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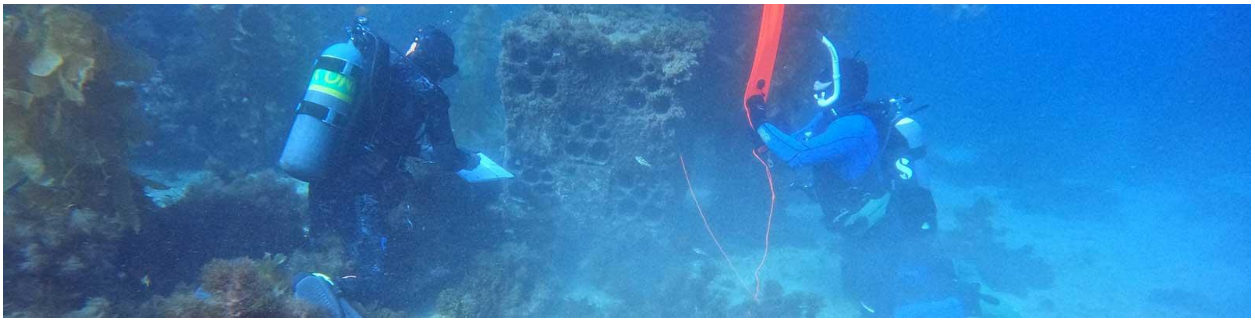
California Artificial Reef Program Plan DRAFT July 2026



Prepared by the
California Artificial Reef Program Plan Technical Writing Group
for the

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Executive Summary

To be written after the comment period.

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GLOSSARY

adaptive management— A science-based, iterative process that improves biological resource management by using new information from monitoring and evaluation to adjust strategies and meet conservation goals.

artificial reef — Manmade or natural objects intentionally placed in selected areas of the marine environment to duplicate the conditions that induce production of fish and invertebrates on natural reefs and rough bottoms, and that stimulate the growth of kelp or other midwater plant life, which creates natural habitat for those species (Fish & G. Code, § 6421).

baycrete — A concrete mixture including natural materials such as local sand, gravel and native oyster shell aggregate.

biological production — The total rate at which native species create living matter (biomass), from algae and plants converting sunlight into organic matter at the base of the food web, through the fish and invertebrates that feed and grow on that organic matter.

biomass — The total mass of living organic matter in ocean environments, including bacteria, algae, plants and animals.

bond or surety device — A legal, financial mechanism required as a permit condition to ensure a developer or landowner fulfills obligations regarding the removal of structures and site restoration.

control site —A location near a project site that experiences similar historic and current conditions, having some level of comparability that is appropriate for deciphering regional environmental patterns and anomalies that may affect project performance; they are typically monitored simultaneously with the project site.

CRANE (Cooperative Research Assessment of Nearshore Ecosystems) — A standardized SCUBA-based survey protocol developed around 2002 to assess nearshore permanently submerged (subtidal) rocky reefs. CRANE standardizes how researchers survey reef communities: counting fish and invertebrates, mapping algae and seafloor cover and measuring the physical structure of the reef. It has been used for baseline and long-term monitoring of subtidal rocky reefs inside and outside California's Marine Protected Areas (MPAs).

dome effect — The gathering of plankton-feeding fish in the water column above an artificial reef. As these fish feed and excrete waste, they transfer nutrients and energy from open waters to the reef below, linking the productivity of the water column to the seafloor community.

ecotone — A transitional area between two different habitat types. In the context of artificial reefs, this refers to the area where the hard structure of the artificial reef meets the surrounding soft sediment (also called the rock-sand ecotone). These areas are critical for foraging and often support high native biodiversity.

goal — A broad, overarching statement of what a project wants to achieve in the long term. In the context of artificial reefs in California, a goal for all projects should be maximizing biological productivity and native biodiversity in the area affected by the project. Projects may have multiple objectives that support this goal and may also have more than one goal. *(see also: purpose)*

halo effect — A zone surrounding an artificial reef where physical processes and biological interactions between reef-associated organisms and adjacent (typically soft-bottom) habitats alter the community structure, environmental conditions and ecosystem function. Within this zone, fish and invertebrate are more abundant and varied than in the surrounding area and grow faster due to the increased availability of food and localized nutrients and organic matter from the reef that enriches the surrounding habitat beyond the artificial reef's physical footprint.

impact — A measurable change, either positive or negative, to physical, chemical or biological conditions of a natural system. Direct or primary effects are caused by a project and occur at the same time and place. Indirect or secondary effects occur later in time or at a greater distance but remain reasonably foreseeable, and may include effects that spur further development, population growth or changes in how land is used, with knock-on consequences for air, water and other natural systems, including ecosystems (Cal. Code Regs., tit. 14, § 15358).

living shoreline — A coastal adaptation and/or erosion control method that is comprised of natural or mostly natural elements, which contributes to the persistence and enhancement of coastal processes and ecological benefits while also protecting inshore areas.

MARINe (Multi-Agency Rocky Intertidal Network) — A partnership of federal, state and private organizations formed in 1997 to collect long-term, standardized data on rocky communities in the tidal zone from Alaska to Mexico. MARINe aims to detect changes, assess impacts (such as oil spills, pollution or climate change), track species trends and inform management decisions.

marine environment — Marine or estuarine areas, including bays, seaward of the mean high tide line or the mouth of a coastal river, including any area of intertidal or subtidal terrain (Fish & G. Code, § 2852) out to three nautical miles.

materials of opportunity — Pre-existing, non-purpose-built materials, often redundant or decommissioned man-made structures (e.g. construction debris), that are repurposed to serve as material to construct artificial reefs.

objectives — Specific, measurable steps or milestones that help achieve a broader goal. Objectives break down the goal into actionable components. In the context of artificial reefs, projects may have multiple objectives that assess — quantitatively where feasible — impacts on native biological production and biodiversity, as well as other ecosystem services including but not limited to shoreline protection, carbon sequestration, increased recreational opportunities and protection or support of cultural uses.

other submerged structure — A structure placed below the mean high tide line in the marine environment designed/engineered to achieve non-biological goals and objectives that does not mimic the structure, function and services of productive naturally occurring rocky reefs by maximizing biological productivity and native biodiversity in the affected area. Such structures are not artificial reefs although they may produce some biological benefits or ecosystem services.

PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans) — A long-term research consortium established in 1999 to study nearshore marine ecosystems within the California Current Large Marine Ecosystem, which spans from Alaska to Baja California.

performance criteria — Measurable, objective, time-bound and enforceable standards or conditions imposed by regulators on development projects to ensure compliance with applicable laws.

purpose — The desired outcome of a project; synonymous with goal. *(see: goal)*

take — To hunt, pursue, catch, capture or kill, or to attempt to hunt, pursue, catch, capture or kill (Fish & G. Code, § 86).

ungranted sovereign tidelands — Lands extending from the ordinary high-water mark (mean high tide line) to three nautical miles offshore, including beds of navigable rivers and lakes that the Legislature has *not* transferred to local jurisdictions such as cities or ports.

ungranted sovereign submerged lands — Lands extending from the ordinary low water mark (mean high tide line) to three nautical miles offshore, including beds of navigable rivers and lakes that have *not* been transferred by the Legislature to local jurisdictions (like cities or ports) via legislative grant.

1 California Artificial Reef Program

The California Legislature created the California Artificial Reef Program (CARP) in 1985 under California Fish and Game Code, sections 6420 – 6423, in response to declines in Southern California marine species that were harming the sport and commercial fishing. The CARP statute requires studying both existing successful artificial reefs and new reefs to determine the design, siting and placement criteria needed to increase fish and invertebrate production. The California Department of Fish and Wildlife (CDFW) administers the CARP.

Since the program's creation, funding and resources have steadily declined, with all dedicated support ending by 2000. The CARP received a one-time $500,000 legislative allocation for the 1985-86 fiscal year, which was quickly spent on reef construction and associated CDFW staffing. The program has received no dedicated funding since. In recent years, interest in artificial reefs has continued to grow, and requests to create new artificial reefs are expected to keep rising.

Both regulators and project developers have called for a programmatic guidance document to establish best practices and improve consistency in artificial reef decisions. A one-time grant from the California Ocean Protection Council (OPC) funded this CARP Plan (the Plan), though it does not cover CDFW's ongoing administrative role. This Plan reviews artificial reefs in California and identifies what future projects need to do to maximize benefits to natural systems while minimizing negative impacts.

CDFW consults with state and federal regulators who issue permits for the construction of artificial reefs, contributing biological expertise to inform their regulatory review. Although CDFW administers the CARP, the current statute does not explicitly grant the department regulatory authority over artificial reef construction. Artificial reefs require a host of federal and state permits (see Section 4.5 and Appendix 1). After an artificial reef is placed, CDFW issues scientific collection permits for any sampling that involves "take" — a legal term for the capture, pursuit or removal — of marine species under CDFW jurisdiction. Depending on the reef's location, the California Coastal Commission, San Francisco Bay Conservation and Development Commission or localities with certified Local Coastal Programs or harbors with certified Port Master Plans may hold jurisdiction over construction. Regional Water Control Boards issue additional required state permits, and a lease for parcels owned by the State Lands Commission (SLC; ungranted sovereign tidelands and submerged lands, see Glossary) is also required. SLC leases expire on a set date and must be renewed for a project to continue. Additional federal and state permits may also apply depending on project specifics.

To shape the Plan, CDFW drew on existing statute requirements and stakeholder as well as regulator meetings held from 2017 to 2020, with additional outreach to California Native American tribes and stakeholders in early 2025 and 2026 (see Appendix 2). To develop the Plan's content, CDFW, OPC and California Sea Grant (CASG) — together forming the Project Team — selected 11 scientific experts to serve as a Technical Writing Group (TWG; see Appendix 3). The TWG developed the Plan's technical content and reviewed other sections containing scientific or technical information to ensure the content aligned with the best available science.

CDFW wrote the remaining sections, guided by the best available science and input from regulators, California Native American tribes and stakeholders. Before the Plan was finalized, CDFW put it through a 60-day extended comment period for California Native American tribes and a concurrent 45-day public comment period. All comments were reviewed and incorporated as appropriate (see Appendix 8). The Plan also underwent a peer review to confirm its scientific accuracy.

1.1 Plan Purpose and Use

The Plan is a programmatic guidance document that establishes best practices for developing artificial reefs in California's marine waters. It creates a shared understanding of the components of well-designed artificial reefs that have the highest likelihood of achieving their goals and objectives. The Plan is consistent with the National Fisheries Enhancement Act and the updated 2007 National Artificial Reef Plan[1] and draws on the best available science to address materials, design, siting and performance monitoring of artificial reefs. It does not provide guidance for the construction of artificial reefs or identify sites for future reefs, and it is nonregulatory and nonbinding. It will help ensure consistent implementation of the CARP as resources are available and gives regulators a common framework for evaluating artificial reef proposals.

In the United States, systematic efforts to experiment with artificial reefs as a tool to increase fishing and diving opportunities began in the 1950s.[2] Today, most artificial reef projects pursue a broader range of socioecological goals and focus on providing benefits across species and ecosystems.[3] Recent proposals to place artificial reefs in California's state marine waters have included objectives such as shoreline protection, kelp enhancement and native oyster restoration. Requests to explore the use of artificial reefs to offset impacts to marine life from ocean and coastal development have also increased.

This growing interest, and the increasing complexity of projects being proposed, has underscored the need for a science-based and stakeholder-informed plan to guide the future development of artificial reefs in California's marine waters.

The Plan identifies important considerations and a high-level framework for planning artificial reefs in ways that improve the likelihood that a proposed project will achieve its goals and objectives. Achieving success will require thorough analyses of the target ecosystem, location and project-specific requirements, but those topics are outside the scope of this document.[4] Instead, the Plan identifies the foundational elements that every project needs to address during conceptualization and early planning, regardless of the target ecosystem or location.

Projects should be sited and designed using materials that maximize biological productivity and native biodiversity as much as possible. Before construction begins, developers must thoroughly survey the project site and nearby control sites to allow for robust performance monitoring and adaptive management. Projects that follow the Plan will be better positioned to efficiently proceed through the permitting process. However, following the Plan does not guarantee permit approval — regulators evaluate each proposal on its own merits. That said, adhering to the best practice recommendations in the Plan is a good first step toward a successful artificial reef.

The Plan establishes standard terminology to improve communication among those involved in artificial reef projects and helps clarify the permitting process. Regulators retain full jurisdictional authority over artificial reef proposals and may choose to deviate from the best practices recommended in the Plan. The Plan is intended to be periodically updated to reflect advances in technology and science, and any changes in marine resource management policies or regulations.

Box 1: Summary of California Artificial Reef Program Plan IS and IS NOT

This document IS guidance; it IS NOT regulations. This Plan is advisory and not a regulatory document or legal standard of review for the actions of any regulatory agency. Regulators retain full jurisdictional authority over artificial reef proposals and may choose to deviate from the best practices recommended in this Plan for any reason.

This document DOES NOT identify locations for new artificial reefs. This Plan does not identify locations where future artificial reefs will or could be placed.

This document DOES NOT provide detailed construction instructions on building an artificial reef. The specific material and design decisions for an artificial reef are project specific and informed by the goals and objectives of the artificial reef project.

This document IS a best practice guide for developers and regulators to inform the potential development of any future artificial reefs. This Plan is a comprehensive, multi-purpose resource. It aggregates best practices based on the best available science and includes generalized recommendations for critical aspects of successful artificial reef development.

This document IS a resource that should inform artificial reef development, it IS NOT a checklist. Since this document is intended for use statewide, it is not specific to a particular geographic location, specific species or specific artificial reef projects. Not all the content will be applicable for all projects. However, the contents of the Plan are at a level of detail that can be used to inform project development regardless of project specifics.

1.2 Founding Legislation, Definitions and Policies

Congress passed the National Fisheries Enhancement Act (NFEA) in 1984 to promote and facilitate responsible and effective efforts to establish artificial reefs. The NFEA's primary goal was to enhance fisheries and fishery opportunities. It also required the creation of a National Artificial Reef Plan to establish national standards for the construction, siting and monitoring of artificial reefs. The first National Artificial Reef Plan was published in 1985 and updated in 2007. After the NFEA was enacted, several state resource agencies adopted their own artificial reef plans and allocated funding, which sparked a surge in reef construction in the 1980s and 1990s. The fishing and recreational diving communities supported these efforts then and continue to do so today. Currently, 17 states, including California, have a formal artificial reef program. However, many of these programs lack consistent funding or staffing. In California, the CARP is established in statute but currently has no dedicated funding or staff to support its implementation or administration.

Building on action at the federal level, California legislators created the CARP in 1985. A central element of the CARP legislation is the definition of an artificial reef. Fish and Game Code section 6421, subdivision (a), defines an artificial reef as *"… manmade or natural objects intentionally placed in selected areas of the marine environment to duplicate those conditions that induce production of fish and invertebrates on natural reefs and rough bottoms, and that stimulate the growth of kelp or other midwater plant life which creates natural habitat for those species."* The following bulleted list clarifies key words and phrases used in the statute as they are applied in the Plan, consistent with current, broadly accepted scientific concepts and terminology.

- "*manmade or natural objects*" — This broad category includes but is not limited to quarry rock, construction rubble, concrete, metal and cleaned ships. Materials must be durable, inert and non-toxic, and must conform to the *Guidelines for Marine Artificial Reef Materials*, 3rd Edition (Gulf States Marine Fisheries Commission, 2020)[5] and the *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs* (U.S. Environmental Protection Agency & Maritime Administration, 2006). See section 3.2 for additional detail.[6]
- "*marine environment*" — Marine or estuarine areas [including bays] seaward of the [mean] high tide line or the mouth of a coastal river, including any area of intertidal or subtidal terrain (Fish & G. Code, § 2852) out to three nautical miles.
- "*duplicate those conditions that induce production of fish and invertebrates*" — This phrase covers the full suite of biological, chemical and physical conditions that support fish and invertebrate production.
- "*stimulate the growth of kelp or other midwater plant life*" — This phrase includes artificial reefs built below the depth zone where kelp grows, because nutrients and organic matter from those deeper reefs can be exported to shallower water and promote kelp growth. The statute's most likely intent was to support the growth of kelp and other photosynthetic organisms found in the water column, such as phytoplankton.[*]
- "*natural habitat*" — The CARP statute's most likely intent in calling for the creation of "natural habitat" is to create that support, emulate and duplicate the functions and services of natural reefs.

The CARP Plan's definition of an artificial reef covers human-made structures intentionally placed in the marine environment, including bays and estuaries, from the mean high tide

[*] This interpretation was informed by contextualizing the existing statute definition of artificial reef to commonly used definitions in other legislation and the scientific literature at the time it was created.

line out to three nautical miles, that are designed to duplicate the conditions of natural temperate rocky reefs and promote fish and invertebrate production. Beyond the definition of artificial reefs in the Fish and Game Code, other California policies also govern where and how artificial reefs may be placed. Appendix 4 lists relevant policies and directives that help determine which reef types and locations are appropriate. That list may not be exhaustive, however, and artificial reef developers should consult regulators early in the planning process to identify all applicable regulations, mandates and policies.

An important distinction exists between artificial structures placed in the marine environment that were not designed to create environmental and/or ecological benefits (such as oil and gas platforms) and a true "artificial reef." Structures of the former type may produce some incidental ecological benefits[7,8], but they differ from an "artificial reef" as defined in California (Fish & G. Code, § 6421, subd. (a).). The CARP Plan does not address the conversion of existing oil and gas infrastructure into artificial reefs, commonly known as Rigs-to-Reefs.[9] The California Marine Resources Legacy Act (Fish & G. Code, §§ 6600-6621), passed in 2010 allows for partial removal of oil and gas infrastructure when there is a net environmental benefit. In 2016, California Senate Bill 233[10] sought to clarify that process but ultimately failed to pass. In 2023, the Bureau of Safety and Environmental Enforcement[11] selected partial oil rig removal as their environmentally preferred alternative, thus keeping this option available in California. If Rigs-to-Reefs becomes a viable option, the CARP Plan could be updated with an addendum to guide that process as resources allow.

1.3 History and Current Status of California Artificial Reefs

CDFW began studying artificial reefs in California in 1958.[12] In 1962, CDFW placed car and streetcar bodies on sandy bottom areas adjacent to Paradise Cove and Redondo Beach. Subsequent surveys documented fish and invertebrates gathering around the new hard structures, but they deteriorated rapidly, especially the six wooden streetcars at Redondo Beach.[12] CDFW also constructed artificial reefs off Malibu, Santa Monica and Hermosa Beach from 1961 to 1962. At each of these locations, streetcars, auto bodies, quarry rock and concrete shelters were tested for their durability and ability to develop a nearshore rocky reef community. CDFW also studied long-standing oil and gas platforms and other artificial structures to document how closely they resembled natural reefs. The studies found that artificial reefs produced higher catch rates than adjacent natural areas and had species compositions like those of natural reefs; they also confirmed that rock was the best construction material.[12,13]

Figure 1. From Carlisle et al. 1964- Biologist-divers Charles H. Turner (left) and John G. Carlisle, Jr. take photos and record data on newly installed an artificial reef. Photograph by Gene Daniels, 1958.

Several additional artificial reefs were built in the 1960s, including Torrey Pines Artificial Reef No. 1, Huntington Beach Artificial Reef Nos 1-4, Marina Del Rey Artificial Reef No. 1, Oceanside Artificial Reef No. 1 and Imperial Beach Pier Artificial Reef. Most of the funding for reef construction during this period came from the Wildlife Conservation Board. In its California State Lands permit application, CDFW stated that the purpose for building reefs during this period was to “improve fishing opportunities”. Correspondence and information from CDFW archives also indicate growing interest in using artificial reefs to restore fish populations, in addition to increasing fishing opportunities.

In the 1970s, local agencies began building artificial reefs, and CDFW expanded its activity to include adding material to existing permitted artificial reef locations. The Palawan Artificial Reef, which was the first in California using a cleaned ship hull, was also completed during this period. Local agencies permitted and constructed reefs to enhance fishing opportunities in their communities, including the Huntington Beach tire reef built by the Los Angeles Rod and Reel Club and Russ Izor, the City of Santa Cruz Wharf tire reef, the

City of Ocean Beach Pier tire reef and the City of San Diego Torrey Pines No. 2 Artificial Reef.

New funding in the 1980s led to several new reef projects, including the Pitas Point Artificial Reef, Santa Monica Bay Artificial Reef, Topanga Artificial Reef, Oceanside Artificial Reef No. 2, Pacific Beach Artificial Reef and Mission Bay Park Artificial Reef. Most were initially built from quarry rock and later supplemented with additional materials of opportunity. An exception was the Bolsa Chica Artificial Reef, built in federal waters, which relied exclusively on materials of opportunity, including concrete, salvaged rock, light poles, demolition-derived concrete rubble and donated steel- and concrete-hulled vessels and barges. Southern California Edison fully funded the Pendleton Artificial Reef, built in 1980. That funding covered CDFW staff time and program costs to study whether artificial reefs could help restore fish, invertebrate and kelp populations and serve as a potential mitigation pathway for power plant impacts.[14–18]

Figure 2. Release of tagged California sheephead (Semicossyphus pulcher) on Pendelton Artificial Reef.

In 1990, CDFW published the *Nearshore Sportfish Habitat Enhancement Program, Artificial Reef Plan,* which included information on the construction of artificial reefs in California up to that point. Drawing primarily on CDFW's reef-building experience in the 1980s, the 1990 Plan offered general guidance on reef placement but relied on limited information. It stated that the purpose for artificial reefs in California was to enhance standing stock, that is the total population, of sport fish and reef-associated communities, and to enhance catch of sport fish. It provided high-level guidelines for siting, materials and design and summarized CDFW's artificial reef studies and the state of knowledge on artificial reef performance at the time.

Among the 1990 Plan's key findings was that artificial reefs could, in certain cases, help offset damage to rocky habitat and damage to giant kelp (*Macrocystis pyrifera*). The 1990 Plan noted that "…*the extent to which artificial reefs benefit fishery stocks, has not been fully investigated. Until this question is satisfactorily addressed, the usefulness of artificial reefs as mitigation must be carefully considered on a case-by-case basis*." At that time, CDFW also revised its position on acceptable materials, requiring that they be durable, at least twice as dense as sea water, nontoxic and structurally complex — ruling out tires, for example. The 1990 Plan lacked key elements needed to guide full CARP implementation.

Artificial reef construction declined significantly in California during the 1990s and 2000s. With no sustained funding to support CARP administration, all activity ceased in 2001. Since the CARP took effect on January 1, 1986, CDFW has constructed 12 artificial reefs. These reefs have been studied to varying degrees and offer important lessons for future artificial reef construction under the CARP. Ongoing studies of reefs built by CDFW and other entities, including those constructed for mitigation, have improved understanding of how artificial reef function. Researchers are also investigating how artificial reefs can deliver benefits beyond the traditional goals of increasing fishing and diving opportunities. Earlier artificial reefs targeted the open coast; more recent projects have expanded to include estuaries as well (Figures 3 and 4).

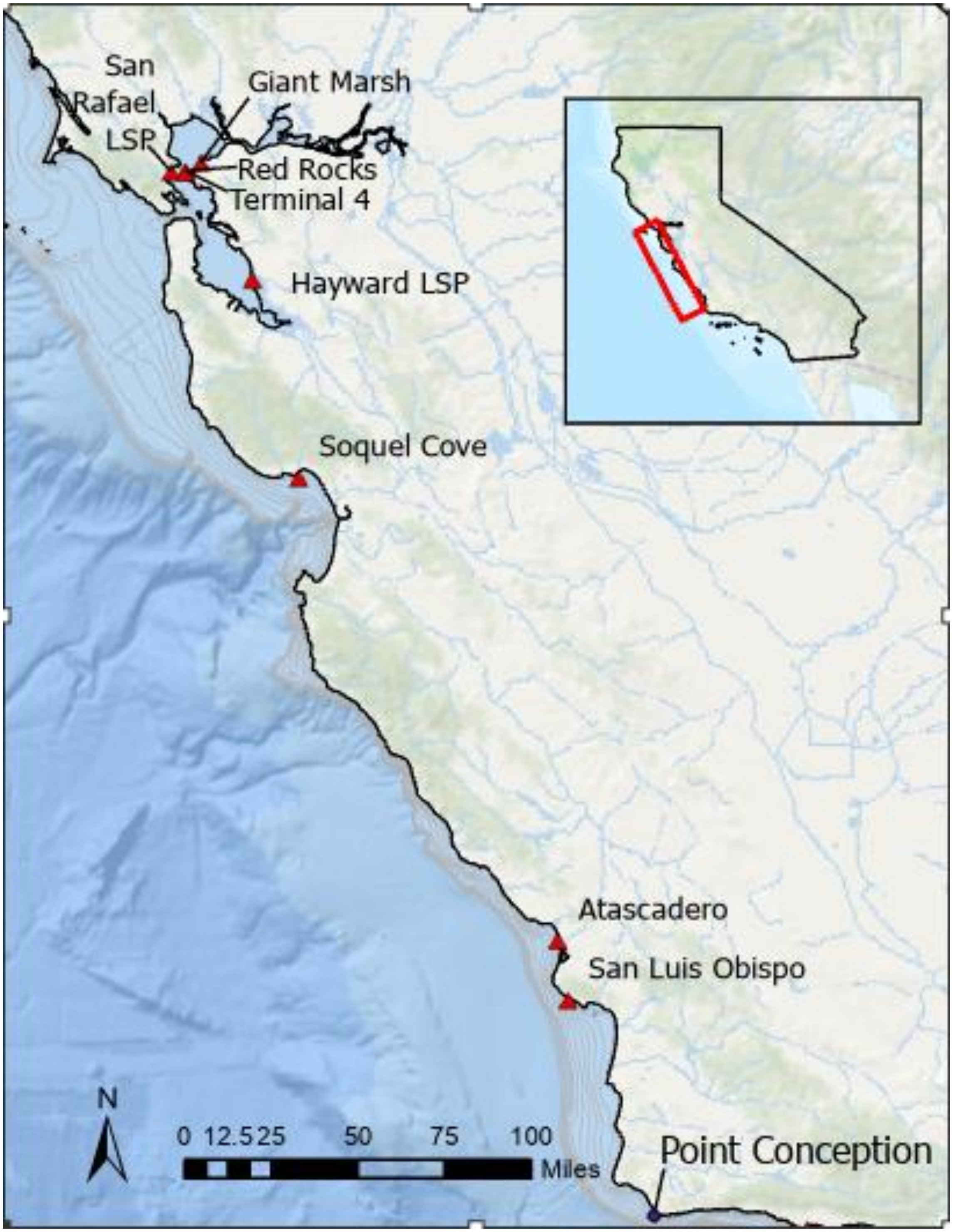

Figure 3. Known artificial reef centroids from San Francisco Bay to Pt. Conception.

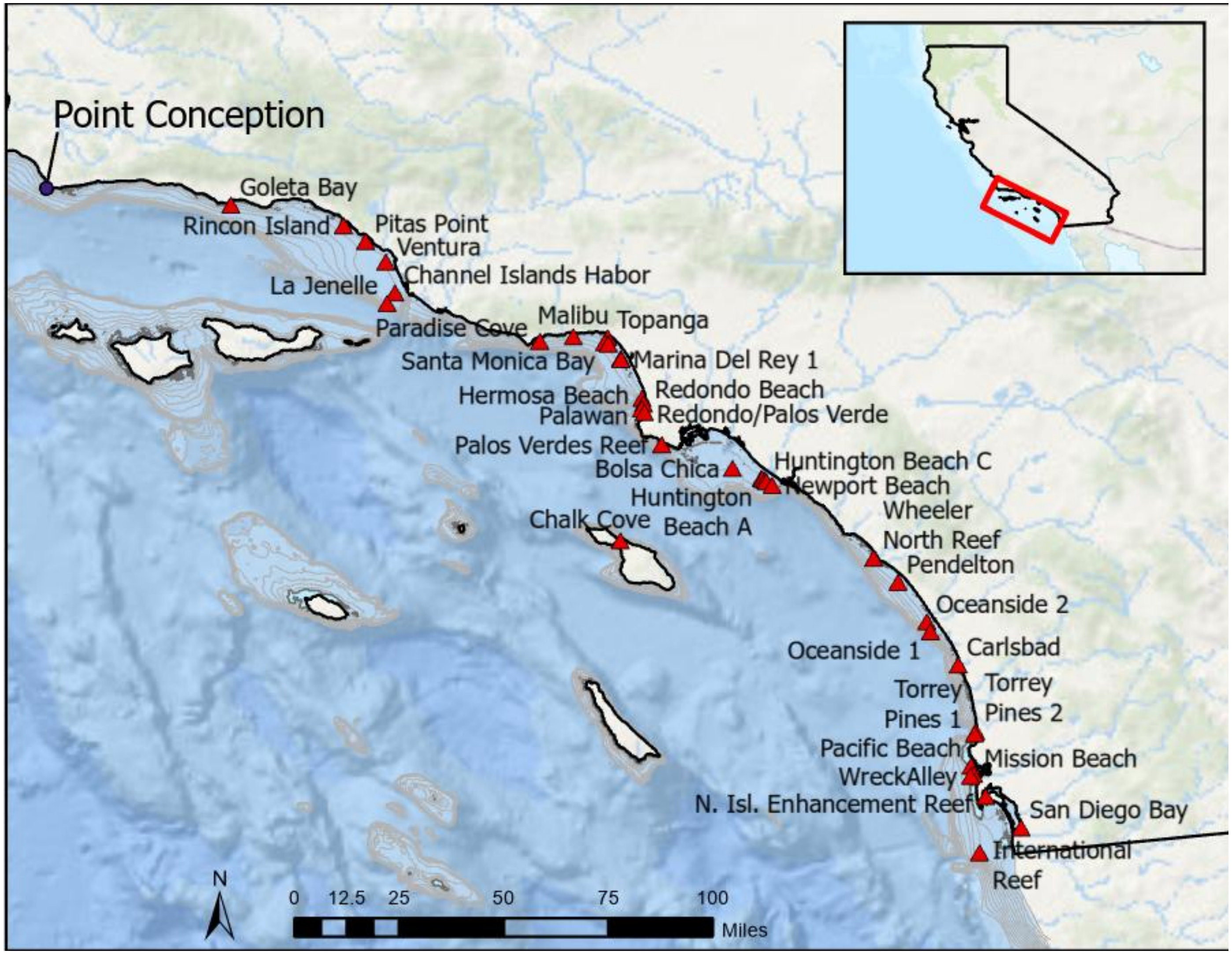

Figure 4. Known artificial reef centroids from Pt. Conception to U.S. Mexico Border.

