Enhanced Protections for Rodriguez Seamount – Scoping Document for the Proposed Chumash Heritage National Marine Sanctuary

MARINE CONSERVATION INSTITUTE

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Summary

Seamounts are massive underwater volcanoes that support incredible levels of biodiversity. These extremely productive features act as oases in the often sparsely populated deep sea, supporting high abundances of benthic and pelagic organisms including corals, sponges, anemones, crabs, fish, sharks, seabirds, turtles, whales, dolphins. Californian seamounts stand poised at a critical conservation junction. With the advent of new technology and increasing commercial interest in the deep sea, a barrage of threats including fishing, oil and natural gas extraction, seafloor mining, and climate change endanger these fragile ecosystems. Despite the high potential to lose these seamount ecosystems in the coming decades they are shockingly bereft of protection, making effective and long-term conservation planning critical for saving these habitats before they are irrevocably damaged.

The proposed Chumash Sanctuary will include in its boundaries Rodriguez Seamount (Figure 1), a 1,700-meter-high seamount located only 60 km offshore. Rodriguez Seamount has particularly special ecological, cultural, and scientific national significance because:

- Rodriguez Seamount has a large diversity and abundance of benthic organisms including cold-water corals and sponges;
- The ecosystem supported by Rodriguez Seamount is unique compared to neighboring seamounts, in part due to its unusual summit conditions;
- The organisms found on the seamount are extremely vulnerable to disturbance, as they are typically extremely long-living and fragile;
- The seamount is still relatively pristine due to lack of historical fishing pressure;
- Rodriguez Seamount was once an ancient island, providing a rare opportunity for expanding geologic knowledge;
- Current and predicted oceanographic conditions above the seamount suggest that it may act as an important climate refuge for a number of deep-sea species;
- The corals and other organisms on Rodriguez Seamount are aesthetically pleasing and likely to be of considerable use for outreach and education purposes, especially considering the seamount’s proximity to shore and major population centers.

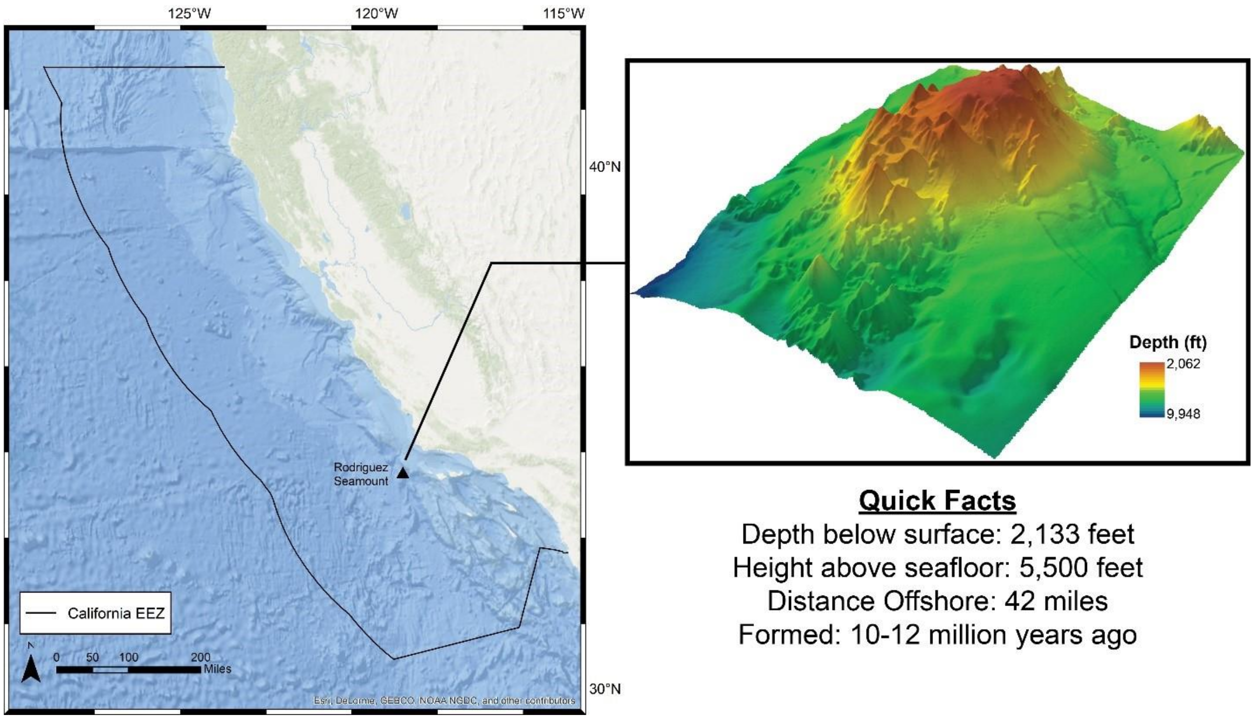


Figure 1. Location and visualization of Rodriguez Seamount.

General Information

Seamounts are massive underwater volcanoes that occur in every ocean basic across the planet. They are traditionally characterized as a discrete underwater terrain feature that extends higher than 1,000 m off the seafloor and are approximately conical (length:width ratio <2) in form (IHO 2008). smaller submarine volcanoes less than 1,000 m tall are typically characterized as knolls, and features less than 500 m tall are typically referred to as hills. The most recent global seamount census identified 10,234 seamounts (including 283 guyots) covering 2.2% of the seafloor (7,859,200 km^2) (Harris et al. 2014). As of 2010, fewer than 300 seamounts have been sampled, limiting our ability to understand and conserve these important habitats (Rowden et al. 2010).

Physical Attributes

Rodriguez Seamount is one of the few seamounts that has been scientifically surveyed (e.g., Lundsten et al. 2009a; 2009b), making it a critically important feature for better understanding the ecology and geology of seamounts within California waters and around the world. The seamount is located approximately 60 km off the coast of Southern California with its base situated midway up the continental slope. The formation is approximately 12.8 km long and has a relatively shallow summit depth of 619 m, and rises approximately 1,700 m off the surrounding seafloor (Lundsten et al. 2009b). Formed via volcanic activity approximately 10-12 million years ago, the seamount was once an ancient island with sandy shores (Davis et al. 2002; Paduan et al. 2009). In its previous life as an island, the seamount stood as tall as 70 m above sea level and had an area of approximately 7 km^2. Erosional forces acting on the top of the seamount before it subsided back beneath the waves created Rodriguez Seamount’s sediment-covered and smooth top, making it a rare example of a guyot, or flat-topped seamount. Scientists estimate that out of the 10,000 seamounts that exist around the world, only 283 are classified as guyots (Harris et al. 2014).

Oceanographical Conditions

Seamounts exert strong influences on both local and global current regimes, and generally have enhanced hydrodynamic activity compared to the surrounding seafloor. Due to their size and shape in the water column, they have a strong influence on the hydrodynamic regime in ways that are often favorable for a plethora of marine life. Seamounts accelerate ocean currents, generate surface and internal waves, form strong eddies, increase upwelling, and amplify tides and mixing (Lueck and Mudge 1997). One of the most ubiquitous circulation patterns observed on seamounts is the Taylor cap (also known as a Taylor column or cone), a stationary circulation pattern that can concentrate and retain food and larvae over the seamount. In some seamounts, these effects have been found to increase primary productivity by as much as 60% (but typically only 5–10%; Pitcher et al. 2007) by transporting and retaining nutrient rich water. Seamounts also significantly alter local currents, often enhancing current flow across steep slopes, pinnacles, and canyons.

Due to its physical influence on local and regional currents as well as its relatively shallow summit, Rodriguez Seamount has notably differing oceanographic conditions than the surrounding seafloor (Figure 2). The seamount's summit has a higher calcium carbonate saturation state of both calcite and aragonite forms than the surrounding seafloor (approximate Ω_{ARAG} of 1.4 versus 0.9). When $\Omega>1$, the precipitation of calcium carbonate is favored, making calcification by corals and other marine organisms less energetically costly (Turley et al. 2007). When $\Omega<1$, the dissolution of existing calcified structures is energetically favored, placing marine calcifiers and the communities that depend at them at serious risk. The vast majority of field observations of cold-water scleractinian corals occur above a saturation state of one (Guinotte et al. 2006; Lunden et al. 2013), and experimental results that demonstrate an energetic cost associated with calcification at low saturation states (e.g., Maier et al. 2009). Calcium carbonate saturation states are expected to decrease significantly due to ocean acidification, placing many marine ecosystems that rely on calcified structures at risk (Guinotte and Fabry 2008). Therefore, the summit and upper flanks of Rodriguez Seamount may act as a climate refuge for many deep-sea calcifiers even in the face of imminent ocean acidification. However, temperature is slightly higher on the summit than the surrounding seafloor (5°C versus 2°C) and dissolved oxygen is considerably lower (15 µmol/L vs 120 µmol/L), raising concerns in light of predicted ocean warming and deoxygenation (e.g. Ross et al. 2020).

> *"The summit and upper flanks of Rodriguez Seamount may act as a climate refuge for many deep-sea calcifiers"*

Food availability is expected to be higher on the summit and upper flanks of Rodriguez Seamount than the surrounding seafloor. Regional currents are estimated to be 90% higher over the seamount, likely partially explaining the high abundances of benthic organisms. Many studies have found that suspension and filter feeders, including cold-water corals and sponges, have strong preferences for stronger current regimes that increase food availability, larval delivery, and waste removal (e.g., Georgian et al. 2014; Rowden et al. 2017). In concert with elevated currents, food availability (assessed via proxy variables including seafloor estimates of particulate organic carbon, nitrogen, and phosphate) are notably elevated over Rodriguez Seamount. These conditions may play an important role in mediating the effects of future climate change on Rodriguez Seamount; an increasing number of studies suggest that high food availability increases the resiliency of ecosystems to anthropogenic disturbances including climate impacts (e.g., Georgian et al. 2016).

