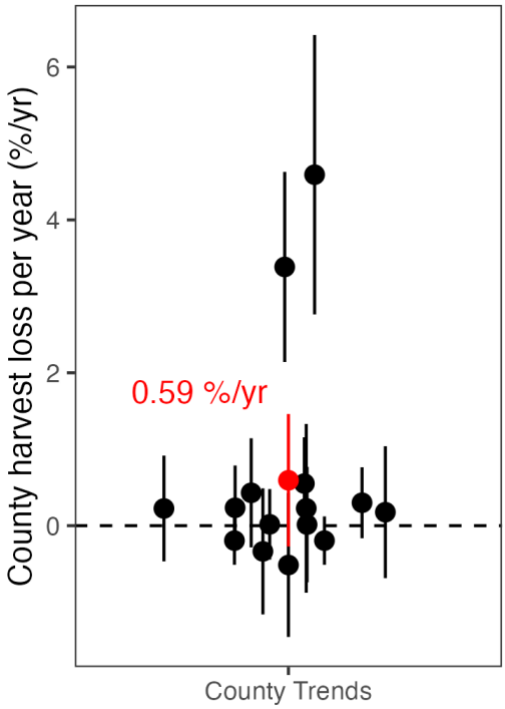

Figure 8.2: County-level slopes (%/yr; +/- 95% CI) and the overall mean of the slopes (red). The coast-wide average slope was not significantly different from zero.

Statewide analyses showed an increase in average harvest loss by 0.72% per year. However, county-level analyses showed no trend. This discrepancy highlights the strong regional contrasts (Figure 8.3): strong increases in northern California drove the statewide trend, while central and southern California showed no change over time.

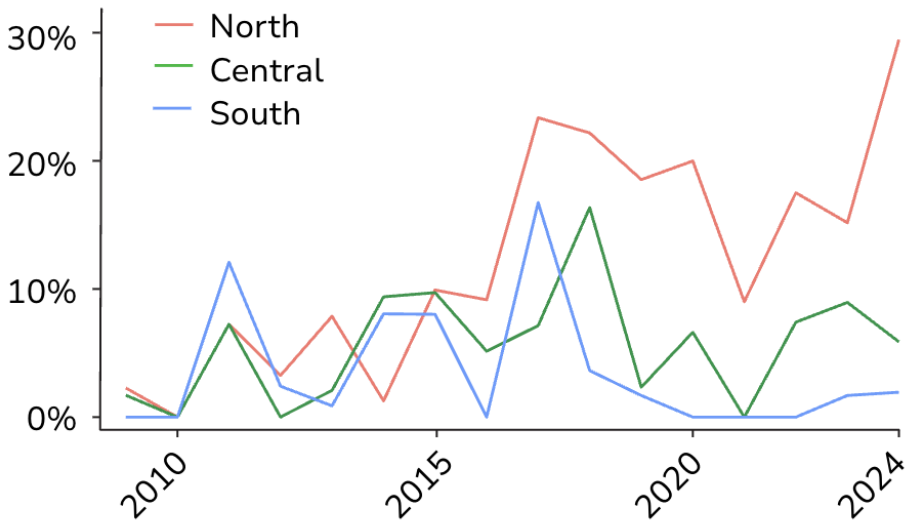

Figure 8.3: Regional loss of harvesting opportunity. Northern California drives the statewide increase in lost opportunity annually.

Discussion

Though this analysis presents a statewide assessment of the impact of HABs, given how HABs vary geographically it was difficult to develop a score that reflects diverse regional impacts. In southern California, marine mammal strandings are the most prominent impact, suggesting that this evaluation may underestimate HAB impacts there since this evaluation did not include impacts on marine mammals. Conversely, shellfishery closures dominate in northern California, producing more robust quantification of impacts for that region. Thus, the working group recommended that future iterations of this analysis be based on sub-regional metrics that apply an and/or approach, using mammals and/or shellfish as the main driver of the score depending on regional context.

The working group developed a metric to capture HAB impacts across both pelagic and benthic environments in nearshore and offshore waters. However, the indicator still underrepresents benthic and offshore pelagic environments. To better evaluate HAB impacts in those environments, the working group considered and excluded several other types of data. Satellite imagery can be used to quantify algal bloom frequency and intensity, but this was deemed unreliable since not all algal species in blooms are harmful and harmful algae do not always produce toxins. Similarly, direct measures of toxins, such as domoic acid (DA), were considered. However, the spatial and temporal extent of DA sampling is limited and not all DA-producing blooms are captured by current monitoring networks.

Marine mammal strandings are a good indicator of HAB impacts on the pelagic environment, but stranding data was not incorporated into this evaluation because 1) stranding events are not consistently or reliably attributed to HABs federal database, and 2) systematic collation of this HABs-related strandings only began in 2019. Additionally, documentation of strandings relies largely on public observations, and northern California's less populated coastline may result in fewer reported strandings compared to more densely populated regions in southern California. Given these limitations, stranding data were not included in the calculation of status and trends but can be used as supporting narrative and evidence.

Future evaluations could include HAB impacts on additional taxa, namely crustaceans and finfish, that were excluded from this analysis due to inconsistent and incomplete datasets. In northern California, Dungeness crab—a culturally and economically important fishery—presented two major challenges: 1) overlapping non-HAB closures (e.g., whale entanglement restrictions) that coincide with HAB season and prevent toxin testing, and 2) a monitoring program that was overhauled in 2015, resulting in a much shorter and less comparable time series than for bivalve shellfish. In southern California, relevant crustacean fisheries such as rock crab and spiny lobster lack systematic HAB monitoring, relying instead on voluntary sample submissions that result in a dataset too patchy to support long-term trend analysis. Finfish face similar issues, with most toxin testing based on voluntary submissions rather than structured monitoring. These data limitations could be improved with the implementation of a standardized, statewide HAB monitoring program.

A future goal for this analysis is to develop a methodology that calculates the economic cost of fishery advisories and closures. While the current indicator captures the frequency and duration of closures, it does not directly convey the scale of economic impacts of these management actions. Establishing a standardized approach to link advisory/closure days with economic loss would provide a more complete picture of the societal consequences of HAB events. Future work could also examine the distribution of these impacts across demographics and social groups to better understand if inequities and food insecurity are exacerbated by HAB events.

Source Data

Recreational bivalve data were compiled from advisory and closure releases from the California Department of Public Health and the California Department of Fish and Wildlife websites. The samples supporting these management decisions were collected by a team of voluntary partners, including Tribes, NGOs, universities, local government agencies, and private citizens.

Commercial closures were obtained through records requested from the California Department of Public Health.

Records of suspected DA-induced marine mammal strandings were collected by the West Coast Marine Mammal Stranding Network and collated by the Southern California Coastal Ocean Observing System.

2.9.OCEAN TEMPERATURE

Despite the long-term global ocean warming trend of approximately 2°F per century, 2024 was a relatively typical year for coastal water temperatures off California. There are early signs that marine species are moving north, likely due to warming temperatures.

Lead Analyst

Andrew Leising, National Oceanic and Atmospheric Administration, National Marine Fisheries Service

Additional Authors and Working Group Members

Isaac Schroeder, Institute of Marine Sciences, University of California Santa Cruz
Jennifer A. Brown, ECOS Consulting, LLC, in support of Sanctuary Watch
Christina Frieder, Southern California Coastal Water Research Project
David Gillett, Southern California Coastal Water Research Project

Executive summary

The status of ocean temperature was assessed using temperature anomalies from the shoreline to 3 miles offshore, and comparing this year's average temperature to the long-term average (1982-2022). 2024 began with warmer, El Niño-like conditions, and then temperatures cooled significantly by mid-year, particularly in the central and northern regions, resulting in an overall ocean temperature score of 0.1 standard deviations above the long-term average. The analyses leveraged data from a combination of platforms, including satellites, ships, buoys, floats, and the statewide Shore Stations program. The data reflect the major marine heatwave in 2014-2016, followed by a return to average temperatures. Recent trends do not reflect long-term ocean warming, which has progressed at approximately 1°C (1.8°F) per century in California, with temperatures in southern California warming faster than other parts of the state. There are early signs that rocky intertidal species are shifting their distributions north, likely due to ocean warming.

Basis of Evaluation

The working group used this place-based approach to describe the status of ocean temperature, evaluating recent temperatures at a given location relative to a long-term average, in the form of temperature anomalies. The working group also examined the impact of temperature on rocky intertidal species. However, the score is based only on sea surface temperature, and impacts on species are included as supporting information.

The sea surface temperature evaluation was developed to reflect California's position in the California Current System (CCS). The CCS is dominated by upwelling, a process that brings deep, cold, nutrient-rich waters to the surface, fueling the growth of plankton that support fisheries and a very productive ocean ecosystem. One of the major basin-scale drivers of variability in the CCS is the El Niño-La Niña cycle, also called the El Niño Southern Oscillation (ENSO), which leads to significant changes in the ocean ecosystem during strong El Niño and La Niña states. El Niño states have warmer coastal waters and increased stratification of the surface waters from early winter to late spring and can thus reduce nutrient transport during springtime upwelling. In contrast, La Niña states have cooler coastal waters, with more effective upwelling. Thus, in California, cooler coastal waters, particularly during the summer, are generally associated with more productive years, and warmer coastal waters, including those caused by marine heatwaves and strong El Niños, are generally associated with less productive years.

However, some species thrive under warmer conditions. For example, tunas prefer warmer waters, so those species appear closer to shore or earlier in the season during warmer years. In contrast, kelp forests were decimated by the marine heatwave in 2014-16, due to the lack of upwelling nutrients.

Data sources were selected to balance spatial and temporal coverage. To calculate a score that accurately describes ocean temperature for the entire state, the working group relied on data from NOAA's Optimum Interpolation Sea-Surface Temperature (OISST V2.1) record, which is primarily satellite-based measurements that assimilate *in situ* data from multiple platforms, including ships, buoys, and floats, to correct the satellite data. The OISST was chosen because it is ground-truthed, has daily values back to 1982, and is interpolated for all locations at a 0.25-degree lat/lon resolution, translating to 38 grid cells covering California (Fig. 9.1). Other data sets may have higher spatial resolution but lack the long time series necessary to accurately assess longer-term changes.

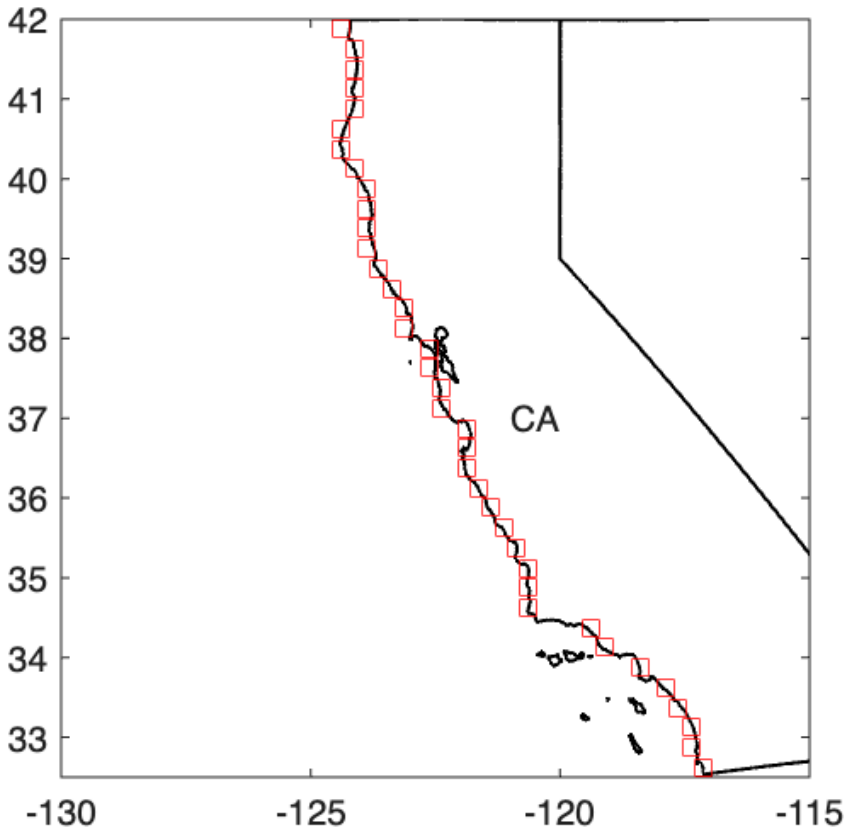

Figure 9.1. Locations of the 38 grid cells used to calculate the coastal SSTa index.

To describe the trend in a way that accurately captures the slow and subtle changes in ocean temperature over a longer historical period, the working group used sea surface temperature data from the Shore Stations program. Scientists in California have been measuring sea surface temperature at shore stations for over a century. The Scripps and UC San Diego shore station program data have limited spatial scope, as they are only available for nine locations across the state, but they have extensive temporal coverage over more than 100 years, so these data provide a valuable historical reference to evaluate trends.

Rocky intertidal species were evaluated as an indicator of long-term change in ocean temperature. Some species, including those in the rocky intertidal zone, are expanding their geographic ranges to the north as average temperatures around their northern geographic extent are warming over time. Other species' geographic ranges are contracting on their southern extent as temperatures in those areas become too warm over time. Rocky intertidal species serve as an indicator here because they are sensitive to temperature stress, highly visible, and have been monitored for decades. For this indicator, the geographic ranges of rocky intertidal species were evaluated using data from the Multi-Agency Rocky Intertidal Network (MARINe), which is a network of research programs that have been monitoring the rocky intertidal zone at over 200 locations for more than 30 years. Data from MARINe were also used in the rocky intertidal zone evaluation (section. 2.4).

Methods

The metric for ocean temperature is based on current temperatures relative to a historical average. This evaluation uses a place-based approach, where each location is evaluated separately and the overall state score is an average of all locations.

Sea surface temperature climatologies for each location and day of year were calculated using the 40 years from 1982 to 2022. Daily climatologies were smoothed with a 90-day running Gaussian mean. These climatologies were then used to calculate SST anomalies (SSTa) for each day at each grid location. Then, the working group created a standardized anomaly, SSTa*, which is the SSTa at each location and for each day of the year, divided by the standard deviation of SSTa at that location and for that day of the year. Thus, the metric for evaluating and grading ocean temperature is a standardized sea surface temperature anomaly, SSTa*, which is comparable among locations and across seasons.

Status

To condense the temporally and spatially explicit values of SSTa* into a single score, first, the daily values for the year were averaged at each location, then the values for all locations were averaged spatially to provide a single value for the entire coast for the whole year. This resulted in the annual coastal temperature index (Fig. 9.2).

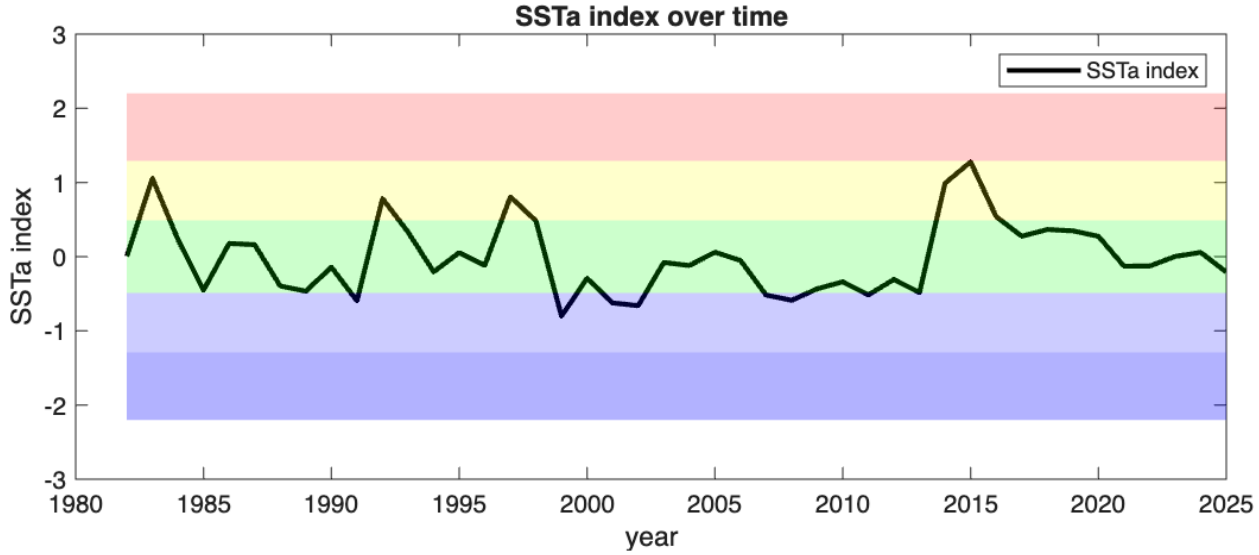

Figure 9.2. Annual ocean temperature index, the spatial and temporal average of SSTa*. Green band indicates ±1 standard deviation from the mean of the time series. Red and dark blue indicate ±1.29 from the mean (i.e., the top and bottom 10% of values given a normal distribution, respectively).

The working group considered two ways to capture the variance of the ocean temperature: spatial and temporal variance. In an exploratory analysis comparing both sources of variance (Fig. 9.3), it was clear that temporal variance was always greater than the spatial variance. Thus, to be conservative, the working group aligned on using temporal variance to represent the overall variance of the annual index value.

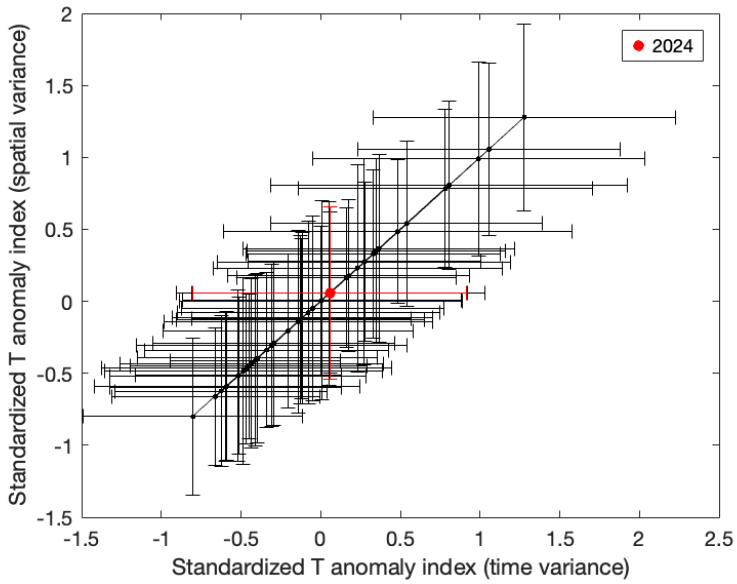

Figure 9.3. Comparison of temporal (x-axis, day to day over a year) and spatial (y-axis, among locations) variance of the sea surface temperature anomaly index for all years 1982-2022; 2024 is highlighted in red. Temporal variance was always greater than spatial variance, so the working group used temporal variance when reporting the annual score.

Trend

Trend in ocean temperature was based on the long-term records of sea surface temperature from three shore stations: Trinidad Bay, Pacific Grove, and La Jolla. These three locations were selected to provide records from Northern, Central, and Southern California, respectively. Trend was reported as the change over the full record: 1973-present for Trinidad Bay, 1919-present for Pacific Grove, and 1916-present for La Jolla.

