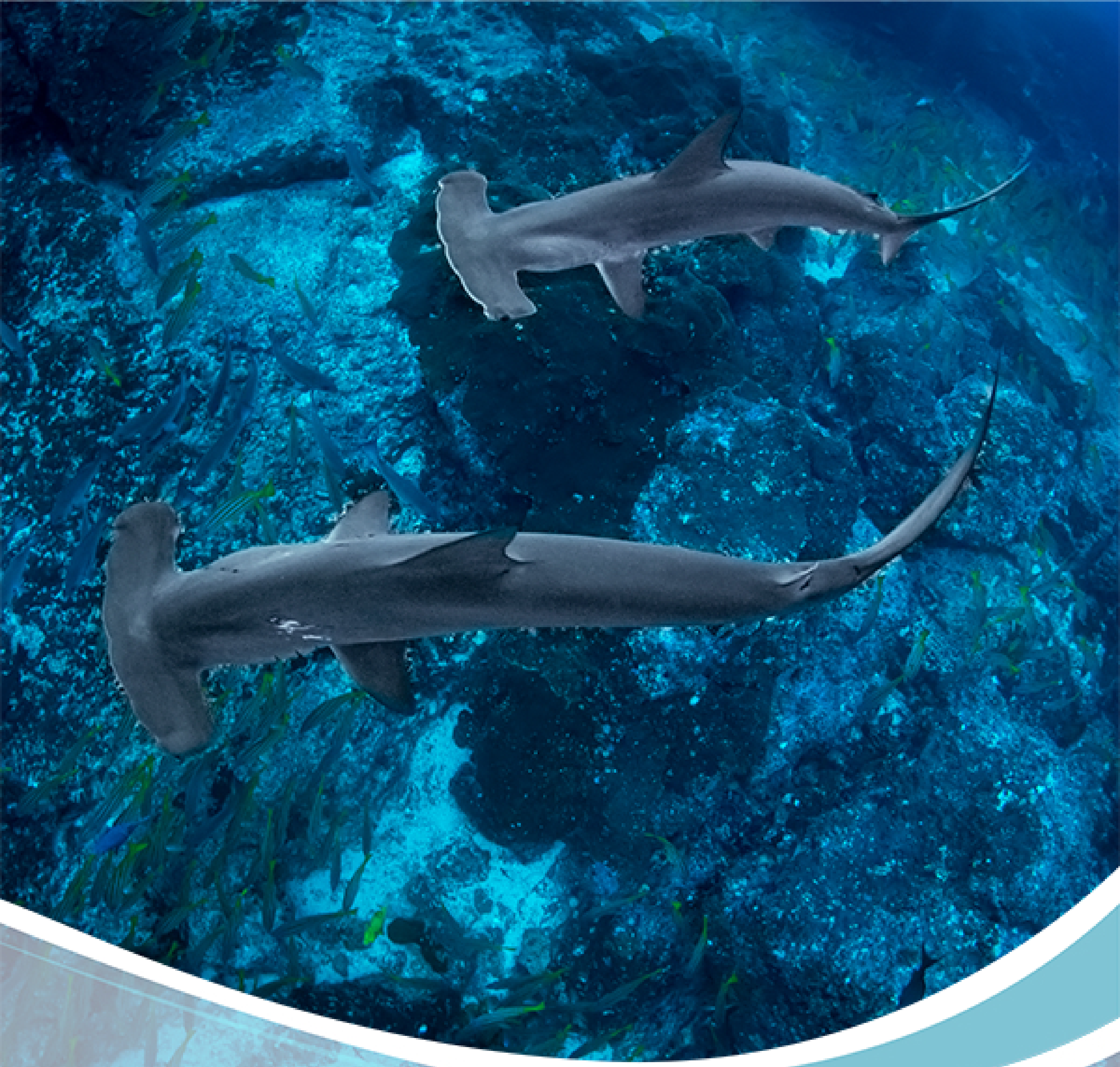

A Blueprint for Marine Spatial Planning of Ecuador's Exclusive Economic Zone around the Galápagos Marine Reserve

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Authors: Alex Hearn[1,2], Susana Cárdenas[1], Harriet Allen[3], Leo Zurita[1,4], María Virginia Gabela-Flores[1], Cesar R. Peñaherrera-Palma[2], Mauricio Castrejón[5], Sebastián Cruz[5], Daniel Kelley[6], Jana Jeglinski[7], John Bruno[8], Jen Jones[9], Alberto Naveira-Garabato[10], Alex Forryan[10], César Viteri[5], Josué Picho[1,4], Andy Donnelly[9], Alexander Tudhope[10], Meriwether Wilson[10], Gunther Reck[1].

[1]Universidad San Francisco de Quito USFQ, College of Biological and Environmental Sciences, Institute of Applied Ecology; [2]MigraMar, Ecuador; [3]Independent Consultant, United Kingdom; [4]Universidad San Francisco de Quito USFQ, GeoCentro Lab; [5]Independent consultant, Ecuador; [6]Hocking College, USA; [7]University of Glasgow, United Kingdom; [8]University of North Carolina, Chapel Hill; [9]Galapagos Conservation Trust, United Kingdom; [10]Southampton Oceanography Centre, United Kingdom; [11]University of Edinburgh, United Kingdom

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Contents

List of Acronyms

ABNJ	Areas Beyond National Jurisdiction
ACAP	Agreement on the Conservation of Albatrosses and Petrels
AIDCP	Agreement on the International Dolphin Conservation Program
AIOS	Ascension Island Ocean Sanctuary
AIS	Automatic Identification System
ASOESPEBLA	Asociación de Exportadores de Pesca Blanca del Ecuador
ATUNEC	Asociación de atuneros de Ecuador
AZE	Alliance for Zero Extinction
BIOT MPA	British Indian Ocean Territory Marine Protected Area
CBD	Convention on Biological Diversity
CBPM	Consultative Board of Participatory Management
CEDENMA	Coordinadora Ecuatoriana de organizaciones para la Defensa de la Naturaleza y el Medio Ambiente
CEIPA	Cámara Ecuatoriana de Industriales y Procesadores Atuneros
CGREG	Governing Council of the Special Regime of the Province of Galápagos
CI	Conservation International
CINP	Cocos Island National Park
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMAR	Eastern Tropical Pacific Marine Conservation Corridor
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CMS	Satellite Monitoring Center
CNP	Cámara Nacional de Pesquería
CNP	Coiba National Park
CPUE	Catch Per Unit Effort
CRMRA	Coiba Ridge Managed Resources Area
CTD	Conductivity Temperature and Depth Sensor
DDT	Dichlorodiphenyltrichloroethane
DIRNEA	National Directorate of Aquatic Spaces
DOL	Dolphin sets
DOM	Dynamic ocean management
DSLL	Deep-set longline
EAF	Ecosystem approach to fisheries
EBSA	Ecologically or Biologically Significant Area
EEZ	Exclusive Economic Zone
ENSO	El Niño Southern Oscillation
EOF	Empirical Orthogonal Function
EPO	Eastern Pacific Ocean
ESW	Equatorial Surface Water
ETP	Eastern Tropical Pacific
EUC	Equatorial Undercurrent
FADs	Fish Aggregation Devices
FAO	Food and Agriculture Organization
FENACOPEC	Federación Nacional de Cooperativas Pesqueras del Ecuador
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GHG	Greenhouse gas
GMR	Galápagos Marine Reserve
GNNP	Gorgona Natural National Park
GNP	Galápagos National Park
GNPD	Galápagos National Park Directorate
GWMO	UNEP Global Waste Management Outlook
IAC	Inter-American Convention for the Protection and Conservation of Sea Turtles
IATTC	Inter-American Tropical Tuna Commission
IBAs	Important Bird and Biodiversity Areas
ICCAT	International Commission for the Conservation of Atlantic Tunas
IFO	Intermediate Fuel Oil
IMA	Inter-institutional Management Authority
IMO	International Maritime Organization
INCOPESCA	Costa Rican Institute of Fisheries and Aquaculture
INEC	Instituto Nacional de Estadística y Censos

INP	National Fisheries Institute of Ecuador
IOTC	Indian Ocean Tuna Commission
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
IUU fishing	Illegal, Unreported and Unregulated fishing
LRIT	Long-Range Identification and Tracking
LOREG	Special Law for Galápagos
LSMPA	Large Scale Marine Protected Area
MARPOL	International Convention for the Prevention of Pollution from Ships
MCG	Coco-Galápagos Swimway
MCM	Coiba-Malpelo Swimway
MERRA	Modern-Era Retrospective Analysis for Research and Applications
MFFS	Malpelo Flora and Fauna Sanctuary
MPA	Marine Protected Area
MSY	Maximum Sustainable Yield
NDF	Non-detriment finding
NEC	North Equatorial Current
NECC	North Equatorial Counter Current
NGO	Non-Government Organization
NM	Nautical miles
NOA	Unassociated sets (purse seine)
OBJ	Floating object sets (purse seine)
OMZ	Oxygen minimum zone
OPSVC	Offshore Pacific Seamount and Vent Closure
PAI-IUU	International Plan of Action to prevent, deter and eliminate IUU fishing
PAN-IUU	National Action Plan to Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated Fishing
PAT-EC	National Action Plan for the Conservation and Management of Sharks of Ecuador
PCBs	polychlorinated biphenyls
PDO	Pacific Decadal Oscillation
PIPA	Phoenix Islands Protected Area
PMB	Participatory Management Board
PM	Papahānaumokuākea Marine National Monument
PRIMNM	Pacific Remote Islands Marine National Monument
PSSA	Particularly Sensitive Sea Area
PU	Planning Unit
RFMO	Regional Fisheries Management Organization
RFZ	Responsible Fishing Zone
SDGs	Sustainable Development Goals
SEC	South Equatorial Current
SENPLADES	National Secretariat of Planning and Development
Sharks MOU	The Memorandum of Understanding on the Conservation of Migratory Sharks
SIAP	Integrated Aquaculture and Fisheries System
SMMA	Seamounts Management Area
SOI	Southern Oscillation Index
SPRFMO	South Pacific Regional Fisheries Organization
SRP-VMAP	Subsecretaria de Recursos Pesqueros-Viceministerio de Acuacultura y Pesca
SS	Stock Synthesis
SSLL	Shallow set longline
SST	Sea Surface Temperature
STSW	Subtropical Surface Water
TSW	Tropical Surface Water
TUNACONS	Tuna Conservation Group
UAV	Unoccupied Aerial Vehicle
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNESCO	United Nations Educational, Scientific and Cultural Organization
USFQ	Universidad San Francisco de Quito
VHF	Very High Frequency
VME	Vulnerable Marine Ecosystem
VMS	Vessel Monitoring System
WCPFC	Western & Central Pacific Fisheries Commission
WWF	World Wide Fund for Nature
YIMND	Yuruparí-Malpelo National District of Integrated Management
YPR	Yield Per Recruit


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Cesar Peñaherrera


Alex Hearn

Executive Summary

The goal of this report is to provide Ecuador with a blueprint for spatial management and conservation of the open waters in the Exclusive Economic Zone (EEZ) surrounding the unique Galápagos Archipelago and Marine Reserve. It responds to concerns expressed by the local community, the national government and biologists, about the effectiveness of the current marine reserve in the face of emerging threats of the 21st century. The information compiled and analyzed in this document was shared with authorities and stakeholders from early 2020 to late 2021, and as technical support for the grassroots *Más Galápagos* campaign, which called for an increase in spatial protection around Galápagos. This culminated in the announcement of the new *"Hermandad*[1]*"* Reserve during the COP meeting in 2021, which was then declared in January 2022 at a ceremony in Galápagos.

Of all oceanic island archipelagos, Galápagos is arguably the most renowned globally, due in no small measure to its contribution towards Charles Darwin's Theory of Evolution, which revolutionized our views about life on this planet. Darwin arrived at his conclusions after noting how similar, but different, species inhabited the different islands, each adapted to its particular environmental conditions. The islands, which are volcanic in nature, were formed over a hotspot to the west, and as the Nazca plate on which they lay moves towards South America, the islands move eastward away from the hotspot. As they do so, they cool and subside, and become more eroded as they age, until they eventually sink below sea level. Thus, the different environmental conditions are due to the age and location of the islands themselves – in the confluence of major ocean currents: the warm Panama Bight from the north and the cool Humboldt Current from the south, join to feed the westward-flowing South Equatorial Current, which in turn is fed from below by shoaling and upwelling of the cold, eastward-flowing subsurface Equatorial Undercurrent. This results in a marked bioregionality, with warmer waters in the northern part of the archipelago, cool waters in the west, and mixed waters in the southeast. In turn, Galápagos does not only display high

Cesar Peñaherrera

1 Spanish for "brotherhood" or "sisterhood"

levels of endemism as a whole, but a significant number of species have highly restricted ranges within the archipelago, or have radiated into discrete species occupying particular niches on certain islands.

The Galápagos Islands were discovered in 1535 and annexed by Ecuador in 1832. Over the centuries since their discovery, successive waves of pirates and whalers threatened the delicate balance of the islands' ecosystems through direct exploitation (e.g. giant tortoises, sperm whales) and introduction of invasive species (e.g. goats, cats, rats, blackberry, ants), and they were declared a National Park in 1959. As recently as the 1970s, only 4,000 people lived on the islands, in the 3% of the land area that lies outside the National Park (on the islands of San Cristobal, Santa Cruz, Isabela and Floreana). However, by the mid 1990s, uncontrolled population growth on the islands and the corresponding increase in risk of invasive species introduction, coupled with intensive pressure on marine resources (both longline industrial fishing for pelagic species, and over-capitalized small-scale fishing for coastal resources such as sea cucumber) formed the backdrop to the creation of the Special Law for Galápagos (also known as LOREG, for its Spanish acronym) in 1998, through which the Galápagos Marine Reserve (GMR) was established – 138,000 km^2 surrounding the islands and extending 40 nautical miles out from a baseline drawn around the farthest points of each island. At the time, it was the second largest MPA on the planet (it is currently the 33rd), and since then, its regional importance has been recognized by its inclusion in several large-scale initiatives such as Conservation International's biodiversity hotspots, World Wide Fund for Nature's priority conservation areas, and Mission Blue's hope spots.

Nearly a quarter of a century later, concerns have been voiced, both from government and at the grassroots level, about the effectiveness of the GMR in the light of new and emerging threats, in particular related to highly mobile or migratory marine species. Almost half of 31 open water species of conservation interest that occur around the GMR have had their IUCN red list statuses updated to reflect a deterioration of their population status (Table i). These species, although belonging to different taxa, all share certain common biological traits – slow growth, low reproductive rates, long-lived and late onset of sexual maturity. These traits mean that they find it hard to recover from additional sources of mortality such as fishing. Our knowledge of the movement ecology of many of these species has increased significantly since the turn of the century, such that we can now identify potential foraging areas outside the GMR, and examples of connectivity between Galápagos and other areas. Notably, several species of sharks and turtles have been documented to move from the GMR to Cocos Island (Costa Rica), approximately 700 km northeastwards along the Cocos Ridge.

Table i | Summary of change in IUCN Red List status of species of conservation interest around the Galápagos Marine Reserve from 1996-2012 to 2020-2022.

Group	Number	Improve	No change	Decline
Sharks	14	1	3	10
Rays	1	0	0	1
Turtles	4	1	3	0
Seabirds	8	0	7	1
Marine Mammals	4	0	2	2
Total	31	2	15	14

Further, the threats facing these species in the region have changed over the course of the last twenty-five years. The main actors in the open waters surrounding the GMR are the industrial tuna fishery (dominated by purse seine and longline vessels), and the mainland-based artisanal longline fishery for large pelagics. While coastal development and degradation of early life stage habitat continues to threaten many of the threatened open water species in the region, the direct threats in the pelagic habitat within the Galápagos EEZ are largely linked with these fisheries.

1. The capacity of the purse seine tuna fleet now exceeds 250,000 m^3 (almost doubling a target capacity level of 150,000 m^3 that was set in 2000). Similarly, the overall fleet size grew from 73 vessels in 1999 to 117 in 2019. The mainland-based large pelagics longline fleets targets tuna, billfish and sharks for half of the year, although Ecuador does not formally recognize a shark fishery. However, over 250,000 sharks are landed, each year, mainly by this fleet, which operates over an area of approximately 3 million km^2, including the Galápagos EEZ.

2. The use of Fish Aggregation Devices (FADs) in the region has increased sevenfold since the turn of the century. The tendency of FADs to concentrate schools of smaller fish has raised concerns about their impact on the sustainability of target species such as bigeye. Further, Galápagos fishermen and other marine users report that FADs deployed to the east of the GMR drift into the reserve, and are fished once they drift out again. Our modeling studies support this, and estimate that FADs deployed to the east of the GMR spend on average 4-8 days inside the reserve, similar to the residence period of fish at the FADs. A further concern is that FADs may pose a safety hazard for marine traffic and contribute to pollution when they become entangled on reefs.

3. Although mother vessels in the large pelagics longline fleet are required to carry satellite tracking systems, the individual fishing skiffs that they tow do not, and these are able to enter the GMR undetected and reach local fishing grounds within only two hours. The Galápagos National Park Directorate reported that between 2018 and 2020, 136 unauthorized fishing vessels had been detected in the GMR.

4. Foreign vessels from at least 15 flag states have carried out fishing activities in the Galápagos EEZ between 2012 and 2015. There is limited public information regarding how many of these were doing so under licenses issued by Ecuador. Further, in part thanks to harmful subsidies, large distant-water fleets have been reported just outside the EEZ in recent years, including both tuna and squid-jigger fleets. There are concerns that the amount of fish and squid taken by these fleets may have impacts across the food chain. There is also evidence of plastic waste originating from some of these vessels, on the beaches of Galápagos, which points to lack of adherence to marine pollution guidelines. Further, at least some of these vessels do not comply with IATTC resolutions for the protection of endangered species, thus presenting a threat to migratory species that move from the GMR into these international waters.

5. Climate change has become a major issue across the planet since the turn of the century. Suitable habitat for species may shift and become compressed both horizontally and vertically as temperatures, oxygen content and pH change. Forecast models for the Eastern Tropical Pacific do not agree, and observed measurements in the region do not currently show ocean warming. Despite this uncertainty, Galápagos already experiences strong climatic variations from El Niño and La Niña events, the former of which have had

significant impacts on terrestrial, coastal and pelagic species in the past. If El Niño events are indications of future impacts due to climate change, we might expect lower productivity to force endemic marine species such as sea lions, fur seals and seabirds to forage further afield, increasing their likelihood of leaving the current GMR and becoming vulnerable to interactions with fisheries.

6. With up to 12 MT of plastics entering the oceans each year, causing an estimated global damage of US$13 billion annually, ocean plastics are now at the forefront of environmental concerns. While urban littering and dumping within Galápagos can be significant, a major source of plastic pollution is the coast of mainland Central and South America. However, a significant amount of plastic occurring at the islands is related to fishing activities (litter from foreign fishing vessels, eel traps, plastic fishing lines, and the aforementioned FADs are some examples). A regional, holistic approach is currently underway to understand polluting sources, to understand ecological and social impacts and to develop mitigation interventions at an effective scale.

Finally, there are challenges to enforcement within the current GMR among local users, with conflicts over zonation and, particularly relevant to the open water ecosystem: ongoing illegal use of longlining and demands to legalize this fishing gear despite at least six experimental fisheries demonstrating unacceptable levels of by-catch. Further, the participatory management system for the GMR was dismantled and a new participatory system has yet to be implemented, creating uncertainty among different stakeholders. These issues related to the internal functioning of the GMR are outside the scope of this study, but important to highlight, as they are factors that must be addressed in order to achieve the long term conservation goals of the Galápagos as a whole.

To address the threats outlined above, we first undertook a systematic spatial planning exercise using the program Marxan. Marxan is a tool that aids in prioritization of areas to achieve conservation-based targets while minimizing costs. In this case, we used two spatially explicit datasets to calculate costs – catch data recorded by onboard observers from Class 6 tuna purse seine vessels between 2007-10; and catch and by-catch data recorded by observers and logbooks for the large pelagics longline


Sofía Green

fleet from 2008-12. We were not provided access to more recent data, but analysis of publicly available aggregated datasets suggested that the relative distribution of effort had not changed. We used 54 conservation layers, including three layers based on ocean productivity (in El Niño, La Niña and neutral years), four layers based on ocean bathymetry and the presence of seamounts or ocean ridges, 31 layers depicting coarse ranges of species of concern, based on IUCN red list distributions, and a further 16 layers depicting tracking data for some of these species, thus highlighting putative foraging areas or migratory routes. We divided the entire EEZ into planning units using a 4 km^2 grid and set targets of 30% and 50% coverage of conservation layers against each fishing layer separately and then combined. We performed 100 runs of Marxan for each scenario and highlighted those areas that were selected on more than 90% of the runs.

We also undertook a modeling exercise, where we used a biogeophysical oceanographic model developed by the Southampton Oceanography Centre to track the movements of FADs deployed at three locations upcurrent of the GMR – on the eastern border, 40 NM outside the reserve, and the international waters separating the Galápagos EEZ with the mainland Ecuador EEZ. We deployed 1,000 FADs on the first day of each month for three representative years (El Niño, La Niña and neutral years) at each location. We found that under all climatic conditions, in most months, except March and April, FADs spent on average 4-8 days inside the GMR, except when deployed outside the EEZ.

We combined the results of both analyses with information generated by other regional conservation initiatives, with knowledge from local fishers about key areas inside the GMR that may attract external illegal fishers, and with existing information on bycatch distribution from the large pelagics longline fleet. We developed six scenarios across the entire Galápagos EEZ (Figure i) to increase protection in the open waters of the EEZ outside the GMR that were designed to address the threats identified above, and to build resilience to climate change by strengthening connectivity, reducing non-climate related stressors to vulnerable species, and protecting cold-water refugia.

Scenario A would provide the maximum protection to the EEZ while leaving key fishing grounds open to national fleets. This scenario would include a new no-take marine reserve extending over 444,470 km^2 to protect critical oceanic ecosystems as well as migratory routes and foraging areas of endangered marine species. It would include two Responsible Fishing Zones (RFZs) available to user groups through exclusive access-type agreements (such as territorial user rights), to be discussed and defined with user groups, and where there should be a commitment to full observer coverage, transition to low bycatch fishing methods and to release bycatch species, including sharks. One zone would cover 195,656 km^2 west of the current GMR, while the second zone to the east of the GMR, would cover 29,287 km^2 and should be free of FADs. A temporal 33,805 km^2 no-take buffer zone along the western margin of the GMR would be implemented during El Niño conditions to reduce the risk to endangered endemic species whose foraging ranges expand in these events.

Scenario B was designed to optimize potential spillover effects for national fleets operating inside the EEZ, while maintaining strict protection along key conservation areas associated with the Cocos and Carnegie Ridges over an area of 378,608 km^2. A similar El Niño buffer zone of 30,215 km^2 was also included as in scenario A, and the two RFZs were enlarged to 259,618 km^2 and 34,869 km^2 respectively.

Scenario C focused on protecting Ecuador's side of the Coco-Galápagos Swimway and on expanding protection along the Galápagos platform to include seamounts on the eastern margin, which would also dissuade illegal fishers from accessing fishing grounds inside the GMR. The total new no-take area under this scenario would be 171,532 km^2, which would also allow Ecuador to achieve the goal of protecting 30% of its ocean. The two RFZs would cover areas of 399,323 km^2 and 55,036 km^2 and would be managed under the same conditions as explained previously, and a further temporal seabird protection longline exclusion area would be implemented from June through August in the southeastern wedge of the EEZ, covering an area of 43,185 km^2. An El Niño buffer zone of 33,805 km^2 would be applied as in scenario A.

Scenario D included the creation of a no-take area of 137,439 km^2 to protect Ecuador's side of the Coco-Galápagos Swimway, and the inclusion of the El Niño buffer zone of 33,805 km^2 would be applied as in scenario A. A single RFZ would cover the remainder of the EEZ (531,650 km^2).

Scenario E included a reduced no-take area of 112,748 km^2 across the northern half of Ecuador's portion of the Coco-Galápagos Swimway, and including a 40 NM fringe around the east of the current GMR to increase protection along the island platform and dissuade illegal longline fishing at artisanal fishing grounds inside the GMR. The remainder of the Swimway area would become a longline and FAD exclusion zone (32,369 km^2), and a further temporal seabird protection longline exclusion area would be implemented from June through August in the southeastern wedge of the EEZ, covering an area of 43,185 km^2. An El Niño buffer zone of 33,805 km^2 would be applied as in scenario A. Two RFZs covering 399,324 km^2 and 81,713 km^2 would be managed under the same conditions as explained in scenario A.

Scenario F includes a 10 NM ring around the entire GMR, which would bring some seamounts to the east under protection, and would also provide some dissuasion to illegal longlining skiffs by extending their roundtrip travel time to fishing grounds inside the GMR by approximately 1.5 hours, assuming an average speed of 15 knots. The El Niño buffer zone would be placed outside this ring, and implemented under the same conditions as described for the previous scenarios.

The impacts of the different scenarios ranged between 2.3% to 6.2% of the total value for the purse seine fishery and 1% to 4.4% of the total value for the longline fishery. A static economic model estimated that this was equivalent to US$ 22.6 million, corresponding to the "maximum conservation" and "spillover and migratory routes" scenarios, to US$ 10.2 million for the "swimway" scenario. However, this model assumed that the resources are static, and that the fishermen do not modify their behavior to adapt. We expect that fishers would rapidly adapt to carry out their fishing activities in other areas to compensate for days lost in the new no-take zones. Static models do not take into account potential spillover effects such as those seen in the current GMR, where purse seine catches doubled in the area adjacent to the GMR boundaries.

After a period of consultation among different stakeholder groups, in January 2022 President Guillermo Lasso Mendoza, ordered the creation of a new protected area called "Reserva Marina Hermandad" which would be integrated into the National System of Protected Areas and covers a total area of 60,000 km^2. The Hermandad Reserve is made up of two zones – a 30,000 km^2 no-take zone, and another 30,000 km^2 responsible fishing zone where longlining is not permitted but other fishing gear (including industrial purse seine) may be used (Figure ii). The stated priority objective of Hermandad is to protect the ranges of migratory species, and as such, it connects with the southwestern edge of Costa Rica's recently created Bicentennial Marine Management Area. Table ii summarizes the contribution of Hermandad to a range of conservation objectives in relation to the scenarios developed in this document, and the relative direct costs to the industrial tuna and mainland-based longline fleets.

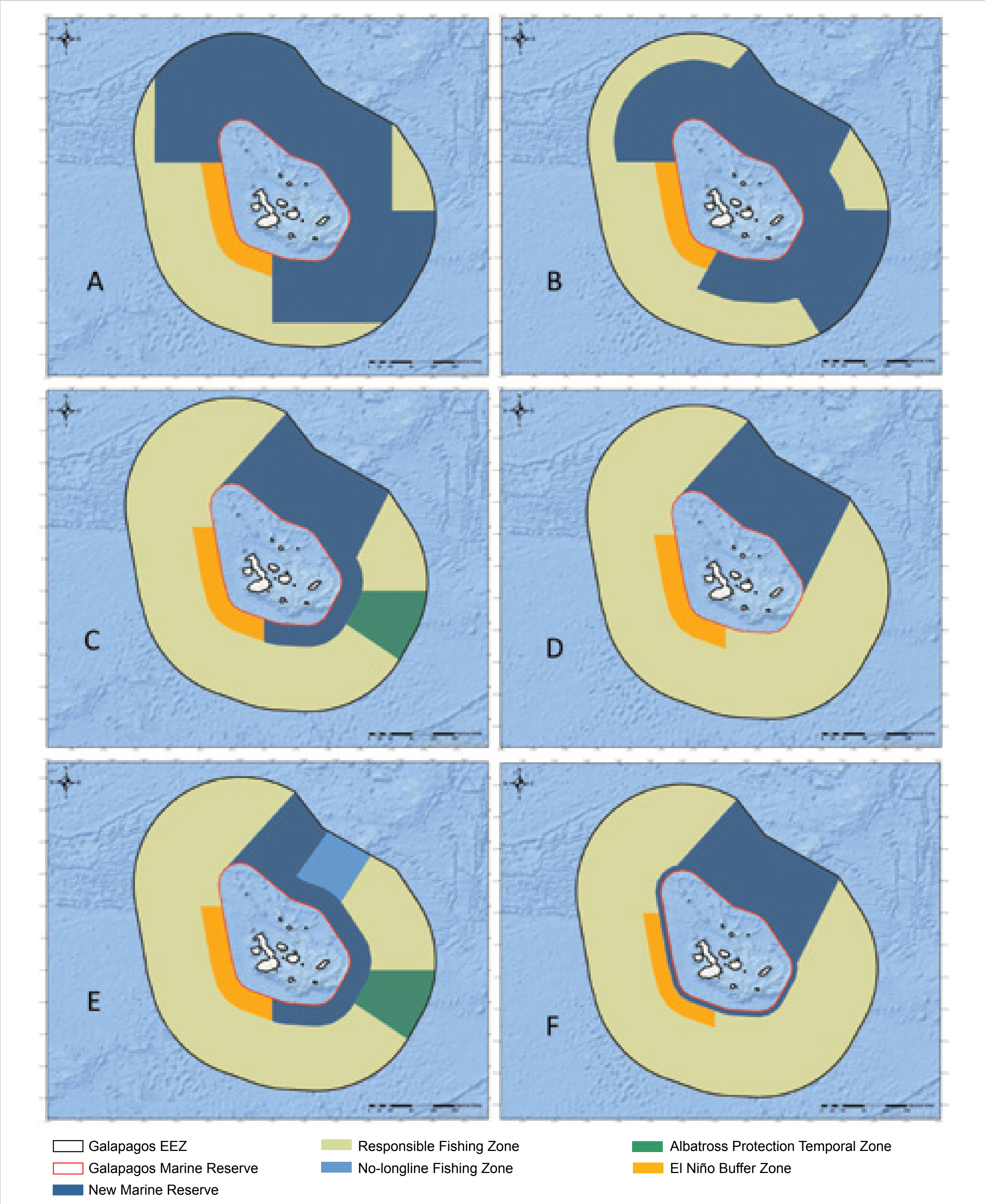


Figure i. Scenarios developed to strengthen protection in the EEZ surrounding the Galápagos Marine Reserve. Dark blue denotes no-take zones, orange denotes El Niño buffer zones, green denotes temporal no-longlines zone to avoid albatross by-catch, light blue denotes a no-longline zone, olive green denotes responsible fishing zones (RFZs).

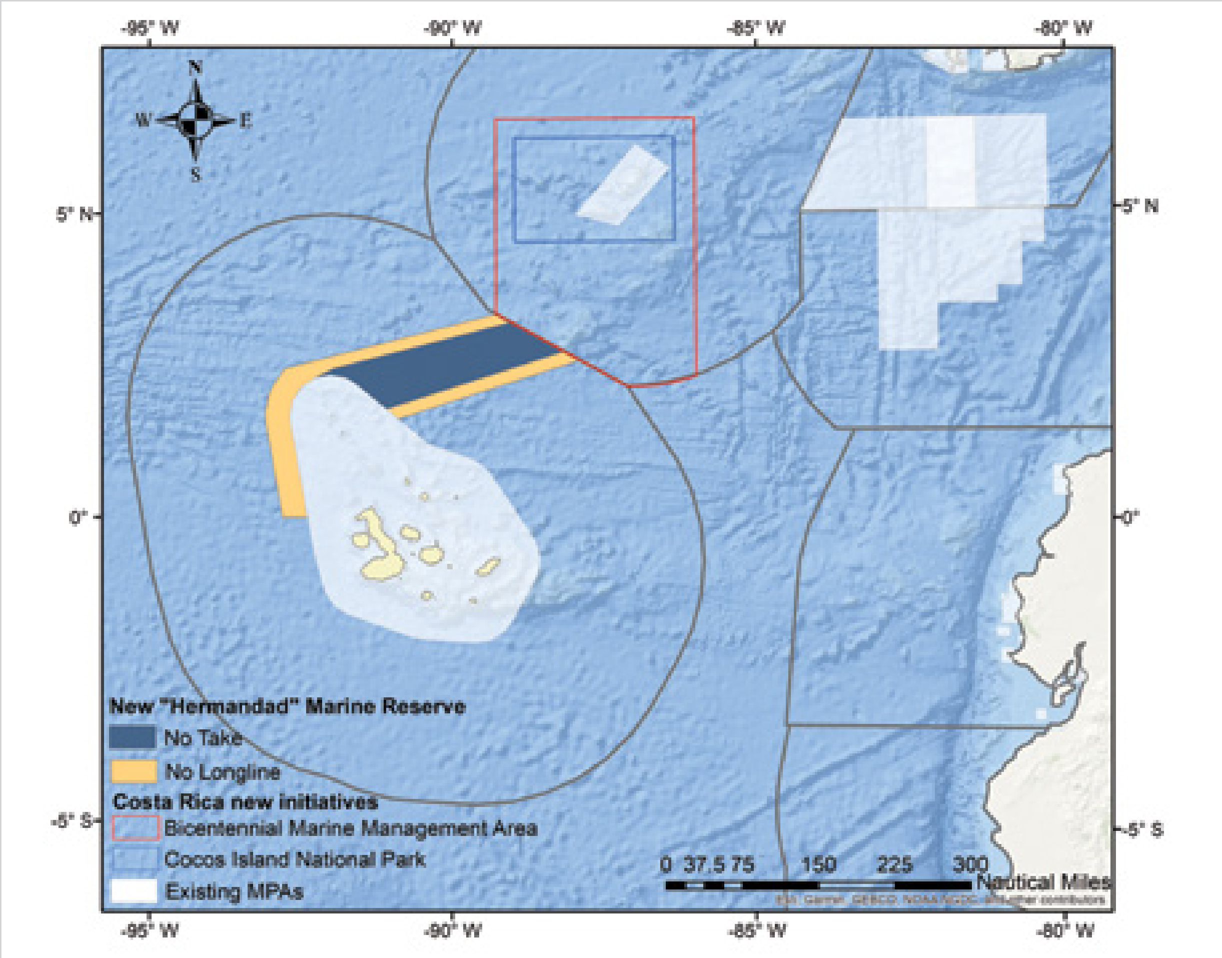


Figure ii. Location and zonation of the new Hermandad Reserve, placed in context with other MPAs regionally and Costa Rica's recent protection initiatives.

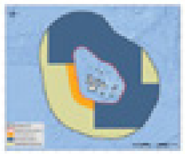
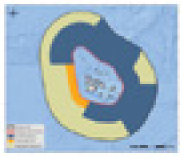
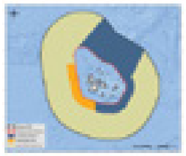
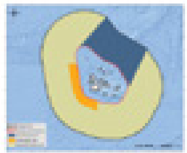
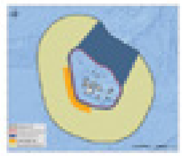
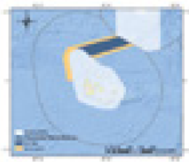
Implementation of Hermandad will involve creating a governance structure around a management plan that includes measurable indices of efficiency, a sustainable financing mechanism to ensure effective control and enforcement mechanisms and monitoring programs, and integrating users into the process. Hermandad possesses the advantage of being adjacent to the GMR, which already has infrastructure and experience in open water protection, and can likely achieve fairly rapid initial implementation once a management plan is approved.

Successful implementation of Hermandad will also depend on addressing the protection of migratory pathways within Costa Rica's Bicentennial Marine Management Area, and on improving governance issues within the existing GMR, in particular related to ongoing use of prohibited fishing gear such as longlines.

Hermandad is another action taken by Ecuador to fulfill its commitment to the global sustainable development goal SDG14, and to increasing effective protection of the oceans to 30% by 2030. While it is an important step in protecting key habitat for endangered marine migratory species, a fully integrated EEZ-wide approach to conservation and sustainable use of Ecuador's open waters should remain a goal that stakeholders and authorities work towards in the coming years.

Table ii | Summary of protection coverage for key conservation features (existing GMR + scenario) and percentage changes in fishery values under the six scenarios evaluated and the Hermandad Reserve, created in 2022.

< 50%	>= 50% and <65%	>= 65% and <80%	>= 80% and <95%	>= 95%

	Scenario A Maximum Conservation	Scenario B Spillover + Migration Routes	Scenario C 30 by 30	Scenario D Coco-Galapagos Swimway	Scenario E Minimum Protection	Scenario F Swimway + 10 nm ring	2022 Declaration Reserva Hermandad
							
CONSERVATION							
Area of new marine reserve (km^2)	444,470	378,608	171,532	137,439	112,748	155,627	30,000 + 30,000
% of available Galapagos EEZ	63%	54%	24%	20%	16%	22%	8%
Conservation objectives met over 50% (total 54)	53	53	27	26	25	26	21
% Marine Protection reached at the country level	54.3%	48.2%	29.2%	26.0%	23.7%	27.7%	18.9%
% Shallow Seamounts (< 500 mts)	100%	100%	100%	91.0%	100%	94.6%	89.3%
% Deep Seamounts (> 500 mts)	99.4%	99.0%	82.0%	72.7%	68.5%	75.2%	50.2%
% Upwelling, neutral year	51.7%	56.9%	44.3%	34.2%	44.3%	42.7%	34.2%
% Leatherback turtle	76.8%	66.8%	46.0%	41.6%	41.9%	43.7%	29.7%
% Green turtle	94.6%	93.3%	93.2%	93.2%	92.9%	93.3%	68.6%
% Waved albatross	91.4%	90.1%	37.0%	22.9%	37.0%	25.6%	21.0%
% Hammerhead shark	90.1%	87.5%	60.9%	59.1%	60.7%	62.1%	43.2%
% Whale shark	76.2%	74.3%	58.3%	57.6%	52.2%	60.5%	34.2%
FISHING							
Areas open to fishing (km^2)	258,979	324,841	531,917	566,010	590,701	547,822	673,338 (purse seine) 643,479 (longline)
% Value of purse seine catch in Galapagos EEZ	73.1%	71.4%	86.1%	89.0%	89.4%	80.3%	97.3%
% Value of longline catch in Galapagos EEZ	81.2%	81.3%	91.9%	93.7%	95.7%	89.2%	99.0%
% Total value of purse seine catch not in new reserve	94.2%	93.8%	97.0%	97.6%	97.7%	95.7%	99.4%
% Total value of longline catch not in new reserve	95.6%	95.7%	98.1%	98.5%	99.0%	97.5%	99.8%

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Background: The Galápagos Marine Reserve

Galápagos – a province of Ecuador

The natural heritage of Ecuador is globally recognized. For a relatively small country (256,370 km^2) it is home to over 17,000 species of vascular plants (Ulloa Ulloa et al. 2017), and is rated globally as the most diverse country (in terms of number of species per area) for amphibians (653 species) (Ron et al. 2019) and reptiles (477 species) (Torres-Carvajal et al. 2019). It hosts 457 species of mammals (Tirira et al. 2021), almost 1,700 bird species (Freile and Poveda 2019) and over 1,100 marine and freshwater fishes (Froese and Pauly 2019). Ecuador hosts two UNESCO Natural World Heritage Sites and seven UNESCO Biosphere Reserves. Its major ecosystems include tropical rainforest, cloud forest, high Andean páramo, coastal rainforest and dry forests and, perhaps most famously, the oceanic Galápagos Islands.

The Galápagos Islands hold a unique place in the human psyche. Their name is inextricably linked to the visit of the young naturalist, Charles Darwin, on board of the HMS Beagle in 1835. During his visit, Darwin made historic observations that would lead to the theory of evolution by natural selection, and forever change our understanding of life on earth. The islands were discovered by chance on March 10th 1535, by a vessel transporting the Bishop of Panama, Fray Tomás de Berlanga, to settle a dispute between Diego de Almagro and Francisco Pizarro in Peru (Woram 2005). The ship became becalmed and drifted out into the Pacific, eventually ending up at the islands. The crew went ashore looking for water and, based on the negative light of their subsequent report of the discovery to Charles V, Spain did not take possession of the islands.

The islands first appeared on maps in Mercator's map of 1569 and Ortelius' map of 1570 (Bahill, 2021). The first real explorers of the islands were the pirates and buccaneers of the seventeenth and eighteenth centuries, such as William Dampier and Lionel Wafer (Woram 2005). Towards the end of the eighteenth century, whalers used the islands as an outpost from which to catch sperm whales at their offshore grounds to the west of the islands (Latorre 2001). It is also estimated that they took over 100,000 giant tortoises in this period (Jackson 1993), and were responsible for the introduction of invasive species such as rats, cats and goats, that would remain a threat to the fragile biodiversity of the islands to this day (Guo 2006). At around this time, the islands hosted


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their first human resident - a sailor known as "Irish Pat" Watkins, who was marooned on Floreana from 1807-1809 (Latorre 2001).