1.4 Looking Forward

To develop the Plan's content, the team conducted a comprehensive review of the scientific literature and gathered input from recognized technical experts, stakeholders, California Native American tribes and artificial reef managers from across the country and around the world (see Appendix 2). That process revealed limitations in the existing statute. Reviewers suggested that California's definition of an artificial reef would better serve the state if it more closely reflected current scientific understanding. Specifically, the language on fish and invertebrate production is not broad or clear enough to address the range of requests regulators are now receiving, nor does it reflect current understanding of how artificial reefs function in the marine environment.

1.5 California Native American Tribes and Artificial Reefs

THIS SECTION WOULD BE WRITTEN BY TRIBAL CONTRIBUTORS IF THEY CHOOSE TO CONTRIBUTE CONTENT

2 Scientific Foundations of Artificial Reef Performance

Humans have placed submerged structures in the marine environment to attract marine species since the Neolithic period.[20–22] Over human history the complexity of the design has increased moving from simple fish attracting structures to attempts to create artificial habitats that mimic naturally occurring habit. Modern artificial reef projects should incorporate the full breadth of the best available science throughout development to maximize the likelihood of creating productive habitat. Artificial reef developers should also strive to meaningfully incorporate Indigenous Traditional Ecological Knowledge through respectful, collaborative co-development with tribal communities to ensure that projects reflect cultural values, long-standing stewardship practices and shared decision-making.

An artificial reef succeeds when it achieves the goals and objectives that were established before development begins.[23,24] Artificial reefs in California should have multiple goals and objectives that are centered around biological productivity and native biodiversity. Structures designed for non-biological goals (such as shoreline protection, sand retention and others) do not qualify as artificial reefs under the CARP and fall outside the best practices discussed in this Plan (see Section 2.4). To develop clear goals and measurable objectives, developers must understand both how artificial reefs function in the marine environment and the specific conditions of the proposed site. They must also prioritize factors that minimize harm and maximize ecological benefits, and plan for future changes in site conditions. This chapter provides a thorough, though not exhaustive, overview of key topics to consider when planning an artificial reef.

Past research on artificial reef performance often focused on whether these reefs simply draw marine life from surrounding areas or actually increase the total amount of marine life.[21] Scientists now broadly agree that framing this as an "attraction versus production" debate is a false dichotomy that does not reflect our current understanding of how artificial reefs actually function.[25–27] Section 2.1 reviews how scientific understanding of artificial reef functioning has evolved and identifies key factors that influence outcomes on artificial reefs. Climate change effects vary widely across locations, time periods, species and habitat types; developers must account carefully for them. Section 2.2 discusses these effects. In most cases, deploying an artificial reef converts one habitat type to another by turning soft sediment (sandy or muddy seafloor) into hard substrate (rock, concrete or other firm surfaces), which can affect an ecosystem's structure (what lives there), function (how it works) and services (the benefits it provides to people). Section 2.3 addresses key habitat conversion considerations. Projects that include structures at or below the waterline that have been designed for non-biological goals, such as sand retention, shoreline protection and surfing reefs, are increasingly common. Section 2.4 explains how these structures relate to artificial reefs as discussed in the Plan. Section 2.5 brings together some key performance planning recommendations.

2.1 Artificial Reef Functioning in the Marine Environment

Research has found that, when designed and sited appropriately, artificial reefs can attract fish and improve fishery yields.[28–33] They can also enhance productivity by creating habitat that supports critical biological functions including feeding, recruitment (the process by which juvenile fish join the adult population), predator-avoidance, growth and breeding.[34–37] However, increases in biological production are not universal, and outcomes depend heavily on geographic location, material and design.[27,35,38,39] As mentioned above, a central research question has been whether reef-associated species simply move to the reef from surrounding areas, or whether artificial reefs generate conditions that produce new biomass that would otherwise not exist.[34,40–43] When artificial reefs do produce new biomass, they can serve as a genuine tool for increasing biological productivity and ecosystem services.[44–46] By contrast, small or poorly designed artificial reefs that concentrate fishing effort or redistribute fish without increasing overall productivity or ecosystem benefits, can worsen localized overfishing rather than increase long-term fish stocks.[34,43,47]

Current research generally supports that well-designed artificial reefs both attract species and produce additional biomass, although measuring productivity across different spatial scales remains challenging.[38,48–52] The “production hypothesis” holds that some species are habitat-limited meaning the availability of suitable habitat, rather than food or other factors, caps their population. Adding new hard substrate can remove this constraint, giving those species more space to live and reproduce, increasing their overall productivity. [53] However, in many areas, populations of marine species have been reduced far below carrying capacity while the amount and quality of available habitat has not changed significantly, supporting that habitat is not a limiting factor.[54–56] Habitat limitation may re-emerge as populations rebound or during strong larval survival and recruitment years, when adding high-quality habitat could enhance post-settlement survival and support population recovery. There is an emerging scientific consensus that the two mechanisms of attraction and production exist on a continuum, with many factors influencing outcomes.[49,57–59]

Artificial reefs were historically built to enhance recreational fishing, which is why early research focused narrowly on the attraction-production question. As uses of artificial reefs have expanded and understanding of marine ecosystems has deepened, researchers now characterize how reefs function across entire ecosystems and species groups. This broader focus has revealed the importance of other factors, including changes in population dynamics as fish densities rise (density-dependent processes, in which crowding affects survival and reproduction), variability in reproductive output and the gradual shifts in community composition as a reef matures over time.[60] Determining whether habitat or other factors, such as recruitment rates or environmental stressors, limit a given species’ productivity is often difficult to disentangle, and requires monitoring a wide range of chemical, physical and biological conditions at the level of individual reefs and across the broader region.[49,61] For most projects, a well-supported approach is to design artificial reefs that serve multiple species and life stages.[3,62] Reef height above seafloor (relief), structural variety (complexity), diversity of habitat types within the reef (heterogeneity) and connections to nearby habitats (connectivity) all contribute to high-functioning artificial reefs.[63] However, planners should also build risk-reduction measures into the project design, since adding novel hard substrate to an area to form an artificial reef can give non-native invasive species a foothold.[64–67]

One effective way to assess whether artificial reefs are meeting their ecological goals is to compare their biological communities with those on natural reefs when possible. This approach emerged early as an important line of inquiry for understanding reef ecology beyond the attraction-production debate.[36] A review of 39 studies by Paxton et al. (2020)[4]

found that artificial reefs generally support fish communities similar to those on natural reefs, though differences linked to geographic location and material did exist. Siting artificial reefs near natural reefs speeds up colonization by reef species and strengthens performance monitoring. Artificial reefs can also improve connections between habitats, nutrient cycling (the movement of nutrients through an ecosystem), species richness and plankton abundance, delivering benefits well beyond providing more habitat for reef-associated species.[35] Researchers are increasingly moving beyond traditional fishery measures, such as fish density, biomass and species composition, to assess reef performance more holistically, examining overall productivity and biodiversity.[49] Accounting for the full range of influencing factors in both design and monitoring is critical to achieving and documenting successful outcomes.[23]

The expanding range of goals and objectives for modern artificial reefs has led researchers to assess biological outcomes across the entire food web spanning from the base, made up photosynthesizers such as algae and phytoplankton, through invertebrates and up to fish and other predators. Growing interest in artificial reefs as a tool to achieve broad net ecological benefits has deepened understanding of how artificial reefs affect both the growth of plants and algal life (primary production) and the animal life that depends on it (secondary production).[68] Increases in primary productivity have been linked to greater secondary production across a wide range of marine species.[69,70] Limitations on primary productivity include low availability of light and nutrients (bottom-up controls) or through grazing by organisms that consume primary producers (top-down controls).[49,71] To address nutrient limitation, some artificial reefs in Japan and China were specifically designed to increase nutrient availability and significantly increased primary productivity as a result.[72–75] It follows that changes in local water circulation that increase nutrient availability along with other inputs provided by the reef itself can boost primary productivity and, in turn secondary productivity.[20,49,76] Artificial reef, planners should survey the site thoroughly, including assessing the plant and algal life that forms the base of the food web and identifying ways to sustain or strengthen it, if possible.

2.2 Climate Change Considerations

Climate change impacts are accelerating and affect multiple aspects of marine ecosystems, with consequences for native marine biodiversity and human well-being.[77,78] How coastal and marine ecosystems respond to climate change-related stressors varies depending on the type of ecosystem, the species present and their interactions and the physical shape and structure of the coastline and seafloor.[78] Existing local human-caused stressors, such as fishing, dredging and shoreline armoring (protective hard structures along the coast), compound these effects. California's marine environment is already experiencing rising sea levels, warmer sea temperatures, marine heat waves, ocean acidification, declining oxygen levels in coastal waters (hypoxia), more intense storms and increased coastal erosion.[79] These changes produce a range of ecological consequences, including species moving toward cooler waters as temperatures rise (species range shifts), loss of native biodiversity, reduced nutrient availability and marine productivity and increases in harmful algal blooms.[80,81]

Reducing the impact of climate change on marine ecosystems and human communities is a California policy priority.[82–84] Nature-based solutions, approaches that work with and enhance natural systems rather than replacing them, form a key part of the state's climate adaptation strategy.[85] Well-designed artificial reefs can improve how ecosystems function under some conditions, and researchers are actively exploring whether they can also strengthen climate resiliency in California. Currently, California's artificial reefs have not yet generated enough data to show whether they can improve ecosystem resilience this way, but researchers worldwide are investigating it. Studies published to date focus primarily on coral reefs and suggest that under some conditions, artificial reefs can help build climate resiliency by supporting ecosystem structure.[86–88] Researchers and practitioners in California are also investigating whether artificial reefs can help reduce shoreline erosion, either by absorbing wave energy or by altering how sand and particles move and accumulate (e.g. widening beaches). Several California artificial reefs projects explicitly combine shoreline protection with biological objectives as part of a climate resilience strategy. Although these projects are in their early stages, a State Coastal Conservancy project in San Rafael on San Francisco Bay reported a 30% reduction in wave energy that may translate into lower shoreline erosion rates.[89–91]

Because climate change affects conditions differently by location,[9293] project developers must factor its impacts into every stage of artificial reef development. Site selection, design and materials all require particular attention (see Chapter 3). A site or design that is well-suited to the project's goals today could become unsuitable as sea levels rise, storms intensify and other environmental conditions shift. Planners can draw on existing data sources and visualization tools to evaluate how conditions at a proposed site may change over time (see Appendix 6). Before deploying any artificial reef, planners should conduct vulnerability assessments to help ensure the reef will remain effective over its intended lifespan.[94–98]

2.3 Habitat Conversion Considerations

Human-caused habitat conversion which is the replacement of one habitat type with another has continuously reshaped California's marine environment since the arrival of

European colonialists in the 1700s.[99] Habitat conversion modifies the structure, function and services of natural ecosystems.[100] Changes to the physical and chemical features of a habitat drive corresponding changes in the biological communities that live there.[101] A common cause of habitat conversion is human-caused chronic sedimentation which is the ongoing buildup of sediment that gradually buries hard surfaces, reducing the rocky seafloor habitat that many species depend on.[102,103] In the context of artificial reefs, habitat conversion most often occurs when hard substrate, such as rock, is placed onto sandy or muddy seafloor (soft sediment habitat). Planners should assess the ratio of soft to hard substrate in the project area to understand how much each habitat type is present and how the planned reef will alter that balance.[104] Understanding both the positive and negative impacts of this conversion is essential to designing artificial reefs that maximize benefits.

Multiple California policies and directives support incorporating net ecological gain into project planning (see Appendix 4). Net ecological gain means that after deployment of a project, there is an increase in ecological functioning that improves the delivery of a valued ecosystem services in the affected environment relative to the conditions prior to project deployment.[105,106] The specific ecosystem attributes, services, and habitat types considered in such assessments may vary depending on project objectives, regulatory mandates, and stakeholder values. Incorporating this concept into planning from the start helps avoid or minimize negative impacts and identify key ecosystem attributes that can be targeted for enhancement in project design [105] (see Appendix 7).

Ecological valuation and equivalency analyses which measure what a habitat is worth and calculate how much new or restored habitat is needed to make up for what is lost are most used in formal legal proceedings that assess harm to natural resources. These tools (such as Habitat Equivalency Analysis, mitigation ratios) can also be applied in the early stages of reef planning to help maximize benefits.[107,108] Sandy and muddy seafloor habitats provide a range of valuable services, such as sequestering carbon, cycling nitrogen pollution from human sources as well as other nutrients and providing nursery and foraging grounds (Table 1).[109–112] When an artificial reef converts this habitat, the lost services can serve as the “impact” in ecological valuation and equivalency analyses. Well-designed projects can potentially offset those initial losses (Figure 5). Planners can achieve this by designing reefs that support the recovery of the seafloor community in the soft sediment between reef modules, or by increasing ecological function in the transition zone between reef and surrounding soft sediment (the ecotone) through the nutrients and organic matter the reef contributes to surrounding habitats.

Ecological habitat valuation and benefit prediction can also guide planners in offsetting the impacts of habitat conversion.[113–115] Applying these concepts requires monitoring meaningful indicators (see Section 3.4), which should be identified during the planning phase, that go beyond simple structural measures like fish density or area covered. Historically, the presence of a habitat-forming species such as kelp or eelgrass has been assumed to mean the ecosystem is functioning as a natural version of that habitat would. However, some studies have shown that this is not always the case: a reef that structurally resembles natural habitat may not deliver the same ecological and ecosystem services.[113,114,116,117] Project planning should account for how the converted habitat will function and how populations of different species may change after the reef's deployment. Monitoring these aspects alongside the production of reef-associated species' biomass provides a more complete picture of reef performance and generates the data regulators and practitioners need to improve future projects. For reef planning to be truly effective, it should incorporate a benefit-maximizing design either on its own or alongside efforts to offset the ecological harm caused by habitat conversion.

Table 1. Potential impacts to the structure and function of soft sediment habitat converted to hard substrate, and potential replacement mechanisms provided by well-designed artificial reef.

Loss of structure	**Loss Function(s) & Service(s)**	**Potential replacement mechanism**
Benthic infauna	Filter feeding, nutrient subsidies, bioturbation, reduction in forage for marine and avian species	Benefits to the soft sediment community between modules, increased function in adjacent soft sediment habitat, sessile invertebrate settlement on hard substrate
Rugosity	Sediment transport, current velocity	Changes may support different but equally valued functions (e.g. slower current velocity may better support settlement of subaquatic vegetation)

Benthic microphytoplankton	Primary production	Replaced by subaquatic vegetation or increases in midwater phytoplankton due to nutrient subsidies, recovery of benthos in and around project

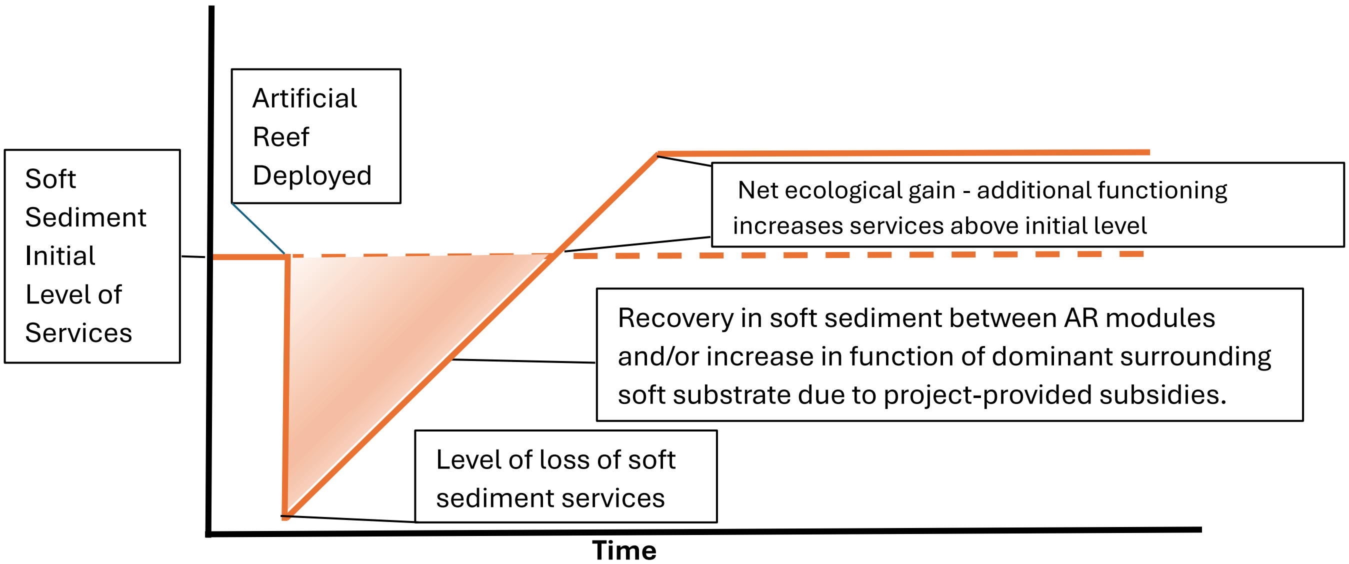

Figure 5. Conceptual model of habitat conversion from soft sediment to hard substrate through development of an artificial reef. Net ecological benefit is shown above dotted line which indicates achieving a structure, function and services that exceed what is lost by the impact to soft sediment habitat.

2.4 Other Submerged Structures

Structures engineered specifically for non-biological goals such as increasing sand retention, providing shoreline protection or creating surfing opportunities are becoming increasingly common.[118–120] Published literature often calls them multi-purpose, multi-objective or multi-functional artificial reefs,[121,122] but that label can be misleading. California's current statute definition of an artificial reef draws a distinction between structures designed for biological production goals and those engineered primarily for non-biological outcomes, even if the latter may incidentally support some reef-like ecological functions. Canada and the European Union recognize the same distinction, as do the United Nations Environment Programme (UNEP) 2009 *Guidelines for the Placement of Artificial Reefs* and the *National Artificial Reef Plan*.[1,123] Projects with elements below the mean high tide line that are engineered for non-biological goals and objectives will be evaluated under California's existing regulatory framework on their merits, but they are not artificial reefs as defined in the California Artificial Reef Program. The CARP Plan does not cover them; its guidance applies only to projects purpose-built to function as artificial reefs, which by definition should increase biological productivity and native biodiversity.

Projects engineered to alter the physical dynamics of coastal or shoreline processes in pursuit of non-biological outcomes have produced variable results.[119,121,124–126] One well-known example is Narrowneck Beach on the Gold Coast of Australia, where a structure built from sand-filled bags made of a permeable synthetic fabric was installed between 1999 and 2000 to address severe beach erosion. Eleven years later, that included periodic sand replenishment, the project had widened the beach to an average of 164 to 328 feet (50 to 100 meters) and helped form a sandbar offshore that improved both beach retention and surfing conditions.[118] Performance declined in subsequent years, and in 2017 the offshore sandbag structures were refurbished to raise them back up to their designed elevation of about 5 feet (1.5 meters) below mean lower low water (the average height of the lower of each day's two low tides).[127] Narrowneck Beach's offshore elements shifted sediment flow, causing sand to accumulate on the side of the structure that faces incoming currents which helped to shield the coastline behind it.[128,129]

Pratte's Reef, off El Segundo, offers a Californian example. It was built in 2001 using large sandbags to improve surfing conditions, as required mitigation for a coastal construction project that had disrupted a nearby offshore surfing wave. Because the project was considered experimental, the design included provisions for removal. The reef deteriorated rapidly under wave attack — it was too small and structurally unable to remain in place and failing to create a reliable surfable wave. Removal was required, but the sand-filled bags proved difficult to extract.[130] In response, the Surfrider Foundation adopted a policy on artificial surfing reefs that emphasizes protection of California's natural surf environment.[131]

Structures like these can be important tools for shoreline and beach protection, but they require careful analysis of existing conditions and clearly defined goals and objectives to be effective. During permitting, regulators may find it useful to credit any incidental biological benefits as harm-reduction measures within the mitigation hierarchy (Cal. Code Regs., tit. 14, § 15370). This approach could reduce biological monitoring requirements, freeing resources for the more intensive physical monitoring that projects focused on altering existing shoreline processes require.

2.5 Performance Planning Recommendations

Use existing information — When available, use data from existing long-term monitoring programs at both project and control sites to better understand how artificial reefs function at both local and broader scales (see Section 3.4 for the types of data to look for.) California has several long-term monitoring programs covering its nearshore ecosystems (see Appendix 6). These programs have established long term-trends in key biological, physical and chemical parameters and offer a basis for evaluating how future artificial reef projects perform relative to adjacent natural reefs and regional trends. These data can also help estimate how deploying an artificial reef affects productivity at both local and regional scales. Tracking established trends using data from both commercial and recreational fishing records and independent scientific surveys at control and project sites (such as Before-After-Control-Impact or Before-After-Gradient) is critical to understanding production at all levels of the food web. Much of these data is publicly available for download or can be obtained by contacting the relevant program via their websites (see Appendix 6).

Account for changing ocean conditions — Build performance monitoring around both biological (such as species composition) and non-biological metrics (such as shoreline erosion rates) that reflect the impacts of climate change and support ecosystem resiliency. There are well-documented approaches to assessing climate change-related impacts in temperate marine ecosystems, and they should be incorporated into both pre-deployment site characterization and post-deployment monitoring[132,133] (See Section 3.4 for suggested performance metrics.)

Use quantitative approaches to model expected gains and losses — Adapt existing tools such as the Puget Sound Nearshore Habitat Conversion Calculator[134] and the Aquatic Resource Type Conversion Evaluation Framework Version 2.0[135] to measure how much ecological function is gained and lost. Regulators and practitioners should continue to advance research to develop a standardized way to measure and compare habitat value to give project developers a clearer basis for designing reefs that deliver the greatest ecological benefit. Likewise developing, a Habitat Service Values Model for canopy-forming and sub-canopy forming kelp would be a valuable tool for improving artificial reef outcomes.

Use pilot-scale projects to evaluate other submerged structures — Pilot-scale projects with clearly defined quantitative physical goals can help determine the effectiveness of structures engineered for non-biological goals. To assess how well these structures perform, monitoring physical metrics at local and broader scales will be required. Developers should secure funding for required monitoring before deployment.

3 General Guidance for Artificial Reefs

Artificial reefs are costly to design, construct, monitor and manage, and they can have negative impacts.[136,137] Developers and regulators must make planning and monitoring decisions about the design, materials, siting and performance with the goal of ensuring each project achieves its intended goals and that the results are clearly documented and accessible. Developers should apply the guidance in this chapter early in the planning process; regulators may also draw on it to help inform the conditions they include in permits. Artificial reef outcomes depend primarily on materials, design and location.[138] The right choices for each element will vary by project and should follow directly from its goals and objectives. Even so, some general principles apply to all artificial reefs regardless of project-specific details. Sections 3.1-3.3 discuss these best practices.

Building a statistically robust sample design into the early planning stages is equally important for project success. Section 3.4 outlines key considerations for developing a thorough monitoring plan as planning progresses. A fully funded monitoring program should be in place before construction of any artificial reef begins. Regulators will set the specific monitoring requirements for each project as a condition of permitting. The general best practices discussed in Section 3.4, including the recommended timing for monitoring, draw on the Technical Writing Group's expertise in California ecosystems and environmental monitoring.

3.1 Materials

Materials selected for artificial reefs should help maximize productivity and native biodiversity by creating the kind of physical structure and ecological conditions that productive and biodiverse natural reefs provide. Decisions about material selection should draw on scientific comparisons of material types and lessons from past artificial reef projects. Artificial reefs can be built using natural materials, materials of opportunity (see below) or prefabricated (purpose-built) materials. All materials must be durable, non-toxic and not react chemically with seawater or surrounding organisms. They must hold up in the marine environment without significant degradation over time.

- **Ecology**: Materials should have the structural, chemical and surface properties needed to support the intended habitat and ecological function without harming nearby marine communities and neighboring habitats. Materials brought in from other locations that could introduce invasive species should not be used unless a special study confirms they are appropriate.

- **Complexity**: Materials should mimic the properties of high-quality natural reefs — for example, supporting high native biodiversity and the production of animal biomass. Depending on project goals and objectives, specially designed structures may be used to increase habitat complexity and variety, such as 3D-printed or modular structures with gaps and crevices. New materials should be tested at pilot scale before large-scale deployment.
- **Stability**: Materials should remain stable and intact within the proposed environment for a sufficiently long time frame to achieve the project goals and objectives. They should not shift or deteriorate because of storms, currents, waves, interactions with fishing gear or other external forces. One exception: biodegradable materials may be used in certain species restoration projects, for example, where a temporary hard surface is needed only until the reef is self-sustaining, as in some oyster reef restorations. This is acceptable only if developers have previously tested the material and shown it works without harmful side effects (such as leaching chemicals or shedding particles into the water).
- **Natural materials**: Rock and materials of biological origin, such as oyster shell, are examples of natural materials. Where scientific data support it, project developers should incorporate natural materials into prefabricated structures to attract and support the attachment and growth of marine organisms. Granite boulders and similar erosion-resistant natural rock are preferred. Developers should also consider including native sediments such as baycrete (see Glossary) in prefabricated structures when appropriate.
- **Engineered and novel materials**: Engineered and novel materials are synthetic and they do not occur naturally. This category includes well tested materials like cement and concrete as well novel materials such as geopolymers. Before deploying any novel material in the marine environment, even at pilot scale, laboratory testing under real-world conditions should confirm it is stable, non-toxic and non-leaching and that it can support the attachment and growth of marine organisms similar to natural materials.
- **Materials of opportunity**: Studies have shown that some materials of opportunity can function ecologically much like natural rocky reefs in California.[14,76,139,140] These discarded or surplus materials that were not originally intended for the marine environment may be easier to obtain and less expensive than purpose-built alternatives. Materials of opportunity such as surplus concrete, rock, steel and ceramic materials may be used for artificial reef construction if developers can show, before placement, that the materials are durable, non-toxic, inert in the

marine environment and able to create high-quality reef habitat that supports the settlement of marine organisms. Some materials of opportunity, such as retired vessels, require certification from the Environmental Protection Agency confirming that their proposed use will be compatible with "applicable water quality standards and other appropriate environmental protection requirements" (16 U.S.C. §1220(b)). Materials should have a pH that supports active settlement for the widest range of species (this is often a neutral pH). Regulators may require documentation of ownership, including prior ownership and any prior uses.

- **Degradation and discharge of toxins**: Degradation includes both the physical breakdown of a material, which could undermine reef stability, and the release of toxic compounds that could harm reef organisms. Materials should be chemically inert in the proposed environment and should not pose a long-term hazard. Plastics should be avoided to the maximum extent feasible; if used, they should be UV-resistant and stable enough to prevent shedding microplastics.
- **Climate change impacts**: Developers should account for the effects of climate change when selecting materials, including sea level rise and increasingly frequent and intense storms.

Additional details about appropriate materials for artificial reef construction can be found in the *Guidance for Marine Artificial Reef Materials* 3rd Edition[5] and *The National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs.*[6]

3.2 Design

During the early planning phase, before submitting permitting applications, project developers should consider the following:

- **Objectives and performance metrics**: Project developers should define clear, measurable ecological and socioeconomic objectives relevant to the project, describe the expected biological and physical outcomes and explain how success will be evaluated over time, for example, through improvements in native biodiversity, productivity, fishery benefits or cultural values.
- **Scale, footprint and layout**: Developers should match the overall project scale, module/habitat element dimensions, and spacing with the stated goals, objectives and available funding. They should estimate the total project area and break it down by the physical footprint of the reef structure, module spacing and the extent of ecotones and halo habitat zones (see Glossary and Figure 6). Developers should characterize existing habitats within that footprint, describe the expected impacts to those habitats and explain how the design will deliver benefits while minimizing

its footprint and disruption to existing marine ecosystem structure, function and services. They should prepare alternative designs tied to site-specific assessments and explain clearly why the chosen design is preferred.