The effects of ocean temperature on rocky intertidal species were measured by measuring geographic shifts in the centers of distribution of organisms that live in this ecosystem between 2001 and 2023. Monitoring data were obtained from the Multi-Agency Rocky Intertidal Network (MARINe) biodiversity monitoring dataset, which regularly surveys taxa in standardized quadrats and transects at 108 sites across California (www.marine.ucsc.edu). For each species with more than five occurrences across the dataset, the annual geographic population center (i.e., abundance-weighted latitude) was calculated each year between 2001 and 2023 by (1) Calculating the relative

abundance for each species at each site (site abundance / statewide total abundance); (2) Multiplying the relative abundances by the latitude of each site to create fractional latitudes; and (3) Summing all fractional latitudes within a year to estimate the geographic population center for each species. Changes in geographic centers were evaluated by linear regression of the geographic population centers across years. Species with a trend of increasing latitude over time were characterized as poleward shifting populations, species with a trend of decreasing latitude over time were characterized as equatorially shifting populations, and species with no trend were characterized as having non-shifting populations.

Results

The 2024 coastal temperature index, which is the SSTa* averaged across all days and all locations, was 0.1. However, there were notable differences in SSTa* across space and time (Fig. 4). In the first part of the year, the ocean was in an El Niño phase, and most of the nearshore water was warmer than usual. By April, the ocean temperature had rapidly cooled. By the end of the year, September through December, warmer anomalies returned in offshore waters (>200 miles) and in the southern part of the state, while central and northern parts of the state remained cooler. These patterns illustrate why it is valuable to examine both the spatial and temporal variability of the index within a year. A year with consistent average temperatures all year long and a year with warmer than normal, then cooler than normal, temperatures (like 2024) would yield similar average yearly index values, but would likely have different realized ecosystem responses.

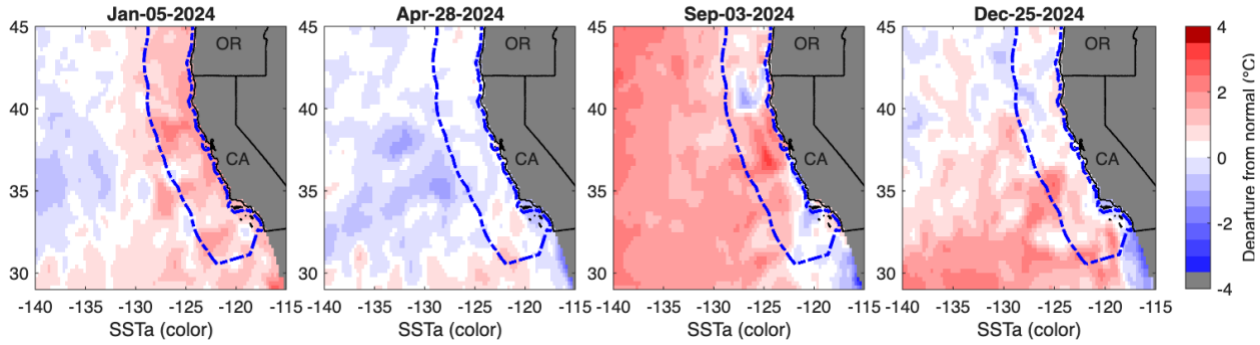

Figure 4. Ocean temperature anomalies throughout 2024. Darker red indicates warmer anomalies, and darker blue indicates colder anomalies. The dotted line indicates the U.S. exclusive economic zone (200 nautical miles offshore).

Of 243 monitored rocky intertidal species, 21% (n = 51) are shifting north toward cooler water and 4% (n = 10) are shifting south toward warmer water. Most species (n = 182) have no geographic shifts over the last 20 years. Populations shifting north are moving their ranges at an average rate of more than 300 km per decade.

Discussion

Overall, 2024 was an average temperature year for California's ocean waters, with parts of the year having sea surface temperatures that were first warmer and then cooler than typical. This "average" temperature year is against a backdrop of sustained global ocean warming. California's coastal waters are warming slower than ocean waters in other parts of the world due to its position in an upwelling system that brings cold water to the surface. California has also experienced extreme marine heatwave events, such as the heatwave in 2014-15 that is evident in by a peak in Figure 2. That heatwave had major impacts on the marine environment and is evident in the analysis of kelp and rocky intertidal elsewhere in this report. More of these marine heatwaves are expected in the future due to climate change [27].

This analysis was based on nearshore sea surface temperature anomalies; other ways to evaluate ocean temperature would yield different results. For example, offshore waters beyond the 200-mile EEZ display different temperature regimes (Figure 4), and conditions in these international waters are important for oceanic organisms like whales, tunas, and seabirds. Alternatively, analysis of ocean heat content that integrates across depth can be more informative about global climate change and impacts, including sea level rise.

Here, we used the latitudinal distribution of rocky intertidal species to evaluate ocean temperature impacts on marine life. Rocky intertidal species are a good way to evaluate changes in range shifts, because these species only live in a narrow band along the coastline and therefore any habitat shifts due to temperature are constrained in a poleward or equatorward direction. Further, the MARINe program provides a comprehensive and convenient statewide database to evaluate long-term distributional changes. There are observed impacts of warming ocean temperatures on numerous other marine species [38-40]. Some species can adapt and change habitats or phenologies, some species change physiologically, and still other species cannot adapt quickly enough to our changing climate. There is much research on climate change effects on California's biodiversity, habitats, and ecosystem services, and future work can examine more closely how the marine environment is responding to a warming ocean.

Acknowledgements

Clarissa Anderson, Southern California Coastal Ocean Observing System (SCCOOS) and NOAA Cooperative Institute for Marine, Earth, and Atmospheric Systems (CIMEAS) at Scripps Institution of Oceanography at UC San Diego

Henry Ruhl, Central and Northern California Ocean Observing System (CeNCOOS)

Justine Kimball, OPC

Source data

- OISST data available from:
  - https://www.ncei.noaa.gov/products/optimum-interpolation-sst
  - https://psl.noaa.gov/data/gridded/data.noaa.oisst.v2.highres.html
  - Data available directly from ERDDAP: https://coastwatch.pfeg.noaa.gov/erddap/griddap/ncdcOisst21Agg.graph
- Shore station data provided by the Shore Stations Program sponsored at Scripps Institution of Oceanography by California Department of Parks and Recreation, Natural Resources Division, Award #C1670003. Available from https://shorestations.ucsd.edu/
- Rocky intertidal data available from MARINe: https://marine.ucsc.edu/

2.10. OCEAN ACIDIFICATION

Ocean acidification is worsening across the state, and today the volume of seawater that is corrosive to shells is six times larger than before the use of fossil fuels. Conditions tend to be more corrosive in Northern California due to stronger upwelling and shelf processes.

Lead Author

Jan Newton, University of Washington and Northwest Association of Networked Ocean Observing Systems (NANOOS)

Lead Analysts

Adrienne Sutton, National Oceanic and Atmospheric Association, Pacific Marine Environmental Laboratory
Kate Hewett, University of Washington
Christina Frieder, Southern California Coastal Water Resources Project

Coordinating Author

Meghan Zulian, California Ocean Science Trust

Working Group Members

Simone Alin, National Oceanic and Atmospheric Association, Pacific Marine Environmental Laboratory
Hana Busse, University of Washington

Executive Summary

The status of ocean acidification was evaluated based on the volume of ocean water that fell below biological thresholds. The biological acidification threshold was set based on conditions that make it harder or easier for marine life to build shells, skeletons, and other hard parts. From 2008-2017, the average volume of water between 15-m and 200-m depth that fell below this threshold was 19.2% compared to 2.35% in the pre-industrial era. Conditions are highly variable across the state. Conditions across the shelf are generally more corrosive off northern California as compared to the southern part of the state, due to a combination of stronger upwelling and shelf processes. Modeling results presented in this analysis are from 2017, which are the most recent years for which comprehensive statewide data are publicly available. The trend of ocean acidification was based on observations near Point Conception from 2010-2025 where approximately one-fifth of the time marine life experienced conditions outside the pre-industrial range.

Basis of Evaluation

The working group used a place-based approach to describe the status of ocean acidification, based on how current conditions differ from the pre-industrial era. This indicator was scored based on regional model data for aragonite saturation state (Ω_{arag}) in the ocean, a measure of how easy or difficult it is for organisms to build shells from the mineral aragonite. Status is the average volume of seawater in which animals would struggle to build shells ($\Omega_{arag} < 1$) in the most recent years statewide model output data were publicly available (2008-2017), compared to before the Industrial Revolution (pre-1840). Trend is the percent of days that aragonite was beyond the pre-industrial range of conditions, based on data from two offshore buoys (Point Conception and the Southern California Current).

This analysis evolved from work conducted by the West Coast Ocean Alliance to develop a coast-wide ocean acidification indicator for the West Coast Ocean Data Portal. The WCOA working group identified two key questions to describe the status of ocean acidification: 1) How different are conditions from the pre-industrial era? 2) Why are these differences important? Thus, the working group developed a dual approach using both modeled and observed data and focused on pre-industrial comparisons through a biological lens, which was ultimately applied here to California waters. Products include the % days conditions exceeded pre-industrial variability (used to assess trend) and the % corrosive volume of shelf waters (used to assess status).

To assess OA on a state-wide basis, Ω_{arag} was selected as the indicator variable due to its biological significance and sensitivity to increasing carbon dioxide (CO_2). High Ω_{arag} supports calcification, while low values indicate corrosive conditions where organisms' protective casings can begin to dissolve. Unlike pH alone, Ω_{arag} reflects both acidity and carbonate availability, making it a

biologically meaningful and management-relevant measure of OA impacts. Biological Ω_{arag} thresholds and pre-industrial estimates were used to examine how current conditions have diverged from pre-industrial conditions and how these differences impact habitat availability.

The working group identified two Ω_{arag} thresholds as indicators of corrosive conditions: one for the full water column, based on the solubility of Ω_{arag} at 1, and one for surface waters, which typically have higher values. Biological sensitivities to Ω_{arag} vary by organism, with the majority of sensitive species (e.g., Pacific oyster, California mussel, calcifying pteropods) experiencing reduced shell growth and calcification occurring between Ω_{arag} 1 and 2, with 1.7 as a commonly used threshold for surface waters [41].

The regional ocean model employed here is useful in examining spatial variability; however, to capture the full magnitude of variability at seasonal to sub- seasonal timescales, high-frequency observations are key. Using methodology developed by Sutton et al. [42], surface ocean observations were used to define both present-day and preindustrial Ω_{arag} variability, allowing the working group to identify when biological thresholds are surpassed and how often surface conditions exceed historical ranges.

Methods

This evaluation used a place-based approach, where each location was evaluated separately and the overall state score is an average of all locations.

Status

The ocean acidification status relies on regional model output of Ω_{arag}. OA conditions vary greatly by depth, utilizing ocean models allows the status metric to reflect the full water column, providing a snapshot of available habitat compared to pre-industrial conditions. Ω_{arag} of <1 was utilized as the threshold for Status due to the incorporation of deep, naturally lower, Ω_{arag} waters. The model used is the regional ocean modeling system coupled to biogeochemical elemental cycling (ROMS-BEC). Analysis of two decades of ROMS-BEC simulations (1997–2017) for the southern California Current System has demonstrated excellent consistency with observations from large to local scales for both the physical and biogeochemical states [43, 44]. The carbon module includes total alkalinity and dissolved inorganic carbon (DIC) as state parameters, from which Ω_{arag} is derived. ROMS-BEC is built on a series of nested domains, and outputs from the 1-km domain are used here because they span the entire California coast and have been validated in prior works [45].

For each year, an annual numeric status was calculated for each of 11 segments along California's coastline (Figure 10.1). The segments were established in approximately 1-degree latitudinal bins,

plus the Channel Islands, and included assessment of the full water column that overlays the shelf, defined as between the 15-m and 200-m bathymetric contours.

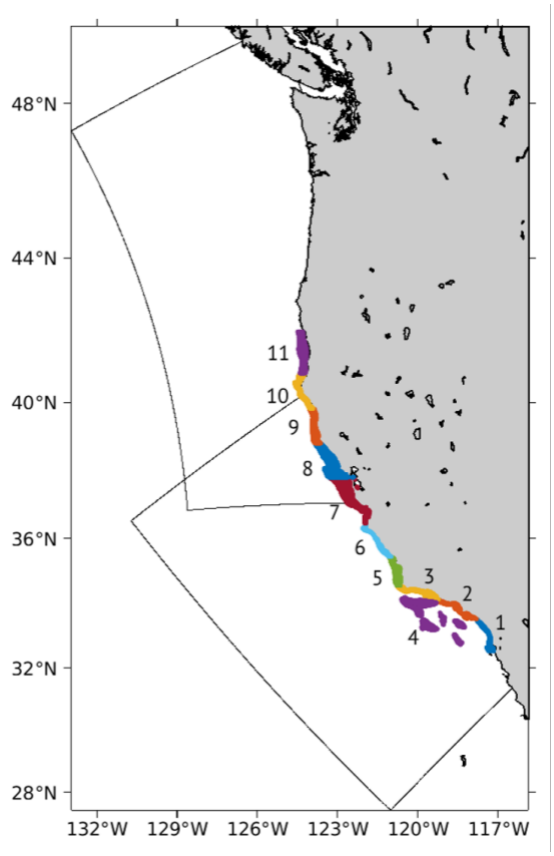

Figure 10.1. Map showing the 1-degree segments used to bin annual status.

The segment-level annual metric was the average amount of corrosive water (as a percent), which was then compared to pre-industrial estimates to obtain a status. Since pre-industrial measurements are not available, they were reconstructed from algorithms that estimate the increase in DIC due to ocean uptake of anthropogenic CO_2 [46]. The pre-industrial estimates of corrosive volumes were estimated for four major regions (Table 10.1).

Table 10.1. Pre-industrial estimates of average annual corrosive conditions.

Region	Pre-industrial % Corrosive Volume
N. California (R8–R11)	3.8
C. California (R5–R7)	2.4
Channel Islands (R4)	1.7
S. California (R1–R3)	1.5

Trend

To explore trends in OA conditions over time, observations from oceanographic buoys were used to assess surface conditions from year to year. Ω_{arag} was calculated from measurements of pCO2, SST, and SSS collected at the Pt. Conception (34.324°N, 120.814°W) and Southern California Current (33.5°N, 122.5°W) moorings. Measurements are taken every 3 hours by moored autonomous pCO2 instruments and Sea-Bird Electronics (SBE) SeaCATs deployed on the surface buoys [47]. In all calculations of Ω_{arag}, PyCO2SYS was used [48] with the carbonic acid dissociation constants of Lueker et al. [49], sulfate dissociation constants of Dickson [50], borate-to-salinity ratio of Uppström [51], and average surface ocean phosphate and silicate concentrations from the World Ocean Atlas [52]. To calculate Ω_{arag}, two carbonate system parameters were used: pCO_2 observations and total alkalinity (AT) estimated from sea surface salinity (Cape Arago [53], Pt. Conception and Southern California Current [54], OCNMS [55]).

To estimate preindustrial Ω_{arag}, researchers used pCO_2 and AT with the following assumptions to adjust present-day observed pCO_2 and SST: (1) seawater pCO2 has increased at the same rate as xCO_2 in the atmosphere, and (2) SST has warmed 0.5°C [56]. This also assumes that small changes in SSS, AT, phosphate, or silicate since the preindustrial era do not have a significant impact on calculated Ω_{arag}. These changes were applied to the monthly mean and range of present-day observations and used PyCO2SYS to calculate preindustrial Ω_{arag}.

Results

Status

From 2008 to 2017, California waters between 15 and 200m depth experienced an average volume of 19.2% corrosive water compared to 2.35% in the pre-industrial era. From the time series of corrosive waters by region (Figure 10.2), researchers calculated the annual average corrosive volume for each segment (Figure 10.1) relative to pre-industrial estimates provided in Table 2. Since model outputs were not yet available for 2024, the current status for OA is estimated from a 10-year average (2008-2017). This period encompassed a range of ocean climate states, including strong upwelling years that transition to a marine heatwave lasting multiple years, and provides an estimate of the current status of OA in California, despite not being resolved for 2024. Table 10.2 provides the average percent of corrosive volume by segment from that 10-year period.

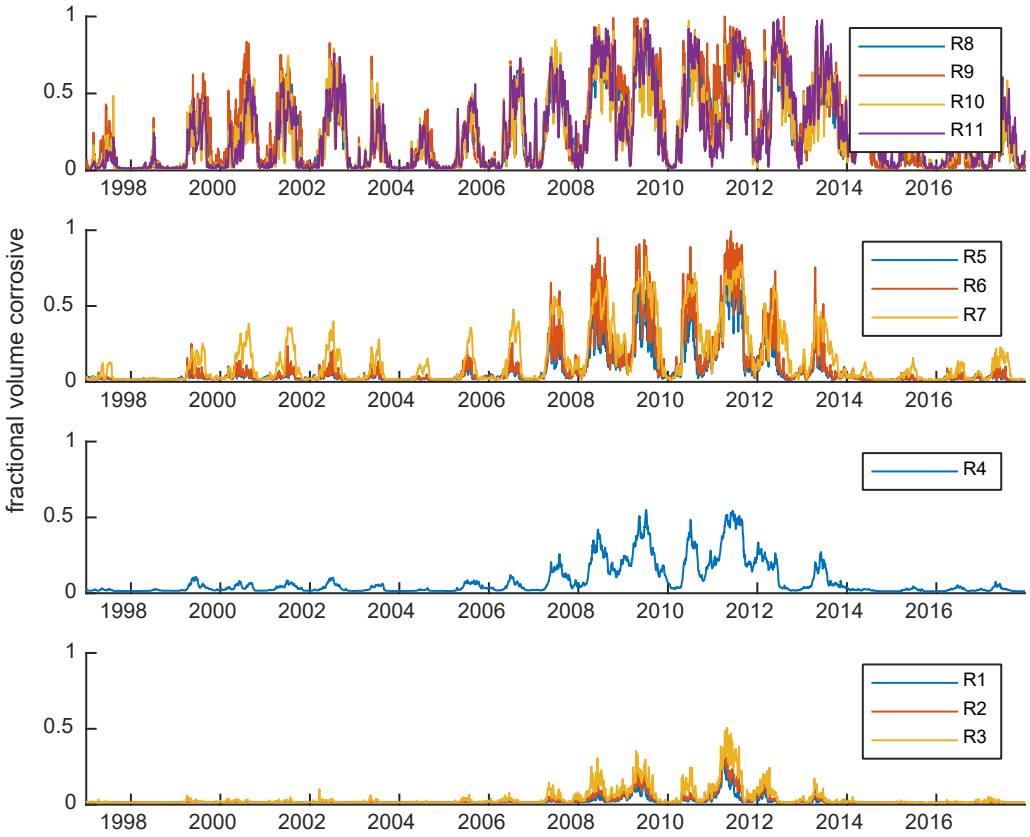

Figure 10.2. The amount of corrosive water (as a percent of the total volume of water) on the shelf for each region: southern California (R1–R3), Channel Islands (R4), Central California (R5–R7); and northern California (R8–R11). Daily corrosive volume estimated from ROMS-BEC model outputs was averaged across the years 1997–2017.

Table 10.2. The average segment-level percent corrosive volume values (status metric) for 2008–2017. Daily values were first averaged across each year. Segment numbers correspond with those shown in the map in Figure 10.1.