In 1830, Ecuador declared independence and broke away from Gran Colombia, a state that encompassed much of northern South America and part of Central America from 1819 to 1831. General José Villamil convinced the newly created Ecuadorian government to take possession of the islands, and on February 12th, 1832, the Galápagos Islands were formally annexed as part of Ecuador (Latorre 2001). Colonies were established on the islands of Floreana and San Cristóbal, but both settlements initially failed within two decades. However, successive waves of colonization by Ecuadorians, Norwegians and Germans eventually gave rise to the population centers of today, based mostly on the islands of San Cristóbal and Santa Cruz, or at smaller settlements on Floreana and in the southern part of Isabela (Lundh 2002). The islands were formally declared a province of Ecuador in 1973, whose capital is Puerto Baquerizo Moreno, on San Cristóbal Island (although Puerto Ayora on Santa Cruz hosts a larger population) (Luna Tobar 1997).

According to article 4 of the new Special Law for Galápagos (Gobierno del Ecuador 2015), the province of Galápagos must be administered by the Governing Council of the Special Regime of the Province of Galápagos (CGREG). The CGREG is responsible for *"planning, managing resources, organizing activities carried out in the territory of the province of Galápagos and inter-institutional coordination with State institutions, within the scope of its powers".* The CGREG is made up of representatives of the Ecuadorian presidency, the ministers of the Environment, Tourism, and Coordinator of Strategic Sectors, the National Secretariat of Planning and Development (SENPLADES), and the municipal governments and parish boards of Santa Cruz, San Cristóbal, and Isabela. Indeed, the public sector is a key employment sector and expenditure per capita is thought to be the highest of all of Ecuador's provinces (Epler 2007).

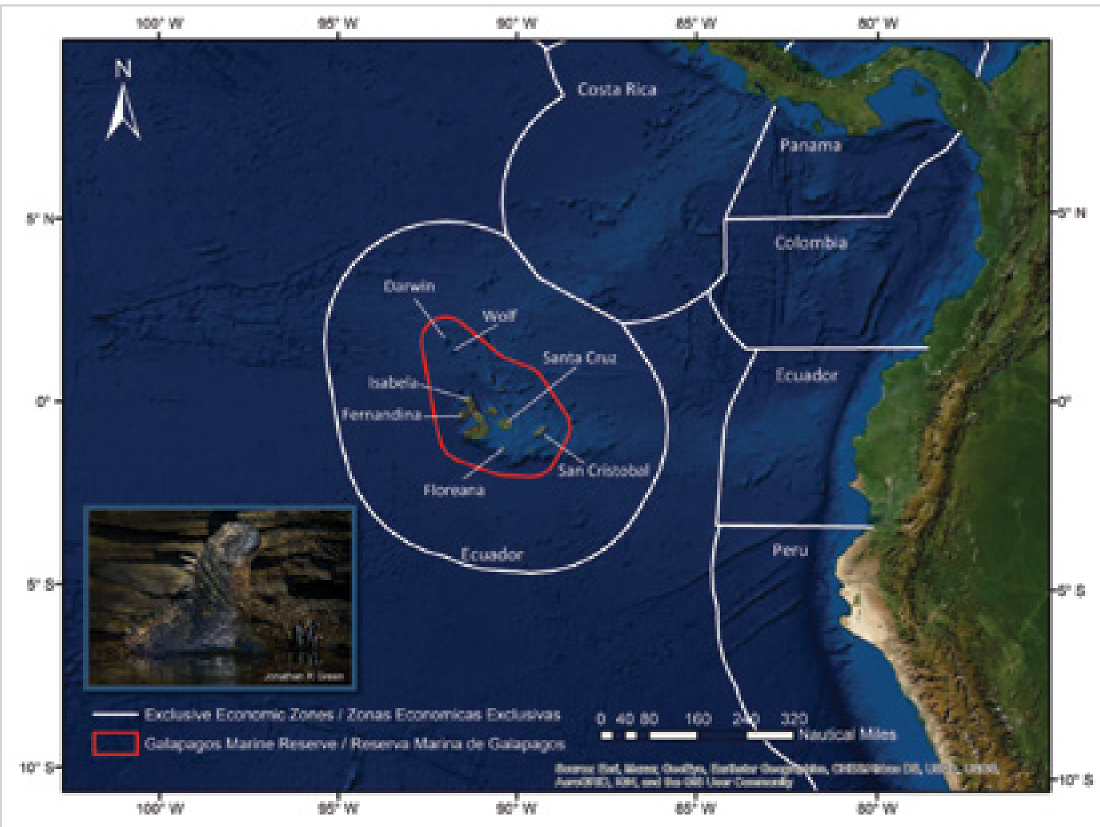

Figure 1. The Galápagos Islands, showing major islands and neighboring Exclusive Economic Zones in the Eastern Tropical Pacific Ocean.

As recently as the 1970s, only 4,000 people lived on the islands. Due to a combination of factors including a boom in tourism, new fishing opportunities, and economic hardship on mainland Ecuador, the population began to rise rapidly around the mid 1980s, reaching an average annual growth rate of 6.4% in the 1990s (INEC 2015). The latest official census, carried out in 2015, placed the population size at 25,244 residents, an annual growth rate of 1.8% since the previous census in 2010 (INEC 2015). The population of the islands is young, with an average age of 29.3 years, a high percentage of under 14s (27.7%) and only 4.1% are over 65 (Figure 2). According to the most recent census in 2015, only 36.1% of residents were born in the province (INEC 2015).

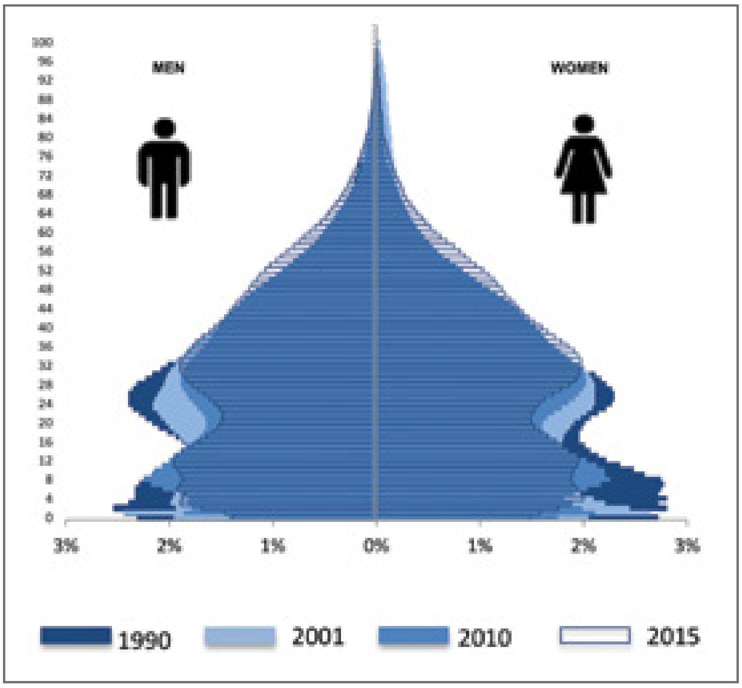

Figure 2. Population pyramids for the Galápagos Islands in different census periods. Reproduced from INEC (2015).

Tourism is by far the most important economic activity (Epler 2007), and has grown at a rate of 6% annually over the 10-year period from 2009-2018. This is largely due to the increase in land-based tourism as opposed to live-aboard cruises, which have remained steady, generally remaining between 70–80,000 annually between 2007 and 2015, and whose growth is limited by caps on the number of berths available (Figure 3) (Observatorio de Turismo de Galápagos 2019). Up until the 1970s, Galápagos remained a highly exclusive tourism destination with less than 5,000 visitors per year. Following Ecuador's oil boom in the 1970s, the islands received government funding to develop their infrastructure and visitors almost tripled within one decade. A carrying capacity of 12,000 was calculated in 1980, only to be exceeded and adjusted upwards in the years to follow. While the large majority of tourists in the 1970s and 1980s came on live-aboard cruises, land-based tourism increased significantly in the early 1990s. In the 1990s, the Galápagos provided "one of the few bright spots in the beleaguered national economy, as its economy was buoyed by tourists' dollars and there was a demand for labor" (Epler 2007). As the resident population grew and some early investments were made, land-based tourist infrastructure flourished, visitor numbers surged and the profile of tourists pivoted from luxurious cruises to low and medium-budget island-hopping. Today, Galápagos is home to approximately 30,000 permanent residents and welcomed almost 280,000 visitors in 2018, prior to the COVID-19 pandemic, of which approximately one third were Ecuadorian (Observatorio de Turismo de Galápagos 2019).

Tourism in the islands supports a broad range of economic activities directly and indirectly. At least 77% of the Galápagos economy depends on tourism (Epler 2007), considering that this economic activity ensures employment and income of many residents in tourism-related sectors (accommodation, food, cruise-operations, etc.) as well as in associated sectors providing services and goods to tourism. This income generated by tourism depends heavily on the ecosystem services provided by the marine and terrestrial biodiversity of the islands. Healthy productive ecosystems are the key to maintaining the flow of benefits to local economies. Prior to the COVID-19 pandemic, there was a growing concern in Galápagos about whether tourism growth was starting to threaten the islands' natural capital (González et al. 2008, García Ferrari et al. 2021). Some studies have shown also that tourists are concerned about their impact on the unique ecosystems of Galápagos, and when asked to choose options of tourism growth, displayed a preference towards more sustainable and lower-impact scenarios (Schep et al. 2014; Viteri Mejía and Brandt 2015).

The islands support a local artisanal fishing sector comprised of 1117 permit holders (DPNG 2021). The sector grew rapidly in the 1990s with the advent of the sea cucumber fishery (Toral-Granda 2001), which collapsed by 2010 and has not recovered (Wolff et al. 2012, Ramírez et al. 2020). It is thought that only a third of the fishers are active, focused on the seasonal coastal lobster resources and on demersal (e.g. the sailfin grouper *Mycteroperca olfax*) and pelagic fin-fish species (e.g. yellowfin tuna *Thunnus albacares*) (DPNG Fisheries Database, accessed in June 2020). Some fishers have switched to other activities such as tourism or *"pesca vivencial"* – a form of artisanal sports fishing which has morphed to become a form of tourism involving snorkeling and beach visits (Schuhbauer and Koch 2013).

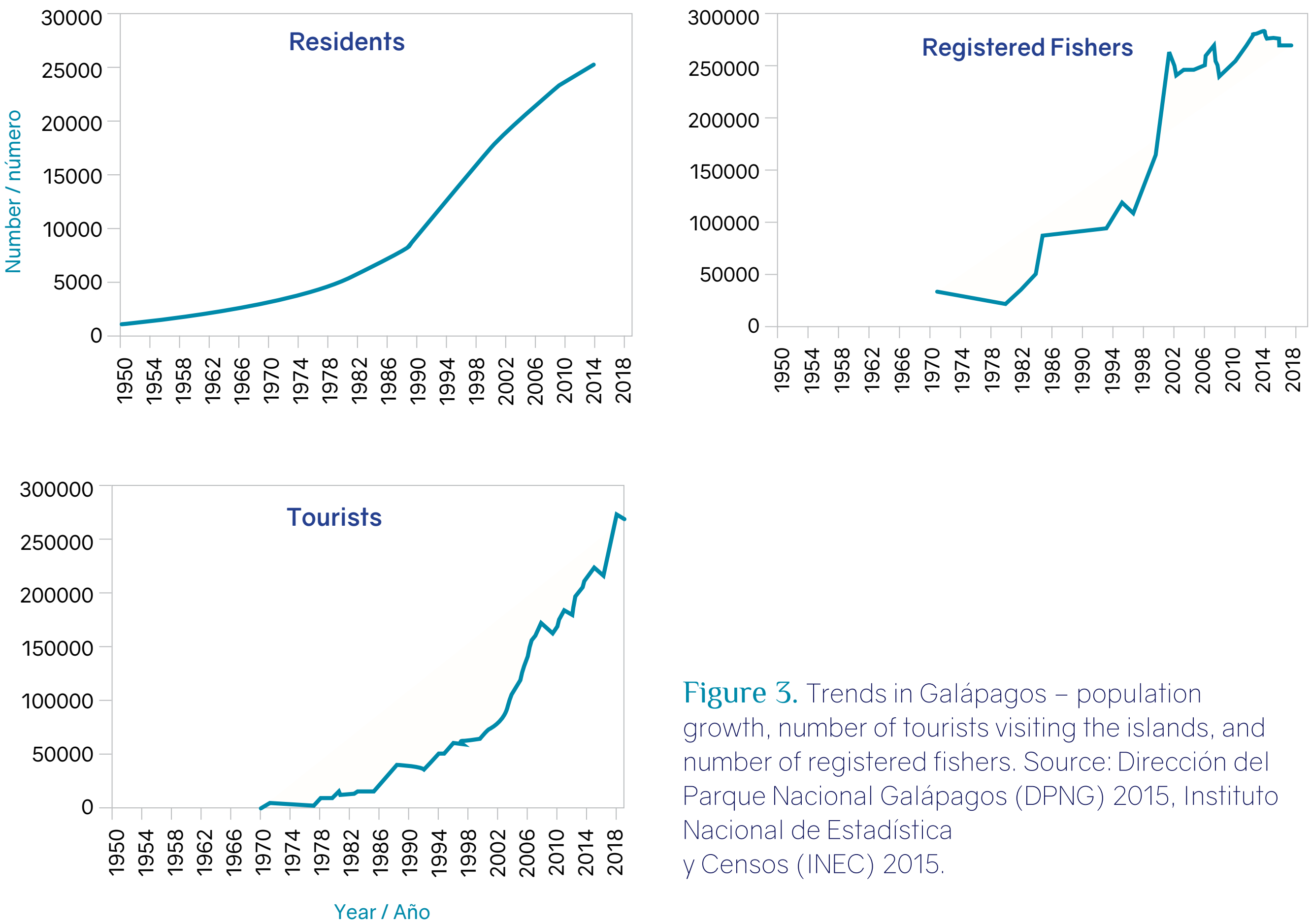

Figure 3. Trends in Galápagos – population growth, number of tourists visiting the islands, and number of registered fishers. Source: Dirección del Parque Nacional Galápagos (DPNG) 2015, Instituto Nacional de Estadística y Censos (INEC) 2015.

There is also a large community of non-governmental and scientific organizations (NGO) present in the islands. The Charles Darwin Foundation, established in 1959, inaugurated its research station on Santa Cruz in 1965, and for many years was the only NGO with a physical presence at the islands. Since the creation of the marine reserve, the number of NGOs carrying out activities related to marine conservation has grown to include Galápagos Conservancy, World Wide Fund for Nature (WWF), WildAid, Island Conservation, Conservation International and other international, national, and local organizations. From an academic perspective, Universidad San Francisco de Quito (USFQ) has a campus on San Cristóbal, and offers subsidized degrees to local students, as well as study abroad programs, which include placing on average 100 students annually in local families for the duration of their stay (USFQ International Programs, pers. Comm.). The Galápagos Science Center, run in partnership with University of North Carolina Chapel Hill, was established in 2011 and hosts a growing number of researchers from across the globe. The importance of Galápagos as a natural laboratory is reflected by the size of this sector.

Biophysical setting of Galápagos

Geology

The Galápagos Islands lie approximately 1,000 km to the west of mainland Ecuador, positioned directly on the equator. The archipelago is made up of fifteen major islands and over 100 islets and emergent rocks, covering a total land area of 7,882 km^2 (Snell et al. 1996). The islands were formed and continue to grow and evolve due to the volcanic activity influenced by the Galápagos hotspot. Generation of magma occurs in the subsurface here due to an anomalously warm region of the mantle at the top of an ascending mantle plume. This molten rock is generated beneath the Galápagos platform (Kurz and Geist 1999), occasionally rising to the surface to erupt at the volcanoes of the Galápagos Islands.

The initiation of volcanic activity above this hotspot occurred from around 95 to 72 million years ago (Ma) (Hoernle et al. 2002). This initial hotspot activity produced excessive volcanism during this time, creating a large plateau on the seafloor, which has since migrated through plate tectonics to the present Caribbean Sea (Thompson et al. 2004). Approximately 22 Ma, the large Farallon Plate broke into the two smaller Cocos and Nazca plates during a major restructuring along the western edge of the Americas (Kelley et al. 2019). Both these plates are moving eastwards, away from the East Pacific Rise, and their divergent boundary is referred to as the Galápagos Spreading Center (Figure 4). These plates eventually subduct into the mantle and are destroyed to the west beneath South America in the case of the Nazca Plate and to the northwest beneath Central America in the case of the Cocos Plate. As spreading continues at the Galápagos Spreading Center, new oceanic crust is formed and thus the Cocos Ridge and the Carnegie Ridge migrate northeastward and eastward respectively while separating from one another. From 20 to 7.5 million years ago, the Galápagos hotspot was centered under the Galápagos Spreading Center (Kelley et al. 2019).

The center of volcanic activity above the Galápagos hotspot is presently beneath the western end of the Galápagos Platform and the western-most of the Galápagos Islands. Volcanic activity creates a thickened area of the oceanic crust, as magma intrudes or erupts on the plate surface. As this moves away from the hotspot, it creates an elongated ridge, which in some cases builds up sufficiently to form seamounts or islands (Kelley et al. 2019).

The Carnegie Ridge consists of thick crust that has continuously been created and migrated over the past 20 million years (Meschede and Barckhausen 2000). Due to the warm rock in the mantle, a buoyant force is generated beneath the western end of the Carnegie Ridge, along the Galápagos platform, which elevates this portion of the plate. As the islands move eastward away from the hotspot, they cool and subside, and become more eroded as they age, until they eventually sink below sea level (Geist et al. 2014; Geist 1996, Kelley et al. 2019).

The chain of volcanic seamounts and islands on the Cocos Plate resulting from the Galápagos hotspot collectively comprise the Cocos Ridge (Kelley et al. 2019) (Figure 4). However, from around 7.5 million years ago until the present, the hotspot has migrated to its present location under the Nazca plate (Barckhausen et al. 2001; Sallarès and Charvis 2003), resulting in the continued building of the Carnegie Ridge. During this time, over the past 7.5 Ma, the hotspot has ceased adding material to the Cocos Ridge. The Cocos Ridge continues to migrate northeastward away from the Galápagos Spreading Center as the new edge of the Cocos plate continues to be created.

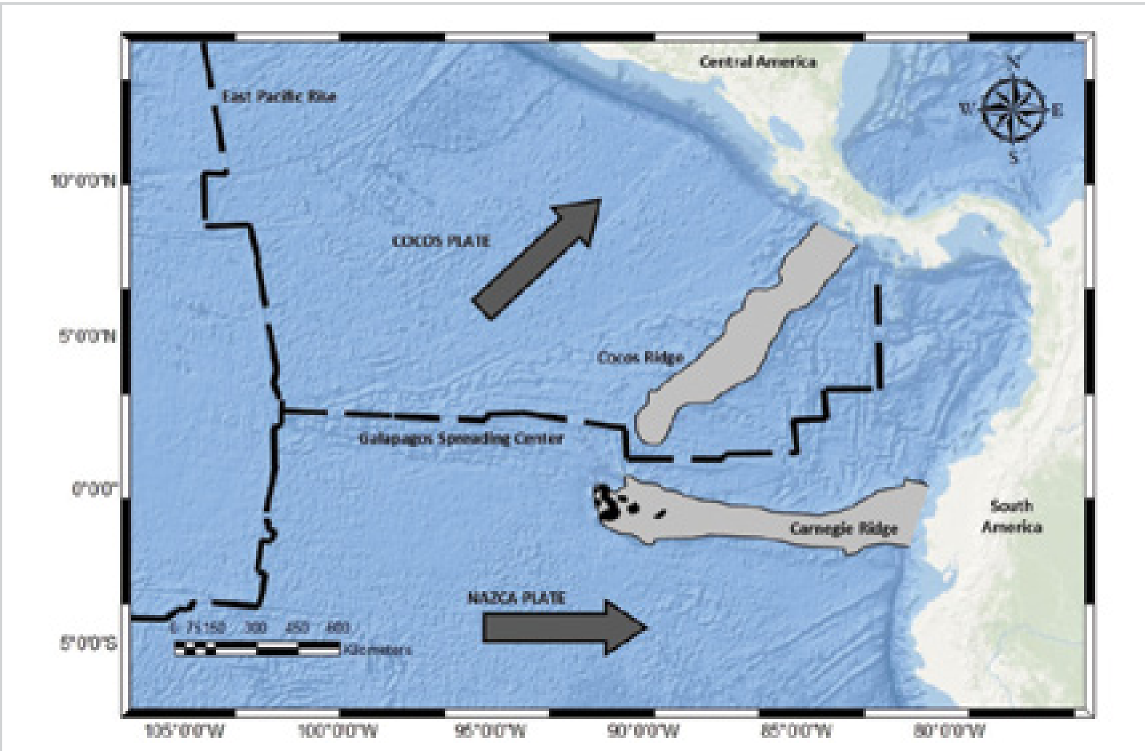

Figure 4. Map showing Nazca Plate and Cocos Plate directions of tectonic movement. The Carnegie Ridge and the Cocos Ridge are shown in grey. The Galápagos Spreading Center and the East Pacific rise are mid-ocean ridges. Source: Kelley et al. (2019).

The plate tectonic history of this region over the past 22 million years has consisted of a spreading center and a hotspot both providing a "bulge" on the seafloor as well as submarine seamounts and thickened crust. Therefore, this entire region, including the Galápagos Platform, the Galápagos Spreading Center, and the Carnegie and Cocos ridges are all areas of shallow sea relative to the wider Pacific Ocean.

Oceanography and climate

Galápagos lies at the southern boundary of the Eastern Tropical Pacific (ETP), a biogeographic realm whose oceanography is highly dynamic both spatially and temporally (Spalding et al. 2007, Peñaherrera-Palma et al. 2018a). The ETP extends from Mexico and the Revillagigedo Islands southwards, to northern Peru in the south, and as far west as approximately 110°W (Figure 5). From an oceanographic perspective, it is bordered to the north and south by subtropical gyres, and by the American landmass to the east, which is the dominant factor in structuring much of its oceanography (Fiedler and Talley 2006, Kessler 2006).

The central part of the ETP is characterized by warm waters with annual average temperatures above 28°C and salinity below 34 g kg^{-1} (Amador et al. 2016; Fiedler and Talley 2006). This warm pool, as it is generally known, extends from the Central American coast to the southwest Pacific Ocean by way of the North Equatorial Current (NEC), which flows parallel to the eastward-flowing North Equatorial Counter Current (NECC) (Kessler 2006). Temperature in this area can be significantly decreased, and productivity be increased, by localized upwelling that occurs off the coasts of Panamá, Costa Rica and Nicaragua (also known as the Costa Rica Thermal Dome) (Fiedler and Lavín 2017). Here, trade winds blowing southwest through gaps in the Central American cordillera push the warm waters, allowing nutrient-rich deep waters to surface. These thermocline domes are short-lived events with a strong seasonal component and a variable spatial extent, but with a positive impact on the regional biodiversity and fisheries productivity. The Costa Rica Thermal Dome features a unique mixture of cyclonic surface waters forced by coastal wind jets that generate enhanced phytoplankton productivity and zooplankton biomass in relation to the surrounding warmer waters (Fiedler 2002a).

To the south, the Humboldt (or Peru) Current limits the tropical range of the ETP with cooler waters that come from the Antarctic and upwelling caused by meridional winds off the coasts of Peru and Chile (Figure 5) (Fiedler and Lavín 2017). The main surface current affecting the Galápagos Islands is the South Equatorial Current (SEC), a broad, westward-flowing current with two branches lying between 5°N and as far south as 20°S, depending on the time of year. This current originates from cool waters from the south by the Peru-Humboldt

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system, by advection and mixing of warmer waters from the north by the NECC and Panama Current, and by equatorial upwelling. Extending from the coast of South America into the central Pacific, the equatorial cold tongue is one of the most prominent structures in the global marine environment (Figure 6) (Fiedler and Lavín 2017). The cold tongue is best developed from August to October, when southeast trade winds are strongest during the southern winter (Wyrtki 1981). Surface water temperatures in the cold tongue are driven by seasonal advection of cool water from the Humboldt Current, and by diapycnal upwelling from the eastward-flowing Equatorial Undercurrent (EUC) (Wyrtki 1966, 1981).

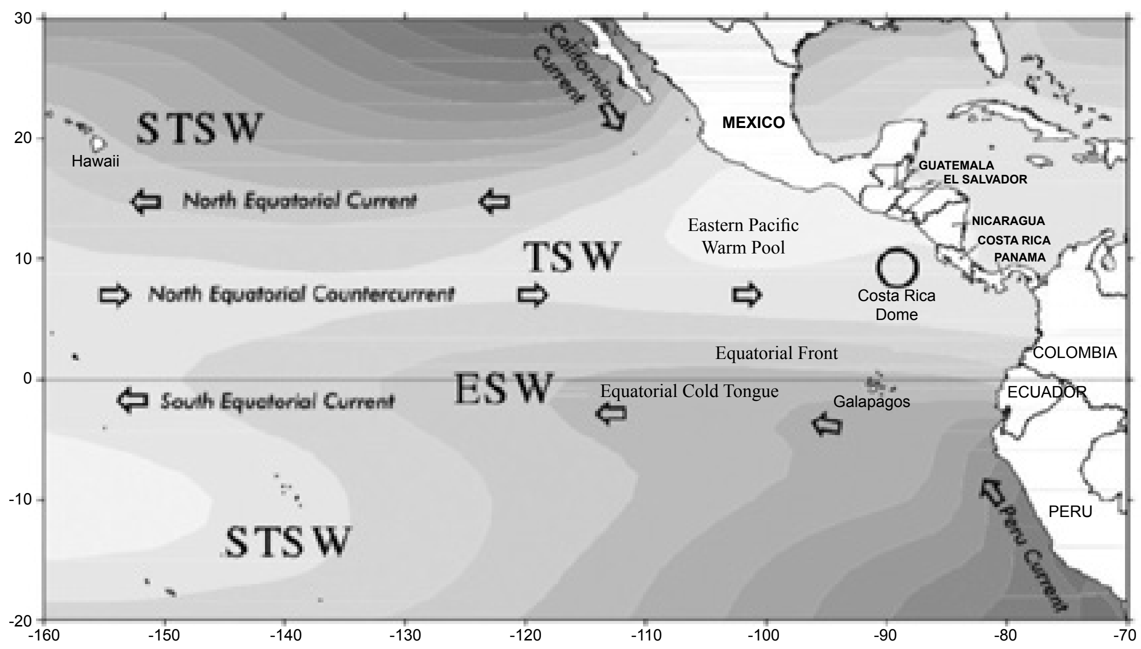

Figure 5. Schematic diagram of surface water masses and currents in the Eastern Tropical Pacific. STSW, Subtropical Surface Water; TDW, Tropical Surface Water; ESW, Equatorial Surface Water. Shading represents mean sea surface temperature (darker = colder). Source: Fiedler and Talley (2006). Note that the Peru Current is the same as the Humboldt Current.

The boundary between the cold tongue and the NECC forms the Equatorial Front (Fiedler and Talley 2006), which is noted for its abundance of planktivorous seabirds and whale sharks (Ballance et al. 2006; Ryan et al. 2017; Spear et al. 2001). Tropical instability waves propagate along the front, generated by the shears between the eastward EUC and NECC and the westward SEC (Figure 6a). Long-term averaging reveals the structure and magnitude of climatological conditions in the region (Figure 6b,c). The area immediately to the west of the Galápagos Islands exhibits the strongest open-ocean mean anomalies in the equatorial Pacific (Fig 6b,c), and can host the coldest open-ocean waters along the equator globally (Fig 6a) (Ryan et al. 2017).

The EUC, also known as the Cromwell Current, is one of the "strongest and most coherent currents in the world, with estimated peak climatological zonal velocity (zonal volume transport) exceeding 130 cm s^{-1}" (Karnauskas et al. 2010). It is centered on the equator as far as slightly west of Isabela Island, where its deviates southward by the physical blocking action of the Galápagos platform lying directly in its path. The EUC shoals as it flows eastwards, with the 20°C isotherm rising from a depth of around 160 m in the western Pacific, to around 80 m at the Galápagos platform (Figure 7) (Johnson et al. 2001). The strong shallow thermocline is thought to be one of the reasons for the rich seabird and fish communities in the region (Ballance et al. 2006), which also supports globally important tuna fisheries, in particular for yellowfin, bigeye and skipjack (Bucaram et al. 2018). CTD profiles taken during research cruises inside Galapagos showed a thermocline depth of 16 m in March 2005, 23 m in November 2005 and 44 m in June 2006 (Sweet et al. 2007).

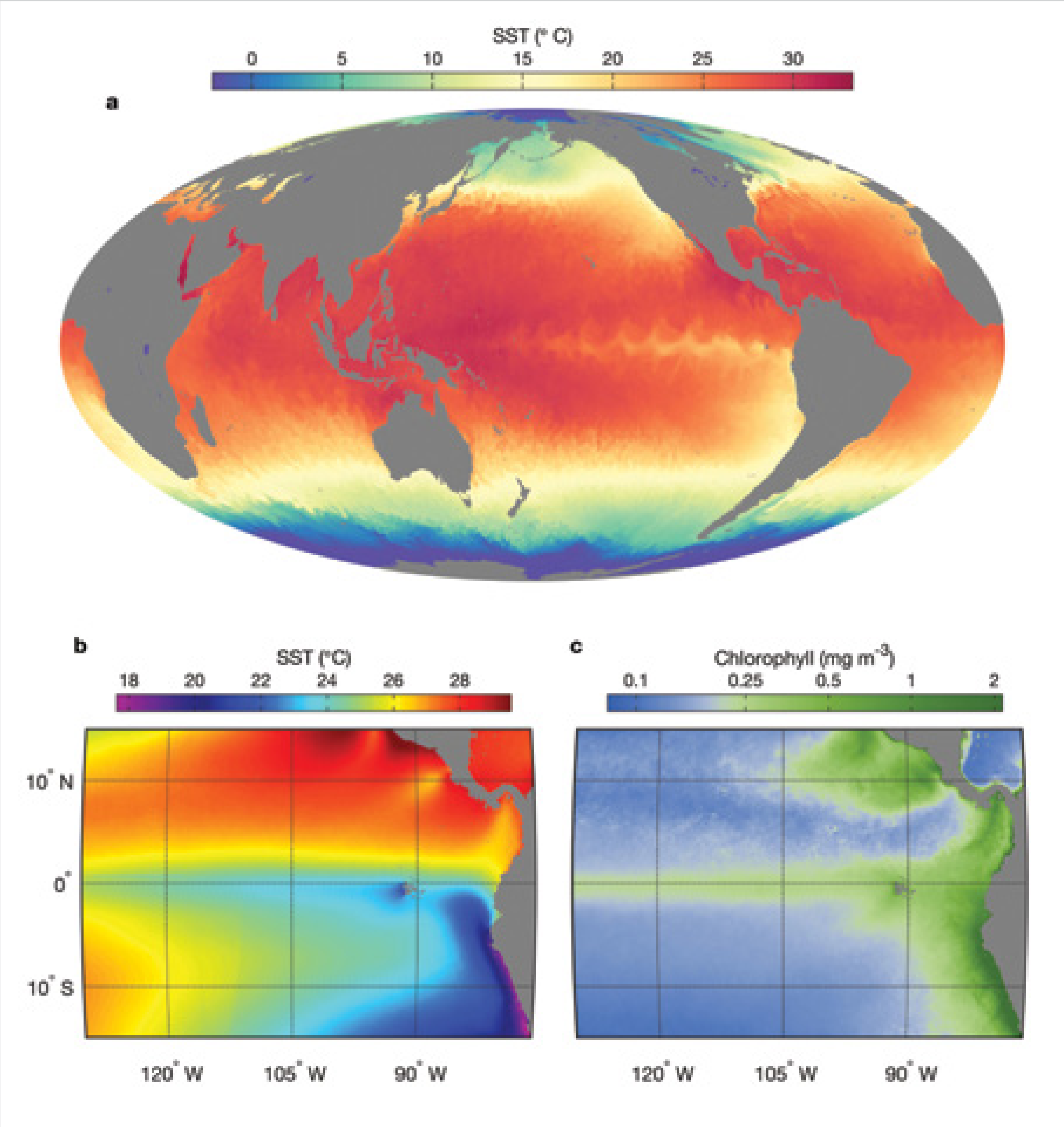

Figure 6. **a.** Synoptic sea surface temperature (SST) represent the dynamic nature of the equatorial Pacific upwelling system (NOAA 5-day analysis centered on October 15, 2016), **b.** Long term mean SST and, **c.** surface chlorophyll-a concentrations derived from satellite remote sensing data. Modified from Ryan et al. (2017).

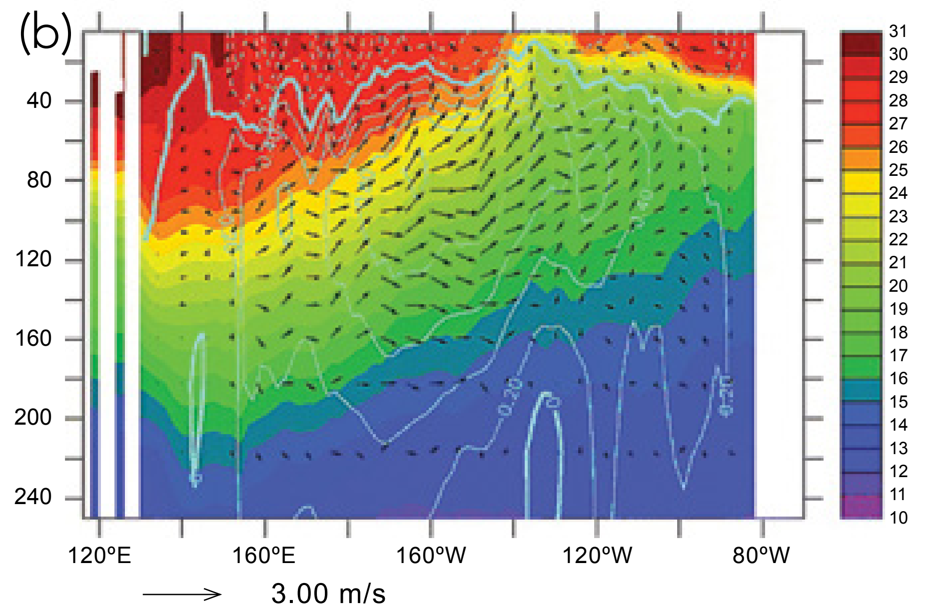

Figure 7. Thermocline depth cross section along the equator over the first 250 m. Colors represent the temperature in °C, arrows the zonal and vertical currents and contours the zonal currents. The arrows have been rotated to compensate the difference in scaling between longitude and depth in the figure, while their magnitudes have been preserved (the arrow of reference corresponds to 3 m s-1. Modified from: Izumo et al. (2002).

The EUC bifurcates into a deeper northern core and a shallower southern core, which impacts the western margin of the islands (Jakoboski et al. 2020). The northern core flows to the north of Isabela, and weakens considerably, while the southern core may upwell off the west coast of Isabela and retroflect westward with the surface current (Karnauskas et al. 2010). Local wind forcing exerts an important control on the intensity of the resulting upwelling along the western margins of the islands (Forryan et al. 2021), extending the Galápagos cold pool 300-500 km westwards from Isabela. Upwelling and iron enrichment from the islands themselves drive the presence of a plume of elevated productivity, extending over 120 km westward of the islands, as evidenced by high levels of chlorophyll-a (Palacios 2002). East of the Galápagos platform, the EUC eastward volume transport decreases by 62% (Karnauskas et al. 2007). Although the EUC may supply some of the coastal upwelling occurring off South America (Lukas 1986), in general it weakens upon impinging on the Galápagos Islands, with the gradual upwelling of successively denser layers exhausting the EUC before it reaches the Pacific ocean's eastern boundary (Pedlosky 1988). Seasonally, the EUC tends to be weaker from October through February, and strongest from March through July (Karnauskas et al. 2010).

The complex nature of the currents surrounding the islands and their effect on the composition and distribution of reef fish and macro-invertebrate communities, provide a natural division of the waters inside the Galápagos Marine Reserve into five biogeographic regions (Figure 8): i) a warm far-northern bioregion around the remote islands of Darwin and Wolf, ii) a warm northern region, iii) a mixed central-southeastern region, iv) a cool western region, and v) a cold bioregion around the western coast of Isabela, where the highest degree of endemism is found (Edgar et al. 2004). According to Spalding et al. (2007), these five bioregions, along with Ecuador's Insular Exclusive Economic

Zone (hereafter referred to as the Galápagos EEZ for simplicity) surrounding the Galápagos, can be grouped into three main zones: north, west and east (Figure 8). The north-south migration of the Inter-Tropical Convergence Zone (ITCZ) drives seasonal variability in oceanic conditions around the Galápagos Islands (Palacios 2004). Sea surface temperatures vary by around 5°C between the islands, and by up to 7°C throughout the year (Figure 9).

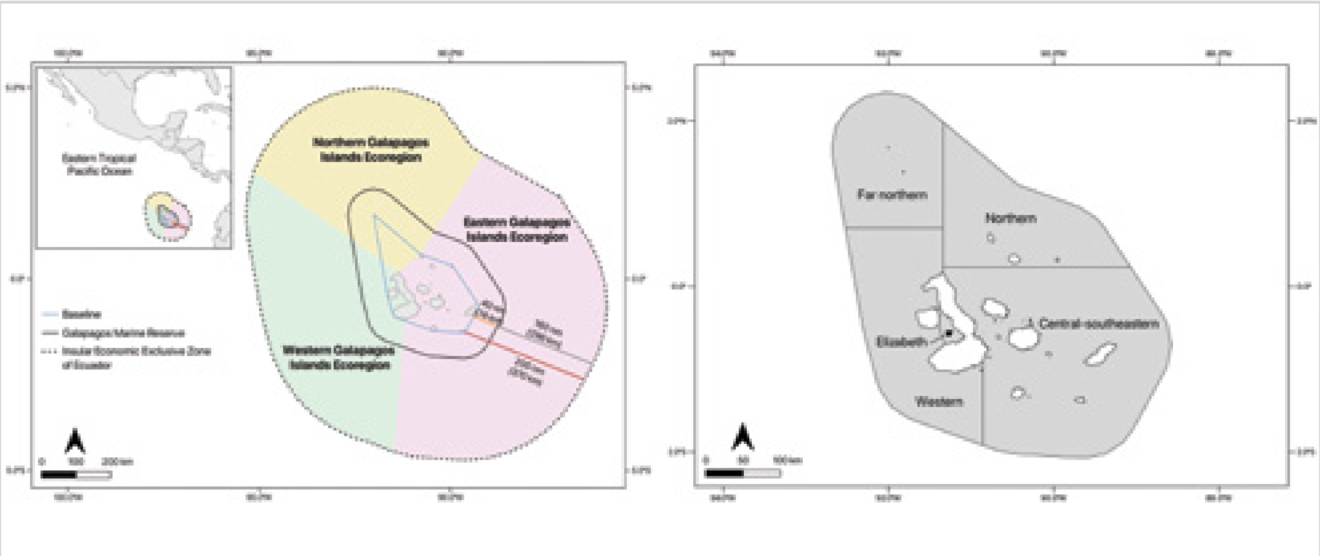

Figure 8. Regional biogeography of the Galápagos Marine Reserve (GMR) and its surrounding Exclusive Economic Zone (EEZ) based on the divisions described by Spalding et al. (2007) (*left*), internal bioregions described by Edgar et al. (2004) (*right*).

Interannual variability around the Galápagos Islands is mainly driven by the El Niño Southern Oscillation (ENSO) (Fiedler and Lavín 2017). During El Niño conditions, the atmospheric pressure gradient from east to west across the Pacific is weakened, which in turn reduces upwelling and leads to pooling of warm surface waters in the Eastern Tropical Pacific (ETP). El Niño irregularly occurs every two to seven years, by way of wind anomalies over the western and central Pacific flattening the equatorial thermocline across the basin (Fiedler 2002b), and typically lasts 6-12 months (Bertrand et al. 2020). These conditions can also alternate with cool La Niña phases of Pacific upper-ocean water masses, which occur when the atmospheric pressure gradient is strengthened. El Niño events generally peak during winter and recede in the following spring. During La Niña, conditions are reversed, and negative SST anomalies prevail in the ETP (Figure 10).