- **Habitat complexity, relief and variety**: Developers should build in habitat complexity at every scale, from fine surface textures and small gaps and crevices to the overall height (relief) and shape of the reef and ecotone habitat (Figure 6) to provide surface and shelter for reef-associated species across life stages and to enhance food availability and the movement of nutrients and eggs/larvae to the reef. Developers should vary these elements across the artificial reef to increase habitat variety, enhance native biodiversity and support production. Design elements can target different species, multiple life stages of a single species and/or specific life stages for which suitable reef habitat is scarce.
- **Depth, elevation and structural stability under changing conditions**: Developers should design depth and elevation, particularly for shallow and nearshore reefs, to ensure resilience to wave action, tidal fluctuations and storm events. They should assess the structural stability of the reef under expected wave and current forces, evaluate how the seafloor is likely to respond, and assess resilience to sediment buildup, erosion or sinking. Project developers should also describe how projected sea level rise and changing storm patterns may affect performance over time.
- **Connectivity within the reef and across the broader marine environment**: Developers should arrange the reef's edges, height (relief) and spacing between structures to encourage species movement and interaction within the reef, including foraging in the halo zone (see Glossary) and feeding in the open water above it, sometimes called the dome effect (see Glossary and Figure 6). They should orient modules to take advantage of prevailing currents, improve the delivery of nutrients and food to the reef and position the reef to strengthen connections between different water depths and with nearby reefs, kelp forests, seagrass beds, estuaries and other marine habitats (see Figures 6 and 7).
- **Intended uses and visual and aesthetic considerations**: Developers should describe the expected uses of the reef, which may include recreational or commercial fishing, diving, cultural practices, education or scientific research. They should explain how the design supports or separates these uses where appropriate. They should assess visual and aesthetic concerns, particularly for reefs visible from the surface or designed to support recreational or cultural activities.
- **Pilot projects, adaptive management and long-term evaluation**: Where novel materials or designs are proposed, developers should test them at pilot-scale before committing to full implementation and include a plan for modifying or removing the reef if it fails to meet its objectives or causes unintended harm.

Developers should build long-term monitoring into the artificial reef design and explain how monitoring results will guide adaptive management decisions (see Section 3.4).

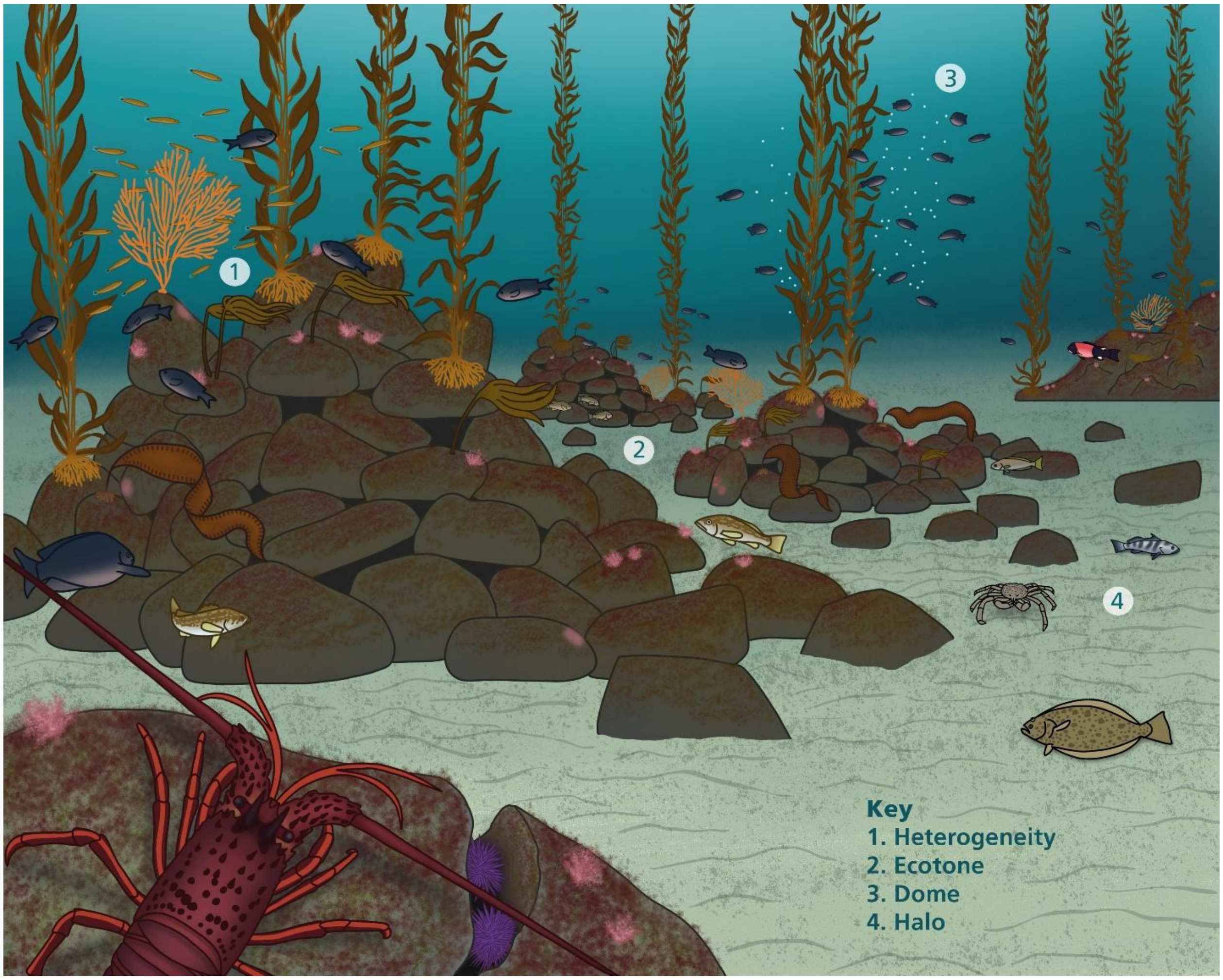

Figure 6. Stylized Southern California nearshore artificial reef constructed of stacked quarry rock adjacent to a natural reef (upper right). (1) Heterogeneity or habitat variety is created by differences in height (for example, tall piles of quarry rock vs. lower-lying areas) and by variation in rock size, creating diverse microhabitats that maximize biodiversity. (2) The ecotone (the transition zone where rock meets sand) is an area where some species tend to concentrate and where reef and sandy-bottom communities interact most intensively. (3) The dome effect occurs above the reef, where fish that feed on plankton gather in the open water and carry nutrients and energy back to the reef through their waste and feeding interactions with other species. (4) The halo effect extends productivity beyond the reef into the surrounding sandy seafloor, where increased feeding by reef-associated organisms and the addition of nutrients and organic matter from the reef boost the overall abundance and growth of fish and invertebrate, while also drawing in species that normally inhabit sandy or muddy bottoms.

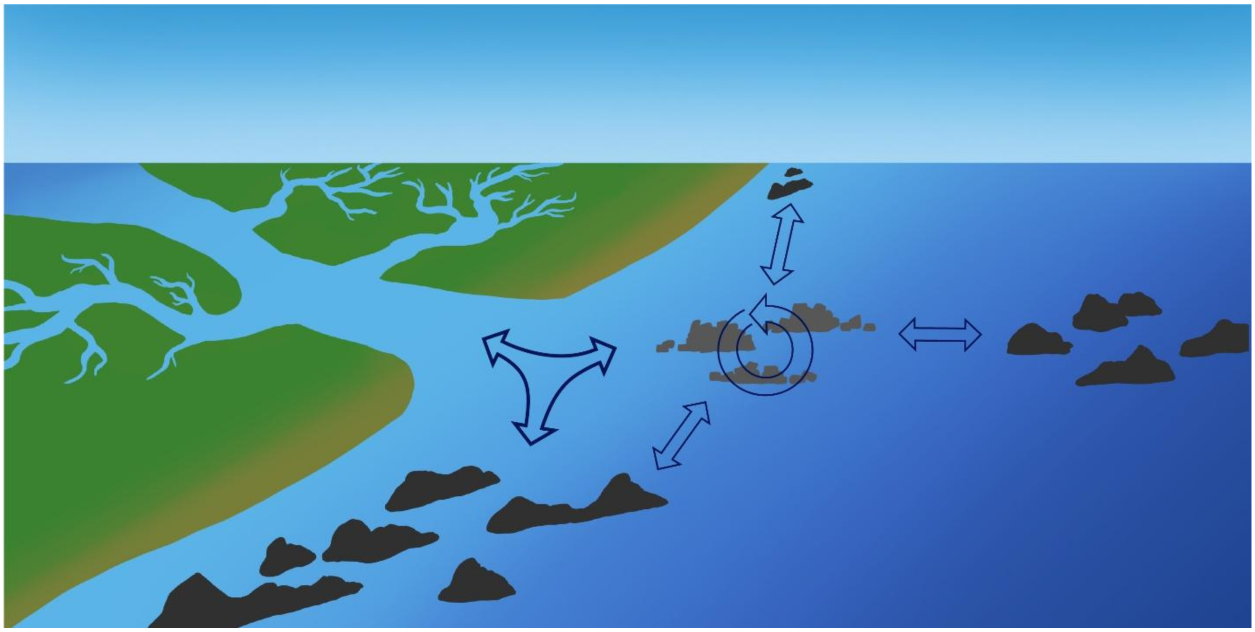

Figure 7. Schematic of idealized connections between an artificial reef, surrounding natural rocky reefs an estuary.

3.3 Location and Siting

Project developers should conduct a comprehensive assessment of the local physical environment, ecological conditions and human uses of the proposed location before placing an artificial reef (see Section 3.4). These assessments should help determine whether the site can support a reef that meets the project's goals and objectives, identify potential conflicts with existing users and establish baseline conditions to compare with future monitoring. A well-chosen location can strengthen ecological processes by increasing connections among habitats (Figure 7). However, artificial reefs can also create problems or conflicts, so project developers should weigh the risks and benefits of placing a reef at each candidate location against the alternative of leaving the site unchanged. Tools such as marine spatial planning, which maps existing ocean uses to minimize conflict, can help identify the best location for a reef while avoiding interference with uses such as defense, shipping, recreation and fishing.[141] Project developers should identify and evaluate multiple candidate locations through site-specific assessments and explain clearly why the chosen area is preferred.

Physical environment aspects to consider:

- Coastal processes, including sediment movement
- Shoreline processes, including erosion, protection and resilience
- Water depths across the site (maximum, minimum, mean)

- Water stratification (the layering of water at different temperatures or salinities at different depths)
- Tidal period
- Direction and velocity of currents
- Wind and wave characteristics
- Distance to the nearest coastline
- Storm frequency and intensity
- Characteristics of the seafloor, including the size and depth of sediment particles
- Local sediment sources
- Water quality, including temperature, salinity, water clarity (turbidity), dissolved oxygen and nutrient levels
- Local concentrations of suspended particles and the erosive effects of currents and waves (scour)

Ecological conditions to consider:

- Proximity to spawning, nursery areas and other sites important for reproduction
- Migration routes and foraging areas of marine species
- Proximity to corridors that marine species use to move between habitats at different stages in their lives including pathways of larval dispersal and recruitment (connectivity) and networks of connected populations
- Proximity to marine protected areas and other management zones, such as National Marine Sanctuaries and Marine Protected Areas, that could enhance habitat connections or draw species away from protected areas into areas where they may be caught or harvested

Human uses to consider:

- California Native American tribal cultural heritage
- Recreational activities such as fishing, boating, surfing and diving
- Tourism
- Commercial fishing
- Areas of natural beauty or cultural, historical or archaeological importance
- Shipping lanes or anchorages
- Designated marine disposal sites
- Seabed pipelines
- Ports and harbors
- Military or defense use areas or exclusion zones, including ordnance dumpsites

- Engineering uses of the seafloor such as seabed mining, undersea cables, water intake and discharge locations, and desalination
- Offshore energy developments and associated infrastructure
- Aquaculture facilities
- Other existing artificial reefs
- Accessibility for monitoring and evaluation
- Vessel transportation routes such as ferry corridors
- Areas used for disposal of dredged material

3.4 Performance Monitoring

Regulatory permits almost always require performance monitoring. Regulators set monitoring requirements based on each project's goals and objectives on a case-by-case basis. The CARP Plan recommends that all future artificial reef projects should include the goal of maximizing biological productivity and native biodiversity, to which project developers can add other goals and objectives. The primary purpose of monitoring artificial reefs is to assess whether a project is achieving its goals and objectives. Because artificial reefs are built to be long-term structures, project developers must plan for ongoing management and monitoring to ensure the reef remains safe and continues to meet its goals and objectives. Regulators typically require permit holders to submit at least annual reports for a specified period, with specific requirements determined on a project-by-project basis. These generally include at minimum a description of construction materials, activities and final design as well as the physical and biological condition of the reef and control sites before and after deployment.

Monitoring should continue until a reef's goals and objectives have been met and persist over a period sufficient to encompass natural variability and relevant ecological time scales for the species and ecosystem functions being assessed. Because ocean conditions change and marine communities are dynamic, monitoring should run long enough to allow a statistically sound comparison of results over time between the artificial reef and nearby natural reefs. It is important to monitor in a way that allows regulators to understand the natural (e.g. seasonal, annual, etc.) variation in environmental conditions and biological populations at a project site. This allows observed changes to be distinguished between natural variation and project-related effects. It takes multiple years of sampling to determine what the natural variation is at a site. The timelines discussed below for 1-5 years are based on understanding the natural variation and every 5 years to determine if changes are occurring at the project site due to natural events, or due to the placement of an artificial reef.

Generally, monitoring should begin before a project is deployed and continue for a minimum of five years after deployment. Regulators will determine specific monitoring requirements, and project developers should budget for monitoring and adaptive management costs during the planning phase, including any course corrections (as allowed by regulators) as the project progresses. Monitoring should test specific predictions about the reef's expected physical, chemical and biological outcomes, tied directly to its goals and objectives. Monitoring can also reveal whether a reef has become hazardous or is failing to meet its goals and objectives, which may indicate the need to remove the project from the marine environment.

Reef designers should develop a conceptual model which is a diagram or framework that maps expected outcomes as well as potential unintended or undesirable results. Figure 8 provides one example that shows desired outcomes of a hypothetical open coast subtidal artificial reef. It shows how reef construction sets off a chain of responses — structural changes, enhanced ecological processes and broader ecosystem effects — using a framework similar to that of Clancy et al. (2009).[142] To make monitoring comprehensive, designers should also prepare a list or flowchart of undesirable outcomes.

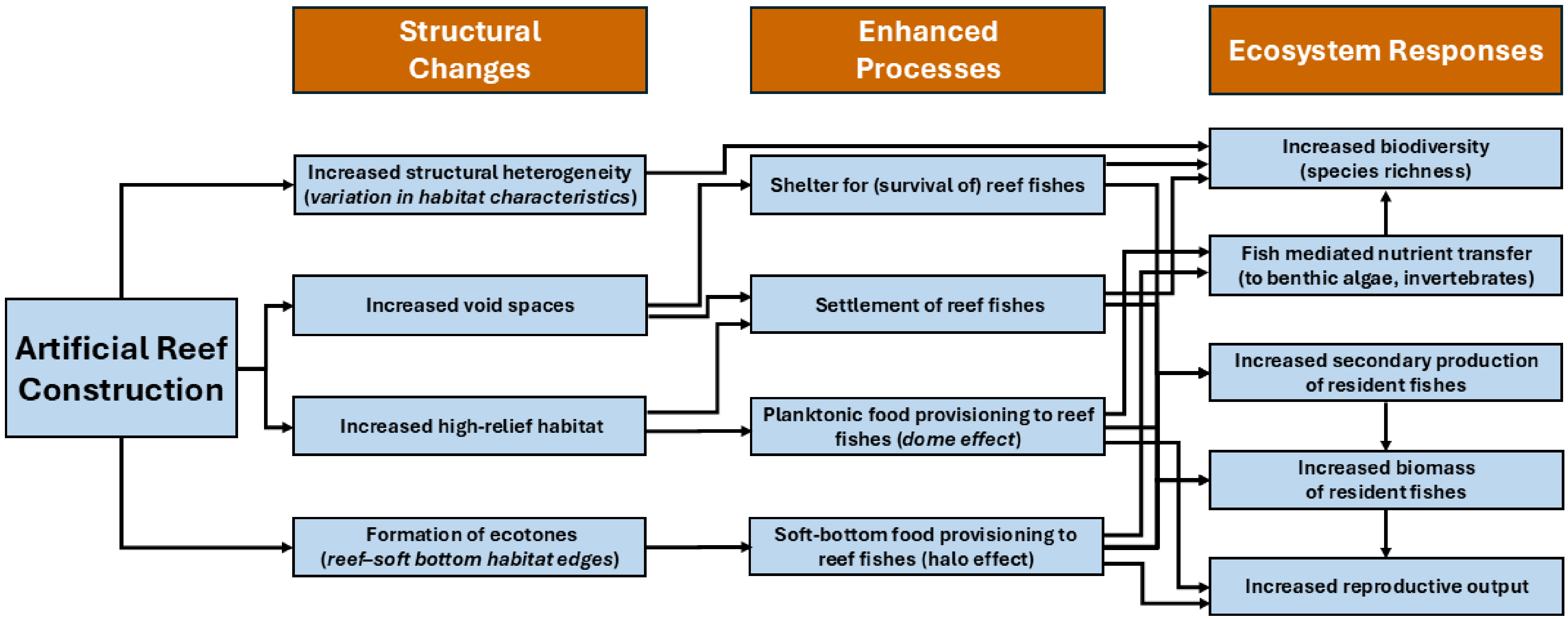

Figure 8. Conceptual model for ecological responses of a hypothetical open coast subtidal artificial reef. Artificial reef construction on the left results in habitat structural changes, which then restore and/or enhance ecological processes and ecosystem responses. Based on similar conceptual models in Clancey et al. (2009) incorporating concepts from Pondella et al. (2022) and Pondella et al. (2025).

Physical and Chemical Monitoring

What to monitor: Monitoring physical and chemical conditions determines how artificial reefs affect the surrounding ecosystem and informs biological monitoring. Project developers select a reef site in part because its conditions appear generally suitable, but those conditions can shift, both gradually due to climate fluctuations and in unexpected ways due to localized currents and eddies. Tracking key water quality conditions (e.g., temperature, salinity, dissolved oxygen, nutrients, pH, turbidity-solar radiation), water dynamics (e.g., currents and waves) and sediment movement (e.g., erosion caused by water flow and sediment buildup) provides important local context for choosing the right site and interpreting biological monitoring results. If unconventional materials are proposed, developers should include contaminant monitoring (e.g., testing sediment chemistry near reef structures or checking for leaching) to confirm the materials are stable and will not cause unintended harm. Developers should also consider monitoring a nearby control site and other strategically selected locations.

Physical and chemical monitoring can strengthen biological monitoring by testing hypotheses made during the design phase. Developers build reefs to create physical conditions that support desired habitat and ecological outcomes, sometimes supplemented by outplanting algae, plants or animals onto the structure. Design decisions should give rise to testable predictions about how the reef structure will interact with the site's physical and chemical conditions. Tracking the biological responses can show whether objectives were met but may not explain *why* results turned out as they did. For example, the Giant Marsh Project in San Francisco Bay (see Section 4.1) conducted biological monitoring but also measured light penetration, water quality, waves, currents and seafloor elevations to document both baseline conditions and conditions near the reef structure that might have been affected by it.[143,144] Repeated sonar surveys can assess how sedimentation is affecting the reef and whether modules remain at the right height and are structurally stable.[145,146] Designers should map these predictions in the conceptual model to help develop a comprehensive monitoring plan for physical and chemical monitoring (Figure 8).

Where to monitor: Monitoring should cover the full reef footprint, halo zone, adjacent habitats and control sites (see Figure 6 and 7). For small to medium projects, sample water quality and sediments around all modules and habitat types at a sufficient level to assess goals and objectives. For larger projects, where physical conditions are more variable, sample proportionally across different zones or habitat types and relevant habitat characteristics such as depth, relief (height), complexity, edges, ecotones (transition zones between habitat types) and slopes to assess goals and objectives.

When to monitor: Baseline monitoring should occur at least one year before construction begins and again within six months before the construction start date, covering all areas: the reef footprint, halo zone, adjacent habitats and control sites (Figures 6 and 7). Baseline conditions should also include a summary of historical environmental conditions using available data from government agencies, academic research and other sources (see Appendix 6) to identify trends relevant to the reef design and performance. Monitoring should continue through the construction phase so that, if serious or unexpected problems arise, designers can modify the reef design as regulators permit. In years one through five, monitor at least once a year, timed consistently by season (typically summer or fall), and coordinate with existing regional programs where possible. After that, sample every five years until the physical and chemical conditions are fully characterized, in conformance to project permits and the approved monitoring plan.

Biological Monitoring

What to monitor: Monitoring should be broad enough to assess effects on native biodiversity (fish, invertebrates, macroalgae, seagrasses and seafloor cover) and productivity,[146–148] adding metrics to evaluate project-specific objectives such as providing habitat for rare or protected species, commercially or recreationally important fish and use by species at different life-stages. Such metrics may include studies of how juvenile fish and invertebrates are settling into the reef, growth and productivity, movements of juveniles and adults as well as reproduction. The monitoring program should also be designed to catch unintended outcomes, including the possible introduction of invasive species and displacement of existing species. Developers should ground the monitoring program in a thorough pre-construction baseline, with clear, testable predictions about what is expected to change, where and when. These predictions should address the reef's expected effects on both nearby and regional habitats, as relevant to the project goals and objectives.

Where to monitor**:** Monitoring should cover the full reef footprint, halo zone, adjacent habitats and control sites located both upcurrent and downcurrent (Figure 7). For small to medium projects, sample all modules, construction materials and habitat types, sufficient to assess goals and objectives. For larger projects, sample proportionally across different zones and habitat types across modules, materials and relevant habitat characteristics such as depth, relief (height), complexity, edges, ecotones (transition zones between habitat types) and slopes. In the halo zone (within about 100 feet of the modules), sample soft-bottom communities to capture halo effects (feeding halos), including stations both upcurrent and downcurrent where practical. At adjacent habitats such as natural reefs, seagrass beds and soft-bottom areas, design monitoring to detect shifts in species distribution, the movement of species from the reef into surrounding areas, movements of juvenile fish and invertebrates to where they settle as adults and the possible arrival of invasive species. Select control sites close to the project area but no more than 0.6 miles from the reef, matched for depth, habitat and wind and wave exposure, to distinguish changes caused by the reef from natural regional variations such as El Niño events. If existing regional monitoring programs use the same sampling protocols, developers can incorporate their data at control sites.

<u>When to monitor:</u> Baseline monitoring should occur at least one year before construction begins and again within six months before the construction start date, covering all areas: the reef footprint, halo zone, adjacent habitats and control sites. Monitoring should continue through the construction phase so that, if serious or unexpected problems arise, designers can modify the reef design as regulators permit. During this time, developers should also monitor the design components described in Section 3.2 and request modifications as needed to meet goals and objectives, subject to regulatory approval. During construction, useful biological monitoring includes observations of habitat types — their location, size, depth, orientation and connectivity — as well as the spawning, nesting, rearing and sheltering habitats, feeding/foraging areas and migration corridors of key species.

Conduct a post-construction survey within six months of completion to confirm structural stability, document initial conditions and detect when species are beginning to colonize the new habitat. In years one through five, sample at least once a year, timed consistently by season (typically summer or fall), coordinate with existing regional monitoring programs where possible and account for seasonal recruitment patterns of key species where relevant. From year six to the end of the lease or permit, monitor at least every five years. The duration of monitoring is determined on a project-specific basis and there are cases where required monitoring could be longer or shorter than 5 years dependent on the project goals and objectives.

After construction, ecological monitoring should continue to track how fish and invertebrate, and algae populations change over time and whether the reef is approaching the maximum number of organisms it can sustainably support (carrying capacity). Long-term monitoring will also yield valuable data on how California's nearshore ocean responds to climate change. Importantly, permit-required monitoring is limited in duration; most monitoring beyond five years after construction would likely be voluntary for most projects. During and after construction, developers should also monitor human use of biological resources where feasible and relevant to project goals and objectives. Such monitoring data will help estimate the ecosystem services the reef provides (see Socioeconomic Monitoring below).

How to monitor: Use established, depth-appropriate standardized existing protocols whenever possible so developers can incorporate data from other regional monitoring programs (see Appendix 6). For SCUBA depths, apply the statewide Marine Protected Area (MPA) kelp forest and rocky reef protocols by PISCO and CRANE (see Glossary), which measure fish sizes, macroinvertebrates, macroalgae, seagrasses and seafloor cover.[146–148] For deeper sites, other methods are more appropriate, such as drop cameras, remotely operated vehicles (ROVs) and baited remote underwater video systems (BRUVs) with stereo video for measuring size.[149–152] For projects that extend into the tidal zone, the MARINe (see Glossary) long-term monitoring protocols are a suitable option. Consider environmental DNA (eDNA) sampling to quickly detect the arrival of invasive species. Design the monitoring program to assess project objectives and test predictions by specifying what to measure, where and how often, covering the reef footprint, halo zone, adjacent habitats and control sites.

Socioeconomic Monitoring

What to monitor: Artificial reefs in California can serve human communities in many ways by providing recreational, research and educational opportunities, among others benefits. To assess how well a reef meets its social and economic objectives, developers should conduct socioeconomic monitoring. Like biological monitoring, socioeconomic monitoring should gather data both before and after construction, guided by clear, testable predictions tied to the reef's goals.

Before construction, developers should identify groups who expect to use the reef and those who do not, and ask both groups about their expectations, anticipated uses and any concerns or potential conflicts. Data collected to track the reef's social and economic performance may include public awareness and attitudes towards artificial reefs, how often it might be used and spending related to the reef and its broader economic effects (e.g., jobs supported, revenue generated). Monitoring should also capture effects on existing uses such as fishing, diving and surfing, as well as educational and promotional activities the reef supports (e.g., scientific research, workshops, curriculum development and fishing tournaments). Both positive as well as negative impacts, such as increased traffic or congestion on water and land, and lost or abandoned fishing gear should be recorded.

Where to monitor: Developers should survey representative samples of relevant user groups and non-user groups, in line with the reef's goals and objectives and stated management needs. Results can be analyzed by community, county, region, state or national level.

When to monitor: Before construction, survey relevant groups of users and non-users often enough to gauge public awareness of the reef (and the potential need to publicize it more), anticipated use of the area and likelihood that people will visit once it is built. If surveys reveal clear concerns or unexpected conflicts, developers can request design modifications, subject to regulatory approval.

Conduct a post-construction survey within, for example, six months of completion to evaluate public awareness, attitudes and use of the new reef and determine whether it meets initial expectations. Survey both user and non-user groups to assess any conflicts or impacts. Monitor annually every two years during the first five years, then at least once every five years from year six to the end of the permit. Long-term monitoring will yield valuable data on how California's artificial reefs deliver ecosystem services and economic benefits, and how those benefits change over time.

How to monitor: Use established human dimension protocols and tools to survey relevant groups. Data collection methods may include in-person, mail, telephone or online surveys, focus group discussions, unstructured interviews or direct observation. In some cases, secondary data sources may also be useful, such as fishing logbooks, recreational catch surveys (creel surveys), vessel tracking systems and human mobility data. Analysis methods will vary depending on the specific objectives and data collection method.

Adaptive Management Based on Monitoring

Adaptive management is an iterative, science-based approach to resource management: managers regularly assess what is working, learn from monitoring results and adjust their decisions accordingly. Adaptive management is particularly useful when managers are uncertain whether a particular action is working. Monitoring the outcomes from that action can help managers make better decisions going forward. For artificial reefs, adaptive management applies both to individual projects and to the California Artificial Reef Program as a whole.

For an individual reef, adaptive management should begin during the initial site assessment before construction starts and continue for the life of the project, tracking how the reef affects conditions both at the site and in the wider region to inform management decisions. Developers should update the reef's design and operations based on analyses of physical, biological, chemical and socioeconomic monitoring data, as regulators permit. Adaptive management for an individual artificial reef may include pre-set warning thresholds which are specific conditions that, if reached, trigger defined actions to address problems. Monitoring is essential both for determining whether those thresholds have been reached and for assessing whether the resulting actions solved the issue. Beyond these thresholds, monitoring should feed into periodic reviews to assess whether the reef is meeting its goals and objectives and whether management adjustments are needed.

One effective approach is to build and monitor a smaller pilot project before committing to the full-scale reef. A pilot reef can reveal unexpected problems that can be corrected in the full-scale design. It can also test alternative reef designs to identify the approach most likely to meet the project goals and objectives. Building in phases offers similar benefits: each stage can apply lessons learned from monitoring early stages, reducing surprises and improving overall performance. During phased construction, diver inspection and post-construction sonar surveys can catch problems early, before the built reef differs significantly from what was planned.

At the program level, data from individual reef projects can inform adaptive management of California's Artificial Reef Program as a whole, helping to ensure that artificial reefs are boosting ecosystem productivity without harming the state's natural marine and estuarine ecosystems. As monitoring of California's artificial reefs generates new knowledge, CDFW should update this Plan accordingly. Monitoring results from existing artificial reefs should influence how developers design and site future reefs to improve their contribution to California's marine ecosystems.

Conclusions and Recommendations

Monitoring is essential to a successful artificial reef project. It serves multiple purposes, including helping regulators verify that a project is meeting its requirements, advance scientific understanding about what makes artificial reefs succeed or fail, guide decisions to fix problems or improve performance on individual reefs and help keep the CARP current with the best available science. To realize these benefits, monitoring must be scientifically rigorous, focused on the right elements to assess success and results must be reported in a consistent, readily usable form.