Segment #	Region	% Corrosive Volume (average 2008–2017)
11	N. CA	36
10	N. CA	32.5
9	N. CA	35.7
8	N. CA	30.8
7	C. CA	21.4
6	C. CA	16.9
5	C. CA	12
3	S. CA	6.3
2	S. CA	4
1	S. CA	3
4	Channel Islands	12.6
	Statewide Average	**20**

As seen through the cyclical nature of corrosive water (Figure 10.3), there is both seasonal and temporal variability in the corrosive volume on the shelf. These trends are likely explained by a combination of upwelling dynamics and shelf processes. Across California, prevailing winds are upwelling-favorable during the spring and summer, a process that supplies the shelf with deep water masses that are rich in pCO_2 and nutrients. The nutrients fuel productivity and eventually contribute to a respiration signal (high CO_2). A combination of retention and respiration modifies shelf water chemistry, which is reflected in changes in corrosive volume (Figure 10.3). As the upwelling season begins, the corrosive volume increases and then peaks in the summer. In the winter months, a transition to downwelling favorable winds occurs across Northern and Central California, which results in a decline in corrosive volume across the shelf. Upwelling favorable winds

are strongest in the Northern portion of the state, and are weakest in Southern California, which also does not experience the same transition to downwelling conditions in the winter months.

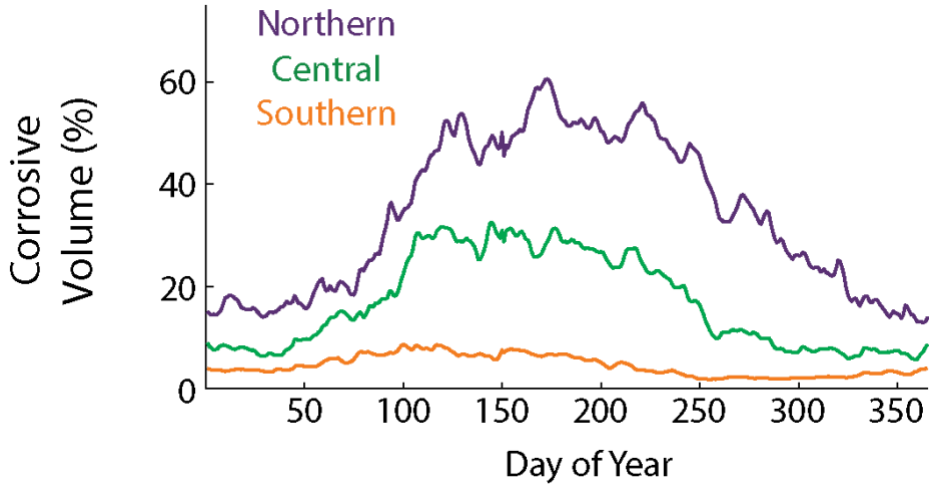

Figure 10.3. Average amount of corrosive water (percent) by region (averaging segments within a region) over a year.

Trend

Marine life experienced conditions beyond those in pre-industrial times in surface waters near Point Conception during 19% of the 2010-2025 observing record (Figure 10.4). During 2025, measured seawater chemical conditions fell outside of pre-industrial conditions for 20% of the year near Pt. Conception, and 100% of the time further offshore in the California current. It is noteworthy that 2017, the model year used to assess status, was a relatively good year in the Pt. Conception data record compared to 2025, with far fewer days when conditions fell outside pre-industrial conditions.

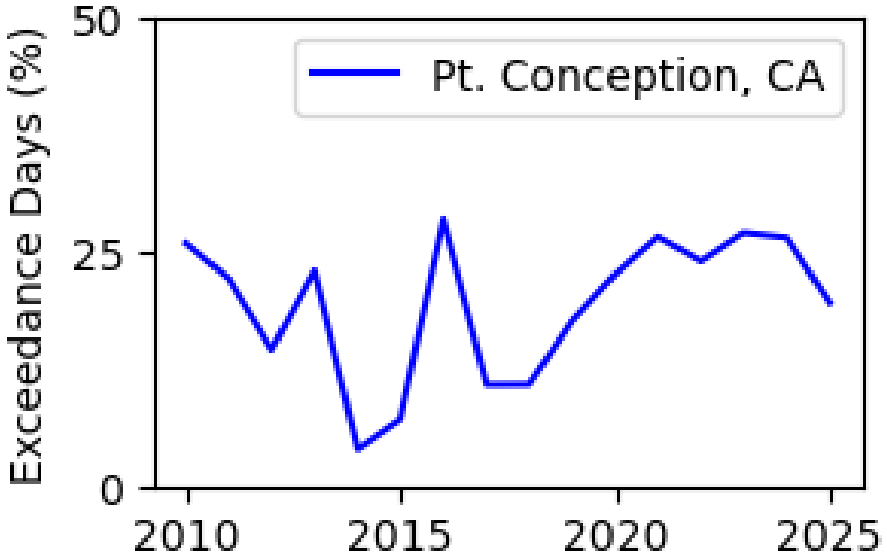

Figure 10.4. Estimates of pre-industrial Ω_{arag} are compared to modern-day values and the percentage of observation days exceeding pre-industrial conditions are calculated annually beginning in 2010 for the Point Conception buoy.

Discussion

This analysis revealed several strengths and challenges with developing a comprehensive statewide status for ocean acidification. Ocean acidification is a result of global climate change processes, regional oceanographic and shelf processes, and can be influenced by land-based nutrient inputs. The focus of this evaluation was to understand the ocean acidification signal and its potential effect on biological organisms in the coastal shelf waters of California.

Model outputs provide a spatially continuous and robust estimate of carbonate chemistry along the California coast, and by employing algorithms to model data (e.g. [46]) we can estimate a change since the beginning of the industrial era. Outputs also capture the importance of regional oceanographic processes such as upwelling, which exerts a significant seasonal effect on carbonate chemistry. However, the results presented in this analysis are from 2008-2017 model outputs, which represent the most recent decade of available model output data for the California coast. 2017 was a relatively good year in the Point Conception data record compared to 2025, underscoring strong temporal variation and the need to look across time. Future evaluations could build upon this work and include nearshore conditions and land-based inputs. Since the state has invested significant funds in incorporating land-based inputs for the Southern California Bight and the central coast, and because equivalent model data for Northern California were not available at the time of this analysis, there are opportunities to expand on this work in future iterations.

Continued and enhanced use of models to assess statewide acidification will require ongoing support from the state.

Developing a trend for ocean acidification also revealed several strengths and challenges. The trend data presented come from two primarily federally funded buoys, selected for their location, instrumentation, and access to data. One buoy is located offshore where it constrains Southern California Current conditions, and the other is located on the coastal shelf off Pt. Conception in the coastal upwelling regime. These buoys were also selected because they use highly precise and accurate measurements and follow rigorous quality control protocols. Both buoys are in the southern half of the state, significantly limiting the spatial coverage of the data used to develop the ocean acidification trend. Additional coastal buoys in the northern part of the state would bolster trend analysis. Further, installation and maintenance of moored sensors on buoys located further nearshore and/or models could be used to evaluate nearshore conditions and terrestrial inputs. Sustained support for existing buoys and further investment in key updates to existing coastal time series and further investment in key updates to existing models will be necessary to continue to have access to robust information on ocean acidification.

Acknowledgements

This evaluation is based on an approach developed with input from:

Roxanne Carini, University of Washington
Richard Feely, National Oceanic and Atmospheric Association, Pacific Marine Environmental Laboratory
Micah Horwith, Washington State Department of Ecology
Andy Lanier, Oregon Department of Land Conservation and Development
Parker MacCready, University of Washington
Stephen B. Weisberg, Southern California Coastal Water Resources Project
Jilian Xiong, formerly University of Washington

2.11. TIDAL WETLANDS

Over 90% of California's tidal wetlands have been lost since the 1800's, but a precise quantitative evaluation of area lost and quality changes will require coordinated statewide monitoring.

Author

Meghan Zulian, California Ocean Science Trust

Contributors

Kathryn Beheshti, University of California, Santa Barbara
Jeff Crooks, Tijuana River National Estuary Research Reserve
Cristina Grosso, San Francisco Estuary Institute
Pete Kauhanen, San Francisco Estuary Institute
Kevin O'Connor, Moss Landing Marine Laboratories
Melissa Ward, Windward Sciences
Christine Whitcraft, California State University, Long Beach

Executive Summary

California once had over 600,000 acres of tidal wetlands. However, 90% were lost to urban and agricultural development that diked, drained, and filled wetlands to create land and divert freshwater for human uses. Today, there are roughly 113,000 acres of tidal wetland habitats in near-historical condition, and an additional 84,000 acres of managed and muted tidal habitats, some of which are restored. Coastwide differences in the intensity of development have created significant variation between the historical (1800s) and current condition of tidal wetlands. The north coast has lost 53% of its historical tidal wetlands, while the San Francisco Bay Area has lost 83%, the central coast has lost 36%, and the south coast has lost 60%. In the San Francisco Bay Area, the largest losses by percent and area were due to extensive agriculture and urban development. Likewise, development on the south coast led to a lesser decline in the extent of tidal wetlands, but many historically large tidal wetland complexes have been reduced to small, fragmented systems.

Basis of Evaluation

Most tidal wetlands in California are threatened by sea level rise, urban, and agricultural development. The latter processes dike, drain, and fill tidal wetlands to create land and divert freshwater for human uses. The cumulative result of these processes is frequently cited as causing a 90% decline in the extent of tidal wetlands from historical values (1800s). However, the true extent of this number remains unresolved. Acknowledging the plethora of benefits tidal wetlands

provide, and their substantive decline from historical extent, OPC has committed to restoring 1500 acres by 2030 [57].

Given that many restoration and protection targets (e.g., California's 30 x 30 initiative) focus on areas of land restored or protected, acreage was chosen as the metric for the present analysis. Acreage and classification of tidal wetland habitats are also the most comprehensive data sources available at this time. For this analysis, researchers calculated a general estimate of current tidal wetland extent and percent change from historic baseline (1800's) using 1) the California Aquatic Resources Inventory (CARI) in EcoAtlas, which is a synthesis of local and regional mapping efforts throughout the state, and 2) research by Brophy *et al*. [58], which uses present-day digital elevation models and modeled high-water levels to estimate areas where tides could historically reach.

Additionally, to best align with available data, this analysis exclusively examines the extent of *tidal* wetlands. There are many other wetland times along part of the coast, including about 250 seasonally tidal estuary wetlands at the mouths of streams and rivers that close off to the ocean for portions of the year, forming freshwater lagoons (i.e., Carmel, Salinas, Pajaro Rivers). While they may be smaller than other larger perennial tidal systems (SF Bay, Morro Bay, etc.), they have a much wider distribution and form a "chain of pearls" of habitat along the coastline. It is currently too challenging to assess habitat loss in these systems using digital elevation models due to their perched elevation.

Methods

To calculate current (1999-present), statewide tidal wetland extent, researchers used CARI's coastal habitat profile tool to sum total acreage across all coastal regions for all wetland types: forested tidal wetlands, tidal flats and marsh pannes, tidal marsh, and managed and muted tidal wetlands.

To calculate the statewide percent decline in tidal wetland extent from historical values, researchers utilized Brothy *et al*. estimates and cross-referenced these values with those reported in the Goals Project Baylands and Climate Change report (2015) for the San Francisco Bay Area, and the Southern California Wetlands Recovery Project Report (2018) for Southern California. Utilizing values from Brophy *et al*., researchers calculated regional percent decline by summing the historical and current acres for sites in each region (North, San Francisco Bay Area, Central, and Southern California). The sites included are grouped into regions as follows:

- Northern California: Smith River, Humboldt Bay, Eel River, Drakes Estero, Bolinas Lagoon
- San Francisco Bay Area: San Francisco Bay, South San Francisco Bay, San Pablo Bay, Suisun-Grizzly Bays, Sacramento-San Joaquin Delta

- Central California: Elkhorn Slough, Morro Bay
- Southern California: Mugu Lagoon, Alamitos Bay, Anaheim Bay, Newport Bay, Huntington Channel, San Diego Bay, Tijuana River

Though Brophy *et al*. cross-reference results for San Francisco Bay Area sites, researchers wanted to examine statewide comparisons to other datasets. For this, they calculated the percent decline using the historical extent provided by Brophy *et al*. and the current extent for vegetated tidal wetland habitats in CARI (forested tidal wetland, tidal marsh).

Results

According to the California Aquatic Resources Inventory, the current extent of tidal wetlands in California is approximately 113,000 acres of tidal wetland habitats in near-historical condition, including 63,000 acres of tidal marsh, 46,000 acres of tidal flats and marsh pannes, and over 4000 acres of forested tidal wetlands. California has an additional 84,000 acres of managed and muted tidal habitats, some of which are restored.

According to the acreages reported in Brophy *et al*., California has lost 91% of its historical vegetated tidal wetlands. Performing the same calculation with historical extents from Brophy *et al*., and current extents from CARI, results in a statewide decline of 89%, with some variation across regions (Table 11.1). Though comprehensive mapping is not available within each of these regions, the Goals Project Baylands Report has comprehensive estimates for the San Francisco Bay Area, and the Southern California Wetlands Recovery Project has comprehensive estimates for Southern California. Based on historical and current mapping, the Baylands Report estimates the San Francisco Bay Area once had 190,000 acres of tidal marsh, of which just 16,000 acres of the original marsh remain, representing a 92% decline. However, we note that these values do not include other vegetated wetland types (i.e., forested tidal wetlands). Likewise, the Southern California Wetlands Recovery Project estimates that Southern California lost 62% of its tidal wetlands, though again, this value includes all tidal wetland types. In Southern California, the lower estimated tidal wetland extent from Elevation-Based Estuary Extent models relative to historical mapping may be due to the high degree of infill, which can lead to underestimates of historical tidal wetland extent. By contrast, given that the Brophy *et al*. study performed cross-validation with San Francisco Bay Area mapping, the discrepancies between these values may represent the greater proportional loss of tidal marshes compared to other vegetated habitat types.

Table 11.1. Percent decline in wetland area across California coastal regions.

Region	**Percent Decline Brophy *et al.***	**Number of Sites**	**Other sources**
Northern California	53%	5	N/A
San Francisco Bay Area	83%	5	92%*
Central California	36%	2	N/A
Southern California	59%	7	62%*
Statewide	**91%**	**19**	**89%**

Discussion

Both approaches used in this analysis had strengths and limitations. The strengths of the Brophy *et al*. study are that it has better geographic coverage of historical extent than the mapping efforts included in the Historical Aquatic Resource Inventory in EcoAtlas, uses the same mapping methodology at each site across the state, includes sites in northern California, and evaluates each site at the same point in time. Some limitations of this method are that it only measures change in vegetated tidal wetlands, and it does not consider managed and muted tidal wetlands in the values it reports, despite this classification making up the majority of wetlands statewide. Additionally, elevation-based models are less accurate than historical mapping in locations where there is extensive infill of wetlands, though there is 95% agreement with the Historical Ecology mapping in the San Francisco Bay Area. Contrasting the Brophy *et al*., 2019 study, CARI has more locally accurate mapping and includes a broader range of tidal habitats (i.e., unvegetated, managed and muted). Its main disadvantages are that the maps within the database were produced at different times and using different methodologies, making it challenging to synthesize information at the statewide level. The database also does not contain any maps from Northern California.

Attempting to calculate wetland extent and percent decline at the statewide level revealed several data gaps and highlighted opportunities presented by new technology. The values for wetland extent and percent decline provided here are only rough estimates because maps of wetland extent across the state come from different time intervals and use different methods. To date, it has not been possible to address these gaps as on the ground, or even drone mapping is a time-intensive and costly process. The use of lidar digital elevation models (DEMs) and water level

models to create Elevation-Based Estuary Extent Models (EBEEM) presents a more feasible opportunity to conduct mapping at regular, standardized methods. Regular mapping will be necessary to precisely track California's progress toward its acreage restoration targets. However, experts also note that the percent of area eligible for restoration is an excellent, alternative forward-looking, area-based metric, that could be utilized if more comprehensive data were available. Additionally, while it makes sense to use acreage (extent) as a metric given California's restoration targets, it is worth acknowledging the drawbacks of acreage-based metrics. Restoring is not equivalent to restoring ecosystem function, which is necessary to provide many of the ecosystem services wetlands provide. Future iterations of this analysis may consider a metric that integrates wetland condition and extent, such as the California Rapid Assessment Method for Wetlands (i.e., CRAM [59]).

Source Data

- Brophy, Laura S., et al. 2019. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. PLOS ONE, vol. 14, no. 8. https://doi.org/10.1371/journal.pone.0218558.
- San Francisco Estuary Institute (SFEI). 2025. "California Aquatic Resource Inventory (CARI) version 3.2." Accessed [date retrieved]. https://www.sfei.org/data/california-aquatic-resource-inventory-cari-version-32-gis-data
- Southern California Wetlands Recovery Project. 2018. Wetlands on the Edge Regional Strategy, *The Future of Southern California's Wetlands*.
- Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015 prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

Target-Based Evaluations

These categories were evaluated based on the percentage of units (e.g., sampling sites, area) that meet a management target. Statewide scores are the percentages of units.

2.12. BEACH WATER QUALITY

81% of monitored sites met regulatory standards for safe water quality. The remaining sites above the regulatory limit are mostly in known problem areas, like storm drains or at enclosed beaches with poor circulation.

Authors

Naomi Meurice, Heal the Bay
Annelisa Moe, Heal the Bay
Tanner Waters, California Ocean Science Trust
Stephen B. Weisberg, Southern California Coastal Water Research Project

Working Group Members

Alexandria Boehm, Stanford University
Christina Frieder, Southern California Coastal Water Research Project
Luke Ginger, California State Water Resources Control Board
John Griffith, Southern California Coastal Water Research Project
Larry Honeybourne, Retired, County of Orange Health Care Agency
Kyla Kelly, California Ocean Protection Council
Josh Steele, Southern California Coastal Water Research Project

Executive Summary

The status of beach water quality was evaluated using bacterial exceedance rates derived from summer-season monitoring at 552 sites statewide. In 2024, California had a statewide average exceedance rate of 7%. Approximately half of the sites had excellent water quality similar to sites with minimal to no pollution influence. However, 19% of sites exceeded the state's regulatory limit. These higher exceedance rates are typically highly localized, such as sites immediately next to storm drains, and water quality often substantially improves a short distance from these sources. There is no long-term statewide trend in water quality, though in the past two years there were slightly elevated exceedance rates due to intense rainfall. As climate change continues to impact

precipitation patterns in the state, more intense storms and greater variability in rainfall may lead to worsening beach water quality.

Basis of Evaluation

The working group used this place-based approach to describe the status of beach water quality, evaluating each location based on concentrations of *Enterococcus* bacteria species. Since 1997, California has required testing for fecal indicator bacteria (FIB) weekly from April 1 to October 31 at all beaches with 50,000 or more annual visitors. Given this extensive monitoring history, the working group used FIB data as the metric for the beach water quality indicator. While the presence of FIB themselves does not usually cause illness in humans, they indicate potential presence of pathogens within the water that do pose health risks to humans. Among the available FIB, enterococci concentration was the most appropriate metric, as enterococci measurements have the greatest positive association among the FIB between concentrations and gastrointestinal illness among swimmers, making them appropriate indicators for public health concerns [57]. Additionally, in 2022, San Diego County became the first approved coastal county in the nation to use droplet digital polymerase chain reaction (ddPCR) to measure *Enterococcus* bacteria for beach water quality testing. This method is faster and more sensitive and can be calibrated to the culture-based methods used in other locations, but with it, San Diego County can only measure *Enterococcus*. To enable the inclusion of San Diego County data, the working group chose to use *Enterococcus* species measurements for the beach water quality indicator.