El Niño impacts marine processes globally. Its effects include a marked reduction in primary productivity in upwelling zones (Taylor et al. 2008), a reduction in the health and marine species richness (Barber and Chavez 1983), the displacement of migratory species (e.g. olive ridley and East Pacific black sea turtles) toward favorable habitat and food (Plotkin 2010, Quiñones et al. 2010), as well as the reduction in ocean productivity and certain fishing yields (Adams and Flores 2016). The strong El Niño events of 1982-83 and 1997-98 had devastating consequences for many of the endemic species that depend on the marine food web for their survival, including marine iguanas, seabirds and sea lions, along with the coral communities around the island coastlines and on local fishing activity. There is concern that increasing intensity and frequency of these events may exceed the inherent resilience of these islands to recover.

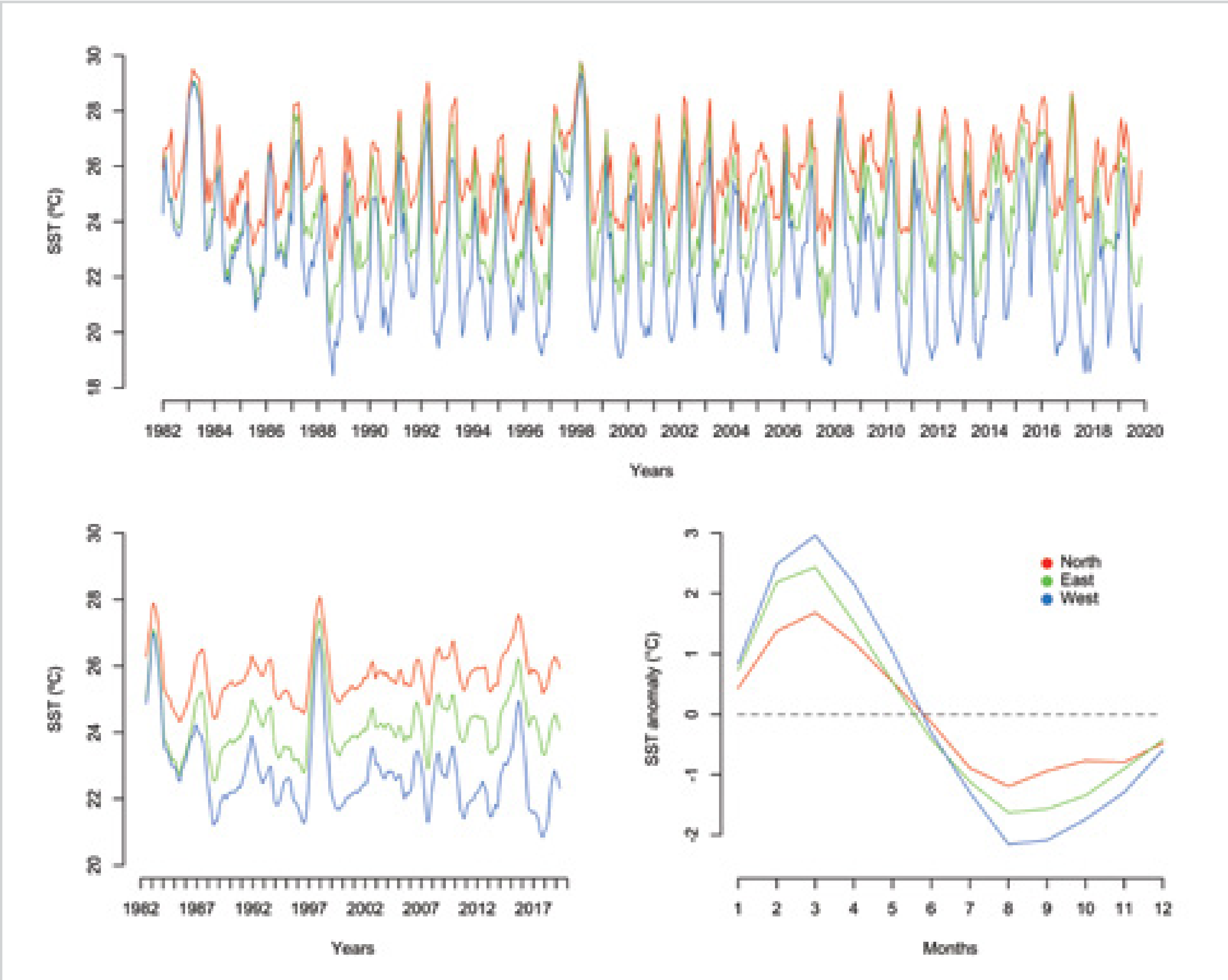

Figure 9. Optimum Interpolated SST (1982-2019) time series raw temperatures (top), trend (bottom left), seasonal SST anomaly (bottom right), based on the average of the same time series for the north, east and west bioregions proposed by Spalding et al. (2007). Seasonal SST data modified from Zevallos Rosado (2020).

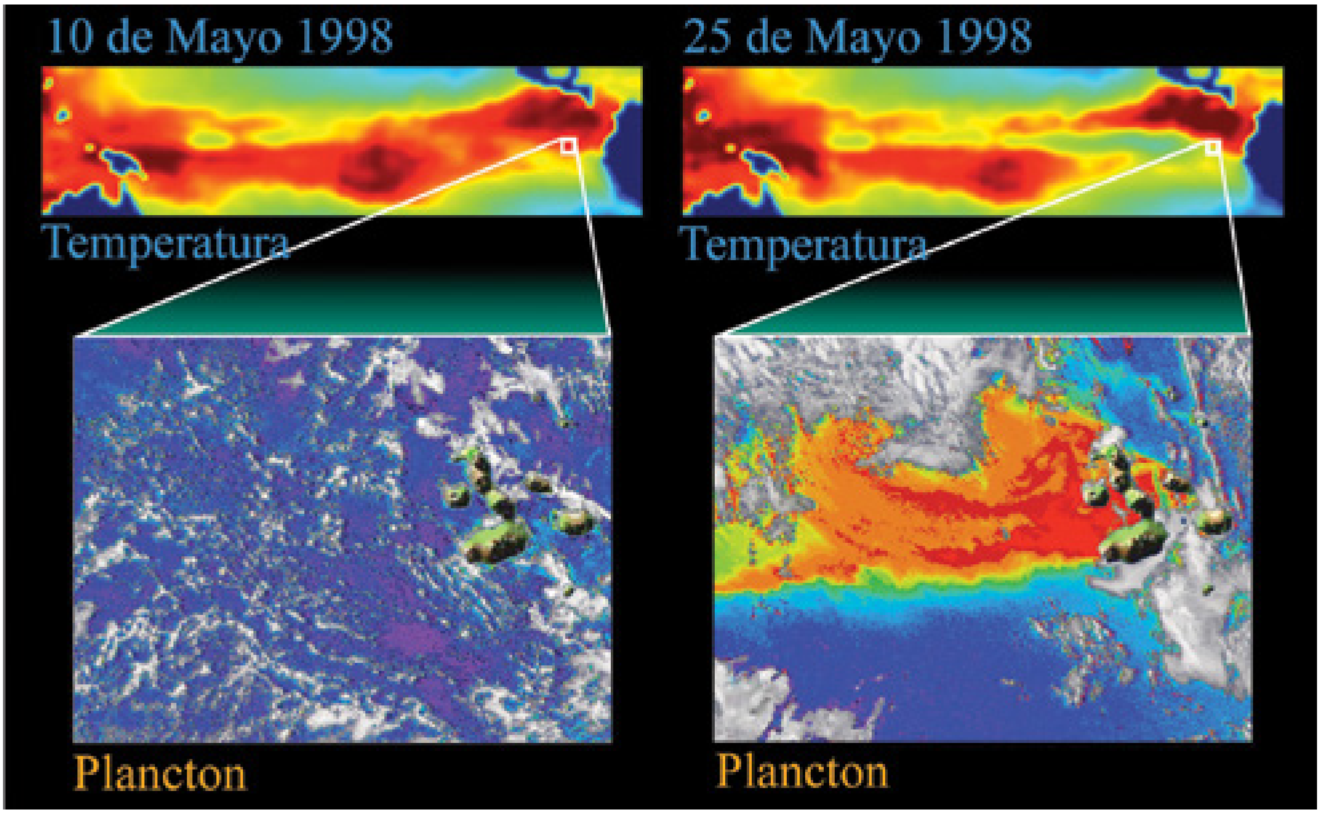

Figure 10. Panel showing rapid and large changes in sea surface temperature experienced in the region due to the steep spatial gradients between upwelling and non-upwelling zones. This is seen during the El Nino event of May 1998 where upwelling reinitiated between 10th and 25th May resulting in a drop in temperature, increased nutrient supply to the surface, and associated phytoplankton bloom. Colors show increasing temperature/ chlorophyll-a, from blue/green to orange/red. Source: NASA-GSFC 2001, reproduced in Banks (2002).

The ENSO cycling occurs against the backdrop of the influence of the Pacific Decadal Oscillation (PDO), which integrates different physical processes (including both remote tropical forcing and local North Pacific atmosphere–ocean interactions) that operate on different time scales and drive SST anomaly patterns (Newman et al. 2016). Studies have shown that the PDO can have a widespread impact on rainfall and water resources (Campozano et al. 2020; Dai 2013), coral and tree growth (Gedalof et al. 2002) and pelagic fisheries (Klyashtorin and Lyubushin 2007). There is no information available to accurately predict the effect of the PDO on the Galápagos marine ecosystems. The range in spatial and temporal variability in Galápagos associated with the combined effects of the PDO and ENSO (including SST and sea level rise) could be as great as the predicted changes under global climate change scenarios over longer time scales Figure 11). This led d'Ozouville et al. (2010) to suggest that the marine reserve ecosystems may have an inbuilt resilience to a certain degree of change.

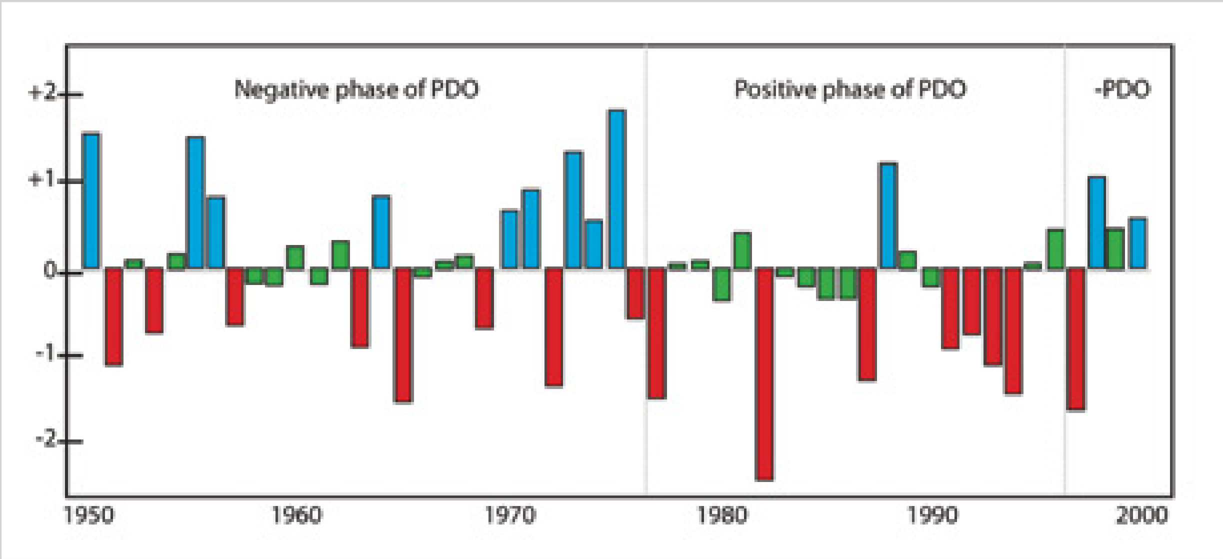

Figure 11. Time series of the Southern Oscillation Index (SOI), overlaid on phase shifts of the Pacific Decadal Oscillation (PDO), with El Niño conditions colored red, and La Niña conditions colored blue. Source: Martinez et al. (2009), reproduced in d'Ozouville et al. (2010).

History of Marine Conservation in Galápagos

Conservation of the marine ecosystem around the Galápagos Islands has been an important topic since the Galápagos National Park was created in 1959 (Figure 12) As early as 1966, Grimwood and Snow proposed the creation of a 1000 m fringe along the shoreline where only small-scale local fishing should occur. In 1974, the Master Plan for the Protection and use of the Galápagos National Park proposed a future marine zone around the shoreline (Reck 2014). These initiatives were largely based on the distribution of land-breeding marine vertebrates (reptiles, birds, mammals). At that time there was little known about the diversity of submarine life, so it was largely ignored during this process.

However, based on those projections, Wellington (1975) carried out an inventory of most coastal intertidal and subtidal habitats down to a depth of 10 m around all the islands. His results showed that there was high species diversity and levels of endemism, and confirmed Abbott's (1966) description that there was biogeographical affinity not only to tropical and subtropical American shores, but also to temperate areas and to western Pacific elements. His studies coincided with others on seabird distribution (Harris 1969, 1973, 1974, 1977) recognizing that there was a distinct regionalization within the archipelago, such that Galápagos was quite unlike other island systems. He proposed extending the National Park out into the marine environment to 2 nautical miles (NM) from the shoreline, which encompassed most of the 200 m depth contour and over 90% of the characteristic biota of the islands, including all known endemic species. He suggested that on-going artisanal fishing activity should be permitted along 96% of the coastline.

However, there was backlash generated by confusion about the rights of local fishers and on the governance of fisheries in this marine area where most local fisheries would be concentrated. Shortly after, fisheries research carried out by the National Fisheries Institute and the Charles Darwin Research Station, showed that artisanal fisheries heavily concentrated on Serranids (groupers), of which several were endemic or at least insular endemic, and that one species, *Epinephelus cifuentesi*, was even new to science (Lavenberg and Grove 1993). Given that these species are particularly vulnerable to overexploitation due to their limited geographic range and movements, around this time, scientists began to consider opportunities for diversification of fisheries, and to look to the open ocean to reduce pressure on coastal resources.

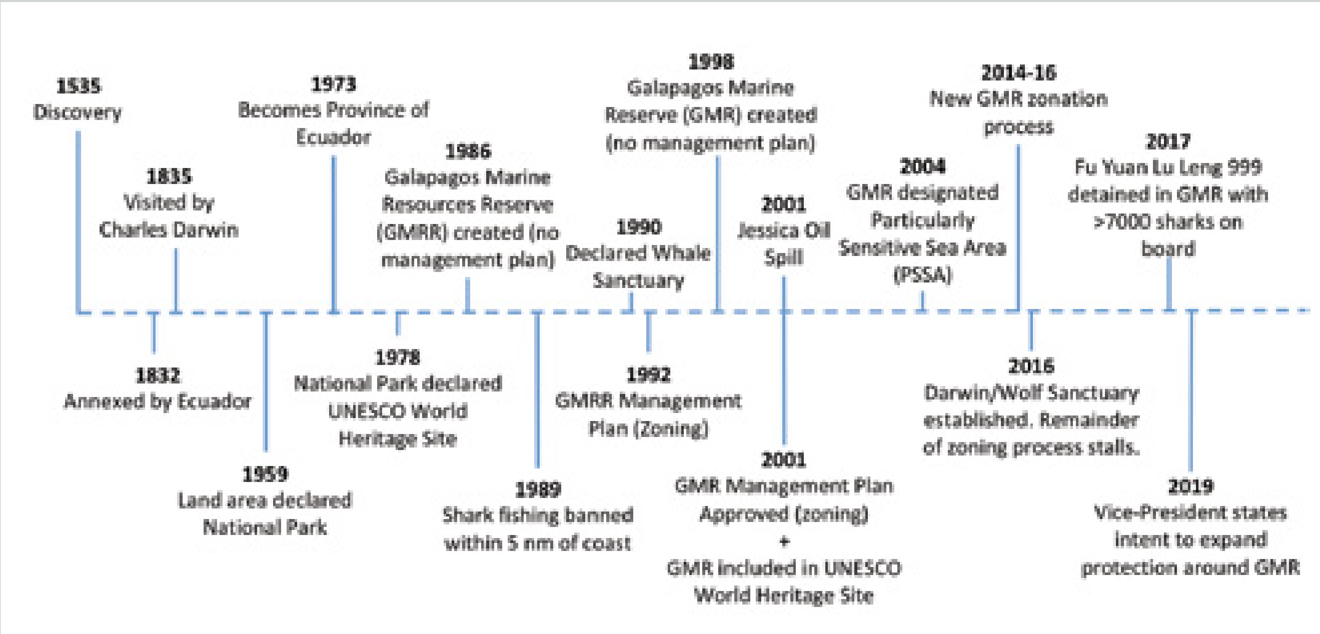

Figure 12. Conservation milestones in the history of the Galápagos Islands and surrounding waters.

In 1986, the Galápagos Marine Resources Reserve with an extension of 15 NM from a baseline (a single polygon drawn around the farthest points of each of the major islands) was created (Gobierno del Ecuador 1986), however a management plan to support it was not concluded until 1992 (Gobierno del Ecuador 1992) and without the participation of the fishing sector (Figure 12). It included a zonation to separate artisanal fisheries from industrial fisheries within the reserve area, and suggested mixed governance between Park, naval and fisheries authorities, which at the time was not feasible, but in the following years permitted several highly participatory workshops on the future of marine conservation. Among the results was a suggestion of local fishermen to extend the reserve area to 40 NM, with the goal of ensuring exclusive fishing rights within this area. Governance of the GMRR was very weak, the category of marine reserve did not exist in the Ecuadorean law, the Protected Area Authority was forestry based, and had no experience in marine conservation, and marine management authorities (Fisheries and Navy) had so far no orientation towards conservation issues further than concern about contamination and profitable resource use.

By the mid 1990s, uncontrolled population growth on the islands and the corresponding increase in risk of invasive species introduction, coupled with intensive pressure on marine resources (both longline industrial fishing for pelagic species, and over-capitalized small-scale fishing for coastal resources such as sea cucumber) formed the backdrop to the creation of the Special Law for Galápagos (also known as LOREG, for its Spanish acronym). A key aspect of the Special Law limited migration to the Islands in an attempt to stabilize the population, which currently stands at around 25,000 (INEC 2015). The timing coincided with a complete revision of the marine management plan by a local stakeholder group called *Grupo Núcleo* (Core Group). This group spearheaded a campaign that led to the creation in 1998 of the Galápagos Marine Reserve (GMR) – a multi-use Marine Protected Area for the exclusive use of local stakeholders: the artisanal fishing sector, the tourism industry (guides and tour operators) and conservation and science users; and managed by a participatory system under the authority of the Galápagos National Park Directorate (GNPD). The inclusion of the local stakeholders' proposal into the law led to broad support among the local population to such a degree, that the fierce opposition of the powerful tuna fishing industry based in Manta was ultimately unsuccessful in its attempts to prevent the law from passing in Parliament. In fact, the strategy of non-cooperation and non-participation by the industrial fishing sector, despite invitations to the table, ultimately backfired, as they were excluded from the entire GMR. The industry went so far as to question Ecuador's sovereignty over its waters, arguing in the Constitutional Court in 2001 to overturn the creation of the GMR, that "... tuna do not belong to Galápagos, they are migratory, and the sustainability of their populations is controlled by the Inter-American Tropical Tuna Commission, IATTC, based in California, and with a global jurisdiction, so that it is not possible to prohibit fishing in our own waters to protect species that even ecologists have been unable to show are in danger of extinction." Needless to say, the fishing sector lost their appeal, and the Court criticized them for "... rather than thinking of public interest, that is, safeguarding Ecuador's heritage, they are looking out for their own sectorial economic gains." (Gobierno del Ecuador 2001). Ironically, two decades later, studies showed that this sector benefited from the spillover effect generated by the reserve (Boerder et al. 2017; Bucaram et al. 2018; Kliffen and Berkes 2015).

The GMR extended 40 NM out from a baseline around the islands, covering an area of approximately 138,000 km^2 (Gobierno del Ecuador 1997). Marine Reserves became a new official category of protected area in the existing legislation, based on Category VI of the IUCN classification (reserves with managed resource use). The GMR management plan had an overall aim to "protect and conserve the coastal and marine ecosystems of the archipelago and its biological diversity for the benefit of humanity, the local population, science and education", and laid out a series of twelve objectives that included (DPNG 1998):

- To protect marine and coastal ecosystems to maintain long term ecological and evolutionary processes
- To complement terrestrial protection with coastal and marine protection for those species and communities that depend on the marine environment
- To protect coastal and marine endemic species
- To ensure the maintenance and/or recovery of fishery resources
- To improve the well-being of Galápagos fishers through fishing activities that are compatible with the biodiversity
- To protect coastal and marine ecosystems as the drivers of economic growth through controlled, low impact tourism

From its inception until 2015, the GMR was managed by a two-tier system (DPNG 1998). A local Participatory Management Board (PMB), made up of representatives from the artisanal fishing sector, naturalist guides guild, tour operators, science and conservation sector and the Galápagos National Park Directorate, would seek to build consensus. The consensus (or lack of it) would be elevated to the Inter-institutional Management Authority (IMA), which would then either ratify a PMB consensus or decide the issue by majority vote. The IMA was made up of four ministries: Environment, Defense, Tourism and Production (Fisheries), by two local stakeholder groups (the artisanal fishing sector and the tour operators) and by a representative of CEDENMA: a national coalition of conservation groups. This collaborative co-management system was modified by the reform made to the LOREG on June 11th 2015, whereby the co-management system was switched from a cooperative to a consultative one. This implied the repeal of the PMB and the creation in its place of the Consultative Board of Participatory Management (CBPM), which is an instance of citizen participation and non-binding advice for the administration and management of GMR. However, at the time of writing this report, the CBPM has not been constituted or put into operation.

While the industrial and mainland Ecuadorian fleets were excluded from the area, this did not signal an end to overexploitation and conflict. The GMR had been divided into temporary user-designated zones around the coasts of the islands (Castrejón and Charles 2013), separating potentially conflictive uses (fishery and tourism), and providing complete protection for a very limited extension of coastline (Figure 13, left), and with a view to generating baseline information (see Danulat and Edgar 2002). A monitoring system was established that would lead to an evaluation and eventually a permanent zoning. During the first decade of the GMR there were several user conflicts around this zoning, overexploitation of coastal resources, particularly related to lobster and sea cucumber quota, the allocation of tourism permits and pressure to allow longlining in the offshore waters within the reserve (Hearn 2008, Jones 2013). Apart from this last issue, the open water component of the reserve received relatively little attention by users, scientists and the media.

In 2014, the GNPD began a stakeholder consultation process to evaluate and modify the GMR zonation. The new zonation took a different approach, recognizing the inherent links between land and sea (Figure 13, right). It included four different types of zone (Ministry of Environment 2015):

- Intangible: mostly pristine sites, where only low impact research and monitoring are permitted (passive management);
- Conservation: sites that may have some introduced species, and where active management, and non-extractive uses are permitted;
- Transition: sites adjacent to human settlements, which may be highly modified, and whose control requires cooperation with other agencies. These areas are open to use by communities, as well as fishing activities;
- Sustainable use zones: areas that have been modified, but ecosystem functioning is retained. Controled human activities such as artisanal fishing are permitted. These areas are permanently managed.

However, although it was approved in 2016, the marine component stalled due to the declaration by the then President of Ecuador of the entire northern section of the GMR as a no-take sanctuary, bypassing the participatory consultation process (Burbano et al. 2020). This generated significant opposition and the sanctuary area is neither recognized by the artisanal fishing sector nor enforced by the authorities (Burbano et al. 2020). In 2021, the Galápagos National Park Directorate were still developing the marine component for the zonation process.

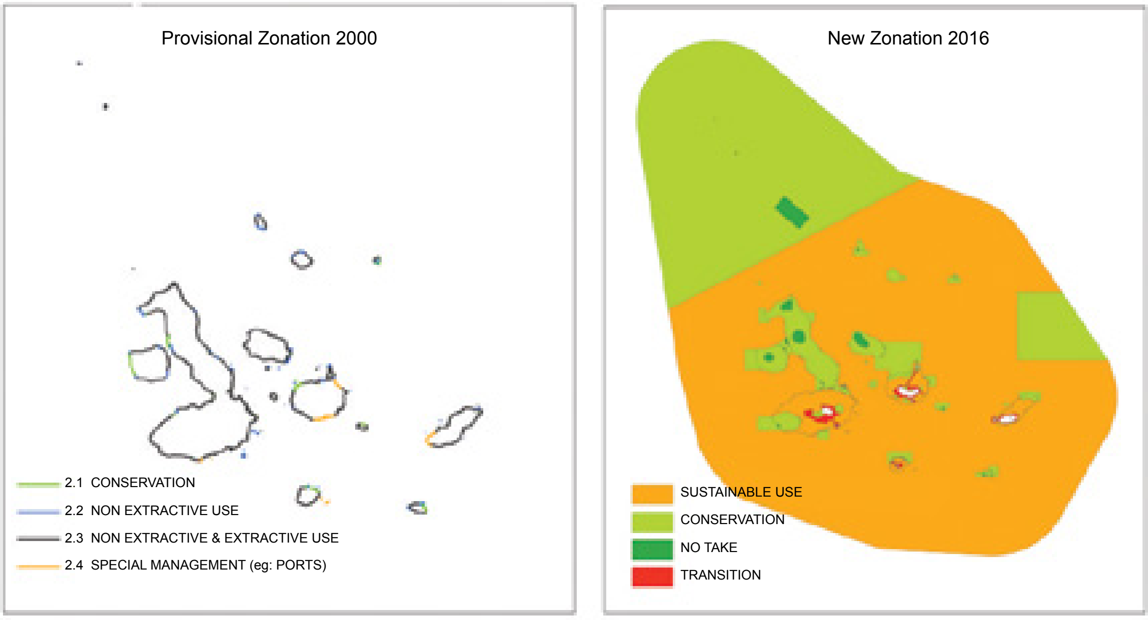

Figure 13. Left: Provisional marine zonation scheme for Galápagos, established in 2000. Note that this scheme is limited to coastal waters (Source: Danulat and Edgar 2002). Right: Zonation scheme proposed in 2016, comprised of terrestrial-marine blocks (not implemented as of 2021) (Source: MAE 2015a).

The most recent Management Plan for the protected areas (now linking both terrestrial and marine systems) in the Galápagos archipelago was adopted in 2014 (DPNG 2014). The Plan takes a more ecosystem-based approach and uses as a basis the well-being of the inhabitants of the islands, through a series of principles that include participation; collaboration; fostering the inter-dependence of marine, terrestrial and human systems; and the sustainable and rational use of natural resources. The vision of the current plan is stated as follows: "The Province of Galápagos achieves the well-being of society by conserving its island and marine ecosystems and its biodiversity, through a territorial model that integrates both protected and inhabited areas" (DPNG 2014). This vision is achieved through the implementation of the following six objectives:

- To manage the conservation of Galápagos biodiversity and ecosystems so that they maintain their capacity to generate services
- To articulate and incorporate conservation policy in territorial planning so as to ensure the sustainable use of resources in the archipelago
- To improve and consolidate the capacity of the Galápagos National Park Directorate to manage the protected areas in an efficient manner
- To actively promote participatory process to foster well-being and an environmentally responsible Galápagos culture
- To increase interdisciplinary scientific knowledge applied to the interactions between the ecosystems and the socio-economic and cultural systems of Galápagos within the context of global change
- To promote national and international cooperation for the conservation of Galápagos biodiversity and ecosystems, following the priorities established by the State of Ecuador through its Territorial and Sustainable Development Plan for the Galápagos Islands.

Control and Surveillance Tools in the Galápagos Marine Reserve

Besides transport and control activities, the following activities are controlled inside the reserve, by means of a strategic collaboration between the Ministries of Defense (Navy), Interior (environmental police force) and of the Environment (GNPD):

- Artisanal Fishing: approximately 300 small-scale vessels
- Tourism: 160 vessels, over 250,000 tourists, 14 kayak operations and 92 visitor sites
- Research activities

The Special Law requires all vessels within the boundaries of the GMR to possess satellite tracking systems. This allows the Galápagos National Park Directorate to track their movements – vessels greater than 20TRB use Vessel Monitoring System (VMS), those smaller use AIS. In 2011, the GNPD installed 9 antennas as part of the AIS detection network, and in 2015, the GNPD donated 400 AIS systems (AIS EM TRAK I100) to the local fishing sector. The control and surveillance center is based at the GNPD headquarters on Santa Cruz. Its objective is to monitor and detect vessels entering the GMR with or without permits, to provide support in case of accidents, to support patrolling operations, and to control the entry of foreign tourism (yachts). Non-compliant vessels tend to be engaged in fishing activity. The control network consists of port systems on Isabela, San Cristóbal and Santa Cruz, and cameras and drones at strategic points, such as landing sites and piers. The GNPD possesses a fleet of coastal and oceanic vessels. The Sierra Negra is one of three ocean-going vessels, and has an autonomy of one month. These vessels operate in addition to a fleet of skiffs and a seaplane, but there are issues of maintenance and costs. A team of trained dogs is employed at checkpoints for sea cucumbers and shark fins. There are fixed checkpoints at airports, on the main road from Puerto Ayora to Baltra (at Santa Rosa) and at the Canal Bolivar hut in the uninhabited western region of the archipelago. Guides are required to submit a weekly report online, which has a section for them to report any irregular activity.

Approximately 35% of the GNPD's budget is devoted to control (P. Buitrón, Galápagos National Park Directorate, pers. comm.). The overall budget however, has declined in recent years, such that for 2019, the budget for control was $1.6 million. Approximate costs for patrolling at sea are $17,000 for a 15-day oceanic patrol, and $1,000 for daily coastal patrols in skiffs. There is a strategic plan for fleet renovation, with vessels expected to have on average a 30-year lifespan. On average there are 1.7 patrols per day within the reserve, and 5 daily inspection operations on land. From 2010-2019, 66 vessels were detected to have entered the marine reserve without authorization. Most of these were long-liners from mainland Ecuador or Guatemala, and most were small skiffs that operate from mother vessels, which remain outside the boundary of the GMR. Some limitations for control include issues with being a public institution and having to comply with public hiring processes for maintenance, which can be long and bureaucratic. Fuel availability is also a limitation; especially since the government introduced austerity measures. The GNPD is seeking the creation of an external fund, which can be used in a more agile fashion.


Micaela Stacey

Regional Conservation Initiatives: Galápagos in the Eastern Tropical Pacific

The prevailing oceanographic conditions and geological structure of the Eastern Tropical Pacific (ETP) create unique habitat systems that permit this region to sustain an elevated species and community richness (Spalding et al. 2007). The high habitat and biological community diversity represent one of the world's most ecologically diverse and functional marine ecosystems (Ramírez-Ortiz et al. 2017; Stuart-Smith et al. 2013). The region's biological richness is not only ecologically important, but generates more than $15 billion annually in ecosystem services (Martin et al. 2016), out of which $2.7 billion comes from the average catch value of the ten most commercially fished species, and $12.9 billion from carbon export to the deep ocean.

A range of spatial conservation initiatives has sought to protect key species and habitats in the region. A recent global study by Gownaris et al. (2019) examined the distribution and level of overlap of 10 UN agency and NGO initiatives globally, and how these were represented within marine protected areas (MPAs). They identified a series of hotspots around the world, where five or more initiatives overlapped. The highest area of overlap was the ocean surrounding the Galápagos Islands. In this section, we summarize and augment the initiatives and examine where the most overlaps occur. However, for our approach, we included MPAs as a category of initiatives, as there is implicit recognition of the conservation value within these areas. We also included a small number of additional initiatives that were not included in the original study.

Marine Protected Areas

Although arguably the most iconic, the Galápagos Marine Reserve (GMR) is by no means the only oceanic MPA in the ETP (Figure 14). The Cocos Island National Park (CINP, Costa Rica), the Malpelo Fauna and Flora Sanctuary (MFFS, Colombia), the Coiba National Park (CNP, Panama) and the Gorgona National Natural Park (GNNP, Colombia) all share similar traits to some extent (Peñaherrera-Palma et al. 2018a). This region has a high similarity in the composition of its benthic communities and also shares similar trophic composition and abundance of apex predators (Soler et al. 2013, White et al. 2015, Acuña-Marrero et al. 2018, Peñaherrera-Palma et al. 2018a).

Large schools of jacks, snappers and hammerhead sharks dominate the region's seascape. Species such as the whale shark, the silky shark and the green sea turtle are also residents of the MPAs of the four nations, but not exclusive of each one. At the moment of its creation in 1998, the Galápagos Marine Reserve was the second largest in the world, after the Great Barrier Reef in Australia (Anderson et al. 2003). However, nearly a quarter of a century later, it now lies 33rd in size (Table 1, World Database on Protected Areas).


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Table 1 Marine Protected Areas ranked by size. Source UNEP-WCMC and IUCN (2020). Sizes are based on the extent of designated protected marine area using the Mollweide projection (Field name: GIS_M_AREA). Note that the reported size of the Galápagos Marine Reserve differs from that used in this study (138,052 km²) due to the use of a different projection.

Rank	Marine Protected Area	Country Code	Year	Total Marine Area (km²)
1	Marae Moana Marine Park	COK	2017	1,968,938
2	Papahanaumokuakea Marine National Monument	USA	2006	1,501,236
3	Natural Park of the Coral Sea	NCL	2014	1,294,950
4	Pacific Remote Islands Marine National Monument	MNP, UMI	2009	1,266,529
5	South Georgia and South Sandwich Islands MPA	SGS	2012	1,065,900
6	Terres Australes et Françaises	FRA	2017	989,612
7	Ross Sea Protected Area (High Seas)	ABNJ	2017	973,705
8	Pitcairn Islands Marine Reserve	PCN	2016	845,599
9	Coral Sea	AUS	2018	688,685
10	Tristan da Cunha	SHN	2020	688,234
11	Chagos (British Indian Ocean Territory)	IOT	2010	642,271
12	Rapa Nui	CHL	2018	569,545
13	Palau National Marine Sanctuary	PLW	2015	503,522
14	Kermadec	NZL	2007	460,087
15	Ascension Island MPA	SHN	2019	448,885
16	Phoenix Islands Protected Area	KIR	2010	408,146
17	Arquipélago de Trindade e Martim Vaz	BRA	2018	402,421
18	Arquipélago De São Pedro e São Paulo	BRA	2018	385,198
19	Great Barrier Reef	AUS	1981	347,768
20	Tuvaijuittuq Marine Protected Area	CAN	2019	316,759
21	Pacífico Mexicano Profundo	MEX	2016	315,793
22	Nazca-Desventuradas	CHL	2016	299,912
23	Mar de Juan Fernandez	CHL	2018	264,922
24	Marianas Trench	MNP	2009	254,638
25	Amirantes to Fortune Bank	SYC	2020	217,373
26	Aldabra Group Marine National Park	SYC	2020	195,288
27	Charlie Gibbs North High Seas MPA (High Seas)	ABNJ	2012	177,412
28	Prince Edward Islands MPA	ZAF	2013	169,732
29	Motu Motiro Hiva Marine Park	CHL	2010	150,119
30	Revillagigedo National Park	MEX	2017	148,628
31	Islas Diego Ramirez y Paso Drake	CHL	2019	143,157
32	Norfolk	NFK	2018	139,254
33	Galápagos Marine Reserve	ECU	1998	138,850

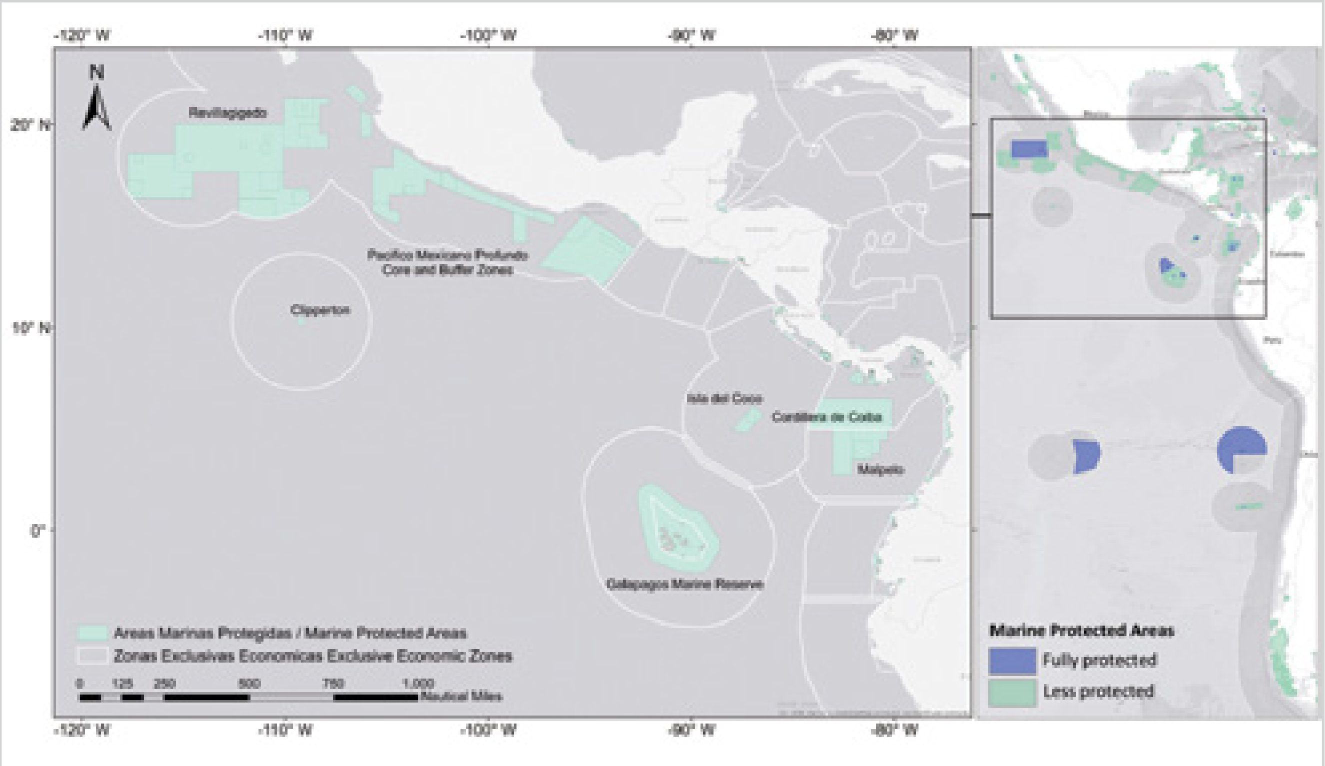


Figure 14. Left: Marine Protected Areas in the ETP. Right: Fully and partially protected MPAs in the Eastern Pacific from Mexico to Chile. Source: www.mpatlas.org.

UN-related or legally binding initiatives

The UNESCO World Heritage Program recognizes the natural and cultural significance of terrestrial and marine sites globally, through their designation as World Heritage Sites (Allan et al. 2017). The Galápagos National Park was declared a Natural World Heritage Site in 1978, and this was extended to the marine reserve in 2001. In 2007, Galápagos was included on the list of World Heritage Sites "In Danger" due to rapid growth in tourism and infrastructure, with the associated risk of invasive species and poor governance structure (Hennessy and McCleary 2011). They were controversially removed from the "In Danger" list in 2010 (UN News 2010). Other UNESCO Natural World Heritage Sites in the region include the Malpelo Fauna and Flora Sanctuary (2006), and Cocos Island National Park (1997). Along the coast of Central America, the Guanacaste Conservation Area in Costa Rica, was declared in 1999, and Coiba National Park, off the coast of Panama, was also inscribed in 2005 (Ehler and Douvere 2011). The most recent inscription in the region was that of the Revillagigedo Archipelago in 2016.

The International Maritime Organization (IMO) recognizes Particularly Sensitive Sea Areas (PSSAs) as areas that "require special protection due to their significance for recognized ecological or socio-economic reasons, and which may be vulnerable to damage by international maritime activities" (UNEP-WCMC 2017). In January 2001, the tanker Jessica ran aground off San Cristóbal, releasing a mixture of diesel and intermediate fuel oil (IFO), which spread across the marine reserve. Fortunately, damage was limited due to the sea state and water temperatures (Edgar et al. 2003). As a result of this incident, and given the vulnerability of the islands and their wildlife, the Galápagos Marine Reserve was declared a PSSA in 2004

(IMO 2020), and the entire reserve was made an "area to avoid" for all ships carrying cargoes of oil or hazardous material and all ships of 500 gross tonnage and above solely in transit.