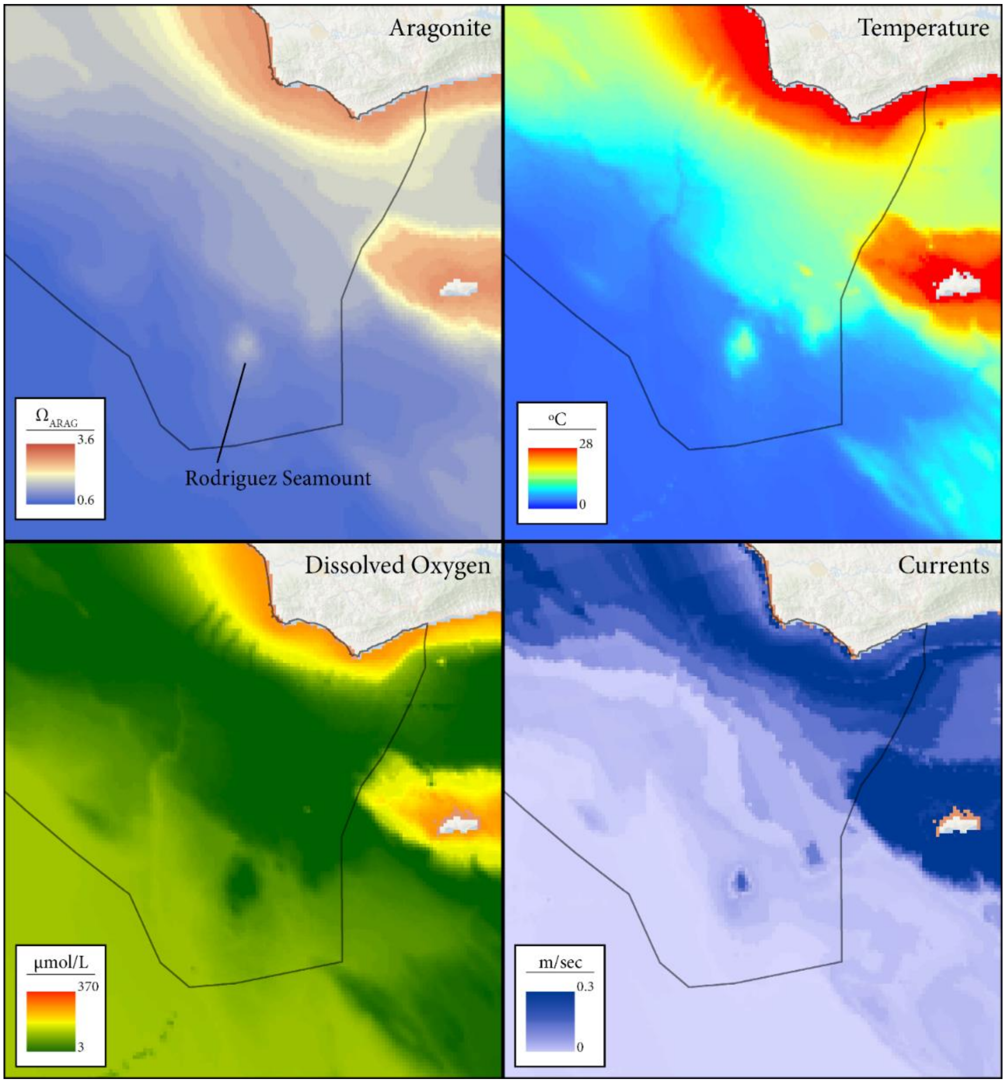


Figure 2. Environmental conditions in the vicinity of Rodriguez Seamount. Temperature (Locarnini et al. 2018) and dissolved oxygen (Garcia et al. 2018) were calculated at the seafloor using World Ocean Atlas data. Regional current data were obtained from Carton et al. (2005) and extrapolated to the seafloor. Aragonite saturation state data were obtained for the seafloor from Steinacher et al. (2009).

Biology of Rodriguez Seamount

Seamounts support a wide array of marine life, creating hotspots of biodiversity in otherwise sparse areas of open-ocean and deep-sea environments (e.g. Figure 3). In part, this stems from the large effects that seamounts exert on the physical environment in their vicinity. This suite of current alterations enhances food and nutrient supply to benthic suspension feeders, removes waste products, reduces sedimentation, transports larva, and enhances primary productivity near the surface (and therefore export productivity to the seafloor) (Rogers 1994; White et al. 2007). A wide variety of benthic ecosystems are associated with seamounts, often founded on the three-dimensional habitat structures created by cold-water corals and sponges. In addition to the factors that drive enhanced biodiversity on seamounts, their isolated nature can drive speciation and gives rise to endemic species (Rogers 1994; de Forges et al. 2000) that are not found on similar ridges or escarpments, or even on neighboring seamounts. On average approximately 20% of seamount species are considered to be endemic to seamounts (Stocks and Hart 2007). While the enhanced current flows past seamounts may increase the transport of larva in some cases, Taylor columns can trap larva in circular eddies, effectively geographically isolating the seamount from even closely neighboring areas (Mullineau and Mills 1997). Due to the lack of extensive field surveying throughout the deep sea, it is likely that many seamounts house currently undiscovered, endemic species –meaning that extensive habitat destruction on even one seamount could potentially result in the loss of a species or subspecies.

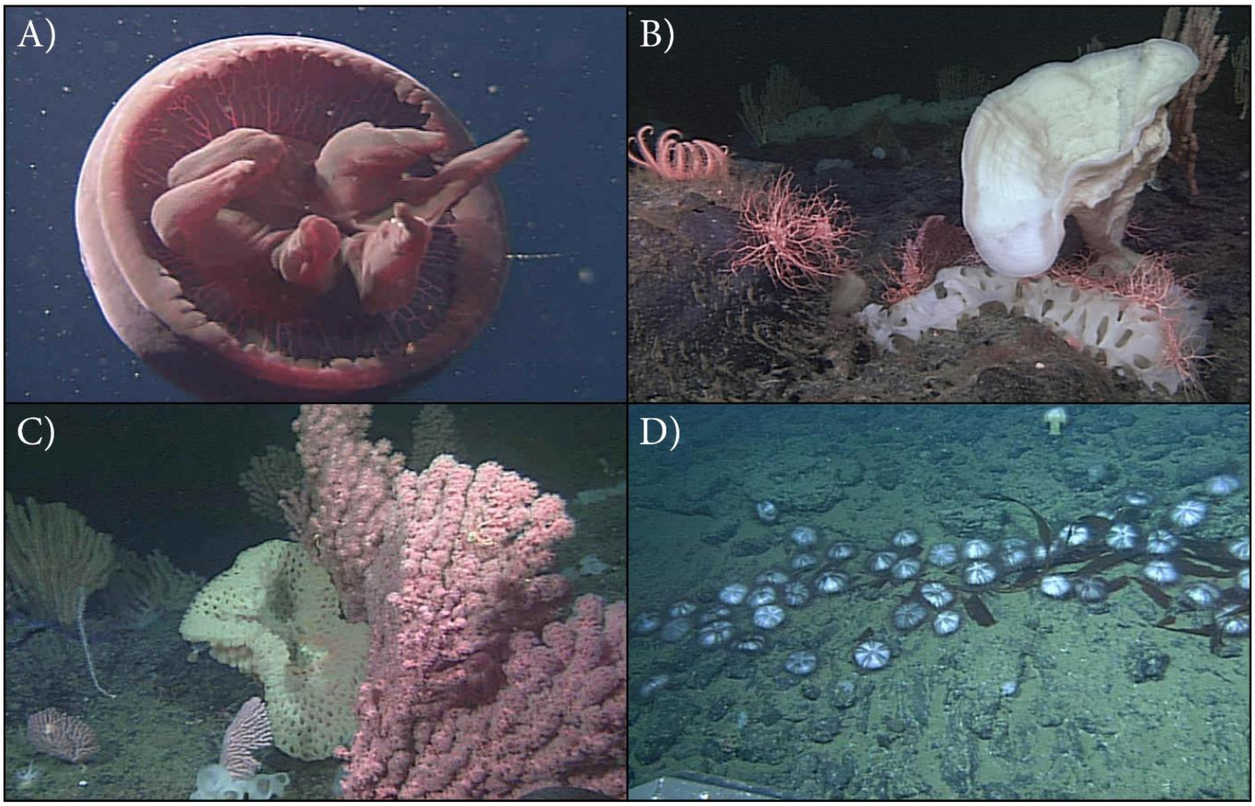


Figure 3. Photographs highlighting some of the benthic diversity found at Rodriguez Seamount. A) The newly discovered Tiburonia granrojo jellyfish, B) A large trumpet sponge surrounded by basket stars, crinoids, and bamboo corals, C) A large Paragorgia coral and associated bamboo corals and sponges, D) Pancake urchins feasting on a recent kelp fall. Images courtesy MBARI.