A wide range of contaminants could be considered indicators of beach water quality, such as nutrients, metals, or viruses. However, most of these do not have recreational water quality standards nor consistent and widespread monitoring, making them inappropriate metrics for evaluating statewide beach water quality. As monitoring improves, more contaminants could be included.

Methods

Status

The metric for beach water quality is based on concentrations of *Enterococcus* species relative to established thresholds for human health. This evaluation uses a target-based approach, where each water quality monitoring site was individually scored based on how *Enterococcus* concentrations there compared to regulatory thresholds. The overall state score is an average of these scores.

The working group used the Heal the Bay fecal indicator bacteria database, which is a compilation of county-reported beach water quality monitoring data. The database contains all reported data from 1997 to present.

First, the dataset was preprocessed to ensure comparability and to standardize the sites. Site data was filtered to include only the summer season (April 1- October 31, as defined by the state law requiring water quality monitoring), which spans 31 weeks and coincides with peak recreational use across the state. To ensure sufficient sampling frequency for this analysis, sites with fewer than 10 sampling events during the summer season were excluded from the data set. After this filtering, the final data included 552 sites across California. Some individual beaches were represented by more than one sampling location.

This dataset contains the enterococci concentrations measured at each site on each sampling date. These measurements were compared to the recreational water quality standards set forth by the US EPA, which developed these recommendations to protect public health and inform beach management decisions. Enterococci thresholds are defined as follows:

- Culture-Based Method: 104 coliform forming units (cfu) / 100 milliliters (mL) of sample
- ddPCR Method: 1413 DNA copies / 100 mL of sample

Based on these standards, each sample was classified as either an "exceedance" or a "non-exceedance." For each site, exceedance rates were calculated as the ratio of samples that exceeded enterococci concentration thresholds to the total number of samples taken. The statewide exceedance rate for 2024 was the average of all site-level exceedance rates.

Fecal indicator bacteria occur naturally at low concentrations due to contamination from wildlife waste, even at undeveloped beaches subject to minimal human impact. Thus, to place these exceedance rates into context compared to naturally occurring exceedance rates, the working group calculated the background exceedance rate for reference beaches. Reference beaches were defined in alignment with the California Stream Condition Index [58] as locations with <3% agricultural development, <3% urban development, or <5% combined agricultural and urban development. The working group applied an additional exclusion criterion based on known site conditions. For example, five sites on Catalina Island at Avalon Beach were removed for elevated bacteria levels that are linked to human impacts. Site data was processed and filtered as described above. For the upper bounds, a 10% monthly statistical threshold value was set as the regulatory limit for exceedance rate (Table 12.1).

Trend

Trend was calculated by employing the same methods as status calculation. To ensure comparability over time, trend analysis was restricted to 2003-2024 when the State's sampling methodology became more consistent in number of sites sampled, frequency of sampling, and

location of sites. The annual average exceedance rates were plotted over time, and a linear regression was used to test for directional trends in statewide beach water quality.

Results

Status

The working group's analysis of historical data from reference beaches showed an average enterococci exceedance rate of 2.5% (SD: 4.0%; median 0%; 95% CI 2.1 - 2.9%). For the upper limit, the State Water Resources Control Board's Water Quality Control Plan for Ocean Waters of California identifies that enterococci sampling should not exceed the enterococci health standard in more than 10% of samples collected within a month before a beach is considered out of compliance. As such, the working group set 2.5% as the lower limit of natural exceedance rates and 10% as the upper limit of exceeding regulatory safety limits (Table 12.1).

In 2024, the average exceedance rate in California was 7%. Statewide, 50.2% of sites had the same, or better, pristine water quality as reference sites, 30.8% were within the limit, and 19% fell above the regulatory limit (Table 12.1, Figure 12.1). While 19% of sites above 10% exceedance rates is relatively high, this number likely overestimates the actual proportion of locations with poor water quality, because areas of known poor water quality are sampled more frequently, precisely because they are problem areas (e.g., beaches adjacent to storm drains).

Table 12.1. Categories of beach water quality exceedance rates and number of sites in each category.

Category	Exceedance Rate	Description	Site Count (%)
At or Below Reference Value	0-2.5%	Consistently safe water quality, comparable to reference or near-pristine conditions, indicating minimal human influence.	277 (50.2%)
Within Limit	>2.5-10%	Safe water quality that is less than the 10% regulatory limit but higher than reference beach conditions.	113 (30.8%)
Above Regulatory Limit	>10%	Water quality exceeds the 10% regulatory limit, indicating a higher frequency of unsafe conditions and reduced public health protection.	195 (19%)

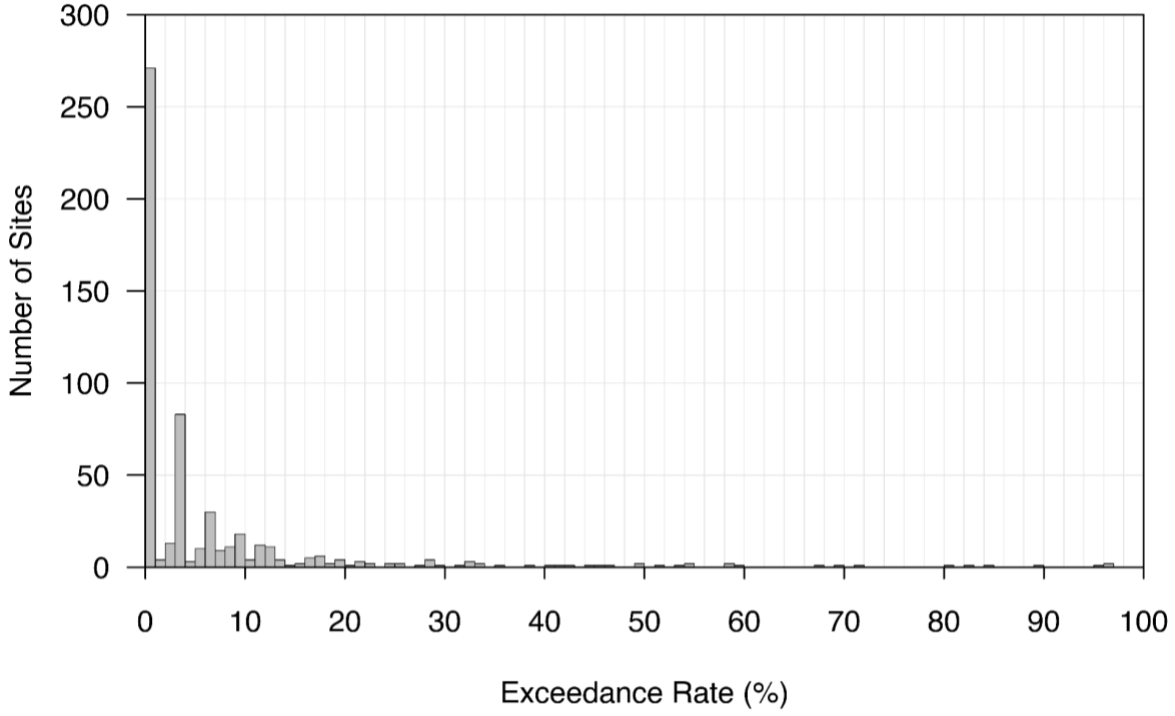

Figure 12.1. Exceedance rates across sites in 2024.

Trends

Over the period of 2003-2024, the annual statewide mean exceedance rate ranged from 2.7% to 8.6% (Figure 12.2). There was no linear trend in statewide exceedance rates across the 22 years (p=0.51). Average exceedance rates in 2023 and 2024 were relatively higher, likely due to heavy rains during this time period. Heavy precipitation causes water quality to temporarily worsen.

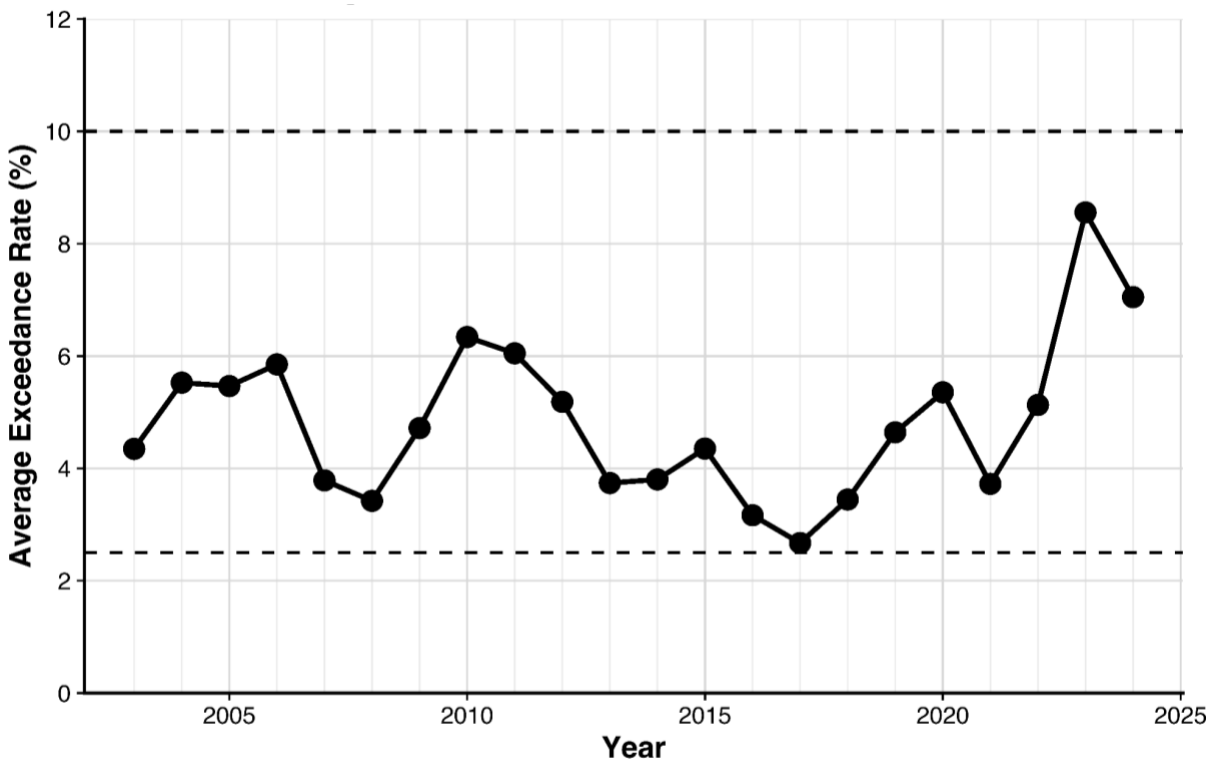

Figure 12.2. California's annual average exceedance rate from 2003-2024. The upper dotted line marks the 10% regulatory limit and the lower dotted line marks the 2.5% reference site exceedance rate.

Discussion

California's beach water quality results indicate that most beaches continue to provide safe conditions for recreation and public health, with half of monitored sites exhibiting exceedance rates at or below near-pristine conditions. The right-skewed distribution of the graph (Figure 12.1) reflects that, while many beaches rarely exceed health standards, a subset of locations greatly exceed the regulatory limit. Importantly, these sites are often intentionally monitored because they are known problem areas, such as beaches next to storm drains, river mouths, or in enclosed bays. The spatial arrangement of sites with low and high exceedance rates also demonstrates that these sites are often in proximity to one another. In many cases, moving 50-100m away from a site with high exceedance rates can result in markedly improved water quality. Over the past two decades, there has been no significant trend in water quality changes, indicating overall stability in statewide beach water quality. However, as climate change continues to impact precipitation patterns in the state, more intense storms and greater variability in rainfall may correspond to elevated exceedance rates across the state.

Source Data

The beach water quality indicator used *Enterococcus* measurements compiled in the Heal the Bay fecal indicator bacteria database. This database is a compilation of county-reported monitoring results. This includes results reported to the State Water Resources Control Board Beach Monitoring database, as well as additional results collected in compliance with local discharge permits, which are reported to Heal the Bay directly. Results within this database are primarily from culture-based testing, but additional ddPCR testing results are included starting in May 2022 when testing with that method began in San Diego.

2.13. COASTAL ACCESS

55% percent of the ocean shoreline is within walking distance of a public access point, and this number has been steadily increasing over time. Most (89%) of public coastal access points have at least one amenity (parking, restrooms, accessibility improvements) that improves the quality of how people access the ocean.

Author

Laura Bliss, West Coast Ocean Data Portal

Working Group Members

Linda Locklin, California Coastal Commission

Stephen B. Weisberg, SCCWRP

Executive Summary

The status of ocean access was assessed as the percentage of open ocean coastline within walking distance of a physical access point, such as parking lots, stairwells, and park entries. This analysis excluded San Francisco Bay and parts of the coastline that are inaccessible because of military use, conservation easements, or steep cliffs. In 2024, 55% of California's ocean coastline was physically accessible to the public. There was greater access in the more populated parts of the state, Southern and Central California, and lower access in Northern California, in part reflecting more inaccessible geomorphology in the north. Statewide, ocean access has increased since the formation of the California Coastal Commission in 1976 and its first formal access survey in 1981. Eighty-nine percent of ocean access points have at least one of the three amenities that improve how the public accesses the coast: parking, restrooms, or accessibility improvements, such as wheelchair-accessible bathrooms. This analysis defined ocean access as physical access, but future

analyses could include visual access, such as coastal parks and blufftop trails, which have well-documented benefits. Limitations on data types and availability led to the exclusion of the San Francisco Bay Area, underscoring the need for an authoritative, comprehensive, statewide coastal land use dataset to evaluate public access to the ocean.

Basis of Evaluation

The working group used a target-based approach to describe the status of coastal access, with the management goal of 100% of public coastline being within walking distance of a physical access point. Publicly accessible shorelines were defined as areas within walking distance, ¼ mile, of a public access point. One-quarter mile is generally considered the distance Americans are willing to walk to reach an outdoor facility [62-64]. Using a larger walking distance would increase the percentage of the California ocean shoreline that is publicly accessible. In addition to physical access, public amenities make the ocean shoreline more available to a broader population. Parking, restrooms, and trash cans have been identified as amenities that improve meaningful access for beachgoers [64]. This analysis did not include parts of the coast that are only accessible by boat or that provide only visual access, such as coastal parks.

Methods

The metric for coastal access is based on the percent of public coastline being within walking distance of a physical access point. This evaluation uses a target-based approach, where each site is scored based on whether it meets the management criteria, and the overall state score is an average of individual scores.

This assessment was based on data from the California Coastal Access Inventory, maps of the California Coastal Trail, and California State Parks databases. This analysis does not include San Francisco Bay or other bays and inlets. The trend shows how the number of access points has changed from 1981 to 2024. The equity category includes further detail regarding the proximity of disadvantaged communities to coastal access points.

There were three steps to estimate the percentage of California’s ocean shoreline that is accessible to the public: (1) delineate the linear representation of California's ocean shoreline, (2) identify all public access points and calculate the amount of shoreline within walking distance, and (3) classify access points with respect to facilities.

Shoreline length was calculated using NOAA’s Environmental Sensitivity Index (ESI) data. Shoreline type (e.g., gravel beaches, coarse-grained sand, riprap) and inaccessible geomorphology, such as cliffs, were identified using the NOAA ESI shoreline descriptions. Military land along the shoreline was identified from the California Department of Transportation, the National Transportation Atlas

Database, and the California Military Land Use Compatibility Analyst. This analysis includes only ocean-facing coastline, excluding islands, harbors, bays, man-made structures, and estuaries.

Access points were identified from the California Coastal Commission's Coastal Access Inventory, spatial data of the California Coastal Trail, and State Parks inventories of parking lots and entry points. Then, the entire shoreline of California was classified as either:

- Public ocean shoreline that is physically accessible to the public, i.e., within ¼ mile of an access point;
- Not open to the public, which included inaccessible geomorphology, military lands, and other uses such as conservation easements, reserves, and storm damage; and
- Public ocean shoreline that is not accessible due to a lack of nearby access points or private property.

Finally, each public access point was assessed based on the presence of basic support facilities: restrooms, parking, and accessibility improvements (e.g., wheelchair-friendly restroom stalls), using data from the California Coastal Commission's access site inventory.

Status

The status of statewide ocean access was assessed by calculating the percent of the eligible public ocean shoreline (total shoreline less inaccessible/military/conservation land use) that is within ¼ mile of a public access point. Sections of the coast that are accessible only by boat or by viewing, such as a coastal park that is not on the beach, were not included.

Trends

Trends were calculated as the change in the number of sites, natural resource sites, and parks with ocean access managed by the California Coastal Commission since its first formal survey in 1981.

Results

Status

Approximately 39% of California's total ocean shoreline is physically accessible to the public, 29% is not open to the public (inaccessible geomorphology, etc.), and 32% is public shoreline that is not accessible to the public due to a lack of nearby access points.

Status was calculated by the percentage of physically accessible ocean shoreline (39%) divided by the total possible available shoreline (100-29% or 71%). Thus, ocean access status is 55% of the eligible public shoreline is within walking distance of a public access point. Ocean access is greater in more populated areas: 77% of the shoreline in Southern California, 73% in Central California,

and 53% in Northern California is accessible to the public, and the more populous counties also have the greatest percentage of publicly accessible ocean shoreline (Table 13.1).

The San Francisco shoreline was not included in this analysis due to differences in data type and availability. About 20% of the state's population lives in the San Francisco Bay Area, and regional governments have invested in the San Francisco Bay Trail and San Francisco Bay Area Water Trail as an important network of ocean access locations for residents and visitors.

Table 13.1: Percentage of publicly accessible shoreline and population by county.

California County	Publicly Accessible Shoreline	2024 Population
Orange County	81%	3,170,435
Santa Cruz County	74%	262,406
Ventura County	71%	835,427
Los Angeles County	67%	9,757,179
San Francisco County	64%	3,298,799
San Diego County	63%	827,526
San Mateo County	49%	485,375
Sonoma County	48%	742,893
San Luis Obispo County	39%	281,843
Monterey County	35%	436,251
Mendocino County	27%	89,175
Del Norte County	26%	27,009
Santa Barbara County	23%	444,500
Humboldt County	22%	132,380
Marin County	21%	256,400

Eighty-nine percent of California's ocean access points featured at least one of the three key support facilities the researchers assessed: parking, restrooms, or accessibility improvements. The availability of parking was the most common facility, while the primary limiting factor for beach access was the availability of accessibility improvements. Forty-one percent of access points have all three support facilities.

Trends

The number of sites, natural resource sites, and parks with ocean access managed by the California Coastal Commission increased from 938 to 1223 between 1981 and 2024.

Discussion

Public shoreline access varies substantially across the three California regions, primarily due to the state's geomorphological features. Ocean access is highest in Southern California (77%) and lowest in Northern California. Access in Northern California is primarily limited by geomorphology. For example, 50% of Mendocino County in Northern California was inaccessible because of its steep, rugged coastline. By contrast, along the flat coastline of Orange County in Southern California, steep cliffs prevent access to less than 1% of the coastline. Coastal access in Central California is limited by the Amtrak rail line, military land use, and large areas of privately-owned ranching land along the Gaviota Coast.