The Eastern Tropical Pacific Marine Conservation Corridor (CMAR, http://cmarpacifico.org), began in 2001 as a corridor connecting oceanic islands, and was formally adopted by the Declaration of San José in 2004, to encompass the entire EEZs of Ecuador, Colombia, Panama and Costa Rica, highlighting the potential connectivity of marine wildlife (in particular leatherback turtles) between the islands belonging to each (Galápagos, Malpelo and Gorgona, Coiba, and Cocos respectively). In its initial stages it was supported largely by Conservation International, which helped to create and implement the infrastructure and working groups around the major themes of its mission. Its objectives included the conservation of endangered and endemic marine species, improved protection and management of MPAs, and the promotion of integral participation of governments in the dissemination of scientific information for the region (Giraldo et al. 2014). The initiative suffered from lack of funding and governance implementation early on, and lack of involvement from key sectors such as the navy and fisheries authorities. In 2015, the initiative was re-set with a new vision (GITEC and MarViva 2015), which eliminated coastal areas, and appeared to be more conceptual than physical (Figure 15). CMAR has been more visionary than effective, aiding site-based, rather than regional conservation efforts (Bensted-Smith and Kirkman 2010). However, it has provided an important platform for knowledge sharing between working groups across the region (Enright et al. 2021).

An Ecologically or Biologically Significant Area (EBSA), described under the Convention on Biological Diversity (CBD) is "an area of the ocean that has special importance in terms of its ecological or biological characteristics, for example, by providing essential habitats, food sources or breeding grounds for particular species" (Johnson et al. 2018). The description of an area as an EBSA does not imply the imposition of any management measures, rather it describes areas that may be of significant importance to stakeholders, thus contributing to the protection and sustainable use of marine biodiversity (Johnson et al. 2018). Galápagos has links with several EBSAs (https://chm.cbd.int):

- The Galápagos Archipelago and western extension, that recognizes the GMR and the pelagic productivity of the western region in particular, and its importance to marine migratory species.
- The Carnegie Ridge – Equatorial Front, which links the GMR with mainland Ecuador and northern Peru along the Carnegie Ridge, an area of high productivity, and also refers to the migratory pathways of sperm whales, humpback whales and smooth hammerhead sharks.
- The Eastern Tropical Pacific Marine Corridor, which essentially validates the importance of the CMAR initiative described above, in particular with reference to migratory connectivity of scalloped hammerhead sharks and blue-footed boobies, among others.
- The Equatorial High Productivity Zone which, although not extending into the GMR, recognizes the high productivity of the band of ocean comprising the cold tongue and equatorial undercurrent.

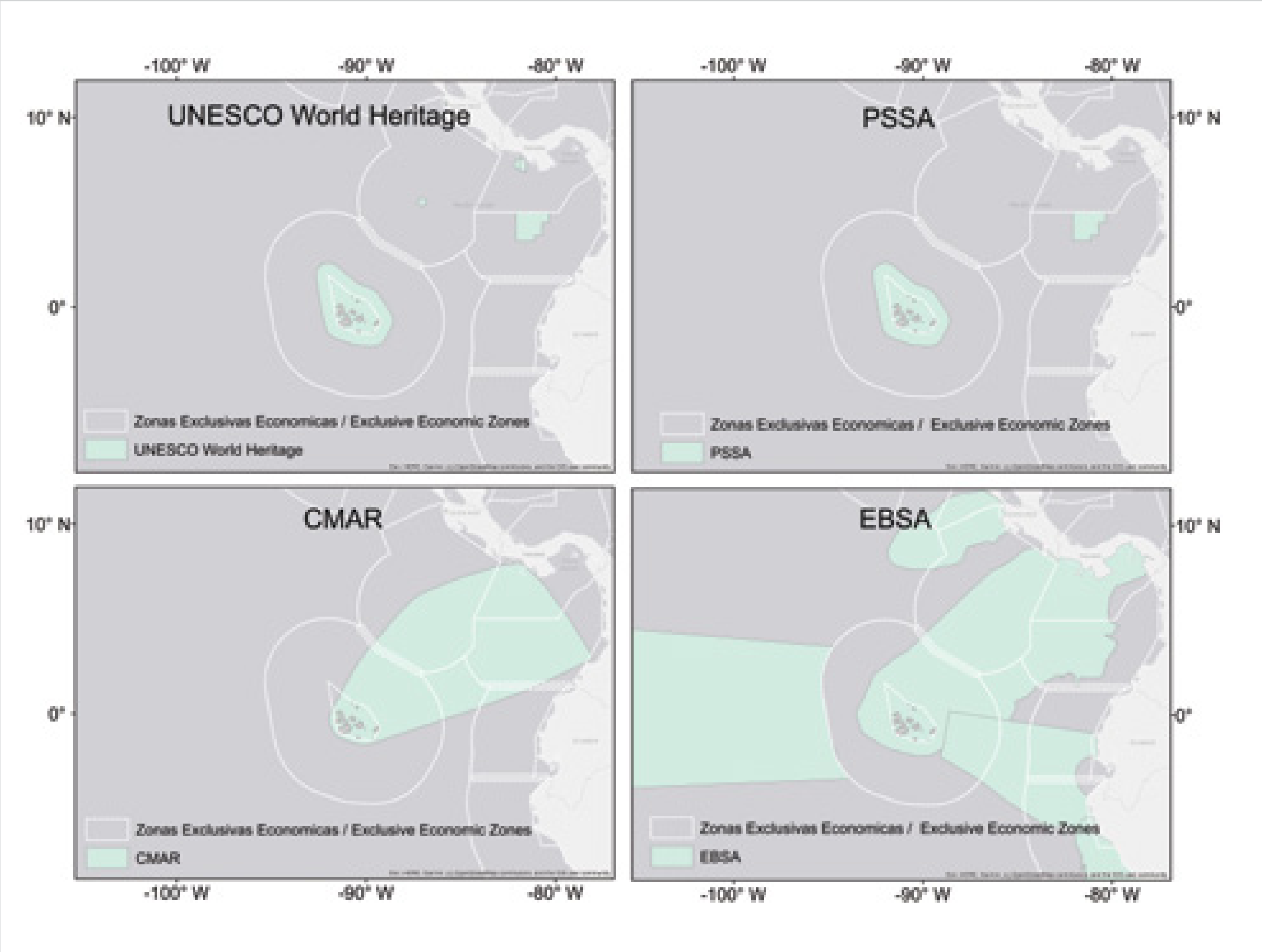


Figure 15. International marine conservation initiatives in the region. WHS: UNESCO World Heritage Sites, PSSA: IMO Particularly Sensitive Sea Areas, CMAR: Eastern Tropical Pacific Marine Corridor Initiative, EBSA: Convention on Biological Diversity Ecologically or Biologically Significant Marine Areas.

NGO-related initiatives

The NGO Conservation International (CI) adopted the theme of biodiversity hotspots as presented by Myers et al. (2000) with a terrestrial focus – the Chocó-Darién hotspot in western Ecuador and Colombia is home to more than 1,600 species of vertebrate wildlife of which over 400 are endemic. The main investment for this area is focused to sustainable development practices along the coast, but the area of action is expanded to include the Galápagos Islands (Figure 16) (CEPF 2021). To the north of this hotspot is the Mesoamerica hotspot, which spans most of Central America. CI also played a key role in the creation and implementation of the CMAR (described above), through its Eastern Tropical Pacific Seascape initiative.

The World Wide Fund for Nature has identified approximately twenty priority conservation places globally, where its stated goal is that by 2020, biodiversity should be protected and well managed. The only such marine site in the ETP is Galápagos, although WWF also recognizes the importance of the Chocó-Darien terrestrial site, as described above for CI.

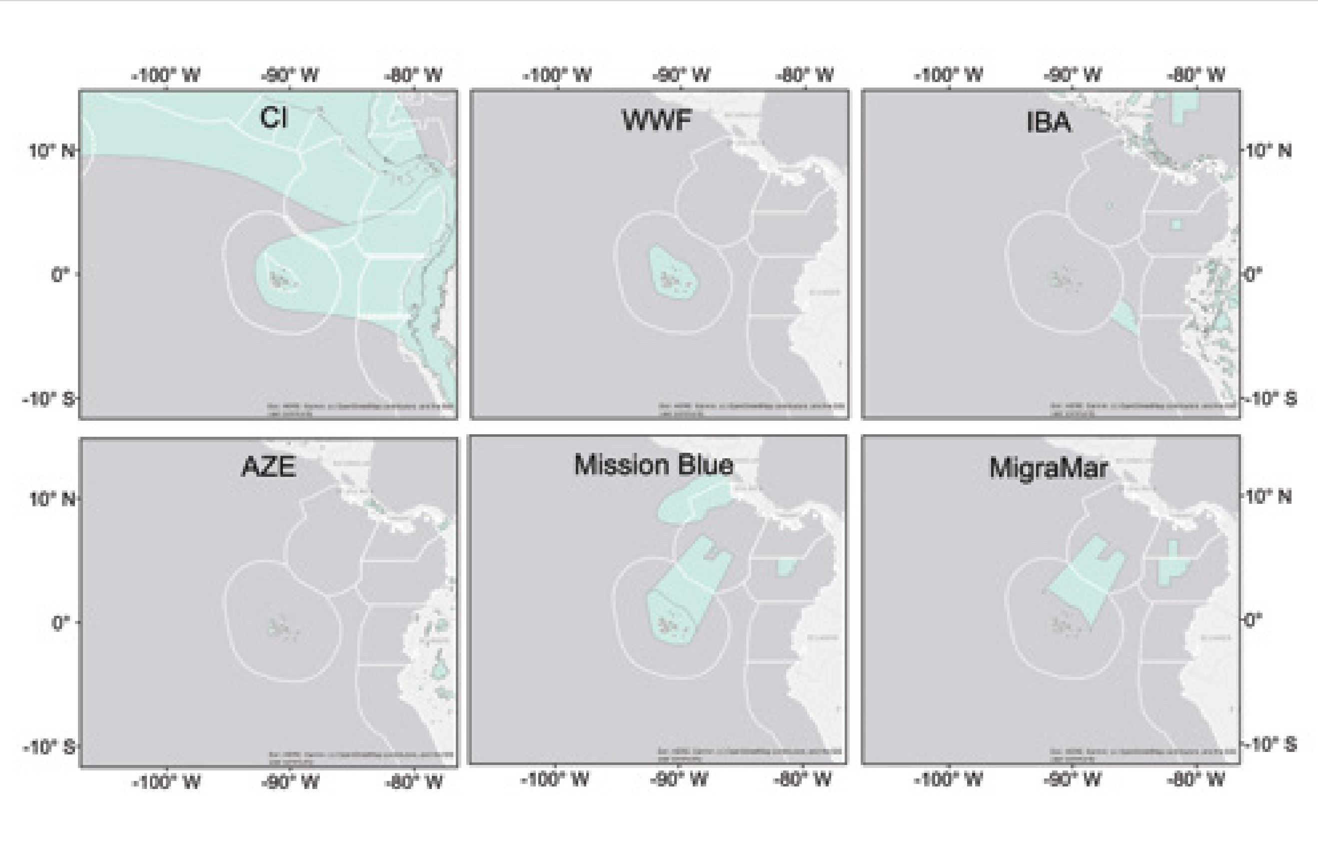


Figure 16. NGO conservation initiatives in the ETP region (CI: Conservation International, WWF: World Wildlife Fund for Nature, IBA: Important Bird and Biodiversity Areas, AZE: Alliance for Zero Extinction).

BirdLife International developed the concept of IBAs (Important Bird and Biodiversity Areas) in 1979 to identify sites of international significance for the conservation of birds and other biodiversity, using an internationally agreed set of criteria (Donald et al. 2019). There are over 100 IBAs in Ecuador alone. In Galápagos, IBAs include the highlands of several of the islands, the wetlands in southern Isabela and some of the islets around the major islands (such as Champion and Gardner islets – the last strongholds of the island-endemic Floreana mockingbird) (Grant et al. 2000). IBAs have also been identified in the marine environment, and the area of Isabela and Fernandina was declared an IBA due to its importance as foraging grounds for endemic species such as the flightless cormorant and Galápagos penguin, among others (Harris 1974, Boersma 1998).

The Alliance for Zero Extinction (AZE) was established to designate and effectively conserve the most important sites for global biodiversity conservation. These sites contain 95% or more of the known population of an Endangered or Critically Endangered species (Parr et al. 2009). In Galápagos, the marine AZE site mirrors the IBA around the western portion of the archipelago.

Hope Spots are ecologically unique areas designated by the NGO Mission Blue, led by renowned oceanographer Dr. Sylvia Earle, and in coordination with the IUCN and several NGO partners. These areas are highlighted globally, through expeditions and site champions. The overarching goal of the Hope Spots program is to have 30% of the ocean fully protected by 2030, in line with the IUCN's mandate to safeguard ocean health (Mission Blue 2020a). There are currently over 130 Hope Spots globally. Several Hope Spots are located in the Eastern Tropical Pacific – from the Revillagigedo Islands in the north, to the tropical sea of Peru in the south, and including the coastal areas of Golfo Dulce (Costa Rica), Coiba Island (Panama) and Tribugá Gulf (Colombia). The immense Eastern Pacific Seascape Hope Spot has recently been split into individual Hope Spots for the three oceanic island groups of Galápagos, Cocos and Malpelo. One of the most recent Hope Spots, declared in 2020, was the Cocos-Galápagos Swimway (Mission Blue 2020b), described below.

The Swimway concept (MigraVías in Spanish) was born in response to the need to safeguard the integrity of both open water and reef ecosystems that are interconnected among the different MPAs in the ETP region (Figure 16). Scientists working throughout the region as part of the MigraMar network (https://migramar.org) (MigraMar 2016), developed the concept of Swimways as a method of denoting areas where migratory species such as sharks and turtles transit between various MPAs, and where important biological, geological and oceanographic processes occur for these species. Swimways seek to implement management and conservation measures for migratory corridors in the Eastern Pacific, with the objective of safeguarding migratory species and ensuring the sustainable use of the region's natural resources. Two Swimway Initiatives are currently under consideration: the MigraVía Coiba-Malpelo (MCM) and the MigraVía Coco-Galápagos (MCG).

The MCM was consolidated following the countries of Colombia and Panama joining forces during 2016 and 2017 to create new MPAs, or expand existing ones, so that they border on each other on the edge of their EEZs. The creation of the Cordillera de Coiba Managed Resources Area (ARMCC) in Panama (Gobierno de Panamá 2015); the expansion of the MFFS (Gobierno de Colombia 2017a), and the creation of the Yuruparí-Malpelo National District of Integrated Management (DNMI) (Gobierno de Colombia 2017b) in Colombia, marked a regional conservation milestone by favoring the transboundary management of highly productive ocean areas of conservation importance. The MCM comprises several points of connectivity between species, many of them in danger of extinction (Bravo-Ormaza et al. 2020). The area of interest shows current connection networks in various categories and functionality for different species. The MCM covers an area of 70,822 km^2. The area that encompasses the MCM has a significant percentage of the migratory movements of the different organisms studied; 7 of the 15 species tagged by satellite telemetry show migrations in the MCM region.

The MCG is yet to be formally established and as a concept is currently under discussion through the CMAR framework and the governments of Ecuador and Costa Rica. This area would link the Cocos and Galápagos MPAs by means of the Cocos Ridge and its series of seamounts across the 700 km that separate them, and is based largely on the evidence of movements of sharks and turtles across this area (Peñaherrera-Palma et al. 2018a).

Fishery-specific spatial initiatives

Fishing activity in the international waters surrounding Ecuador's insular EEZ are managed by two Regional Fishery Management Organizations (RFMOs): the Inter-American Tropical Tuna Commission (IATTC, www.iattc.org) and the South Pacific Regional Management Organisation (SPRFMO, www.sprfmo.int).

The IATTC is the RFMO responsible for the conservation and management of tuna and other large pelagic resources in the ETP. There are 21 member countries and organizational members, plus five Cooperating Non-Members. The IATTC created a temporal-spatial closure around a 1.2 million km^2 box known as the "Corralito" west of the EEZ (Figure 17) where, according to Resolution C-17-02 (IATTC 2017a):

- Each purse-seine vessel of over 182 metric tons carrying capacity (IATTC size classes 4, 5 and 6) that fishes for tunas in the Eastern Pacific Ocean (EPO) shall cease fishing from either (1) 29 July to 8 October 2020; or (2) 9 November 2020 to 19 January 2021.
- Each IATTC Member and Cooperating Non-Member (CPC) shall ensure that every one of its vessels ceases to fish during one of these two periods.

Costa Rica also established no-take zones for purse seine vessels in two offshore areas, one of which is adjacent to the northern area of the Galápagos EEZ (Figure 18) (Gobierno de Costa Rica 2014).

The SPRFMO is "an inter-governmental organization committed to the long-term conservation and sustainable use of the fishery resources of the South Pacific Ocean and, in so doing, safeguarding the marine ecosystems in which the resources occur. The SPRFMO Convention applies to the high seas of the South Pacific, covering about a fourth of the Earth's high seas areas. Currently, the main commercial resources fished in the SPRFMO Area are Jack mackerel and jumbo flying squid in the Southeast Pacific and, to a much lesser degree, deep-sea species often associated with seamounts in the Southwest Pacific" (https://www.sprfmo.int/). The Commission has currently 15 Members from Asia, Europe, the Americas, and Oceania, and four Cooperating non-Contracting Parties. The SPRFMO has 21 conservation and management measures in place detailing "various provisions such as the application of technical measures or output and input controls, requirements for data collection and reporting, as well as regulations for monitoring, control and surveillance and enforcement" (https://www.sprfmo.int/).

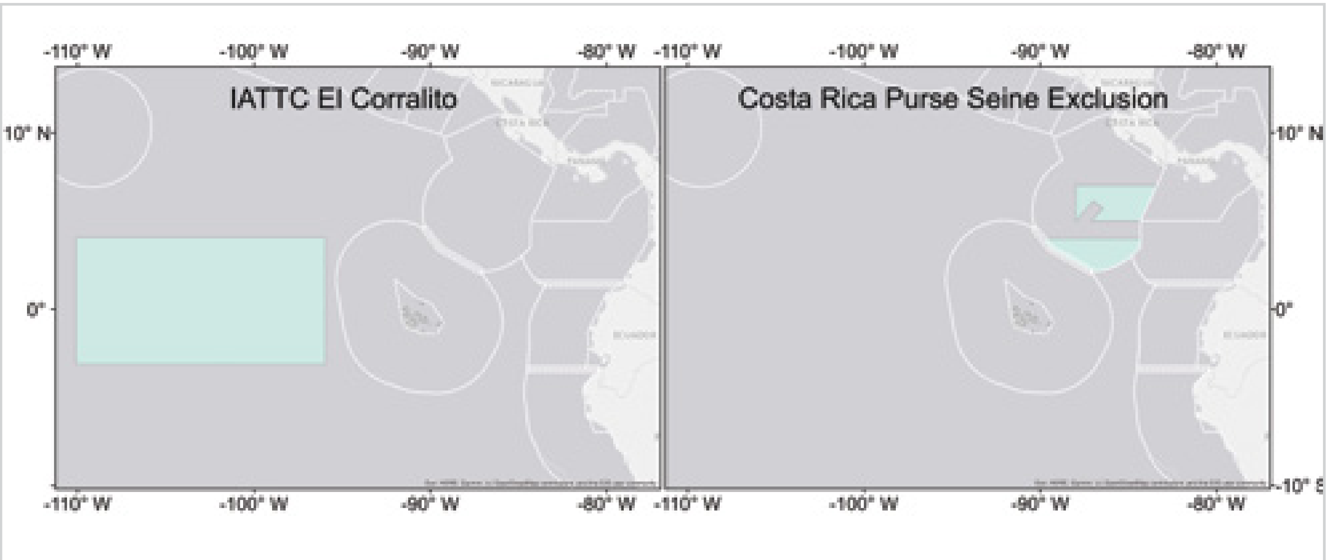


Figure 17. Spatial management measures for fisheries in the ETP region. Left – the temporal "El Corralito" closure (IATTC), right: offshore purse seine exclusion zones in Costa Rica EEZ.

Conservation Areas of Interest: Overlaps

By superimposing the different initiatives, there is appovent consensus among government and NGO organizations, in that Galápagos, Cocos and Malpelo form a "golden triangle" for biodiversity conservation priority (Figure 18). This is in part due to the levels of endemism displayed at each island group, but also a reflection of the oceanic connectivity between them, and in particular between Galápagos and Cocos. However, it is worthy of note that the open ocean west of the islands is not identified by any to these initiatives, despite being an important area of upwelling and the primary driver of productivity in the region.

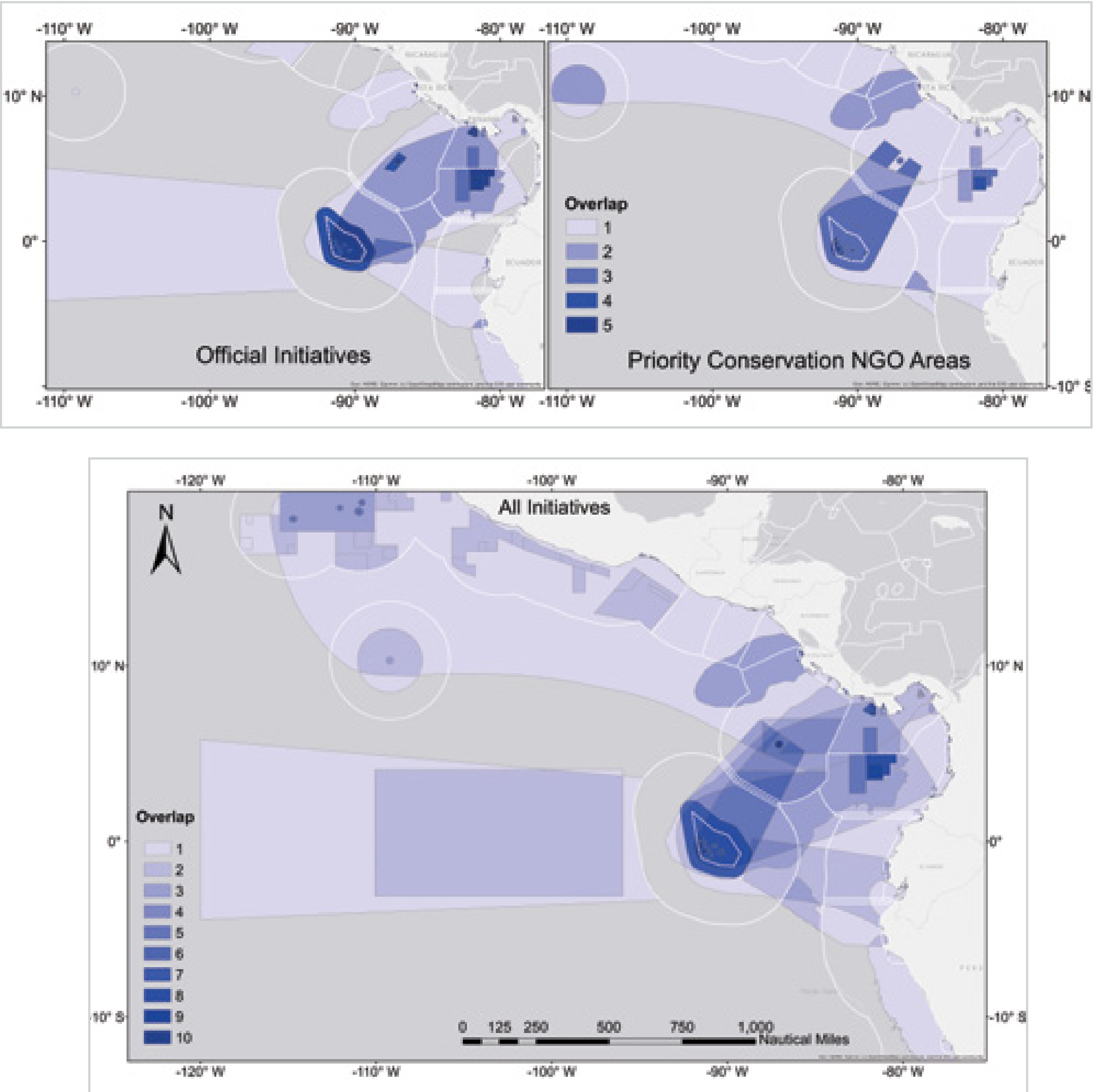


Figure 18. Overlapping marine conservation initiatives in the ETP. Top left: legally binding conservation initiatives; top right: NGO designations. Bottom: All initiatives, including major offshore fishery no-take zones.

Edwar Herreno

Introduction

Justification

Nearly a quarter of a century after the creation of the Galápagos Marine Reserve (GMR), recent years have seen growing concern about its effectiveness in the face of current and emerging threats. This concern has been expressed at different levels of society. At a grassroots level, the Galápagos community formed a citizen association called "Frente Insular" following the seizure in August 2017 of a Chinese reefer vessel, the Fu Yuan Yu Leng 999, inside the waters of the GMR. Among the 572 tons of fish found on board, were 7,639 sharks, including endangered species (Alava et al. 2017, Bonaccorso et al. 2021). Although the origin of the catch is uncertain, the unauthorized entry into the GMR in possession of endangered species constituted a violation that resulted in prison sentences for the crew of the vessel, a significant fine for the vessel owner, and the confiscation of the vessel itself (Bonaccorso et al. 2021). Outrage over the incident led to street protests in Galápagos, and to calls by the "Frente Insular" to increase the size of the Galápagos Marine Reserve. In July 2020, a distant water fleet of over 300 vessels, mostly targeting jumbo squid, was detected just outside the southern border of the Galápagos EEZ (Reuters 2020). Local Galápagos residents denounced the arrival of plastic trash likely originating from these vessels, and again expressed concern about the environmental impact caused by the presence of distant-water fleets without observers around the EEZ. Plastic pollution is an issue that is taken seriously in Galápagos – plastic straws and single use bags have been banned since 2018 (CGREG 2015), and local fishermen, park rangers and NGOs undertake regular beach cleanups around the islands. The same currents that originally brought new species to colonize the islands are now bringing plastics from a range of sources, from coastal cities to fishing fleets (van Sebille et al. 2019). The threat from fishing is not limited to international vessels. More recently, the Galápagos National Park Directorate reported that 136 Ecuadorian fishing vessels made illegal incursions into the GMR between 2018 and 2020 (El Universo 2020b).

At top government levels, in early 2019, Vice-President Otto Sonnenholzner stated that "If it is found that the size of the current marine reserve is insufficient to preserve such a fragile ecosystem as that of Galápagos, we as the Government will promote an international process to request that expansion and put it for the world's consideration" (El Comercio 2019). At that time, the focus of his declaration was on the impact that intensive industrial fishing in international waters surrounding the EEZ might have on the populations of endangered species within, given their mobile nature. However, later in the same year, the President of Ecuador, Lenín Moreno, laid out the threats to Galápagos at the 25th United Nations Climate Change Conference in Madrid: "Our Galápagos Islands are facing challenges: climate change, continental plastic pollution, pressure from fishing fleets and illegal fishing, that is why we continue to strengthen the protection of our marine reserve and we are analyzing its expansion to take care of that heritage" (Sputnik 2019). In July 2020, the President announced the creation of a Special Commission, led by former Minister of Environment and Yolanda Kakabadse, and former mayor of Quito, Roque Sevilla, to design a strategy to protect Galápagos and its surrounding waters (El Comercio 2020a).

Scientific knowledge about open-water systems and highly mobile marine species in and around Galápagos has increased significantly since the mid 1990s, when the GMR was designed. Indeed, the first comprehensive compendium of the GMR and its ecology, published in 2002, focused more on subtidal community ecology and fishery resources (Danulat and Edgar 2002). This reflected the priorities at that time, which included an evaluation of the provisional coastal zoning process and attempts to sustainably manage lobster and sea cucumber resources. What little information existed at the time on large-bodied, highly mobile organisms that utilize open waters, was limited mainly to diet and colony size and distribution in the case of Galápagos sea lions and fur seals (Salazar 2002); species lists and locations of sightings in the case of cetaceans (Palacios and Salazar 2002); nesting behavior for green turtles (Zárate and Dutton 2002); distribution of seabirds with some movement data on waved albatrosses (Jiménez Uzcátegui and Wiedenfeld 2002); and a species list and description of fin seizures for sharks (Zárate 2002).

Technological developments since then, especially in the fields of tracking technology, have allowed scientists a better understanding of the population connectivity and spatial ecology of several open water species, including Eastern Pacific leatherback turtles (Shillinger et al. 2011), waved albatrosses (Anderson et al. 2003) and scalloped hammerhead sharks (Hearn et al. 2010), all of which are classified as Critically Endangered on the IUCN Red List. Studies across taxa repeatedly showed organisms either utilizing open water habitat outside the GMR or making migratory movements to or from other areas. These studies have resulted in initiatives to extend protection beyond current boundaries, including the proposal to create a protected "Swimway" linking Galápagos and Cocos along the Cocos Ridge, described in the previous section (Peñaherrera-Palma et al. 2018a).

Other studies have shown the economic benefits that the GMR had for the national tuna fleet (Boerder et al. 2017; Bucaram et al. 2018), but also brought attention to increasing fishing pressure in the region and potential impacts for species vulnerable to fishing gear, and for the sustainability of the fishery itself, especially as the use of Fish Aggregation Devices (FADs) has increased significantly over this period. After the Fu Yuan Yu Leng 999 incident outlined above, scientists alerted the general public to the fact that over 200,000 sharks are landed annually as bycatch on mainland Ecuador (Hearn and Bucaram 2017) by the national longline fleet which extends its operations from the mainland all the way to the EEZ around Galápagos and beyond (Martinez-Ortiz et al. 2015).

Calls for increased protection around Galápagos have occurred at a time when other Latin-American states are already taking action within their national jurisdictions to increase marine protection by either expanding existing MPAs (Table 2) or creating new MPAs adjacent to, or that envelop, existing ones. Noteworthy cases of the former approach include the expansions of protected waters around the Revillagigedo Islands (Mexico) in 2017, increasing protection by a factor of 20, and that of the Malpelo Fauna and Flora Sanctuary (Colombia) in the same year. In fact, this was the second time that the protected waters around Malpelo had been extended – in 2005, the original 388 km^2 MPA had been extended to 9,585 km^2. At approximately the same time of the latest expansion, the Yuruparí-Malpelo National Integrated Management District (an additional 27,450 km^2) was declared adjacent to Malpelo (PNNC 2017). In 2021, Panama created a large offshore MPA along the Coiba Ridge, covering over 67,000 km^2, and in the process protecting 30% of its ocean nine years before the target date (Maldonado 2021).

At Cocos Island (Costa Rica), the island itself was declared a National Park in 1978, but it was not until 1984 that the first marine protection occurred, covering an area of 5 km around the coastline (Alvarado et al. 2012). This was subsequently expanded to 15 km in 1991 and then to 12 NM (22.22 km), covering 1,997 km^2, in 2001 (Alvarado et al. 2012, Gonzáles-Andrés et al. 2016). In 2011, the Seamounts Marine Management Area (SMMA) was created to provide additional protection in the waters surrounding the Cocos Island National Park (Figure 19). This area covers 9,649 km^2 and considered two no-take zones – a semi-circular band of 5 NM (9.26 km) width from the northwest of the Cocos Island National Park clockwise to the southeast, covering a strip of 724 km^2; and a 2,720 km^2 box in the southwestern end of the SMMA, encompassing the Las Gemelas seamounts (SINAC 2013). These seamounts are considered the first "stepping stones" along the Cocos Ridge, linking Cocos with Galápagos, and were protected in the spirit of the San José Declaration of 2004, which envisages the creation of a marine corridor linking Galápagos and Cocos. An expedition in 2009 highlighted the biodiversity of the seamounts (National Geographic 2009; Starr et al. 2012), while recently, Chávez et al. (2020) established connectivity of hammerheads between Cocos Island and Las Gemelas. Despite the development of a fully comprehensive management plan, the SMMA has not been implemented due to the lack of specific regulations; while the announcement of the former President Luis Guillermo Solís to make the entire area a no-take zone, never materialized (Solano 2016).

Table 2 | Recent measures taken by East Pacific states to increase protection around existing MPAs. Note that some locations, such as Malpelo and Cocos Island, have expanded their area of protections more than once. Only latest expansions are shown. *Where reserves are both marine and terrestrial, size refers to the marine component only.

Country	MPA	Year Creation	Size (km^2)	Year Expansion	Size (km^2)*
Mexico	Revillagigedo	1994	6,367	2017	150,000
Costa Rica	Cocos	1984	55	2001	1,997
Colombia	Malpelo SFF	1996	388	2017	27,096
Ecuador	Muisne River Estuary Wildlife Refuge	2003	32	2016	923
	Pacoche Wildlife Refuge	2008	135	2014	315
	El Salado Mangrove Fauna Production Reserve	2002	37	2012	155
Chile	Isla Magdalena National Park	1983	1576	2017	2,497
	Juan Fernández MPA	2016	11,028	2018	24,000

Within Ecuador, since the turn of the 21st century, both approaches (expansion of existing MPAs and creation of new MPAs adjacent to existing ones) have been taken. For instance, the Cantagallo-Machalilla MPA was created in 2015 (MAE 2015b) to fill a gap in the Machalilla National Park, which covered the coastal terrestrial habitat around Puerto López and a 2 NM (3.7 km) fringe of coastal waters, and the offshore Isla de La Plata and its surrounding waters 5 NM (9.26 km) around the island (Figure 19). Furthermore, at least three coastal-estuarine protected areas were expanded within the last decade (Table 2).

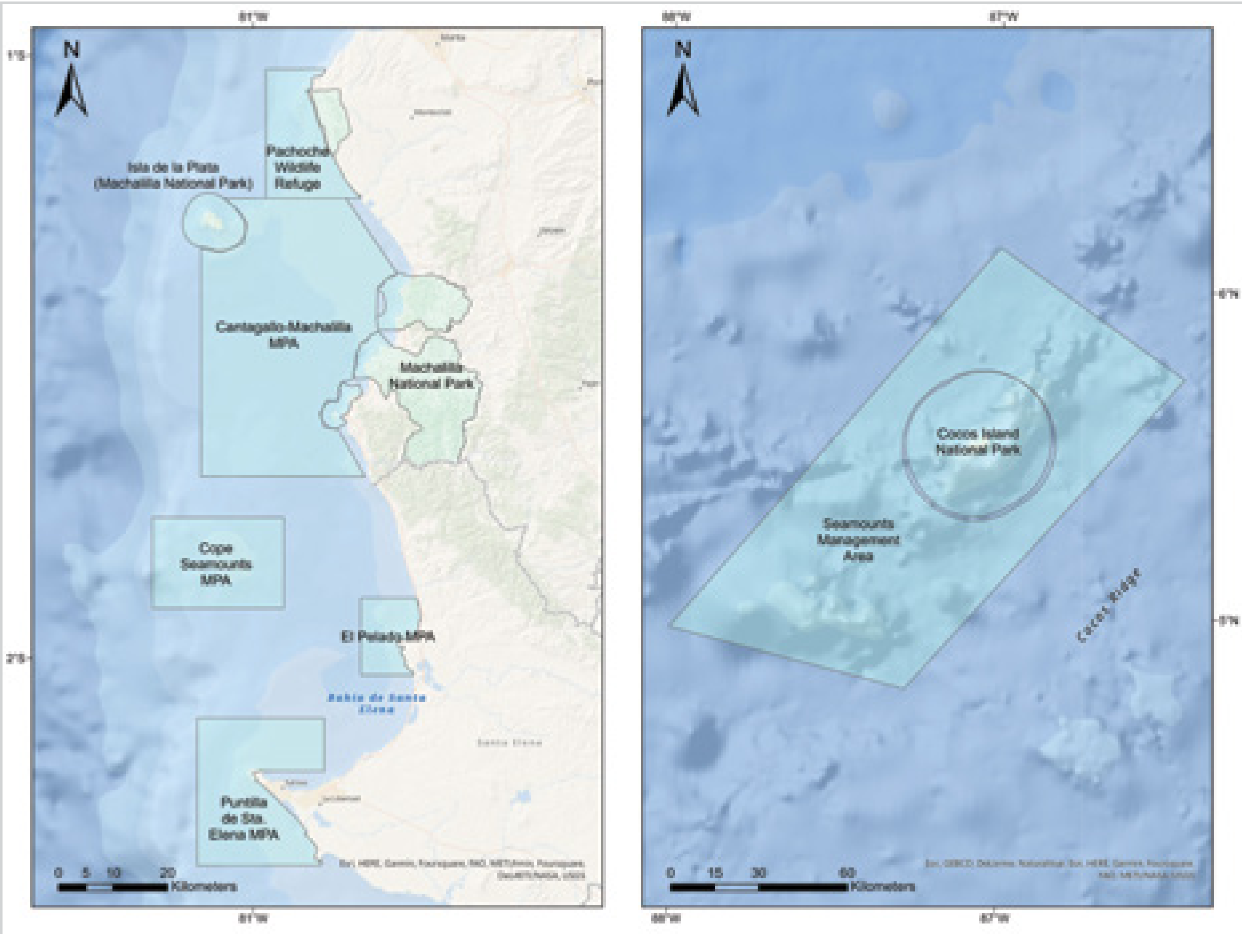


Figure 19. Machalilla National Park and adjacent Cantagallo (left). Cocos Island National Park and adjacent Seamounts Management Area, created in 2001 (right). Note that figures are in different scales.

Ecuador has also assumed its role in the international community. Although it has been a member of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 1975, it became a member state of the Bonn Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2004 and, under the auspices of this treaty, a signatory to the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and Memorandum of Understanding on the Conservation of Migratory Sharks in 2017. Ecuador became a signatory of the United Nations Convention on the Law of the Sea (UNCLOS) in 2012, and in 2016 adhered to the Agreement on the Application of the Provisions of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. In terms of spatial protection, Ecuador has exceeded the Aichi Target 11 of 10%, thanks largely to the Galápagos Marine Reserve, which makes up just over 13% of Ecuador's two EEZs. A network of small coastal MPAs contributes approximately an additional 6,950 km^2 (Table 3, Figure 20). However, this target includes references to "effective conservation" (Rees et al. 2018), and other qualitative terms such as "well-connected", "representative" and "equitably managed" among others (Meehan et al. 2020), and Ecuador's MPA network has not been assessed against these indicators. In addition, it still falls short of the 30% by 2030 commitment agreed by the IUCN and by the Global Ocean Alliance to which Ecuador adhered in 2020. This commitment is also now part of the post-2020 Global Biodiversity Framework (Convention on Biological Diversity 2020).

Table 3 Ecuador's Marine Protected Areas, by category, date of designation and area (km²). Source UNEP-WCMC and IUCN (2020). Sizes are based on the extent of designated protected marine area using the Mollweide projection (Field name: GIS_M_AREA), except those shown in italics, which were reported to the database, and the recently declared Puerto Cabuyal – Punta San Clemente marine reserve, projected in UTM17S (MAATE 2021). Note that the reported size of the Galápagos Marine Reserve differs from that used in this study (138,052 km²) due to the use of a different projection.

Name	Type	Year	Area (km²)
Galápagos Marine Reserve	World Heritage Site	1978	138,850
Machalilla	National Park	1994	176
Manglares Churute	Ecological Reserve	2001	71
Refugio de Vida Silvestre Isla Santa Clara	Ramsar Site	2002	10
Reserva Ecológica de Manglares Cayapas-Mataje	Ramsar Site	2003	*448*
Manglares Cayapas Mataje	Ecological Reserve	2004	194
Manglares El Morro	Wildlife Refuge	2007	102
Puntilla De Santa Elena	Fauna Production Reserve	2008	525
Manglares Estuario del Río Esmeraldas	Wildlife Refuge	2008	2
Galera San Francisco	Marine Reserve	2009	538
Playas De Villamil	National Recreation Area	2011	25
El Pelado	Marine Reserve	2012	131
Islas Corazón y Las Islas Fragatas	Wildlife Refuge	2012	9
Manglares del Estuario Interior del Golfo de Guayaquil	Ramsar Site	2012	*153*
Pacoche	Wildlife Refuge	2014	266
Cantagallo - Machalilla	Marine Reserve	2015	1,429
Bajo Copé	Marine Reserve	2016	402
Isla Santa Clara	Wildlife Refuge	2016	377
Manglares Estuario del Río Muisne	Fauna Production Reserve	2017	794
Puerto Cabuyal – Punta San Clemente	Marine Reserve	2021	1,304

Spatial measures are not the only tools that Ecuador has employed to protect and sustainably use its marine resources. Ecuador has formally applied the FAO Code of Conduct for Responsible Fisheries since 1995. Further, in 2005 it implemented a National Plan of Action for Sharks, which has been updated twice since. Ecuador does not recognize a targeted shark fishery, and shark finning has been banned since 1993 (SRP 1993). A total ban on landing sharks was established in 2004 (Gobierno del Ecuador 2004), however, due in part to lobby from the fishing sector, and in part to concerns that the activity simply moved underground, the ban was overturned in 2008. Since then, artisanal fishers (including the oceanic longline fleet) are permitted to land sharks caught during their fishing activities. At least a quarter of a million sharks are landed in this way each year (Martinez-Ortiz et al. 2015), and Ecuador remains a key exporter of shark fins nonetheless. In 2020, the Ecuadorian Government issued a Ministerial Decree (MPCI 2020), partly in response to the updated red list status of scalloped hammerhead sharks to Critically Endangered (Rigby et al. 2019i), and partly due to the seizure in Hong Kong of two illegally exported containers from Ecuador with 28 tons of CITES-listed shark fins (mostly silky sharks and pelagic thresher sharks). This decree included a ban on all sales and exports of hammerhead and oceanic whitetip sharks. Further, more fishery inspectors were hired, and initiatives to improve traceability and reduce bycatch were launched (El Universo 2020a). However, only months later, 8 tons of hammerhead and thresher shark fins of Ecuadorean origin were seized in Peru, highlighting the gap between regulatory measures and their implementation (El Universo 2020c). A further commitment to develop required non-detriment findings (NDFs) for CITES-listed shark species has yet to be followed up.