Benthic Ecosystem

A wide variety of benthic ecosystems are associated with seamounts, often founded on the three-dimensional habitat structures created by cold-water corals and sponges. Cold-water corals and sponges are critical foundation species in the deep sea and frequently occur on seamount habitats. These organisms provide vital ecological services including the creation of complex habitat structures (Cordes et al. 2008), the alteration of local hydrodynamic conditions (Dorschel et al. 2007; Mienis et al. 2009), carbon sequestration (van Weering et al. 2003), and nutrient and carbon cycling (van Oevelen et al. 2009). As a result, deep-sea coral and sponge communities house a large diversity of associated organisms (Costello et al. 2005; Roberts et al. 2006) and act as important habitats and nurseries for commercially important fish (e.g., Baillon et al. 2012). Many cold-water corals are extraordinarily long lived, with many species living hundreds to thousands of years (Roark et al. 2009; Roberts et al. 2009). Deep-sea sponges are the oldest known animals in the world, with one specimen estimated to have lived for 11,000 years (Jochum et al. 2012). This extreme longevity, coupled with slow growth rates (Roberts et al. 2009), limited dispersal ability (Brooke and Stone 2007), low reproductive outputs (Orejas et al. 2002), and high mortality rates of new recruits (Doughty et al. 2014) makes it difficult or even impossible for these communities to fully recover from significant disturbances (Prouty et al. 2011; Van Dover et al. 2014).

Table 1. Taxonomic records of major deep-sea taxa within the proposed Chumash Heritage National Marine Sanctuary boundary and on Rodriguez Seamount. Data obtained from the NOAA Deep-Sea Coral and Sponge Data Portal (NOAA 2022).

Taxa	Proposed Boundary	Rodriguez Seamount
Stony corals	442	15 (3.4%)
Soft corals	2,573	2,549 (99.1%)
Gorgonian corals	9,908	9,414 (95.0%)
Black corals	14	9 (64.3%)
Sea pens	2,066	742 (35.9%)
Glass sponges	4,372	4,316 (98.7%)
Demosponges	170	31 (18.2%)
Other sponges	2,204	1,634 (74.1%)
Total	**21,749**	**18,710 (86.0%)**

While the vast majority of Rodriguez Seamount remains unexplored, it has been the site of multiple scientific surveys, with an estimated 91% of its depth range sampled (Lundsten et al. 2009a; 2009b). The seamount contains the vast majority (86%) of the known taxonomic records of major deep-sea taxa within the proposed boundary for the Chumash Heritage National Marine Sanctuary, including 99.1% of soft coral records, 95.0% of gorgonian coral records, 35.9% of sea pen records, and a combined 88.7% of all sponge records (Table 1; Figure 4; NOAA 2022). While this skewed distribution is almost certainly partially attributable to sampling bias with a larger number of surveys targeting the seamount, the data are also likely reflective of the seamount's enhanced habitat quality for corals, sponges, and associated species.

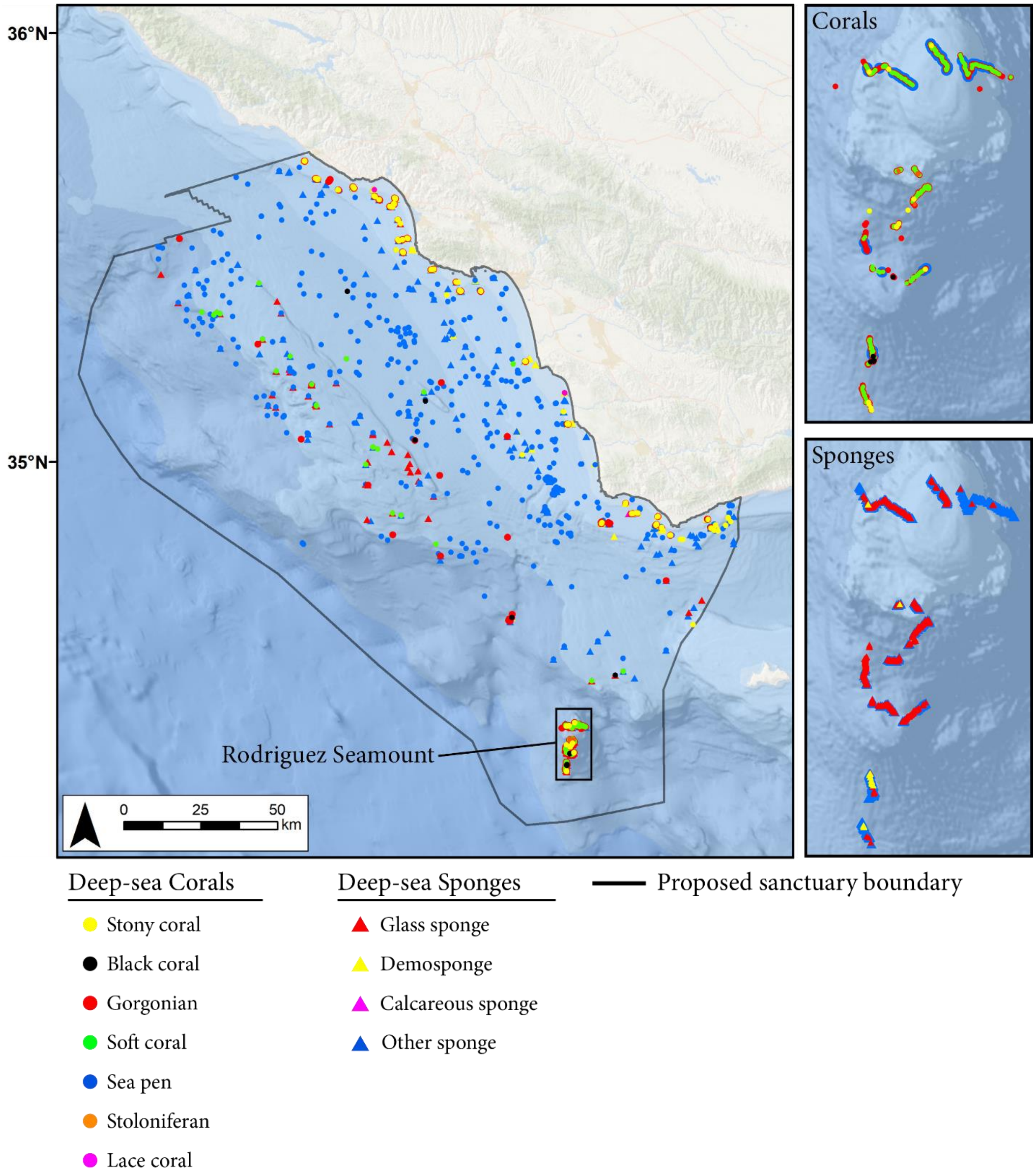


Figure 4. Known distribution of deep-sea corals and sponges within the proposed Chumash Heritage National Marine Sanctuary. Insets on right show Rodriguez Seamount. Data obtained from the NOAA Deep-Sea Coral and Sponge Data Portal (NOAA 2022).

Rodriguez Seamount is known to contain diverse (133 currently identified taxa) and abundant communities structured largely by 26 species of cold-waters corals including massive bubblegum (*Paragorgia*) and bamboo (*Isidella*) coral colonies. The habitat created by these corals supports a large number of associated sponges, crinoids, brittle stars, anemones, sea urchins, sea cucumbers, worms, crabs, and more than 20 fish taxa. In 2004, a new octocoral species *Gersemia juliepackardae* was discovered on the seamount, and in 2008 the bamboo coral *Isidella tentaculum* was described based on observations from both Rodriguez and Pioneer Seamounts (Etnoyer 2008). As recently as 2009 observations made at Rodriguez and San Juan seamounts resulted in a range extension for a hard coral called *Caryophyllia quadragenaria*. These observations extend the bathymetric range of the species by about 1,00 meters, and the latitudinal range by 65 degrees in this region (Gonzalez-Romero et al. 2009). Other novel taxa found on Rodriguez include a new species of soft corals in the Nephtheidae family (Williams and Lundsten unpublished) and a newly discovered predatory sponge (*Cladorhiza pteron*; Reiswig and Lee 2007).

The summit of Rodriguez Seamount houses a notably distinct benthic community than neighboring seamounts (Lundsten et al. 2009a; 2009b). While true endemism (i.e., single-seamount species) that has previously been reported to occur frequently on seamounts (de Forges et al. 2000) appears to be rarer in seamounts in California waters, 15.4% of the taxa observed on Rodriguez were not observed on the nearby Davidson or Pioneer Seamounts. In part, this is likely due to the fact that its summit lies within the oxygen minimum zone, where extremely low oxygen concentrations (see Figure 2) may prevent many typical seamount-taxa from thriving. Its unique morphology as a guyot may also be a driving factor. The flat, sandy dome of Rodriguez Seamount lacks the rocky habitats that many corals, sponges, and other filter or suspension feeders require. Instead, the summit is dominated by species well-adapted to sedimented environments including sea cucumbers (Holothuroidea) and sea pens (Pennatulacea), one of the few deep-sea corals that are able to grow in sand and mud sediments. In fact, across the entire depth range of the seamount that has been sampled, 45.5% of all observations were echinoderms, with sea cucumbers representing 37.9% of echinoderm observations (Lundsten et al. 2009a). Sea urchins, often observed on kelp falls from shallower depths on the continental margin, comprised 14.2% of all observations (Lundsten et al. 2009a). Sea pens, noted to be rare at neighboring Davidson and Pioneer seamounts, comprised 5.5% of corals observed at Rodriguez (Lundsten 2009a). In addition to its unique summit community, Rodriguez seamount was found to have a higher concentration of carnivores than neighboring seamounts, as well as a greater collection of mobile organisms (Lundsten et al. 2009a; Lundsten 2007). In part, the unique summit conditions and other topographical features of Rodriguez likely contribute to its overall diversity, with observational data suggesting that different taxa occupy very distinct niches on the seamount with regards to small differences in slope angle, aspect, depth, and seafloor topography (Lundsten 2007).