This section has provided general guidance about these elements, but more can be done to improve the usefulness of monitoring across projects. Standardized methods and protocols do not yet exist for all the aspects of monitoring covered in this section. While every project is unique and regulators cannot apply identical conditions to all of them, greater standardization would be valuable and would likely improve outcomes. Standardized monitoring has proven valuable for coastal wetlands in California, California's Marine Protected Area Network and for oyster reef restoration on the East Coast.

As resources allow, California should develop standardized recommendations for monitoring metrics, performance standards and monitoring duration for artificial reefs. That effort should account for the full range of reef types and environmental conditions in California and provide tailored guidance for different situations.

4 Best Practices for Artificial Reef Development

This chapter reviews what California has learned about artificial reefs and offers practical guidance for building new ones. Section 4.1 reviews highlights from the history of California's artificial reefs and examines five case studies: 1) CDFW's historic fishing reefs, 2) selected sunken ships, 3) Wheeler North Reef in San Clemente, 4) Giant Marsh in San Francisco Bay and 5) the Palos Verdes Reef in Los Angeles County. Each case illustrates the ecological and socioeconomic outcomes from an existing artificial reef and draws lessons for future projects.

Section 4.2 uses lessons from California and around the world to present a framework for artificial reef design, siting and placement. The framework specifically addresses: 1) how artificial reefs can support biological productivity and native biodiversity; and 2) how artificial reefs can also replicate other ecosystem services that healthy natural systems provide to people, such as food, coastal protection and recreational opportunities.

California reefs should be purpose-built to prioritize and maximize production and native biodiversity. Section 4.2.1 provides specific recommendations on materials, design and location conditions that advance those goals. Section 4.2.2 reviews the science and offers suggestions for designing reefs that deliver additional services, including recreational opportunities, research and education, carbon sequestration, shoreline protection and cultural heritage and tradition.

Section 4.3 addresses the use of artificial reefs for compensatory mitigation — the practice of offsetting environmental damage from a development project by creating or restoring habitat elsewhere. It offers key considerations related to in-kind mitigation (replacing lost habitat with the same type) and out-of-kind mitigation (substituting a different habitat type). The section also examines the challenges of expanding this use of artificial reefs, including measuring initial losses, setting performance standards, managing the trade-offs of converting soft-bottom habitat (sandy or muddy seafloor) to hard substrate (rocky or structured reef material) and properly scaling mitigation over time and across locations.

Section 4.4 lays out a step-by-step process for developing an artificial reef, covering conceptualization, feasibility, measurable objectives, planning, design, construction, evaluation, management and communication. The chapter closes with a discussion of permitting: existing spatial management measures (Section 4.5.1), tribal engagement (Section 4.5.2), the permitting process itself (Section 4.5.3) and liability and fiscal responsibility (Section 4.5.4).

4.1 Case Studies

California's level of involvement in building artificial reefs has changed over the decades. Early efforts focused on sport fishing and used whatever materials were at hand, including car bodies and streetcars (Figure 9), with little attention to ecological design (see Section 1.3). Over time the program grew more systematic, with experimental reef complexes built on soft-bottom habitat away from large natural reefs, using quarry rock or recycled concrete materials (such as pier pilings, telephone poles and dock floats). Researchers also studied how well shipwrecks support marine life, both vessels that sank accidentally or those deliberately sunk to create additional hard substrate on the sea bottom.

Figure 9. Car bodies being placed on Ventura Artificial Reef in 1960.

As scientific understanding grew and regulatory expectations rose, reef projects took on broader goals and objectives. Projects focused on compensatory mitigation and habitat restoration began incorporating explicit measurable targets, experimental designs and performance monitoring. Three projects were selected as case studies to discuss this modern phase of artificial reef development in California. At 151 hectares (126 acres), the Wheeler North Reef in San Clemente is the largest artificial rocky reef of its kind in California. It was constructed as an in-kind mitigation using a single layer of boulder-sized quarry rock on soft-bottom seafloor. The Giant Marsh Living Shorelines project in Richmond is part of East Bay Regional Parks District's Point Pinole Regional Shoreline on San Francisco Bay. It created and restored a range of habitats from shallow seafloor through the low intertidal zone up to the boundary between marsh and dry land. The Palos Verdes Reef in Los Angeles County used tall, structurally varied quarry rock restoration placed next to existing kelp forests to restore reef habitat that had been buried by sediment and damaged by erosion.

CDFW's Early Fishing Reefs

Background, goals and reef design

CDFW built California's first artificial fishing reefs in the late 1950s to test reef designs for attracting sport fish and promoting kelp growth (see Section 1.3).[12] By 1989, CDFW had built 35 reefs — most made of quarry — stretching from Soquel Cove in Santa Cruz County south to San Diego County (see Appendix 5).[153,154] CDFW built these reefs in various designs using whatever materials were available, as part of its Nearshore Sportfish Habitat Enhancement Program. Materials were added to these reefs over time; the Bolsa Chica Artificial Reef (also known as Izor's Reef) received several expansions, with the last in 1999. CDFW also built seven smaller reefs around fishing piers, though no records of the materials used were kept.[153] Most stood at depths less than 105 feet (32 meters), although CDFW built the International Reef at 164 feet (50 meters) south of Point Loma, using quarry rock, concrete rubble and a steel missile tower.[153,154] Early CDFW studies found that fish on these reefs were feeding on bottom-dwelling invertebrates, plankton and small prey, showing that artificial structures provided real food sources that supported fish growth. These reefs were successful fishing reefs and many are still fished today where reef material remains.[32,155]

Monitoring Results

The most intensive early evaluation focused on the Pendleton Artificial Reef (PAR), built in 1980. PAR consisted of eight separate reef structures, each measuring roughly 430 square feet (40 square meters), with a height of 10 feet (3 meters), totaling approximately 10,000 tons of rock across about 3.5 acres (1.4 hectares). Researchers designed PAR to test whether an artificial reef could offset fish production losses associated with the San Onofre Nuclear Generating Station (SONGS).[156] Fish arrived quickly: surfperches (Embiotocidae, such as black perch and white seaperch) and sea basses (Serranidae, such as kelp bass and barred sand bass) showed up within a day after construction, and within a year a fish community typical of rocky reefs had established itself.[16]

Subsequent studies found that fish use of different parts of the reef (i.e., the crest, slope, surrounding sand and the ecotone) varied markedly.[15] Juvenile fish, primarily blacksmith, concentrated on the slopes and crest of the reef structures. Larger fish tended to be most common in the ecotone and surrounding sand, where barred sand bass dominated. Compared to the nearby San Onofre Kelp Bed, a natural reef of rounded rocks (cobble), PAR had 2.5 times the overall fish density and 10 times the density of resident fish, though the total weight of fish per unit area was similar at both sites.[157] Researchers also observed black perch and California sheephead foraging in the ecotone, confirming its importance. These studies also highlighted a practical challenge: As a reef grows larger, fish density tends to level off,[158] complicating efforts to estimate total fish production. Even so, larger reefs may still support greater overall production through more varied habitat and their ability to moderate the local environmental conditions. As DeMartini et al. (1989)[159] and Ambrose and Swarbrick (1989)[158] pointed out, it is important to incorporate ecotone habitat and smaller, but structurally complex reef structures in these calculations.

Later studies at the Torrey Pines Artificial Reef (TPAR) focused more directly on measuring fish production.[160,161] TPAR consisted of a single structure measuring 46 feet wide (14 meters) by 87 feet long (26.5 meters) by 23 feet tall (7 meters), covering 0.44 acres (0.18 hectares) and made from 1,000 tons of quarry rock in pieces ranging from 0.5 to 2 tons. Researchers measured fish body growth and reproductive output[160,161], tracked how closely fish stayed to the reef and analyzed their diets. For the first time in a non-tropical reef setting, these studies confirmed that an artificial reef directly supported fish production: fish tended to stay close to the reef and their growth and reproduction were directly linked to food from the reef and its surrounding ecotone.[160,161] About 70% of the reef fish diet came from the reef itself, with another 20 to 25% from the ecotone. This pattern is consistent with the halo effect (see Glossary), first described for coral reefs[162] and later documented around a range of artificial reefs.[14,146,163] Research in Australia [163]found this zone extends 108 feet (33 meters) beyond a reef's edge.[163] The sediment within this zone is richer in nutrients and decomposing material than the surrounding seafloor.[164,165]

More recently, researchers used sonar to map habitat characteristics and survey marine life at structures from 10 artificial reef complexes across Southern California.[166] These historic CDFW fishing reefs, built decades ago on isolated soft-bottom seafloor, currently support fish, invertebrates and macroalgal communities that are distinct from those on nearby natural reefs.[148,166] Some structures have sunk substantially into the sediment while others still stand 6.5 to 9.8 feet (2 to 3 meters) above the seafloor.

Overall, fish and invertebrate densities on these artificial reefs were comparable to natural reefs at similar depths, though seaweed coverage was much lower.[148,166] Taller, more structurally complex quarry rock structures, such as those at the Santa Monica Bay and Marina del Rey 2 complexes, supported more fish species and higher fish abundance, biomass and growth than structures made of scattered concrete or lower-profile quarry rock.[166] Higher numbers of commercially and recreationally important fish, including plankton-eating blacksmith and larger species such as barred sand bass, kelp bass and California sheephead, drove this pattern. By contrast, concrete structures made of scattered pilings, light poles and rubble tended to sit lower in the water and contained more soft-bottom patches within the area they covered, resulting in fewer species and lower fish abundance and production.[166] A remotely operated vehicle (ROV) survey of the Bolsa Chica Artificial Reef Complex confirmed the finding that construction material strongly influenced fish communities, with the highest fish densities on the tallest concrete pier-piling structures.[152]

Selected Sunken Ships

Background, goals and reef design

Sunken ships are among the earliest artificial structures to appear in California coastal marine waters. Accidental wrecks have come to rest on both rocky reef habitats and soft-bottom seafloor. The SS *Dominator*, which grounded at Palos Verdes Point in 1961, and the SS *Avalon*, which sank off the Palos Verdes Peninsula in 1964, now lie on rocky reef. The *Star of Scotland*, which sank off Santa Monica in 1942, the *Olympic* and the *Georgia Straits*, both of which sank off Long Beach Harbor in 1940 and 1965 respectively, and the *Humble SM-1* which sank near Point Conception in 1961 came to rest on soft-bottom seafloor. CDFW also deliberately sank ships in California, particularly through its Nearshore Sportfish Habitat Enhancement Program. CDFW sank the *Palawan*, a Liberty ship (a type of cargo vessel mass-produced during World War II) in Santa Monica Bay in 1977 to improve fishing opportunities. Several more vessels were deliberately sunk off Mission Bay in San Diego from the 1980s through 2000, creating a cluster of dive sites known as Wreck Alley” to support regional diving interests.

Monitoring Results

Biological surveys show that shipwrecks can function ecologically much like purpose-built artificial reefs, though their structure changes as they deteriorate. Height above seafloor declines gradually over time; recent measurements recorded only 9.5 feet (2.9 meters) remaining on the *Star of Scotland*, 3.9 feet (1.2 meters) on the *Georgia Straits* and 12.1 feet (3.7 meters) on the *Olympic*.[154] Even so, studies indicate that shipwrecks in California can support fish communities comparable to those on natural reefs or tall artificial structures.

Monitoring on the *SM1*, *Avalon* and *Olympic* observed the pattern of juvenile rockfish arriving and establishing themselves similar to that seen on deeper natural pinnacle reefs.[167] ROV surveys of the Bolsa Chica Artificial Reef and nearby shipwrecks (*Olympic* and *Georgia Straits*) found that fish communities on the wrecks most closely matched those on the reef's tallest concrete pier-piling structures. Blacksmith were especially abundant on the *Olympic*, with large adults present in numbers that exceeded those on any Bolsa Chica structures.[152] Similarly, researchers conducting SCUBA surveys of the *Star of Scotland*, which lies on soft-bottom seafloor in Santa Monica Bay, found it supported a fish community comparable to those on taller quarry rock artificial reefs in the area and on nearby natural reefs. Its invertebrate community resembled those on other artificial reefs and showed the low seaweed cover typical of artificial structures.[166] A 2005 study of the HMCS *Yukon*, sunk off San Diego in 2000, found that diversity of fish, invertebrates and algae was significantly lower than on Southern California natural reefs at similar depths with similar habitat.[168] A community-led diver photographic inventory project conducted from 2015 to 2020 at the HMCS *Yukon* documented 55 species of fish and invertebrates through 206 research-grade observations submitted by eight divers to iNaturalist.[169,170]

Wheeler North Reef — Built in Phases (1999, 2008 and 2020)

Background, goals and reef design

In 1974, the California Coastal Zone Conservation Commission issued a permit (CDP 6-81-330-A, formerly CDP 183-73) to Southern California Edison (SCE) for the construction of Units 2 and 3 of the San Onofre Nuclear Generating Station (SONGS). The permit required SCE to study and address the environmental impacts of the station's operations. An independent panel of scientists found that the SONGS cooling water system caused substantial losses to the nearby San Onofre Kelp (SOK) forest and its associated community.[171] To compensate, regulators required SCE to build an artificial reef as in-kind mitigation large enough to support 28 tons of reef fish and a least 150 acres (60.7 ha) of giant kelp (*Macrocystis pyrifera)* forest. The artificial reef, named Wheeler North Reef (WNR), was built in three phases: 1) a 25-acre (10.1 ha) experimental reef built in 1999 to test reef design options, 2) a 150-acre (60.7 ha) mitigation reef built in 2008 based on results from the experimental reef and 3) a 198-acre (80.1 ha) remediation reef built in 2019 to 2020 after the first two phases fell short of requirements for fish standing stock (the total weight of fish living on the reef at any given time) and kelp coverage (Figure 10).

SCE built WNR near SONGS but outside the area affected by its operations, to ensure the reef compensated for the resources lost there. WNR must meet its permit requirements for the same length of time that SONGS operates, 32 years, to earn full mitigation credit. The permit established measurable targets for reef substrate, giant kelp, fish, invertebrates and low-growing seaweed beneath the kelp canopy. These targets took two forms: fixed targets (absolute standards) measured only at WNR, tied to estimated losses at SOK, and comparative targets (relative standards) requiring WNR to perform similarly to natural control reefs nearby. Researchers selected two natural reefs, San Mateo Kelp and Barn Kelp, for concurrent monitoring alongside WNR, because they are close to WNR but unaffected by SONGS, are low reefs that are similar in structure and depth and have a history of sustaining giant kelp.

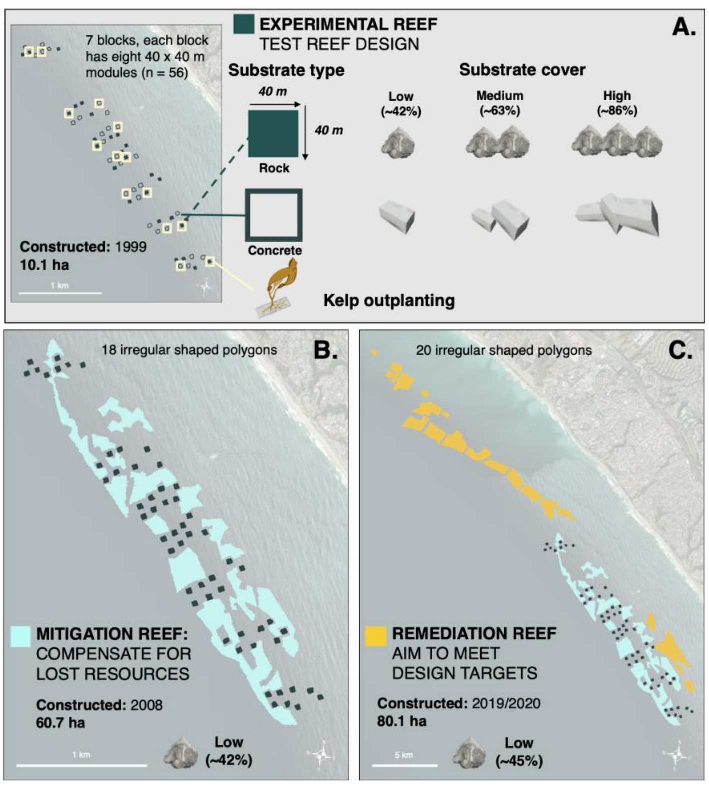

Figure 10. Map of the Wheeler North Reef (WNR) artificial reef complex. WNR was built in three phases, including (A) a 10.1 ha experimental reef built in 1999 to test reef design, (B) a 60.7 ha mitigation reef built in 2008 to compensate for lost marine resources and (C) a 80.1 ha remediation reef built in 2019/2020 to better meet reef performance targets.

The Wheeler North Reef was designed to mimic the impacted SOK reef: a low-lying expanse of boulders with little height variation. All phases were built on mostly sandy seafloor at depths of 43 to 52 feet (13 to 16 meters), approximately 0.6 miles (1 kilometer) offshore of San Clemente. The experimental reef tested eight designs that varied in material composition (quarry rock boulders or recycled concrete rubble), reef cover (low at 42%, medium at 63% or high at 86%) and whether kelp was transplanted onto the structure (Figure 10). The 56 structures were each 131 x 131 feet (40 x 40 meters) and sat low to the seafloor. Researchers divided them into seven groups of eight, evenly spaced along 2.2 miles (3.5 kilometers) of coastline. After five years of monitoring, all reef designs provided suitable habitat for kelp forest communities comparable to natural control reefs.[172,173] Outplanting laboratory-grown kelp onto the structures proved unnecessary — kelp spores arrived naturally from nearby reefs and established themselves.[174]

SCE built the low-relief mitigation reef from boulder-sized quarry rock, depositing it in a single layer to create 18 irregularly shaped patches of varying sizes, each with at least 42% of the seafloor covered by reef material. No kelp was outplanted onto the mitigation reef. Monitoring from 2009 to 2015 found that the combined area of the experimental and mitigation reefs was not large enough to support the required fish standing stock or kelp coverage.[175] To address this, SCE expanded WNR by building 20 irregular patches north of and closer to the shore than the two previous reefs (Figure 10). This remediation reef used quarry rock and averaged 45% reef coverage at depths of 28 to 49 feet (8.5 to 15 meters). At 373 acres (151 hectares) total, WNR is the largest artificial rocky reef of its kind in California, spanning 4.3 miles (7 kilometers) of coastline.

Monitoring Results

Annual monitoring from 2000 to 2025 shows that WNR has met many of its objectives. WNR has maintained its area of hard surface over time, has not been overrun by invasive or undesirable species, consistently performs similarly to natural control reefs across a wide range of reef functions and, following reef expansion, is now meeting its fish standing stock targets. In 2023, WNR satisfied the permit requirements for reducing monitoring from full annual surveys to annual site inspections.[176] For additional details on WNR's monitoring and performance, see the 2024 Monitoring Plan Update[177] and the 2025 Annual Report and future annual reports.[178]

Long-term study of WNR has considerably advanced understanding of how artificial reefs can support productivity and native biodiversity. On both its experimental and mitigation reefs, researchers conducted surveys along fixed underwater lines (transect surveys) to measure the density and variety of resident adult and juvenile fish (less than a year old) as well as low-growing (understory) seaweed and invertebrates, comparing results to those at two natural control reefs (San Mateo Kelp and Barn Kelp). These surveys also tracked changes in overall fish standing stock across the reef over time. On the mitigation reef, fish samples collected from five common reef fish species (black perch, blacksmith, señorita, California sheephead and kelp bass) have been used to evaluate fish growth, reproduction, and the food web. A recent study found that from 2002 to 2022, both fish arriving from surrounding areas and juvenile fish settling on the reef contributed to the overall fish population, with fish arriving from elsewhere far outnumbering new settlers throughout the study period.[52]

Studies of the fish community on the WNR experimental reef from 2000 to 2004 found that the six designs which did not include outplanting but did include varying material (rock or concrete) and reef coverage (42%, 63% or 86%) provided suitable fish habitat.[172,173] Fish standing stock, the density of adult and juvenile fish and the variety of fish species were all similar to or higher than at the two nearby control reefs.[172,173] Reef coverage, but not type of material, influenced fish communities, with greater fish density and variety on designs with higher coverage.[172,173] Sessile invertebrates (that attach to and remain fixed on the reef surface) and understory algae showed similar patterns, with coverage but not material influencing results.[179] Sessile invertebrate coverage and species variety both increased with reef coverage, while the abundance and variety of understory algae decreased with distance from the nearest natural reef, San Mateo.[179]

Studies of the fish community on the WNR mitigation reef found that density of adult and juvenile fish, fish variety, total fish weight, fish growth, reproduction and the food web connecting the seafloor to fish were all comparable to or higher than at natural control reefs starting in the first year after construction.[174,180] These patterns have been maintained ever since, indicating that well-designed artificial reefs can sustain fish communities comparable to those on natural reefs for more than 15 years.[174,180] Studies of both free-moving and sessile invertebrate communities on the WNR mitigation reef found that coverage density and variety were generally comparable to or exceeded natural control reefs within two to four years of construction.[174,180] Understory seaweed, however, showed a different trend: while its coverage and variety matched control reefs in the first year, both have since lagged behind control reef levels.[180] Researchers attribute this to competition for light with shading from giant kelp above and competition for space with sessile invertebrates below.[181] These findings highlight the importance of ecosystem-wide monitoring — tracking multiple groups of species at the same time so that interactions between them can be taken into account when interpreting how any one group is trending.

Conclusions

The Wheeler North Reef illustrates several best practices for artificial reef design and development:

1. The project used an adaptive management approach by setting clear objectives at the outset, developing measurable targets to assess each objective and building in a mechanism to modify the project if it fell short that ultimately led to the third phase of construction.
2. The project required long-term monitoring to measure performance over time. Because WNR was built as a mitigation requirement, the monitoring period was tied to the length of time SONGS operated, ensuring the public was fully compensated for lost resources. Monitoring funding was secured because it was a permit requirement. Long-term monitoring is important for projects not tied to mitigation requirements as well: reef communities can continue to change long after the first community establishes itself. At WNR, for example, kelp coverage changed substantially in ways that only became apparent years into monitoring.
3. A pilot reef phase allowed researchers to test multiple design options before committing to a design for the larger-scale buildout. This helped ensure the chosen design was likely to meet project goals. The pilot phase also showed that kelp outplanting was unnecessary because kelp spores arrived naturally in sufficient numbers to support a healthy kelp canopy, thereby reducing overall reef costs.
4. Researchers evaluated reef performance in two ways: by comparing WNR to multiple natural control sites and by setting reef-specific numerical targets for fish, kelp and reef surface characteristics. Regulators set reef-specific targets for fish standing stock and kelp area because they had numerical estimates of what was lost due to SONGS operations. This type of target is most relevant for mitigation projects but applying numerical targets to non-mitigation reefs is a useful tool to evaluate performance that should be considered when feasible. The comparison to multiple control reefs, should be used for any artificial reef project as it accounts for variability driven by natural regional factors such as shifting ocean conditions, including El Niño events.
5. By tracking multiple groups of species simultaneously, the project assessed how the reef functioned as part of the broader ecosystem. This approach is well-suited to the overarching goal of increasing biological productivity and native biodiversity and advances understanding how species affect one another's numbers.

Giant Marsh Living Shorelines Project, San Francisco Bay (Built 2019)

Background, goals and reef design

The Giant Marsh Living Shorelines Project (GMLSP) in San Francisco Bay was constructed in 2019 with upland work continuing into early 2022. The goal was to restore the ecological health and ecosystem resilience of a stretch of shoreline by creating a range of habitat types spanning from the shallow seafloor (subtidal) through the zone between high and low tide (intertidal) and into the area where marsh meets dry land.[182–184] The project covered 170 acres (69 hectares) within Point Pinole Regional Shoreline along the eastern shores of San Pablo Bay. The site encompasses areas managed by local and state partners and features a sandy-clay estuarine shore and intertidal mudflats south of the rocky Point Pinole headland, with a backshore of tidal marsh and adjacent coastal meadows and grasslands. The tidal range is about 6.6 feet (2 meters) and the site is exposed to waves up to 3.3 feet (1 meter) high depending on tide and water depth. The GMLSP was led by the California State Coastal Conservancy, which worked with multiple engineering and ecological consultants on the design and monitoring, including San Francisco State University Estuary and Ocean Science Center, the Smithsonian Environmental Research Center, the U.S. Geological Survey Western Ecological Research Center, Olofson Environmental, Inc., Environmental Science Associates and others.

Native Olympia oyster (*Ostrea lurida)* enhancement was a central component of the GMLSP, and the project ensured this through three testing distinct reef treatments that differed in their height above the waterline, structural design and ecological purpose. This section focuses on the artificial reef elements of the projects, which tested different designs to determine how effectively native Olympia oysters could be encouraged to settle and grow. Construction took place from April 9 through May 9, 2019. Researchers built three groups of reef structures — one offshore paired with eelgrass plantings, one at mid-shore paired with Pacific rockweed plantings and one nearshore paired with Pacific cordgrass plantings. The structures were built from pre-fabricated Reef Balls® or oyster blocks made of baycrete (see Glossary) to provide surfaces for native oysters and other invertebrate as well as seaweed species to attach to, and to establish eelgrass, rockweed and cordgrass to improve the shoreline's resilience to storms and sea level rise.

Researchers configured the reef structures to test whether they would reduce wave energy and thereby stabilize sediment and promote the establishment of eelgrass, rockweed and cordgrass, as well as reduce erosion of the salt marsh vegetation along the shore. They used an experimental framework to compare different groupings of reef structures and plantings across a range of depths from approximately 1.6 feet (0.5 meters) below to 2 feet (0.6 meters) above the average height of mean lower low water (the average height of the lowest daily tide, MLLW). One key target established in advance was for 1 adult oyster per 4.4 square feet (2.5 oysters per square meter) to settle on offshore reef surfaces within five years. These targets were based on results from similar projects in San Rafael constructed in 2012 and Red Rocks constructed in 2018.

Treatment 1: Offshore eelgrass and oyster reef

Pre-fabricated baycrete Reef Balls and bags of clean, recycled Pacific oyster shell (Figure 11) were arranged in a grid pattern to support native Olympia oysters and eelgrass (*Zostera marina*) was planted to test whether its proximity to the reefs improved outcomes. Treatment 1 provided the largest oyster restoration surface of the three treatments: three modules, each containing 60 large Reef Balls topped with two to three mesh bags of oyster shells, for a total of 180 elements. This was the deepest of the three treatments, with the bases of the Reef Balls at approximately 1.7 feet (0.52 meters) below MLLW.

Treatment 2: Mid-shore rockweed and oyster reef

Treatment 2 had three main objectives: 1) identify the best elevations for native Olympia oyster settlement and survival, 2) develop and refine methods for transplanting the Pacific rockweed to restoration projects and 3) test whether the presence of Pacific rockweed affected the establishment of the sessile invertebrates, particularly oysters, across a range of tidal elevations. Constructed baycrete oyster blocks were placed at a range of elevations approximately 0, 1 and 2 feet (0, 0.3 and 0.6 meters together with transplants of Pacific rockweed (*Fucus distichus*), to test whether the seaweed could protect the oysters at higher elevations from drying out during low tides. Treatment 2 consisted of three rows of 10 oyster blocks each, at three tidal elevations: a low row at approximately 2 inches (6 centimeters) below MLLW, a mid row at approximately 10.3 inches (26 centimeters) above MLLW and a high row at approximately 1.8 feet (56 centimeters) above MLLW. The oyster blocks were stacked to heights of 4, 8, 12 and 16 inches (10, 20, 30 and 40 centimeters) above the base structure.

Treatment 3. Nearshore cordgrass and oyster reef

Treatment 3 had three main objectives: 1) assess oyster growth and survival at higher position in the intertidal zone, 2) compare the performance of Pacific cordgrass plantings with and without oyster reefs and 3) protect the marsh from erosion. Researchers built 140 oyster blocks nearshore at approximately 2 feet (0.6 meters) above MLLW. The blocks were arranged parallel to the shoreline in two staggered rows separated by a central corridor. Of the three, this treatment was the closest to the shore, with oyster block bases at approximately 1.4 feet (43 centimeters) above MLLW. Researchers measured wave reduction by the reef across a narrow tidal range of approximately 3.5 to 5.5 feet (1.1 to 1.7 meters), broadly consistent with the height of the reef structures. Although the blocks were placed higher than the ideal zone for oyster growth, the lower portions of the blocks could still provide settlement space for oysters, and the middle and upper portions could become productive oyster habitat as sea levels rise over time.

Figure 11. Reef Ball elements constructed of baycrete with oyster shell bags on top, Giant Marsh. Source: Boyer et al. (2020).[143]

Monitoring Results

Year-to-year variation in environmental conditions, particularly salinity and temperature extremes, strongly shaped project outcomes.[185] A wet winter in 2019 brought increased freshwater flows that depressed regional oyster populations, delaying recruitment during the first project year. Despite that, an estimated 1.2 million oysters were found on the three reef arrays as of 2022. A second extremely wet winter in 2023 caused prolonged low-salinity conditions below 10 parts per thousand (ppt) and at times below 5 ppm, coinciding with periods of high air temperature during low tides. Salinities above 15 ppt are generally considered favorable for native oysters. Oysters closer to the high-tide line and exposed to air for longer periods when the tide went out suffered the most from these conditions.