While this analysis defines ocean access as the parts of the ocean shoreline the public can physically access, "toes in the water," people engage with and benefit from the ocean in numerous ways. Visual enjoyment of coastal views and direct use of the shoreline are other important dimensions of ocean access that are protected by the California Coastal Act. For example, while it does not provide physical access, the San Francisco Bay Trail and San Francisco Bay Area Water Trail are an important network of ocean access locations for residents and visitors. About 20% of the state's population lives in the San Francisco Bay Area and benefits from regional governments' investments in this trail system. Future analyses may consider whether, and how to include visual access.

California's lack of authoritative, comprehensive coastal land use data led to the exclusion of the San Francisco Bay Area, and presented significant challenges in analyzing access on the outer coast. Although the California Coastal Commission has increased its documentation of coastal access with its digital inventory and the YourCoast App, this inventory does not include lateral access opportunities such as street parking or beachfront parking lots. For this evaluation, lateral access opportunities were measured manually by patching together several databases that were not created for that purpose. In contrast, Oregon's public access sites and access through parking lots and trails are digitally documented across the entire coastline every 10 years by the Oregon Coastal Management Program, which aids Oregon's protection of access from future development, and improves its coastal access estimates. California could improve access estimates by supporting the development of comprehensive coastal access and coastal land use datasets, which will only become more valuable in the context of climate change.

Source Data

- California Coastal Access Inventory from the California Coastal Commission
- California Coastal Trail, Beach or Shoreline Access from the California Coastal Commission

- California State Park Entry Points from the California Natural Resources Agency
- California State Park Parking Lots from the California Natural Resources Agency
- Shoreline Linear Length and Sediment Type from CDFW and NOAA Office for Coastal Management
- California Reserves and Conservation Easements from the California Conservation Easement Database
- Military Airports from Caltrans
- Military Bases from the National Transportation Atlas Database
- Military Use Zones from the California Military Land Use Compatibility Analyst

The evaluation is supported by the following publication:

Bliss, L.M., Locklin, L., Weisberg, S.B. (2026) Assessing and mapping public access along California's coastline: A spatial analysis for the California Ocean Health Report Card. Shore & Beach *in press*.

Cross-Cutting Evaluations

2.14. OCEAN EQUITY

Disadvantaged communities have disproportionately lower access to the ocean: they are 28% of California's total population, but only 3% of the population within 1 mile of the ocean.

Authors

Kiki Patsch, California State University Channel Islands

Dan R. Reineman, California State University Channel Islands

Katherine Seto, University of California, Santa Cruz

Contributors

Andrés Cisneros-Montemayor, Simon Fraser University and Ocean Nexus

Jill Harris, California Ocean Science Trust

Executive Summary

Ocean equity was evaluated through the lens of distributional equity, meaning who has access to ocean-related benefits and harms. Starting from an assumption that people must be able to physically access the coast in order to fully benefit from it, equity was evaluated by comparing the proportion of the population living in disadvantaged communities (DAC) at walking and short

driving distances from public coastal access points. For this evaluation, DAC are defined as areas of relatively high poverty and unemployment, poor health outcomes, and high ambient pollution. These proportions were then evaluated against scores from four other categories that affect the quality of ocean access: 1) public amenities, as evaluated in the Coastal Access category; 2) Beach Water Quality; 3) Sandy Beaches (eroding or accreting); and 4) Sea Level Rise Planning. In 2024, DAC composed 28% of California's total population, 3% of the population within walking distance of coastal access points, and 21% of the population within short driving distance from coastal access points. Thus, in general, DAC have disproportionately lower access to all coastal areas across California.

- Disadvantaged communities must travel further, on average, to reach the ocean and coast. Even where disadvantaged communities have proportionately more access to quality ocean resources, they still have much lower access compared to non-disadvantaged communities:
- Disadvantaged communities have disproportionately more access to beaches with unsafe or poor water quality.
- Disadvantaged communities have disproportionately higher access to ocean access points not subject to sea level rise planning requirements under SB 272, such as state parks.
- Disadvantaged communities have lower access to beaches in general across California. However, of the beaches accessed by disadvantaged communities, more of those beaches are widening than eroding.

Basis of Evaluation

Equity, as applied here, is a multifaceted concept that emerged from the environmental justice movement and focuses on the distribution of ocean-related benefits and harms. It intersects with many other dimensions of equity, including Indigenous rights and stewardship. The Ocean Protection Council defines equity as fairness of outcomes for all groups, where no one factor, such as race or gender, can be used to predict outcomes. Ocean equity, in a fuller sense, includes three dimensions:

- *Distributional equity:* ensuring that the benefits and costs of ocean resources are distributed according to people's needs;
- *Recognitional equity:* acknowledging diverse cultural values and histories in the management of the coast and ocean; and
- *Procedural equity:* establishing inclusive processes and decision-making.

As the first known attempt to quantitatively evaluate ocean equity in California, this analysis addresses only the distributional equity of who has access to ocean and coastal benefits and harms.

Several conceptual frameworks for evaluating ocean equity were considered in developing this evaluation. One framework was the Biden Administration's federal Ocean Justice Strategy, which focused on distributional equity and environmental justice around the use of the ocean for economic, cultural, spiritual, recreational, and food purposes [65]. The strategy was a guide for entities to develop their own methods to evaluate equity and did not include any metrics or ways to assess these components. Another framework is the former federal Environmental Justice Scorecard [66], which was a compilation of snapshots about how federal agencies were implementing the Justice40 initiative to have 40% of benefits from federal investments go to disadvantaged communities, but this scorecard similarly did not include scoring.

In California, several state environmental agencies publish data related to environmental equity, but there is no evaluation associated with the data. The Coastal Commission focuses on some aspects of procedural equity in measuring engagement (e.g., materials translated into multiple languages) and distributional equity in funding (e.g., % of projects located in disadvantaged communities). The Water Board publishes demographics of communities that benefit from funding to improve water quality and that live near polluted waters identified in the Integrated Report. It also tracks engagement of community, Tribal, and BIPOC groups in decision-making and the translation of official materials into multiple languages.

Outside of California, the Chesapeake Bay & Watershed Report Card, created by the University of Maryland Center for Environmental Science, is the only coastal or ocean report card in the country that scores equity components. This report card evaluates equity-related indicators in the census tracts surrounding the Bay, including social factors (e.g., social vulnerability index, heat vulnerability, walkability, civic engagement and stewardship) and economic factors (e.g., median household income, income inequality, job growth, housing affordability). The group behind this report card is currently developing a new environmental justice index that will integrate environmental burden. While this report card does score these factors, they are more general social and economic conditions that are not directly related to the health of the Bay itself. To date, no programs have quantitatively evaluated ocean equity on a scale that matches the breadth of topics and geographic scale of this evaluation.

This novel analysis of distributional coastal and ocean equity was founded upon the core assumption that in order to realize the benefits or harms of the ocean and coast, an individual must physically reach the ocean and coast. Thus, this analysis did not consider intangible benefits, such as existence value, or provisioning services, such as seafood and milder microclimates. This analysis focused on the variability in access to ocean and coastal benefits and harms among different groups of people through a spatial lens, i.e., distributional equity.

The working group established the following priorities for data selection:

- Preexisting (novel data collection was outside the scope of the project)
- Statewide (piecemeal datasets were not considered; only those comprehensive of the whole state)
- State-generated and/or vetted (publicly available data created and approved for use in California policy were selected over private, external, federal, or other sources)
- Representative of the best available science
- Repeatable in future assessments and as newer data are released
- Integratable with other categories

Several datasets that meet the above criteria were combined to evaluate the spatial distribution of disadvantaged communities relative to ocean access points: Demographic and socioeconomic data came from the U.S. Census Bureau, including the 2020 Decennial Census and 2016–2020 American Community Survey 5-year estimates. These provided information on population, income, housing, and other community characteristics. Environmental vulnerability data were from CalEnviroScreen 4.0, developed by the Office of Environmental Health Hazard Assessment, which identifies census tracts considered disadvantaged communities (DACs).

These were combined to measure equity of physical access to the ocean and coast, and then further combined with results from four other categories: ocean access amenities, sandy beaches, beach water quality, and sea level rise planning.

Methods

Ocean equity was evaluated using a place-based approach, where each location was evaluated separately, and the overall state score is an average of all locations.

The general approach for the equity indicator was to identify the proportion of people living near public ocean access points who are part of disadvantaged communities, and examine how that proportion compares to the statewide average and how it varies with the quality of ocean benefits and harms at each access point. Disadvantaged communities are defined here as designated by CalEnviroScreen: communities in the 25% highest scoring census tracts in CalEnviroScreen 4.0, census tracts previously identified in the top 25% in CalEnviroScreen 3.0, census tracts with high amounts of pollution and low populations, and federally recognized tribal areas as identified by the Census in the 2021 American Indian Areas Related National Geodatabase.

First, all public beach and pier access points were identified using the Coastal Commission's Public Access Inventory (2024). Each site was linked to the scores for four categories that are spatially

explicit and reflect important aspects of coastal quality and resilience. The scores for each category were grouped to describe the following conditions:

- *Ocean Access Amenities*: High (parking, restrooms, and lifeguards), Medium (parking and restrooms, no lifeguards), Low (no facilities), or Other (partial or unclassified amenities)
- *Beach Water Quality:* the percentage of days when pollutant levels exceeded state health standards, categorized as High (Good to Excellent), Low (Poor to Fair), Unsafe (Very Poor), or No Data (if no monitoring within 0.5 miles of an access point).
- *Sandy Beaches:* Whether the beach at the site is accreting (widening) or eroding (narrowing)
- *Sea Level Rise (SLR) Planning:* Whether the local jurisdiction has completed, started, or not begun planning for SLR in their local coastal program and adaptation plan.

Then, 1-mile (walking distance) and 10-mile (driving distance) zones were delineated around each public beach and pier access point using ArcGIS Pro's Network Analyst tool. The researchers selected access points and associated zones with data for any of the four categories, then dissolved the multiple zones into a single polygon such that the 1-mile polygon includes all areas within 1 mile on California roads of access points meeting the above condition, and the 10-mile polygon includes all areas within 10 miles. Once dissolved, some zones overlapped, which meant that the population-weighted centroids for some census tracts fell into more than one distance band for different indicator conditions.

Within each zone, disadvantaged and non-disadvantaged communities were identified using demographic and environmental vulnerability data. Demographic and socioeconomic data, including total population, income, and home values, came from the 2020 U.S. Census and 2016–2020 American Community Survey 5-year estimates. Disadvantaged communities were identified by measuring environmental vulnerability using CalEnviroScreen 4.0.

For each condition of each category and for the two zone distances, the working group described the proportion of people in that zone who live in DACs compared to the statewide average and to the total population living within all dissolved access zones for that distance band. This comparison showed how the population and DAC proportions for each category condition differed from both the statewide population distribution and the overall population in all access zones. These comparisons help identify whether certain conditions are associated with higher or lower representation of DAC populations relative to broader ocean access patterns.

Results

In 2024, disadvantaged communities were 28% of California's total population, 3% of the population within 1 mile travel distance of ocean access points, and 21% of the population within

10 miles of ocean access points. Thus, in general, DACs had disproportionately lower access to all coastal areas across California.

Ocean Access Amenities

The proportion of DACs was slightly higher near ocean access points with better quality amenities (Table 14.1). While this suggests that meaningful, safe ocean access is proportionally more available to DACs than lower-quality, amenity-free access, the overall level of access is still substantially less than for non-disadvantaged communities. This trend is largely driven by the proximity of disadvantaged communities to large public beaches with amenities in areas around the Los Angeles South Bay, the Ports of Los Angeles and Long Beach, and southern San Diego County.

Table 141. Percent of disadvantaged communities near ocean access points by quality of amenities. Statewide, DACs are 3% of the population within 1 mile and 21% of the population within 10 miles of ocean access points.

Access	**1 mile**	**10 miles**
Overall access (all access points)	3%	21%
Low-quality amenities (no restrooms or parking)	2%	14%
Moderate quality amenities (restrooms and parking)	3%	20%
High-quality amenities (restrooms, parking, and lifeguards)	4%	25%

Beach Water Quality

Disadvantaged communities had slightly less access to areas with high water quality compared to low and unsafe water quality, for both walking (1 mile) and driving (10 miles) distances (Table 14.2). Additionally, 27% of public ocean access points have no water quality testing within 1/2 mile. Typically, water quality monitoring targets areas with known problems, so areas with no water quality data could be safe. However, the absence of testing in these areas raises equity concerns.

Table 14.2. Percent of disadvantaged communities with access to the ocean by level of beach water quality. Statewide, DACs are 3% of the population within 1 mile and 21% of the population within 10 miles of ocean access points.

Beach Water Quality	**1 mile**	**10 miles**
Unsafe water quality (very poor grades)	5%	23%
Low water quality (fair & poor grades)	5%	22%
High water quality (good & excellent grades)	2%	18%
No Data	5%	12%

Beach Size

Disadvantaged communities had slightly more access to beaches that are widening than eroding (Table 14.3). There was a small difference between access to beaches by status, so generally, there is no equity issue with regard to erosional status.

Table 14.3. Percent of disadvantaged communities with access to sandy beaches by widening and eroding status. Statewide, DACs are 3% of the population within 1 mile and 21% of the population within 10 miles of ocean access points.

Beach Size	**1 mile**	**10 miles**
Widening beaches	4%	20%
Eroding beaches	1%	18%
No data	3%	21%

Sea Level Rise Planning

This evaluation included only public coastal access points within city and county jurisdictions and thus subject to SB 272 sea level rise planning requirements. There is no data for areas not subject to SB 272 requirements, such as military land, state and national parks, special districts, and land owned by utilities. In 2024, very few jurisdictions had complete plans for sea level rise adaptation. There were no disadvantaged communities within 1 mile of access points covered by complete sea level rise adaptation plans, but DACs were 35% of the population within 10 miles of those fully-

planned ocean access points (Table 14.4). However, given the limited coverage of complete adaptation plans statewide, this conclusion is not strongly diagnostic.

Table 14.4. Percent of disadvantaged communities with access to public access points covered by sea level rise adaptation plans. Statewide, DACs are 3% of the population within 1 mile and 21% of the population within 10 miles of ocean access points.

Status of Sea Level Rise Adaptation Plans	1 mile	10 miles
Complete	0%	35%
Partial	4%	21%
Not Started	2%	21%
Areas Not Subject to SB 272 Requirements	7%	11%

Discussion

In California, access to the ocean and coast is not equitable. Current inequities are largely rooted in broader geographic trends: while disadvantaged communities make up 28% of California's total population, they are underrepresented among those living nearer to the coast. This uneven distribution directly influences how ocean-related benefits and harms are experienced. As climate change, rising housing costs, and resilience initiatives reshape the coastline, proactive measures are required to ensure that the coast and ocean remain public resources for all. Achieving this may require improved data, targeted infrastructure investment, and inclusive planning frameworks. For example, ensuring that areas with high proportions of DACs are covered by comprehensive sea level rise adaptation plans is an important future opportunity for equity.

This evaluation identified a high proportion of DACs near ocean access points with poor water quality. However, monitoring has demonstrated that water quality is highly variable over short distances. Often, a single beach has both safe and unsafe water quality within 100 yards of each other. One way to improve the equity of beach water quality is to improve signage and public education about where and when it is safe to swim.

The most promising finding from this evaluation is that in Southern California, major public beaches near communities with higher proportions of DACs have more public amenities. Continued work to provide access to, and amenities at, public coastal access points will be a key strategy for ensuring equitable access to the coast and ocean for all Californians. Similarly, as the state continues to

support local municipalities in planning for sea level rise adaptation, early and consistent community engagement ensures that adaptation plans reflect community values and priorities.

As the first quantitative evaluation of coastal and ocean equity in California, several data gaps were identified. While these data gaps do not inherently indicate inequity, they do highlight areas where additional monitoring is necessary to fully understand the distribution of ocean-related benefits and burdens:

- 27% of public access points are not monitored for water quality, because existing water quality monitoring often targets known problem areas
- 7% of coastal access points are in areas not subject to the state's sea level rise planning requirement, and these access points are proximate to DACs at a substantially higher proportion. Some of these areas may be covered by other planning processes, so evaluating their planning status is an important future opportunity.

Identifying local-to-regional trends is particularly valuable in understanding and addressing equity, and statewide evaluations can obscure these finer-scale findings. For example, the statewide evaluation was driven in large part by large DACs in southern California, where beaches are likewise large and widening with robust amenities and consistent water quality data. Finer scale analyses, at city-to-county levels, would likely reveal additional locations of concern.

Future ocean equity evaluations should incorporate additional dimensions of equity to include procedural and recognitional equity. By including other ways that the ocean benefits people, like proximity, food provisioning, and existence value, we can broaden our understanding of access, impacts, and benefits of California's coast and ocean for all Californians.

Acknowledgements

The authors gratefully acknowledge the helpful contributions of Maria Rodriguez, OPC, and members of the OPC Environmental Justice Advisory Board.

Source Data

- 2020 U.S. Census: https://www.census.gov/programs-surveys/decennial-census/decade/2020/2020-census-main.html
- 2016–2020 American Community Survey 5-year estimates: https://www.census.gov/programs-surveys/acs.html
- CalEnviroScreen 4.0: https://oehha.ca.gov/calenviroscreen
- Public ocean access locations, along with infrastructure and amenity information such as restrooms, parking, and lifeguards, were obtained from the California Coastal Commission's

Public Access Inventory: https://experience.arcgis.com/experience/61840fda04474fab9d1b5778740ad1b5

- Beach width data came from USGS shoreline change analyses developed by the sandy beach working group (Section 2.7).
- Sea level rise planning data were compiled by OPC and OST using data from the California Coastal Commission's records on Local Coastal Program updates and other jurisdiction-level adaptation plans (Appendix B).
- Beach water quality data were provided by Heal the Bay and analyzed by the beach water quality working group (Section 2.12).

2.15. OCEAN ECONOMY

The ocean economy contributes more than $50 billion to the economy and supports over 500,000 jobs, accounting for a larger share of GDP and jobs in more rural counties like Del Norte.

Authors

Charlie Colgan, Middlebury Institute for the Blue Economy

Anthony Castelletto, Middlebury Institute for the Blue Economy

Phil King, San Francisco State University

Rosemary Kosaka, National Oceanic and Atmospheric Administration

Contributor

Staci Lewis, California Ocean Protection Council

Executive Summary

California's ocean economy is a pillar of the state's overall economy, contributing $51.3 billion to the GDP and supporting over 500,000 jobs. The ocean economy is dominated by the tourism and shipping sectors, which together account for 89% of ocean-dependent activity. The impact of the ocean economy is strongest in rural coastal counties, where it represents up to 10% of total employment. California's forward-looking transition toward a "blue economy" prioritizes sustainable growth in ocean sectors like offshore wind, aquaculture, and decarbonized shipping to balance economic output with the protection of marine biodiversity. However, the blue economy sector faces escalating risks from climate change, particularly through sea-level rise and beach erosion, which threaten both the $10 billion annual non-market value of coastal recreation and the critical infrastructure of working waterfronts. Addressing these challenges requires an

understanding of natural capital and equitable investment in local adaptation to ensure the ocean remains a sustainable driver of prosperity for all Californians.

Introduction

California's ocean and coastal resources are vital drivers of the state's economy, worth $51.3 billion and employing over 500,000 people.[1] This represents about 2% of the state's total GDP (Figure 15.1), which is larger than the agriculture sector and similar to the ratio at the national level. The ocean economy as a percent of the state's GDP has declined over time because other parts of the economy are growing more rapidly; the ocean economy itself remains strong.