> *"…the assemblages of animals were distinct from any we have seen on other seamounts farther north…"*
>
> *-Dr. David Clague, MBARI*

Preliminary species distribution models generated for four coral taxa (stony corals, black corals, soft corals, and gorgonians) across a large region of the North Pacific Ocean at a spatial resolution of 1 km support the hypothesis that Rodriguez Seamount has notably higher diversity and abundance of key taxa than the surrounding area (Figure 5; Georgian, unpublished data). See Georgian et al. (2021) for approximate modeling methodology. Model outputs predicting habitat suitability appear to generally reflect the known distribution of corals in the region. The models predict lower suitability for stony and black corals on the seamount, which reflects survey results (a combined 0.14% of observations at Rodriguez were stony or black corals; Lundsten et al. 2009a). In contrast, soft and gorgonian corals consistently dominated observations during surveys (19.6% of coral observations were Alcyonaceans;

Lundsten et al. 2009a), which also had the highest predictions of habitat suitability at the seamount. Therefore, based on both field observations and modeling results, there is a high confidence that Rodriguez Seamount provides critically important habitat for soft and gorgonian corals as well as a wide array of associated taxa including sponges, demersal fish, and other invertebrates.

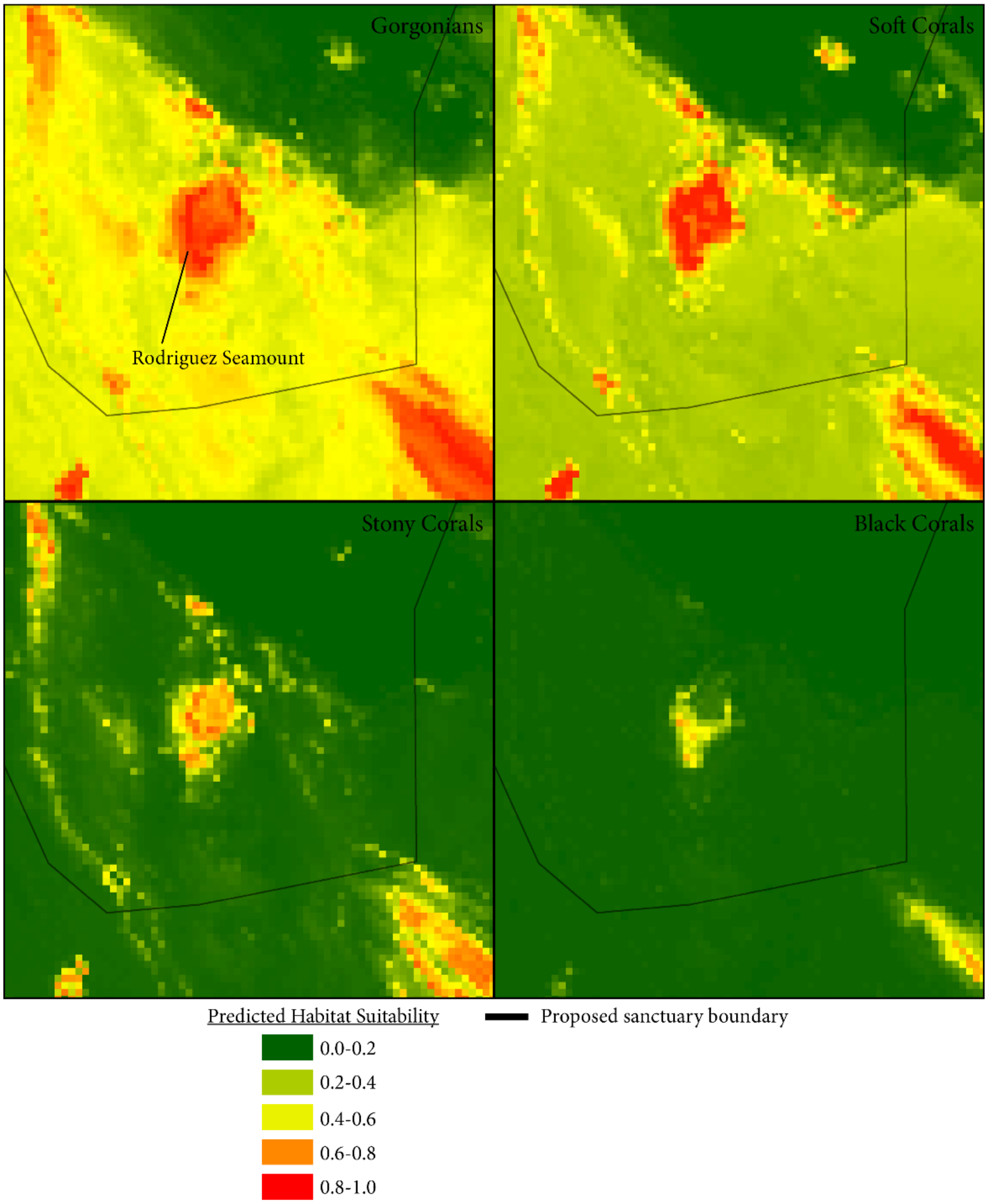


Figure 5. Preliminary ensemble species distribution models (Georgian, unpublished) for gorgonian corals, soft corals, stony corals, and black corals in the vicinity of the proposed Chumash Heritage National Marine Sanctuary. Warmer colors indicate more suitable habitat. See Georgian et al. (2021) for approximate methodology.

Demersal Fish Populations

Seamount aggregating fishes differ from other fish taxa in taxonomy, life history, and metabolism (Koslow 1997), suggesting that seamounts represent critical habitat for many deep-sea fish (also see Morato and Clark 2007; Rogers 2018). Over twenty demersal taxa have been observed on

Rodriguez Seamount, dominated by thornyheads (*Sebastolobus*; 64.2%) and rattails (*Coryphaenoides*; 13.5%), followed by codlings (Antimora; 3.9%), eelpouts (*Bothrocara*; 2.5%), righteye flounders (*Microstomus*; 2.5%), and Pacific sleeper shark (*Somniosus pacificus*) (Lundsten et al. 2009b). The prevalence of thornyheads, a common Pacific Ocean genus across the continental shelf, can likely be explained due to Rodriguez Seamount's proximity to shore, location on the continental margin, shallow summit, and greater extent of flat and sedimented substrate. The fish population on Rodriguez generally includes more provincial, continental slope species due its shallower depth and location on the continental margin, with community most closely resembling the community on Pioneer Seamount. Both communities exhibited signs of depth differentiation, expected due to these ecosystem's reliance on sinking organic matter from the euphotic zone which decreases by as much as 90% for every km of depth (Martin et al. 1987). However, differences in fish assemblages may also be caused by seamount topography and distance from shore (Wilson and Kaufman 1987). Perhaps the result of Rodriguez Seamount's unique and shallow summit, demersal fish had a shallower overall distribution than on neighboring seamounts (e.g., Davidson Seamount which has a lower abundance comprised primarily of abyssal taxa). Accordingly, Rodriguez Seamount fish also had the highest proportion of total biotic observations (2.8%), as compared to Davidson (0.73%) and Pioneer (1.9%) seamounts (Lundsten 2007).

Water-column and Surface Ecosystems

In addition to the diverse benthic communities often found on seamounts, a wide variety of pelagic organisms also rely on seamount habitat, including tuna, billfish, sharks, sea turtles, seabirds, and marine mammals (Sedberry and Loefer 2001; Waring et al. 2001; Santos et al. 2007; Morato et al. 2008; Morato et al. 2010). Seamounts have dramatic effects on the ocean currents around them; these altered current systems frequently enhance and concentrate the supply of nutrients, food, and larvae above seamounts (Morato et al. 2010). As a result, the waters overlying seamounts are often oases with higher than normal productivity (Worm et al. 2003) and a significantly higher species diversity within 40 km of their summits (Morato et al. 2010). The enhanced productivity and retention of food sources above seamounts appears to favor species at higher tropic levels, resulting in large aggregations of pelagic predators (Genin 2004). In addition, seamounts are important aggregating locations for migratory species including sharks, billfish, teleost fish, and whales (Tsukamoto 2006; Pitcher et al. 2007; Morato et al. 2008). In some cases, the strong magnetic signature of seamounts allows these migratory species to more effectively navigate the open ocean and provides a method for species with large open ocean ranges to meet for mating (e.g., Klimley 1993). The enhanced productivity and navigation utility of seamounts results in a large number of pelagic species–including many commercially important species –using them as nurseries, feeding grounds, migratory pathways, and mating grounds. The waters above Rodriguez Seamount have been particularly noted for their frequency of common dolphin sightings. It is believed that a pelagic population of dolphins returns every winter; their movements suggest an intentional tracking of a network of escarpments and seamounts throughout the offshore region, including Rodriguez (Dohl et al. 1986). However, there is an alarming lack of key water column data from directly over Rodriguez Seamount, including primary productivity, local current patterns, prevalence of commercial fish taxa, and the frequency and timing of use by sea turtles, seabirds, and marine mammals. Therefore, more research is urgently required to better characterize the waters above the seamount, particularly before any further adverse impacts are allowed to occur.

Geology of Rodriguez Seamount

Seamounts are volcanic in origin, most often created on oceanic crust either on spreading ridges, subduction zones, or on the interior of plates over mantle hotspots. They typically follow a geologic pattern of initial growth, subsequent volcanic activity, subsidence (sinking), and eventually extinction (cessation of volcanic activity). As lava erupts on the deep seafloor, a seamount typically begins to grow with axial symmetry (i.e., the typical cone-shape commonly observed in terrestrial volcanoes), but large seamounts often lose this shape and become more ridge-like as the uneven distribution of stress leads to rifting and fissure eruptions outside the primary cone.

