



The Salas y Gómez and Nazca ridges: A review of the importance, opportunities and challenges for protecting a global diversity hotspot on the high seas

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ABSTRACT

The Salas y Gómez and Nazca ridges are two seamount chains of volcanic origin, which include over 110 seamounts that collectively stretch across over 2,900 km in the southeastern Pacific. Ecosystems in this region are isolated by the Atacama Trench, the Humboldt Current System, and an extreme oxygen minimum zone. This isolation has produced a unique biodiversity that is marked by one of the highest levels of marine endemism on Earth. These areas also provide important habitats and ecological stepping stones for whales, sea turtles, corals, and a multitude of other ecologically important species, including 82 species that are threatened or endangered. Recent explorations in this region have documented one of the deepest light-dependent marine ecosystems on Earth, as well as numerous species that are new to science. Waters surrounding the Salas y Gómez and Nazca ridges are mostly located in areas beyond national jurisdiction (ABNJ), with smaller portions located in the national waters of Chile and Peru. Within this region, Chile has already protected all the ridge features that fall

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within its jurisdiction, and Peru is evaluating a proposal that would protect the seafloor that falls within its national waters. However, all of the ABNJ in the region, which cover over 73% of the Salas y Gómez and Nazca ridges, are unprotected and under threat from a variety of stressors, including climate change, plastic pollution, overfishing, and potential deep-sea mining in the future. Importantly, fishing and other commercial activities are at low levels in international waters of this region, so there is a time-sensitive opportunity to protect its unique natural and cultural resources before they are degraded. This study provides a synthesis of the relevant science that has been conducted on the Salas y Gómez and Nazca ridges, and discusses the opportunities and challenges for protecting this unique region via existing sectoral organizations and through the emerging international agreement on biodiversity beyond national jurisdiction (BBNJ). Given its exceptional natural and cultural significance, the Salas y Gómez and Nazca ridges should be comprehensively protected from exploitation, pollution and other anthropogenic threats using the best available conservation measures.

1. Introduction

Stretching across over 2,900 km off the west coast of South America (Fig. 1) lies one of the most unique marine biodiversity hotspots on Earth [5–16]. The Salas y Gómez and Nazca ridges are two adjacent seamount chains of volcanic origin that lie in the southeastern Pacific [13,17–22]. The more adjacent ridge to South America, the Nazca Ridge, stretches across ~1,100 km of seafloor between the subduction zone off the Peruvian coast and the eastern edge of the Salas y Gómez Ridge (Fig. 1). The Nazca Ridge is located mostly in areas beyond national jurisdiction (ABNJ), with a smaller northeastern section located in the national waters of Peru. The Salas y Gómez Ridge stretches across ~1,600 km between the Nazca Ridge and Rapa Nui, also known as Easter Island (Fig. 1). The central portion of the Salas y Gómez Ridge is located in ABNJ, whereas both ends of this ridge fall within the Chilean exclusive economic zone (EEZ) around the islands of Rapa Nui and Salas y Gómez to the west, and the Desventuradas Islands to the east. Collectively, the Salas y Gómez and Nazca ridges contain over 110 seamounts, which represent approximately 41% of seamounts found in the southeastern Pacific [13,18,21]. The shallow waters of the Salas y Gómez and Nazca ridges span across three different ecoregions, including the Easter Island, the Humboldtian, and the Juan Fernández and Desventuradas Ecoregions [12,23,24]. The deep waters of this region include two bathyal biogeographic provinces (Southeast Pacific Ridges and Nazca Plate), and one abyssal province (Chile, Peru, and Guatemala Basin) [25]. The purpose of this study is to provide a synthesis of the relevant science that has been conducted on the Salas y Gómez and Nazca ridges, and discuss the opportunities and challenges for conservation of this unique region via existing sectoral organizations and through the emerging international agreement on biodiversity beyond national jurisdiction (BBNJ).

2. Geology

The southeastern Pacific is a geologically active region, with multiple geological hotspots [26–29] and active hydrothermal vents [30,31]. Seamounts located on the Salas y Gómez and Nazca ridges are all thought to have been produced by a common hotspot that is located close to the present location of Salas y Gómez Island [17,29,32–36]. Moving eastward along the ridges, the seamounts become progressively older, from 2 million years on the western portion of the chain, to over 27 million years towards the northeastern end [17,32,34]. These seamounts provide a detailed chronological record of the geological formation of the Salas y Gómez and Nazca ridges that tracks the movement of the Nazca Plate as it moves northeastward before it is subducted under South America [37]. In general, the summits of these seamounts become progressively deeper from west to east, and range between just a few meters below the surface on the western portion of the chain to over 3,000 m towards the northeastern end. However, seamounts near the junction of these two ridges are shallower and extend to just a few hundred meters below the surface [38]. Many of these seamounts are drowned coral atolls with nearly intact atoll structures, including drowned fringing and barrier reefs [6].

3. Biology and oceanography

Despite its geographic proximity to South America, the biodiversity of the Salas y Gómez and Nazca ridges is isolated from South America by the Humboldt Current System and the Atacama Trench (Fig. 1; [39]). As a result, the marine fauna of this region has higher biogeographical affinities to the Western Indo-Pacific than to the Eastern Pacific [5–9, 11–14,16,40–43]. The isolation of the Salas y Gómez and Nazca ridges has produced a unique biodiversity that is marked by one of the highest levels of marine endemism on Earth. For many taxonomic groups, close to half of the species are endemic to the region and found nowhere else on our planet [5–16,141].

In addition to hosting a high diversity of unique organisms, seamounts on the Salas y Gómez and Nazca ridges provide important habitat and ecological stepping stones for whales, sea turtles, swordfish, sharks, jack mackerel, deep-water corals, shallow-water corals, and myriad other ecologically important species (Figs. 2–3; [13,18,19,21,44, 45]). In particular, the Salas y Gómez and Nazca ridges are home to 82 species that are endangered, near threatened, or vulnerable to extinction, including 25 species of sharks and rays, 21 species of birds, 16 species of corals, seven species of marine mammals, seven species of bony fishes, five species of marine turtles, and one species of sea cucumber ([46]; Supplementary table 1). These species include two that are critically endangered, twelve that are endangered, 33 that are near threatened, and 35 that are vulnerable to extinction (Supplementary table 1). Due to its high productivity, the region also provides important foraging grounds for a high diversity and abundance of seabirds [19,47].

The Salas y Gómez Ridge and the southern portion of the Nazca Ridge are located near the center of the South Pacific Gyre, an area characterized by extremely nutrient-poor waters [39,48,142]. Water clarity in the central portion of this region, particularly around the Salas y Gómez Ridge, is exceptionally high. This clarity allows sunlight to reach greater depths than in other parts of the ocean. Recent scientific explorations of seamounts on the Salas y Gómez and Nazca ridges indicate that photosynthetic marine communities in this region occur below 300 m depth, one of the deepest recorded on Earth [20].