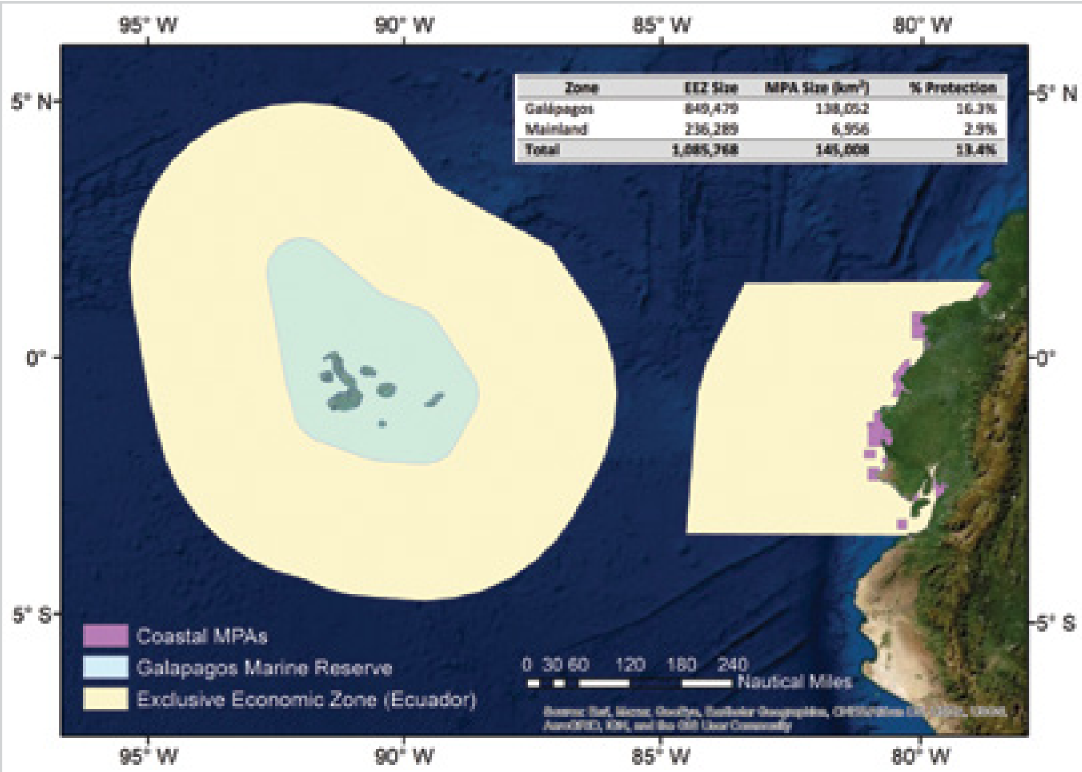


Figure 20. Area of Ecuador's two Exclusive Economic Zones, showing MPAs. Inset table shows sizes of areas in km².

From a regional fishery perspective, Ecuador, with the largest tuna fleet in the Eastern Pacific Ocean, is a member state of the Inter-American Tropical Tuna Commission (IATTC), and also of the South Pacific Regional Fisheries Management Organisation (SPRFMO), which manages non-tuna shared stocks, such as jumbo squid (which Ecuador has expressed an interest in developing a fishery for) and jack mackerel among others.

These regional fishery management organizations (RFMOs) have also recognized growing concerns about both the sustainability of their resources and the environmental impacts of their activities, and have made steps to improve their practices, including but not limited to the following regionwide regulations:

- Resolution C-04-05 which consolidates a range of bycatch related issues to reduce mortality of juvenile target species and on handling and release of turtles (IATTC 2006).
- Resolution C-11-02 that provides for mitigation measures to reduce seabird entrapment on longline vessels (IATTC 2011a)
- Resolution C-11-10 that prohibits purse seine vessels from retaining, transhipping, landing or storing carcasses of oceanic whitetip sharks (IATTC 2011b).

- Resolution C-16-06 (currently extended via C-21-06) that prohibits purse seine vessels from retaining, transhipping, landing or storing carcasses of silky sharks, and limiting silky shark bycatch on longline vessels to 20%, among other measures for this species (IATTC 2016, 2021).
- Resolution C-19-06 that prohibits purse seine vessels from deliberately setting a purse-seine net on a school of tunas associated with a live whale shark (IATTC 2019b).
- Resolution C-15-04 that prohibits members and cooperating non-members from retaining manta rays and other mobulids, and requiring them to release them alive where possible (IATTC 2015).
- Resolution C-07-03 that implements FAO guidelines to reduce sea turtle mortality in fishing operations (IATTC 2007b).

The IATTC also manages a temporal closure west of the Galápagos EEZ in an area known as El Corralito (1.2 million km^2) which purse seiners class 4-6 (greater than 182 metric tons carrying capacity) must avoid for 72 days each year (IATTC 2017a and extensions to IATTC 2020b).

Nationally, Ecuador passed a new Fishery Law in 2020, strengthening surveillance tools and fines, among other measures. An action plan has been developed to transition towards biodegradable Fish Aggregation Devices (MAP 2018), and the implementation of a National Plan of Action for Dorado *(Coryphaena hippurus)* reflects an interest by the artisanal large pelagic longline fleet to achieve Marine Stewardship Council certification (Martínez-Ortíz and Guerrero-Verduga 2013). Some of the actions taken by Ecuador have been in response to the 'yellow card' warning issued by the European Commission (2019), which expressed concern about IUU fishing by Ecuadorian vessels, in particular about enforcement, control and traceability of the catch. Notably, Ecuador adhered to the Agreement on Port State Measures in 2019, and is currently in the process of implementing the agreement on a national level. Table 4 summarizes some of the key national legislation to manage fisheries, protect endangered species and reduce IUU fishing.

All these efforts, both in terms of increased marine protection and sustainable fishery management strategies, contribute to international commitments including the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD 2011) and the United Nations Sustainable Development Goals (SDGs) (United Nations 2015). Under these commitments, specific conservation and sustainability objectives and targets were set for the ocean considering its importance for human development and well-being. SDG 14 Target 5 and Aichi Biodiversity Target 11 share the goal of conserving at least 10% of coastal and marine areas by 2020. SDG 14 also includes a call for an effective, ending overfishing and enhancing equitable and sustainable fishing. Recent studies have also emphasized on the connections between SDG 14 and other dimensions of sustainability, especially the strong links with food security and poverty reduction (Ntona and Morgera 2018; Singh et al. 2018), in particular with SDG 14.4 and the elimination of IUU fishing. In addition to the global environmental commitments, various regional and global marine conservation initiatives are promoting increased marine protection, in particular the aforementioned Global Ocean Alliance – a commitment to protect 30% of the world's oceans by 2030, which Ecuador joined in August 2020 (Alvarado 2020) and which also forms part of the CBD Global Biodiversity Framework.

Table 4 | Most relevant legislation and plans that regulate the management of tuna and tuna-like fisheries, the protection of sharks, and the prevention and eradication of IUU fishing in Ecuador.

Legislation	Objective
Management of tuna and tuna-like fisheries	
Decree No. 1 050 of 1973.	Establishes the regulations for the use and destination of tuna catches to ensure the supply of tuna required by the canning companies established in the country.
Agreement No. 18 of 2000.	Establishes the monitoring and verification system for tuna caught in the EPO, according to the guidelines of the Agreement on the International Dolphin Conservation Program (AIDCP).
Ministerial Agreement 031, RO No.451 (October 27, 2004).	Prohibits the capture, transport, possession, processing, and marketing of mahi-mahi specimens below a total length of 80 cm.
Tuna national action plan (PAN-Tuna), Ministerial Agreement 0184-A of December 2019.	Promotes sustainable exploitation of the tuna fishery, bycatch reduction; strengthening of monitoring, control, and surveillance systems; the implementation of a national traceability system, among others.
National action plan for the conservation and management of mahi-mahi (PAN-Dorado 2019-2024).	Aims to ensure the conservation and sustainable use of mahi-mahi in Ecuador.
Management of tuna and tuna-like fisheries	
Ministerial Agreement 147, RO No. 581 (December 12th, 1990)	Establishes that all species of marine turtles in Ecuadorian waters must be protected by the State. It prohibits their capture, processing, and marketing.
Executive Decree 486 of 2007.	Prohibits shark finning nationwide and directed fishing for this species. Bans the use of steel leaders on longlines. Allows sale of sharks only if caught incidentally and landed whole (fins and body), except in the Galápagos Marine Reserve where sharks are afforded complete protection.
Executive Decree 902 of 2008.	Adopts the National Action Plan for the Conservation and Management of Sharks of Ecuador (PAT-Ec)
National Action Plan for the Conservation and Management of Sharks of Ecuador (PAT-Ec 2020-2024).	Its objective is to ensure the conservation, sustainable management, and recovery of the populations of sharks, rays, guitarfish, and chimeras distributed within the Ecuadorian maritime territory.
Ministerial Agreement 093, RO No. 273 (September 7, 2010).	Prohibits fishing that targets giant manta ray *(Mobula birostris)* and mobulas *(Mobula japanica, M. thurstoni, M. munkiana and M. tarapacana)*
Ministerial Agreement MPCEIP-SRP-2020-0084-A.	Bans the possession, sale and export of all hammerhead shark species and oceanic whitetip sharks.
Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated (IUU) Fishing	
Maritime Police Code and its regulations.	Establishes the norms referring to the registration of ships and naval artifacts; a registry of naval property, patents and navigation passers, use of the flag, reception, and dispatch of ships and inspections.
National Action Plan to Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated Fishing (PAN-IUU), approved in 2005.	The PAN-IUU was developed with the advice of FAO and under the guidelines of the *"International Plan of Action to prevent, deter and eliminate IUU fishing (PAI-IUU)"* (FAO 2001).
Executive Decree No. 723 of July 10, 2015.	Defines the powers between the National Directorate of Aquatic Spaces (DIRNEA) and the Undersecretariat of Ports and Maritime Transport regarding flag, port and coastal State measures, in the context of the Maritime Authority.
National Plan for the Control of Fishing Resources, approved through Agreement No. MAP-SRP-2018-0102-A.	It establishes guidelines to guarantee the traceability of fishery products and more efficiently control of all actors involved in the fishing activity. It establishes landing sites that must be controlled by fisheries inspectors at the national level, using technological tools such as the Integrated Aquaculture and Fisheries System (SIAP) and the Satellite Monitoring Center (CMS), and adequate process manuals to carry out standardized actions to prevent, discourage and eliminate IUU fishing.

Guiding Principles for Spatial Management of the EEZ around Galápagos

Within this context of changing threats, overfishing and illegal fishing, climate change, ocean plastics and increased knowledge on the connectivity and movement ecology of endangered species, the effectiveness of the current management strategy in and around the Galápagos Marine Reserve was called into question (La Hora 2019). A grassroots campaign (Más Galápagos), calling for increased protection around the GMR, was launched, with the support of over 100 local, national and international organizations (http://www.masgalapagos.info/cada-dia-somos-mas/). They organized a petition, which reached over 32,000 signatures (https://only.one/act/galapagos) and was handed to the Presidency in January 2021 (Más Galápagos 2021).

In November 2019, a technical workshop was held in San Cristóbal (Galápagos Islands), bringing together a group of national and international researchers with expertise on current threats to open water ecosystems, and the ecology of the open waters surrounding the Galápagos Marine Reserve (to review the Workshop Proceedings see Hearn and Cardenas 2020). The goal of the workshop was to start developing a scientific and economic assessment of the threats facing the GMR, and to explore the costs and benefits of different conservation strategies, including spatial and regulatory tools, to address these threats. The scope of the study was the entire EEZ surrounding the GMR. Over the subsequent months, based on the workshop outcomes and on meetings with groups of local fishers, the following management principles were proposed to guide the process:

- Implement ecosystem-based management through marine spatial planning of the entire EEZ surrounding Galápagos, to ecologically connect and maintain the benefits of oceanic ecosystems and the services they provide.
- Ensure, through the creation of responsible fishing zones and control of illegal fishing, that national fleets have exclusive access to spillover effects arising from increased protection.
- Protect the current GMR from illegal fishing.
- Support measures to build economic and ecological resilience to mitigate the impacts of climate change on species of both commercial and conservation interests.
- Protect highly productive areas and cold-water refugia: upwelling events related to seamounts and persistent frontal zones.
- Maintain and protect the unique genetic resources of the GMR (for example, endemic species which may forage outside the current reserve) and maintain genetic diversity of highly migratory species.
- Protect migratory routes to maintain and strengthen connectivity of threatened marine species between biologically important areas (for example the Coco-Galápagos Swimway) across the ETP region.
- Support measures to reverse the declining population trends of migratory species and of species that forage in open waters around the GMR.
- Support Sustainable Development Goal 14 and its objectives to protect and sustainably utilize the oceans and marine resources in order to maintain ecosystem services and economic benefits in the long term, and preparation for commitments to the post-2020 Global Biodiversity Framework (Convention on Biological Diversity 2020).

This document explores how different combinations of spatial and regulatory measures can contribute to the long-term sustainability of marine biodiversity and the ecosystem services that it provides to Ecuador and the Eastern Tropical Pacific region as a whole.

The goal of this document is to compile, synthesize and analyze the best available information regarding the ecology and distribution of conservation features and known threats facing the open water species and assemblages around the Galápagos, and to assess the potential of different protection scenarios in the EEZ surrounding the current marine reserve.

Specific objectives

1. To identify conservation features (key species, habitats and ecological processes) that may benefit from increased protection
2. To characterize the human activities and threats facing the open waters around Galápagos
3. To construct and compare different spatial management scenarios that would fulfil the management objectives proposed above.
4. To propose a scenario that would form the basis for a national process.
5. To evaluate potential costs and benefits of the proposed scenario compared to other alternative scenarios of marine spatial management for the Galápagos EEZ.
6. To discuss key issues that should be considered for the effective implementation of the proposed marine spatial planning scenario.

Alex Hearn

Conservation Objectives

The open waters surrounding the Galápagos Marine Reserve drive many of the biophysical processes that occur in and around the islands. For example, the complex system of currents and upwelling processes is largely responsible for the differences in the makeup of coastal marine communities across the reserve (Edgar et al. 2004), while the underwater ridges provide physical connectivity with other areas across the region (Peñaherrera-Palma et al. 2018a). The conservation features described below include key ecosystem features and processes as well as the species that inhabit or utilize these waters.

Species of Conservation Interest

We developed a list of conservation features based on a study of threatened marine species of the Galápagos Marine Reserve (Edgar et al. 2008) and updated to show new red-listing statuses. To this list we added relevant species of conservation importance to the island ecosystem whose red-list status was not Vulnerable or above (Table 5). These species can be grouped taxonomically into elasmobranchs, marine turtles, seabirds and marine mammals. The species in these groups all share common traits – in relation to many commercial fish species they are long lived, mature late in life, and have low reproductive rates. Many are also highly charismatic and important for tourism at the islands, and many are also vulnerable to fishing gear.

Sharks and Rays

Sharks (together with rays and chimaeras) belong to an ancient lineage of marine vertebrates whose skeletons are primarily composed of cartilage, making them distinct from all other jawed vertebrates. They first appeared in the fossil record some 500 million years ago, and approximately 500 extant species have been identified to date (Klimley 2013). At least 36 species of sharks have been reported from the Galápagos Marine Reserve, which is globally recognized as a shark hotspot (Hearn et al. 2014, Bonaccorso et al. 2021). These include the Critically Endangered scalloped hammerhead shark *(Sphyrna lewini)*, which aggregates in large numbers particularly at the northernmost islands (Peñaherrera-Palma 2016), the blacktip shark *(Carcharhinus limbatus)* which utilizes coastal mangrove-fringed lagoons as nursery grounds (Chiriboga 2018; Goodman 2020; Llerena et al. 2015), and the diminutive Galápagos catshark *(Bythaelurus giddingsi)*, which inhabits the benthic zone at depths greater than 400 m (McCosker et al. 2012).

In general, sharks display life traits that make them particularly vulnerable to overexploitation – slow growth rates, late onset of sexual maturity, low reproductive rates, and low natural mortality (Klimley 2013). Sharks as a group are threatened globally from both climate change (Chin et al. 2010) and fisheries (Queiroz et al. 2019). In a study of the global status of sharks, at least a quarter of shark species were found to be threatened with extinction and only a little over a third of all shark species assessed were considered "safe" (Dulvy et al. 2014). The IUCN Red List update in September 2021 included 37% of shark species as threatened with extinction (IUCN 2021). Further, there has been an apparent decline of 71% in the global abundance of sharks and rays since 1970, which is largely driven by fishing pressure (Pacoureau et al. 2021). It is thought that an estimated 26-73 million are landed annually, about half of which end up in the shark fin market (Clarke et al. 2006b). Ecuador does not recognize a target fishery for sharks, and sharks are protected within the waters of the Galápagos Marine

Reserve. However, illegal shark fishing is an ongoing problem, and at least 250,000 sharks are landed in coastal ports on mainland Ecuador annually as permitted bycatch (Martínez-Ortiz et al. 2015). Also within the GMR, a series of experimental longline fisheries have been implemented over the years, with significant bycatch of sharks (Cerutti-Pereyra et al. 2020; Murillo et al. 2004) from 4-77% (for details see section on Galapagos Artisanal Fishing Sector and Table 13).

For the past fifteen years, researchers in the Galápagos Islands and throughout the Eastern Tropical Pacific have engaged in a large-scale collaborative program to tag and track shark movements across the region (MigraMar 2016). As a result, much more is known currently about the residency and movement patterns of some of these species than when the GMR was declared in 1998.

Marine Turtles

Marine turtles are a small group of aquatic reptiles from the order Testudines, found throughout the world's oceans except in polar regions. There are seven extant species, of which four occur in and around the Galápagos Islands (Zárate and Dutton 2002). Turtles display complex life histories, and may migrate over thousands of kilometers, using geomagnetic navigation cues (Lohmann et al. 2008) to move between foraging grounds and nesting beaches, in many cases displaying varying degrees of philopatry.

Marine turtles are highly susceptible to climate change – from sea level rise affecting nesting beach dynamics, to temperature rise affecting the sex ratio of their offspring (sex in sea turtles is determined by temperature). All sea turtle species (except the loggerhead, which is listed as Vulnerable) are endangered, and although targeted capture is no longer permitted in most countries, they are commonly entangled in nets and lines.

For the past twenty years, the Galápagos National Park Directorate and the Charles Darwin Foundation have been monitoring nesting success at key beaches around the Galápagos Islands (Zarate 2002). Several research groups have tracked green, hawksbill and leatherback turtles both in the GMR and in neighboring areas (Muñoz-Pérez et al. 2018; Seminoff et al. 2008; Shillinger et al. 2008). The identification of a clear post-nesting migratory route for leatherback turtles from beaches in Costa Rica, along the Cocos Ridge and through the GMR was one of the primary reasons for the creation of the Eastern Tropical Pacific Marine Corridor Initiative (Shillinger et al. 2008).

Alex Hearn

Seabirds

Seabirds are a large group of avian species that depend exclusively on the marine environment (Schreiber and Burger 2001). Several unique adaptations to foraging at sea make marine birds wide-ranging predators that can occupy vast areas of the ocean in search of food (Weimerskirch 2007). Seabird and humans have interacted for centuries, as indicators of fish for fishermen, land proximity for sailors, and a source of food for settlers on islands (Schreiber and Burger 2001). Seabird guano, a great natural fertilizer, transports nutrients from marine ecosystems to terrestrial environments (Rodrigues and Micael 2021). Furthermore, because breeding success of seabirds reflects the conditions in the marine environment, and they are relatively easy to observe, they are widely regarded as good indicators of marine ecosystems (Einoder 2009; Schreiber and Burger 2001).

The Galápagos Islands are a hotspot for seabirds, with 19 species nesting on the islands (Gusmao et al. 2020). Likewise, endemism is also among the highest, approximately ~30% of the species are endemic to the archipelago (Harris 1977). These include exceptional species such as the only flightless cormorant in the world *(Phalocrocorax harrisi)*, the only tropical penguin and albatross species in the world *(Spheniscus mendiculus, Phoebastria irrorata)*, and the only nocturnal gull in the world (*Creagrus furcatus)* (Swash and Still 2000).

Seabirds, as a group, are one of the most threatened groups of birds, with 31% of species considered globally threatened (Dias et al. 2019). The main threats are bycatch in fisheries and introduced predators in their nesting sites. Unfortunately, seabirds in the Galápagos reflect this trend. For example, both the waved albatross and the Galápagos petrel are listed as Critically Endangered (BirdLife International 2018c).

Seabirds utilize marine, terrestrial and aerial habitats, and are therefore sensitive to multiple and synergistic climate variations (Sydeman et al. 2012). The effects of climate change on seabirds may be indirect in most cases, operating through changes in local to regional food webs and the pelagic habitat. Some seabirds may fare well in a warming ocean, change their distribution and others may become extinct (Sydeman et al. 2012).

For the past 40 years, a number of research teams have collected movement data on marine birds breeding in the Galápagos. Beginning with the ground-breaking study of the foraging movements of Nazca and blue-footed boobies on Española using radio-telemetry (Anderson and Ricklefs 1987). Advancements in technology have allowed a proliferation of these studies to occur on the islands. It has become evident that animal movement plays an important role in the ecosystem functions in Galápagos. Understanding where seabirds go, find food, and migrate to, is crucial for their conservation and management.

Seabirds, like many top marine predators in the Pacific, are facing multiple threats that have resulted in population declines both globally and in Galápagos. Factors such as bycatch in fisheries, overfishing, introduced species, climate change and naturally small populations, all play a role. In its current form, the GMR partially protects the foraging distribution of the seabirds reported in this document. Pelagic seabirds are highly mobile, foraging ranges can span several thousand kilometers. Additionally, the movement data so far gathered from multiple seabird species indicate that the Humboldt upwelling system is an important area for seabirds that rely on this highly productive zone.

Marine Mammals

Galápagos is home to two endemic marine mammals – the Galápagos sea lion and the Galápagos fur seal (Salazar 2002). In addition, at least 26 whale and dolphin species either visit or reside in the waters surrounding the islands

(Denkinger et al. 2013). Indeed, early human visitors to the Galápagos Islands included the whalers of the late eighteenth century who, as well as depleting populations of sperm whales at their offshore grounds, also targeted sea lion and fur seal populations, along with giant tortoises, causing dramatic population reductions in all these species (Denkinger et al. 2013). All these species are now protected locally, nationally and internationally.

A total of 26 cetacean species in six families are reported in the Galápagos Marine Reserve (Denkinger et al. 2013). Research on marine mammals in and around Galápagos has mostly been limited to onboard tracking using visual cues and hydrophones, along with behavioral and ecological studies of key species (Denkinger et al. 2013; Eguiguren et al. 2020; Smith and Whitehead 2000). However, satellite tracking in the region in recent years has shown individuals moving to and through the GMR, e.g. blue whales (Hucke-Gaete et al. 2018).

For each species identified in these groups, we retrieved information on the description, distribution and habitat, movements, population status, threats and current conservation measures. Distribution and habitat, and movement information was obtained from three sources: maps of their geographic range from IUCN Red List (www.iucnredlist.org), maps of their geographical range obtained from satellite telemetry data where available, and spatial information from catch and bycatch data published by Bucaram et al. (2018) and Martínez-Ortiz et al. (2015). Species descriptions, population status, threats and current conservation measures information were gathered with a focus on Galápagos and the Eastern Tropical Pacific where information was available. Threat data was further assessed by using bycatch data published by Martínez-Ortiz et al. (2015) and IATTC reports.

From our list of 31 species (14 sharks, one ray, four marine turtles, eight seabirds and four marine mammals), the red-list status of almost half of these (14 species) had changed for the worse over the past 25 years. Only two species, the Galápagos shark and the olive-ridley turtle, had improved their conservation status. The change was particularly notable for sharks, of which nine species had had their conservation status changed to reflect a worsening situation. Although they belong to different taxonomic groups, sharks, sea turtles and seabirds have a series of characteristics in common, including a long-life expectancy, late onset of sexual maturity and low reproductive and natural mortality rates. These traits make these species especially vulnerable to population collapses if their mortality rates increase due to anthropogenic activities, particularly fisheries bycatch and illegal fishing.

While many of the species in the list have global or widespread distributions, some endemic and near-endemic species of Galápagos, such as the Galápagos fur seal, Galápagos sea lion and waved albatross, had also had their statuses changed to reflect greater threats.

The following sections provide information on the ecology, population dynamics and conservation status for the species in Table 5, along with their overall distribution, and distribution within the Galápagos EEZ. Where available, we have included relevant population trends and movement patterns/habitat use, either from published research articles or directly from researchers who have contributed to this document. Also, spatially explicit bycatch data gathered by the Ecuadorian artisanal fishery landings monitoring program: the *Sistema de Control y Monitoreo*, during 2008–2012. This dataset was provided and previously published by Martínez-Ortiz et al. (2015). This dataset set spans from 2008-12, and was collected on board artisanal fishing boats operating from mainland Ecuador. For further details on how maps were created, see Methods & Materials section.

Table 5 Main open-water or migratory marine species in the Galápagos EEZ, and changes in their conservation status over the past 25 years. Red: species whose status has worsened, yellow: species whose status has remained the same, green: species whose status has improved, white: species at lower risk. Information obtained from www.iucnredlist.org.

Type	Species	Common name	IUCN Red List status		
			1996-2012	2022	Change
Shark	*Alopias pelagicus*	Pelagic thresher shark	VU (2009)	EN (2018)	
Shark	*Alopias superciliosus*	Bigeye thresher shark	VU (2009)	VU (2018)	
Shark	*Carcharhinus longimanus*	Oceanic whitetip shark	LR/NT (2000)	CR (2018)	
Shark	*Prionace glauca*	Blue shark	LR/NT (2000)	NT (2018)	
Shark	*Isurus oxyrinchus*	Shortfin mako shark	LR/NT (2000)	EN (2018)	
Shark	*Isurus paucus*	Longfin mako shark	VU (2006)	EN (2018)	
Shark	*Carcharhinus galapagensis*	Galápagos shark	NT (2003)	LC (2018)	
Shark	*Carcharhinus limbatus*	Blacktip shark	LR/NT (2000)	VU (2020)	
Shark	*Galeocerdo cuvier*	Tiger shark	LR/NT (2000)	NT (2018)	
Shark	*Carcharhinus falciformis*	Silky shark	LR/LC (2000)	VU (2017)	
Shark	*Sphyrna lewini*	Scalloped hammerhead shark	LR/NT (2000)	CR (2018)	
Shark	*Sphyrna zygaena*	Smooth hammerhead shark	LR/NT (2000)	VU (2018)	
Shark	*Sphyrna mokarran*	Great hammerhead shark	DD (2000)	CR (2018)	
Shark	*Rhincodon typus*	Whale shark	VU (2000)	EN (2016)	
Ray	*Mobula birostris*	Giant manta ray	VU (2011)	EN (2019)	
Turtle	*Dermochelys coriacea*	Leatherback turtle*	CR (2000)	CR (2013)	
Turtle	*Chelonia mydas*	Green turtle	EN (1996)	EN (2004)	
Turtle	*Eretmochelys imbricata*	Hawksbill turtle	CR (1996)	CR (2008)	
Turtle	*Lepidochelys olivacea*	Olive ridley turtle	EN (1996)	VU (2008)	
Seabird	*Phoebastria irrorata*	Waved albatross	VU (2000)	CR (2018)	
Seabird	*Pterodroma phaeopygia*	Galápagos petrel	CR (2000)	CR (2018)	
Seabird	*Creagrus furcatus*	Swallow-tailed gull	LR/LC (2000)	LC (2018)	
Seabird	*Fregata minor*	Great frigatebird	LR/LC (1988)	LC (2019)	
Seabird	*Fregata magnificens*	Magnificent frigatebird	LR/LC (2000)	LC (2020)	
Seabird	*Sula granti*	Nazca booby	LR/LC (2000)	LC (2019)	
Seabird	*Sula nebouxii*	Blue-footed booby	LR/LC (2000)	LC (2020)	
Seabird	*Sula sula*	Red-footed booby	LR/LC (2000)	LC (2020)	
Marine Mammal	*Zalophus wollebaeki*	Galápagos sea lion	VU (1996)	EN (2014)	
Marine Mammal	*Arctocephalus galapagoensis*	Galápagos fur seal	VU (1996)	EN (2014)	
Marine Mammal	*Balaenoptera musculus*	Blue whale	EN (1996)	EN (2018)	
Marine Mammal	*Physeter macrocephalus*	Sperm whale	VU (1996)	VU (2008)	

*East Pacific subpopulation. Note that the global status of the leatherback turtle is now VU (Wallace et al. 2013c).


Jonathan R. Green

Pelagic thresher shark

The pelagic thresher shark *(Alopias pelagicus)* is a large (up to 365 cm total length [TL]) open water species classified as Endangered by the IUCN (Rigby et al. 2019a). It occurs in tropical and subtropical waters of the Indian and Pacific Oceans (Trejo 2005), and can be found throughout the Galápagos EEZ (Figure 21). This species is primarily oceanic and epipelagic, however can be found near the coast with a narrow continental shelf (Compagno 2001), from the surface to a depth of 300 m (Weigmann 2016). The populations living in the ETP are genetically distinct from those of the western Pacific (Cardeñosa et al. 2014). This is an active prey-pursuing and strong-swimming shark (Compagno 2001; Frumkin and Shimada 2020). Pelagic thresher sharks are thought to be night feeders, which hunt using their caudal fins to stun fish and squid (Calle-Morán and Galván-Magaña 2020). They are thought to have an annual reproductive cycle and give birth to two pups (158–190 cm) with a sex ratio of 1:1 (Compagno 2001; Liu et al. 1999). Gestation periods are uncertain because females pup year round. Females and males mature at 8–9 years (282–292 cm) and 6–9 years (259–276 cm) respectively. Longevity is about 29 years for females and 20 years for males (Compagno 2001). The annual rate of population increase is 0.033 (Dulvy et al. 2008). Stomach content analyses carried out in Ecuador and the Galápagos Islands showed that the pelagic thresher shark is a specialist tertiary predator (Calle-Morán and Galván-Magaña 2020; Polo-Silva et al. 2013), although isotopic analyses suggest it is more of a generalist (Páez-Rosas et al. 2018).

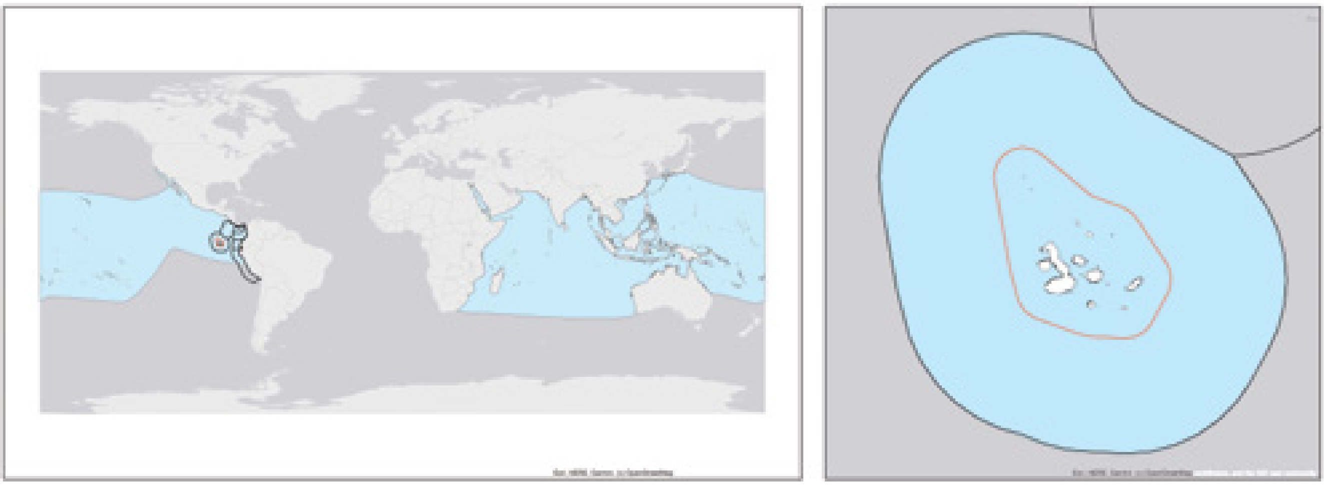


Figure 21. Global range of the pelagic thresher shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019a).

Factors such as temperature and ocean currents greatly influence its distribution, e.g. it is found near the equator in winter, but not in summer (CMS 2014). Its movements within the ETP have only been studied in the Colombian Pacific where tagged individuals made movements ranging from the Colombian coast almost to Cocos Island National Park (Peñaherrera-Palma et al. 2018a).

In the Pacific Ocean, a trend analysis from 1996 to 2014 using combined observer data for all thresher shark species, "revealed annual rates of reduction of 2.1%, an estimated median reduction of 71.5%, with a probability of 50–79% reduction over three generation lengths (55.5 years)" (Rigby et al. 2019a). Also for the same region, a demographic analysis was carried out reporting a projected stock reduction of 34.3% over twenty years (Tsai et al. 2010).

Throughout its range, it is caught by coastal and offshore fisheries (longline, purse seine, and gillnet) as both target and bycatch (Compagno 2001). High at-vessel mortality remains a threat even where retention is prohibited. The pelagic thresher is especially susceptible to fisheries exploitation due to "its epipelagic habitat occurring within the range of numerous largely unregulated and under-reported, small-scale and artisanal gillnet and longline fisheries, in which it is readily caught" (Rigby et al. 2019a). The pelagic thresher shark is one of the main shark species landed by the Ecuadorian large pelagic longline fishing fleet - representing between 67 % of the annual landings by weight of all sharks (Martínez-Ortiz et al. 2015).

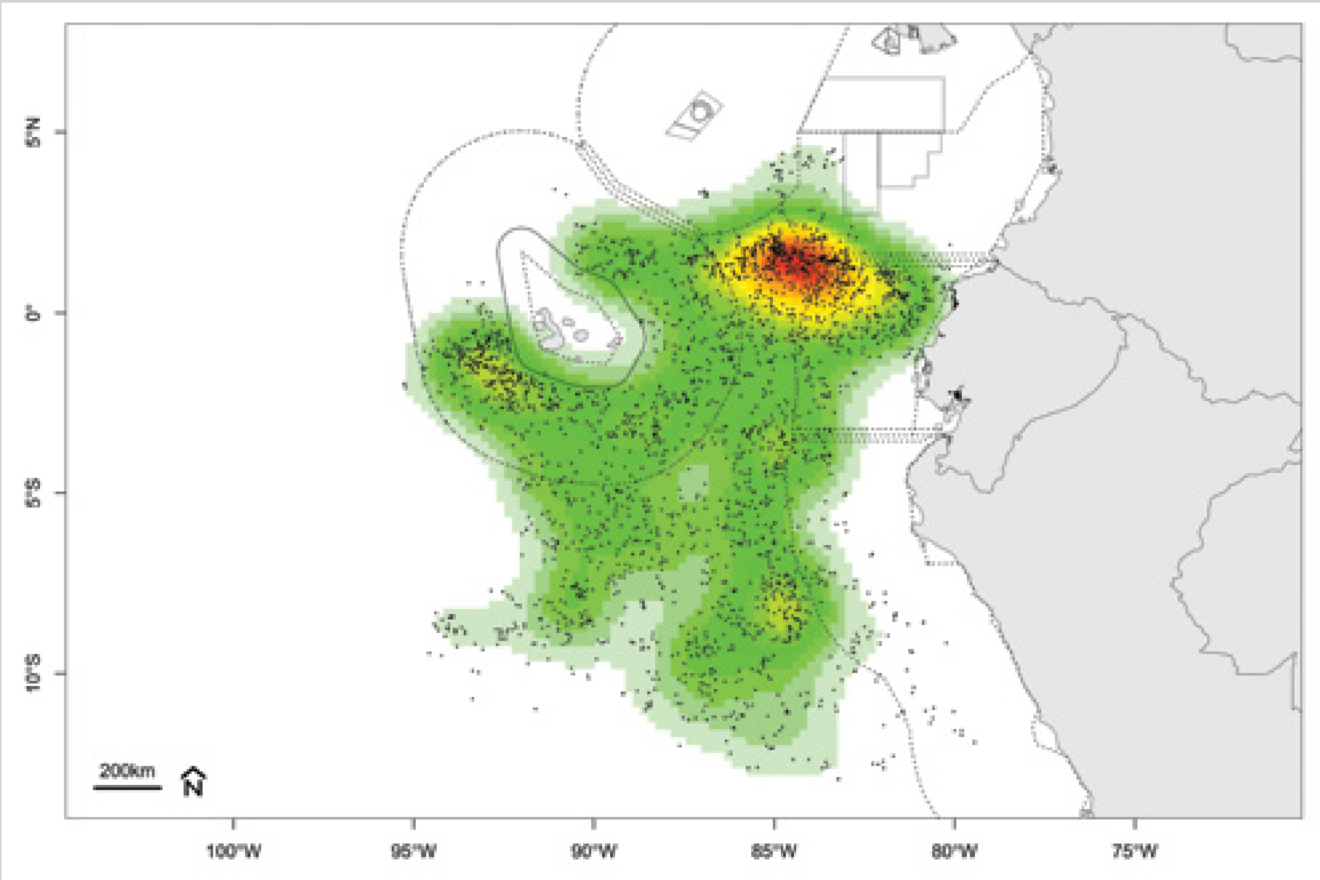


Figure 22. Location of catches of pelagic thresher sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Bigeye thresher shark

The bigeye thresher shark *(Alopias superciliosus)* is a large (up to 484 cm TL) pelagic species classified as Vulnerable by the IUCN (Rigby et al. 2019b). It occurs worldwide in tropical and temperate seas (Rigby et al. 2019b), where it occupies nearshore environments over the continental shelf and epipelagic waters in the open ocean (Compagno 2001). It is also found near the bottom in deep water on the continental slopes, from the surface to a depth of 955 m (Coelho et al. 2015), but mostly below 100 m depth. Although its "possibly extant range" within the Galápagos EEZ according to the IUCN only includes the waters to the west of the GMR (Figure 23, left), in reality this species is reported throughout the EEZ, based on longline data from both inside the GMR (Murillo et al. 2004) and from the Ecuadorian Fisheries Agency observer program (see Figure 24), so we have modified its distribution map accordingly (Figure 23, right).

Bigeye thresher sharks have an annual reproductive cycle, with a suspected gestation period of 12 months, and a litter size of two pups but sometimes with 3 or 4 (100–140 cm) with sex ratio of 1:1 (Compagno 2001). The bigeye thresher shark has "the lowest rate of annual increase of all the thresher shark species, estimated at 1.6% or 0.002–0.009 under sustainable exploitation" (Rigby et al. 2019b). Females mature at 12–13 years (294–355 cm) and males at 9–10 years (279–300 cm). Longevity is about 20 years for females and 19 years for males (Compagno 2001). Studies carried out in Ecuador and the Galápagos Islands showed that the bigeye thresher can be classified as a secondary-tertiary predator, thus is an important component of mesopelagic food webs (Polo-Silva et al. 2009).