Seamounts are ubiquitous throughout California waters due to the large amount of tectonic activity in the region. These seamounts provide important benthic habitats that are geologically distinct from neighboring deep-sea environments. While large portions of the deep sea are flat and sediment covered, seamounts often provide the exposed hard substrate and complex and steep terrain features that are necessary for many species of cold-water corals, sponges, and associated species to survive. Seamounts in California waters are largely comprised of various forms of basalt –a common volcanic rock type that forms when iron-rich lava cools in the cold seawater of the deep ocean. Other observed rock types include granite and sandstone (erratics transported from neighboring environments), hawaiite, mugearite, andesite, glass sands, hyaloclastic, and trachyandesite (Davis et al. 2002). Sampled rocks, including those from Rodriguez Seamount, were frequently found to be encrusted with manganese oxide, a potential target for deep-sea mining operations (Davis et al. 2002).

The distribution, morphology, and orientation of the California seamounts reflects the convoluted tectonic history of the region. As they occur near the continental margin, their morphology differs noticeably from open ocean and ridge seamounts, which often occur as isolated, fairly symmetrical cones (Clague et al. 2000). Instead, they typically have a complex morphology that generally includes an elongated axis, northeast to southwest orientation, and a series of multiple cones and ridges with sediment filled troughs (Davis et al. 2002). In addition, they typically formed from a large series of relatively small eruptions spanning several million years, rather than fewer, larger eruptions over a short period of time (Davis et al. 2010).

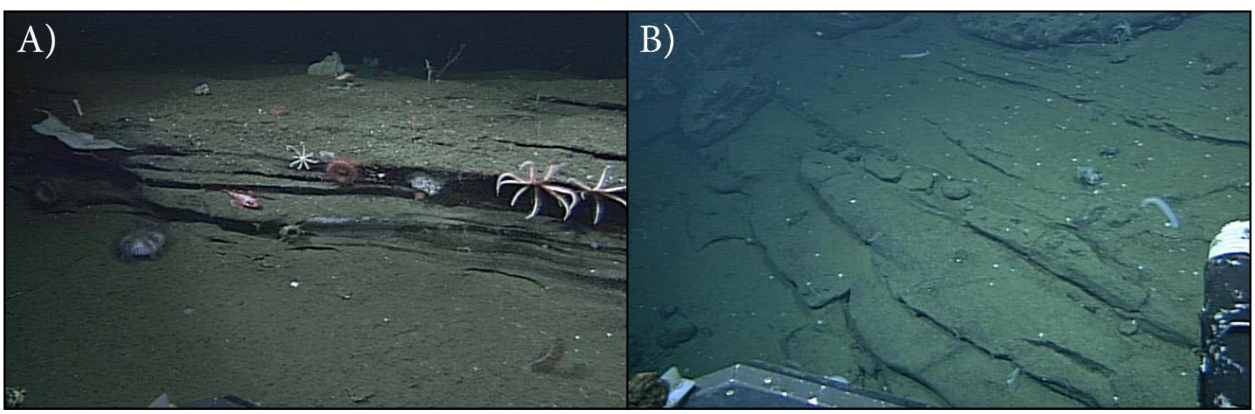


Figure 6. Photographs from Rodriguez Seamount highlighting some of the seamount's unique geology. A) An ancient landslide reveals stacked lava flows, B) Possible evidence of ancient shorelines discovered on the summit. Images courtesy MBARI.

Rodriguez Seamount formed between 10-12 million years ago, and was once an island standing as tall as 70 meters above sea level with an area of seven square kilometers (Paduan et al. 2009). It has since sunk back beneath the waves largely due to the subsidence of the ocean crust beneath it. Seamounts are so massive that they cause the ocean crust beneath them to flex and compress, leading to the subsidence of the entire feature (Detrick et al. 1978). The crust below seamounts can also cool if volcanic activity ceases or significantly slows, resulting in thermal contraction that causes further subsidence. Due to the erosional forces it was exposed to as an island, its modern summit largely consists of a large flat dome, qualifying Rodriguez as a guyot –a flat-topped seamount. Rodriguez has a particularly sharp slope-break at approximately 700 m depth, suggesting that strong erosional forces (i.e., wave planation) acted on this layer following cessation of volcanic activity (Davis et al. 2002).

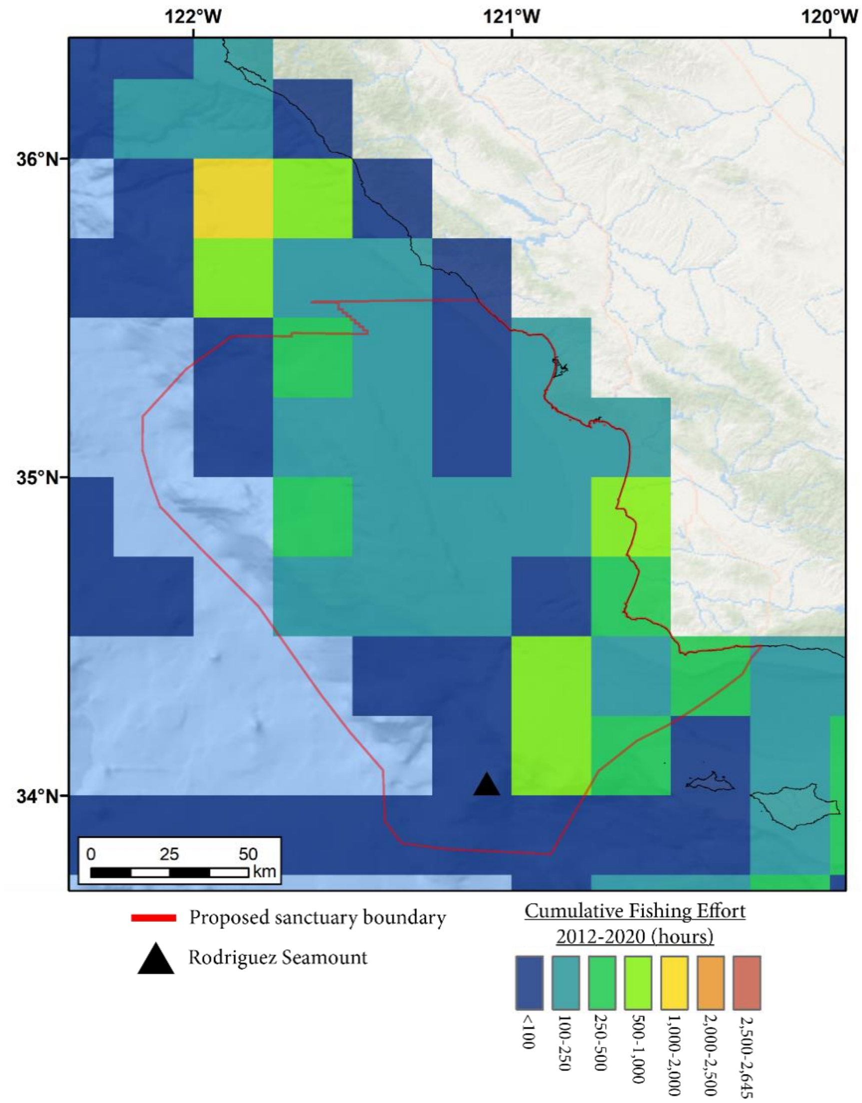
Rodriguez Seamount is an example of an intraplate volcano, along with nearby seamounts including Gumdrop Seamount, Pioneer Seamount, Guide Seamount, and Davidson Seamount (Davis et al. 2002). These intraplate volcanoes generally did not form over hotspots however, as is commonly observed in other parts of the Pacific Ocean (e.g. the Hawaii-Emperor Chain). Instead, Rodriguez Seamount formed when magma forced its way through ancient spreading centers in part due to decompression melting, a process in which the Earth's mantle melts as it moves upwards through the crust due to rapid decreases in pressure. Rodriguez was volcanically active for around 2 million years as it formed, with evidence suggesting that its more recent eruptions occurred in shallow water. Like other guyots, the erosional forces of wind and waves scoured the summit into a flat top prior to its subsidence back beneath the waves, producing the flat, sandy dome observed today. Features such as rounded summits blanketed with sediment, bedded sandstone deposits, sculpted rocks that appear weathered and lava flows that are typical of flows above water have been observed on Rodriguez (Figure 6; Paduan et al. 2009). In addition to these features, Rodriguez houses a large number of continental erratic rocks, transported from near-shore environments via human transport, pinnipeds, kelp falls, and driftwood (Paduan et al. 2007).

Potential Threats

Fisheries

Fisheries currently represent the most widespread, direct anthropogenic threat to deep-sea ecosystems (reviewed in Clark et al. 2015), and are considered to have the largest impact on seamounts (Halpern et al. 2009). Bottom-trawling for groundfish is particularly damaging to fragile cold-water coral and sponge ecosystems on seamounts, which are often targeted by fisheries. Once disturbed, these communities may not recover for decades or longer (Gage et al. 2005), even if effective protection is later implemented (Huvenne et al. 2016). Seamount fish populations are also significantly more likely to collapse than non-seamount fisheries, with 64% of assessed seamount-only fisheries having been found to have collapsed (Watson and Morato 2004). Within shallow depths <1,000 meters, an estimated 30% of the seafloor on the U.S. west coast has been trawled at some point (Amoroso et al. 2018).