Employment in the ocean economy has grown steadily over the last decade (Figure 15.1): California gained about 100,800 jobs between 2010-2019, and employment in ocean industries has largely recovered from the significant dip during the COVID-19 pandemic. Most of these jobs are in the tourism and recreation sector, and there has been modest growth in the shipping sector. Notably, these employment figures do not include the fishing industry: most commercial fishers are self-employed, so employment figures are not recorded the same way as other industries. In 2023, there were around 3,000 registered commercial fishing vessels and 5,000 licenses.

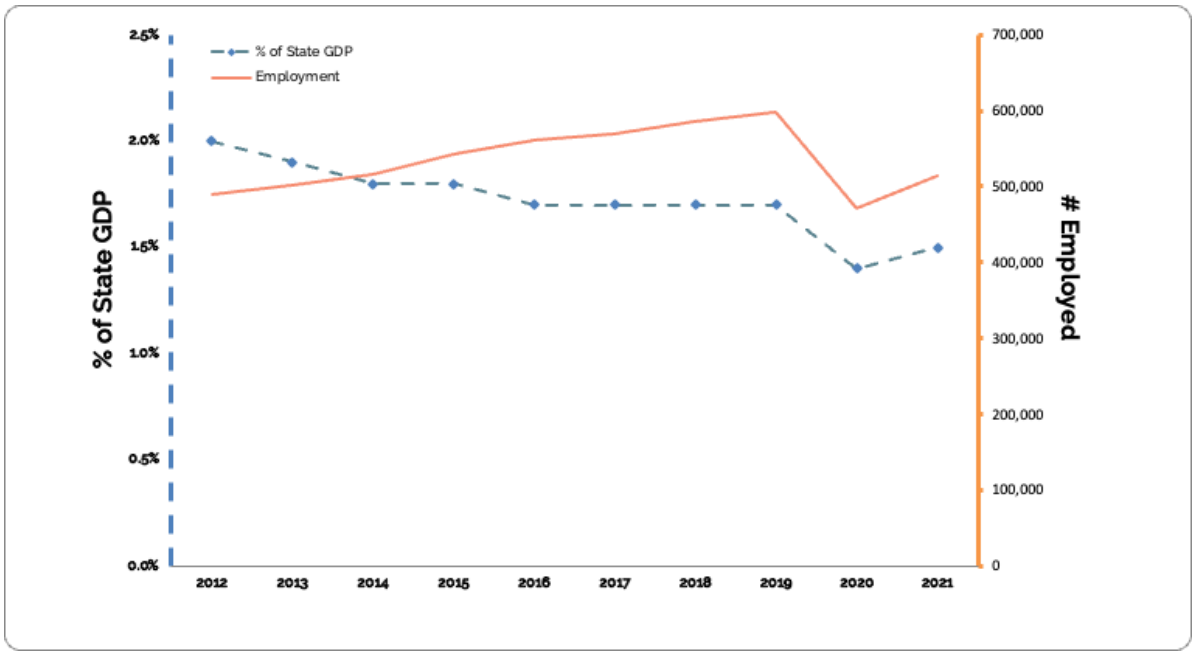

Figure 15.1. Ocean economy over time as a percent of state GDP and as total employment in ocean industries.

[1] 2021 numbers

The ocean economy is a small fraction of the state's total economy, but it plays an outsized role in more rural counties. In Del Norte and San Joaquin counties, around 10% of all jobs rely on the ocean. In Del Norte, Humboldt, San Joaquin, Monterey, and Santa Barbara counties, more than 5% of the total GDP is from the ocean economy (Figure 15.2). Thus, the importance of the ocean economy varies by region. There is no single ocean economy.

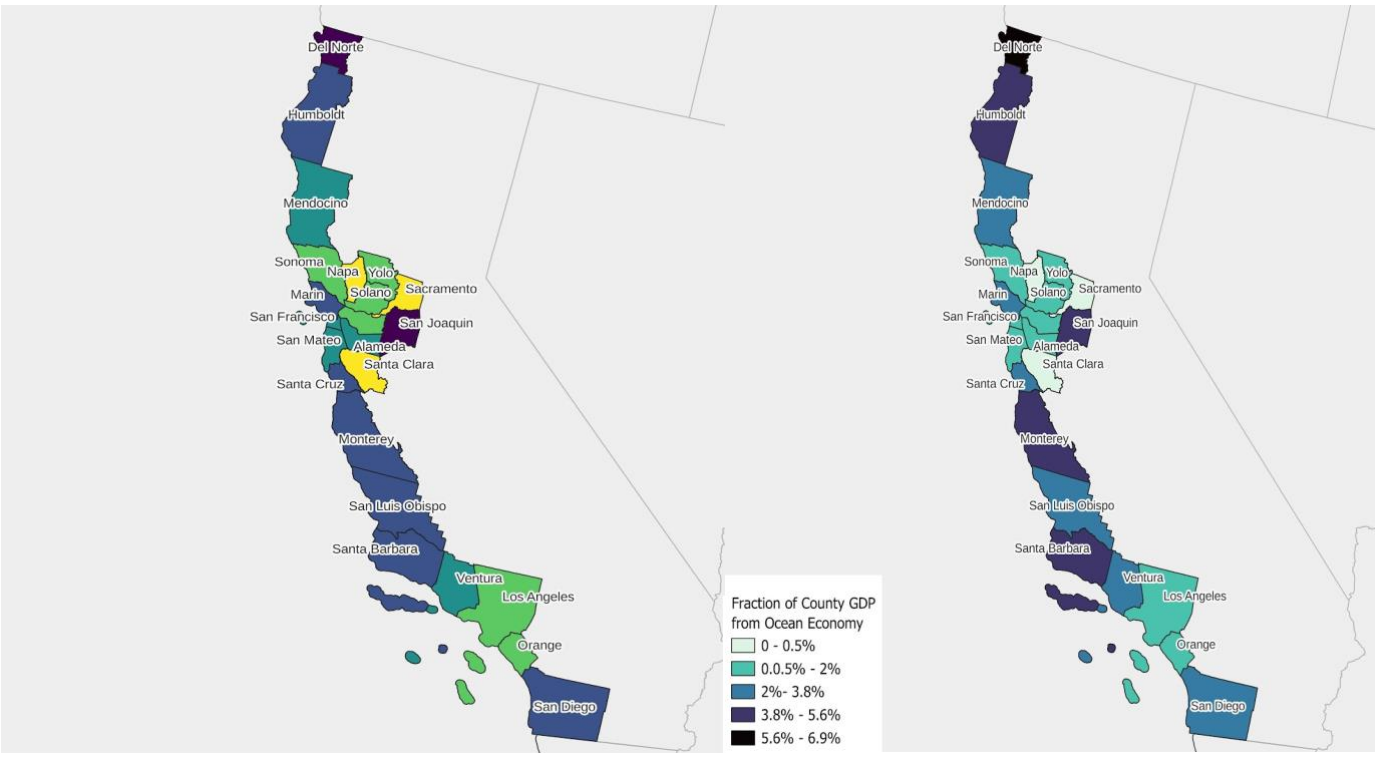

Figure 15.2. Ocean economy as a fraction of the total employment (left) and total GDP (right) in each of 23 coastal counties, including counties bordering San Francisco Bay and the Sacramento-San Joaquin Delta. Total employment colors are yellow (0-0.1%), green (0.1-4%), light blue (4-6%), dark blue (6-9%), purple (9-12%).

For this assessment, ocean economy was defined as economic activities that depend on the coast and ocean, comprising the following sectors:

- Shipping and Marine Transportation
- Tourism and Recreation
- Fisheries and Living Marine Resources
- Mineral Extraction
- Marine Construction
- Shipbuilding
- Marine Research and Education

- Electricity Generation
- Local Government Spending on Coast and Ocean (infrastructure, parks, planning, etc.)

Just two of these sectors, shipping and tourism, together account for 89% of California's ocean economy. These figures underestimate the true value of the ocean to California's economy because they do not include categories such as real estate, where value is driven by proximity to the coast.

California's Blue Economy

In addition to supporting ocean-dependent industries, OPC is committed to supporting a thriving blue economy, which is the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs, all while protecting our state's marine biodiversity, fish, and wildlife. While the terms ocean economy and blue economy are sometimes used interchangeably, here we define the ocean economy to broadly include all ocean-dependent activities and the blue economy to include only those economic activities that promote or protect ocean health.

The blue economy is a small and growing fraction of California's broader ocean economy and includes activities such as sustainable fishing, the shipping industry's efforts to reduce whale strikes and improve air quality around ports, the development of offshore wind energy to reduce reliance on fossil fuels, the development of an aquaculture industry that is compatible with wild fisheries and causes minimal harm to the marine environment, and sustainable tourism activities such as whale watching, diving, and snorkeling. There is debate about the sustainability of these industries, but they are part of the blue economy because they support economic growth while minimizing negative impacts and promoting environmental protection.

How Will Climate Change Impact the Ocean Economy?

California's ocean economy is expected to continue growing even as impacts from climate change continue. Variable impacts on sectors of the ocean and blue economies are anticipated, with economic winners and losers. Impacts include changes in the intensity and frequency of storms (e.g., waterfront infrastructure damage and repair), sea level rise in some areas (e.g., coastal erosion and remediation), and shifts in the distribution of economically important fish stocks (e.g., which species are harvested and where they are landed).

California will lose beaches due to coastal flooding, shoreline change, and cliff retreat. California is projected to lose 24-75% of its beaches by 2100 [67]. Local governments bear the brunt of the cost of beach loss, which includes sand replacement, retention and armoring structures, and the loss of coastal property. Although geologic beach loss does not translate directly to reduced recreational beach use, because people still go to shrinking beaches, smaller beaches will eventually lead to a

loss in tourism revenue for California's coastal communities and a diminishment of the (nonmarket) value of these beaches to the millions of Californians and others who go to our beaches every year, to swim, surf, lay on the sand, picnic and be with family and friends.

Adapting to sea level rises poses high costs to coastal communities, such as ensuring resilient infrastructure for working waterfronts, economic losses from fisheries crises, restoring wetlands to protect habitats and communities, and implementing managed retreat for coastal infrastructure. Highways 1 and 101 are essential transportation and public access corridors for much of coastal California, and much of this iconic road is vulnerable to sea level rise.

The costs of preparing for and responding to sea level rise come with equity considerations. Most of these costs will be borne by local governments, and there is an uneven distribution of wealth across municipalities.

Evaluating the Ocean Economy

Economists have developed other techniques to estimate the value of ocean resources. Non-market value is a way to measure the value of "free" resources such as California's beaches. It takes into account the value beaches provide for things like tourism, quality of life, and property value. The non-market value of all the beaches in San Diego County is over $1 billion per year [68], and could be more than $10 billion per year for the entire state.

Another approach is natural capital accounting, in which ecosystems and the services they provide are valued the same way that physical capital, like buildings, is valued. Investments in ecosystem protection and restoration can be evaluated in terms of returns on investment and contributions to economic growth.

Source Data

- National Ocean Economics Program
- NOAA Digital Coast ENOW (Economics: National Ocean Watch)

Data-Limited Categories

These categories had insufficient statewide data to provide quantitative, statewide evaluations. They are included here as important dimensions of California's coast and ocean, with summaries of existing data and suggestions for building statewide monitoring to enable comprehensive evaluation in the future.

2.16. EELGRASS

Eelgrass was not evaluated quantitatively due to insufficient statewide data.

Eelgrass meadows provide many of the same benefits, and are concentrated in many of the same locations, as tidal wetlands. Large eelgrass meadows are also found throughout the Channel Islands. Eelgrass has declined significantly from its historical extent due to dredging and processes that affect sunlight availability, such as poor water quality from nutrient runoff. However, very limited eelgrass mapping prevents scientists from estimating either the current or historical extent of seagrass meadows with much precision. California has committed to restoring 200 acres of eelgrass by 2030.

2.17. COASTAL FLOODING

Coastal flooding was not evaluated quantitatively due to insufficient statewide data.

Coastal flooding occurs when the ocean spills onto low-elevation coastal areas due to extreme high tides, El Niño events, large waves, or storm surges. Coastal areas also flood due to heavy rainfall, groundwater rise, or overflowing rivers.

The most direct measurement of coastal flooding would be the number of days and the area over which ocean waters spill onto coastal land. This data does not currently exist at the statewide level, though advances in satellite imagery analysis make this a plausible source of data in the near future. Another common measure of coastal flooding is based on the NOAA tides and currents gauges, which monitor the frequency that local sea levels rise above locally defined flooding thresholds. Tidal gauge height is an indirect measure of coastal flooding frequency and extent, and the existing network of gauges does not provide sufficient coverage in California to comprehensively evaluate coastal flooding across the state.

There are several useful tools that map modeled and/or projected coastal flooding based on measured sea levels, local tidal heights, and hydrological connectivity, such as the NOAA Sea Level Rise Viewer and the USGS Our Coast, Our Future tool.

However, coastal flooding is already affecting Californians. Flooding impacts are greater now than in the past due to the effects of climate change on rainfall and wave energy and because of more development and people in coastal areas. California communities need to be aware of and prepared for a likely rapid increase in the frequency of coastal flooding in the 2030s. Across the United States, the number of flood days has roughly doubled over the past 25 years. In California, coastal flooding is becoming more common but has not worsened as quickly as in other regions. This trend is partly due to natural coastal features along the West Coast, like steep cliffs, that lower the risk of flooding. These features can only offer so much protection before worsening sea level rise and stronger storms overwhelm their protective capacity.

2.18. MARINE DEBRIS

Marine debris was not evaluated quantitatively due to insufficient statewide data.

Marine debris is any trash that ends up on the beach or in the ocean. This includes metal and glass, but the main type of marine debris is plastic. Plastic pollution ranges in size from large fishing nets to microscopic pieces known as microplastics. Microplastics include synthetic fibers from clothes, particles from tires, microbeads from personal care products, or smaller pieces of plastic that break down from larger plastics.

Each year, millions of pounds of marine debris enter rivers, bays, and the ocean. An estimated 60-80% of this debris comes from land, and 80% of it is plastic. On California's beaches, the most common large debris are single-use plastics like cigarettes, food wrappers, and bottle caps.

There is currently no comprehensive statewide quantitative data about the amount of marine debris in the oceans and coastlines. OPC's Statewide Microplastics Strategy calls for standardized monitoring methods [69], and there is work currently in progress by SCCWRP and the San Francisco Estuary Institute to develop standard microplastics collection and evaluation methods and develop a statewide plastics monitoring plan. Datasets from public beach cleanups and trash-traps could provide statewide coverage for macroplastics if these datasets were standardized by effort and survey area.

2.19. INVASIVE SPECIES

Invasive species were not evaluated quantitatively due to insufficient statewide data.

Invasive species are plants, animals, or other organisms from other ecosystems or environments that, once introduced, quickly become established, spread to adjacent habitats, and disrupt local ecosystems and the economy. Invasive species compete with native species for resources, spread diseases, and change the local environment chemically and physically. Knowing where they've been

introduced, how they spread, and the harm they cause is important to managing their impact and preventing future invasions.

Currently, there is no comprehensive monitoring program or regularly updated database capturing the distribution and population of invasive species in coastal and offshore waters in California. The CAL-NEMO database tracks occurrence and rates of spread, but does not provide consistent and coordinated quantitative data on the presence and distribution of marine invasive species.

Generally speaking, there is an increase in both new invasive species and spread of existing invasions, due in part to climate change. Warmer oceans, changing currents, and more frequent disturbances will make it easier for invasive species to become established as they spread along the coast.

Source Data

California Non-native Estuarine and Marine Organisms (CAL-NEMO) Database

3. Data Gaps and Opportunities for Additional Monitoring

The process of synthesizing monitoring data at a statewide scale highlighted gaps where expanded monitoring or improved coordination will be instrumental in developing a comprehensive understanding of the state of California's coast and ocean. Cohesive, robust monitoring is a key component of OPC's 2026-2030 Strategic Plan to protect and restore California's coast and ocean [54]. The following recommendations are strategic steps to improve monitoring and strengthen the state's scientific enterprise:

- **Maintain and strengthen existing monitoring programs in California.** This statewide Coast and Ocean Assessment relied heavily on data from California's long-term monitoring programs. Having consistent, long-term, and standardized methodologies enabled us to detect change, track patterns, and identify priorities for action. Continued support for these programs will be critical to maintaining the state's ability to assess system conditions over time in the face of climate change as well as completing future statewide evaluations. In some cases, as described below, expansion of these programs can help to improve our understanding of the status and trends in California's coasts and oceans.
- **Develop new coordinated statewide monitoring of data-limited categories.** The process of synthesizing monitoring data for this assessment identified several categories that could not be evaluated quantitatively using our framework. This included four categories recognized as important and informative components of the coastal and ocean system but lacking sufficient data statewide evaluation: eelgrass and seagrass, coastal flooding, marine debris and microplastics, and invasive species. While some data do exist for these categories, available datasets either lack standardization, have insufficient spatial coverage, or cover a relatively short time series. Strategic investments in coordinated statewide monitoring of these categories will make future coast and ocean assessments more holistic.
- **Expand spatial coverage of existing monitoring efforts**
    - *Monitoring coverage in Northern California*: Many categories had less data coverage in Northern California than in the rest of the state. There have been some recent efforts to expand monitoring programs to northern California, such as statewide fish monitoring surveys that have recently expanded to (RREAS, CCFRP, MPA monitoring), or are scoping the potential to expand to (CalCOFI), the north coast and soon will have sufficient temporal coverage to include in this evaluation. Additional

intentional support to achieve even geographic coverage across monitoring programs will ensure that future evaluations more accurately reflect conditions across the entire state. Efforts to expand monitoring in the North Coast are a prime opportunity to collaborate with Indigenous-led monitoring programs, such as for the Yurok-Tolowa Dee-ni' Indigenous Marine Stewardship Area and the Tribal Marine Stewards Network.

  - *More instrumentation and/or model expansion for OA*: The evaluation of ocean acidification was based on a combination of data from oceanographic monitoring and models. Currently, only two federally-funded NOAA-PMEL buoys have the most precise technology used in this evaluation, and both are located in offshore waters in Southern California. Additional buoys, gliders, and ship-based sampling would provide more complete coverage of conditions in Northern California and in coastal waters. A complementary approach to expanding buoy coverage is to support the expansion and updating of existing models, which provide a spatially continuous estimate of ocean carbonate conditions. However, existing models are only updated through 2017 and do not account for land-based impacts on ocean acidification in Southern California. Updating these models is costly in terms of time and resources, but the information to be gleaned from expanded model and buoy coverage would be invaluable for obtaining a complete picture of both coastal and offshore acidification conditions across the entire state.

- **Reduce taxonomic gaps**
  - *Support sampling that detects the full range of fish species in the ecosystem:* The evaluation of fishes was based on data from five major monitoring programs, which collectively recorded 417 of California's 571 known marine fish species. However, robust and actionable data were available for only 144 species. Notably, there is less monitoring of species that are not commercially fished. Getting accurate information about the broad diversity of California marine fishes will require expanding existing monitoring in northern California, expanding taxonomic coverage in existing monitoring programs, and supporting innovative methods to detect rare species.
  - *Support for expanded whale monitoring*: There was insufficient data to evaluate more than one-third (14 out of 40) marine mammal stocks, meaning the most recent survey was more than eight years old. Many of these "data-deficient" stocks are rare and/or endangered species, so getting accurate and updated population information is of the utmost importance. Expanded monitoring could include investments in traditional

methods, like research cruises, or more innovative monitoring technology such as drones, satellite imagery, and eDNA.