Limited deep-sea explorations that surveyed seamounts across the Salas y Gómez Ridge found that every seamount appears to have a unique community composition, with very few species shared between opposite ends of the ridge [49]. These results indicate that protecting only some of these seamounts may be insufficient to fully conserve representative biodiversity. Furthermore, these deep-sea explorations have documented numerous species that are new to science [9,20, 50–62]. For instance, recent remotely operated vehicle (ROV) surveys at 160–280 m depths recorded six new species of fishes [63], as well as two new genera of echinoderms [14]. This high rate of new species discoveries indicates that the marine fauna of this region still contains a large number of undiscovered species, which represent an enormous opportunity for future scientific exploration and conservation [10,63,64]. As an example, live individuals of the gastropod *Architectonica karsteni* were recently found on seamounts of the Nazca Ridge [65]. This ancient gastropod was previously only known to occur in the South Pacific from Miocene paleontologic records [65].

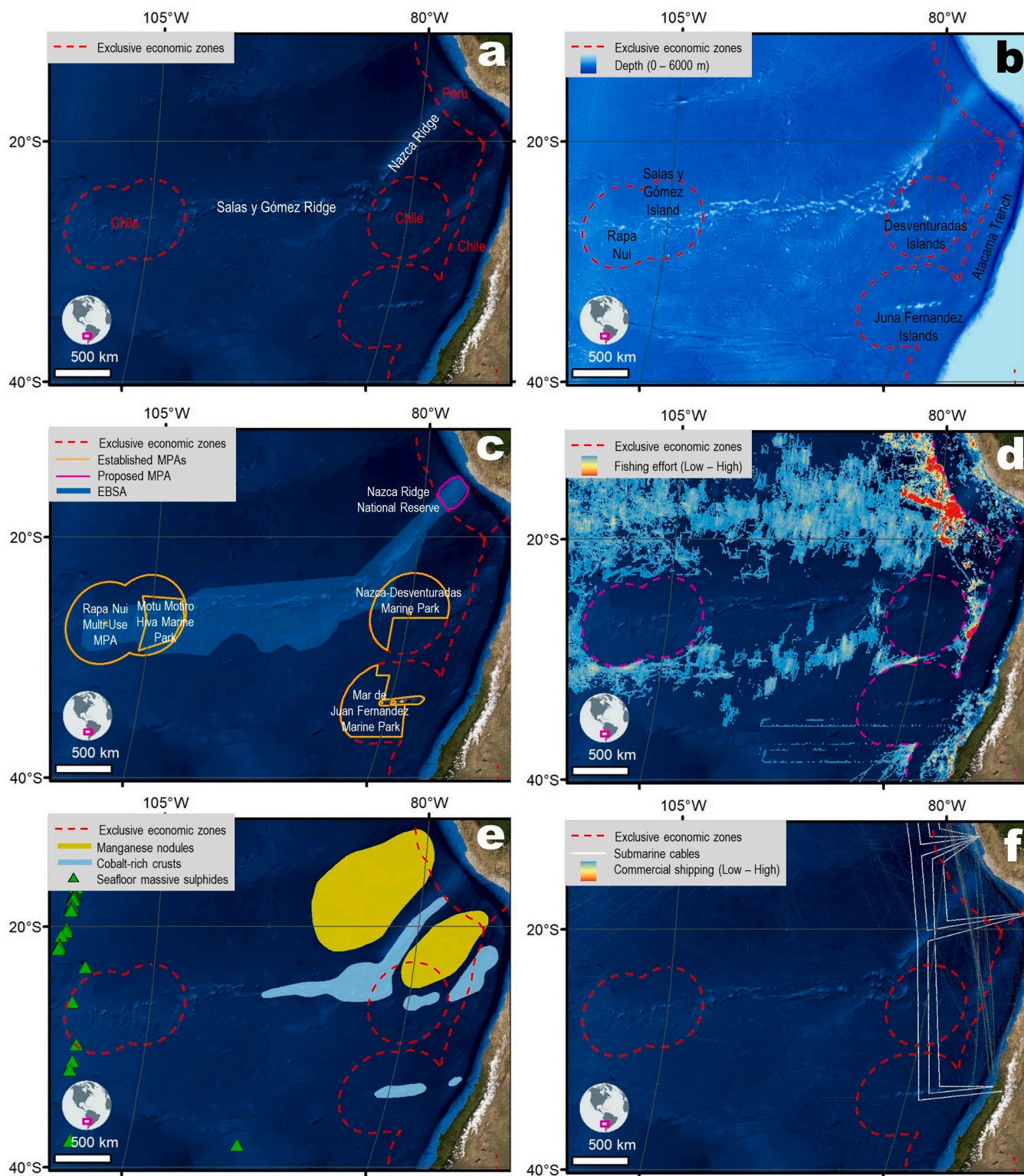


Fig. 1. Maps showing the location of the Salas y Gómez and Nazca ridges a. Jurisdictional boundaries of the national waters of Chile and Peru. b. Seafloor bathymetry derived from satellite altimetry c. Area recognized by Convention of Biology Diversity as an ecologically or biologically significant area (EBSA), as well as established and proposed marine protected areas (MPAs). d. Annual fishing effort in 2016. e. Commercially valuable deep-sea minerals (note that no oil or gas reserves are known to occur in this region). f. Distribution of commercial shipping activity (excluding fishing) and known submarine cables. Data sources: a. [150]. b. NOAA. [151] c. [152], [1] and [2]. d. [153]; e. [3] f. [155] and [4].

The deep waters of the Salas y Gómez and Nazca ridges intersect a region that has some of the most oxygen-poor waters in the world [66–68]. While there is very limited information on the deep-water fauna in this oxygen minimum zone, studies in other parts of the world have shown that such deoxygenated waters host unique assemblages of species [69,70]. Much like the Humboldt Current System (see above), the oxygen minimum zone near the Salas y Gómez and Nazca ridges may act as an additional biogeographical barrier to dispersal, thereby leading to increases in deep-water speciation.