In the waters above seamounts, California's set gillnet and drift gillnet fisheries represent a significant threat as the second and the fourth worst bycatch fisheries in the nation, with staggering bycatch rates of 65% and 63%, respectively (Keledjian et al. 2014). The drift gillnet fishery for swordfish and thresher sharks is a major conservation concern in these waters, as the nets, extending a mile in length, are cast overnight to drift and catch large, pelagic fish. The expansive nets inevitably entangle other species, including sea turtles and whales that drown or are seriously injured from entanglement. The drift gillnet fishery was responsible for the entanglement or death of almost 550 marine mammals over a five-year period, and entanglements on the United States West Coast have been steeply rising since 2015. This fishery's estimated worth was $1.1 million in 2011 (NOAA 2013). The set gillnet industry uses nets anchored to the seafloor, targets California halibut, angel shark and white seabass, and is also



a serious conservation concern. Because of their devastating ecological impacts, gillnets were banned in nearshore waters off southern California in 1994, but they are still permitted in federal waters (Keledjian et al. 2014). In just a three-year period, the set gillnet fishery discarded more than 30,000 sharks and rays. The estimated worth of this fishery was $450,000 in 2011 (Keledjian et al. 2014). Despite conservation efforts to further restrict fishing activities in California waters, West Coast fishery landings appear to be increasing, with a 27.4% rise from 2016 to 2017 and an associated 12.3% increase in revenue (Harvey et al. 2019).

Figure 7: Global fishing watch data in the vicinity of the proposed Chumash Heritage National Marine Sanctuary. Fishing effort is given as cumulative fishing hours from 2012-2020 in 23 km blocks.

Despite the large threat that fisheries impose on deep-water ecosystems in waters off the coast of California, there is evidence to suggest that Rodriguez Seamount has not been heavily fished in the past. Although one remotely operated vehicle dive observed evidence of bottom trawl scarring on the seafloor (Lundsten et al. 2009a), other surveys have not reported trawl damage or lost fishing gear. Lundsten et al. (2009b) suggested that while overall fish abundance was higher on Rodriguez than neighboring seamounts, there were no large aggregations of commercially-fished species. An analysis of Global Fishing Watch data from 2012-2020 suggested that the aggregate fishing effort of all types (measured as vessel fishing hours) was relatively low directly above the seamount (Figure 7).

Oil and Natural Gas

While there is no current oil or natural gas infrastructure in the immediate vicinity of Rodriguez Seamount, California has four oil platforms off its coast, and the California State Lands Commissions administers 29 offshore oil and gas agreements in its state waters. The Federal Government, through the Bureau of Ocean Energy Management, has granted 43 active leases in Southern California's Pacific Outer Continental Shelf Region, with 23 oil and gas production facilities installed off the coast of California. The California State Lands Commission halted new leasing of state offshore tracts after the 1969 Santa Barbara oil spill that spewed an estimated 4.2 million gallons of crude oil (Foster et al. 1970; Foster 1972). This spill created a 35-mile-long oil slick along California's coast and killed thousands of birds, fish and marine mammals. The California legislature passed the California Coastal Sanctuary Act in 1994 to prohibit new offshore leasing. Even so, in 2015, 142,800 gallons of crude oil spewed onto a biologically diverse coastline after a corroded, old pipeline ruptured near Refugio State Beach in Santa Barbara County (Addassi et al. 2017; Defran et al. 2017). Any new offshore oil and gas exploitation allowed off the coast of California may very well occur at the ultimate expense of seamount habitats.

Deep-sea Mining

The deep sea is believed to hold large quantities of untouched energy resources, precious metals, and minerals (reviewed in Boschen et al. 2013). Manganese nodules and other polymetallic nodules are likely targets for mining operations, which could result in seamount habitats being targeted for future mining expeditions. Technological advancements have enabled greater access to deep-sea resources, making deep-sea mining increasingly possible. Though early mineral leases off the coast of California were abandoned due to a lack of technology and low commodity prices (Van Dover 2011), recent renewed interest in mining means that deep-sea habitats in California could one day be targeted.

The abundance of manganese-oxide crusts at Rodriguez (Davis et al. 2002) raises the concern that this region could one day be exploited by deep-sea mining companies, that in some cases are already exploring the possibility of extracting mineral-rich oxide crusts from seamounts (Stocks 2009). Deep-sea mining is extremely physically destructive to the seabed, and will generate turbid, potentially toxic sediment plumes that are likely to affect benthic communities over a wider area (Sharma et al. 2001). The ecological recovery of disturbed sites would then be dependent on recolonization from nearby populations, but little is known about the connectivity of these populations and full recovery could take decades or even hundreds of years (Levin et al. 2016).

Shipping Traffic

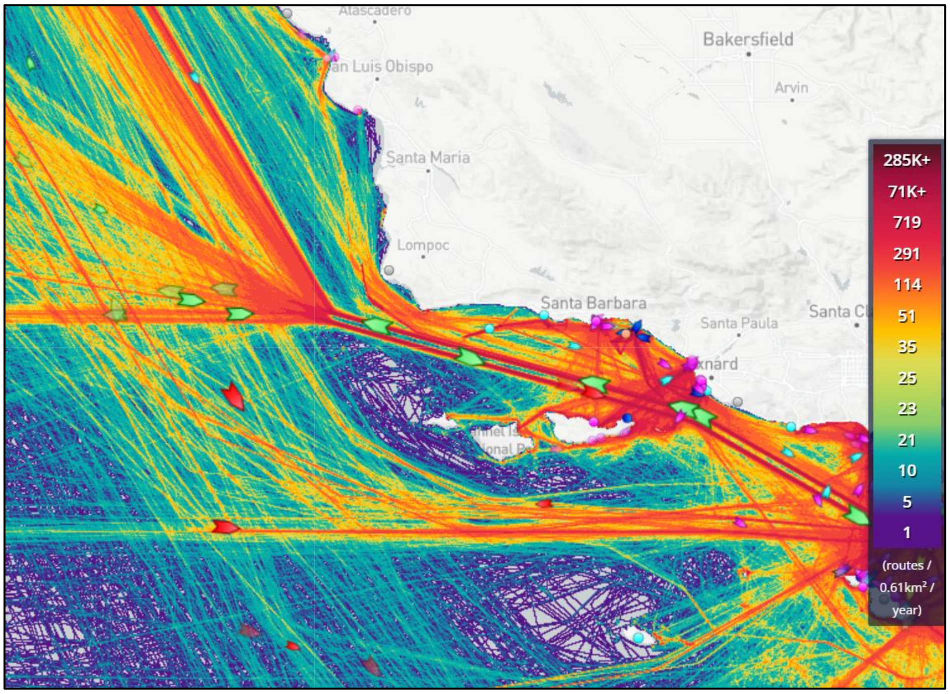


Figure 8. Density map showing shipping traffic in the vicinity of the proposed Chumash Heritage National Marine Sanctuary in 2020. Data from: marinetraffic.com.

California hosts 11 major ports spanning its long coast between the North Coast and San Diego County. Los Angeles and Long Beach Ports contain the U.S.' largest port complex and are essential elements in global enterprise. Together, these ports facilitate one-fourth of all container cargo traffic in the United States and vessel traffic poses a number of threats to the marine environment, including oil or chemical spills, discharges, pollution, exchange of ballast water, introduction of invasive species, and noise pollution (MBNMS 2012). In 2008, the State of California passed regulations requiring the use of cleaner marine fuels in vessels within 24 nautical miles of the coast in an effort to combat air and water pollution (PMSR 2020). However, in many cases, commercial shipping traffic has simply opted to remain outside the 24 nautical mile threshold to burn less expensive – and higher polluting – fuel, placing these vessels in the vicinity of Rodriguez Seamount. The proposed Chumash Heritage National Marine Sanctuary boundary includes two major shipping channels, the Santa Barbara Channel Northern and Western Approaches (see Figure 8). Most traffic moves through the Northern Approach, with the Western Approach, crossing closely to Rodriguez Seamount, primarily created for supertankers.

The U.S. Navy uses state and federal waters along the western seaboard for a wide variety of activities, and have documented many diverse environmental impacts including explosive byproducts, acoustic pollution, and vessel strikes (Boerger et al. 2013; United States Department of the Navy 2014). The majority of the proposed Chumash Heritage National Marine Sanctuary will be located within the Point Mugu Sea Range, including Rodriguez Seamount (Figure 9; PMSR 2020). The Point Mugu Sea Range extends over 36,000 square miles and has a high volume of shipping traffic with 7,000 commercial vessels and a further 800 Navy vessels expected annually. Vessel strikes by Navy vessels represent a considerable percentage of known strikes (17%; Jensen and Silber 2004), suggesting that naval activities in the region represent a significant threat to whales and other marine mammals visiting or migrating past Rodriguez Seamount.