- **Improve statewide coordination and collaboration of ocean monitoring programs**
    - *Strengthen collaborations in seabird monitoring:* The evaluation of seabirds was based on data from twelve distinct monitoring programs. Because many of these monitoring programs are species-specific or focused on one location and are often managed by independent non-profit organizations, the process of synthesizing statewide seabird data relied heavily on volunteer collaboration. Formalized coordination and sustained financial support would enable the state to move toward a unified and robust monitoring enterprise.
    - *Standardizing methods for measuring wetland extent:* The primary obstacle to a statewide wetlands evaluation was the lack of standardized, widespread monitoring methods used at regular intervals. Mapping wetland extent on the ground or via drone is accurate but resource-intensive. Conversely, model-based estimates, such as lidar-derived digital elevations or water levels, provide broader spatial coverage but are less accurate and may not account for all wetland types. Getting an accurate understanding of the past, current, and future extent of wetlands statewide will enable California to monitor progress toward its ambitious targets for wetland restoration.

4. Lessons Learned and Next Steps

For most categories, developing single, quantitative, statewide metrics was an effective way to provide a highly synthesized yet accurate representation of conditions. However, the process of developing these metrics also identified specific topics that require more granular detail:

1. **A single statewide metric can mask significant regional differences.** For example, while HABs are a coastwide phenomenon, regional environmental differences result in varying HAB impacts. The major sea lion rookeries are in Southern California, so this is where HAB impacts on mammal strandings are observed most acutely. Shellfish such as razor clams and Dungeness crab, both susceptible to HAB toxins, are found in Northern California, so this is where HAB impacts on shellfish harvesting are most acutely observed. Thus, for categories like HABs where impacts vary regionally, a multi-variate index or regional reporting framework would better capture these distinct conditions.
2. **A single statewide metric makes it difficult to discern species-specific vulnerabilities.** For example, both marine mammals and commercial fisheries scored highly. While working group members agreed that these scores accurately reflect general current conditions compared to historical conditions, the single aggregate scores obscured important facts: several whale species in California waters are highly endangered, and several commercial fisheries have been declared disasters. Marine mammal species and fisheries are not interchangeable; that is, the stability of one species does not offset the potential extinction (or fishery closure) of another. Thus, for species-based categories like whales and fisheries, statewide evaluations should be accompanied by evaluations of individual species.
3. **A single statewide metric obscures local dynamics.** For example, the dynamics of sandy beaches are highly localized, with neighboring beaches often exhibiting opposite patterns of widening or narrowing. This pattern is evident when viewing regional or statewide patterns, where one can observe a tidy alternating pattern of widening and eroding beaches across the full California coastline ([70]). Given that coastal management decisions and climate adaptation strategies in response to beach dynamics are implemented at the local level, providing disaggregated, local-scale information would be more valuable to local decision-makers than a single, state-level status.

The categories in this evaluation, taken collectively, present a broad picture of the state of the system based on currently available data. As scientific methods and data collection evolve, this framework can be expanded to include additional categories. For example, management-oriented

evaluations can be developed similar to the approach used to evaluate progress toward the state's sea level rise planning targets (Appendix B).

This framework was designed to be repeated at regular intervals, incorporating new data and adding categories that reflect emerging priorities. Repeating this analysis is important to monitor change over time and evaluate progress toward improving coastal and ocean health.

References

1. Wagner N, Velander S, Biber-Freudenberger L, Dietz T. Effectiveness factors and impacts on policymaking of science-policy interfaces in the environmental sustainability context. Environ Sci Policy. 2023;140:56-67. doi:10.1016/j.envsci.2022.11.008
2. Caldeira M, Sekinairai AT, Vierros M. Weaving science and traditional knowledge: Toward sustainable solutions for ocean management. Mar Policy. 2025;174:106591. doi:10.1016/j.marpol.2025.106591
3. Proulx M, Ross L, Macdonald C, Fitzsimmons S, Smit M. Indigenous traditional ecological knowledge and ocean observing: a review of successful partnerships. Front Mar Sci. 2021;8:703938. doi:10.3389/fmars.2021.703938
4. Ocean Protection Council Science Advisory Team. Establishing Science-Based Indicators for California's Oceans and Coasts. California Ocean Protection Council, California Ocean Science Trust; 2024.
5. California Ocean Science Trust. 2025 Coast and Ocean Report Card Update. Agenda Item 4, Exhibit B presented at: Ocean Protection Council Meeting; March 3, 2025. https://opc.ca.gov/wp-content/uploads/2025/02/Item-4-Exhibit-B-Report-Card-Update-508.pdf
6. Levin PS, Fogarty MJ, Murawski SA, Fluharty D. Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. PLoS Biol. 2009;7(1):e1000014. doi:10.1371/journal.pbio.1000014
7. Frawley T, Provost M, Bellquist L, et al. A collaborative climate vulnerability assessment of California marine fishery species. Benkeblia N, ed. PLOS Clim. 2025;4(2):e0000574. doi:10.1371/journal.pclm.0000574
8. Gallo ND, Bowlin NM, Thompson AR, Satterthwaite EV, Brady B, Semmens BX. Fisheries Surveys Are Essential Ocean Observing Programs in a Time of Global Change: A Synthesis of Oceanographic and Ecological Data From U.S. West Coast Fisheries Surveys. Front Mar Sci. 2022;9:757124. doi:10.3389/fmars.2022.757124
9. Lasker R, ed. An Egg Production Method for Estimating Spawning Biomass of Pelagic Fish: Application to the Northern Anchovy Engraulis Mordax. U.S. Department of Commerce NOAA NMFS; 1985.
10. Moser HG, Charter RL, Watson W, et al. The CalCOFI ichthyoplankton time series: Potential contributions to the management of rocky-shore fishes. CalCOFI Rep. 2001;42:112-128. https://calcofi.org/downloads/publications/calcofireports/v42/Vol_42_Moser_etal.pdf
11. Tran B, Barton AD, Muhling B, et al. Temporal dynamics and distributions of sardine and anchovy in the southern California Current Ecosystem. Can J Fish Aquat Sci. 2025;82:1-15. doi:10.1139/cjfas-2024-0151
12. Koslow, Anthony J, Goericke R, Watson W. Fish assemblages in the Southern California Current: relationships with climate, 1951–2008. Fish Oceanogr. 2013;22(3):207-219. doi:10.1111/fog.12018
13. Ward EJ, Hunsicker ME, Marshall KN, et al. Leveraging ecological indicators to improve short term forecasts of fish recruitment. Fish Fish. 2024;25(6):895-909. doi:10.1111/faf.12850
14. Santora J, Schroeder I, Bograd S, et al. Pelagic Biodiversity, Ecosystem Function, and Services: An Integrated Observing and Modeling Approach. Oceanography. 2021;34(2). doi:10.5670/oceanog.2021.212
15. Field JC, Miller RR, Santora JA, et al. Spatiotemporal patterns of variability in the abundance and distribution of winter-spawned pelagic juvenile rockfish in the California Current. Ottersen G, ed. PLOS ONE. 2021;16(5):e0251638. doi:10.1371/journal.pone.0251638
16. Keller AA, Wallace JR, Methot RD. The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey: History, Design, and Description. NOAA Northwest Fisheries Science Center (NOAA Technical Memorandum No. NMFS-NWFSC-136); 2017.

17. Pondella II DJ, Piacenza S, Claisse J, et al. Assessing drivers of rocky reef fish biomass density from the Southern California Bight. Mar Ecol Prog Ser. 2019;628:125-140. doi:10.3354/meps13103
18. Spiecker B, Carr MH, Malone DP, et al. Measuring biological effectiveness across a very large, coherent network of coastal marine protected areas. Ecol Appl. 2025;35(5):e70074. doi:10.1002/eap.70074
19. Miller DJ, Lea RN. Guide to the Coastal Marine Fishes of California. California Department of Fish and Game Fish Bulletin; 1972.
20. Allen L, Pondella II DJ, Horn MH, eds. The Ecology of Marine Fishes California and Adjacent Waters. University of California Press; 2006. doi:10.1525/california/9780520246539.001.0001
21. Ricard D, Minto C, Jensen OP, Baum JK. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. Fish Fish. 2012;13(4):380-398. doi:10.1111/j.1467-2979.2011.00435.x
22. Anderson SC, Ward EJ, English PA, Barnett LAK, Thorson JT. sdmTMB: An R Package for Fast, Flexible, and User-Friendly Generalized Linear Mixed Effects Models with Spatial and Spatiotemporal Random Fields. Ecology. Preprint posted online March 27, 2022. doi:10.1101/2022.03.24.485545
23. Rousseeuw PJ, Leroy AM. Robust Regression and Outlier Detection. 1st ed. Wiley; 1987. doi:10.1002/0471725382
24. Frederiksen M, Mavor R, Wanless S. Seabirds as environmental indicators: the advantages of combining data sets. Mar Ecol Prog Ser. 2007;352:205-211. doi:10.3354/meps07071
25. NOAA Fisheries. Understanding Why North Pacific Right Whales Are Endangered. https://www.fisheries.noaa.gov/insight/understanding-why-north-pacific-right-whales-are-endangered
26. Miner CM, Burnaford JL, Ammann K, et al. Latitudinal variation in long-term stability of North American rocky intertidal communities. J Anim Ecol. 2021;90(9):2077-2093. doi:10.1111/1365-2656.13504
27. Frölicher TL, Fischer EM, Gruber N. Marine heatwaves under global warming. Nature. 2018;560(7718):360-364. doi:10.1038/s41586-018-0383-9
28. Lucas BJ, Smith JR. Alterations in human visitation patterns and behaviors in southern California rocky intertidal ecosystems over two-decades following increased management efforts. Ocean Coast Manag. 2016;121:128-140. doi:10.1016/j.ocecoaman.2015.12.014
29. Perng LY, Walden J, Leong KM, et al. Identifying social thresholds and measuring social achievement in social-ecological systems: A cross-regional comparison of fisheries in the United States. Mar Policy. 2023;152:105595. doi:10.1016/j.marpol.2023.105595
30. Block S, Emerson JW, Esty DC, de Sherbin. 2024 Environmental Performance Index.
31. Anderson JL, Anderson CM, Chu J, et al. The Fishery Performance Indicators: A management tool for triple bottom line outcomes. Tserpes G, ed. PLOS ONE. 2015;10(5):e0122809. doi:10.1371/journal.pone.0122809
32. California Governor's Office. California Salmon Strategy for a Hotter, Drier Future: Restoring Aquatic Ecosystems in the Age of Climate Change. 2024. https://www.gov.ca.gov/wp-content/uploads/2024/01/Salmon-Strategy-for-a-Hotter-Drier-Future.pdf
33. Schlacher TA, Schoeman DS, Jones AR, et al. Metrics to assess ecological condition, change, and impacts in sandy beach ecosystems. J Environ Manage. 2014;144:322-335. doi:10.1016/j.jenvman.2014.05.036
34. Baxter T, Walker IJ, Dugan JE, et al. Significant Coastal Dune Loss Challenges California's Climate Resilience and Biodiversity Goals. Earths Future *in review*.
35. Vos, K., Harley, M. D., Turner, I. L. & Splinter, K. D. (2023) Pacific shoreline erosion and accretion patterns controlled by El Niño/Southern Oscillation. Nat. Geosci. 16, 140–146.
36. Warrick, J. A. et al. (2025) Shoreline Seasonality of California's Beaches. JGR Earth Surface 130, e2024JF007836.

37. Vos, K. (2025) Time-series of shoreline change along the Pacific Rim. Zenodo https://doi.org/10.5281/zenodo.7758183.
38. Schiel DR, Steinbeck JR, Foster MS. Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. Ecology. 2004;85(7):1833-1839. doi:10.1890/03-3107
39. Sanford E, Sones JL, García-Reyes M, Goddard JHR, Largier JL. Widespread shifts in the coastal biota of northern California during the 2014–2016 marine heatwaves. Sci Rep. 2019;9(1):4216. doi:10.1038/s41598-019-40784-3
40. Lonhart SI, Jeppesen R, Beas-Luna R, Crooks JA, Lorda J. Shifts in the distribution and abundance of coastal marine species along the eastern Pacific Ocean during marine heatwaves from 2013 to 2018. Mar Biodivers Rec. 2019;12(1):13. doi:10.1186/s41200-019-0171-8
41. Feely RA, Alin SR, Carter B, et al. Chemical and biological impacts of ocean acidification along the west coast of North America. Estuar Coast Shelf Sci. 2016;183:260-270. doi:10.1016/j.ecss.2016.08.043
42. Sutton AJ, Sabine CL, Maenner-Jones S, et al. A high-frequency atmospheric and seawater p CO2 data set from 14 open-ocean sites using a moored autonomous system. Earth Syst Sci Data. 2014;6(2):353-366. doi:10.5194/essd-6-353-2014
43. Deutsch C, Frenzel H, McWilliams JC, et al. Biogeochemical variability in the California Current System. Prog Oceanogr. 2021;196:102565. doi:10.1016/j.pocean.2021.102565
44. Renault L, McWilliams JC, Kessouri F, et al. Evaluation of high-resolution atmospheric and oceanic simulations of the California Current System. Prog Oceanogr. 2021;195:102564. doi:10.1016/j.pocean.2021.102564
45. Damien P, Bianchi D, Kessouri F, McWilliams JC. Extremes and short-term fluctuations in coastal ocean acidification and hypoxia. J Geophys Res Oceans. 2024;129(11):e2024JC021197. doi:10.1029/2024JC021197
46. Carter BR, Schwinger J, Sonnerup R, et al. Tracer-based Rapid Anthropogenic Carbon Estimation (TRACE). Earth Syst Sci Data. 2025;17(6):3073-3088. doi:10.5194/essd-17-3073-2025
47. Sutton AJ, Feely RA, Sabine CL, et al. Natural variability and anthropogenic change in equatorial Pacific surface ocean p CO2 and pH. Glob Biogeochem Cycles. 2014;28(2):131-145. doi:10.1002/2013GB004679
48. Humphreys MP. Temperature effect on seawater ƒCO2 revisited: theoretical basis, uncertainty analysis, and implications for parameterising carbonic acid equilibrium constants. Analytic Theory/Biogeochemistry and nutrient cycles. Preprint posted online March 5, 2024. doi:10.5194/egusphere-2024-626
49. Lueker TJ, Dickson AG, Keeling CD. Ocean pCO2 calculated from dissolved inorganic carbon, alkalinity, and equations for K1 and K2: validation based on laboratory measurements of CO2 in gas and seawater at equilibrium. Mar Chem. 2000;70(1-3):105-119. doi:10.1016/S0304-4203(00)00022-0
50. Dickson AG. Standard potential of the reaction: AgCL(s) + 12H2(g) = Ag(s) + Hcl(aq) and the standard acidity constant of the ion HSO4− in synthetic sea water from 273.15 to 318.15 K. J Chem Thermodyn. 1990;22(2):113-127. doi:10.1016/0021-9614(90)90074-Z
51. Uppström LR. The boron/chlorinity ratio of deep-sea water from the Pacific Ocean. Deep Sea Res Oceanogr Abstr. 1974;21(2):161-162. doi:10.1016/0011-7471(74)90074-6
52. Garcia HE, Locarnini RA, Boyer TP, et al. World Ocean Atlas. 4: Nutrients (phosphate, nitrate, silicate). US Government Printing Office; 2009.
53. Cullison Gray SE, DeGrandpre MD, Moore TS, Martz TR, Friederich GE, Johnson KS. Applications of in situ pH measurements for inorganic carbon calculations. Mar Chem. 2011;125(1-4):82-90. doi:10.1016/j.marchem.2011.02.005

54. Frazão HC, Send U, Sutton AJ, et al. Open Ocean Versus Upwelling Regimes: Air-Sea CO2 Fluxes and p CO2 Inter-Annual Variability in the Southern California Current System. J Geophys Res Oceans. 2025;130(7):e2024JC022126. doi:10.1029/2024JC022126
55. Fassbender AJ, Alin SR, Feely RA, Sutton AJ, Newton JA, Byrne RH. Estimating Total Alkalinity in the Washington State Coastal Zone: Complexities and Surprising Utility for Ocean Acidification Research. Estuaries Coasts. 2017;40(2):404-418. doi:10.1007/s12237-016-0168-z
56. Intergovernmental Panel on Climate Change. Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the IPCC. 1st ed. Cambridge University Press; 2021. doi:10.1017/9781009157896
57. Ocean Protection Council. Strategic Plan 2026-2030. 2025. https://opc.ca.gov/wp-content/uploads/2025/11/2026-2030-OPC-Strategic-Plan-508.pdf
58. Brophy LS, Greene CM, Hare VC, et al. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. Dias JM, ed. PLOS ONE. 2019;14(8):e0218558. doi:10.1371/journal.pone.0218558
59. Collins J, Stein ED. California Rapid Assessment Method for Wetlands and Riparian Areas (CRAM). In: Wetland and Stream Rapid Assessments. Elsevier; 2018:353-361. doi:10.1016/B978-0-12-805091-0.00044-X
60. Wade TJ, Calderon RL, Sams E, Beach M, Brenner KP, Williams AH, Dufour AP. Rapidly measured indicators of recreational water quality are predictive of swimming-associated gastrointestinal illness. Environmental Health Perspectives. 2005;114(1):24
61. Rehn AC, Mazor RD, Ode PR. The California Stream Condition Index (CSCI): A New Statewide Biological Scoring Tool for Assessing the Health of Freshwater Streams. Surface Water Ambient Monitoring Program; 2015. SWAMP Technical Memorandum SWAMP-TM-2020-0002. Edited February 2024. https://www.waterboards.ca.gov/water_issues/programs/swamp/bioassessment/docs/csci_tech_memo.pdf
62. Wolch, J., Wilson, J.P., and J. Fehrenbach, 2005. "Parks and Park Funding in Los Angeles: An Equity-Mapping Analysis." Urban Geography 26, 4–35. https://doi.org/10.2747/0272-3638.26.1.4.
63. Boone, C. G., Buckley, G. L., Grove, J. M., and Sister, C, 2009. "Parks and People: An Environmental Justice Inquiry in Baltimore, Maryland." Annals of the Association of American Geographers, 99(4), 767–787. https://doi.org/10.1080/00045600903102949.
64. Christensen J, King P. Access for All: A New Generation's Challenge on the California Coast. Summary Statistics from Beach Intercept Surveys Conducted in Southern California in Summer 2016. UCLA Institute of the Environment and Sustainability; 2017. https://www.ioes.ucla.edu/project/coastal-access-california/
65. Ocean Justice Strategy Workgroup, Ocean Policy Committee. Federal Ocean Justice Strategy. 2023. https://bidenwhitehouse.archives.gov/wp-content/uploads/2023/12/Ocean-Justice-Strategy.pdf
66. White House Council on Environmental Quality. Environmental Justice Scorecard. 2023:80697-80699. https://www.federalregister.gov/documents/2023/11/20/2023-25508/environmental-justice-scorecard
67. Vitousek S, Vos K, Splinter KD, Erikson L, Barnard PL. A Model Integrating Satellite-Derived Shoreline Observations for Predicting Fine-Scale Shoreline Response to Waves and Sea-Level Rise Across Large Coastal Regions. J Geophys Res Earth Surf. 2023;128(7):e2022JF006936. doi:10.1029/2022JF006936
68. AECOM, Coastal Frontiers Corporation, Moffatt & Nichol, Merkel & Associates, King P. Regional Beach Sand Project III Feasibility Study. San Diego Association of Governments; 2025. https://www.sandag.org/-/media/SANDAG/Documents/PDF/projects-and-programs/environment/shoreline-management/beach-sand-management/beach-sand-replenishment/regional-beach-sand-project-3-final-feasibility-study-and-appendices-2025-08-28.pdf