4. International conservation distinctions

Several studies have been conducted to identify priority conservation areas in ABNJ [71–76]. While these studies used widely different approaches and datasets, all of these studies identified the Salas y Gómez and Nazca ridges as one of the most important areas to protect in ABNJ globally. The Salas y Gómez and Nazca ridges have also been highlighted

for their natural and cultural significance by numerous international bodies and organizations (Table 1). In 2014, the Salas y Gómez and Nazca ridges were recognized as an ecologically or biologically significant marine area (EBSA) at the 12th Meeting of the Conference of the Parties [77], following a regional workshop to facilitate the description of EBSAs in the Eastern Tropical and Temperate Pacific (Fig. 1; [78]). Prior to the workshop, Parties, Governments, and other organizations provided detailed scientific justifications to describe potential EBSAs [79]. Two separate scientific proposals were submitted for the Salas y Gómez and Nazca ridges that summarized the significance of this region [18,21]. As defined by the Conference of the Parties to the Convention of Biological Diversity, EBSAs are significant marine areas that are in need of protection or enhanced management and are evaluated based on seven criteria, including uniqueness, special importance for life history stages of species, importance for threatened or endangered species, vulnerability, biological productivity, biological diversity, and naturalness [80]. The Salas y Gómez and Nazca ridges were determined to be of high importance on all

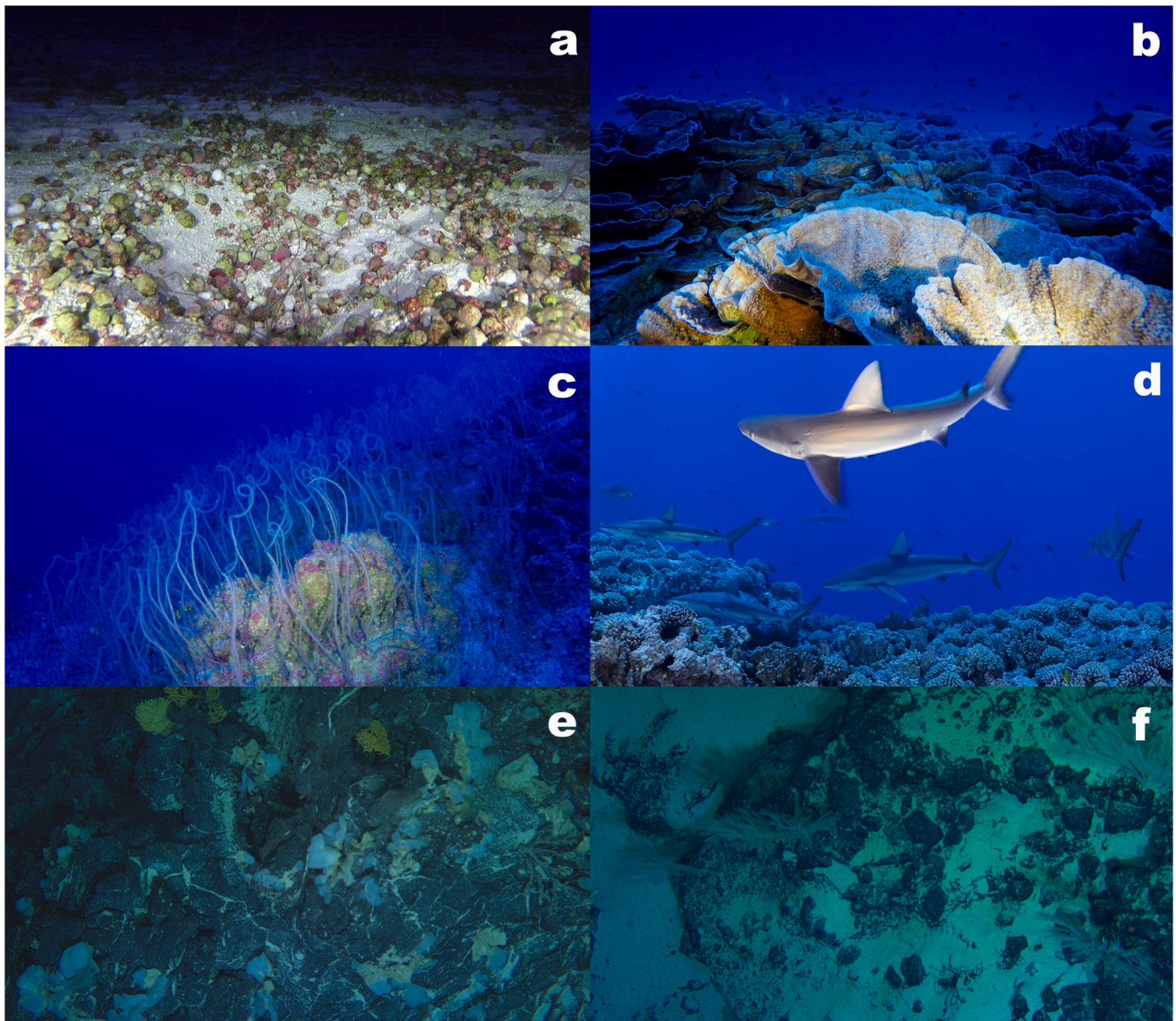


Fig. 2. Images of previous explorations of the marine biodiversity of the Salas y Gómez and Nazca ridges a. Rhodolith beds on Pukao Seamount at 220 m (credit: Matthias Gorny, Oceana). b. Mesophotic coral ecosystems at 80 m off Anakena, Rapa Nui (credit: Matthias Gorny, Oceana). c. Black corals at 130 m off Vaihū, Rapa Nui (credit: Matthias Gorny, Oceana). d. Sharks on coral reef at 10 m depth off Salas y Gómez Island (credit: Enric Sala, National Geographic). e. Deep-water coral and sponge community on an unnamed seamount on Salas y Gómez ridge at 520 m (credit: JAMSTEC). f. Deep-water coral community off San Ambrosio at 570 m (credit: JAMSTEC).

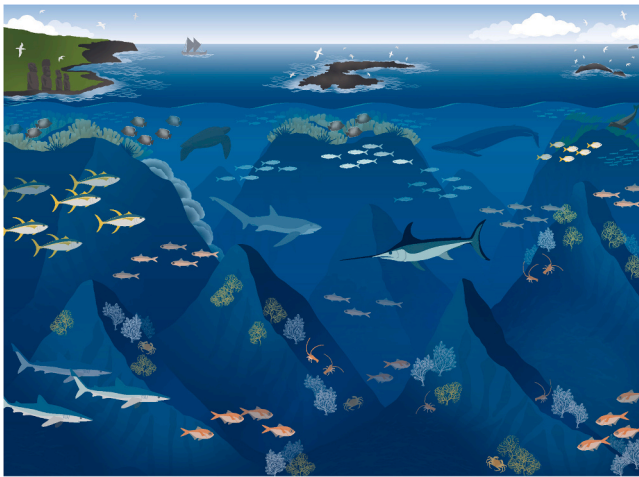


Fig. 3. Diagram showing the natural and cultural significance of the Salas y Gómez and Nazca ridges.

but two of the EBSA criteria (productivity and rarity), thereby underscoring the exceptional importance of protecting this region [77].