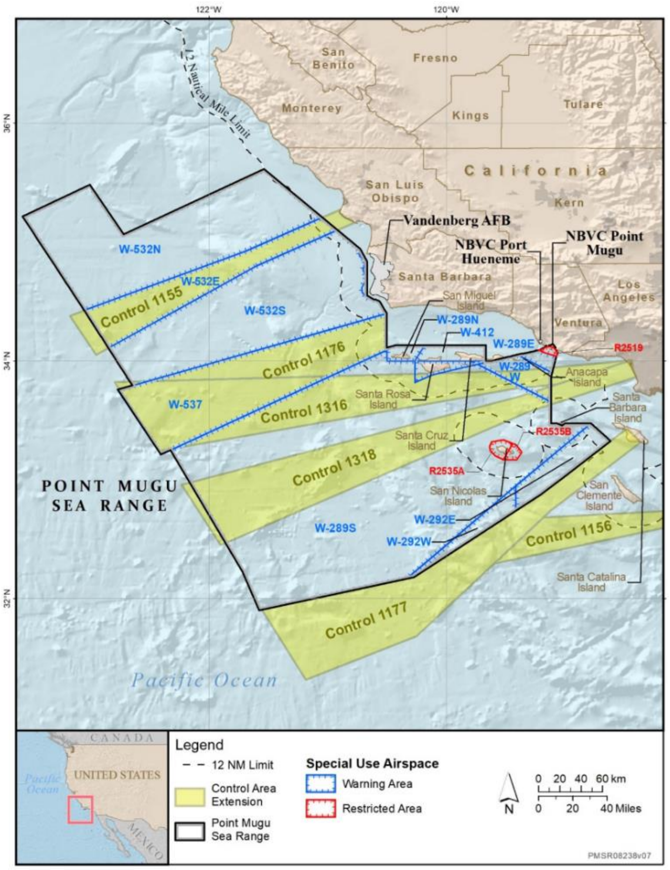


Figure 9. Extent of the Point Mugu Sea Range, a 36,000 square mile U.S. Navy test sea range for the evaluation of missiles, free-fall weapons, and electronic warfare systems. Obtained from PMSR (2020).

Marine Litter

Despite their remoteness, California seamounts are not immune to the detrimental effects of human waste products that are intentionally or accidentally deposited into the ocean. Marine litter is rapidly becoming a global issue, with an estimated 6.4 million tons of litter entering the oceans each year (Jeftic et al. 2009), including intentionally or accidentally abandoned or disposed of fishing gear, plastics, and other solid waste products. Woodall et al. (2015) examined marine litter across multiple ocean basins and found that litter was prevalent throughout the entire study region regardless of remoteness and distance from shore. The authors also found that marine litter, primarily comprised of derelict fishing gear, was especially widespread on seamount habitats, ostensibly due to the targeting of these locations by fisheries. On some seamounts, fishing gear accounts for over 70% of the marine litter present (Pham et al. 2014). This litter has considerable implications for ecosystem health via the physical disruption of benthic environments (e.g., entanglement with corals; Pham et al. 2013) and ghost fishing, in which marine species continue to be caught or killed by abandoned nets, traps, lines, and other litter. A comprehensive assessment review of litter off the coast of Monterey, California revealed that litter was most abundant in deep waters (between depths of 2,000–4,000 m; however, fishing litter was more common in shallower waters), was comprised of 33% plastic and 23% metal, and tended to cluster together due to the topography of the seafloor (Schlining et al. 2013). While there have been no assessments of litter on Rodriguez Seamount, considering its proximity to shore and the litter found in similar habitats, it is safe to assume that litter comprises a threat to the seamount ecosystem.

Climate Change

Seamounts off the coast of California will be subject to ongoing and future climate change and ocean acidification. As humans emit increasing amounts of carbon dioxide into the atmosphere, a cascading chain of events will significantly affect marine ecosystems around the world. The excess accumulation of carbon dioxide and other greenhouse gases in the atmosphere is causing global temperatures to rise; ultimately, 80% of this surplus heat is stored in the oceans (Levitus et al. 2005). Bathyal habitats between 200–3,000 m in depth in the Pacific Ocean are expected to see increases in temperature of up to 3.6°C by the year 2100 (Sweetman et al. 2017), pushing many seamount inhabitants out of their viable niche space. Increased vertical stratification and long equilibrium times of deep-ocean convection suggests that temperatures in the deep sea will continue to rise for centuries even if atmospheric warming is stopped or even reversed (Purkey and Johnson 2010).

Ocean warming will also lead to considerable decreases in dissolved oxygen concentrations, due to the lower solubility of oxygen in warm water and reductions in oxygen transport to deep waters (Keeling et al. 2010). In addition to global warming, increased carbon dioxide emissions will directly affect marine ecosystems via ocean acidification. The oceans absorb 25-30% of the carbon dioxide that humans produce, resulting in significant alterations to the entire carbonate system (Sabine and Feely 2007). pH levels will decrease (giving rise to the term 'ocean acidification'), fewer carbonate ions will be available (the ions typically used by marine calcifiers), and the saturation state of calcium carbonate will be lowered. Lower saturation states make it more energetically costly for marine calcifiers, including cold-water corals, to produce calcium-carbonate structures. pH in the bathyal zone of the Pacific Ocean is predicted to be reduced by as much as 0.31 units by the year 2100, a magnitude of change that has been found to considerably reduce calcification in reef-building cold-water corals (Lunden et al. 2014; Georgian et al. 2016).

Of the climate-related environmental variables known on Rodriguez Seamount (see Figure 2), dissolved oxygen is likely the most concerning. The summit and upper flanks of Rodriguez already exist in an oxygen minimum zone and are subject to low dissolved oxygen concentrations that are noted to play a role in structuring its unique summit community (Lundsten et al. 2009a). Further reductions due to predicted deoxygenation could cause mass mortality events, hamper physiological processes including calcification and growth, and decrease biodiversity (Hughes et al. 2020). However, the fact that the community on Rodriguez is already selected by and adapted to chronically low oxygen conditions suggest that it may be less affected than other seamounts.

The relatively low saturation state of calcium carbonate on Rodriguez Seamount is of additional concern. While the upper portion of the seamount is currently supersaturated (Ω of 1.4) with respects to calcium carbonate (energetically favoring calcification), reductions caused by ocean acidification could bring these habitats near the saturation horizon (Ω=1) or even into undersaturated waters. In these conditions, calcification is possible but energetically costly (e.g. Orr et al. 2005), and dissolution of existing skeletal materials is possible. Ocean acidification impacts on coral habitat, while generally intense, are also likely to be less extreme for seamounts than for other deep-sea habitats, as they may act as 'shallow-water' refugia for stony corals from the detrimental effects of ocean acidification at greater depths (Tittensor et al. 2010). However, the region is not projected to experience the drastic changes that are expected to occur in many other deep-sea habitats and in coastal environments. Seamounts in particular have been hypothesized to serve as important climate refugia in the future, as their upper flanks and summits will experience more moderate changes than other deep-sea habitats (Tittensor et al. 2010).

Whether Rodriguez Seamount will serve as a climate refugia or not may depend largely on food availability. In regions where the particulate organic carbon (POC) flux to the seafloor will remain largely unchanged, there may be sufficient food supply to allow organisms to metabolically compensate for other climate stressors. Seamounts ecosystems that rely on the upwelling of nutrient-rich waters may be more climate-resilient, as upwelling is predicted to increase with global warming (Bakun 1990). Previous studies on deep-sea corals have found that when feeding rates can be maintained or elevated, corals were still able to calcify new skeletal material even under very low pH conditions (Georgian et al. 2016). High food availability (driven by elevated currents, particulate organic carbon, and nutrients) currently found on Rodriguez Seamount, coupled with relatively low regionally predicted decreases due to climate change (Mora et al. 2014), suggests that the seamount may have potential to act as an important climate refuge in the future.

Protection of Rodriguez Seamount

Existing Protections

Beyond the few, small state reserves established close to shore (see MPAtlas 2022), most of the proposed Chumash Heritage National Marine Sanctuary is currently managed by the Pacific Fishery Management Council (PFMC). The PFMC ultimately derives its authority from the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), the primary law governing fisheries management in US federal waters. The MSFCMA's ultimate goal is to promote the 'optimal exploitation' of coastal fisheries, accomplished via the creation of eight regional councils with the task of managing fish stocks and associated ecosystems. The PFMC is the regional council responsible for governing the United States exclusive economic zone off the coast of Washington, Oregon, and California–a total area of 317,690 square miles. The council manages approximately 119 species of fish including salmon, groundfish, sardines, anchovies, mackerel, tunas, sharks, and swordfish. While the council's stated focus is fisheries management, they are also mandated by the MSFCMA to identify and protect essential fish habitat (EFH), defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity". EFH closures are one of the primary tools employed by the PFMC in accordance with their mandate to "prevent, mitigate, or minimize any adverse effects from fishing…".