69. Ocean Protection Council. Statewide Microplastics Strategy. 2022. https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20220223/Item_6_Exhibit_A_Statewide_Microplastics_Strategy.pdf
70. O'Reilly WC, Merrifield MA, Cagigal L, et al. Interannual wave-driven shoreline change on the California coast. Nat Commun. 2025;16(1):9967. doi:10.1038/s41467-025-65944-0

Appendix A: Additional Details for Seabirds & Shorebirds Assessment

Datasets, filters, and covariates

- **Ashy Storm-petrel colony mist-netting:** Standardized mist-netting conducted during the breeding season at the Farallon Islands was used to estimate annual catch per unit effort (CPUE). Data from 1997–2024 were included in the analysis.
- **At-sea survey data from CalCOFI and Rockfish cruises (RREAS):** All available surveys from 1997–2024 were analyzed, with the exception of RREAS cruises in 2000, which were excluded due to inadequate coverage. Surveys conducted north of 41°N were also excluded because of the limited number of years available. Only survey bins with the standard width (0.3 km) and lengths between 1.2 and 4.8 km were included in the analysis. CalCOFI surveys outside the "core" area were excluded. Fall surveys were omitted, while winter surveys were retained only for species that breed locally. To account for seasonal variation, day of year ("Julian day") was included as a covariate. Eight species met the criteria for analysis, defined as taxa with an average of at least 40 individuals observed per year across the full survey range. These species were: Black-footed Albatross (BFAL), Brandt's Cormorant (BRAC), Brown Pelican (BRPE), Cassin's Auklet (CAAU), California Gull (CAGU), Common Murre (COMU), Sooty Shearwater (SOSH), and Western Gull (WEGU). To control for geographic variation in abundance, survey bins were aggregated into 0.5° latitude × 0.5° longitude cells (153 in total). These spatial cells were included as a random effect to account for spatial variability. Cells with no records of a given species across the full dataset were excluded from analyses for that species.
- **Colony data for Brandt's Cormorant, Cassin's Auklet, Common Murre, and Western Gull**: Estimates of breeding individuals for Brandt's Cormorants and Western Gulls (based on peak nest counts) were obtained from Año Nuevo Island (1997–2023) and Vandenberg SFB (1999–2024). Additional counts for Brandt's Cormorants, Common Murres, and Western Gulls were available from the Farallon Islands for 1997–2024. For Cassin's Auklets, breeding population size was estimated from Farallon Islands data for 1997–2024. For Brandt's Cormorants and Western Gulls, colony location (Año Nuevo Island, Vandenberg SFB, and Farallones) was included as a fixed effect in the analyses.
- **Double-crested Cormorant colony surveys:** Colony survey data for Double-crested Cormorants in San Francisco Bay were provided by the San Francisco Bay Bird Observatory for 1997–2024. Because survey coverage varied across sites, only colonies with data for at least 50% of the years in this period were included in the analysis. A total of 10 colonies met this criterion.
- **Least Tern colony survey data:** Counts of breeding pairs were analyzed from 1997–2023 across all coastal regions of California, with colony location included as a random effect in the models.

- **Marbled Murrelet boat-based surveys:** Boat-based surveys of Marbled Murrelets were used to estimate densities across California for 2000–2023 (W. McIver [USFWS] et al. 2024). Data for 2024 were not available. Density estimates were scaled up to generate total population estimates, which were used in the analysis.
- **Midwinter Waterfowl Surveys:** Four taxa were analyzed: Canvasback, Bufflehead, Scaup species (Greater and Lesser), and Scoter species (Surf, White-winged, and Black). Data covered the period 1997–2024 and included surveys from San Francisco Bay, San Pablo Bay (both open-water and shoreline areas), and adjacent Pacific coast regions. We followed the methods of S. De La Cruz, L. Hall, et al. (2025), who previously analyzed these data. Years without Open Bay surveys (2017, 2019, 2021, and 2022) were excluded. Counts were summed by subregion, adjusted for survey effort (De La Cruz, Hall, et al. 2025), and analyzed with subregion included as a fixed effect.
- **Pacific Flyway Shorebird Surveys:** Three taxa were analyzed: Marbled Godwit, Dowitchers (Long-billed and Short-billed), and *Calidris* species (primarily Western Sandpiper and Least Sandpiper, with additional records of Dunlin and Sanderling). Data spanned 2012–2024, representing the full range available. Analyses were conducted by Dr. B. Barbaree, who controlled for survey location as random effect and size of surveyed area, and provided annual density estimates using mixed effects generalized linear models. These estimates were used as the basis for the analyses presented here.
- **Pigeon Guillemot colony surveys:** The number of individuals recorded in raft surveys (i.e., counts conducted in the waters adjacent to Pigeon Guillemot breeding colonies) was analyzed for the Farallon Islands (2002–2024, years available) and for Vandenberg SFB (1999–2024).
- **Snowy Plover survey data:** Counts of individuals from breeding season window surveys were analyzed for the period 2005–2023 across all regions of coastal California. Survey location was included as a random effect in the models. To ensure sufficient data quality, only locations with at least nine individuals recorded over the full time series were included in the analysis; sites with no observations of individuals, or with only a few individuals ever recorded, were thus excluded.

Summary of models fit for trends and annual values

Overview: Variation in abundance among years was modeled in three ways: 1) linear trend for the full time series (1997-2024, if available, or shorter series as described above), i.e., long-term trend; 2) linear trend for 2019-2024, i.e., short-term trend; 3) year as a factor (i.e., categorical), the model generating a predicted value for each year of the time series. The latter was used in calculating a score for each species-study (see Methods in the main body). Models controlled for spatial location (e.g., colonies, subsites, and subregions), depending on the dataset, as described below. Any additional covariates are listed below for specific datasets.

- **Ashy Storm-petrel colony mist-netting:** Breeding season data for standardized mist-netting was used to estimate annual catch per unit effort (CPUE) for the Farallon islands; data from 1997-2024 were analyzed. A linear model of CPUE was fit for the single location.

- **At sea cruises:** For each of eight species (BFAL, BRAC, BRPE, CAAU, CAGU, COMU, SOSH, and WEGU), models were fit using mixed-effects negative binomial regression, with latitude–longitude grid cell as a random effect to control for spatial variation. For Black-footed Albatross (BFAL) and Sooty Shearwater (SOSH), only spring and summer surveys were included; for the other six species, winter surveys were also analyzed. Covariates included day of year ("Julian date"), modeled as a cubic (third-order) polynomial to account for seasonal variation, and survey bin area (km^2), log-transformed. All covariates were highly significant.
- **Colony data for Brandt's Cormorant and Western Gull**: Linear model on ln(counts) with location as fixed effect.
- **Colony data for Common Murre and Cassin's Auklet**: Linear model on ln(counts); only a single location was analyzed.
- **Double-crested Cormorant colony surveys:** Mixed effects linear model (colony as a random effect).
- **Least Tern colony survey data:** Mixed effects linear model with location as the random effect.
- **Marbled Murrelet boat-based surveys:** Linear model of density, ln-transformed. Annual density was provided.
- **Midwinter Waterfowl Surveys:** Linear model on ln(abundance) with subregion as fixed effect, as described above.
- **Pacific Flyway Shorebird Surveys:** Linear model on ln(density). Annual ln(density) values were calculated and reported as described above.
- **Pigeon Guillemot colony surveys:** Linear model on ln(counts) with location as fixed effect.
- **Snowy Plover survey:** Mixed effects negative binomial regression model with location as the random effect.

Regional analysis: Where data were sufficient, in addition to overall trends, we fit region-specific trends for Northern and Central California and Southern California, divided at Point Conception. This was done within a single model with region as a factor. For the at-sea cruise data, most RREAS data was in Northern and Central California, but some were in Southern California. The converse was true for CalCOFI data.

Appendix B: Sea Level Rise Planning Evaluation

Coast and ocean assessments in other jurisdictions are sometimes designed specifically to assess management effectiveness. In response to California's recently enacted policy on sea level rise planning (SB 272), here we present a quantitative assessment of sea level rise planning progress to illustrate a potential approach for management-oriented evaluations and to illuminate data needs for further analysis and insight.

Authors
Meghan Zulian, California Ocean Science Trust
Paige Thionnet, California Ocean Protection Council
Ella McDougall, California Ocean Protection Council

Contributors
Patrick Barnard, University of California Santa Cruz
Gary Griggs, University of California Santa Cruz
Justine Kimball, California Ocean Protection Council
Charles Lester, University of California, Santa Barbara

Executive Summary
The status of sea level rise planning was evaluated based on the percent of land within the county and city jurisdictions of the California Coastal Commission and the San Francisco Bay Conservation and Development Commission with fully updated sea level rise plans. In 2024, 5% of this land had completed planning and regulatory frameworks that incorporate best available science and management guidance for sea level rise planning. The North Coast had the highest proportion of land covered by sea level rise plans, in part due to recent updates to Sonoma County's Local Coastal Program, which covers 16% of Northern California's coastal areas. The equity section (2.14) includes further detail regarding sea level rise planning in disadvantaged communities. This evaluation represents one year of progress since the founding legislation that requires all coastal and San Francisco Bay Area local governments to plan for sea level rise by 2034 (SB 272). These numbers are underestimates of significant statewide progress on sea level rise planning, because the metric used in this analysis counted only planning documents that incorporate the most recent, best available science management and guidance since SB 272 was passed. Thus, jurisdictions deemed to have "partially complete" plans could have either fairly robust plans, components of

plans (such as a vulnerability assessment) or minimum plan components, and therefore this categorization has limited diagnostic power.

Basis of Evaluation

The working group used the target-based approach to describe the status of sea level rise planning, based on the statewide mandate (SB 272) that all coastal and San Francisco Bay Area jurisdictions have updated and comprehensive sea level rise planning by 2034. In 2022, the California legislature appropriated $37.5 million to the California Ocean Protection Council (OPC) to support the implementation of SB 1, which directs the state to provide funding to local and regional governments to develop sea level rise adaptation plans and implementation projects. OPC's SB 1 SLR Adaptation Planning Grant Program provides funding for local governments on the Coast and in San Francisco Bay that are looking to develop SLR adaptation plans and implement projects to build resilience to SLR along the entire coast of California and San Francisco Bay. As part of the grant program, in 2025, OPC developed minimum criteria that SLR adaptation plans must fulfill to receive funding from the SB 1 Grant Program, namely basing plans on best available science and management considerations.

This SLR planning evaluation measures progress towards achieving coastal resilience through the development of adaptation plans that align with criteria set by OPC's SB 1 Grant Program. As such, California cities and counties in the outer coastal zone and in San Francisco Bay were assessed on the completeness of SLR planning through two planning efforts: the first was to what extent SLR was considered in updated local coastal programs (outer coast) or in subregional shoreline adaptation plans (San Francisco Bay). The second was if, and to what degree, a local jurisdiction had undergone a standalone SLR adaptation planning effort and whether it met the criteria set by the California Ocean Protection Council (2025).

This method builds on a previous analysis completed for the California Ocean Protection Council's 2023 Annual Report, which assessed sea level rise planning progress for the outer coastal zone. Rationale for the initial analysis was that it made use of the most comprehensive database on sea level rise planning (California Coastal Adaptation Planning Inventory; see Lester et al., 2023; 2024), and used criteria vetted by all affiliated agencies in California's Sea Level Rise Collaborative.

This analysis relied on several additional data sources beyond the California Coastal Adaptation Planning Inventory, including:

- California Coastal Commission 2024 meeting agenda notes and documents
- Bay Adapt Currents Dashboard
- Planning documents found on city and county websites, through targeted web searches

Methods

The metric for sea level rise planning is based on the area covered by fully updated planning documents. This evaluation uses a target-based approach, where each municipality is scored based on how sea level rise considerations measure up to best available science and management advice put forth by the state.

The primary data source for this indicator was the California Coastal Adaptation Planning Inventory, from which researchers assessed cities and counties using the "adaptation planning" subsection. However, because this database is only current through August 2024, it was supplemented with information from the Bay Adapts Currents cities and counties sea level rise planning database, which is updated through December 2024. Additionally, researchers made use of targeted keyword searches of individual city and county webpages, with the following terms: "sea level rise", "Sea-level rise", "SLR", "adaptation plan", "hazard mitigation plan", "vulnerability assessment", "land use plans", "land use plan".

In evaluating California cities and counties' local coastal programs (LCP; outer coast) and subregional shoreline adaptation plans (SSAP; San Francisco Bay Area), researchers described the degree of sea level rise planning based on whether it met criteria described by the California Ocean Protection Council SB 1 grant program. In parallel with evaluating LCPs and SSAPs, California cities and counties were also evaluated based on the rigor of their sea level rise adaptation plans. Researchers assigned each LCP and SSAP, and adaptation plan a label of:

- Yes, indicating that the plan has comprehensive sea level rise planning that includes a scientifically sound vulnerability assessment, short- and long-term adaptation strategies, and a number of other basic topics;
- In Part, indicating there are some considerations for sea level rise, but not all elements necessary to be considered comprehensive; or
- No, indicating that there is little or no mention of sea level rise in the plan.

The score for each individual city and county was the combined evaluation of sea level rise considerations in land use plans (yes, in part, no) and the sea level rise considerations in adaptation plans (yes, in part, no). Only those with "yes" for both were considered fully updated, or "yes" overall for sea level rise planning. Those with no on both were marked as no overall. All remaining combinations were marked as "in part".

Finally, to evaluate the percentage of land with comprehensive sea level rise adaptation plans, they calculated the percentage of coastal land in each category. For cities and counties on the outer coast, they calculated this area using the California Coastal Commission Local Coastal Program

Segments ArcGIS Shapefile. For cities and counties in the San Francisco Bay Area, they estimated the area under jurisdiction of the Bay Conservation and Development Commission by multiplying the shoreline miles found in the California Coastal Adaptation Planning Inventory by 100 feet, and converting that to acres.

Results

In 2024, 5% of relevant coastal and Bay Area land was covered by a plan that met all criteria for sea level rise planning, 51% by a plan that met some criteria, and 44% was not covered by any SLR plans. The distribution of completed, partially completed, and incomplete differed by coastal region. Sonoma County's recent Local Coastal Program updates and long stretch of coastline are responsible for 16% of the eligible area in the North Coast with completed sea level rise planning; the highest proportion of any coastal region. The San Francisco Bay Area has the largest proportion of cities and counties with partially completed sea level rise plans (71%). The progression to fully completed plans may be rapid for this region, as the RSAP guidelines were released in 2024. Central and Southern California have comparable proportions of cities and counties with partially complete (58%) and incomplete (42%) sea level rise planning (Table B1).

Table B1. Percent of area within the jurisdiction of the California Coastal Commission and Bay Conservation and Development Commission covered by complete, partially complete, or incomplete sea level rise planning. Northern California excludes the Bay Area as this was analyzed separately.

Region	Complete	Partially Complete	Incomplete
Northern California	16%	57%	27%
SF Bay Area	0%	71%	21%
Central California	0%	58%	42%
Southern California	1%	58%	41%

Discussion

This analysis specifically measures progress toward SB 272, which stipulates that all coastal and San Francisco Bay Area local governments must plan for sea level rise by 2034. To be considered “complete” in this evaluation, adaptation plans had to meet rigorous criteria set by the California Ocean Protection Council (2024) that reflect the best available science management and guidance. While it is critical to hold jurisdictions accountable to rigorous standards, the metric used in this analysis inherently underestimates general progress on sea level rise planning in the state. Millions

of dollars in investments and decades of progress on sea level rise planning that do not meet the most recent criteria (OPC, 2024), are captured under the category of "partially complete" in this analysis, which covers a substantial range of sea level rise planning in the state. Cities and counties with "partially complete" planning could have one partially complete and one incomplete local coastal program (LCP) or SSAP, and one adaptation plan (AP). They could have one that is fully complete and one that is partially complete. Future iterations of this indicator may explore other metrics, such as complete vulnerability assessments; consider separately tracking progress toward SB 272 and SB 1 criteria; and consider a complementary evaluation to track implementation beyond planning efforts.

Another complicating factor in using area covered by updated sea level rise measures is the difference in area under the jurisdiction of the San Francisco Bay Conservation and Development Commission and the California Coastal Commission. The current metric for sea level rise planning is the percent of Coastal Commission and BCDC jurisdictional area covered by updated sea level rise planning. Given that the California Coastal Commission jurisdiction covers as much as five miles inland in some locations, and BCDC's jurisdiction covers just 100 feet inland from the San Francisco Bay shoreline, using a land area metric does not really capture the relative completion rates of sea level rise planning progress of *jurisdictions* along the outer coast and within the San Francisco Bay Area. To demonstrate the impact, even if 100% of Bay Area jurisdictions had fully planned for sea level rise, the total percentage of land in the coastal zone and SF Bay Area (as measured by the CCC's LCP jurisdiction and BCDC's 100-foot jurisdiction) covered by fully updated sea level rise plans would change by < 1%. Future iterations of this assessment may explore avenues to equalize these contributions. Future iterations of this indicator may explore metrics that evaluate the percentage of jurisdictions with completed plans, rather than the percentage of area covered.

Repeating this analysis in the future will require additional effort due to the lack of a comprehensive, statewide, and regularly updated database. To complete this analysis, researchers heavily relied on agenda meeting notes from the California Coastal Commission, raw data from the Bay Adapts Currents Dashboard, and the California Coastal Adaptation Planning Inventory, which is only updated through late 2024. As illustrated, finding data for this analysis is already labor-intensive, but without further updates to the California Coastal Adaptation Planning Inventory, it will be increasingly challenging. In the future, the state should consider funding a centralized tracking database for adaptation plans.

Source data and data contributors:

- California Coastal Adaptation Planning Inventory:

https://ucsb.maps.arcgis.com/apps/instant/sidebar/index.html?appid=ac50d124761b42c6983b672f8ce863c3

- The San Francisco Bay Conservation and Development Commission. (2025). *Bay Adapt Currents Dashboard* [Sea level Rise in General Plans]. Available at https://www.bayadapt.org
- Coastal Commission: https://www.coastal.ca.gov/meetings/archive/#/
- Lester, Charles, Manley, C., Dinh, Y., Rozal, S., Cooper, A., Winters, L., Munster, K., Bok, T., Wrubel, N., 2023. Planning for Sea Level Rise on California's Coast: Status, Trends, and Recommendations. Ocean and Coastal Policy Center, Marine Science Institute, University of California, Santa Barbara, California. Available at https://ocpc.msi.ucsb.edu/california-coastal-adaptation-project.
- Lester, Charles, Rozal, S., Cooper, A., Scalzo, M., Wrubel, N., Howard, N., 2024. Planning for Sea Level Rise on California's Coast Supplemental Report: San Francisco Bay, Federal Lands, Tribal Lands, and State Parks. Ocean and Coastal Policy Center, Marine Science Institute, University of California, Santa Barbara, California. Available at https://ocpc.msi.ucsb.edu/california-coastal-adaptation-project.