In addition to its status as an EBSA, the Salas y Gómez and Nazca ridges have also been recognized as an important area by the Global Ocean Biodiversity Initiative and the Global Census of Marine Life on Seamounts [81,82]. Furthermore, these ridges were recognized by Mission Blue as a Hope Spot, which are special places that are scientifically identified as critical to the global health of our ocean [147]. The islands of Salas y Gómez, San Félix and San Ambrosio are all considered Important Bird Areas by BirdLife International, as these islands host important colonies of Christmas Island Shearwater (*Puffinus nativitatis*), Masked Booby (*Sula dactylatra*), White-throated Storm-petrel (*Nesofregatta fuliginosa*), de Filippi's Petrel (*Pterodroma defilippiana*), and Chatham Petrel (*Pterodroma axillaris*; [19]). These islands, as well as Rapa Nui, are considered key biodiversity areas (KBA) by the KBA Partnership Program [83]. The waters around the islands of Salas y Gómez, San Félix and San Ambrosio are all considered critical habitats, as defined by the criteria of the International Finance Corporation's Performance Standard [84].

In addition to its natural significance, the region has also been recognized internationally based on its rich cultural heritage. The island of Rapa Nui includes one of the most renowned archaeological sites on Earth, which has been distinguished globally as a World Heritage Site by the United Nations, Educational, Scientific and Cultural Organization [85]. The broader region that contains the Salas y Gómez and Nazca ridges represents the easternmost extent of the Polynesian Triangle, a region with an exceptionally rich and long history of seafaring cultures [86–88]. Recent evidence suggests that Polynesian voyagers traveled along the Salas y Gómez and Nazca ridges to the South American Continent long before European contact [87].

5. Existing and proposed marine protections

Several protected areas have been established around the Salas y Gómez and Nazca ridges (Table 1; Fig. 1). Within Chilean waters of the region there are five marine protected areas (MPAs), which protect large ocean areas around Rapa Nui, Salas y Gómez, the Desventuradas Islands, and the Juan Fernández Archipelago (Fig. 1). While the Juan Fernández Archipelago is not part of the Salas y Gómez and Nazca ridges, it is included here since it highlights advances in protecting the marine biodiversity of the region. MPAs in the region include: (1) the Mar de Juan Fernández Marine Park, which is a no-take MPA designated in 2018 that protects 262,000 km² offshore of the Juan Fernández Archipelago, in addition to the Mar de Juan Fernández Multiple-Use Coastal Marine Protected Area that was designated in 2016 and expanded in

Table 1

Timeline of international distinctions that highlight the natural and cultural significance of the Salas y Gómez and Nazca ridges. Note that the Juan Fernández Archipelago is not part of the Salas y Gómez and Nazca ridges (see Fig. 1), but included here since they highlight important advances by the government of Chile to safeguard the offshore marine biodiversity of the region.

Year	Distinction
1966	Chile establishes the Rapa Nui National Park to protect ~40% of the terrestrial areas of Easter Island for their extraordinary cultural significance.
1976	Chile establishes the Salas y Gómez Nature Sanctuary to protect the entire land of Salas y Gómez Island.
1995	The United Nations, Educational, Scientific and Cultural Organization recognizes the Rapa Nui National Park as a World Heritage Site for its exceptional cultural significance.
2010	BirdLife International recognizes the islands of Salas y Gómez, San Félix and San Ambrosio as Important Bird Areas.
2010	Chile establishes the Motu Motiro Hiva Marine Park to protect 150,000 km ² around Salas y Gómez Island.
2011	The Salas y Gómez & Nazca ridges are recognized as an important area by the Global Ocean Biodiversity Initiative and the Census of Marine Life on Seamounts.
2014	The Salas y Gómez & Nazca ridges are recognized as an ecologically or biologically significant area at the 12th Meeting of the Conference of the Parties to the Convention of Biological Diversity.
2014	Chile passes the Vulnerable Marine Ecosystem Law, thereby protecting all seamounts in Chilean waters surrounding the Salas y Gómez and Nazca ridges from bottom trawling.
2015	Mission Blue recognizes the Salas y Gómez & Nazca ridges as a Hope Spot, which are special places that are critical to the health of our global ocean.
2016	Chile establishes the Nazca-Desventuradas Marine Park to protect 300,035 km ² around the islands of San Félix and San Ambrosio, also known as the Desventuradas Islands.
2016	Chile designates the Mar de Juan Fernández Multiple-Use Coastal Marine Protected Area to protect 12,000 km ² around the Juan Fernández Archipelago.
2018	Chile establishes the Rapa Nui Multiple-Use Coastal Marine Protected Area, which protects 579,368 km ² around Easter Island, thereby making it the largest marine protected area in the Americas.
2018	Chile establishes the Mar de Juan Fernández Marine Park to protect 286,000 km ² around the Juan Fernández Archipelago.
2018	Chile expands the Mar de Juan Fernández Multiple-Use Coastal Marine Protected Area to protect 24,000 km ² around the Juan Fernández Islands.
2019	Peru announces its proposal to create the Nazca Ridge National Reserve, which would protect 62,392 km ² in Peruvian national waters around the Nazca Ridge.

2018 to protect 24,000 km² around the islands, (2) the Nazca-Desventuradas Marine Park, which is a no-take MPA designated in 2016 that protects 300,035 km² around the islands of San Félix and San Ambrosio, (3) the Motu Motiro Hiva Marine Park, which is a no-take MPA designated in 2010 that protects 150,000 km² around Salas y Gómez Island, and (4) the Rapa Nui Multiple-Use Coastal Marine Protected Area designated in 2018, which bans all industrial fishing and deep-sea mining in the 579,368 km² around Easter Island, but allows the Rapa Nui people to fish with traditional methods [1,89]. The Rapa Nui Multiple-Use Coastal Marine Protected Area is currently the largest MPA in the Americas [90,91]. Furthermore, the Rapa Nui National Park and World Heritage Site protects 68 km² or ~40% of the land of Easter Island, and the Salas y Gómez Nature Sanctuary protects all of the 0.15 km² of land on Salas y Gómez Island [1]. Since 2014, all seamounts located within the Chilean waters are protected from bottom trawling by the Chilean Vulnerable Marine Ecosystems Law [149].

In 2019, the Peruvian Government announced its intention to create the Nazca Ridge National Reserve, which would protect 62,392 km² around the Nazca Ridge (Fig. 1; [2]). Specifically, the proposed reserve seeks to prohibit all extractive activities at depths >600 m, thereby protecting all of the seafloor of the Nazca Ridge that falls within Peruvian waters [2].

While the recent efforts by Chile and Peru provide important advances to safeguarding the unique biodiversity and cultural resources of this region, all of the areas that fall outside these countries' national

jurisdictions are unprotected and under threat from various stressors. Importantly, ABNJ represent over 73% of the area recognized as ecologically or biologically significant around the Salas y Gómez and Nazca ridges, as well as the most threatened from several stressors (see below).