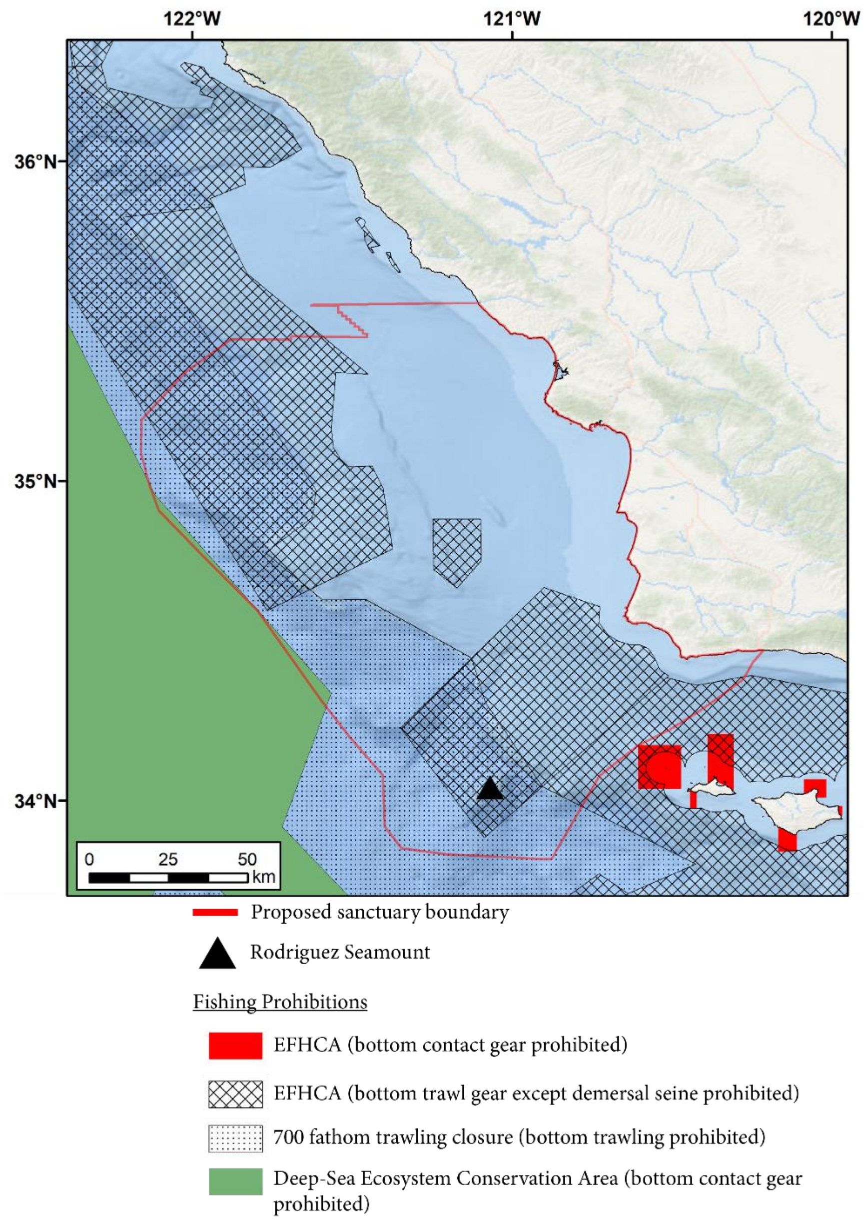


Figure 10. Existing deep-water bottom fishing prohibitions within the proposed Chumash Heritage National Marine Sanctuary boundary.

In the year 2000, the depletion of nine groundfish stocks on the U.S. West Coast led to a series of including catch limits, area closures, and year-round Rockfish Conservation Areas (RCAs) intended to rebuild fish stocks for later harvest (PFMC 2019). In 2006, the PFMC introduced Amendment 19 that froze the trawl footprint to previously fished areas (delineated by the 700-fathom contour), and enacted a large number of closures in priority habitats (Shester and Warrenchuk 2007). However, it should be noted that the trawl footprint was a compromise as previous trawls occurred up to 1,000 fathoms, and there was industry interest in future trawling at these depths (Shester et al. 2021). In January 2020, the council enacted new regulations (Amendment 28) that added 44,498 km^2 in EFH conservation areas at fishable depths, reopened previous trawl closures, and introduced a precautionary ban on bottom contact gears in waters deeper than 3,500 meters. The region encompassing Rodriguez Seamount is currently afforded some protection by overlapping EFH closures (Figure 10), and has also been designated as a 'Rocky Reefs' Habitat Area of Particular Concern (HAPC). The Point Conception EFH Conservation Area (Regulations 660.79 (ii); 660.112(a)(5)) prohibits bottom trawl gear other than demersal seine, and the Groundfish EFH in the Pacific Coast EEZ seaward of 700 fathoms (Regulations 660.76 (b); 660.112(a)(5)) prohibits bottom trawl gear.

Comparison to Davidson Seamount

Davidson Seamount was the first seamount in U.S. waters to be offered relatively strong protection from fisheries and other impacts, and is often held as a guiding example for seamount conservation. Recognizing the special importance of Davidson Seamount and its sensitive ecosystems, the Office of National Marine Sanctuaries committed to developing and implementing a protection plan, increasing our scientific understanding of the seamount and its habitats, and developing an education and outreach program. In 2008, the seamount was added to the Monterey Bay National Marine Sanctuary, providing strong protections for the seafloor and below 500 fathoms. However, the Office of National Marine Sanctuaries stopped short of protecting the entire water column above the seamount, raising concerns that migratory, open ocean, and pelagic species that rely on the seamount may still be at significant risk from human activities.

Despite its status as one of the best-explored seamounts in U.S. waters, new surveys at Davidson continue to yield new insights into the region's deep-sea ecology, including the discovery of a whale fall and the incredible aggregation of brooding octopuses in just the last five years. If Davidson Seamount had not been previously granted protection from trawling and other threats, these sites – along with many other diversity hotspots – could have been destroyed long before being discovered. While Rodriguez Seamount has not been surveyed as extensively, there is already reason to believe that it's communities rival that of Davidson. 15.4% of taxa observed on Rodriguez were not found to occur on either Davidson or Pioneer Seamounts (Lundsten et al. 2009a), and many novel taxa have already been observed on Rodriguez (See 'Benthic Ecosystem' section). Even when comparing similar communities between these seamounts, Rodriguez often contains species not found in neighboring habitats; for example, while Davidson and Rodriguez have similar abundances of sponges, Rodriguez contains sponges not yet discovered on Davidson. Rodriguez also has a higher density of demersal fish, higher species diversity than Pioneer Seamount, and higher abundance of mobile organisms and carnivores (Lundsten 2007; Lundsten et al. 2009a; 2009b).

Proposed Protection Measures

Unlike the narrow purview of the Fishery Management Council, the Sanctuary program is tasked with a larger scope of resource protection. The Office of National Marine Sanctuaries (ONMS) is responsible for identifying, designating, and managing ocean and Great Lake areas of special national significance as national marine sanctuaries. Sanctuaries are managed to protect and conserve their resources and to allow uses that are compatible with resource protection. As such the resources of the Sanctuary extend beyond species of economic interest and should result in a comprehensive suite of protections including those that extend beyond the seabed.

While Rodriguez Seamount already receives protections of some kind from overlapping EFH closures, the Office of National Marine Sanctuaries should seize the opportunity to enact permanent, strong protection for the seamount and surrounding waters. The new regulations enacted in 2020 by the PFMC provide some level of prevention for the California seamounts and other deep-water habitats, but also highlight the need for stronger and more permanent protection from human impacts. The cessation of bottom trawling in coral and sponge habitats is critical in preventing the extensive damage that trawls do to these fragile habitats. However, these regulations can be reverted by future council actions, again opening up sensitive ecosystems to damage from destructive fishing practices. Deep-sea coral and sponge communities are extremely long-lived and slow-growing. Once they have been trawled, they will not fully recover in the span of a few decades. Therefore, conservation measures must not only be effective, they must be long-lasting to fully safeguard these important ecosystems. We need to act now to secure strong and permanent protections for seamount habitats before they are irrevocably damaged.

Legally, EFH management is reconsidered every five years, which provides the opportunity for adaptive management but also opens the possibility that protected areas will be opened to fishing long before benthic ecosystems have recovered fully. Therefore, EFH closures should only be considered as an interim step in a longer process designed to more fully protect key habitats and ecosystems (see Shester and Warrenchuk 2007). Given the low level of observed anthropogenic impact on Rodriguez Seamount, there is an opportunity to provide substantial protection for a sensitive and ecologically crucial habitat while minimizing impacts to the fishing industry and other commercial interests. Given the large extent of benthic habitat that remains unexplored, and the paucity of data concerning water column and surface taxa, a precautionary management approach should be applied and coupled with the expanded scientific observation and assessment of the seamount and surrounding area. While the priority should remain closing the seafloor to destructive commercial fishing practices (especially bottom trawling and dredging, although pots and traps, bottom longlines, hooks and line, and set and drift gillnets also pose considerable risks), the importance of the seamount for the entire regional ecosystem warrants a precautionary approach. Therefore, both the seafloor and the entirety of the water column above the seamount should be closed to commercial fishing, and preemptively closed to possible future deep-sea mining, oil and natural gas exploration or extraction. Additional regulations should be included as necessary to combat marine litter and pollution, ban destructive infrastructure such as cable laying or waste storage, and reduce the impacts of shipping traffic. In all cases, given the long recovery times of benthic ecosystems, it is imperative to enact strong protections prior to significant adverse impacts.

Conclusions

Rodriguez Seamount provides critical habitat for an extremely diverse and abundant array of marine life and deserves to be granted strong and permanent protection. Due to its unique biology and geology, and associated importance for broader ecosystem functioning, scientific research, education, and aesthetics, the seamount has special national significance that warrants special protections under by the Office of National Marine Sanctuaries. The relatively low anthropogenic disturbance to Rodriguez Seamount provides a unique and time-sensitive conservation opportunity to protect sensitive habitats without significant socioeconomic tradeoffs or opposition from commercial stakeholders. In addition, the lack of historical damage to the physical substrate and benthic ecosystems makes the seamount well suited to better understand the ecology and geology of seamounts both within California waters and globally. Rodriguez Seamount should be used as a guiding pilot project that aids policymakers and stakeholders in the spatial management of other seamounts and important deep-sea ecosystems. In the case of Rodriguez, as well as most other seamounts, we often have only explored a small fraction of the total habitat and cannot fully assess the value of the ecosystems and the functions and services they provide; warranting a precautionary conservation approach. It is also important to note that once damaged, fragile seamount ecosystems may not recover in our lifetime, and that ecological restoration efforts are likely to be cost-prohibitive or technologically infeasible in deep-sea habitats (Van Dover et al. 2014).

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