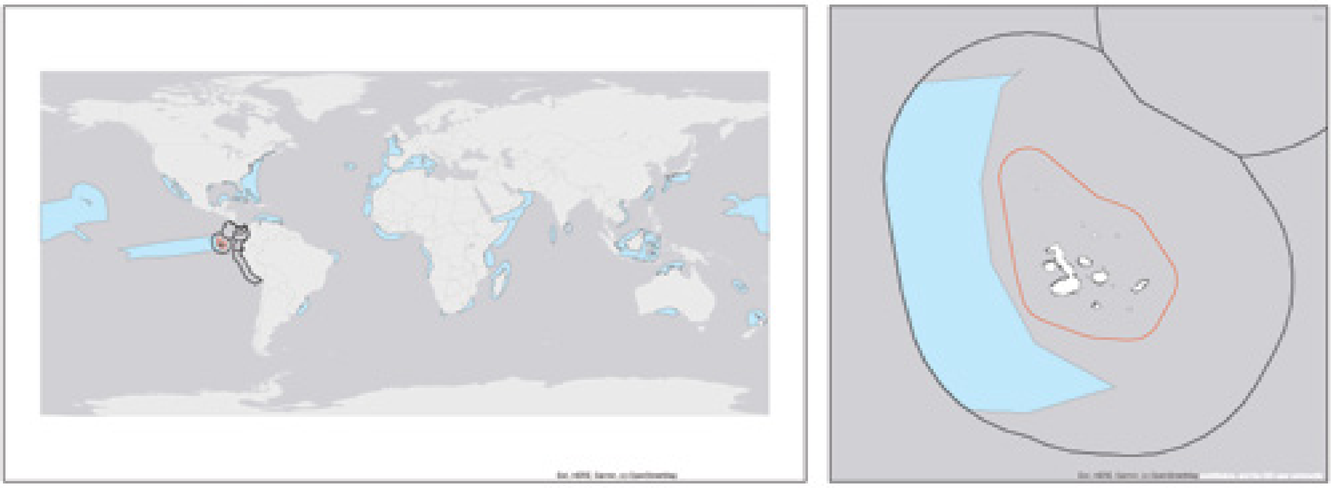


Figure 23. Global range of the bigeye thresher shark (left) and distribution within the Galápagos EEZ (right), corrected following Martínez-Ortiz et al. (2015), Murillo et al. (2004), Rigby et al. (2019b).

The population structure of the bigeye thresher shark in the Pacific Ocean is unknown, although genetic results suggest one global population (Morales et al. 2018). Nevertheless, there is genetic divergence between the Atlantic and Indo-Pacific populations (Trejo 2005). Although migrations of the genus *Alopias* have not been in-depth studied, all species are probably migratory at least within parts of their range (CMS 2014). One shark fitted with a tag traveled from the northeastern coast of the USA to the Gulf of Mexico, a straight line of 2,767 km (Weng and Block 2004). Bigeye thresher sharks fitted with conventional tags off the east coast of the USA moved outside the EEZ into the high seas and into the Gulf of Mexico (Kohler et al. 1998).

For the Pacific Ocean, fishing mortality exceeded the maximum impact sustainable threshold in some years (Fu et al. 2016). For the Central Pacific (which may not be representative of the entire region), catch per unit effort (CPUE) from Hawaii longline observer data showed annual rates of population increase of 0.4%, and a median increase of 24% over 55.5 years (Rigby et al. 2019b).

A. *superciliosus* is caught as target and bycatch in pelagic and coastal fisheries. Its meat, fins, liver oil and skin are used (Compagno 2001). It is also captured in trammel nets, and sometimes trawls, particularly in areas with narrow continental shelves (Martinez-Ortiz et al. 2015). Nevertheless, high at-vessel mortality remains a threat even where retention is prohibited. In Ecuador, this species represents between 2–3% of the annual landings by weight of all sharks, and over half the individuals landed are immature (INP 2018b). Its meat, fins, jaws, teeth, cartilage, skin and viscera are used, is found in the domestic market, sold as fresh or frozen meat (Martínez-Ortiz and García-Domínguez 2013).

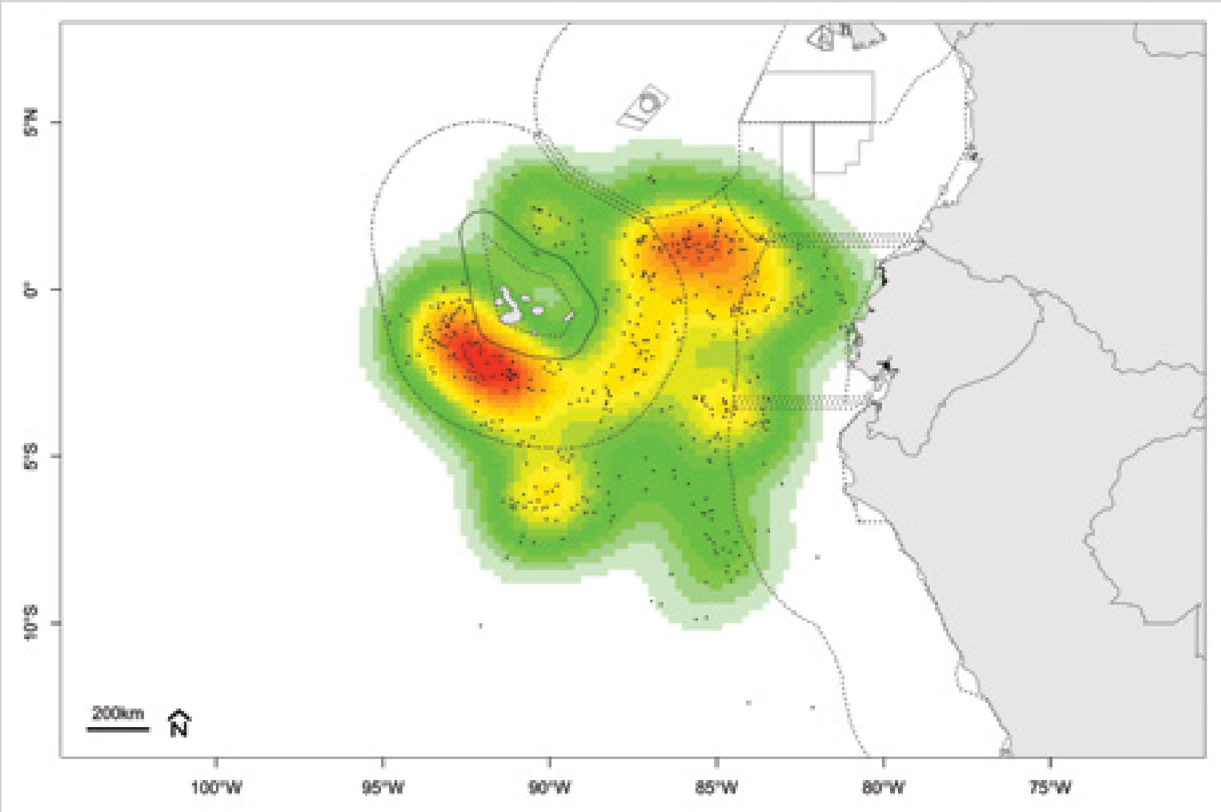


Figure 24. Location of catches of bigeye thresher sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

All thresher sharks (family Alopiidae) are listed on Annex 1 (Highly Migratory Species) of UNCLOS (Fowler 2014). In 2014, the pelagic thresher was included in Appendix II and the Annex I Memorandum of Understanding for Migratory Sharks (Sharks MOU) of the Convention on Migratory Species (CMS), which are aimed to regionally work towards conservation of those species (CMS 2020). In 2016, it was listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which requires exports from CITES Parties to be accompanied by permits that ensure individuals are sourced from legal and sustainable fisheries, based on a non-detriment finding (NDF). Ecuador's NDF for these sharks was developed in 2019, and concluded that the sale of this species did not place it at risk, however it also recognized the lack of data and the need to carry out an ecological risk assessment (INP 2018b). This NDF expired after one year and has not been updated or replaced.

Oceanic whitetip shark

The oceanic whitetip shark *(Carcharhinus longimanus)* is a large oceanic species that may attain total lengths of 350–395 cm, but usually is under 3 m (Compagno 1984). It is classified as Critically Endangered by the IUCN (Rigby et al. 2019c). It is a widespread species occurring in tropical and subtropical waters (Young et al. 2017) including the entire Galápagos EEZ (Figure 25), and may be found far offshore in the open sea (Compagno 1984). It appears to be thermally sensitive and exhibits a strong preference for the surface mixed layer in warm waters above 20 °C (Young and Carlson 2020). However, it can reach depths of 1,082 m (Weigmann 2016).

Oceanic whitetip sharks are generalist predators. They are thought to have a biennial reproductive cycle (Compagno 1984) with a gestation period of around 12 months, a litter size of 1–14 pups with larger females giving birth to larger litters (Young and Carlson 2020). Onset of sexual maturity varies between regions from 175–224 cm for females and 168–198 cm for males, with longevity being around 20.4 years (Rigby et al. 2019c), and the annual rate of increase is about 0.110 (Dulvy et al. 2008).

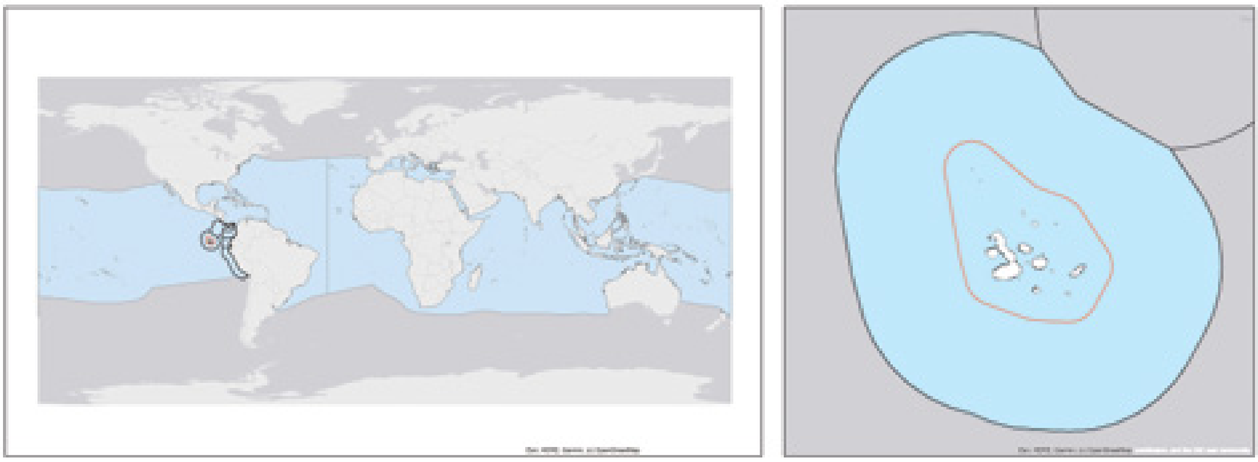


Figure 25. Global range of the oceanic whitetip shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019c).

Satellite tagging studies showed that *C. longimanus* spend most of their time in surface waters (<200 m) (Carlson and Gulak 2012; Howey-Jordan et al. 2013; Musyl et al. 2011). They usually explore environments with deep depths and/or low temperatures as a potential foraging strategy (Howey-Jordan et al. 2013). Oceanic whitetip sharks are highly migratory and display evidence of philopatry (Young et al. 2017). There is a genetic differentiation between the Indian Ocean, and eastern and western Atlantic Ocean populations (Camargo et al. 2016), but a weak differentiation between western Atlantic and Indo-Pacific Ocean populations (Ruck 2016). Nevertheless, Young et al. (2017) suggest the evidence is insufficient to determine whether or not there is separation between Atlantic and Indo-Pacific subpopulations.

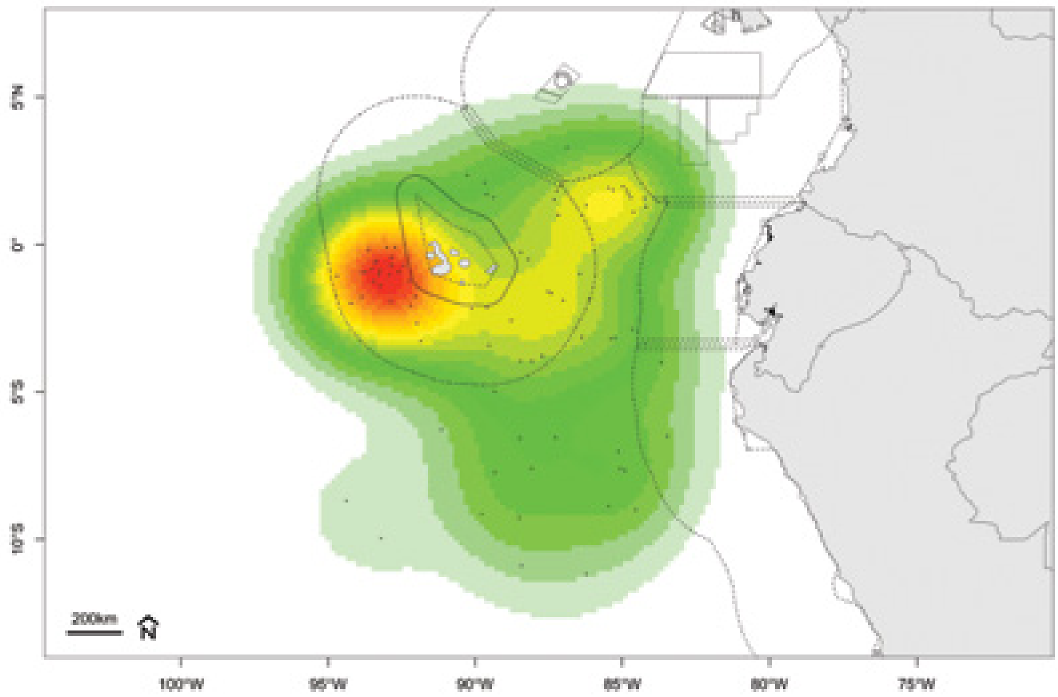


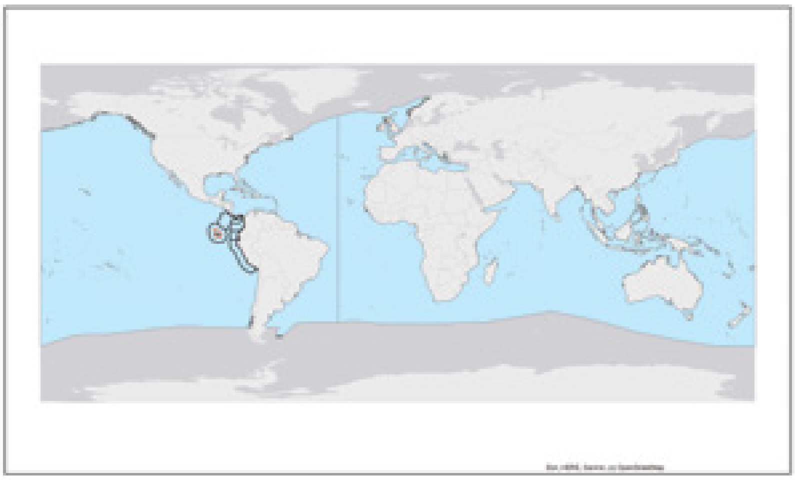
Figure 26. Location of catches of oceanic whitetip sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Bycatch in commercial fisheries is the single most important threat to this species. In Ecuador, it is caught by both the large pelagic longline fishery and the tuna purse seine fleet (Figure 26) (Martínez-Ortiz and García-Domínguez 2013). In Galápagos, this species has been reported as bycatch in yellowfin and swordfish longline experimental fisheries (Cerutti-Pereyra et al. 2020). Although the oceanic whitetip shark is generally not a targeted species, its tendency to remain in surface waters to at least 152 m, and in tropical latitudes where fishing pressure is often most concentrated for target species such as tuna and swordfish, results in frequent interactions in numerous fisheries throughout its global range (Young et al. 2018). Oceanic whitetip sharks can also command a high price in the Asian fin market. Large-scale effects, such as global climate change, affecting water temperature and currents, and possibly the dynamics of food webs could have detrimental negative effects on the species (Young et al. 2017).

The oceanic whitetip shark was the first and is still currently the only shark species to be subject to prohibitions on retention, transshipment, storage, and landing by all four major Regional Fishery Management Organizations: the International Commission for the Conservation of Atlantic Tunas (ICCAT) (Recommendation 2010/07), IATTC (Resolution C-11-10), Indian Ocean Tuna Commission (IOTC) (Resolution 13-06), and the Western and Central Pacific Fisheries Management Commission (WCPFC) (Conservation and Management Measure 2011-04) protect the species by prohibiting its retention, improving data reporting, and expanding research (IATTC 2011; ICCAT 2010; IOTC 2013a; WCPFC 2012a). In 2013, the oceanic whitetip shark was listed under Appendix II of CITES (CITES 2020). In 2018, this species was added to Annex I Sharks MOU of the CMS, and in 2020, it was listed in Appendix I of the CMS (CMS 2020). It is also listed on Annex I of UNCLOS (Fowler 2014). In 2020, Ecuador banned the sale and export of this species (MPCI 2020).

Blue shark

The blue shark *(Prionace glauca)* is a large (400 cm TL) oceanic-pelagic species classified as Near Threatened by the IUCN (Rigby et al. 2019d). Is one of the most wide-ranging of all sharks, found worldwide in temperate and tropical waters at temperatures of 12–20°C (Figure 27). It is oceanic and epipelagic, and ranges from the surface to at least 1000 m depth (Weigmann 2016); occasionally it occurs close inshore where the continental shelf is narrow (Compagno 2001; Nakano and Stevens 2008).



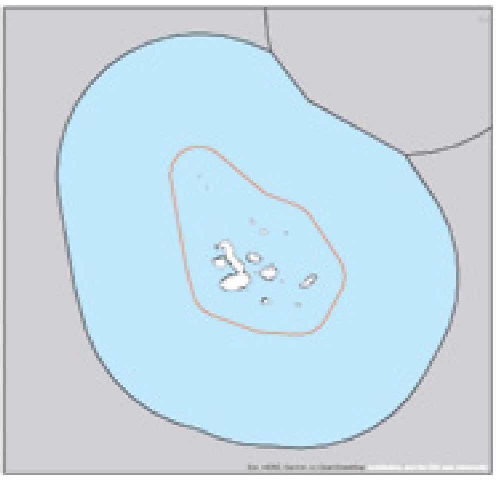


Figure 27. Global range of the blue shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019d).

The blue shark makes frequent foraging excursions between the surface and several hundred meters depth, and is most active in the early evening (Carey et al. 1990). Its diet consists mainly of small pelagic fish and cephalopods, particularly squid, crustaceans and seabirds. It may have a biennial reproductive cycle with a gestation period of around 9-12 months and a litter size of around 30 pups (35–50 cm) (Briones-Mendoza et al. 2016; Nakano and Stevens 2008). The annual rate of population increase is between 0.287-0.331 (Dulvy et al. 2008; Rigby et al. 2019d). Onset of sexual maturity differs between regions: for females it occurs at 5–7 years (183–221 cm) and for males at 4–6 years (182–218 cm) (Nakano and Stevens 2008). Longevity is 15 years for females and 16 years for males (Dulvy et al. 2008).

Tagging studies have shown that blue sharks make extensive movements with numerous transoceanic migrations (Nakano and Stevens 2008). In the Northeast Atlantic, mature females undergo seasonal latitudinal migrations on both sides of the ocean and then are followed by smaller individuals (Nakano and Seki 2003). In a study of five individuals tagged in the GMR over an average of 29.8 days (18-46 days), two individuals ranged into the high seas in the south and the Peruvian EEZ in the southeast respectively, while the remaining individuals made more localized movements both inside and outside of the GMR borders (Figure 28) (Palomino Gaviria 2019).

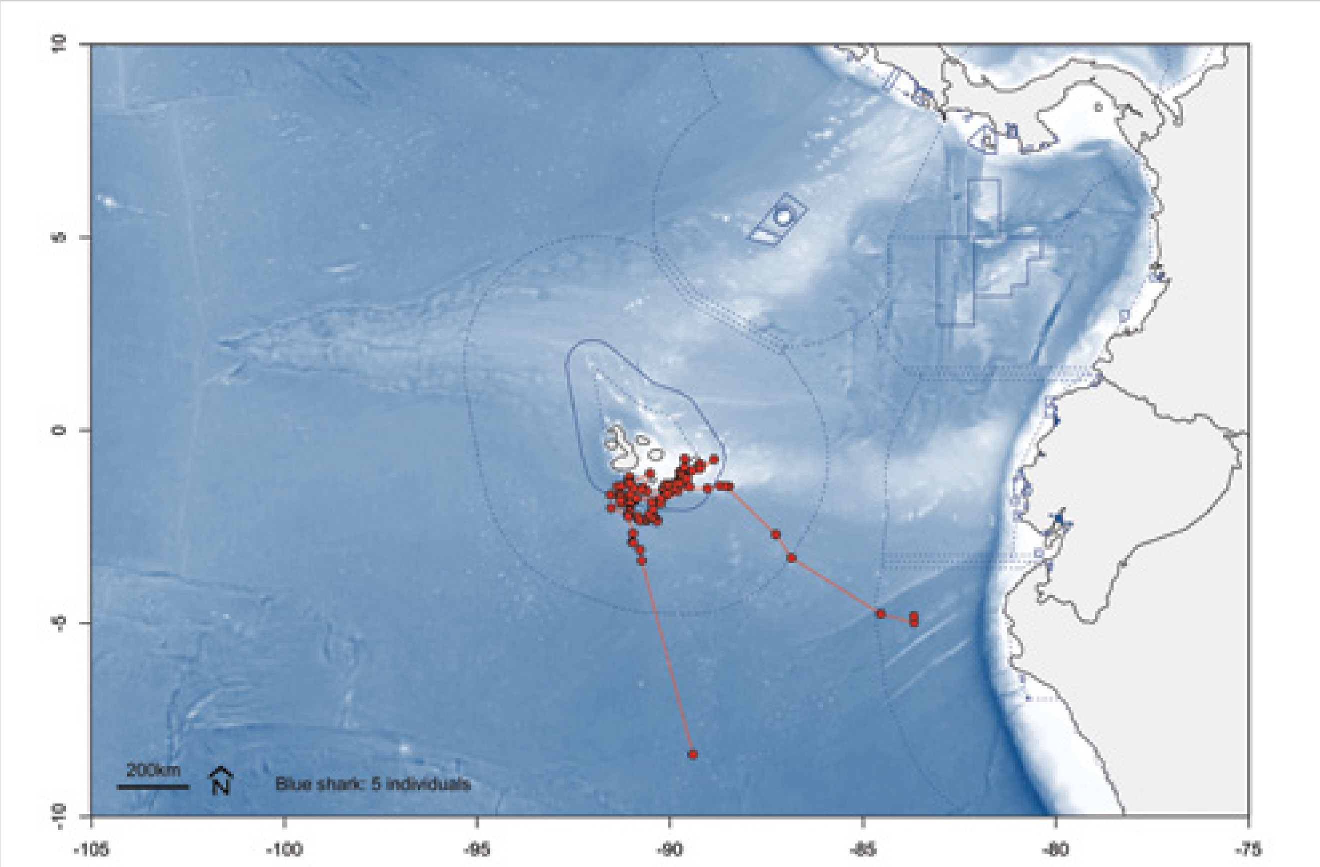


Figure 28. Tracks of five blue sharks fitted with satellite tags in 2019 (average track length 29.8 days) in the Galápagos Marine Reserve (adapted from Palomino Gaviria 2019).

There appears to be a single global population of blue sharks, although there is some weak genetic differentiation between ocean basins (Bailleul et al. 2018; Ovenden et al. 2009; Veríssimo et al. 2017). Estimations suggest a global population reduction of 20-29% over three generation lengths (30–31.5 years). For the North Pacific, annual rates of change from 1971–2015 were -0.1 to 0.4% with a median increase of 8.5% over three generations. For the South Pacific, there was an annual rate of increase of 0.2% from 1994 to 2014 and a median increase of 5.7% over three generations (Rigby et al. 2019d).

Blue sharks make up a significant proportion (17-64.2% depending on the study) of shark fins imported to Hong Kong (Clarke et al. 2006a; Fields et al. 2017). It is caught as target and bycatch in commercial and small-scale pelagic fisheries, predominantly in areas with narrow continental shelves (Martínez-Ortiz et al. 2015). It is also taken by sport fishers in several regions (Nakano and Stevens 2008). In Ecuador, *P. glauca* is caught mostly in the west of the Galápagos and in international waters between the EEZ of Ecuador, Costa Rica and Colombia (Figure 29). It is the second most abundant species caught in artisanal fisheries representing between 13.85-19.36% of the annual landings by weight of all sharks. Its meat (sold as fresh or frozen), fins, jaws, teeth, cartilage, skin and viscera are all used in the domestic and export market (Martínez-Ortiz and García-Domínguez 2013). In 2017, the blue shark was listed under Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS 2020).

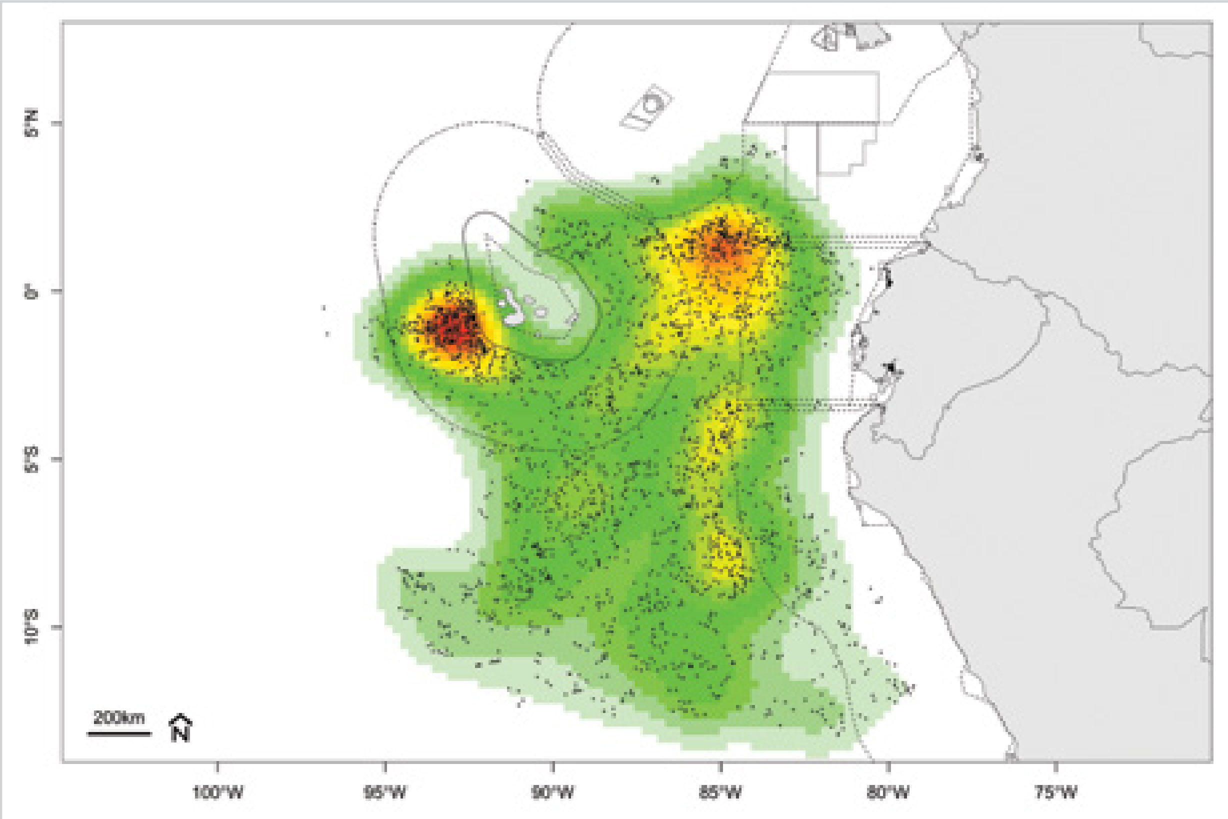


Figure 29. Location of catches of blue sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Shortfin mako shark

The shortfin mako shark *(Isurus oxyrinchus)* is a large (445 cm TL) pelagic shark (Weigmann 2016) classified as Endangered by the IUCN (Rigby et al. 2019f). *I. oxyrinchus* inhabits coastal-pelagic zones in all the world's temperate and tropical seas (Figure 30) but rarely in waters below 16°C (Compagno 2001). It is found from the surface down to 750 m (Weigmann 2016). Although they occur mostly offshore, shortfin mako sharks can move into coastal waters in areas where the continental shelves are very narrow (Compagno 2001).

Shortfin makos sharks feed on bony fishes, elasmobranchs, marine reptiles, marine mammals, and squids. They have a triennial reproductive cycle with a gestation period of 15–18 months, and a litter size of 4–30 pups (60–70 cm) (Compagno 2001). The annual rate of population increases between 0.034–0.047. Onset of sexual maturity differs between regions: for females this occurs at 18–21 years (280–311 cm) and for males at 7–9 years (196–202 cm). Longevity is between 28–32 years for females and 29 years for males (Dulvy et al. 2008).

This species is one of the fastest fishes and is highly migratory. It usually makes long distance journeys across ocean basins, and tends to follow the movements of warm water masses towards the poles in summer in the most southern and northern parts of its range, and moves between deep waters on continental slopes and coastal areas, mainly where the shelf is narrow. Several of these migrations have been described from a combination of genetic studies, as well as tracking and tagging (Casey and Kohler 1992; Compagno 2001; Schrey and Heist 2003).

There appears to be a single global population of shortfin mako sharks, although there is some genetic differentiation between ocean basins (Corrigan et al. 2018; Schrey and Heist 2003). Across its distribution, its population is declining, except in the south Pacific around New Zealand (Francis et al 2014, Rigby et al. 2019f), where catch data suggest a median increase of 35.2% over three generations (72-75 years). The overall global median reduction in population size is 46.6% over the same period. In the North Pacific there was a 0.6% annual rate of decline from 1975-2016, with a median decline of 36.5% over three generations (Rigby et al. 2019f).

The shortfin mako shark is caught as target and bycatch in pelagic commercial and small-scale longline, purse seine, and gillnet fisheries throughout its range (Rigby et al. 2019f). The meat, liver oil, jaws, skin and specially the fins are used (Rigby et al. 2019f) and traded in Hong Kong (Fields et al. 2018). In mainland Ecuador this species represents 2% of the annual landings by weight of all sharks (Martínez-Ortiz and García-Domínguez 2013), and it is mostly caught in international waters off the shelf break (Figure 31).

The shortfin mako shark was included in Appendix II of CMS in 2008 and Annex I Sharks MOU of the CMS in 2010 (CITES 2019a). In 2019, it was listed under Appendix II of CITES (CITES 2019b), but Ecuador has not yet established a non-detriment finding (NDF). It is also listed on Annex I of UNCLOS (Sellheim 2020).

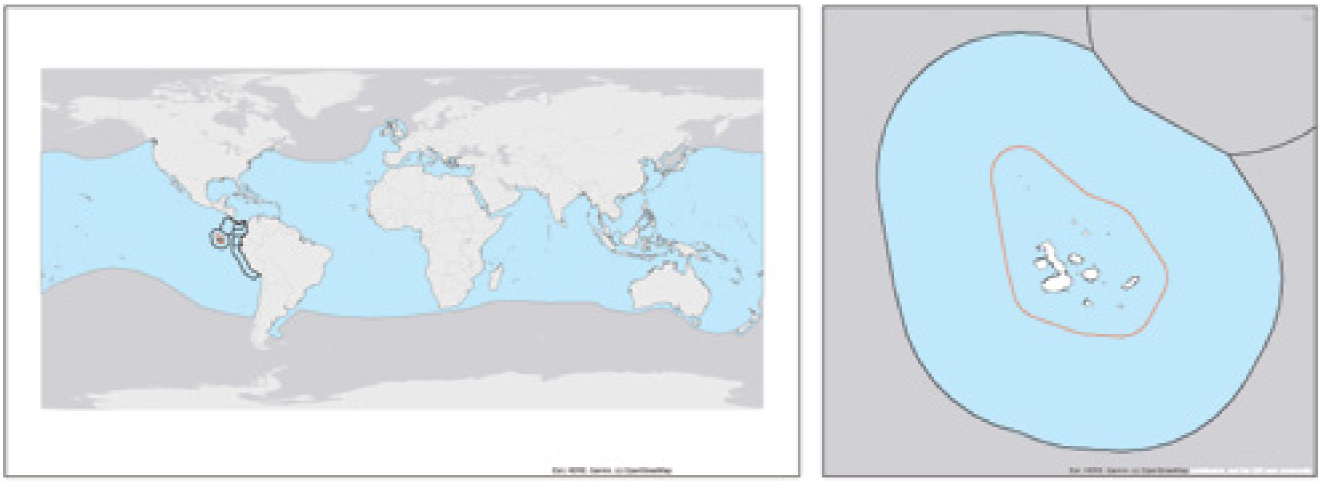


Figure 30. Global range of the shortfin mako shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019f).

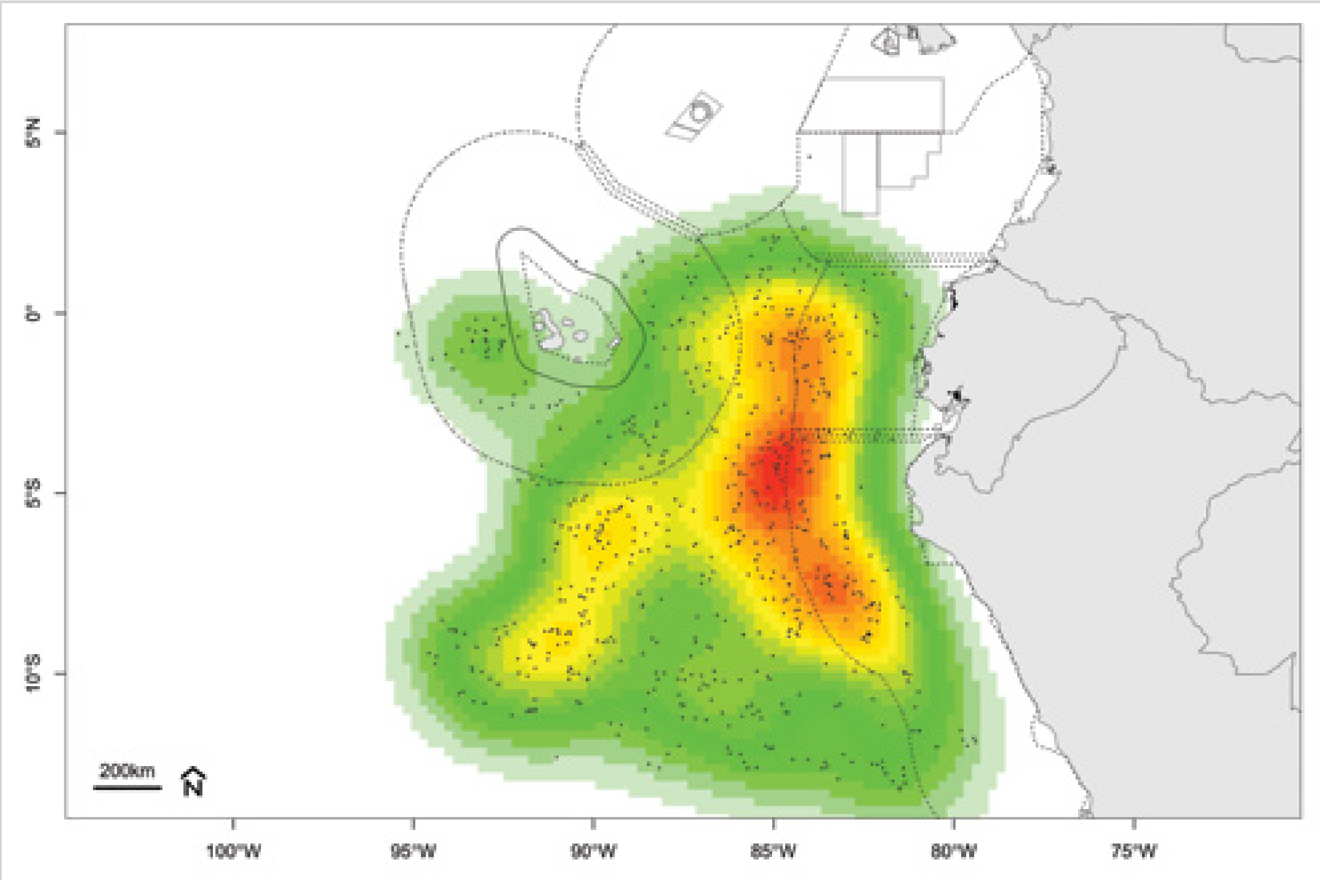
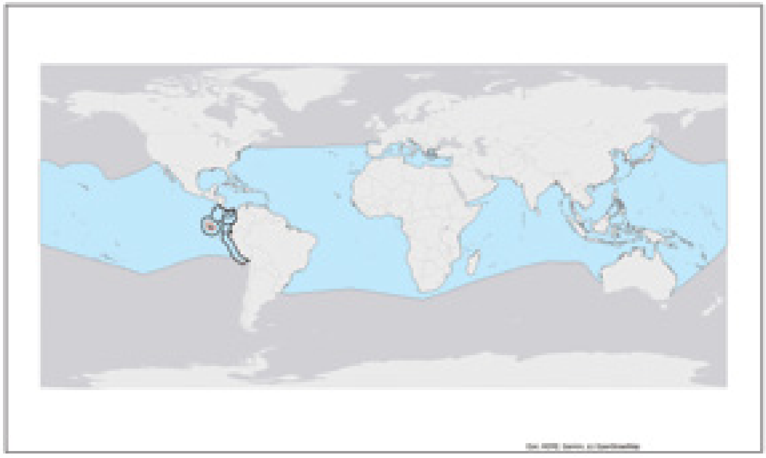


Figure 31. Location of catches of shortfin mako sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Longfin mako shark

The longfin mako *(Isurus paucus)* is a species of mackerel shark from the Lamnidae family (Compagno et al. 2005a). It is a large (up to 427 cm TL) pelagic shark classified as Endangered on the IUCN red list (Rigby et al. 2019g). This species is epipelagic, inhabiting tropical and warm-temperate waters where it feeds upon schooling fish and pelagic cephalopods (Figure 32, left) (Compagno 2001). Its range includes the entire Galápagos EEZ (Figure 32, right) (Rigby et al. 2019g). It is mostly found offshore at depths from 760 to 1752 m (Weigmann 2016). Males may mature at sizes ranging from 189-225 cm TL (Varghese et al. 2017), and mature females were 245 cm TL and above (Compagno 2001). This species is ovoviviparous, with a litter size of 2 to 8, giving birth fully developed juveniles measuring 92 to 120 cm at full-term (Compagno et al. 2005a). Intra-uterine cannibalism has been reported for this species (Gilmore et al. 2005).

This species is common in the western Atlantic and central Pacific oceans, yet its distribution and movements are confused with the shortfin mako due to their physical similarities (Compagno et al. 2005a). Using satellite tags, longfin mako movements have been reported from the northwestern coast of Cuba (in February) into the Gulf of Mexico (in April



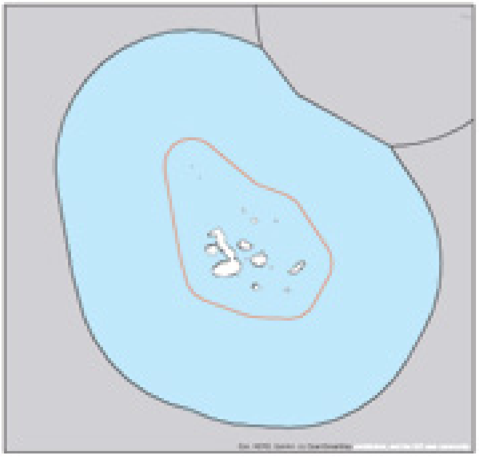


Figure 32. Global range of the longfin mako shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019g).

and May) and off the US mid-Atlantic coast (in July) (Hueter et al. 2017). Northern Cuba is an important highway for the migration of this and other pelagic species among the Gulf of Mexico, Caribbean Sea, and northwest Atlantic (Aguilar et al. 2014). There is no information about the movement ecology of this species in the ETP.

A recent evaluation by the IUCN has classified this species as declining (Rigby et al. 2019g). Populations in the Atlantic Ocean have shown annual decline rates of 3.7%, a median decline of 93.4% and a high probability of >80% reduction over three generation lengths (75 years). Global analyses have estimated a median decline of 60.4% with the highest probability of >80% reduction over 75 years (Rigby et al. 2019g).

The longfin mako shark is thought to have a greater depth range than the shortfin mako, and this may explain why it is less commonly caught on shallow pelagic longlines (Mucientes et al. 2013). A such, this species is not a target but bycatch species in pelagic commercial and small-scale longline fisheries (Mucientes et al. 2013). In Ecuador, this species is also caught in the small-scale artisanal and semi-industrial longlines and gillnet fisheries, but is quite rare, with only 47 records from 2008-12, in comparison with 27,864 records of shortfin mako (Martínez-Ortiz et al. 2015). The body parts are often used as meat and in cosmetic industries (Martínez-Ortiz and García-Domínguez 2013), and their fins can be found mixed with those of shortfin mako and thresher sharks, in shark fin markets in Hong Kong (Clarke et al. 2006a).