6. Historic fishing activity

Soviet trawling occurred on seamounts of the Salas y Gómez and Nazca ridges for Chilean jack mackerel (*Trachurus murphyi*) and redbaits (*Emmelichthys* spp.) in the 1970s and 1980s [6,92–94]. On seamounts around the Juan Fernández Archipelago, a commercial fishery for orange roughy (*Hoplostethus atlanticus*) and alfonsino (*Beryx splendens*) developed in 1998, but was closed in 2006 following decreasing catches [95]. On the Nazca Ridge, Chilean and Russian vessels fished for Chilean jagged lobster (*Projasus bahamondei*) and golden crab (*Chaceon chilensis*; [6,13,93,96–99]). On the Salas y Gómez and Nazca ridges there has been historic pelagic long-line fishing, which has impacted sharks, juvenile swordfish and other pelagic species [11,82,97].

There has been historical fishing targeting Chilean jack mackerel (*T. murphyi*), squid (*Dosidicus gigas*), tuna (*Thunnus alalunga*, *T. obesus*, *T. albacares*, and *Katsuwonus pelamis*), striped bonito (*Sarda orientalis*), marlin (*Makaira indica* and *M. nigricans*), and swordfish (*Xiphias gladius*) on the Salas y Gómez and Nazca ridges [13,97,100]. Today most of the fishing in this region targets pelagic species and is primarily focused on ABNJ outside Peruvian national waters of the Nazca Ridge (Fig. 1; [153]). Catch data on jack mackerel, squid, and orange roughy in this region are available from the South Pacific Regional Fishery Management Organization (SPRFMO; Table 2; [101]), whereas catch data on tuna, billfish, and sharks are available from the Inter-American Tropical Tuna Commission (IATTC; Table 3; [102]). Additional fishing effort data in this region are available from Global Fishing Watch [153], which makes automatic identification system data publicly available (Fig. 1; Supplementary table 3).

As noted above, the orange roughy fishery has been closed in this region since 2006, and therefore there is no current catch data from the Salas y Gómez and Nazca ridges for this species (Table 2; [101]). According to data reported by SPRFMO, squid fishing is also low in high seas waters of the Nazca and Salas y Gómez Ridges. In 2008–2015, SPRFMO catch data only shows two vessels fishing in the area, for a cumulative effort of 20.5 hrs (Table 2). SPRFMO reported catch data for jack mackerel and other unidentified bony fishes is also low (Table 2). In 2008–2016, the total cumulative fishing effort was 2.17 hrs for jack mackerel and 297 hrs for other unidentified bony fishes [101]. The total amount of jack mackerel caught in this region from 2010 to 2016 was zero [101].

Data from IATTC [102] indicate that the vast majority of fishing activity occurring in high seas waters of the Salas y Gómez and Nazca ridges targets tuna, specifically skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), and yellowfin tuna (*Thunnus albacares*; Table 3), and occurs just outside Peruvian national waters (Fig. 1). Catch data for most species of billfishes and sharks has been zero in the last decade, with the exception of black marlin (*Makaira indica*), blue marlin (*Makaira nigricans*), striped marlin (*Tetrapturus audax*), and swordfish (*Xiphias gladius*; Table 3). However, catch for these species has also been very low,

Table 2

Recent catch data for species managed by the South Pacific Regional Fishery Management Organization (SPRFMO) in the Salas y Gómez and Nazca ridges ecologically or biologically significant marine area (see Fig. 1). Data source [101].

Common name	Species	Years	Effort (hrs)	Comment
Orange roughy	<i>Hoplostethus atlanticus</i>	2007–2017	0	Fishery closed since 2006
Squid	<i>Dosidicus gigas</i>	2008–2015	20.5	Only effort recorded in 2016 (all other years it was zero)
Chilean jack mackerel	<i>Trachurus murphyi</i>	2008–2016	2.17	Only effort recorded in 2011 (all other years it was zero)
Unidentified bony fishes	Osteichthyes	2008–2015	297	Only effort recorded in 2008 (all other years it was zero)

Table 3

Retained catch data for species managed by the Inter American Tropical Tuna Commission (IATTC) in high seas waters of the Salas y Gómez and Nazca ridges ecologically or biologically significant marine area (see Fig. 1). Catch data represents cumulative retained catch of the indicated species for the period between 2010 and 2019. Data source IATTC (2020), [102].

Common name	Species	Catch (MT)
Albacore	<i>Thunnus alalunga</i>	0
Bigeye tuna	<i>Thunnus obesus</i>	3,449
Black skipjack	<i>Euthynnus lineatus</i>	0
Bonitos nei	<i>Sarda</i> spp.	0
Pacific bluefin tuna	<i>Thunnus orientalis</i>	0
Skipjack tuna	<i>Katsuwonus pelamis</i>	18,326
Yellowfin tuna	<i>Thunnus albacares</i>	3,577
Marlins, sailfishes and spearfishes	Istiophoridae	10
Black marlin	<i>Makaira indica</i>	6
Blue marlin	<i>Makaira nigricans</i>	20
Striped marlin	<i>Tetrapturus audax</i>	3
Indo-Pacific sailfish	<i>Istiophorus platypterus</i>	0
Shortbill spearfish	<i>Tetrapturus angustirostris</i>	0
Swordfish	<i>Xiphias gladius</i>	1
Blue shark	<i>Prionace glauca</i>	0
Blacktip shark	<i>Carcharhinus limbatus</i>	0
Silky shark	<i>Carcharhinus falciformis</i>	0
Oceanic whitetip shark	<i>Carcharhinus longimanus</i>	0
Various sharks	<i>Selachimorpha (Pleurotremata)</i>	0
Scalloped hammerhead	<i>Sphyrna lewini</i>	0
Hammerhead sharks	<i>Sphyrna</i> spp.	0
Smooth hammerhead	<i>Sphyrna zygaena</i>	0
Thresher sharks	<i>Alopias</i> spp.	0

and cumulatively accounted for only 40 metric tons in the last ten years (Table 3).