Treatment 1, the offshore eelgrass and oyster habitat reef, first supported oysters in 2020, with steady population growth through 2022. At peak abundance, the offshore artificial reefs supported an estimated 1.26 million oysters, largely concentrated on shell bags. Following the extreme freshwater events of winter–spring 2023, the population declined sharply to an estimated 330,000 oysters, an approximately 75% reduction. Even so, oyster numbers remained higher than at natural sites used as control points. Importantly, oysters survived across all age groups, suggesting the die-off did not target any one life stage. Oysters on the Reef Ball were not monitored as intensively as the shell bags and consistently had lower numbers but seemingly had better survivability. Their numbers fell by roughly 50% in 2023, which, though substantial, was less severe than the losses in the shell bags. This suggests that the slightly lower position of the Reef Ball, farther from the high-tide line and submerged more of the time, provided a partial refuge from combined low-salinity and heat stress.

Treatment 1 reef structures supported a diverse mix of species, both those that attach to surfaces and those that move freely. About 30 species were recorded across the three reef installations. Even in 2023, shell bags provided shelter for juvenile fish and crustaceans including Dungeness crab (*Metacarcinus magister*), Pacific rock crab (*Romaleon antennarium*) and non-native Oriental shrimp (*Palaemon macrodactylus*) near the eelgrass-artificial reef groups. Eelgrass was most abundant on the shore side of the reefs. More waterbirds visited at low tide once the offshore reef and artificial reef/eelgrass treatments were in place, and the types of birds present were similar in treatment and control areas.

Treatment 2 tested oyster performance at a range of elevations and explored whether shading by Pacific rockweed (*Fucus distichus*, referred to below as *Fucus*) could help oysters cope with heat and dryness at low tide. In summer 2021, investigators found that *Fucus* boosted oyster and barnacle numbers and held back some of the negative effects, such as habitat smothering, from the seaweed *Ulva* spp. However, despite three transplanting attempts (two in 2019 and one in 2021), investigators could not get *Fucus* established at Giant Marsh, likely because heat waves killed the rockweed before it could take hold. The alga survived in sparse patches lower down on the reef and on its north-facing side. The benefit to oyster survival and recruitment was real but short-lived, as the *Fucus* died off. Smaller-scale experiments in 2021 told a clearer story: under a *Fucus* canopy, temperatures were lower and humidity higher during low tides, and study plots beneath *Fucus* had approximately three times the oyster and barnacle cover of nearby untreated areas, while also suppressing *Ulva*. These findings offer rare evidence in San Francisco Bay that a canopy-forming seaweed can improve oyster survival by keeping conditions cooler and more moist, even if establishing that canopy long-term remains a challenge.

At Treatment 2, the higher up the oysters lived, the fewer and smaller they were; this pattern held across all years. The row of structures nearest to the low-tide mark consistently had the most oysters, and the largest. In 2021–2022, there were more oysters on these low-lying blocks than on the offshore Reef Balls, showing that oysters in the tidal zone can outperform those permanently submerged, at least in good years. In 2023, however, oysters higher up on the shore suffered declines of more than 90%, with Treatment 2's total count dropping from more than 20,000 in 2022 to fewer than 2,000. Researchers attributed these losses to prolonged exposure to followed by heat stress when the tide went out.

Treatment 3, the nearshore oyster/habitat reef near the marsh edge, was mainly designed to protect the shoreline but also supported oysters and species living on hard surfaces. Fewer oysters settled there than in Treatments 1 and 2, but the numbers were in line with those at natural control sites. In 2019 and 2020, Environmental Science Associates deployed wave monitoring equipment near the reef to measure how much wave energy it absorbed. Researchers compared key wave measurements — such as wave energy and wave height — between sensors, and the team used a numerical wave model to assess the reef's performance across a range of water levels and conditions.

The reef absorbed approximately 30% of the incoming wave energy when the tide was at roughly mid-height or lower. The effect faded as the water got deeper. The tops of the reef elements sit approximately 1.5 feet (45 centimeters) above the seafloor, and the reef had no measurable effect at water depths greater than approximately 2.5 feet (76 centimeters) or about 1.7 times the reef's height. Using these measurements alongside a reconstruction of wave conditions going back to 2012, projections suggest the reef blocks approximately 10% of the total wave energy per year; mostly during low to mid-tides. Structures block waves most effectively when their tops reach up to or above the high-tide mark. At that height, however, oysters do not thrive.

Shoreline surveys showed that the mudflats were generally building up, gaining 0 to 0.2 feet (0 to 6 centimeters) between 2019 and 2023. Sediment accumulated on the sheltered side of the nearshore oyster reef, supporting the idea that the reef was blocking wave energy; higher mudflats can, in turn, further protect the marsh edge from waves. The reef elements at both offshore and nearshore locations remained stable and upright through the first five years after installation and may have grown slightly as barnacles and oysters accumulated. The two reef installations sank at different rates: the offshore reef elements settled at an average of 0.4 feet (12.2 centimeters) over five years, while the mud immediately around them sank by an average of 0.6 feet (18.3 centimeters). The nearshore oyster reef elements, sitting on firmer, sandy ground, did not sink at all. At Giant Marsh, then, the best location for wave protection is not the same as the best location for oysters — but a single reef design can still serve both purposes while also supporting seaweeds and invertebrates that provide food and shelter for fish, birds and other wildlife.

The project met its main goal — identifying the best techniques for living shoreline work across the full range of habitats, from open water through tidal marsh to the upland edge — and all five specific project objectives:

1) Create or improve habitats across the full range of shoreline zones, from open shallow water through tidal marsh to the upland edge.
2) Test restoration techniques in each of these habitat zones.

3) Support the enhancement of species under pressure, including Pacific cordgrass, eelgrass and Olympia oysters.
4) Assess how wildlife, including invertebrates, fish and birds, use the artificial reef areas.
5) Measure how well nearshore reefs reduce wave energy and protect the shoreline from erosion.

Conclusions

This project produced five key recommendations:

1) The abundance of key species such as the native Olympia oyster can vary dramatically from year to year and living shoreline projects should take place across multiple sites rather than concentrating effort in one location. Spreading the work across sites reduces the risk that a single bad year wipes out the gains. Varying the design within each site adds another layer of protection, providing a better chance of weathering unexpected setbacks.
2) Monitoring should go beyond the project site to track where juvenile oysters, fish and plant life are coming from and how well connected the project site is to those source populations. Understanding these connections helps interpret results and can guide decisions about where and when to enhance habitat availability, to bring the most juvenile organisms to each site.
3) This project showed how important it is to track restored sites over both short and long time frames, and especially through extreme events. Project goals and timelines need to be flexible enough to account for temporary setbacks, and project sites should not be held to a higher standard than natural ones when faced with the same unpredictable conditions.
4) The results encourage further testing of ways that species and habitat enhancement techniques can work together in future projects — for instance, the way seaweed supported native oysters in this project, or the way project elements helped eelgrass establish and spread.
5) Five years of intensive post-construction monitoring — voluntary in this case — was just enough to identify meaningful patterns and trends. The authors recommend longer-term monitoring for this and similar projects where resources allow, tailored to each project's scale, design, goals and risk.

The Giant Marsh Living Shorelines Project shows that artificial reefs designed to benefit multiple species can meaningfully improve habitat quality, support native biodiversity and strengthen shoreline resilience, which is especially important as climate conditions grow more unpredictable.[143,144,186] By combining rigorous experimentation, clear success targets and long-term monitoring, the project offers a strong model for successful artificial reef projects that can adapt as climate conditions change, both in San Francisco Bay and in similar estuary settings.

Palos Verdes Reef (Built in 2020)

Background, goals and reef design

The Palos Verdes Reef (PVR) is California's first artificial reef built specifically to restore lost rocky reef habitat. Designers placed clusters of quarry rock of varying height near extensive natural reef habitat to restore native biodiversity and boost the reef's overall productivity, meaning the growth of algae and other marine plants as well as the fish and invertebrates that depend on them.[145,187 188] Unlike artificial reefs built to offset damage caused by a development project (compensatory mitigation), PVR carried no predefined performance targets. This gave researchers the flexibility to evaluate performance more broadly, in terms of how well native marine life recovered and how the ecosystem functioned overall. The project aimed specifically to recover reef habitat buried and damaged by erosion from ongoing landslides and to support the recovery of fish populations.[188]

Crews completed the reef in 2020, placing 52,729 tons of quarry rock (Figure 12) across 18 modules that collectively cover 7.9 acres (3.2 hectares) within the broader 87-acre (35.2-hectare) restoration area.[145,187] The reef was constructed from large boulders, weighing approximately 1 ton each, because habitats with large rocks and gaps and crevices of varying sizes support greater fish abundance.[189,190] The reef was placed adjacent to the existing natural reef, directly over areas where the original reef had been buried by sediment. Because the surrounding area suffers from poor water clarity (high turbidity) and erosion from sediment moving along the shoreline, builders constructed the modules to a minimum height of 3.3 feet (1 meter) to raise the reef surface above the seafloor zone most affected by these conditions.

Researchers placed the 18 modules at depths of 51 to 65 feet (15.5 to 19.7 meters) which is the range found to support the highest fish populations in this region.[189] They modeled the design of the modules on a nearby natural reef feature known as KOU Rock, a unique high relief feature in the area, which has remained highly productive despite the region's persistent sediment buildup and erosion.[187,189] Each module consists of six 52-by-52-foot (16-by-16 meter) piles of quarry rock reaching heights of 3 to 13 feet (1 to 4 meters), creating varied habitats that include tall formations, lower-lying areas and sloped surfaces.[145,187] The tallest pile in each module reaches between 9 and 15 feet (2.8 to 4.7 meters).[166]

Three modules were grouped into a block, with each block separated by approximately 33-foot (10-meter) sand channels designed to mimic the natural ridge pattern of the area. These channels allow sediment to flow around the modules, rather than accumulate against them, and help maximize the reef's halo effect. Designers also offset the piles within each module to maximize the reef's outer perimeter and the area of sand-rock transition habitat known as the ecotone (Figure 13). Together, these design choices optimized the use of quarry rock by creating varied, structurally complex habitats rather than simply spreading rock in a single low-lying layer across the seafloor. The location itself also favors fish production as it sits near the continental shelf, where tidal action regularly sweeps cool, nutrient-rich water up from the ocean depths.[27,145,191]

Monitoring results

PVR demonstrated rapid and substantial ecological gains within the first few years following construction.[187,192] Fish arrived quickly and a typical rocky reef community rapidly took hold — consistent with what researchers have observed at other artificial structures.[145,187] PVR supported a greater variety of fish, large invertebrates such as crabs and sea urchins and brown algae such as kelp. Its species communities were notably different from those found at the older CDFW artificial reef complexes built for fishing and more closely resembled those of mainland natural reefs at comparable depths. Location likely explains this difference: PVR sits adjacent to extensive natural reefs, while the older complexes sat in broad sandy seafloor isolated from rocky habitat.[166,192]

The total weight of fish (biomass) and the rate at which the reef generated new fish growth (annual fish production) both increased more than tenfold on the modules compared to the what the same area supported before construction, when sediment had buried the habitat. The roughly 100-foot-wide (30-meter-wide) halo surrounding the modules covers approximately three times the seafloor area of the modules, yet contributed nearly as much total production as the modules themselves. This underscores how important the halo is to the project's overall success.[187] Four species drove most of the reef's secondary production which is the growth of animals that feed on other organisms and included the plankton-eating blacksmith, the plant-and-animal-eating opaleye and two predators important to commercial and recreational fisheries, the kelp bass and California sheephead.

Conclusions

Within three years, the restoration effort nearly doubled fish biomass and production capacity across the 87-acre (35.2 hectare) restoration area, even though the reef modules themselves covered less than 10% of that space.[187] Placing the modules near a natural reef led to rapid colonization characterized by fish and other marine life quickly moving in, and the broader ecological community developing steadily over time. Production increased not only on the modules but across the entire restoration area.[187]

The location of the PVR benefits from strong tidal flushing — the regular exchange of water driven by tidal movement — and access to cool, nutrient-rich currents that boost the availability of plankton.[27,145] The variety of structures within the modules — rock piles of varying heights — increased native biodiversity. Fish that fed on plankton gathered in greatest numbers on the tallest, most seaward portions of the modules[193] where design choices maximized water flow and feeding opportunities in the water column.[189,190] By concentrating these fish above the reef, the design creates a critical link in the food web. The fish consume plankton and release nutrients through waste, which fuels kelp and algae growth and drives overall fish production reflecting an exchange of energy between the water column and the seafloor a process scientist call benthic-pelagic coupling.[27,191]

These results show that carefully sited, tall and structurally complex artificial reefs can restore lost reef habitat function, support native reef biodiversity and substantially boost productivity well beyond their physical footprint.[145,187] The PVR is an example of how design, placement and local environment work together to drive successful reef restoration and healthier fish populations.

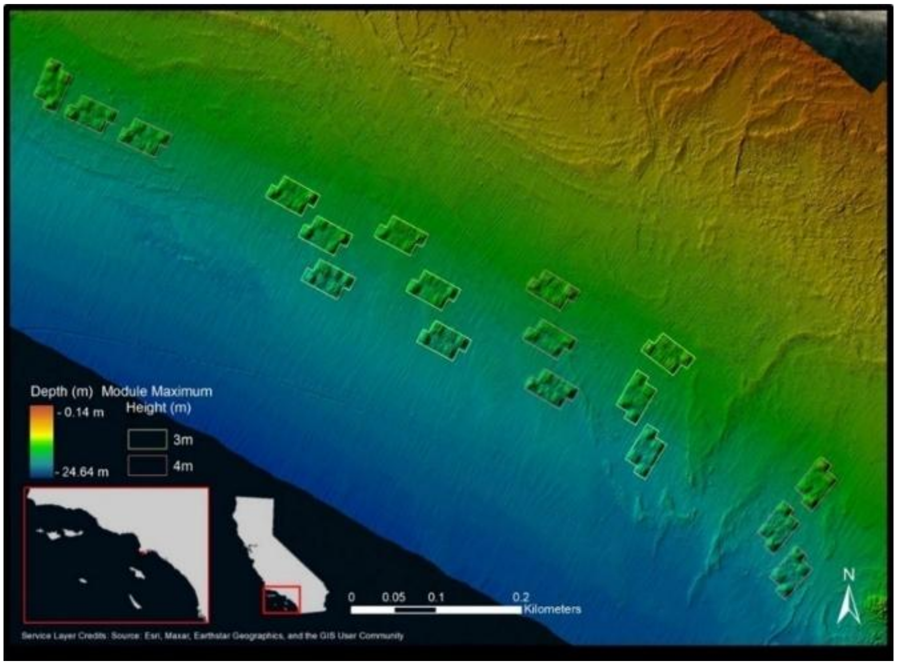

Figure 12. Side scan imagery of the Palos Verdes Reef and nearby habitat.

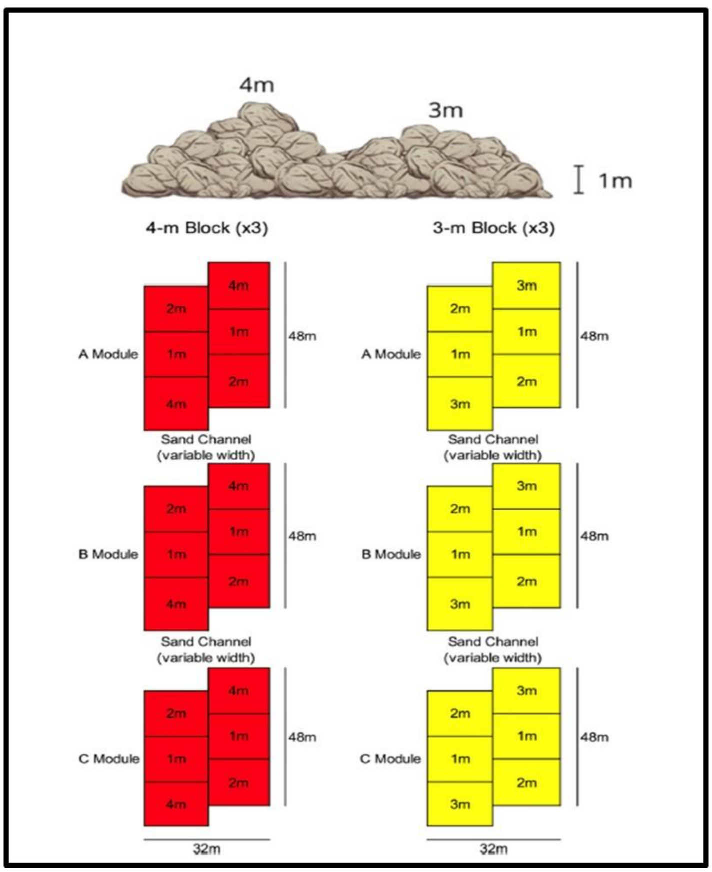

Figure 13. Design of the Palos Verdes Reef.

4.2 Maximizing Benefits from Artificial Reefs

To meet California's legal requirements and policy goals and to align with the best available science, developers should design artificial reefs to boost biological productivity (the rate at which a habitat generates living matter including fish, invertebrates, algae and the organisms that support them) and native biodiversity as the core goal. Materials, design and siting decisions should maximize those outcomes in ways that mirror the functions and variety of productive natural reefs.[173] Artificial reefs can also deliver broader benefits in what scientists call ecosystem services, such as shoreline protection, research and education, fishing and diving opportunities, cultural uses and carbon sequestration (the natural capture and long-term storage of carbon). These additional benefits are desirable, but they should complement, not replace, the core goals.

Research consistently shows that high biological productivity and native biodiversity yield a wide range of benefits for both people and ecosystems.[194] Choosing the right materials, design and location for an artificial reef can maximize those benefits. Planning that aims to mimic both the structure and function of natural reefs is a well-supported approach to achieving the broadest range of benefits for nature and humans and aligns with key California policy priorities (see Appendix 4). A single, well-designed reef can deliver multiple ecosystem services depending on the materials, design and location chosen (Figure 14).

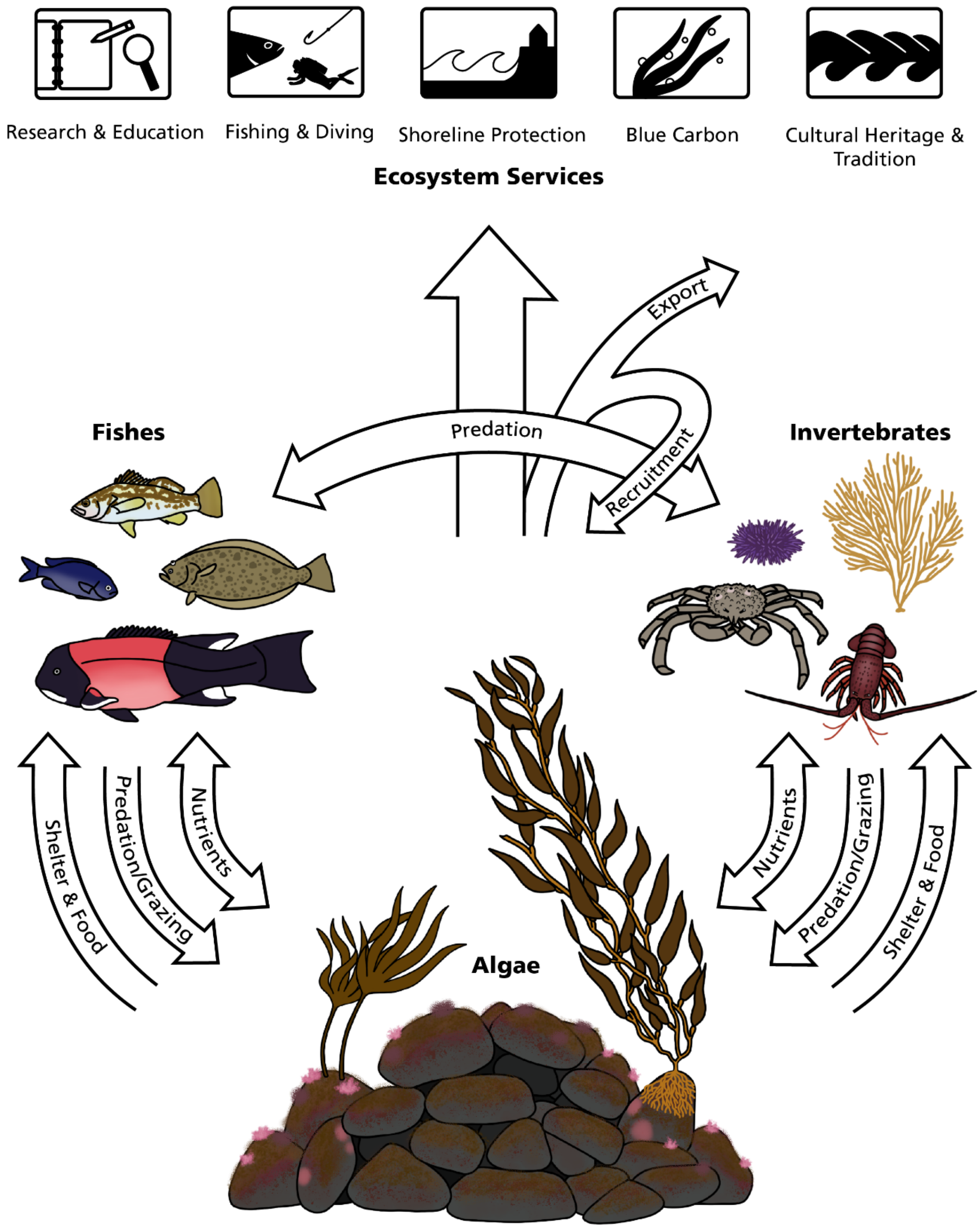

Figure 14. Simplified biological processes at work on a productive temperate artificial reef, and the benefits they create for biological productivity, native biodiversity and ecosystem services.

4.2.1 Productivity and Native Biodiversity

Studies in California show that natural materials such as quarry rock and man-made material such as concrete are the most effective surfaces for supporting biological productivity on artificial reefs. They support fish equally well when artificial reefs mimic the structure, connectivity and functions of productive natural reefs.[173,195] Metal objects, including car bodies, street cars, barges and sunken ships, break down over time and eventually disappear. Wooden structures similarly underperform and disappear over time.[32] On newly constructed reefs in California, fish move in quickly. Typically, the first species to appear in southern California are kelp bass, barred sand bass and surfperch. This rapid movement into new habitats suggests these species are running out of suitable natural habitat and highlights the importance of ecological succession which is the gradual process by which a reef community develops and matures over time. Succession is a critical measure of artificial reef performance because helps establish if the reef develops into a self-sustaining ecosystem over the long term, rather than simply attracting fish in the short term.

A well-designed reef should include multiple distinct zones that serve different species at different stages in life such as nursery areas for juvenile fish, transitional habitat for juveniles and adult habitat. This structural complexity, which is a mix of shapes, heights and textures, makes a reef more productive because it supports a greater range of ways of living and feeding. That same principle of habitat heterogeneity plays out across marine ecosystems when the physical structure and habitat created by living organisms (biogenic habitat) combine to increase the types of habitats available. When giant kelp takes hold onto a rocky reef, when eelgrass colonizes sandy bottom or when mangroves and coral reefs interact, biodiversity and productivity rise. On an artificial reef, adding more of those distinct zones can boost fish production in a stepwise fashion toward a peak level (Figure 15).[196]

However, the relationship between a reef's vertical height, what scientists call relief, and its productivity is not a straight line showing increasing productivity to a theoretical maximum. As relief increases, productivity levels rather than continuing to climb, in most cases. This is because eventually other mechanisms, such as limitations in food or space, that are triggered as the number of individuals increase (density-dependence) cause productivity to plateau. Exceptions to this pattern can occur if another type of relief is added, such as the establishment of a kelp canopy which can trigger an additional jump in productivity which eventually also levels off. In this example, the addition of kelp increases habitat heterogeneity as well as relief. Oil and gas platforms have extreme vertical relief but do not adhere to this pattern. Platforms have a fixed quantity of relief that does not change even with the addition of biogenic habitat like kelp. Studies consistently find that fish production around these tall, complex structures is significantly higher than around low-profile reefs and likely follows a linear path to its peak level of productivity.[158,190,197]

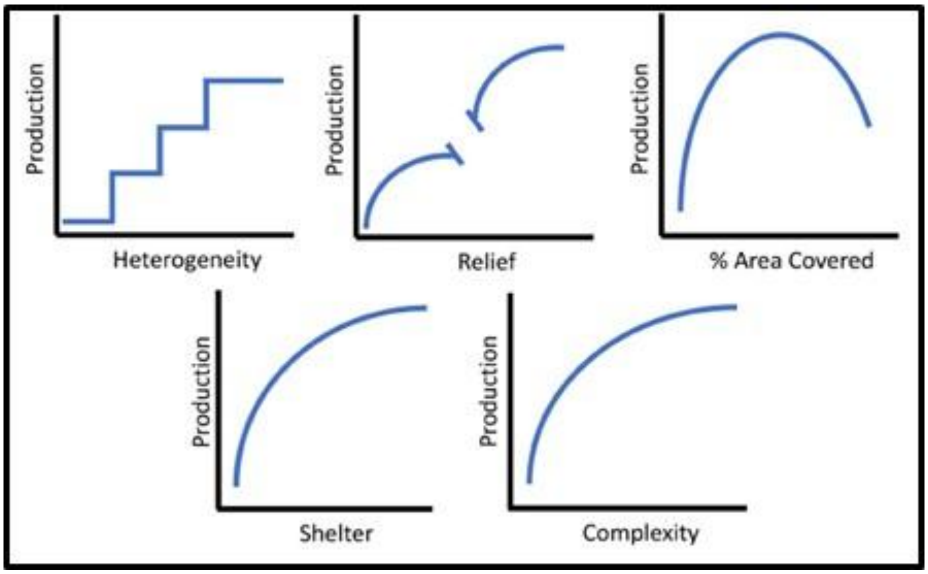

Figure 15. How fish production relates to structural variety, vertical height (relief), percent of seafloor covered, shelter availability and structural complexity, based on Pondella et al. (2022).

The relationship between the size, the amount of shelter and the complexity of the artificial reef to fish production all follow a typical pattern of increasing quickly then leveling off or declining. A reef's productivity does not simply increase with size. Peak fish production depends not only on the physical characteristics of the reef structure itself, but also on the ecotones, halos and flow of plankton through and around the reef. Overly dense reef placement reduces these critical elements, leveling off production. Marine species shelter on reefs to avoid predators and feed on plankton drifting through the water and small organisms living on hard surfaces. Shelter typically takes the form of holes and crevices in the reef structure. Surface roughness and the number of open spaces within the structure create complexity. More complex reefs naturally provide more shelter. They also offer surface area relative to their size, which increases the availability of small organisms for fish to feed on. Because a reef can only contain a finite number of such spaces and areas to shelter in, fish production tied to shelter also levels off after an initial steep rise (Figure 15).