In 2019, the longfin mako shark was listed under Appendix II of CITES (CITES 2019b), but Ecuador has not yet established a non-detriment finding (NDF). It is also listed on Annex I of the UNCLOS (Sellheim 2020).

Galápagos shark

The Galápagos shark *(Carcharhinus galapagensis)* is a large (370 cm TL) coastal pelagic species (Compagno 2001) classified as Least Concern by the IUCN (Kyne et al. 2019). This species occurs globally in throughout tropics (Figure 33), but has a patchy distribution, generally around archipelagos, and coastal and oceanic seamounts (Compagno et al. 2005b), where it can be the most abundant local shark species (Compagno 2001), in particular in the northwestern Hawaiian, Galápagos, and Clipperton Islands.

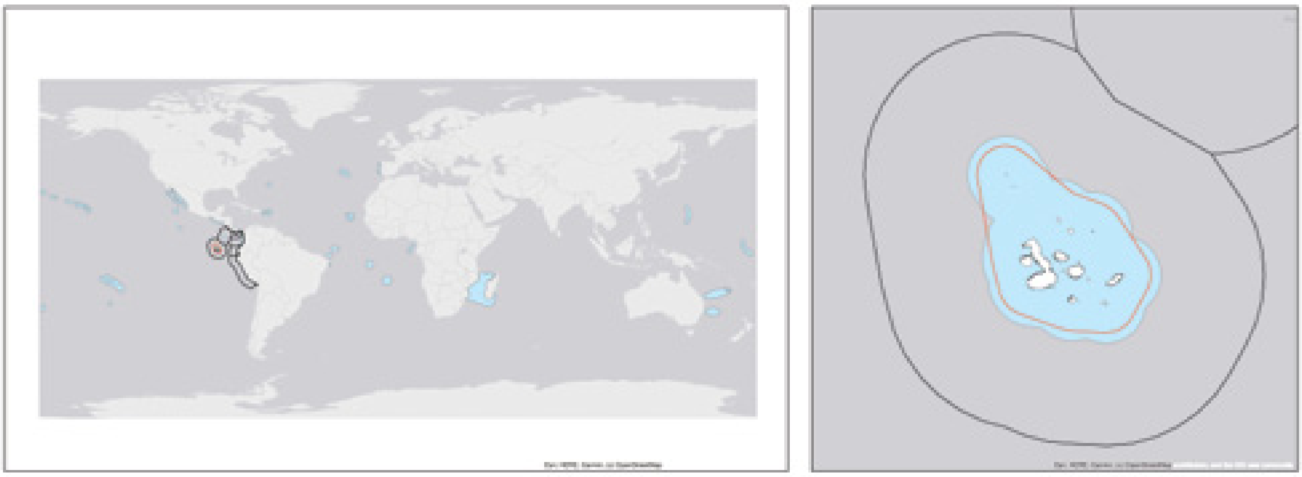


Figure 33. Global range of the Galápagos shark (left) and distribution within the Galápagos EEZ (right). Source: Kyne et al. (2019).

Their reproductive cycle may be biennial or triennial (Kyne et al. 2019), and they have a gestation period of 12 months with litter sizes of 4–16 pups (57–81 cm). The pups stay in shallow water nursery areas to avoid predation and cannibalism from members of their own species, eventually moving out to deeper waters as they mature (Compagno et al. 2005b). Females mature at 6.5–9 years (215–245 cm) and males at 6–8 years (205–239 cm) (Wetherbee et al. 1996). Longevity is about 24 years (Castro 1983). Studies carried out in the Galápagos Archipelago showed that the removal of these high trophic level predators would modify the composition and abundance of their prey species, directly or indirectly affecting the rest of the marine organisms, resulting in an imbalance on food webs and also have a serious impact on ecotourism (Danulat and Edgar 2002).

Studies in Hawaii using both acoustic and satellite transmitters suggest that these sharks are more resident around oceanic islands (Meyer et al. 2010). Tagging in the ETP region supports this, although some inter-island movements have been recorded, notably between Socorro-Clipperton-Galápagos and between Malpelo-Galápagos (unpublished data). Four Galápagos sharks fitted with satellite tags inside the GMR mostly stayed in coastal waters around the islands where they were tagged (Figure 34) (Hearn et al. 2017).

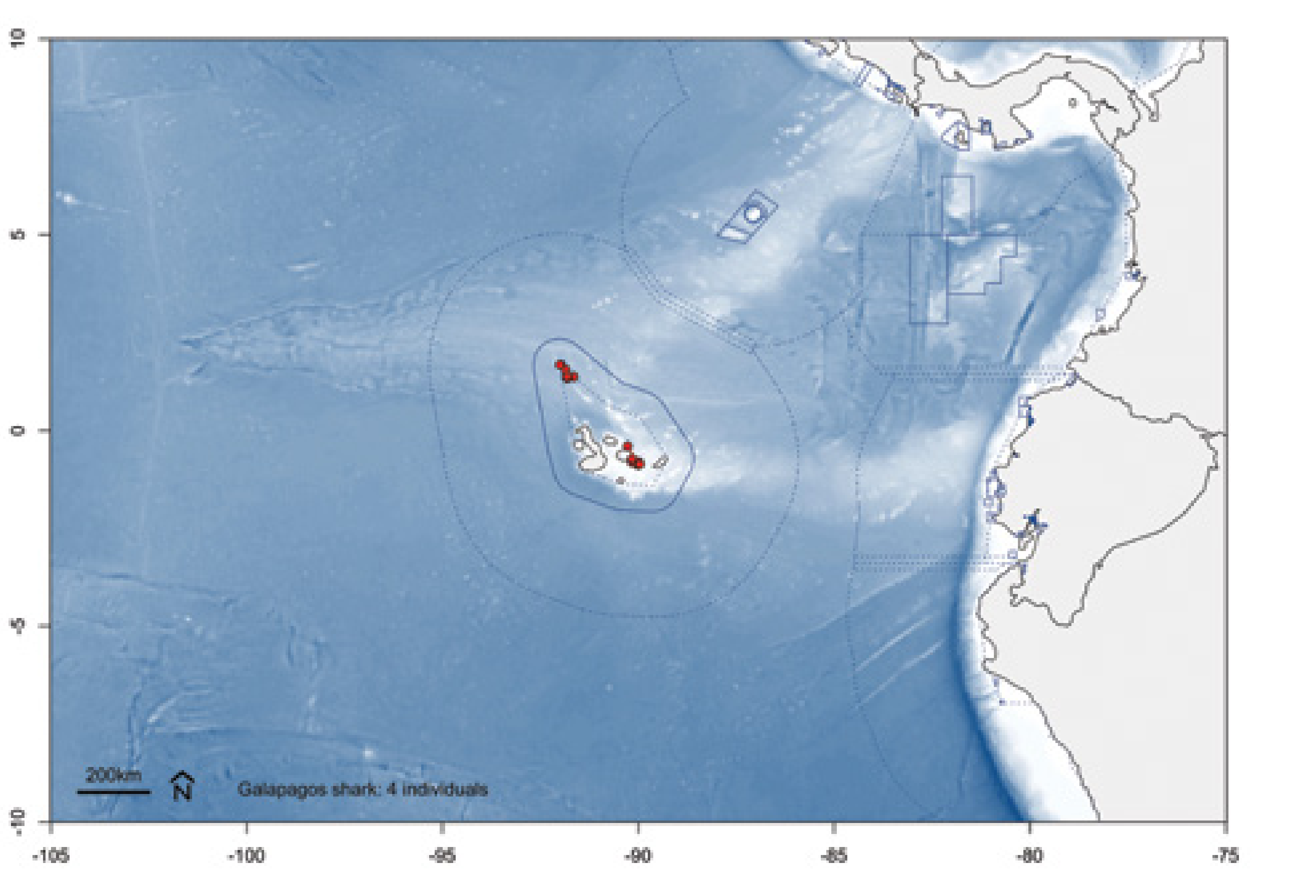


Figure 34. Satellite tracks of four Galápagos sharks tagged in the Galápagos Marine Reserve 2006-2012 (average track length 40 days). Source: Hearn et al. (2017) and one unpublished track (Hearn, unpublished data).

Galápagos sharks display genetic differences between the ETP and the rest of the Pacific (Pazmiño et al. 2018). It is thought that the "Pacific Galapagos sharks are currently genetically healthy overall, with the central-west Pacific Galapagos shark stock having almost five-fold more breeding individuals than the east Pacific population" (Pazmiño et al. 2018). The Galápagos shark has a very different story in each region. A survey of perceptions of dive guides in the GMR suggested that its abundance declined by approximately 30% from the 1980s to the 2010s and then stabilized (Peñaherrera-Palma et al. 2018b). Nevertheless, over a twenty-one year period, the observation frequency increased by 33% per year at Cocos Island National Park (White et al. 2015). There are no clear trends for this shark around Malpelo (Soler et al. 2013).

"The Galapagos shark is caught as bycatch in commercial and small-scale longline, purse seine, and gillnet fisheries, both in pelagic oceanic waters and around islands and seamounts" (Kyne et al. 2019; Martínez-Ortiz et al. 2015), and are often retained by fishers (Clarke et al. 2006a; Fields et al. 2018). In Ecuador, *C. galapagensis* is caught as bycatch by artisanal fiberglass boats, ships motheboats (wood and fiberglass) and industrial purse seine vessels, in particular around the GMR (Figure 35) (García-Domínguez and Martínez-Ortiz 2013). Galápagos sharks are listed on Annex I of UNCLOS (Fowler 2014).

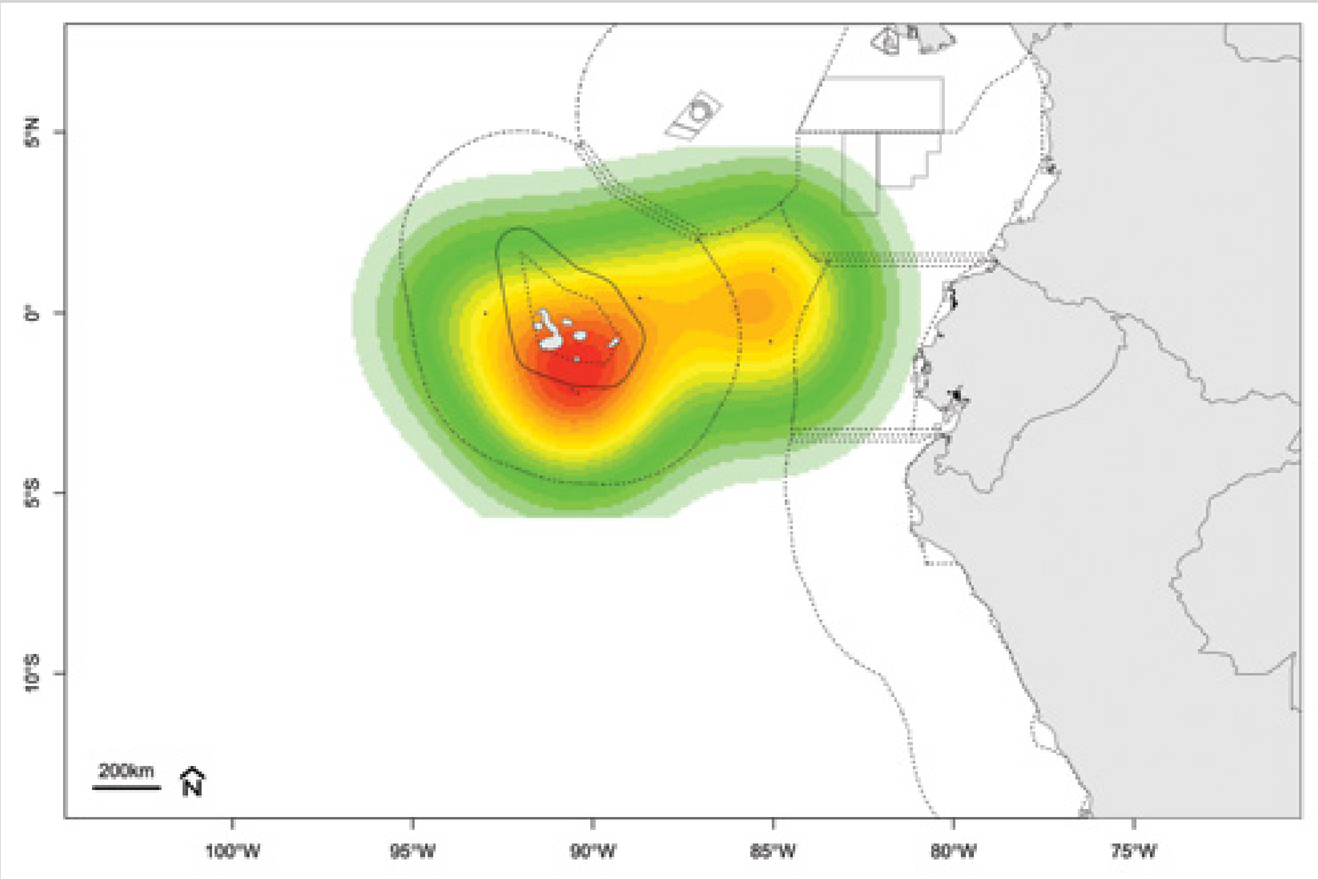


Figure 35. Location of catches of Galápagos sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Blacktip shark

The blacktip shark *(Carcharhinus limbatus)* is a medium-sized (286 cm TL) coastal-pelagic species classified as Vulnerable by the IUCN (Froese and Pauly 2019, Rigby et al. 2021a). *C. limbatus* inhabits all tropical seas in the world, and tends to associate with coastal-benthic and seamount zones (Figure 36) (Compagno et al. 2005b). They mainly live in coastal surface waters to depths of 30 m though they may dive to 140 m (Froese and Pauly 2019, Rigby et al. 2021a). Blacktip sharks may also occur near the coast around the mouths of rivers, bays, mangroves and estuaries (Martínez-Ortiz and García-Domínguez 2013).

These are active and fast-swimming sharks that often occur in large schools at the surface. Blacktip sharks can leap out of the water, earning them their Spanish nickname – tiburón volador (flying shark). They feed on small schooling fishes, cephalopods, rays and crustaceans (Compagno 1984). Blacktip sharks commonly follow fishing trawlers consuming discarded bycatch (Burgess and Branstetter 2009). They have a biennial reproductive cycle (Martínez-Ortiz and García-Domínguez 2013). Females mature at 165–180 cm and males at 173–185 cm (Dávalos Malo 2018). Gestation period is 10-12 months and litter sizes range from 1–10 pups (Compagno 1984). Nursery grounds are located inshore where pregnant females go to pup; longevity is about 12 years (Compagno 1984).

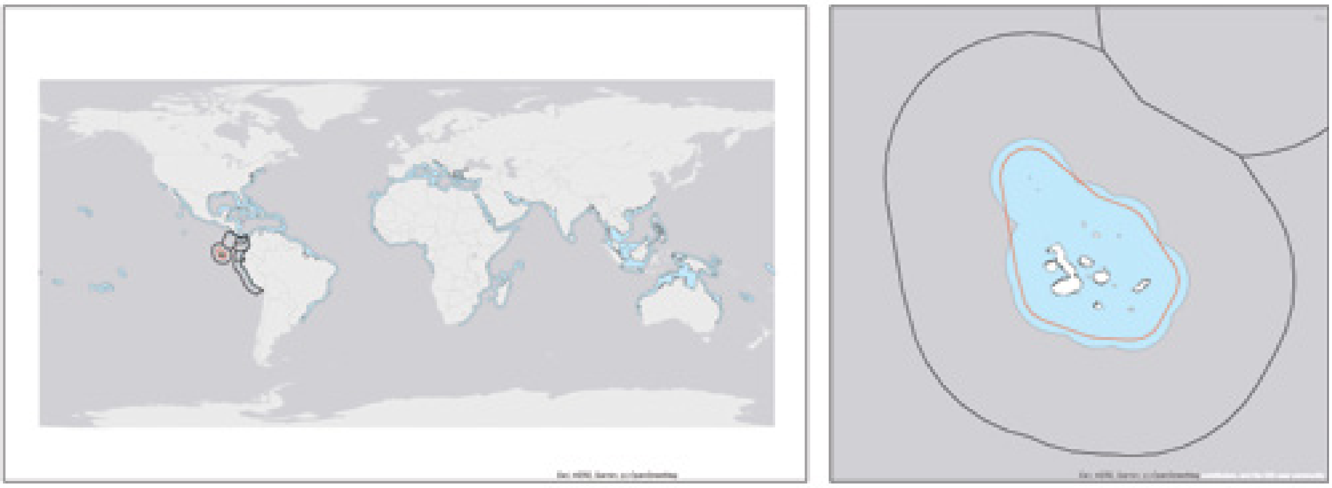


Figure 36. Global range of the blacktip shark (left) and distribution within the Galápagos EEZ (right). Source: Burgess and Branstetter (2009).

Blacktip sharks have been tagged and tracked in the GMR. Tagged sharks stayed within the GMR (Figure 37), and with preference for SST average of 25.7°C (Peñaherrera-Palma et al. In review). Nursery grounds at mangrove-fringed bays have been identified and studied in both Santa Cruz and San Cristóbal Islands (Chiriboga Paredes 2018; Goodman 2020; Llerena et al. 2015). This species displays a high fidelity to its breeding and feeding areas, using olfactory signals and potentiallt several other mechanisms such as geomagnetic information and tides, to recognize their specific home range (Gardiner et al. 2015).

The current worldwide population trend is unknown (Burgess and Branstetter 2009). In the ETP region, the blacktip shark is the only studied species of shark that has shown some indications of an increase in abundance. In the GMR, a study of perceptions among dive guides indicated that the abundance of blacktip sharks may have increased, after having suffered declines over the last three decades since the 1980s (Peñaherrera-Palma et al. 2018b). At Cocos Island, dive surveys indicated a 9% annual increase in abundance over a 21-year period (White et al. 2015).

This shark species is an important component of the shark catches in the western North Atlantic, in Mexico and in the Indian Ocean. Its fins are dried and shipped to Asia (Burgess and Branstetter 2009). In Ecuador, this species is sometimes caught as bycatch in longline and purse seine fisheries (Figure 38), and represents between 0.09–0.31% of annual landings by weight of all sharks (Martínez-Ortiz and García-Domínguez 2013). Blacktip sharks are listed on Annex I of UNCLOS (Fowler 2014).

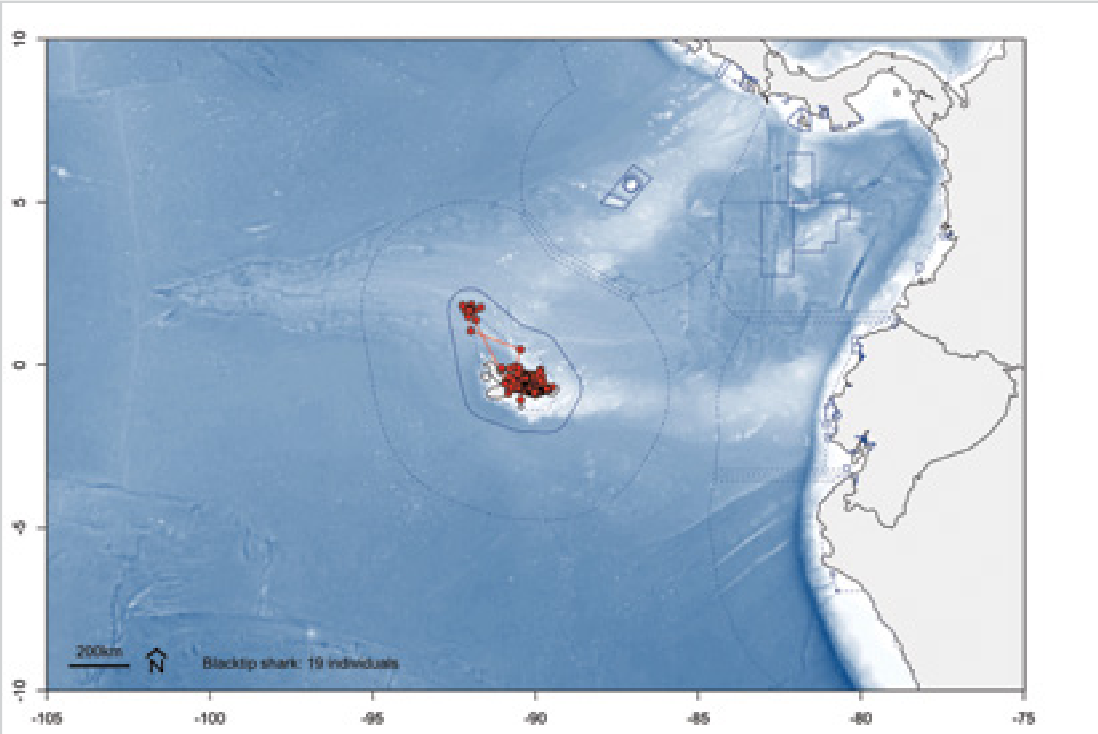


Figure 37. Satellite tracks of nineteen blacktip sharks tagged in the Galápagos Marine Reserve, 2006-2014 (average track length 101 days). Adapted from Peñaherrera-Palma (2016) and includes one unpublished track (Hearn unpublished data).

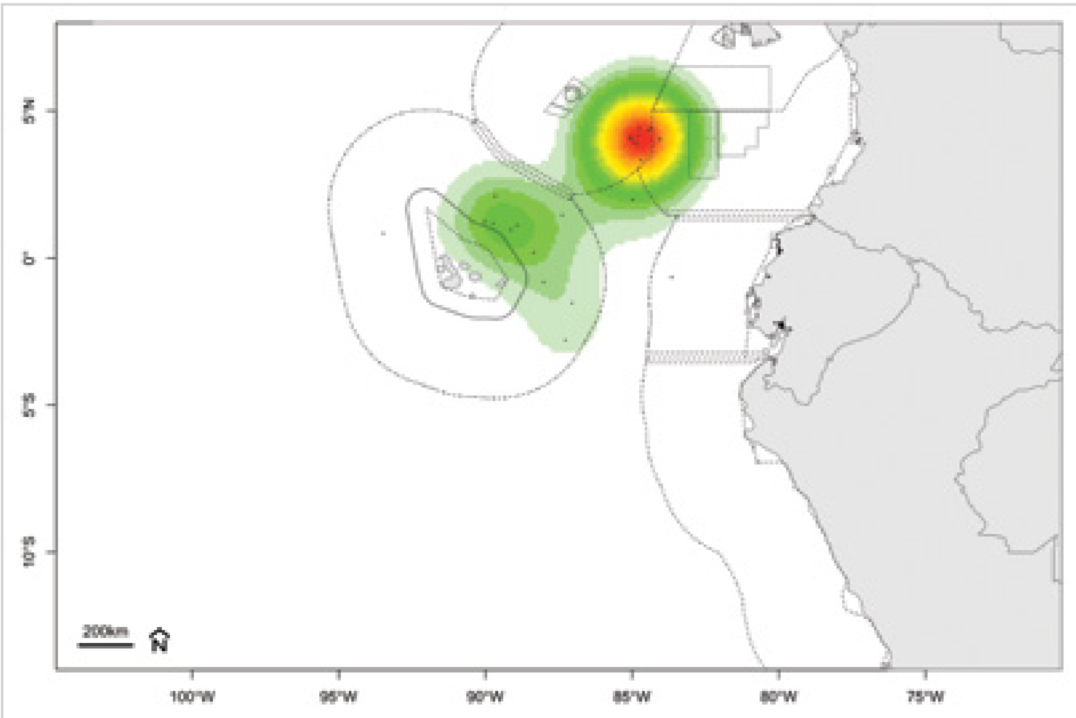


Figure 38. Location of catches of blacktip sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Tiger shark

The tiger shark *(Galeocerdo cuvier)* is a large (740 cm TL) tropical shark (Compagno 1984) classified as Near Threatened by the IUCN (Ferreira and Simpfendorfer 2019). G. cuvier inhabits coastal-pelagic zones in all the world's tropical seas (Figure 39) (Compagno et al. 2005b), particularly those with water temperatures between 20°C and 26°C (Holmes et al. 2014). This species lives mainly in coastal waters to usually 100 m deep though they may dive to depths greater than 1,000 m. It prefers shady areas with large freshwater inputs and sometimes coral reefs (Ferreira and Simpfendorfer 2019).

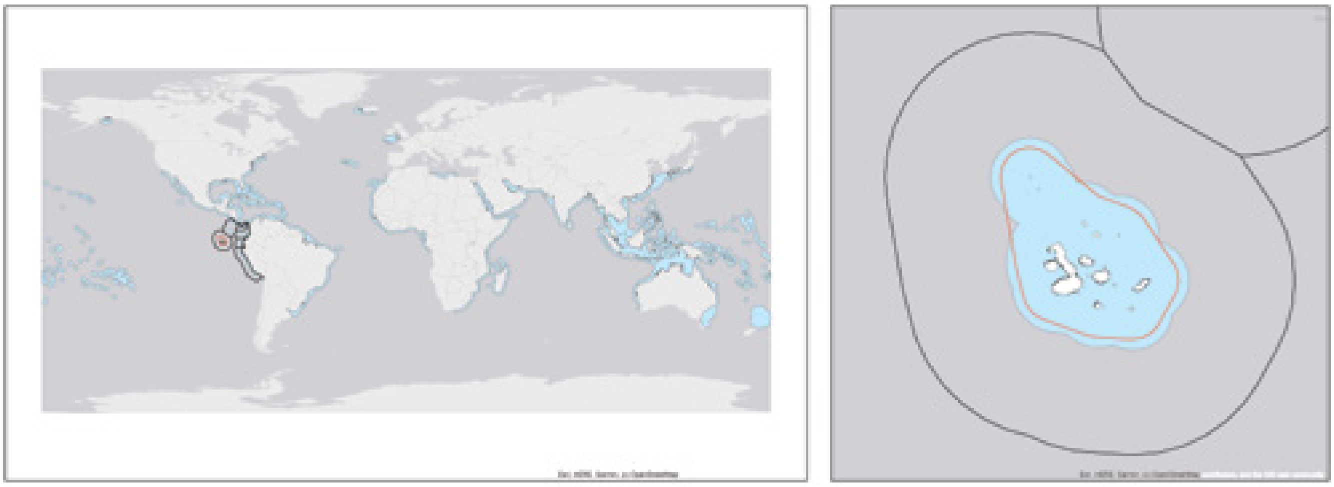


Figure 39. Global range of the tiger shark (left) and distribution within the Galápagos EEZ (right). Source: Ferreira and Simpfendorfer (2019). Note that they are known to move outside the GMR (see text), and therefore their distribution within the Galápagos EEZ is wider than shown.

Tiger sharks are generalist predators, and are known to feed on a wide range of taxonomic groups, from mollusks to seabirds and mammals (Compagno 1984). Their reproductive cycle is biennial and, in some regions, triennial (Martínez-Ortiz and García-Domínguez 2013; Whitney and Crow 2007). Their gestation period is around 13–16 months, and litters sizes range from 26–82 pups (51–90 cm). They can live up to 27-37 years (Ferreira and Simpfendorfer 2019), and have an intrinsic population increase rate of 0.227 (Dudley and Simpfendorfer 2006).

Tiger sharks movement patterns range from resident to highly migratory behavior (Holland et al. 2019). The majority of studies have taken place in the Eastern Central Pacific where tiger sharks usually display site fidelity to core islands but also move between islands for foraging purposes (Meyer et al. 2010). Tagging work carried out the ETP suggests long-term residency at Galápagos; Figure 40), punctuated by long-distance movements into the open ocean or to mainland coastal waters (Acuña-Marrero et al. 2017). Tiger sharks in the western North Atlantic show basin-wide connectivity, from temperate to tropical ecosystems (Lea et al. 2015). In Florida and Bahamas, these sharks exhibit associations with oceanic currents, apparently due to the high productivity (Hammerschlag et al. 2012). In the Gulf of Mexico, "sub-adult and adult sharks achieved significantly higher movement rates and used off-shelf deeper habitats at greater proportions than juvenile sharks", also female maximum rate of movement was higher than males (Ajemian et al. 2020).

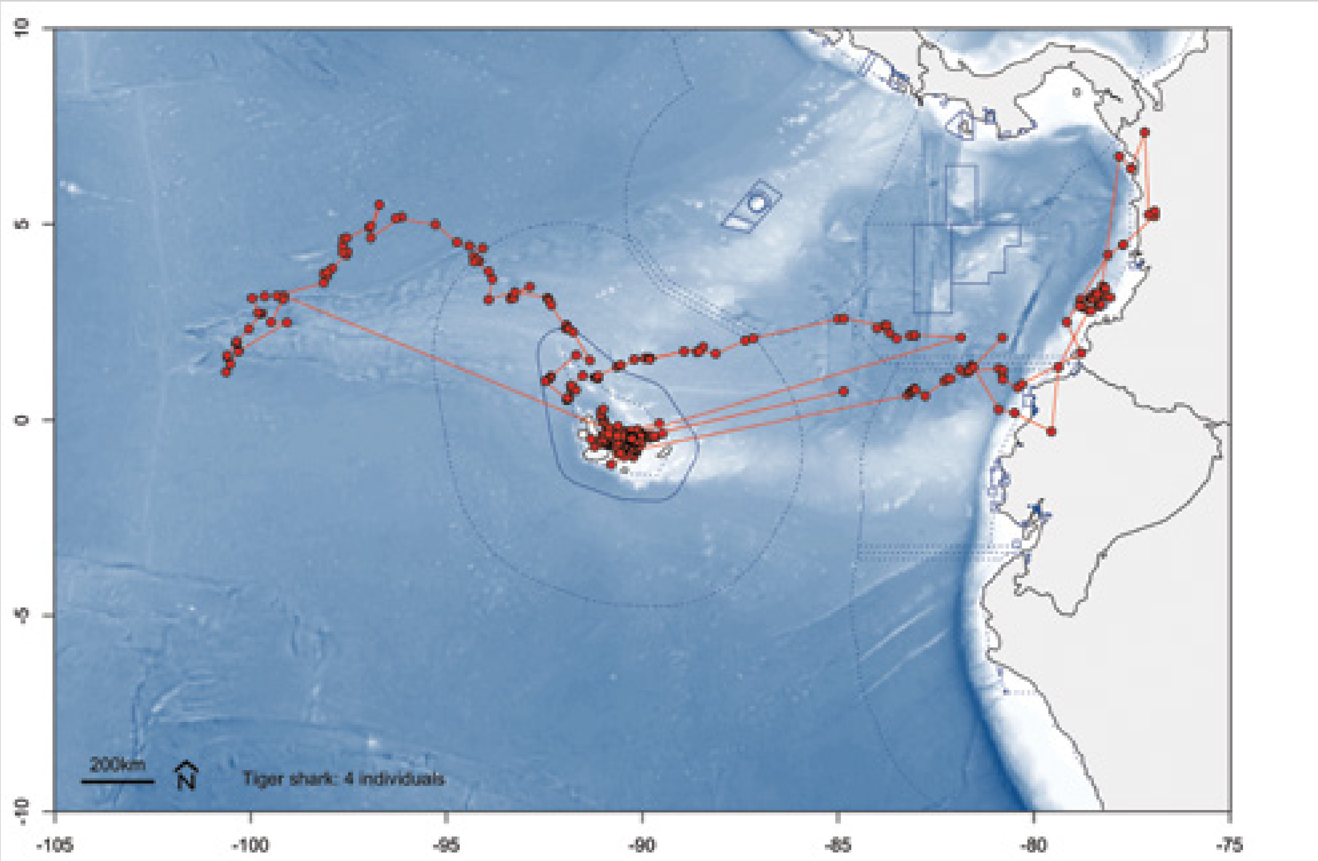


Figure 40. Satellite tracks of four tiger sharks tagged in the Galápagos Marine Reserve in 2014 (average track length 197 days). Adapted from Acuña-Marrero et al. (2017).

Studies in mainland Ecuador and the Galápagos Archipelago suggest that the removal of this species affect the ecotourism and the composition and abundance of their prey species, affecting the rest of the marine organisms, resulting in an imbalance on food webs (Danulat and Edgar 2002; Martínez-Ortiz and García-Domínguez 2013).

Globally, tiger sharks have experienced a population reduction of close to 30% over the past three generations (53–68 years) (Ferreira and Simpfendorfer 2019), however in some places their numbers are increasing moderately – such as in South Africa (Dudley and Simpfendorfer 2006). At Cocos Island, tiger sharks were absent at least since the mid 1990s until 2007, after which the odds of encountering a tiger shark increased by 79% annually, and they are now one of the main attractions at certain sites (White et al. 2015). Population trends in the GMR are unknown, because it is rare to encounter a tiger shark while diving, however they are regularly seen at the surface off turtle nesting beaches in the central archipelago. One tiger shark tagged in the GMR in 2014 was recently detected at Cocos Island (El Comercio 2021a).

Globally, *G. cuvier* is caught in target shark fisheries and as bycatch in commercial and artisanal fisheries. The fishing gears used are longline, gillnets, purse seine and trawl fisheries. The species has been increasingly exploited by fisheries due to the increasing demand from the shark fin trade (Ferreira and Simpfendorfer 2019). In mainland Ecuador it is occasionally caught and landed by the longline fleet (Figure 41). Tiger sharks are listed on Annex I of UNCLOS (Fowler 2014).

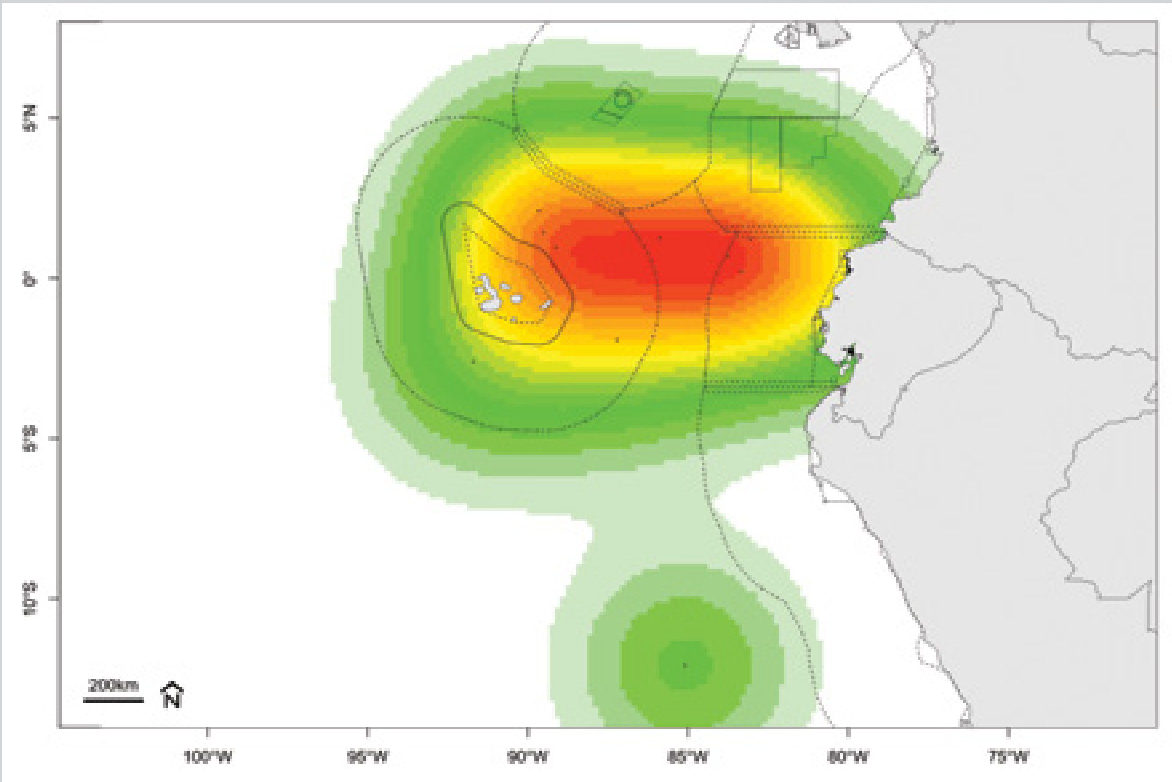


Figure 41. Location of catches of tiger sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Silky shark

The silky shark *(Carcharhinus falciformis)* is a coastal-pelagic species (maximum 316 cm TL) classified as Vulnerable by the IUCN. It is a common shark found globally in tropical and sub-tropical seas (Figure 42) (Rigby et al. 2017, 2021b). It can be found near the edge of continental shelves and oceanic islands, but also far from land in the open sea. In the open ocean it occurs from the surface to at least 500 m depth (Compagno 1984).

Silky sharks feed mainly on bony fishes but also take squids, pelagic crabs and turtles (Compagno 1984; Estupiñán-Montaño et al. 2017). Their gestation period is from 9 to 12 months, with litter sizes of 2–14 pups (65–81 cm) (Martínez-Ortiz and García-Domínguez 2013) and annual rate of increase about 0.067 (Dulvy et al. 2008). In the eastern central Pacific, both males and females matured at 180-182 cm (7-8 years) and maximum ages for each sex were 14 and 16 years respectively (Rigby et al. 2017, 2021b). Studies carried out in Ecuadorian waters showed that silky sharks are specialist predators in the food web (Estupiñán-Montaño et al. 2017), while stable isotope studies from the Galápagos Islands suggest that they are generalist predators (Páez-Rosas et al. 2018).

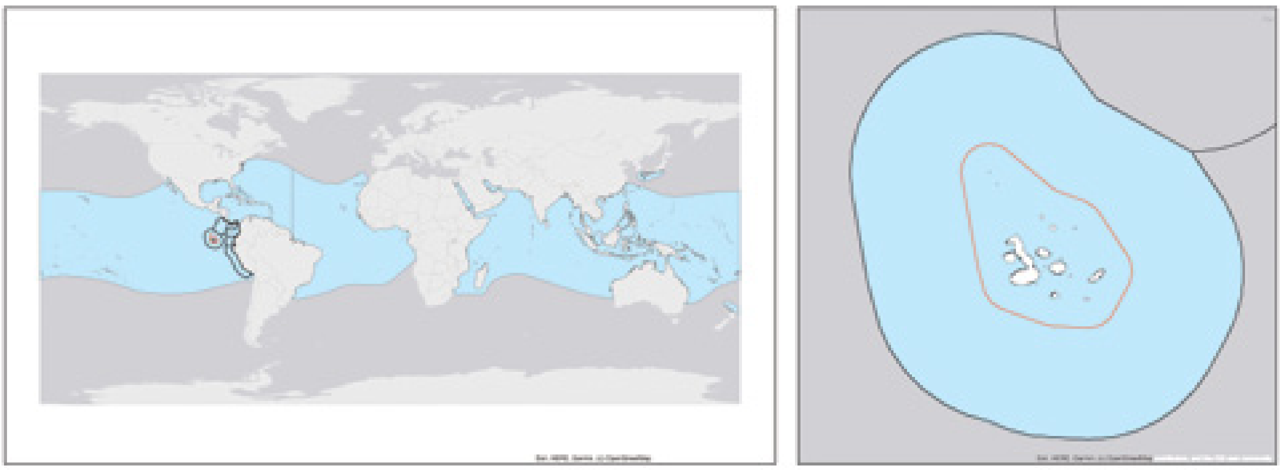


Figure 42. Global range of the silky shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2017, 2021b).

Silky sharks may travel great distances over short time periods (Clarke et al. 2011). They move between oceanic and coastal systems and between the northern and southern regions, potentially using warm currents and islands as stepping stone areas (Galván-Tirado et al. 2013). In the eastern Pacific, seven individuals with pop-off archival tags moved along the EEZ of six countries in Central America (Kohin et al. 2006). Silky sharks fitted with ultrasonic tags in the GMR have displayed long term residency, but occasional absences – for example one individual made two return movements to Clipperton Island, some 1500 km from Galápagos (Hearn et al. (2017); Hearn et al., unpublished data) Satellite tracks mostly showed a strong site fidelity to the islands (Figure 43) (Hearn et al. 2017; Peñaherrera-Palma et al. 2018a).