7. Other threats

The majority of the Salas y Gómez Ridge and the southern portion of the Nazca Ridge are located near the center of the South Pacific Gyre, a large-scale oceanographic feature characterized by extremely nutrient-poor waters [39,48,142]. This paucity of nutrients makes this region particularly susceptible to anthropogenic and climatic disturbances [103]. For example, model climate change predictions indicate that in the next 20–40 years the seafloor of this region will experience increases in temperature, decreases in dissolved oxygen, acidification, and declining export of particulate organic carbon [104,105]. Decreases in dissolved oxygen concentrations are of particular concern, because this region already contains one of the most deoxygenated water masses in the world [66–68]. Further decreases of dissolved oxygen levels may make some areas inhabitable for certain species, thereby leading to substantial changes in biodiversity and biogeochemical cycles [106–108]. Climate change prediction models further indicate that the Salas y Gómez and Nazca ridges will experience substantial negative impacts by 2100, with the Nazca Ridge being most impacted [104,105]. Plausible consequences of these changes include biogeographic range shifts, habitat loss, decreased biodiversity, and decreased resilience, among others. Importantly, many of these consequences will be compounded by the El Niño Southern Oscillation and the Pacific Decadal Oscillation, which already have widespread impacts throughout the

region [109,110]. The Southeast Pacific Subtropical Anticyclone, which is the dominant forcing mechanism of major currents in the region, has already experienced a poleward shift as a result of climate change and this shift is projected to continue [109,111,112].

Due to its proximity to the center of the South Pacific Gyre, concentrations of floating marine debris are relatively high in this region, as these pollutants are concentrated in the circulating waters of this gyre [113–115,140]. Floating marine debris in this region mostly consists of large plastic fragments, lines, buoys, plastic trays, plastic bags and nets [115,116]. These floating pollutants primarily originate from sources on the continental coasts, including cities, beach-goers, aquaculture, and fisheries [116]. This litter severely affects at least 97 species of marine vertebrates in the region, particularly sharks, fishes, turtles, birds, and mammals, through entanglement and ingestion [116].

There are no known oil or gas reserves on or near the Salas y Gómez or Nazca ridges [117], despite several efforts to explore offshore areas in this region [28]. However, seamounts on the Salas y Gómez and Nazca ridges are known to possess cobalt-rich ferromanganese crusts, and commercially valuable manganese nodules are known to exist on both sides of the Nazca Ridge (Fig. 1; [3,28,118,119]). Polymetallic massive sulfides are known from hydrothermal vents located northwest of the Salas y Gómez Ridge (Fig. 1; [28]). While there are currently no contracts to explore or prospect deep-sea minerals in this region [118,120], these resources could attract mining interests in the future.

Threats from commercial shipping are generally low throughout the region, with the exception of the northern section of the Nazca Ridge, which intersects a major international shipping route (Fig. 1; [4]). Additionally, waters surrounding the Salas y Gómez or Nazca ridges have been identified as a major global transshipment location for distant-water fishing fleets [118,121]. Several submarine cables run across the Nazca Ridge, including in ABNJ of this region (Fig. 1 [154]). However, in comparison to other human activities in the deep sea, submarine cables are considered to have a relatively low impact on the environment. That said, because the Salas y Gómez and Nazca ridges provide habitat for many fragile benthic species like corals [13,18–21, 73], any future cable laying through this area should be carefully evaluated and planned.

8. Competent bodies in ABNJ of the Salas y Gómez or Nazca ridges

The United Nations Convention on the Law of the Sea (UNCLOS) establishes the rules governing uses of the ocean and its resources [122]. While UNCLOS provides a general obligation for States to protect and preserve the marine environment, it does not specify in detail how States should exercise that obligation with regard to the conservation and sustainable use of biodiversity in ABNJ [122]. As a result, a host of regional and sectoral agreements covering sectors like fisheries, shipping, and mining were developed both before and after UNCLOS came into effect in 1994. As in other regions in ABNJ, human activities in international waters around the Salas y Gómez and Nazca ridges are regulated by different intergovernmental bodies, including the International Seabed Authority (ISA, mining), the International Maritime Organization (IMO, shipping), and regional fishery management bodies (fishing), specifically IATTC for tuna and other highly-migratory fishery species and SPRFMO for non-highly migratory fishery species [113, 123]. The Permanent Commission for the South Pacific (CPPS) is a strategic regional alliance that aims to foster collaboration amongst Chile, Peru, Ecuador, and Colombia in marine policy, resource exploitation, conservation, environmental protection, and research [123,124]. In 2012, CPPS member States signed the Galápagos Commitment, in which they committed to promote coordinated action regarding their interests in living and non-living resources in ABNJ [113,123,125].

SPRFMO regulates fishery resources of non-highly migratory species located in the high seas of the South Pacific, including the Salas y Gómez and Nazca ridges. There are 15 current members of SPRFMO (Australia,

Chile, China, Cook Islands, Cuba, Ecuador, European Union, Denmark [in respect of the Faroe Islands], Republic of Korea, New Zealand, Peru, Russia, Chinese Taipei, USA, and Vanuatu), as well as four cooperating parties (Colombia, Curaçao, Liberia, and Panama). SPRFMO has implemented fishing effort measures, including total allowable catch, total allowable effort, and allocations by States for some fishery species. Additionally, SPRFMO prohibits the use of large-scale pelagic driftnets and deep-water gillnets, and has by-catch management measures in place for seabirds. SPRFMO maintains a vessel monitoring system, measures on control, inspections in port and at sea, regulates transshipment, and implements an on-board observer system. Since 2013, SPRFMO has implemented total allowable catch and total applied effort limitations for Chilean jack mackerel. SPRFMO also maintains measures for the protection of vulnerable marine ecosystems, however, none of these have been identified on the Salas y Gómez and Nazca ridges [126]. Regarding bottom fishing, SPRFMO requires a research assessment of potential impacts prior to opening new bottom-fishing areas. Specifically, all flagged vessels of SPRFMO member States and cooperating non-contracting Parties are not authorised to engage in bottom-fishing activities in the SPRFMO Convention Area without approval from the SPRFMO Commission [126]. Currently, areas that allow for bottom fishing in the SPRFMO Convention Area are all located in the Western Pacific, including in the Tasman Sea and on the Louisville Ridge [126].

IATTC is responsible for the conservation and management of tuna and other highly-migratory fishery resources in the eastern Pacific. IATTC has 21 members (Belize, Canada, China, Chinese Taipei, Colombia, Costa Rica, Ecuador, El Salvador, European Union, France, Guatemala, Japan, Kiribati, Republic of Korea, Mexico, Nicaragua, Panama, Peru, USA, Vanuatu, and Venezuela) and five cooperating non-members (Bolivia, Chile, Honduras, Indonesia, and Liberia). The geographical scope of IATTC covers both the national jurisdiction of its member States and the high seas in the Eastern Pacific, including those of the Salas y Gómez and Nazca ridges. The main fisheries species managed by the IATTC are yellowfin, albacore, skipjack, bigeye, Pacific bluefin tuna, and various species of billfish and sailfish. Conservation measures implemented by the IATTC in 2017 included restricting purse-seine fishing activity through spatio-temporal closures (72-day annual closure of the entire fishery, as well as 30-day annual closure of an area west of the Galápagos Islands known as El Corralito), limiting the number of fish-aggregating devices each purse seine fishing vessel can have at a given time, and total annual catch limits for bigeye tuna caught by long-line fishing vessels [127].