Well-designed artificial reefs that provide adequate shelter, structural variety, vertical height, complexity and appropriate spacing oriented to take advantage of current flow can maximize overall total fish production.[196] When human activity such as pollution, coastal development and overfishing damages or destroys habitat, both the variety of fish species and the reef's overall productivity declines.[198] Theoretically, adding habitat features that serve multiple life stages, like nursery areas, shelter and spawning sites, and that support high species diversity can boost local and regional fish production well beyond a reef's physical footprint. High quality reef habitats improve recruitment, which is the process by which juvenile fish successfully settle into a habitat, as well as increase survival after settling. They also attract large reproductively active adults, whose presence boosts the surrounding ecosystem through greater reproductive output. This process of increasing localized production can produce a spillover effect on surrounding areas that has been well documented in marine protected areas and can also apply to well-designed artificial reefs under certain conditons.[199,200]

4.2.2 Ecosystem Services

Ecosystems produce a wide range of direct and indirect benefits to people through their natural functions, processes and characteristics.[201] These benefits, referred to as Ecosystem Services, range from goods that are used directly by humans (e.g., as food) to services such as habitat for species, minimizing climate variability, and filtering air and water pollution. The United Nations' Millennium Ecosystem Assessment[201] organized ecosystem services into four broad categories. Provisioning services are the tangible goods ecosystems supply such as food, water, wood and other raw materials. Regulating services help maintain a stable, healthy environment through processes such as climate regulation, water purification, crop pollination, erosion control and natural pest management. Cultural services deliver intangible benefits such as opportunities for recreation, education, spiritual or religious inspiration and cultural heritage. Finally, supporting services encompass the foundational background processes such as soil formation, the movement of nutrients and water through the ecosystem and providing sheltered areas where species can breed, feed, migrate and find protection. Together, these four categories form the core of most ecosystem service frameworks (Figure 16).[202]

A comprehensive review of scientific literature found that artificial reefs can support a broad suite of these services across all four categories, among them water purification, support for species through their full life cycles, nutrients for the ocean, coastal protection, climate regulation, species population regulation, raw biological materials, symbolic and aesthetic value, spiritual and cultural inspiration, educational opportunities, food provision and recreational and tourism opportunities.[203]

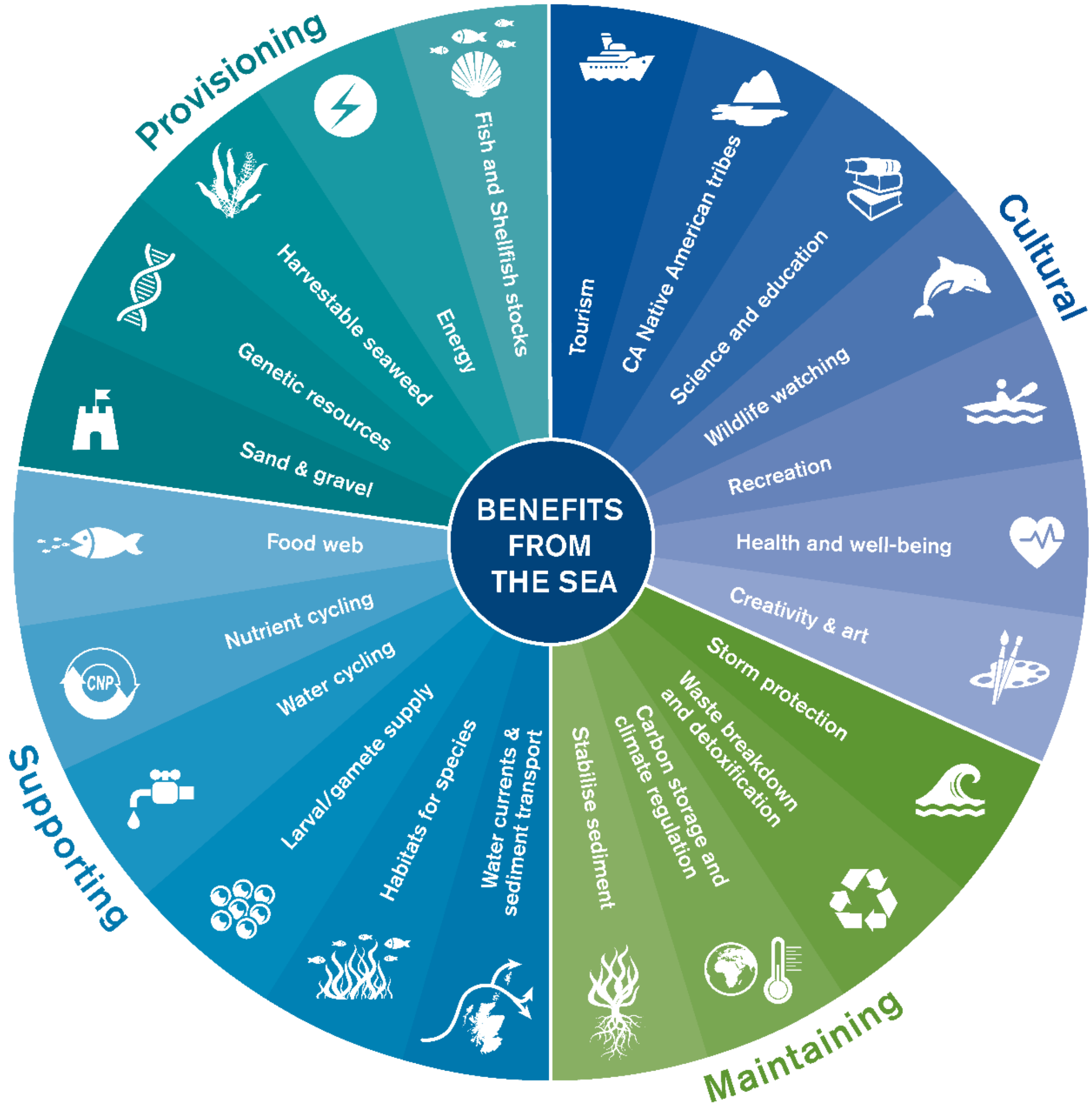

Figure 16. The range of ecosystems services that high-functioning ocean ecosystems provide. Adapted from NatureScot.[204]

Delivering ecosystem services is a secondary outcome for artificial reefs in California. The services flow from centering the goal of California artificial reefs which is to enhance biological productivity and native biodiversity. A useful way to think about this is a layered cake. The bottom layer — the foundation that everything else depends on — is the biological productivity and native biodiversity the reef structure enables. The next layers represent a range of ecosystem services that are project specific, such as improved habitat,[205] sheltered breeding and migration areas, nursery zones for juvenile fish and surfaces where larvae can settle and grow.[206] This includes benefits most visible to people like recreational fishing, diving, education and tourism.[207] While the specific ecosystem services a reef provides will vary depending on its materials, design and location, this layered structure applies to all well-designed artificial reefs, underscoring why enhancing biological productivity and native biodiversity is the core requirement. The ecosystem services discussed in this section focus on those most clearly documented in the scientific literature and are not an exhaustive account of every benefit artificial reefs could provide.

Artificial Reefs that Promote Recreational Opportunities

Artificial reefs can provide or enhance a variety of recreational opportunities such as fishing, diving, boating and others.[207] Although most research on reef-related recreation has focused on coral and oyster reefs, studies have found that artificial reefs can increase visits by boat (particularly reefs that are close to shore),[208] improve recreational fishing thereby potentially reducing fishing pressure on natural reefs[209] and offer recreational diving, diver training and snorkeling opportunities that may also ease pressure on natural reefs.[210]

In California, artificial reefs designed with recreation in mind might serve:

- Recreational fishing, including charters, private vessel and spearfishing
- Diving, including scuba diving, free diving, snorkeling and underwater photography
- Ecotourism, including kayaking, canoeing and boating

Installing artificial reefs that also promote recreation is widely seen as a potential way to offset losses and impacts to naturally occurring reefs. Two recent surveys support this view: 75% of respondents in Florida[211] and 49% in Europe[212] believed that recreation on artificial reefs may help reduce pressure on natural reefs. Artificial reefs used for recreation can also generate significant economic activity. In Florida, for instance, artificial reefs are estimated to support 39,118 jobs, generate approximately $3.1 billion in economic output and approximately $250 million in state revenue.[213] Although divers and snorkelers typically take more trips to natural reefs, many do visit artificial reefs.[214]

Recommendations for artificial reefs that promote recreational opportunities

Artificial reefs can be intentionally designed to promote recreational opportunities. Divers, for example, prefer reefs based on depth, travel time from port and water visibility.[215] Therefore, artificial reefs intended for diving should be placed within recreational diving depth limits (typically 130 feet, or 40 meters) and in areas with generally good water clarity. Different reef materials appeal differently to users. Divers typically prefer ships and other large structures over other reef materials, including concrete culverts and concrete modules.[216,217] These preferences may reflect real differences in the marine life each type of reef supports. For example, artificial reefs that rise higher from the seafloor and offer greater structural complexity, such as those created by sinking decommissioned and cleaned ships, can host different marine communities than lower-lying reefs composed of concrete modules or repurposed concrete.[168,205,218]

To promote recreational fishing, planners should consider whether the reef will support populations of fish species, how far it is from port and the water depth.[219] Recreational anglers also tend to prefer reefs that are marked with buoys. Planners should also consider reef spacing — the distance between structures or number of reef complexes in the area — since crowding can frustrate anglers and concentrate fishing pressure on target species. A survey of Texas offshore boaters found that only 57% had knowledge of the Texas Parks and Wildlife Department's artificial reef program.[219] Thus, if recreational anglers are an intended user group, outreach should inform them about reef locations and the goals of California's artificial reef program.

Managers can also designate reefs for specific uses to reduce conflict among groups. For example, fishing activity may reduce the experience and the ecosystem benefit available to non-fishing users such as divers. When diving is a reef's key objective, managers may want to limit fishing. California could survey recreational stakeholders to identify preferences for reef attributes such as depth and distance from shore, and materials such as ships versus concrete or low-relief versus high-relief. This information could then guide the design and placement of reefs to match the preferences of target user groups. Artificial reefs have traditionally focused on recreational fishing and diving.[220,221] If a reef is also intended to support kayaking, canoeing, or boating, planners should weigh the potential for congestion or conflict among the different user groups.[222,223]

Artificial Reefs that Promote Research and Education

Artificial reefs can and should be used for research and education to improve future reef development and management as well as raise public awareness of the California Artificial Reef Program. Many questions remain about optimizing the materials, design and siting to maximize benefits of artificial reefs. Well-designed scientifically robust research projects can provide insight into these data gaps and should be considered early in project development when feasible. Education and outreach are critical to building support for new reef projects, conserving marine resources and generating new ecosystem services. Effective outreach can raise awareness of how artificial reefs benefit marine ecosystems and local economies, encourage public participation in monitoring through community science and connect interested parties with funding opportunities for reef creation, research and monitoring. These efforts can inform the general public, user groups such as fishers and divers and school groups about artificial reefs and their role in marine conservation, while also deepening knowledge of local marine ecosystems.

Guidelines for artificial reefs that promote research and education

To encourage research at artificial reefs, an open, two-way communication should be fostered between managers and researchers. Managers should clearly articulate the specific questions they need answered, while researchers should share their ideas and logistical requirements. This dialogue matters because resource agencies — the government bodies responsible for managing natural resources — develop broad familiarity with current and emerging research through activities such as proposal reviews and are often asked to help identify the state's science priorities. Communication should begin early — ideally during the initial planning phase. Regular updates help teams adapt to shifting timelines, streamline planning and help identify funding sources. Early engagement also supports stronger study designs. For example, one of the most effective research approaches is the before-after control-impact study, which compares conditions at the reef sites and at nearby control sites, both before construction and for an equivalent or longer period afterward.[224–226] [225,226] Research conducted after a reef is in place is also valuable, and comparing outcomes across existing artificial reefs can answer many questions about best practices.[224,227,228]

Artificial Reefs that Promote Carbon Sequestration

Artificial reefs in California may be installed to enhance carbon sequestration (the capture and long-term storage of carbon dioxide from the atmosphere), which may help to slow climate change impacts. Early research suggests that well-designed and well-placed artificial reefs can serve as carbon sequestration tools. At the Rio Grande Valley Artificial Reef in South Texas, for example, the artificial reef complex was estimated to hold approximately 4.5 tons of blue carbon (carbon stored by ocean and coastal ecosystems), with corals and sponges holding the largest concentrations.[229] Much of the evidence for the carbon storage ability of artificial reefs comes from tropical seagrass systems, where fish gather around reefs and their waste fertilizes the surrounding seagrass, helping it grow and store more carbon.[49,230]

Aquaculture offers additional evidence. In the Gulf of Aqaba in the Red Sea, artificial reefs placed beneath an aquaculture facility developed a community of encrusting organisms, such as mussels, barnacles, sponges and algae. Within ten months of deployment, these communities were estimated to capture about 1.4 ounces (40 grams) of carbon per day.[231]

Artificial reefs around another aquaculture facility in Hong Kong developed a similar encrusting community within one year of deployment, capturing approximately 5,185 pounds (2,352 kilograms) of carbon per year.[232]

Recommendations for artificial reefs that promote carbon sequestration

As of late 2025, no marine artificial reefs are known to have been intentionally designed for carbon sequestration. However, a study on the Giant Marsh Project in San Francisco Bay found that a project with specific objectives around increasing localized eelgrass populations showed a trend toward the reef structures enhancing organic carbon in shoreward restored eelgrass meadows (see Section 4.1).[144] Additionally, researchers continue to gain knowledge on how natural coastal ecosystems store carbon and how habitat restoration efforts may promote carbon storage.[233–235] Those planning to deploy artificial reefs with carbon sequestration objectives can draw on lessons from California-based projects that use carbon storing coastal habitats as nature-based solutions to help meet the state's climate goals.[236,237]

Artificial Reefs that Promote Shoreline Protection

A living shoreline is a coastal adaptation and/or erosion control method that is comprised of natural or mostly natural elements, which contributes to the persistence and enhancement of coastal processes and ecological benefits while also protecting inshore areas against storms and sea level rise. Although designers can include man-made elements where appropriate, they must not interrupt the natural flow between water and land.[236] Developers have proposed and built artificial reefs as underwater elements of living shoreline projects to provide shoreline protection while also improving habitat and recreational opportunities. These reefs can act as offshore barriers that reduce the force of incoming waves and stabilize sand movement, helping to maintain wider beaches and other coastal features. A single reef may therefore have multiple objectives that do not necessarily carry equal weight. Research from Grenada documented how multi-objective artificial reefs can improve habitat and ecological function while reinforcing the shoreline protection that existing coral reefs already provide.[238] Other research also shows the successful use of such reefs for habitat restoration, shoreline protection and coastal erosion control.[239] It is important to note, however, that the California Coastal Act (Pub. Resources Code, § 30235) permits new shoreline protection structures, including artificial reefs with a shoreline protection component, only under specific, limited circumstances and this may apply to artificial reefs with a shoreline protection component.

Recommendations for artificial reefs that promote shoreline protection

Artificial reefs seeking to provide shoreline protection in addition to maximizing biological production and native biodiversity, must reduce the force of incoming waves and stabilize sediment movement to limit coastal erosion. No single design works in all settings, but advances in reef engineering show real promise for such erosion control and shoreline protection.[240,241] All such reefs must avoid blocking navigation and avoid adverse impacts to water-oriented recreational activities and fishing. Planners should seek input from user groups before and after placement to minimize conflicts and ensure that projects realize added benefits such as new habitat and recreational opportunities.

Artificial Reefs that Promote Cultural Heritage and Tradition

In the context of artificial reefs, cultural heritage and tradition can refer to two distinct concepts: Indigenous practices and traditions, or maritime cultural resources. Indigenous practices and traditions are activities, practices or expressions deeply tied to a group's shared heritage, beliefs and traditions.[242]They often carry spiritual or community significance that reinforces identity and are passed down through generations (16 USC § 539m-1(16); US Legal 2025). Maritime culture resources are the physical remains of past human interactions like shipwrecks, that hold historical, archaeological, architectural or cultural value.

Empirical research on how artificial reefs may restore or support cultural resource use remains limited. However, given that research has established that artificial reefs can deliver a range of ecosystem services, their cultural dimensions are worth exploring further. The types of cultural ecosystem services artificial reefs may provide include:

- Provisioning services: supplying traditional foods, materials and medicines.
- Regulation services: protecting coastal heritage sites or maintaining water quality needed for religious practices.
- Supporting services: protecting native biodiversity and habitats to help maintain and honor kinship relationships embedded in tribal worldviews.
- Cultural services: restoring or supporting spiritual and ceremonial practices by improving access to meaningful places or to culturally significant species.

Separate from Indigenous uses, researchers are also exploring whether artificial reefs can help reduce pressure on underwater maritime heritage resources. For example, studies have begun to investigate whether divers may choose to dive on artificial reefs rather than historic shipwrecks[243] or natural reefs,[210] thereby potentially reducing diving pressure on historical or ecological sensitive sites.

Guidelines for artificial reefs that promote cultural uses

Projects that aim to support Indigenous cultural uses should follow the guidance in Section 4.5.2 on Tribal Engagement. Early, meaningful and respectful engagement with California Native American tribes is essential. Biocultural restoration approaches — an approach that links the restoration of biological functions with the cultural uses and values associated with them — may provide a useful framework for projects that aim to incorporate cultural uses. Making Indigenous and local knowledge central throughout the project development can help preserve traditional knowledge and cultural heritage and should be a guiding principle from the start.[244]

4.3 Artificial Reefs and Mitigation

When a development project damages or destroys marine habitat, regulators may require the developer to compensate for that loss through a process called compensatory mitigation. Artificial reefs are one tool that can serve this purpose.[172,173,179,195,245–249] Mitigation can take several forms: improving an existing habitat (enhancement), recovering a damaged one (restoration) or building an entirely new one (creation). Habitat enhancement typically adds hard substrate such as rock or concrete to an existing reef to make it more productive. Habitat restoration rebuilds a reef where one existed before it was degraded — for example because accumulated sand or silt buried and smothered the original habitat — with the goal of bringing the site back to something close to its natural state.[245] Habitat creation goes further, placing a reef in an area that was never a reef habitat before. It is worth noting that both habitat restoration and creation replace one type of seafloor environment with another typically converting soft seafloor (sand, mud or other loose material) into hard substrate. It is important to account for this trade-off, because soft seafloor habitats support their own distinct communities of species and provide their own ecological benefits and ecosystem services. Planners need to weigh those losses against the expected gains (see Section 2.3).

The foundation of any mitigation project is demonstrating that what is being built replaces what was lost.[115,245,246,250] Making that case requires measuring the damage carefully, by quantitatively describing for example area of kelp lost, the fish populations affected, the species displaced, then demonstrating that the artificial reef will replace those losses. Losses can be measured using habitat-based measures (such as acres of kelp canopy or hard substrate) or species-based measures (such as total fish weight or number of species present).[251] Mitigation can replace a lost resource with the same type called in-kind mitigation or with a different but comparable one, called out-of-kind mitigation. Either way, if using artificial reefs for mitigation, the accounting must be thorough: gains need to fully offset losses.

In California's coastal zone, compensatory mitigation has typically, though not exclusively, focused on in-kind mitigation, either right at the location where the damage occurred or close to it. That said, California actually has few examples of artificial reefs built specifically for mitigation (see San Diego Bay Eelgrass mitigation[195] and the Wheeler North mitigation reef, also described in Section 4.1).[172,173,175] However, as coastal development continues, some projects will likely cause environmental damage and developers may look to artificial reefs as a way to offset that harm. Artificial reefs are best suited for in-kind compensatory mitigation when what was lost is closely tied to productivity and native biodiversity. As described earlier, research supports that well-designed artificial reefs can restore both (see Sections 2.1 and 4.2.1), making them a credible option when productivity and native biodiversity are the resources that need replacing.

Choosing the right measures of success is critical. For in-kind mitigation, losses and gains can be calculated in a common currency using habitat-based metrics (e.g., area of kelp canopy, hard substrate, etc.) or species-based metrics (e.g., fish biomass, number of species).[251] The choice of these metrics should be tied to the mitigation project objectives related to 1) environmental impact that requires compensation and 2) the desired ecosystem structure, functions or services that must be achieved. For example, when the Wheeler North mitigation reef was built, regulators set specific targets based on documented losses: at full performance, the reef was expected to support 150 acres (60.7 hectares) of kelp canopy and produce 28 tons of fish per year. It also had to demonstrate that its ecological communities — the density and variety of fish, seaweed and both free-moving and fixed invertebrates such as mussels or barnacles — were comparable to those found on nearby natural reefs used as a control point.

Artificial reef design should be driven by such targets: what material, design and location will most effectively produce the required compensation for losses? Reefs can also deliver benefits beyond productivity and native biodiversity, such as improved fishing opportunities, and planners may consider these for mitigation as well (see Section 4.2.2) as long as those benefits are directly tied to what the project was required to replace. For less established benefits where no clear standard yet exists, the groundwork for measuring them would need to be laid before an artificial reef could count toward mitigation for those losses.

The scientific literature broadly supports the use of artificial reefs for mitigation, yet several challenges and uncertainties have limited their widespread use.[17,43,158,252] The scarcity of real-world examples, combined with the tendency of the few existing projects to focus on meeting permit requirements rather than documenting research outcomes, leaves only a thin body of published work to draw on when establishing best practices. Beyond this information gap, multiple challenges arise at every stage of the mitigation process. It is difficult to quantify the initial loss that mitigation must compensate for, especially for projects on limited budgets. This is because ecosystems are complex, harm from multiple sources tends to add up over time and it is hard to trace the downstream effects of any single disturbance through the food web and across habitats.[253,254] Practitioners should weigh the uncertainty associated with different calculation methods, because mitigation requirements can vary significantly depending on how the impact is calculated.

Setting meaningful performance metrics is equally challenging. As noted earlier, these metrics typically ask two broad questions: Is the reef generating enough life — enough fish, invertebrates and algae — to replace what was lost? And is it functioning the way a healthy reef should, providing benefits like food, habitat and other services? How artificial reefs perform varies considerably[205,255,256] often depending on their design and location (see Chapter 3), which makes it difficult to set standards that apply consistently across sites. There is also the risk that if regulators tie mitigation requirements to the current quality of a habitat, developers may have an incentive to allow degradation of an intact site before a project begins, in order to lower the ecological baseline and reduce their mitigation obligations.[115] Beyond physical structure and ecological function, projects should also account for ecosystem services when setting mitigation requirements. That said, the science for predicting whether any given reef will reliably deliver those services is still developing.[86,129]

Some projects determine mitigation requirements using a mitigation ratio, which sets a fixed multiplier for how much habitat must be restored or created to compensate for a given impact such as restoring three acres of reef for every one acre damaged. This approach is an alternative to detailed functional assessments that evaluate how well a habitat is actually performing its ecological roles.[257,258] Ratios can be a practical option when uncertainty is high, since they build in a buffer against undercompensation.[115] The problem is that researchers have studied too few artificial reef mitigation projects to establish what an appropriate ratio for this type of project would be. That uncertainty adds to the uncertainty already present in the original impact estimates.

As more projects are completed and studied, regulators could calibrate ratios to better reflect the level of uncertainty involved in artificial reef mitigation. Site-specific factors — the magnitude of the damage, the ecological quality of both the affected site and the location where compensatory habitat is created or restored as well as the mitigation method chosen — could inform more realistic, localized ratios.[250] For now, given the limited data available, regulators will consider mitigation metrics for artificial reefs on a case-by-case basis as consistent with their individual mandates.

Building an artificial reef most often means converting soft-bottom habitat, sandy or muddy seafloor, into hard reef structures, and understanding the trade-offs involved presents another challenge (see Section 2.3). Most coastal ecosystems have limited mitigation options based on the amount of suitable area to restore or enhance. California's nearshore coastal systems contain large areas of soft-bottom habitat below the low-tide line that developers could theoretically convert. However, conversion of soft-bottom habitat involves trade-offs, and the availability of this habitat alone is not a sufficient reason to select it as a site for an artificial reef. Developers and regulators should consider carefully the impacts of the construction of a hard reef on the sandy or muddy seafloor communities and the associated services that may be reduced or eliminated.[164]

The design principles in Section 3 should guide every mitigation project to ensure developers build the reef in a way that meets its goals and accounts for the habitat it displaces. For example, a reef with a tall, complex structure that rises well above the seafloor might be the right choice for a project trying to compensate for lost fish productivity, whereas a low-relief reef that is flatter and more spread out might better serve a project focused on rebuilding a broader reef community that includes kelp, understory algae and invertebrates. Project teams should design monitoring plans with those same goals in mind (see Section 3.4).

A related challenge involves scale — both in time and space. A key question is whether artificial reefs built for mitigation continue to do their job over the long term. The biological communities living on a reef, the ecological functions it performs and the services it provides can all shift as the reef matures and different species move in and establish themselves — a natural process called succession.[259–261] Given how little researchers know about how mitigation reefs change over time, monitoring should continue for years or even decades (see Section 3.4). Mitigation monitoring should prioritize study designs that allow comparisons not only over time but also in space (e.g., control vs. impact) to fully evaluate whether artificial reefs are meeting their quantitative mitigation targets.[23,48] Developers should furthermore factor in how long the reef will need to last, particularly given long-term pressures such as rising sea levels, more intense storms and changing ocean conditions. This is particularly important in a mitigation context: a mitigation reef needs to keep performing for as long as the habitat it replaced would have, which also highlights the need to build it from durable materials.

Beyond in-kind mitigation, which replaces a lost habitat with the same type, artificial reefs could also serve as out-of-kind mitigation, when regulatory frameworks allow compensating for a lost habitat by providing a different kind of ecological benefit. The challenge is determining how much out-of-kind mitigation is enough. Simple measures such as primary productivity, which is the rate at which plants and algae produce organic matter through photosynthesis forming the base of the food web, or secondary productivity, the growth of animals that feed on primary producers, can provide a starting point, but they do not capture the full range of ecological value that a lost habitat provides. Because researchers lack solid data on productivity levels across different habitat types, projects risk setting compensation requirements too low[120] and many regulatory scenarios only allow for in-kind mitigation. Despite these gaps, developers will likely propose artificial reefs more often as an out-of-kind mitigation option, especially as suitable sites for traditional in-kind mitigation — such as coastal wetlands — become harder to find. When that happens, anyone proposing to use an artificial reef for out-of-kind mitigation should support that proposal with rigorous, site-by-site analyses to ensure it genuinely compensates for what was lost.

Overall, as coastal development in California continues, developers will likely increasingly see artificial reefs as a useful tool to compensate for environmental impacts. Yet few real-world examples exist, and the challenges outlined above could limit how widely they are used. Artificial reefs are most likely to work well as in-kind mitigation — replacing lost habitat with the same type, compensating for losses of fish, invertebrates and the broader reef community — while the field still needs to determine when they might be appropriate for out-of-kind mitigation, which compensates for lost habitat by providing a different kind of ecological benefit, or to replace alternative ecosystem functions and services of a healthy reef.

Developers should ground every mitigation proposal in rigorous analysis of the impacts involved; the design goals and the measures regulators will use to track success to ensure the compensation genuinely covers what was lost. Given all this complexity, no one-size-fits-all answer exists: regulators and developers must evaluate every project on its own terms, with a clear look at what is required and what trade-offs they are willing to accept. That evaluation should include how activities permitted on the reef like fishing might interfere with meeting the project's regulatory requirements.

4.4 Framework to Guide Artificial Reef Development

Developing an artificial reef is a complex undertaking that requires evidence-based decisions at every stage. As early chapters discussed, the materials, design and location are the main factors driving how well a reef performs. Developers should also take advantage of tools such as computer-aided designs and mathematical models, which allow testing and refining reef configurations before anything is built.[62,196,262,263] Research on all aspects of artificial reef development and performance is growing rapidly, and developers should review the latest findings before starting a project.[263] Early in planning, project teams should also use a marine spatial planning approach which is a structured process for coordinating different uses of ocean space, such as fishing, recreation, conservation and shipping, to reduce conflicts and improve outcomes for people and the environment.[35,141]

All California artificial reefs should have the overarching goal of maximizing biological productivity and native biodiversity. Developers may add further goals and objectives related to ecosystem services provided that those additions do not compromise the primary aim. Breaking the process into clear steps is an effective way to keep a project on track. The major milestones in developing a well-designed artificial reef are: conceptualization, feasibility assessment, the setting of measurable objectives, planning, design, construction, evaluation, management and communication. Figure 17 and Table 2 work together to illustrate the multi-step process and the key decisions required at each milestone.

Developers should contact regulators very early in the process — during the feasibility stage — so both sides have a clear picture of what the regulatory process will require (see Section 4.5.3). Developers should also build funding for permit compliance into the budget from the start. Regulators may require developers to put in place a funding mechanism such as a bond or other surety device (see Glossary), before the project goes in the water. Permit conditions such as monitoring before, during and after construction as well as potential removal requirements can be costly. Past permits for California artificial reef projects have included provisions for removal if a project fails to meet its objectives, creates a safety hazard or harms how the reef community is organized and functions in ways that outweigh any benefits the reef provides. Removal conditions have also been applied to pilot projects to allow learning and refinement of design before building a full scale project.

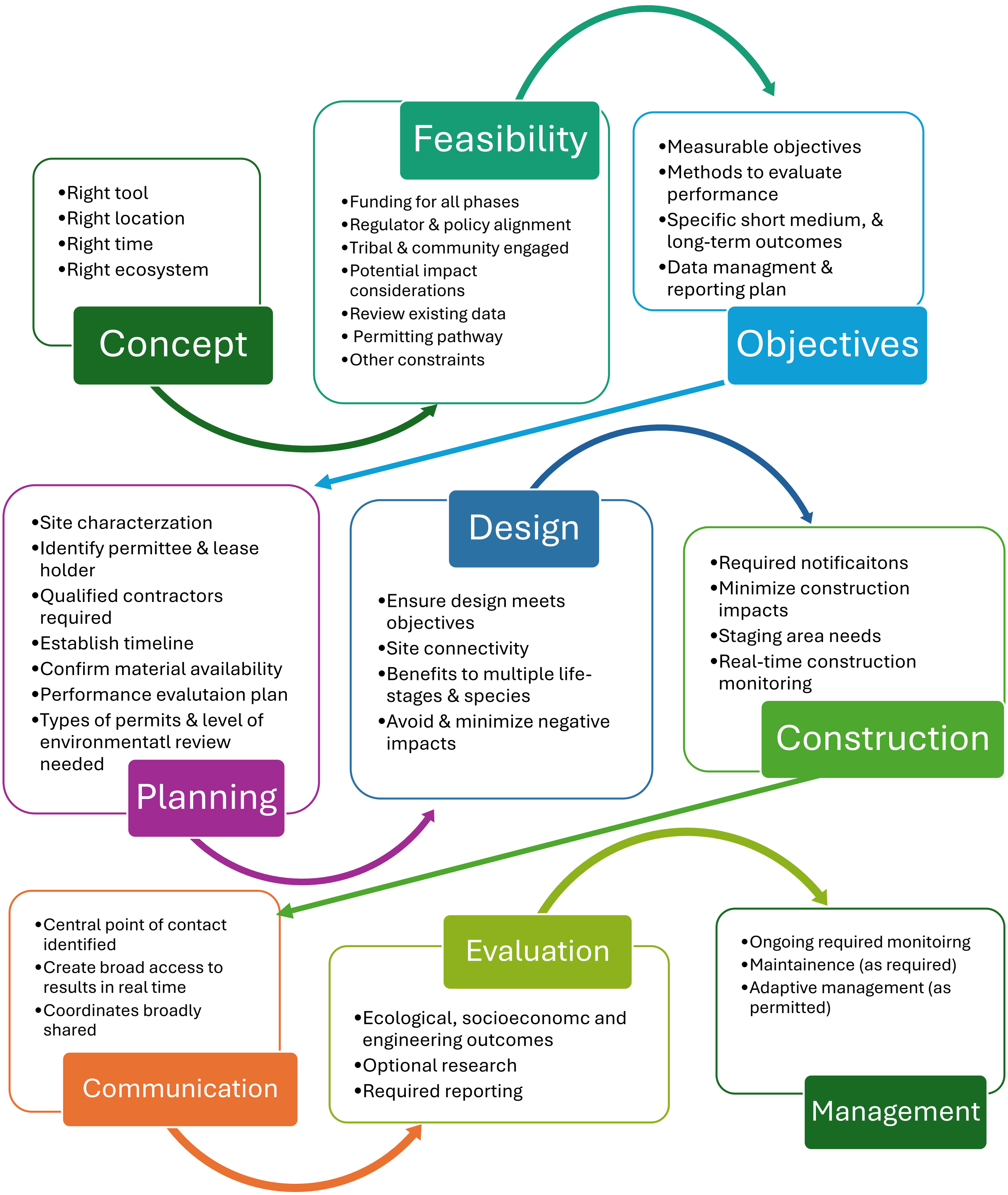

Figure 17. Process steps to a well-designed artificial reef to be used in conjunction with California Artificial Reef Program Plan Table 2. Each box contains key actions or decision points that should occur during that step in the development process.

Table 2. Key components and questions to consider for planning and implementing artificial reef development best practices. Adapted from Lindberg, W.J. and Seaman, W. (Eds.). (2011). "Guidelines and management practices for artificial reef siting, use, construction, and anchoring in Southeast Florida." Florida Department of Environmental Protection.[264]

Planning Component	**Example of Key Questions to Consider**
CONCEPT: The initial idea for a reef, and the brainstorming to judge its soundness.	What structure and function in the ecosystem will be enhanced? How will the artificial reef and the existing ecosystem interact? Are there other management tools that would be more effective? Is the project restoring habitat or creating new habitat? What ecosystem services will be provided?
FEASIBILITY: Identify required project elements are in place and conduct impact assessment.	Are local tribes and stakeholders informed and engaged? Do regulators foresee any regulatory challenges or obstacles? Are there adequate funds for all phases of the project? What are the potential biological, ecological, socioeconomic and cultural impacts (+/-) through all phases of the project? What existing scientific studies and data are available to inform selection of objectives and location? What constraints are there (e.g. protected species/habitats)? Is there an achievable permitting pathway? What material, design and siting alternatives exist that would serve to maximize benefits based on site characterizations and existing best available information?
OBJECTIVES: Measurable outcomes that quantitatively define success.	What are the specific measurable objectives of the reef? How will the expected outcomes be measured? What is the expected timeline for benefits to accrue? What is the plan for managing, analyzing and reporting technical data?
PLANNING: The approach for turning the concept into reality.	What methods and data will be used to determine design? What are past, present and future conditions at the proposed site? Who will hold permits and lease if required? What is the performance evaluation approach and control sites for the reef? What qualified contractors are needed? What is the timetable for each phase of the project? What are the construction methods and associated impact avoidance and minimization measures available? Are the construction materials and equipment available? What permits and level of environmental review are needed?

DESIGN: The technical specifications of the reef as dictated by its purposes and its environmental setting.	What is the site plan for the reef? How does the reef design meet the project's goals and objective(s)? Has connectivity been considered and maximized? What is the biological and technical basis for the physical shape, size, orientation, spacing, complexity, material and proposed location? How will the reef affect the surrounding ecosystem's natural structure, function and services? How will reef design provide benefits across taxa and life stages? Which of the options analyzed provides the most benefits?
CONSTRUCTION: The "nuts-and-bolts" aspects of deployment of the reef.	How can scheduling be used to minimize impacts? What kind of staging area is needed? What are required notifications prior to construction? What is the onsite real-time construction monitoring plan to ensure specifications and permit conditions are met?
COMMUNICATION: Providing high-quality information to ocean users and regulators.	Is there a central point of contact for the artificial reef? How will ocean users access information and performance evaluations? Have the reef coordinates been published to common databases and map applications?
EVALUATION: Measuring the outcomes in relation to the original goal and objectives.	What are the outcomes for ecological, socioeconomic and physical/engineering objectives? Is there an opportunity for third parties to conduct additional research? Are all permit conditions for monitoring being met or exceeded? Are metrics required for evaluation consistently reported to allow comparisons at project site(s) and control site(s) over time?
MANAGEMENT: Adaptive management process.	Are there conditions in the permit that trigger management actions? What maintenance of the reef is required? What is the required evaluation period? Is monitoring required after project removal (if applicable)? What is the contingency plan for unplanned events (e.g. debris from reef or relocation caused by large storms)?

4.5 Permitting

Both federal and state regulators play a role in permitting artificial reef projects (see Appendix 1). Which agencies participate will depend on the project and its location. Essential first steps in developing an artificial reef include understanding the management measures already in place, which regulators have jurisdiction and how the permitting process works. This section summarizes the regulatory landscape as it exists as of this writing and identifies other key factors that may affect whether a project in California state marine waters can proceed. Consulting regulators early is critical to identifying the site- and project-specific permitting requirements.

4.5.1 Existing Spatial Management Measures

Several spatial management measures may restrict or affect where developers can build artificial reefs within California's state marine waters — the zone extending 0 to 3 nautical miles offshore. Marine Protected Areas (MPAs), designated under the Marine Life Protection Act (Fish & G. Code, §§ 2850-2863) and classified under the Marine Managed Area Improvement Act (Pub. Resources Code, §§ 36600-36900), generally prohibit new artificial structures within their boundaries. Exceptions exist for research, restoration, monitoring and health and safety, but CDFW has historically not extended those exceptions to structures placed for non-scientific purposes. In practice, CDFW evaluates proposed structures against three criteria: whether the structure is necessary to achieve a specific scientific goal, whether it employs scientifically accepted methods and whether it would benefit wildlife (Cal. Code Regs., tit. 14, § 650, subds. (b)(19)(B), (c), (i) & (r)(1)(D-E).). Restrictions may also apply near sensitive infrastructure such as wastewater outfall pipes, pipelines, oil platforms and underwater cables.

Federal laws and regulations also govern where developers can place artificial reefs in state waters. The National Marine Sanctuary Program (NMSP) generally prohibits deploying artificial reefs in designated National Marine Sanctuaries (NMSs; 15 CF.R. § 922).[265] California has five NMSs, Greater Farallones, Cordell Bank, Monterey Bay, Chumash Heritage and Channel Islands, covering approximately 512 miles (824 kilometers) of the mainland coastline and the entire coastline of the five Northern Channel Islands. In 2003, the NMSP published guidelines outlining requirements and review procedures for artificial reef proposals in sanctuaries where regulations may allow an exception;[265] applicants must submit a comprehensive proposal demonstrating the project's technical merits, expected effects and overall value. Other federal laws may also affect where reefs can be sited. These include but are not limited to, the Magnuson Stevens Fishery Conservation Management Act, which requires protecting Essential Fish Habitat (areas of ocean considered critical to the life cycles of federally managed fish species) and the Endangered Species Act, which designates and protects critical habitat for threatened and endangered species.

Both state and federal laws protect the historic and cultural resources of California Native American tribes. These resources may include village sites, seasonal camps, fishing grounds, historic buildings, burial sites and natural landscape features of traditional cultural significance.[266] These types of resources have been documented below the mean high tide line in areas where artificial reefs might be placed. Relevant protections include the National Historic Preservation Act, Native American Graves Protection and Repatriation Act, the California Environmental Quality Act, Assembly Bill 52 (2014) and Senate Bill 18 (2004). Best practices, and in some cases the law itself, requires early and meaningful consultation with California Native American tribes whenever a proposed project could affect their cultural resources. See Section 4.5.2 for general guidance on actions and process steps to meaningfully and respectfully engage California Native American tribes in planning artificial reef projects in their traditional territories.

4.5.2 Tribal Engagement

Meaningfully engaging with California Native American tribes throughout a project's development, construction and monitoring is essential to conserving and protecting California's natural resources. California has 109 federally recognized tribes and more than 60 non-federally recognized tribes that the Native American Heritage Commission (NAHC) identifies for cultural resource assessments. The contemporary land owned by these sovereign governments and their ancestral lands and traditional territories span every part of the state including adjacent marine waters. Marine waters remain critical to California Native American tribal culture and provide ongoing food, materials and other resources tribes rely on for daily needs. Development projects can affect tribal cultural resources and culturally significant species; thus project developers should begin notifying, coordinating and engaging with California Native American tribes early and maintain that engagement throughout the life of a project.

Respect, reciprocity, recurring outreach, accountability and trust are key elements of effective tribal engagement.[267–270] California Native American tribes have unique histories, cultures, languages, traditions and governance structures, as well as unique priorities and perspectives, rooted in their particular relationships with California's governmental institutions. Tragic chapters in the state's governance and policy history — including periods when the widespread mistreatment of Native American communities was official state policy — have shaped each tribe's viewpoint and must inform how project developers approach engagement. Federally recognized tribes have the inherent right and legal status to self-govern, known as sovereignty, and to represent their members in negotiations with other governments. Always approach interactions with tribal government officials formally unless they direct otherwise. Like any government, tribal governments balance many competing priorities, and institutional support and staffing will shape each tribe's capacity to engage with a project. Developers should always strive to provide extra time for outreach and engagement and, whenever possible, offer support resources for tribal involvement, such as personnel time support, travel support and professional facilitation.

The NAHC maintains the Sacred Lands Inventory (a statewide database of culturally significant sites) and provides contact lists to requesting parties. Based on the geographic boundaries of a proposed project, the NAHC supplies a filtered list of tribal contacts for tribes that may be affected but will not provide the specific location of tribal cultural resources. While the NAHC's legal framework primarily applies to government agencies, it also accommodates public requests. Developers can ask for a Tribal Contact List through the form on the NAHC website (https://nahc.ca.gov/resources/forms/). Note that the list may not include contacts for specific tribal departments, such as tribal natural resources departments, and there may be a delay before newly updated tribal representation appears on the NAHC list.

An additional step is researching which traditional territory and ancestral land a proposed project would occupy. A useful starting point is the NAHC Digital Atlas,[271] which displays 60 cultural regions in California with links to affiliated tribes. Many California Native American tribes have seasonal, cultural or familial ties to coastal areas even if their traditional territories shown in the Digital Atlas are not located along the coast. It is strongly recommended to not rely solely on geography when identifying potentially affected tribes. Developers should also review official tribal government websites to identify representatives and staff.[269]

The California Natural Resources Agency's Tribal Consultation Policy (Appendix 2: Tribal Consultation Best Practices)[272] and the California Ocean Protection Council Tribal Engagement Strategy[273] offer detailed guidance on tribal engagement from the state's perspective. Because each California Native American tribe is unique, best practices will vary, and developers should allow adequate time to build a collaborative relationship and establish an effective engagement process. Communicate information clearly and well in advance of any meeting. Tribal staff and governments may choose to engage or not engage, either formally or informally, for any reason at any point in the development process.

4.5.3 Permitting Process Steps

Permitting an artificial reef project in California is a complex undertaking, involving state, federal and sometimes local regulators, with differing requirements and timelines. The agencies involved and what they require depend on the type of project and its location. Mitigation projects where regulators require compensation for environmental damage caused by a development project follow a different process which this section does not cover (see Section 4.3).

In general, permitting for an artificial reef project moves through three phases: pre-permitting, permit application and environmental review, and monitoring and reporting. Understanding these requirements, including the key regulators involved and best practices for engaging them, helps developers set clear expectations and timelines. Because each project carries its own specific requirements, applicants should contact regulators early in the planning process to identify the most efficient path forward (see Appendix 1, Figure 17 and Table 2).

Agencies holding jurisdiction are responsible for implementing the laws, ordinances and regulations that govern development projects. The goal of these efforts is to protect and conserve existing uses, natural resources, ecological processes and community values. Regulators accomplish this by accurately identifying any negative environmental impacts and, wherever possible, avoiding or reducing them — and offsetting them when avoidance is not feasible. Regulators meet this responsibility by thoroughly reviewing permit applications under their jurisdiction, drawing on in-house expertise and the best available science, and consulting formally and informally with other agencies to ensure a comprehensive review.

Figure 18. Generalized permitting process for artificial reef projects in California.

Pre-Permitting

During the pre-permitting phase, applicants should take several initial steps including reviewing the CARP Plan, examining relevant existing data and identifying key stakeholders and California Native American tribes in the project area. Before collecting any new data, applicants should speak with regulators to confirm what information the permit application will require and obtain all necessary data collection permits (e.g., a Scientific Collecting Permit). Clearly defining the project scope, goals, purpose and measurable objectives from the outset is essential, as it lays the groundwork for early conversations with regulators, stakeholders and California Native American tribes.

Applicants should summarize the project scope in a detailed plan that defines the project's goals, measurable objectives, potential positive and negative impacts, proposed location, materials (e.g., concrete or quarry rock), design (e.g. module spacing, elevation, texture and shape) and overall project footprint. Engineering and architectural plans are neither required nor recommended at this stage, but the more details an applicant can provide, the more useful regulators' advice will be. Where possible, applicants should meet with all relevant regulators in a group rather than separately, which is one of the most effective ways to streamline the permitting process.

After regulators provide guidance during those consultations, applicants should research potential environmental impacts and conduct pre-application site characterization studies which are systematic assessments of the site's physical, biological, human use and cultural conditions before any construction begins. Applicants should collect scientific data and develop maps that demonstrate the project's expected benefits for biological productivity and native biodiversity, which regulators will need to evaluate the application and to avoid delays. Applicants should also consider collecting baseline data, including seafloor depth mapping (bathymetric mapping), water quality testing, biological surveys including any endangered or threatened species and the types of seafloor material (substrate) present. Assessments of cultural resources (places, objects or landscapes of historical or cultural significance) and impacts to existing uses should also be documented. Applicants should identify potential impacts on coastal and marine resources, public access and recreation, water quality, fisheries, cultural resources, underserved communities and existing infrastructure.

Permit Application and Environmental Review

The next step is submitting the permit applications for environmental review. Before any state, local or federal agency can approve an artificial reef project and issue the necessary permits, the project must undergo environmental review under the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA). Depending on the project's potential impacts on natural habitat or water quality, state agencies may require either an Initial Study/Mitigated Negative Declaration (IS/MND) — a streamlined review used when a project's impacts can be reduced to acceptable levels —or a full Environmental Impact Report (EIR), which is a more thorough analysis required for projects with potentially significant impacts. For federal permits, agencies may require either an Environmental Assessment (EA) or Environmental Impact Statement (EIS), with the EIS representing the more detailed of the two. These environmental documents analyze a project's potential impacts, assess how significant those impacts are and identify feasible measures to avoid, reduce or compensate for them. EIRs and EISs also analyze a reasonable range of feasible alternatives that would avoid or substantially reduce the project's significant environmental impacts.

When a project requires both state or local permits and federal permits, agencies commonly prepare joint CEQA/NEPA documents to promote efficiency, consistency, and public transparency. This coordinated process allows environmental documents to be circulated for public review and comment through a single review process. Applicants who chose this approach should coordinate carefully and early with state and federal agencies to ensure alignment between the two processes. Multiple regulators may require and issue permits for an artificial reef project in California — Appendix 1 describes each regulator's role and the permits they may issue. Applicants should also know that additional agencies or adjacent landowners not listed in Appendix 1 may also be involved in the permitting process.

Monitoring and Reporting

Responsible development of an artificial reef requires permit holders to take a comprehensive approach to compliance. This includes ongoing monitoring to confirm the project is meeting its objectives and to identify any unforeseen impacts to marine resources during construction, operation, and, if applicable, removal. Developing a centralized process to track and publicly report all permit conditions and monitoring results is an effective way to ensure that nothing is overlooked. Local, state, and federal permit conditions will define what must be measured, how often monitoring must occur, the duration of monitoring, and the methods used to assess performance. A strong monitoring program should also include statistical justification for the selected sampling methods — including power analyses, which determine how much data is needed to reliably detect a change — along with clearly defined performance criteria for evaluating success. Permit conditions will also specify how frequently permit holders must submit written performance reports to regulatory agencies.

Box 2 Regulators and the type of permit they may issue for the development of an artificial reef project in California.

Coastal Commission – Coastal Development Permit (CDP) for areas of the Commission's retained permit jurisdiction and in areas without a certified Local Coastal Program or where a certified LCP does not apply. Commission federal consistency review may also be required under the California Coastal Management Program for federal agency projects and activities and for projects requiring a federal permit, authorization, or funding.
Local Jurisdictions (e.g. counties or cities) – Issues CDPs for areas with certified Local Coastal Program located outside of the Coastal Commission's retained permit jurisdiction.
State Lands Commission – Issues bottom leases for submerged tidelands.
Bay Conservation and Development Commission – Development permits in San Francisco Bay.
Ports & Harbors[1] – Several ports, harbors and districts issue development permits within their boundaries.
Regional Water Control Boards – Issues Clean Water Act Section 401 Water Quality Certification.
Department of Fish and Wildlife – Incidental Take Permits for protected species and Scientific Collecting Permit if there is take.
U.S. Army Corps of Engineers – Issues individual permit under Section 10 of Rivers and Harbors Act .
U.S. Fish and Wildlife – Issues Special Use Permit if project is in National Wildlife Refuge and manages Sec. 6 and 7 ESA outside of Refuges.
NOAA Fisheries/NMFS – Permits related to impacts to special status/protected species.
U.S. Coast Guard – Adds navigational marking requirements to USACE Section 10 permit if required.
U.S. Environmental Protection Agency – Permits the use of dredged or fill material.

NOTE: See Appendix 1 for a detailed description of the roles and responsibilities of each regulator. Additional agencies or adjacent landowners not listed may be involved in permitting or consulting on permit applications.
[1] Port of Hueneme, Port of Long Beach, Port of Los Angeles, Port of San Diego, Crescent City Harbor District, Humboldt Bay Harbor, Recreation, and Conservation District. Moss Landing Harbor District, Noyo Harbor District, Port of Oakland, Port of Redwood City, Port San Luis Harbor District, Port of San Francisco, San Mateo County Harbor District, and Santa Cruz Port District.

4.5.4 Liability and Fiscal Responsibility

The National Fisheries Enhancement Act (33 U.S.C. § 2104(c)) defines the liability that permit holders carry under the U.S. Army Corps of Engineers for construction of artificial reefs in state or federal waters. The California Coastal Commission and other state regulators require permits for artificial reef projects to include liability waivers — agreements in which permit holders accept responsibility for specified risks associated with the project. Most regulators will also require applicants to show they have sufficient funding to cover all phases of the project, including full removal of the reef, if required, before issuing permits. Applicants should check with each permitting agency for its specific requirements.

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Appendix 1- Regulator Roles Related to Artificial Reefs

Artificial reef activities are regulated by a combination of federal, state, and local authorities. At the state level, virtually all natural resource agencies with responsibilities for marine resource management, environmental protection, coastal access and marine habitat enhancement participate in permitting artificial reef activities. These agencies regulate artificial reef development and the placement of solid materials into coastal waters within their respective jurisdictions.

The **California State Lands Commission** (CSLC) has jurisdiction and management authority over all ungranted tidelands, submerged lands, and the beds of natural navigable lakes and waterways. The SLC also has certain residual and review authority for tidelands and submerged lands legislatively granted in trust to local jurisdictions (Public Resources Code, Section 6009, subd. (c); 6009.1; 6301; 6306). All tidelands and submerged lands, granted or ungranted, as well as navigable lakes and waterways, are subject to the protections of the common law Public Trust Doctrine.

As general background, the State of California acquired sovereign ownership of all tidelands and submerged lands and beds of navigable lakes and waterways upon its admission to the United States in 1850. The State stewards these lands for the benefit of all people of the State for Public Trust purposes, which include but are not limited to waterborne commerce, navigation, fisheries, water-related recreation, habitat preservation, and open space. On the open coast, the State's sovereign fee ownership extends from the ordinary high-water mark, as measured by the mean high tide line, except for areas of fill or artificial accretion or where the boundary has been fixed by agreement or a court decision, to the State/federal boundary, approximately three geographic miles offshore. Such boundaries may not be readily apparent from present day site inspections. Activities and improvements or infrastructure on or over these sovereign lands typically require a lease from SLC. The SLC is a trustee agency for projects that could directly or indirectly affect sovereign land and accompanying Public Trust resources or uses.

Additionally, pursuant to Senate Bill (SB) 286 (McGuire, Chapter 386, Statutes of 2023) and Public Resources Code, section 30601.4, subdivision (b)(1), the CSLC will act as the California Environmental Quality Act (CEQA) lead agency for offshore wind energy projects (with certain specified exceptions).[2]

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[2] Bill Text - SB-286 Offshore wind energy projects. (ca.gov) (https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202320240SB286)

The **California Coastal Commission** (CCC) was established by voter initiative in 1972 (Proposition 20) and later made permanent by the Legislature through adoption of the California Coastal Act of 1976 (Public Resources Code Section 30000 *et seq*.). In partnership with coastal cities and counties, the CCC plans and regulates development in the coastal zone. Development activities, which are broadly defined by the Coastal Act to include (among others) construction of buildings, divisions of land, and activities that change the intensity of use of land or public access to coastal waters, generally require a coastal development permit (CDP) from either the CCC or a local government, depending on location and if the CCC has delegated CDP authority to that local government. Additionally, the CCC reviews federal activities and development, and projects requiring a federal permit, authorization, or funding for consistency with Chapter 3 of the California Coastal Act.

The **California Department of Fish and Wildlife (**CDFW) is California's Trustee Agency for fish and wildlife resources and holds those resources in trust by statute for all the people of the State. (Fish and Game Code, Section 711.7, subd. (a) & 1802; Public Resources Code, Section 21070; CEQA Guidelines Section 15386, subd. (a).) The CDFW, in its trustee capacity, has jurisdiction over the conservation, protection, and management of fish, wildlife, native plants, and habitat necessary for biologically sustainable populations of those species. (*Id.*, Section 1802.) The CDFW is also responsible for marine native biodiversity protection and the management of marine protected areas under the Marine Life Protection Act (Fish and Game Code, Section 2850-2863) and the Marine Managed Areas Improvement Act (Public Resources Code, Section 36700) in state marine waters of California and ensuring fisheries are sustainably managed under the Marine Life Management Act (Fish and Game Code Sections: 90 - 99.5, 105, 7050 - 7090, 8585 - 8589.7, 8842, and 9001.7).

The **San Francisco Bay (Bay) Conservation and Development Commission** (BCDC) was established in 1965 when the State of California enacted the McAteer-Petric Act to save the San Francisco Bay. BCDC has jurisdiction and authority over the Bay and its shoreline within the nine counties and forty-six cities that touch the Bay. BCDC was created a decade before either the CCC or the passage of the federal Coastal Zone Management Act. As the Nation's oldest coastal zone management agency, BCDC works in partnership with government agencies at all levels, and its actions and plans are reviewed every five years by the National Oceanic and Atmospheric Administration as required by federal law. BCDC's purpose is to permit only the minimum amount of Bay fill appropriate for approved development projects and provide the public with maximum feasible access to the Bay.

Regional Water Boards

The State Water Resources Control Board was created by the State Legislature in 1967 and has jurisdiction throughout California to protect water quality by setting statewide policy, establishing water quality control plans, coordinating and supporting the Regional Water Board efforts, and reviewing petitions that contest Regional Water Board actions. In 1969, the State Legislature enacted the Porter-Cologne Water Quality Control Act, which provides authority for the regulation of the state's water quality by the State Water Resources Control Board and nine Regional Water Boards. The nine Regional Water Boards are semi-autonomous and are comprised of seven part-time Board members appointed by the Governor and confirmed by the Senate. Regional boundaries are based on watersheds and water quality requirements are based on the unique differences in climate, topography, geology, and hydrology for each watershed. Each Regional Water Board makes critical water quality decisions for its region, including setting standards, issuing waste discharge requirements, determining compliance with those requirements, and taking appropriate enforcement actions. The nine Regional Water Boards are follows:

- Region 1 -- North Coast Regional Water Quality Control Board
- Region 2 -- San Francisco Regional Water Quality Control Board
- Region 3 -- Central Coast Regional Water Quality Control Board
- Region 4 -- Los Angeles Regional Water Quality Control Board
- Region 5 -- Central Valley Regional Water Quality Control Board
- Region 6 -- Lahontan Regional Water Quality Control Board
- Region 7 -- Colorado River Regional Water Quality Control Board
- Region 8 -- Santa Ana Regional Water Quality Control Board
- Region 9 -- San Diego Regional Water Quality Control Board

The State Water Resources Control Board and the Regional Water Boards have the authority to regulate discharges of dredged or fill material to waters of the state under section 401 of the Clean Water Act (CWA) and the Porter-Cologne Water Quality Control Act (Porter-Cologne). CWA section 401 water quality certifications are issued to applicants for a federal license or permit for activities that may result in a discharge into waters of the United States, including but not limited to the discharge or dredged or fill material. Waste discharge requirements under Porter-Cologne are issued for discharges of dredged or fill material to waters of the state. Artificial reef applicants may be required to obtain Section 401 certification to ensure no water quality degradation.

The **California Department of Parks and Recreation** State Parks) has jurisdiction over the California State Park System and preserves California's natural, cultural, and historical treasures through management of 280 state park units, over 340 miles of coastlines, 970 miles of lake and river frontage, 15,000 campsites, 5,200 miles of trails, 3,195 historic buildings, and more than 11,000 known prehistoric and historic archaeological sites. Some of the areas that the State Park System includes are beaches, marine parks, natural reserves, seashores, and recreation areas. The State Park System lands also protect and preserve an unparalleled collection of culturally and environmentally sensitive structures and habitats, threatened plant and animal species, ancient Native American sites, historic structures and artifacts.

The **California Ocean Protection Council** (OPC) is a Cabinet-level state policy body within the California Natural Resources Agency that advances the Governor's priorities for coastal and ocean policy and works broadly to protect healthy coastal and ocean ecosystems for current and future generations. OPC was established by the California Ocean Protection Act (Public Resources Code Section 35500 *et seq*.), and its actions are guided by this statute and the Strategic Plan to Protect California's Ocean and Coast (2020-2025). OPC prioritizes collaboration between state and federal agencies and other partners to maximize consistency in decision-making and safeguard California's coast and ocean.

Federal Agencies

The **United States Army Corps of Engineers** (USACE) provides vital public engineering services for water resources, the environment, and military infrastructure. USACE acts as the nation's environmental engineer by managing waterways, controlling floods, restoring ecosystems, cleaning contaminated sites, designing miliary facilities, and handling disaster response.
Most artificial reef development projects will require a permit from USACE pursuant to the USACE's authority under section 10 of the Rivers and Harbors Act and/or section 404 of the Clean Water Act. In addition to USACE's responsibilities for permitting the construction of artificial reefs under the National Fishing Enhancement Act (NFEA), USACE is responsible for regulating certain activities in waters of the United States under Sections 9, 10, 11, 13, and 14 of the Rivers and Harbors Act of 1899 (RHA) (33 U.S.C. §401 et seq.). USACE also has permit authority under Section 404 of the Clean Water Act (CWA) (33 U.S.C. §1344), and Section 103 of the Marine Protection, Research and Sanctuaries Act (MPRSA) (33 U.S.C. §1413). USACE regulates work on structures under the RHA and the transport of dredged material under the MPRSA. USACE has very specific regulatory authorities under the CWA and retains responsibility for processing and issuing permits under Section 404 of the CWA except where regulatory authority has been delegated to the states. Specifically, USACE is the lead federal agency responsible for permitting artificial reef development under authority of the National Fishing Enhancement Act of 1984. Pursuant to Section 203 of the Act, USACE promulgated rules for permitting artificial reef development activities in 33 CFR, Parts 320 through 330, November 13, 1986. USACE has responsibility for the protection of submerged archaeological resources. One key piece of protective legislation for archaeological resources is the National Historic Preservation Act (NHPA) (16 U.S.C. §470 et seq.). USACE is responsible for assessing potential reef sites for possible impacts to submerged archaeological resources under section106 of the NHPA.

The **U.S. Fish and Wildlife Service** (USFWS) administers the Federal Aid in Sport Fish Restoration Program, which provides matching grants to the states to undertake sport fish restoration and boating projects. Money for this program is collected from excise taxes on fishing tackle and motorboat fuels in a user-pays/user-benefits program. The 1984 Wallop-Breaux Amendment to the Sport Fish Restoration Act significantly enhanced the states' abilities to undertake artificial reef programs through increased financial assistance for such projects. Consequently, this funding has influenced the direction of artificial reef programs nationwide towards a greater focus on enhancement of recreational fisheries and increased fishing opportunities by improving access to the fisheries resources. In addition, the USFWS participates in the cooperative Interstate Fishery Management Program of the Atlantic States Marine Fisheries Commission (ASMFC) to develop and implement fishery management plans under the Atlantic Coastal Fisheries Act. The USFWS has responsibility to provide technical assistance in various consultation processes under the Endangered Species Act, the National Environmental Policy Act, the Coastal Zone Management Act, and Section 404 of the Clean Water Act. The USFWS also provides a critical function in co-chairing, with NMFS, the National Recreational Fisheries Resources Conservation Council. Through its participation in these programs and consultation process, the USFWS has the potential to influence artificial reef development.