ISA regulates mineral-related activities in the international seabed beyond the limits of national jurisdiction, also known as the “Area” [122,146]. It does so by adopting regulations for the exploration and (in the future) exploitation of seabed minerals, setting terms for the approval of contracts, and is charged with establishing the necessary measures for the effective protection of the marine environment from the harmful effects of mining activities, and otherwise acting on behalf of humankind as a whole [144,146]. To date, such measures have been focused on designating areas of particular environmental interest (APEI), which are provisionally protected from future mining activities [120]. Though there are currently no exploration contracts for deep-sea minerals in the Area of the South Pacific, there are also no areas closed to mining in this region [118,120]. In other Pacific areas, ISA has previously issued exploration contracts in the Clarion-Clipperton Zone (CCZ) and the North West Pacific [120]. A prerequisite for any future exploitation contracts in the current discussions around draft regulations for exploitation [128] is that a regional environmental management plan (REMP) must be in place. Therefore, REMPs provide for regional-scale management of deep-sea mining, but it is unclear to what extent other uses and values will be considered in management planning for seabed mining. There is at present a REMF for the CCZ, and workshops were held in 2020 to develop REMPs for the international seabed Area in the North West Pacific and the Mid-Atlantic Ridge. There are no current discussions for REMPs for the South Pacific in the Area surrounding the

Salas y Gómez and Nazca ridges.

IMO regulates international shipping activities, including through the designation of particular sensitive sea areas (PSSAs), which may be protected by ship routing measures, such as areas to be avoided by all ships, or by certain classes of ships [113,129]. There are currently no PSSAs anywhere in international waters, nor are there any PSSAs or shipping route limitations around the Salas y Gómez and Nazca ridges. However, with the exception of the northern section of the Nazca Ridge, this region does not contain any major commercial shipping routes (Fig. 1; [4]). Additionally, through the International Convention for the Prevention of Pollution from Ships (MARPOL), IMO defines certain sea areas as “special areas” in which the adoption of special mandatory methods for the prevention of sea pollution is required. There are no MARPOL special areas in the South Pacific. Within the Chilean waters of this region, the Chilean Navy is currently developing higher standards for ballast water release within all oceanic MPAs of the region (Fig. 1).

CPPS is a strategic regional alliance that aims to foster collaboration in marine policy, conservation, and research amongst its members. CPPS has four member States (Chile, Peru, Ecuador, and Colombia), and the CPPS is also the Executive Secretariat of the Southeast Regional Seas Programme, to which Panama is a member. CPPS promotes mechanisms for political coordination between these five States on marine pollution, including on the development and management of MPAs. While the jurisdiction of CPPS generally lies in the national jurisdictions of its member States, under Article 1 of the 1981 Lima Convention, the CPPS jurisdiction can extend to adjacent high seas areas that could be affected by marine pollution [123,124]. Given the large amount of floating pollutants in international waters surrounding the Salas y Gómez and Nazca ridges that originate from the South American coasts [114,116], CPPS could play an important role in helping to address this issue. Specifically, it could encourage its member States to implement coordinated measures to increase garbage collection systems in coastal municipalities, eliminate discharges from vessels including through improved port waste reception facilities, and reduce the widespread use of disposable materials that could eventually become marine debris. CPPS already has a protocol for the protection of the marine environment from land-based sources that has been ratified by all of its members [130]. Furthermore, CPPS has an active working group on marine biological diversity in ABNJ, whose main goal is studying, monitoring and advising about conservation and sustainable use in these areas.

As noted above, a host of regional and global agreements covering different sectors regulate human activities in international waters around the Salas y Gómez and Nazca ridges; and these all already have established mechanisms for implementing conservation measures. To date, there has been a lack of coordination between these international bodies. To overcome these challenges, in 2015 the United Nations General Assembly agreed to develop an international legally-binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity in ABNJ, also known as the BBNJ agreement. The negotiations for the BBNJ agreement are still ongoing, with the fourth and final scheduled session being postponed as a result of the international coronavirus crisis.

9. States with relevant commercial and non-commercial interests

States with interests in ABNJ surrounding the Salas y Gómez and Nazca ridges include adjacent coastal States, namely Chile, Peru, Ecuador, and Colombia, as well as more distant States that conduct activities in these waters. Among adjacent coastal states, Chile and Peru are particularly important, both in terms of their geographic proximity to the region, as well as their recent efforts to protect the marine biodiversity of the ridges that falls within their respective jurisdictions (Fig. 1; Table 1). In the case of Chile it is important to note that in October 2020 the Chilean Government announced plans to submit a claim to the United Nations Commission on the Limits of the Continental

Shelf covering 550,000 km² on the western portion of the Salas y Gómez Ridge [131]. If this claim is granted, Chile would obtain sovereign rights over the seafloor and its resources in additional areas of the Salas y Gómez Ridge, but the water column above it would still be considered high seas and managed accordingly (i.e., SPRFMO and IATTC for fisheries, IMO for shipping).

Fishing is currently the primary commercial activity that occurs in international waters of this region (Fig. 1). Global Fishing Watch data indicates that in 2012–2020 vessels flagged by a total of 42 States operated in international waters surrounding the Salas y Gómez and Nazca ridges (Supplementary table 3). However, most of the recent fishing effort in this region is attributable to vessels flagged by China (72.7%), Spain (16.5%), Japan (3.4%), Taiwan (1.9%), and the Republic of Korea (1.7%), which collectively account for over 96% of the fishing effort in the region (Supplementary table 3). Other vessel flags with minor fishing effort include Peru (0.8%), Ecuador (0.5%), Portugal (0.5%), Colombia (0.2%), and Panama (0.2%). In addition to these States, all members of SPRFMO and IATTC in principle have interests over fishery resources in this broader region of the Pacific. These States include Australia, Belize, Canada, Chile, China, Chinese Taipei, Colombia, Cook Islands, Costa Rica, Cuba, Ecuador, El Salvador, European Union, Denmark, France, Guatemala, Japan, Kiribati, Republic of Korea, Mexico, New Zealand, Nicaragua, Panama, Peru, Russian Federation, USA, Vanuatu, and Venezuela.

In addition to fishing, commercial shipping is an important interest to consider because the northern section of the Nazca Ridge intersects a major international shipping route connecting ports along the west coast of South America (Fig. 1). These shipping routes include those connecting Chile, Peru, Ecuador, and Colombia, as well as connect to many other States, including very distant ones. Finally, several submarine cables run across ABNJ of the Nazca Ridge (Fig. 1). While UNCLOS already affords all States the freedom to lay submarine cables in ABNJ [122], activities required to maintain or repair cables need to be considered in this region.