The **National Oceanic and Atmospheric Administration Fisheries** (NOAA Fisheries**)**, also known as The National Marine Fisheries Service (NMFS) carries out responsibilities of the Department of Commerce (DOC) related to conservation and management of living marine resources and their habitats. NMFS' authority to conserve and manage fishery and living marine resources is established by a suite of Federal laws, including the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. §1801 et seq.), the Endangered Species Act (16 U.S.C. §§1531-1543), the Fish and Wildlife Coordination Act (16 U.S.C. §§661-666c), and others (see Regulatory Requirements section). NMFS plays an obvious part in artificial reef development, management, and regulation through its role as the lead agency in the development of the NOAA National Artificial Reef Plan as Amended: Guidelines for Siting, Construction, and Development of Artificial Reefs. Additionally, NMFS is involved in a general oversight capacity in such activities as providing comments on artificial reef permits; research; establishment of acceptable standards for the transfer, cleaning, and preparation of certain reef materials; and in establishment of fishery regulations pertaining specifically to the development of artificial reef sites.

NMFS also provides scientific input and conducts research that affects many of the biological considerations in the creation and siting of artificial reefs, as well as the study of feasibility of using artificial reefs to gather information about habitat requirements of marine organisms. In addition to its regulatory and policy development responsibilities, the Restoration Center (housed with the NMFS Office of Habitat Conservation) also plays a role in artificial reef development. The Restoration Center (RC) has authority to respond to the recommendations from the Office of Response and Restoration (ORR) Program within the National Oceans Service (NOS) to use funds available from responsible parties involved in a release or spill of hazardous materials into estuarine-marine waters to construct artificial reefs. These artificial reefs are used to restore lost or injured reef-like habitat, or reef-related fisheries resources, or to compensate for a loss of public access to recreational fishery resources because of the release or spill or from physical damage to natural reef habitat, such as by vessel groundings. The RC also offers funding for voluntary habitat restoration projects, which can include artificial reef construction.

The **NOAA West Coast Region Office of National Marine Sanctuaries** manages 19,876 square miles of marine protected areas around Channel Islands, Chumash Heritage, Cordell Bank, Greater Farallones, Monterey Bay, and Olympic Coast. Since 1972, the Office of National Marine Sanctuaries has worked cooperatively with the public and federal, state and local officials to promote conservation while allowing compatible commercial and recreational activities.

Sanctuary managers rely on a variety of mechanisms to understand and protect the sanctuary's living and historical resources. The National Marine Sanctuaries Act, along with site-specific legislation and regulations, provides the legal framework outlining the activities that are allowed or prohibited. The sanctuaries implement a permit system to regulate and oversee potentially harmful activities in sanctuaries. This framework may be enhanced by the adoption of state and other federal laws and regulations.

Section 310 of the National Marine Sanctuaries Act (16 U.S.C. § 1441; NMSA) allows the Secretary of Commerce, delegated to the Office of National Marine Sanctuaries) to issue special use permits to authorize the conduct of specific activities in a sanctuary if such authorization is necessary (1) to establish conditions of access to and use of any sanctuary resource or (2) to promote public use and understanding of a sanctuary resource. Special use permits are generally issued for concessionaire-type activities and other commercial activities that require access to the sanctuary to achieve a desired goal.

The **U.S. Coast Guard Pacific Area** has authority to: 1) promulgate regulations dealing with lights, warning devices, and other public and private aids to navigation on offshore installations; 2) establish safety fairways and traffic separation schemes for safe movement of vessel traffic under the Ports and Waterways Safety Act; 3) establish safety zones around offshore facilities; 4) enforce fishery laws; and 5) monitor and enforce compliance with international conventions and statutes on environmental protection.

Placement of fill material or structures, such as those used to create artificial reefs, is subject to USACE permitting authority under Section 404 of the Clean Water Act (CWA). CWA Section 404 applies to “waters of the United States,” which as a general matter include most inland waterbodies as well as the territorial seas (which for CWA purposes extend three miles from the baseline). In issuing CWA Section 404 permits, the Corps applies the Section 404(b)(1) guidelines, which were developed by the United States Environmental Protection Agency (EPA) in conjunction with USACE. The guidelines (which can be found at 40 C.F.R. Part 230) prohibit issuance of 404 permits that would cause or contribute to violations of applicable water quality standards and also generally preclude discharges that would cause or contribute to significant degradation of waters of the United States. In addition, CWA Section 404(c) authorizes EPA to prohibit, withdraw, or restrict the use of defined areas as a dredged or fill material disposal site in any waters of the U.S., including the Territorial Sea, if EPA determines that the discharge will have unacceptable adverse effects on municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational areas. Artificial reef creations beyond the Territorial Sea are regulated under Section 10 of the Rivers and Harbors Act of 1899.

Under the Liberty Ship Act, which allows states to apply to the Secretary of the Department of Transportation (DOT) for use of obsolete vessels to create artificial reefs, the state application to the DOT must include a certification from EPA that the proposed use of the vessel will be compatible with “applicable water quality standards and other appropriate environmental protection requirements” (16 U.S.C. §1220(b)).

Although the EPA has not developed guidelines for materials used for artificial reef construction, the CWA Section 404(b)(1) guidelines and ocean dumping criteria (promulgated under the MPRSA) can be used to as guidance to determine the acceptability of certain artificial reef materials in waters of the United States. While these guidelines do not supercede the guidelines outlined in this document, they can be used in conjunction. The placement of materials for the purpose of creating an artificial reef is not regulated as ocean dumping under the MPRSA. As part of its involvement in ReefEX, EPA also developed specific criteria for preparation of de-militarized combat vehicles prior to their use for reef construction in the Gulf of Mexico.

Appendix 2 - Outreach Activities

Outreach Summary

- In-person Open Listening Sessions, Sacramento, Oxnard and Los Alamitos — 2017
- Artificial Reef Recreational Use Online Survey — 2018-ongoing
- California Artificial Reef Science Workshop, hosted by CDFW's Marine Region — 2021
- Launch of new California Artificial Reef Program webpages — November 2024
- Letter to California Native American tribes notifying them of the statewide project to develop the CARP Plan — December 2024
- Online Pre-project Tribal Listening Sessions — January 22 and 23, 2025
- Online Pre-project Open Listening Session — February 26 and March 20, 2025
- Online Tribal Listening Sessions — January 28 and 29, 2026
- Open Listening Sessions — February 3 and 4, 2026

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Appendix 4 - California Policies Relevant to the Placement of Artificial Reefs

The policies and directives in Appendix 4 may not include all relevant policies that may affect the placement of artificial reefs in state marine waters. Artificial reef developers should contact regulators early to ensure they can incorporate all relevant directives and polices into their planning. The policies and directives below are helpful in evaluating which types of artificial reefs and locations would be considered appropriate for artificial reef placement.

The Statewide Wildlife Action Plan (SWAP) is a foundational document updated at least every 10 years for the state to be eligible for federal funds that support wildlife conservation. The 2025 SWAP serves as a blueprint for conserving California's aquatic, marine and terrestrial resources. The 2025 SWAP lays out a multi-species ecosystem framework to guide priority conservation actions in the marine environment. This includes highlighting the need to maintain and increase ecosystem and native species distribution, while sustaining and enhancing species abundance; maintaining and improving ecological conditions; and maintaining and improving ecosystem function and processes vital for sustaining California ecosystems. The 2025 SWAP further underscores the importance of prioritizing biological production and native biodiversity in any artificial reef project.

The Marine Life Protection Act establishes Marine Protected Areas (MPAs) (Fish & G. Code, §§ 2850-2863.) The Marine Managed Area Improvement Act classifies these areas (Pub. Resources Code, §§ 36600-36900.) As a general rule, regulators do not allow new artificial structures in MPAs. While exceptions exist for research, restoration and monitoring, CDFW has historically not interpreted these exceptions to permit artificial structures placed for non-scientific purposes. To qualify for an exception, a proposed structure must be necessary to achieve a relevant scientific goal, use scientifically accepted methods and benefit wildlife (Cal. Code Regs., tit. 14, § 650, subds. (b)(19)(B), (c), (i) & (r)(1)(D-E).)

The California Eelgrass Mitigation Policy (CEMP) requires that projects result in no net loss of the ecological function that eelgrass provides. The CEMP directs regulators to avoid any negative impacts on eelgrass in all projects including conservation, restoration and enhancement projects, which in turn shapes how regulators evaluate the siting of coastal development projects.

The California Coastal Act (Pub. Resources Code, §§ 30000-30900) requires that all development in the coastal zone, including artificial reefs, protect and enhance California's coastal resources. To highlight several policies of particular relevance to artificial reef proposals, § 30231 requires projects to maintain the biological productivity and the quality of coastal waters appropriate to maintain optimum populations of marine organisms and for the protection of human health. Coastal Act § 30230 requires that marine resources be maintained, enhanced, and where feasible, restored. Coastal Act § 30233 lists the specific activities and uses for which diking, filling, or dredging of open coastal waters, estuaries, and wetlands is allowed. The placement of material such as sediment or rock for an artificial reef would be considered “fill”, and the purpose would need to qualify as one or more of the allowable uses. The Coastal Act also contains policies protecting public access and recreation, commercial and recreational fishing, and environmentally sensitive habitat. Further, it requires that projects neither create nor contribute significantly to erosion, and Coastal Act § 30235 limits the approval of shoreline protection devices to very limited circumstances, namely when required to serve coastal-dependent uses or to protect public beaches or existing structures in danger from erosion, and only when designed to eliminate or mitigate adverse impacts on local shoreline sand supply. ‘

Appendix 5 - Known Artificial Reefs in California

SiteName	Latitude	Longitude	AvgDepth_ft	Material	Area_acres	YearBuilt	LastYearWork
Giant Marsh	37.994289	-122.362868	7	baycrete reef balls and oyster modules	2	2017	2025
Red Rocks	37.965501	-122.426764	5	baycrete reef balls and oyster modules	2	?	?
San Rafael LSP	37.963685	-122.487663	5	baycrete reef balls and oyster modules	2	2012	2014
Terminal 4	37.963585	-122.42913	5	rock and concrete	2	?	?
Hayward LSP	37.609571	-122.14843	6	baycrete reef balls and oyster modules	2	2015	?
Soquel Cove	36.95	-121.955	45	480 Concrete culvert pipes	0.6	1981	1981
Atascadero	35.3933372	-120.8755722	55	3,500 tons quarry rock	0.4	1985	1985
San Luis Obispo	35.1902809	-120.831955	43	concrete tribar and rubble	13	1984	1984
Goleta Bay	34.405767	-119.83415	40	16 concrete sea caves	0.1	2024	2024
Rincon Island	34.3472222	-119.4447222		120 car bodies augemented with 10,000 tires		1958	1958
Pitas Point	34.302227	-119.3683472	28	7,200 tons quarry rock	1.1	1984	1984
Ventura	34.2436111	-119.298888	60	2000 ton quary rock	8.8	1965	1965
Channel Islands Habor	34.1552777	-119.2672222	60	60,000 tires		1979	1979
La Jenelle	34.125	-119.294444	95	Vessel superstructure La Jenelle		1975	1975
Malibu	34.0302811	-118.6505661	60	333 tons quarry rock, concrete blocks, pier pilings, and rubble	0.5	1961	1961
Topanga	34.0272255	-118.5325089	28	10,000 tons quarry rock	13	1987	1987
Paradise Cove	34.016666	-118.766666	50	20 car bodies	0.5	1958	1961

Santa Monica Bay	34.0130615	-118.542511	57	streetcars, autobodies, 20,000 tons quarry rock and concrete shelters	256	1987	1987
Santa Monica	34.009449	-118.5297318	60	100 tons concrete pier pilings, 330 tons quarry rock concrete shelters, can bodies streetcar	0.5	1961/1971	1971
Marina Del Rey 2	33.968338	-118.4864044	65	10,000 tons quarry rock	6.9	1985	1985
Marina Del Rey 1	33.965004	-118.4861221	65	2000 tons concrete rubble quarry rock and 4000 tons dock floats	3.2	1965/1978	1978
Hermosa Beach	33.8536148	-118.4133453	60	streetcar, car bodies, 330 tons quarry rock concrete shelters concrete pier pilings	0.5	1960	1960
Redondo Beach	33.8375053	-118.4086227	72	concrete dock floats, quarry rock barge concrete pier pilings	1.6	1962/1978	1978
Palawan	33.823616	-118.4147339	120	450 ft sunken liberty ship	0.6	1977	1977
Redondo/Palos Verde	33.813333	-118.405	60	6 street cars	0.1	1962	1958
Palos Verdes Reef	33.7208939	-118.3451004		quarry rock	32	2020	2020
Bolsa Chica	33.6527596	-118.100502	93	10,400 tons steel and concrete barges, edison lightpoles, pier pilings, quarry rock concrete rubble, concrete chimneys, fired bricks	220	1986	1966
Huntington Beach A	33.6238937	-118.0008469	60	1,000 tons quarry rock each	3.7	1963	1963
Huntington Beach B	33.6213951	-117.9975128	60	1,000 tons quarry rock each	3.7	1963	1963
Huntington Beach C	33.6191711	-117.9880676	60	1,000 tons quarry rock each	3.7	1963	1963

Huntington Beach D	33.6144485	-117.9830704	60	1,000 tons quarry rock each	3.7	1963	1963
Newport Beach	33.6036148	-117.963623	72	10,675 tons concrete blocks, pilings,& rubble	8	1984	1984
Chalk Cove	33.4442863	-118.4883728		constructed concrete blocks with tubes	unknown	1979	1979
Wheeler North Reef	33.3944588	-117.6126175		quarry rock	370.7	1999/2008/2020	2020
Pendelton	33.3250046	-117.5283432	43	quarry rock	3.5	1980	1980
Oceanside 2	33.2111626	-117.4288483	57	quarry rock	256	1987	1987
Oceanside 1	33.1825066	-117.4166794	91	quarry rock concrete dock floats	4	1964	1987
Carlsbad	33.0865059	-117.320343	49	10,000 tons quarry rock and concrete dock floats	6	1991	1991
Torrey Pines 2	32.8930626	-117.2597351	444	3,000 tons quarry rock	1 acre	1975	1975
Torrey Pines 1	32.886673	-117.2639008	67	1,000 tons quarry rock	Unknown	1964	1964
Pacific Beach	32.7930603	-117.2763977	57	10,000 tons quarry rock	109	1987	1987
Mission Beach	32.7700043	-117.2677917		concrete roadway rubble	173	1992	1992
WreckAlley	32.7641716	-117.2772369		3 ships and radar tower	173	1987-2000	2000
N. Isl. Enhancement Reef	32.7047958	-117.2254562		quarry rock concrete rubble	Unknown	1997	1997
San Diego Bay	32.614275	-117.103353		reef balls		2021	2021
International Reef	32.5415878	-117.2465134		quarry rock concrete rubble 4 story missile platform	75	1992-1993	1993

Appendix 6 - Selected Long-term Monitoring Programs and Visualization Tools

PISCO: The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) is a group of university scientists who maintain a long-term research and monitoring program. This program aims to understand the California Current Large Marine Ecosystem with their research extending more than 1200 miles. The findings of this work are used in conservation and management decisions. https://piscoweb.org/data-access

CRANE: The Cooperative Research and Assessment of Nearshore Ecosystems (CRANE) program was established in 2002 per the recommendation of California Department of Fish and Game and the Marine Life Management Reform Project to meet the goals of the Marine Life Management Act (MLMA). The Marine Life Management Act (MLMA) stipulates several new fisheries management and conservation objectives for California's marine living resources, and calls for an ecosystem-wide approach to management. CRANE involves the integration of several study (e.g., habitat mapping, life history research, oceanography) and sampling approaches (e.g., fishery-dependent and independent CPUE estimates, ROV surveys, plankton-larval surveys) in shallow rocky reef ecosystems. Collaborators in the central California region include the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), University of California at Santa Cruz, CDFG, and Sanctuary staff. https://sanctuarysimon.org/dbtools/project-database/project-info-ajax.php?ID=100154

Reef Check: Reef Check is an international non-profit organization with a focus on conserving coral reef and kelp forest ecosystems. Reef check trains volunteers consisting of citizen scientists collect data on reef health and climate change impacts. This data is used by scientists, policy makers, and resource managers to make sound decisions regarding these coastal systems. Reef check also promotes public education about reefs to promote stewardship. https://www.reefcheck.org/global-reef-tracker/

CCFRP: The California Collaborative Fisheries Research Program is a community-based science program involving researchers from six California universities, the captains and crew of 36 sportfishing vessels, more than 2,000 volunteer anglers, and partnerships with conservation and resource management agencies. By combining the expertise and ideas of a diverse group, CCFRP has successfully established protocols to evaluate Marine Protected Areas (MPAs), the status of nearshore fish stocks, and how climate change is impacting marine resources in California. https://www.ccfrp.org/publications-reports

CeNCOOS and SCCOOS: The Central and Northern California Ocean Observing System (CeNCOOS) and the Southern California Coastal Ocean Observing System (SCCOOS) are two of eleven regions that contribute to the national U.S. Integrated Ocean Observing System (IOOS). The regional observing systems work to collect, integrate, and deliver coastal and ocean observations in order to improve safety, enhance the economy, and protect the environment. The principal goal of CeNCOOS and SCCOOS is to provide observations and products to a diverse stakeholder community of managers and planners, operational decision makers, scientists, and the general public. CeNCOOS and SCCOOS have developed the capabilities to support short-term decision-making and long-term assessment by implementing and leveraging biological, chemical, and physical observations and models, many of which are available in near real-time. Central and Northern California Ocean Observing System, Southern California Coastal Observing System

CalCOFI: CalCOFI is a long-term ecosystem research program off the coast of California that holistically studies the physics, chemistry, and biology of the ocean to inform the sustainable management of marine ecosystems in the context of climate variability and change. CalCOFI has been surveying the California Current since 1949 and conducts quarterly cruises from north of San Francisco Bay to San Diego and extends from the coast to 300 miles (500 km) offshore, spanning state, national, and international waters. CalCOFI is a unique partnership between government and academic organizations including NOAA's Fisheries Service (federal partner), California Department of Fish & Wildlife (state partner), and Scripps Institution of Oceanography (academic partner). California Cooperative Oceanic Fisheries Investigations

SCBRMP: The Southern California Bight Regional Monitoring Program is an ongoing marine monitoring collaboration that examines how human activities have affected the health of more than 1,500 square miles of Southern California's coastal waters. Via this partnership that is facilitated by the Southern California Coastal Water Research Project (SCCWRP), dozens of participating organizations pool their resources and expertise to investigate the condition of marine ecosystems across both time and space. Both regulated and regulatory agencies, as well as nongovernmental and academic organizations, come together to design studies, interpret findings, and speak with a common voice about the ecological health of the Southern California Bight. Southern California Bight Regional Monitoring Program

CalEMP and EMPA: The California Estuary Monitoring Program (CalEMP) is an ongoing, statewide effort to assess the quality and condition of California estuaries by leveraging regional and local monitoring programs and projects. The program is designed to evaluate estuarine health and condition using a standardized, comprehensive, function-based assessment framework. Program partners have collaboratively developed assessment frameworks, standardized monitoring protocols, data structures, and quality control measures to ensure consistency and comparability across projects and sites.The development of the program began in 2020 with the creation of the California Estuary Marine Protected Area (EMPA) Monitoring Program, which was designed to evaluate estuarine health and the efficacy of Marine Protected Area (MPA) designation. Since its inception, the EMPA assessment framework has been adopted by many regional and local projects and is increasingly being incorporated into agency permits and grant programs. EMPA Monitoring Program lays the foundation for the California Estuary Monitoring Program (CalEMP). California Estuary Monitoring Program (CalEMP), Projects | California Estuary Monitoring Program (CalEMP)

SF WRMP: The WRMP improves the success of tidal wetland restoration by making monitoring more cost effective and producing data and analyses that meet wetland decision-makers' needs. The WRMP uses practical, collaboratively developed questions to guide wetland monitoring. These questions support informed, science-based decisions to promote healthier wetlands and a more resilient Estuary. To answer these questions, the WRMP established a Monitoring Site Network, which includes three wetland types—mature (Benchmark), evolving (Reference), and newly restored (Project) sites — to understand changes following restoration and guide better restoration practices. The WRMP has an open data sharing policy to ensure Bay Area residents, nonprofit organizations, academic institutes, Tribes, regulatory agencies and local governments can access scientific data to respond and adapt to environmental hazards and recurrent coastal flooding. Home - Wetlands Regional Monitoring Program **SCWRP RMP**: The Southern California Wetland Recovery Project Regional Monitoring Program (WRP RMP) provides a coordinated approach for coastal wetland monitoring in southern California to track progress towards achieving objectives of the WRP Regional Strategy. The WRP RMP also serves as a regional implementation of the statewide EMPA assessment framework. The WRP RMP aims to develop comparable approaches for coastal wetland monitoring and incorporate these into permit- and funding-required monitoring programs. Comparable monitoring information is critical to evaluate whether the goals and objectives of the WRP Regional Strategy are being achieved, inform future funding decisions, and protect past investments in wetland restoration from the rapidly advancing impacts of sea level rise. Projects | California Estuary Monitoring Program (CalEMP)

LTER: California Current Ecosystem Long-Term Ecological Research: The California Current Ecosystem LTER became part of the U.S. National Science Foundation-supported Long-Term Ecological Research network in 2004. The CCE LTER program focuses on interdisciplinary oceanographic research aiming to communicate the effects of long-term climate variability on the California Current pelagic ecosystem, and utilizes diverse observational platforms, process studies, and modeling approaches to investigate ecosystem change. CCE is based at the Scripps Institution of Oceanography/University of California, San Diego, but currently includes partners at several other institutions (Florida State University, Rice University, Brown University, Farallon Institute, and the Southwest Fisheries Science Center/National Marine Fisheries Service, among others). The CCE LTER site is located off the southern coast of California, extending from San Diego north to San Luis Obispo and westward over 500 km. This area comprises an ecosystem that includes the California Current. The CCE region has been studied intensively for over 75 years by the California Cooperative Oceanic Fisheries Investigations (CalCOFI). California Current Ecosystem LTER.

Santa Barbara Coastal Long-Term Ecological Research: The Santa Barbara Coastal LTER is an interdisciplinary program established in 2000 to understand the ecology of coastal kelp forest ecosystems. The research is focused on the nearshore waters of southern California, where ocean currents and environmental conditions are highly variable with season and longer-term cycles, including the El Niño-Southern Oscillation and the Pacific Decadal Oscillation. SBC's principal study domain is a 10,000 square kilometer area of the northern portion of the Southern California Bight that includes the Santa Barbara Channel and the steep coastal watersheds, small estuaries and sandy beaches that border the Channel. The SBC LTER is based at the University of California, Santa Barbara (UCSB) Marine Science Institute, and is part of the National Science Foundation's (NSF) Long Term Ecological Research (LTER) Network. Santa Barbara Coastal LTER.

SONGS: In 1974, the California Coastal Commission (CCC) issued a coastal development permit to Southern California Edison company (SCE) for operation of the San Onofre Nuclear Generating Station (SONGS) Units 2 and 3. A condition of the Permit required the establishment of a three-member independent Marine Review Committee (MRC) to direct comprehensive studies to assess potential impacts of the operation of Units 2 and 3 on the marine environment offshore from San Onofre, and mitigation of any adverse impacts. Based on the MRC's findings the CCC added new conditions to the SONGS Coastal Development Permit for mitigation of impacts identified by the MRC. The two major areas of SONGS mitigation involve biological and physical monitoring of southern California wetlands and kelp forests. The monitoring is being conducted by scientists at the Marine Science Institute, University of California, Santa Barbara. Overview | Marine Mitigation

VRG: The Vantuna Research Group has been monitoring and researching the marine environment of Southern and Baja California since 1966. VRG is dedicated to studying long-term and large spatial scale ecological processes in the Southern California Bight. Their research program features both the longest continual time series studies of rocky reefs in the world and the largest spatial-scale studies of reefs in the Bight. They also focus on the taxonomy and life history of southern California marine fishes and ichthyoplankton and complete extensive larval and adult studies using otoliths. As a non-profit educational program, VRG encourages undergraduate students to participate in all aspects of research, from data collection to publishing in peer-reviewed journals, in order to help prepare them for graduate programs or careers in marine science. https://www.oxy.edu/academics/vantuna-research-group

NOAA fisheries and ecosystem monitoring: NOAA Fisheries' science-based conservation and management of sustainable fisheries, marine mammals, endangered species, and their habitats have become global models for marine stewardship and sustainability.

Our research surveys provide data critical to the stewardship of our nation's ocean resources and their habitat. For 150 years, our scientists and partners have collected survey data to understand current and changing ocean conditions and monitor marine life. The insights we gain are the heart of our science-based conservation and management.

Effective science-based conservation and management are essential to ensuring sustainable domestic seafood production, maintaining and enhancing fishing opportunities, recovering protected species, and safeguarding ecosystem health. National Oceanic and Atmospheric Administration Fisheries ocean, ecosystem and fisheries monitoring.

Our Coasts Our Future: *Our Coast, Our Future* is a partnership between Point Blue Conservation Science and the USGS Pacific Coastal and Marine Science Center, and was collaboratively developed with many local, state, and federal partners as it expanded across California. As of January 2026, it provides sea level rise and storm scenarios for the entire coast of California, including San Francisco Bay and the Channel Islands. It was originally launched in 2011 and focused on the San Francisco Bay and outer coast area. The USGS led the modeling, Point Blue Conservation Science developed the online platform and supported end-user engagement, and staff from the Greater Farallones National Marine Sanctuary, Corovai, the San Francisco Bay National Estuarine Research Reserve, and NOAA’s Office for Coastal Management led a technical assistance and outreach effort to co-develop the tool with end-users. Our Coasts Our Future

Shore Stations Program: The Shore Stations Program collects and provides access to current and historical sea surface temperature (SST) and salinity (SSS) measurements observed at shoreline stations along the west coast of the United States. Historically, stations ranged from the southernmost station in La Jolla, California, up to the northernmost point on the western coast, Neah Bay, Washington, which sits at the entrance of the Straits of Juan de Fuca. Currently, all active stations are located in California. Shore Stations Program

Climate Explorer SLR: The Climate Explorer contains interactive viewers allowing users to explore predicted changes in temperature and precipitation, sea level rise and storm severity, and opportunities to implement nature-based solutions, which are actions that work with and enhance nature to help address societal challenges on California's landscapes. California is doubling down on efforts to achieve carbon neutrality and build resilience to the impacts of climate change. The best available science tells us that impacts will continue into the future and will include increases in annual temperatures, changes to precipitation patterns such as longer and more intense droughts, increases in wildfire areas and severity, sea level rise, ocean warming, and the spread of invasive species. Climate Explorer SLR

Appendix 7 - Net Ecological Gain

Washington State has emerged as one of the leading U.S. jurisdictions exploring the integration of "Net Ecological Gain" (NEG) into environmental policy and resource management. Beginning with legislative directives in 2021 and continuing through ongoing implementation work in 2024–2025, the Washington Department of Fish and Wildlife (WDFW) has developed a framework intended to move beyond traditional "No Net Loss" (NNL) mitigation standards toward policies that actively improve ecological function, biodiversity, and resilience over time.

Washington's 2022 NEG report[1] concluded that existing NNL policies have not prevented long-term ecosystem decline and that future environmental management should require measurable ecological improvements rather than simply offsetting impacts. The report defines NEG as ecological functions and values that "are improved over current conditions" through cumulative restoration and enhancement actions. The framework emphasizes measurable ecological performance, monitoring, adaptive management, Tribal engagement, cumulative-scale restoration, and integration of biodiversity and climate resilience objectives into public projects.

Applying a Washington-style NEG framework[2] in California could help ensure that future artificial reef projects are evaluated to determine if they generate measurable ecological improvements relative to baseline conditions. Washington's emphasis on cumulative ecological accounting is particularly relevant for California. Rather than evaluating reefs only at the project footprint scale, California could consider adopting regional performance metrics that assess how networks of artificial reefs contribute to broader ecosystem recovery goals, including kelp forest restoration, climate adaptation, and fisheries enhancement.

Washington's NEG framework also provides a useful governance model. The WDFW process emphasizes interagency coordination, Tribal consultation, monitoring standards, and long-term funding mechanisms. Similar structures could strengthen implementation of California's Artificial Reef Program by creating clearer statewide performance standards, improving consistency across permitting agencies, and ensuring long-term monitoring and maintenance obligations are adequately funded.

Importantly, Washington's work recognizes that ecological gains must be measurable, enforceable, and transparent. This principle could help California avoid past shortcomings associated with poorly monitored reef projects and ensure that future artificial reefs contribute demonstrably to ecosystem recovery rather than functioning solely as compensatory mitigation or fishing enhancement structures.

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[1] Washington Department of Fish and Wildlife (WDFW). 2022. *Net Ecological Gain Standard Proviso Summary Report*. Washington Department of Fish and Wildlife, Olympia, Washington. December 2022.
[2] Washington Department of Fish and Wildlife (WDFW). 2024. *Net Ecological Gain Interim Proviso Report*. Washington Department of Fish and Wildlife, Olympia, Washington. June 2024.

Finally, Washington's explicit integration of Tribal consultation and ecosystem stewardship provides a particularly important precedent for California. The CARP Plan acknowledges the importance of incorporating Indigenous Traditional Ecological Knowledge and collaborative Tribal engagement into future reef planning and management. A California NEG framework for artificial reefs could formalize these relationships and ensure that reef development supports cultural, ecological, and subsistence values alongside broader biodiversity objectives.

As California considers the next generation of artificial reef projects under changing ocean conditions, Washington's evolving NEG framework offers a promising policy model for aligning artificial reef development with long-term ecosystem recovery, biodiversity enhancement, and climate resilience goals.

Appendix 8 California Native American Tribes and public comment summary on DRAFT California Artificial Reef Program Plan