Other States with an interest include those that are (1) Parties to the Convention of Biological Diversity which recognizes that the conservation of biological diversity is a common concern of humankind [132], (2) States Parties to the Convention on Migratory Species which pledges States to cooperate in the conservation of migratory marine species including those that migrate through this region [133], and (3) States Parties to UNCLOS for whom the seabed and its resources are to be managed on behalf of humankind, as well as obliges them to protect rare and fragile ecosystems and habitats of depleted, threatened, and endangered species [122]. States Parties to the World Heritage Convention are also relevant, as they recognize that parts of the cultural and natural heritage are of outstanding interest and therefore need to be preserved as part of the heritage of humankind [134,135]. In addition, stakeholders in many States have participated or benefited from marine scientific research in the region, and also enjoy the intrinsic value of marine biodiversity, ecosystem services and the many other benefits the region provides.

10. Discussion: protecting international waters and seafloor of the Salas y Gómez or Nazca ridges

Many previous studies have documented the extraordinary natural and cultural significance of the Salas y Gómez and Nazca ridges. These studies note not only the uniqueness of species and habitats of this region, but also their vulnerability to human impacts. As a result, Chile has already protected most of the habitats of the region that fall within its jurisdiction, and Peru is considering a proposal to protect a large portion of the deep-water habitats that lie within its national waters (Fig. 1; Table 1). However, the majority of the seamounts in this region are in ABNJ, where they are unprotected and already being impacted by fishing, climate change and plastic pollution, with potential future impacts from overfishing and seabed mining. While an MPA will not

resolve the climate change and plastic pollution problems, an MPA with associated management measures can support ecological resilience [136–138]. In addition, MPAs in combination with other area-based management measures are well suited to addressing the direct impacts of human activities on marine biodiversity, including from current and future uses.

Deep-water surveys of this region have noted that every seamount may have a unique faunal composition [49], thereby emphasizing that it is not enough to protect only some of them. While the recent efforts by Chile and Peru to establish MPAs in the national waters of this region provide important advances, these efforts could be undermined if surrounding ecosystems in ABNJ are not properly conserved. This is particularly important, because the high seas between these MPAs are known to serve as important migration corridors and ecological stepping stones for numerous species [13,18,19,21,45].

The nutrient-poor waters that surround a large portion of the Salas y Gómez and Nazca ridges makes this region particularly susceptible to climate change impacts, which are predicted to intensify substantially in the next decades. According to United Nations General Resolution 71/123, regional fishery management organizations, including SPRFMO and IATTC, should take into account the potential impacts of climate change in taking measures to manage deep-sea fisheries and protect vulnerable marine ecosystems. The high seas play a critical role as a global carbon sink [139,143], and protecting international waters of the Salas y Gómez and Nazca ridges would represent an important global contribution towards mitigating impacts of anthropogenic carbon emissions. By removing many human stressors, MPAs can enhance global resilience to environmental change, while also safeguarding biodiversity and enhancing biomass [136–138].

There is currently no global mechanism to establish MPAs that holistically conserve marine biodiversity in ABNJ; however, the ongoing United Nations negotiations on a BBNJ agreement aim to address this critical gap. In the interim, sectoral organizations like SPRFMO, IATTC, IMO, and ISA already have mechanisms to protect the biodiversity of the region from harmful practices. For most of the ABNJ, there is very little scientific information available, thereby making conservation planning difficult. In contrast, there is a great amount of scientific information available for the Salas y Gómez and Nazca ridges, particularly in shallower waters of this region, all of which indicates that this region is of great natural and cultural significance, as well as threatened by a myriad of impending impacts. Commercial fishing activities in this region have historically been relatively low, and deep-sea mining exploration has not commenced, so there is a time-sensitive opportunity to conserve its biodiversity and related ecosystem services before they are degraded.

International cooperation will be essential for this effort, both in terms of States that have a commercial as well as non-commercial interest in this region (see above), as well as in terms of activities that would be required to manage a potential protected area after it is created. This effort should build upon previous international collaborations that are relevant to this region, such as relevant committees at SPRFMO, IATTC, CPPS, IMO and ISA, but would also benefit from being opened to reflect the wider conservation interests of the global community, including through the future BBNJ agreement. International collaboration is also essential to foster marine scientific research and environmental assessments, and should build on the work done prior to the Salas y Gómez and Nazca ridges being recognized as an EBSA by the Conference of the Parties to the Convention of Biological Diversity [77]. For example, the regional workshop that preceded the EBSA recognition identified specific knowledge gaps in the region, as well as provided specific recommendations on how to fill these gaps [78]. The latter included recommendations to conduct more thorough biodiversity surveys, seafloor mapping surveys, analyses of satellite data to study long-term oceanographic and weather patterns, recompilation of fishing data from IATTC and SPRFMO, studies on the links between benthic and pelagic ecosystems, and satellite tagging studies on seabirds and mammals, among others [78].

Protecting the Salas y Gómez and Nazca ridges would have major global benefits for ecosystem connectivity, climate regulation, food security, and other ecosystem services. Seamounts and other rich deep-water communities that are widespread throughout the Salas y Gómez and Nazca ridges likely represent important reservoirs of global marine biodiversity [145], and via connectivity with surrounding waters, they also play a critical role of sustaining productivity more broadly [148].

11. Conclusion

Protecting the Salas y Gómez and Nazca ridges from exploitation, pollution and other anthropogenic threats would be a global accomplishment, and provide an example for conserving biodiversity in ABNJ. Specifically, it could serve as an important precedent for regional and other States taking action to protect a high seas area based on their common interests in a shared ecosystem, even before the new BBNJ agreement comes into force. The BBNJ agreement can also serve to enable global support, universal recognition and more comprehensive management of high seas biodiversity. Regionally-agreed MPAs in ABNJ have already been established in other areas by member countries of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the Convention on the Conservation of Antarctic Marine Life (CCAMLR), which established MPAs in ABNJ of the Northeast Atlantic and Southern Ocean, respectively [123]. While these MPAs provide advances in protecting biodiversity on the high seas, they only apply to the States involved and only cover a very small portion of the international ocean, thereby providing little hope to safeguard important ecological processes throughout the ocean. At present, increased marine protection could be achieved for the Salas y Gómez and Nazca ridges via sectoral organizations like SPRFMO, IATTC, ISA and IMO, with minimal impacts on the sectors managed by these bodies. Such increased protections would provide important advances in safeguarding the unique natural and cultural resources of the region from future threats. Furthermore, it would showcase the global leadership of the member countries of these sectoral organizations, as well as accelerate implementation of the objectives of the emerging BBNJ agreement for the benefit of present and future generations.

CRedit authorship contribution statement

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.marpol.2020.104377](https://doi.org/10.1016/j.marpol.2020.104377).

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