Silky sharks display low genetic variation in the Pacific Ocean, but may be comprised of at least two, and maybe even three distinct populations – a western Pacific stock and two eastern Pacific stocks separated around the equator (Galván-Tirado et al. 2013). Silky sharks in the GMR likely belong to the southern stock. In the eastern Pacific, the northern stock showed a 32% in CPUE from 1994-2015 but variability in catches implies high uncertainty, and the value of estimated decline over three generations varies from 17% to 60% depending on whether the data for 1994 is used or not. For the southeast Pacific stock, following a sharp decline in the period from 1994-2004, there was a period of stability followed by an increase in 2014 and in 2015, resulting in an overall decline of 60% between 1994-2015 (Lennert-Cody et al. 2016; Rigby et al. 2021b). This species appears to be experiencing a negative trend in the Galápagos with a perceived reduction in abundance of 25% (Peñaherrera-Palma et al. 2018b). In Cocos Island, its abundance dropped nearly 91% between 1993-2013 (White et al. 2015), suggesting this decline reflects its regional distribution status.

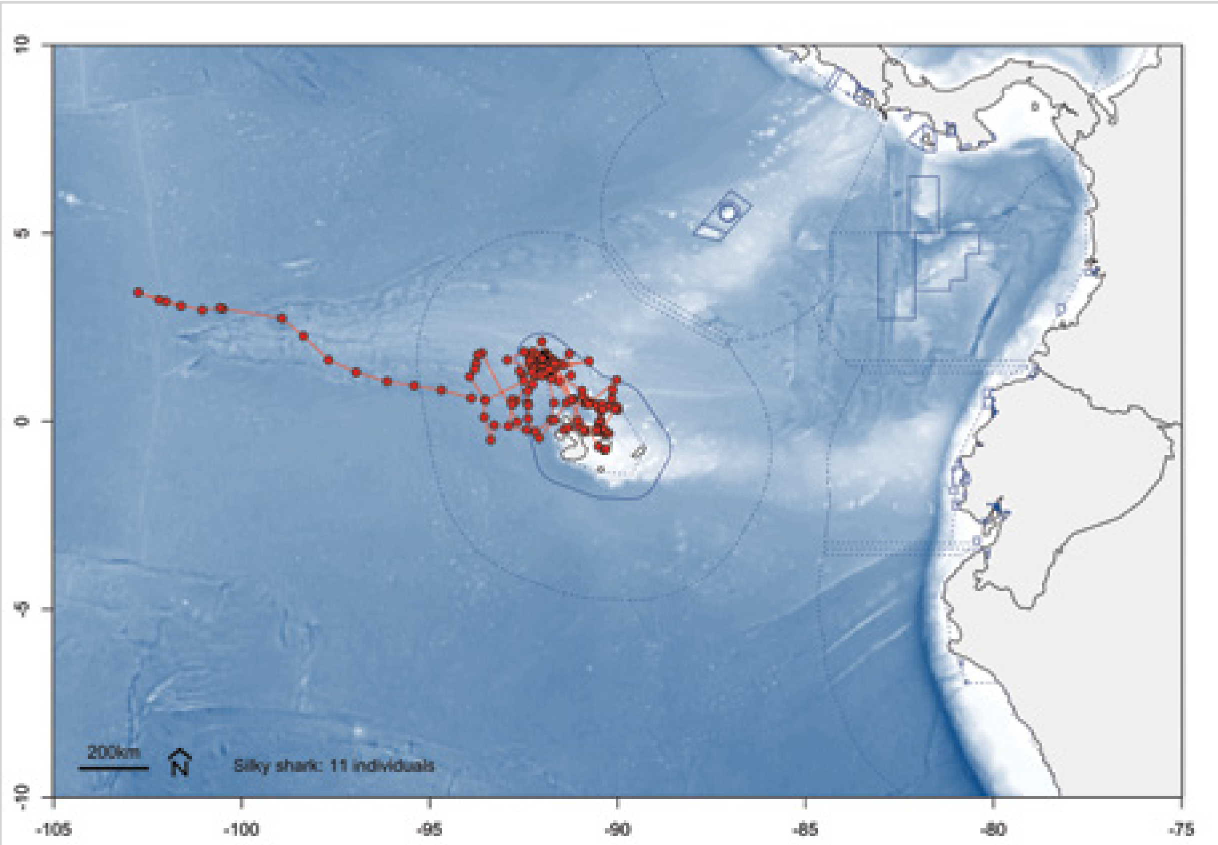


Figure 43. Tracks from eleven silky sharks fitted with satellite tags in the Galápagos Marine Reserve 2006-2014 (average track length 73 days). Source: Hearn et al. (2017).

The silky shark is either targeted or caught as bycatch by longline and purse seine fisheries, especially those using FADs. It is often "either retained for its meat and fins where regulations allow, or released with high mortality rates apparent in the tropical purse seine fisheries" (Rigby et al. 2021b). This species represents between 3-4% of the fins auctioned in Hong Kong (Clarke et al. 2006a). In the Eastern Pacific Ocean, the silky shark is the most common caught species of shark in the tuna purse seine fishery (IATTC 2007a). In Ecuador, this species ranks third in importance (5.2-9.7% by weight of all sharks) in annual landings by longline fisheries, but first in landings by the tuna purse seine fisheries (Figure 44).

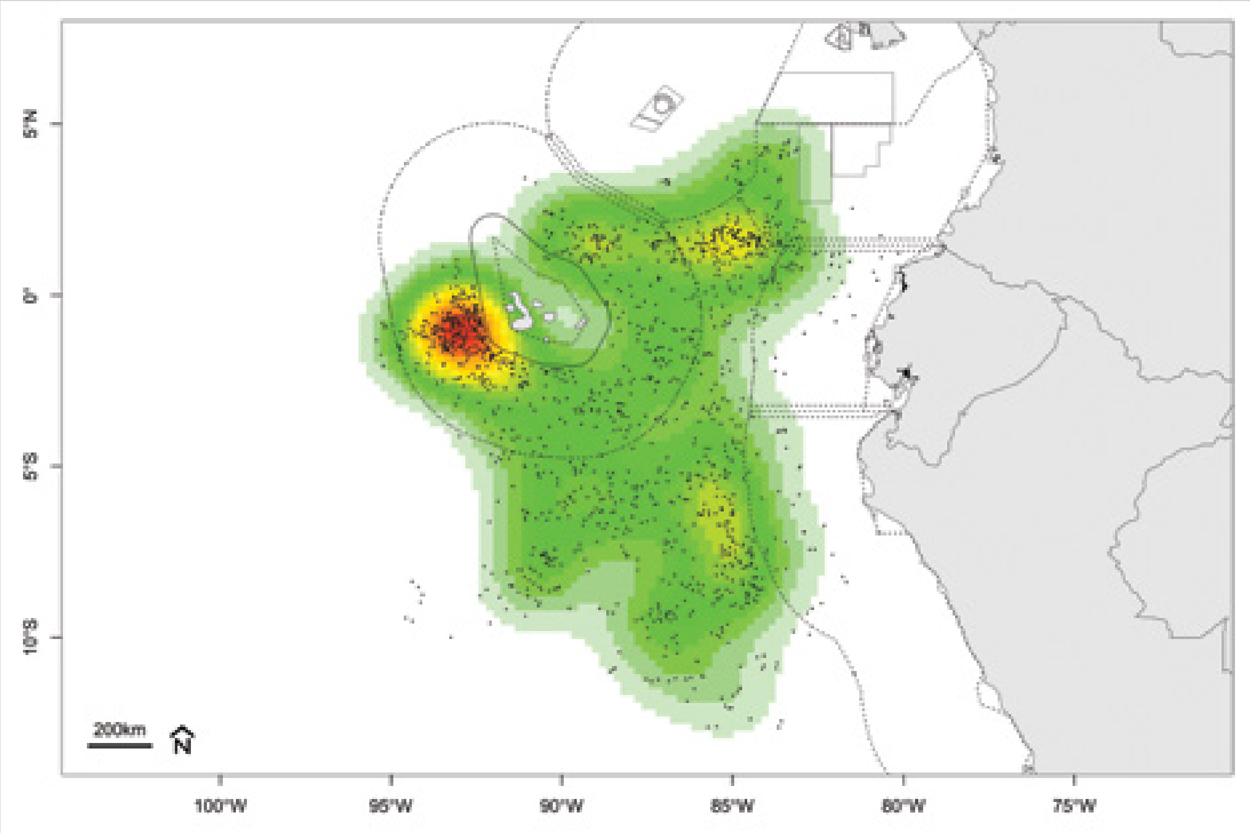


Figure 44. Location of catches of silky sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Silky sharks are listed on Annex I of UNCLOS (Fowler 2014). In 2014, they were included in Appendix II of the CMS and in 2016 they were added to Annex I Sharks MOU of the CMS under Appendix II (CMS 2020). Silky shark finning bans are in place for ICCAT, IATTC and the Western and Central Pacific Fisheries Commission (WCPFC), plus any silky shark that is brought on board must be released (IATTC 2019a; ICCAT 2011; WCPFC 2013). In 2016, the IATTC "prohibited retention of silky sharks on purse seine vessels, limited longline vessel silky shark bycatch to a maximum of 20% by weight of total catch per fishing trip" (Rigby et al. 2021b). Silky sharks were included in Appendix II of CITES in 2017 (CITES 2017). Ecuador's NDF concluded that the sale and export of silky sharks was not detrimental to the species, and did not place a limit on amounts (INP 2018a). The NDF was effective for one year and has not been renewed or replaced.

Scalloped hammerhead shark

The scalloped hammerhead shark *(Sphyrna lewini)* is a large (420 cm TL) coastal and semi-oceanic pelagic species classified as Critically Endangered by the IUCN (Rigby et al. 2019i). This species occurs in warm-temperate and tropical waters circumglobally, and in particular in aggregations around islands and seamounts (Compagno et al. 2005b) preferring temperatures between 23°C and 26°C, mostly at depths above the thermocline (Ketchum et al. 2014a). This species can be found near the coast and even entering estuarine habitats and offshore up to 275 m depth (Martínez-Ortiz and García-Domínguez 2013), although it makes extensive excursions in the mesopelagic zone (650-971 m) (Spaet et al. 2017) and has been recorded to 1,042 m (Moore and Gates 2015). Its IUCN distribution map (Figure 45, left) does not include Cocos or Malpelo, two known scalloped hammerhead shark hotspots (Bessudo et al. 2011; Nalesso et al. 2019), or the far north of the Galápagos Marine Reserve. In addition, catch data from longline vessels (see Figure 47) show that species is found throughout the EEZ, so we have amended the distribution within the Galápagos EEZ accordingly (Figure 45, right).

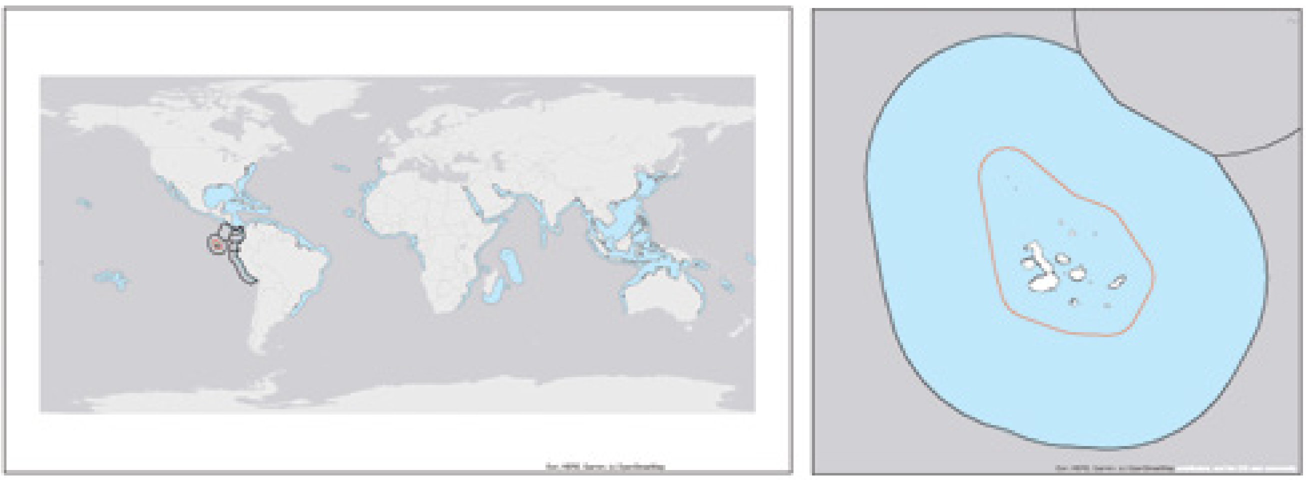


Figure 45. Global range of the scalloped hammerhead shark, based on IUCN red list (left) and distribution within the Galápagos EEZ (right) following (Hearn et al. 2017), and Rigby et al. (2019i).

This species forms large schools around oceanic islands and seamounts, including the Galápagos, Cocos and Malpelo island groups (Hearn et al. 2010, Bessudo et al. 2011, Nalesso et al. 2019). These schools mostly disperse at night as sharks move offshore, presumably to forage, as an important component of their diet in the region are squid (Estupiñan-Montaño et al. 2009, Ketchum et al. 2014a). They have an annual or biennial reproductive cycle (Rigby et al. 2019i), and litter sizes of 12–41 pups (31–57 cm) and annual population growth rate estimates are 0.10–1.22 per year (Rigby et al. 2019i). Onset of sexual maturity for females is 13.2 years (200–250 cm) and 8.9 years for males (140–198 cm). Longevity is thought to be about 35 years for females and 19 years for males (Drew et al. 2015). The species appears to segregate by sex at certain phases of their life cycle (Compagno 1984). Pregnant females can migrate to nearshore waters to give birth and males can be found over the continental shelf. In addition to cross-shelf migration, there is also long-shelf migration (Stevens and Lyle 1989). Nursery populations linked by continuous coastlines have high connectivity (Duncan et al. 2006). Neonate hammerhead sharks were recently discovered in at least two locations in the GMR, suggesting that the islands may play a more important role for early life stages than previously expected (Chiriboga-Paredes et al. 2022).

The populations that inhabit ETP are genetically connected mostly due to the migrations of males (Daly-Engel et al. 2012); nevertheless, the genetic flow is relatively low (Nance et al. 2011). Sharks fitted with ultrasonic receivers have displayed movements between Malpelo, Cocos and Galápagos, especially between the latter two sites (Bessudo et al. 2011; Ketchum et al. 2014b; Nalesso et al. 2019).

The scalloped hammerhead shark is one of the most abundant species in Galápagos Archipelago, particularly in the in northern islands (Peñaherrera-Palma et al. 2017) from June through December each year (Hearn et al. 2017). It is one of the most important species for the dive tourism industry. The removal of this species can affect ecotourism and the composition and abundance of their prey species, affecting the rest of the marine organisms, resulting in an imbalance on food webs (Danulat and Edgar 2002).

Satellite tracks (Hearn et al. unpublished) support the ultrasonic data showing intense use of the waters inside and around the GMR, including connectivity with seamounts beyond the GMR boundaries and along the Cocos Ridge (Figure 46).

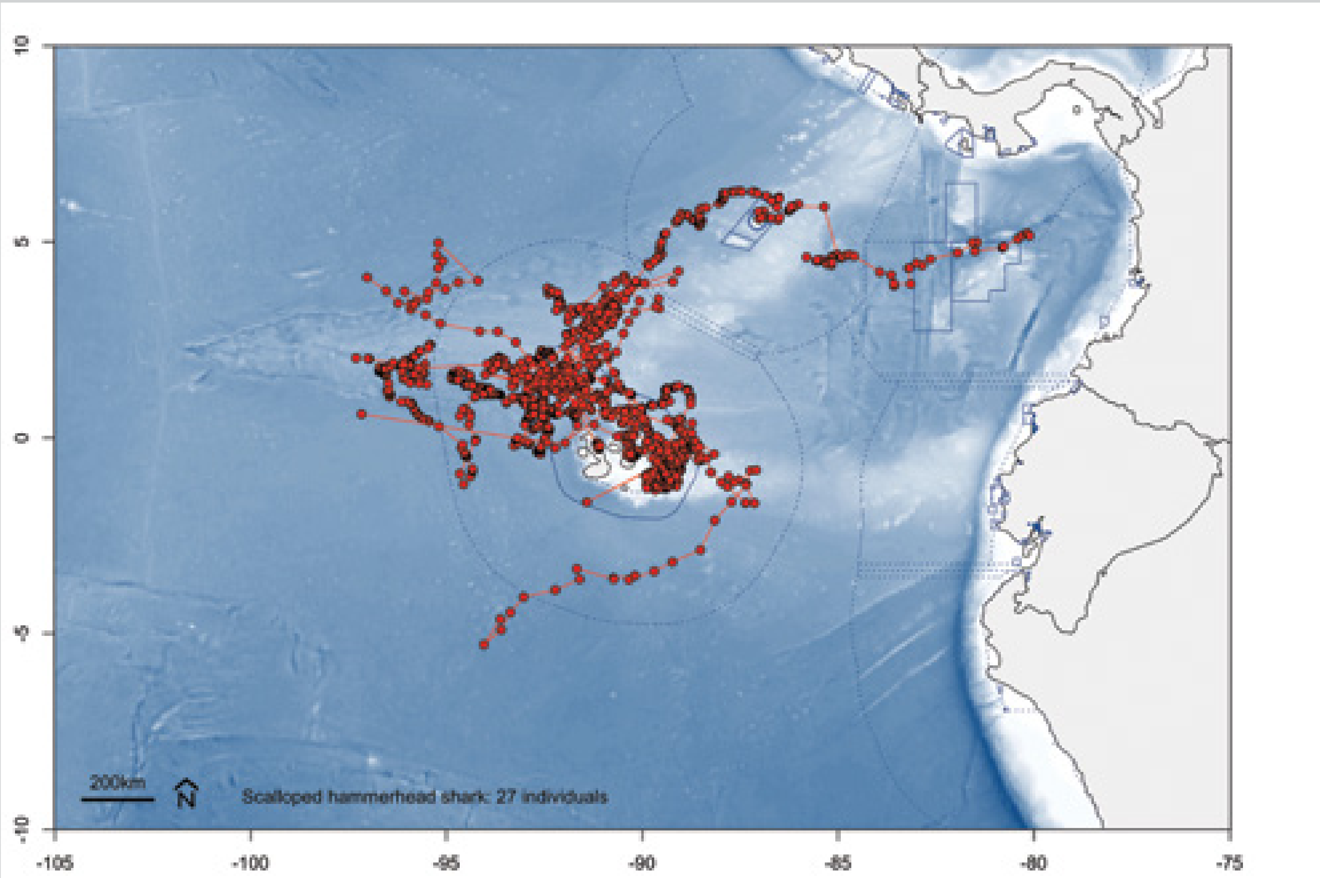


Figure 46. Scalloped hammerhead shark satellite tracks based on 27 individuals tagged in the Galápagos Marine Reserve, 2006-2019 (average track length 48 days). Adapted from Hearn et al. (2017), Palomino Gaviria (2019), and Hearn (unpublished data).

The conservation status of the scalloped hammerhead shark was recently updated from Endangered to Critically Endangered, with a median population reduction of 76.9–97.3% over three generation lengths. For the South Pacific, the trend analyses from 1964–2004 showed annual rates of reduction of 8.4%, a median reduction of 99.8% and the highest probability of >80% of reduction over three generation lengths (Rigby et al. 2019i). Its abundance at Cocos Island declined by 45% from 1993-2013 (White et al. 2015), and interview-based surveys at Galápagos suggest similar declines (Peñaherrera-Palma et al. 2018b).

Scalloped hammerhead sharks are caught throughout their range and bycatch in commercial and small-scale fisheries (Martínez-Ortiz et al. 2015). They are usually retained for the meat and fins; together with great and smooth hammerhead sharks, they may represent >7% (Fields et al. 2018) or 5.9% (Clarke et al. 2006a) of the fins imported to Hong Kong. In addition, there is high post-release mortality for injured released sharks, reported as up to 100% in purse seines (Eddy et al. 2016). In Ecuador, from 2008-2012, this species represents between 0.2% of annual landings by weight of all sharks (Martinez-Ortiz et al. 2015), and it is caught mostly in the Galápagos EEZ as bycatch by the large pelagics longline fleet (Figure 47).

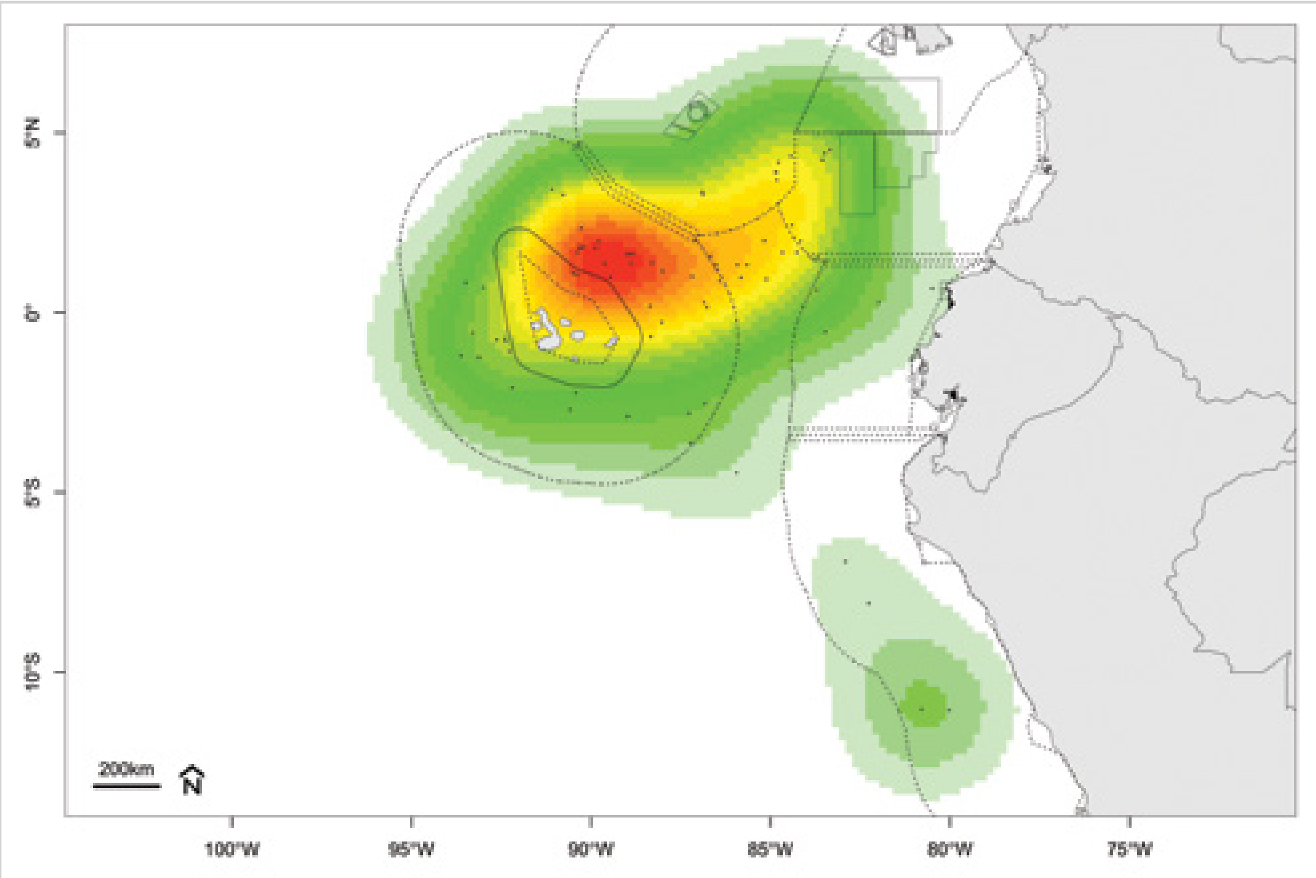


Figure 47. Location of catches of scalloped hammerhead sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

The scalloped hammerhead shark is listed in Annex 1 of UNCLOS (Fowler 2014), and was included in Appendix II of CITES in 2013 and in Appendix II and the Sharks MOU of the CMS in 2014. In Ecuador, a Ministerial Agreement in 2013 limited landings to 5 individuals below 150 cm for the artisanal fleet, and a ban on landings by industrial vessels (SRP 2013). In 2020, Ecuador strengthened protection by banning the retention, transshipment, storage, sale and exportation of 5 species *(Carcharhinus longimanus, Sphyrna zygaena, Sphyrna mokarran, Sphyrna tiburo and Sphyrna lewini)*. In case of incidental catch they must be returned to the sea dead or alive (MPCI 2020).

Smooth hammerhead shark

The smooth hammerhead shark *(Sphyrna zygaena)* is a large (up to 400 cm TL) coastal and semi-oceanic pelagic species classified as Vulnerable by the IUCN (Rigby et al. 2019h). It is found globally in temperate and tropical seas, mostly in coastal-pelagic and semi-oceanic environments (Figure 48), close inshore and in shallow waters over the continental shelf and near oceanic islands, from the surface to 200 m depth (Martínez-Ortiz and García-Domínguez 2013), although there are reports of them attaining depth of 420 m and 500 m (Weigmann 2016).

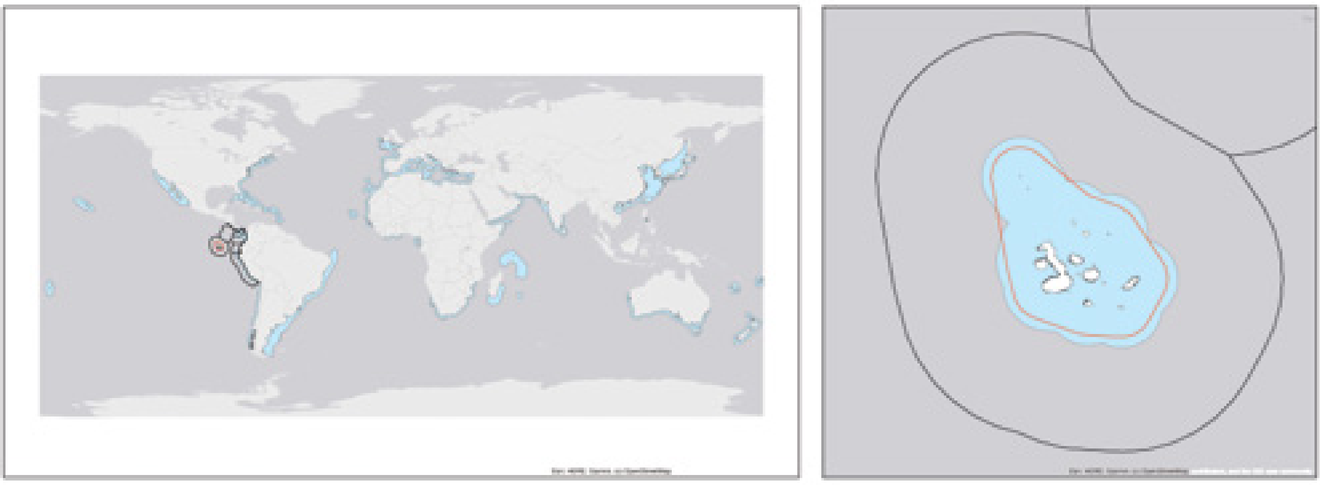


Figure 48. Global range of the smooth hammerhead shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019h).

The diet of smooth hammerhead sharks consists mainly of bony fishes, cephalopods, crustacean and also small sharks (Compagno 1984). They have an annual reproductive cycle with a gestation period of 10-11 months and litter sizes of 20–40 pups (50 cm at birth) (Martínez-Ortiz and García-Domínguez 2013). Their population growth rate estimate is 0.225 per year (Cortés et al. 2015). Onset of sexual maturity occurs at 246–265 cm for females and 250–260 cm for males (Rigby et al. 2019h).

Genetic studies indicate female philopatry and male mediated gene flow (Testerman 2014).

In the Pacific Ocean, they move over long distances (Clarke et al. 2015). One individual fitted with a satellite-tag moved from California to Mexico and back, covering over 1,000 miles in two months (SWFSC 2015). Off southern Brazil, smooth hammerhead sharks migrate inshore between October and February, most likely to pup (Amorim et al. 2011). The longest migration ever documented for this species was in the Atlantic Ocean (> 6,600 km) across hemispheres (Santos and Coelho 2018).

Rigby et al. (2019h) used expert judgement elicitation to estimate a global population reduction of 30-49% over three generations (72 years), but there is insufficient data in the southeast Pacific in order to estimate trends within this region. This species is caught within its range as target and bycatch in commercial and small-scale fisheries (Martínez-Ortiz et al. 2015). Catches reported by the Ecuadorian longline fleet are mostly in the high seas off Peru (Figure 49). In northern Peru, fishers heavily target neonates and juveniles (Gonzalez-Pestana et al. 2016), while in Ecuador over 90% of individuals landed are immature (Martínez-Ortiz and Galván-Magaña 2007). Estimated at-vessel mortality in the Atlantic is 71% (Coelho et al. 2012), and there is high post-release mortality for injured released sharks, reported as 100% for species of the same genus in purse seines (Eddy et al. 2016). In Ecuador, this species represented 0.5% of annual landings from 2008-2012 by weight of all sharks (Martínez-Ortiz et al. 2015).

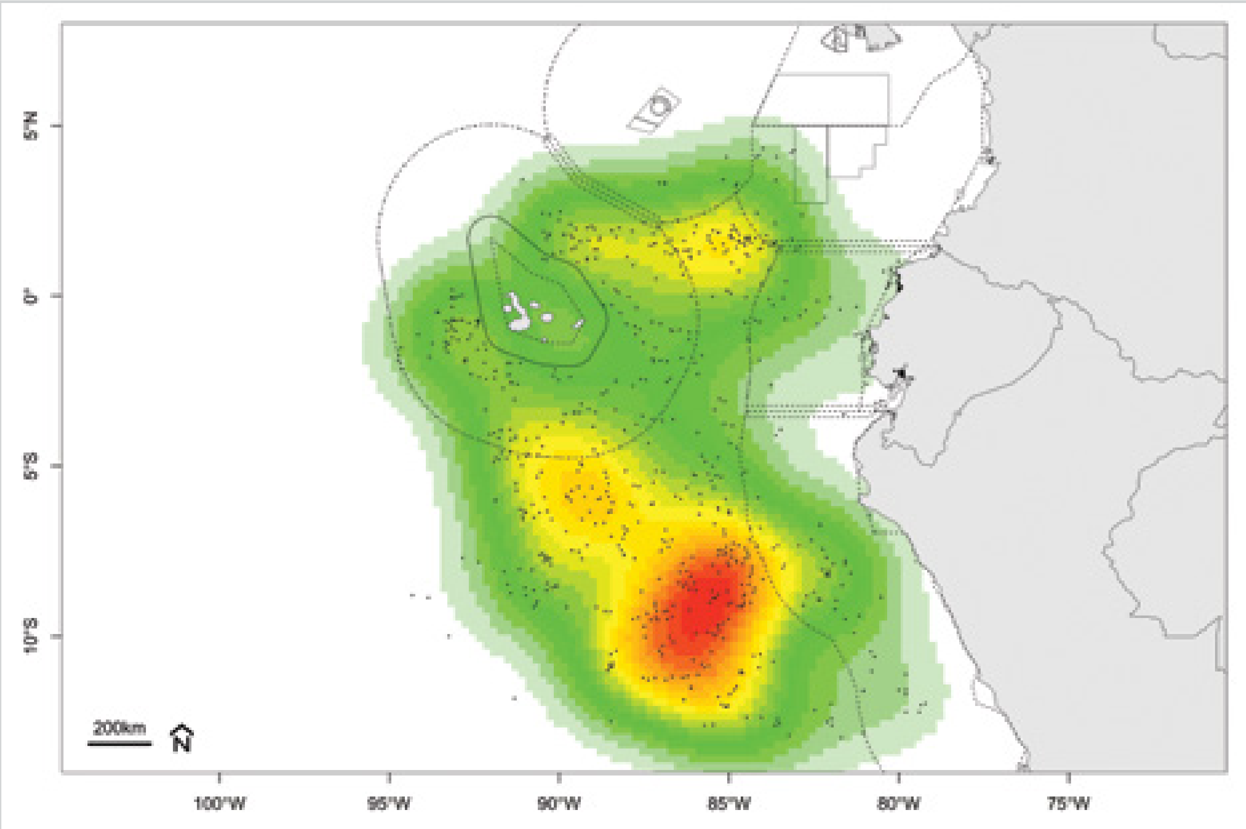


Figure 49. Location of catches of smooth hammerhead sharks as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

The smooth hammerhead shark is listed in Annex 1 of UNCLOS (Fowler 2014), and was included in Appendix II of CITES in 2013 and in the Sharks MOU of the CMS in 2014, although it is not listed in a CMS Appendix. In Ecuador, a Ministerial Agreement in 2013 limited landings to 5 individuals below 150 cm for the artisanal fleet, and a ban on landings by industrial vessels (SRP 2013). In 2020, Ecuador strengthened protection by banning the retention, transshipment, storage, sale and exportation of 5 species *(Carcharhinus longimanus, Sphyrna zygaena, Sphyrna mokarran, Sphyrna tiburo and Sphyrna lewini).* In case of incidental capture they must be returned to the sea dead or alive (MPCI 2020).

Great hammerhead shark

The great hammerhead *(Sphyrna mokarran)* is a large (610 cm TL) shark classified as Critically Endangered by the IUCN (Rigby et al. 2019e). This species is found in coastal pelagic and semi-oceanic tropical seas (Figure 50, left), occurring both inshore and offshore over the continental shelves and island terraces (Compagno 1984). There is only a single report of this species in Galápagos: in the 1960s there was a single sighting of an individual at Gordon Rocks, off the island of Santa Cruz (Grove and Lavenberg 1997).

The great hammerhead inhabits waters from the surface to 300 m (Weigmann 2016), where they feed upon stingrays, other batoids, groupers, catfishes, crabs and squids (Compagno et al. 2005a). Unlike other members of the Sphyrnidae family, the great hammerhead shark is nomadic and migratory across its range, and not usually found in aggregations (CMS 2015b).

The great hammerhead shark is viviparous with yolk sac placenta (Compagno 1984), and with a gestation period of 11 months (Clarke et al. 2015). The number of offspring varies from 6-42, and the pups measure from 50-70 cm TL at birth (Rigby et al. 2019e). Population growth rate was estimated at 0.07 per year (Cortés et al. 2015). Males reach maturity at 225–269 cm TL, and females at 210–300 cm TL (Rigby et al. 2019e). Longevity is estimated in about 39–44 years (Rigby et al. 2019e).

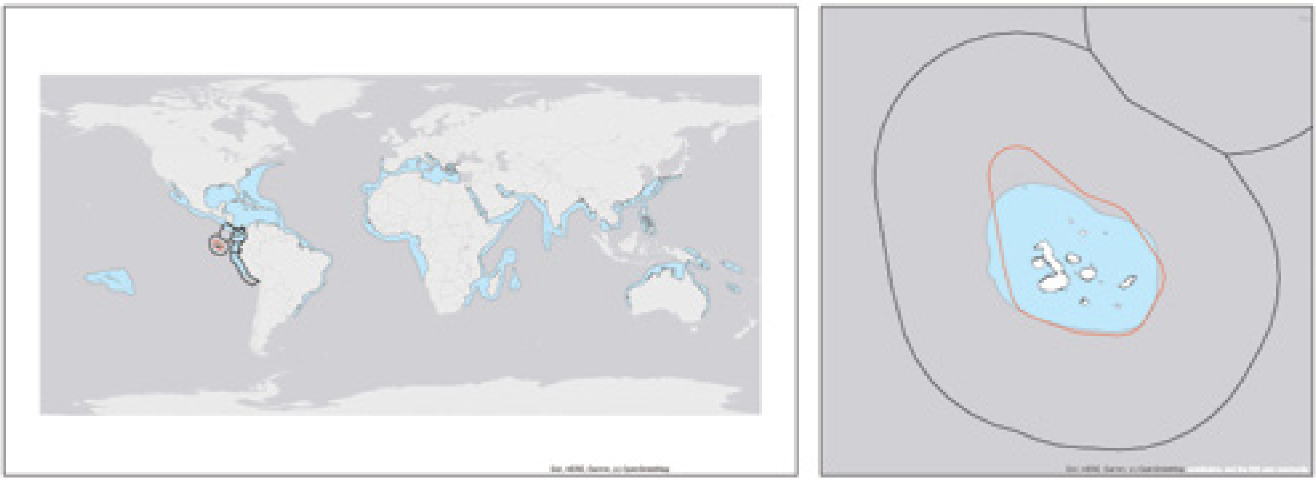


Figure 50. Global range of the great hammerhead shark (left) and distribution within the Galápagos EEZ (right). Source: Rigby et al. (2019e).

This species is capable of long distant migrations with a strong seasonal component. A single individual tracked off South Florida travelled at least 1,200 km into the mid-Atlantic Ocean off the coast of New Jersey (Hammerschlag et al. 2011). Nevertheless, longer movements have been identified (3,030 km), and strong seasonal residency (up to 5 months) and site fidelity (annual return) for the same region and the Bahamas (Guttridge et al. 2017). The vertical movements of this species have been recorded to vary from 5 to 98 m while migrating across the Gulf of Mexico (Drymon and Wells 2017).

There are no data available on the global population size of *S. mokarran*. For the Northwest Atlantic, a trend analysis from 1981-2005 showed an annual reduction of 0.4%, "consistent with an estimated median reduction of 29.1% over three generation lengths (74.4

years), with the highest probability of <20% reduction over three generation lengths" (Rigby et al. 2019e). "The Atlantic subpopulation is inferred to have undergone a >50% reduction over three generation lengths (74.4 years); although there is possible recovery in the Northwest Atlantic, there is also a high degree of uncertainty in the data and high levels of exploitation. The Indo-Pacific subpopulation is inferred to have undergone a >80% reduction over three generation lengths (71.1 years)" (Rigby et al. 2019e). The global population trend shows a reduction between 50.9–62.4%, with the highest probability of >80% reduction over three generation lengths (Rigby et al. 2019e).

This species is caught globally as target and bycatch in commercial and small-scale pelagic longline, purse seine, gillnet fisheries and trawls, particularly in areas with narrow continental shelves (Rigby et al. 2019e). At-vessel mortality is estimated as 56% on US shark bottom longlines and 30.8% on Western Australia demersal longlines (Braccini and Waltrick 2019; Gulak et al. 2015). Post-release mortality is higher for injured released sharks and has been reported as 100% for the closely-related scalloped hammerhead in purse seines (Eddy et al. 2016). Great hammerhead sharks are rare in Ecuador, and no individuals were reported from the longline fishery observer program between 2008-2012 (Martínez-Ortiz et al. 2015)

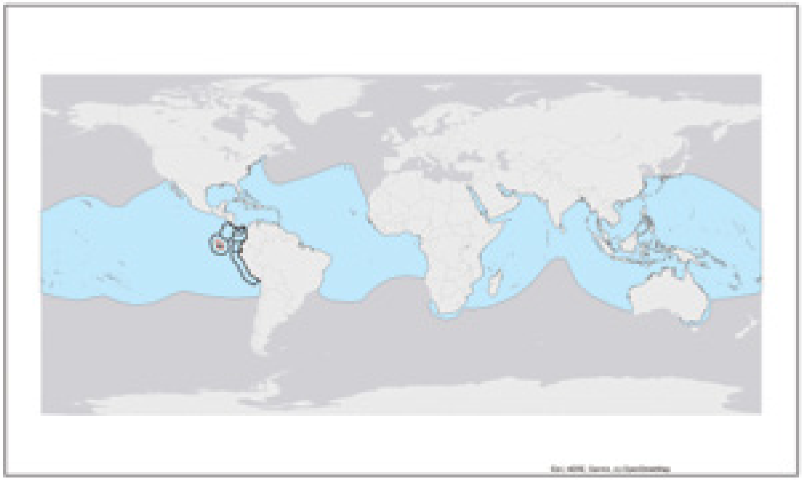
In 2014, the great hammerhead shark was added to Appendix II of CITES (CITES 2014). In 2014, it was listed on Appendix II of the CMS in 2014, and on Annex I Sharks MOU of the CMS in 2016 (CMS 2016). The species was also listed as part of the highly migratory or possibly migratory species in Annex I of UNCLOS (Fowler 2014). In 2020, Ecuador banned the retention, transshipment, storage, sale and exportation of 5 species *(Carcharhinus longimanus, Sphyrna zygaena, Sphyrna mokarran, Sphyrna tiburo and Sphyrna lewini).* In case of incidental catch they must be returned to the sea dead or alive (MPCI 2020).


Jonathan R. Green

Whale shark

The whale shark *(Rhincodon typus)* is the world's largest living fish (2,000 cm TL, although rarely larger than 1,400 cm) (Dove et al. 2021), and is classified as Endangered by the IUCN (Pierce and Norman 2016). The whale shark is an epipelagic and neritic, oceanic and coastal, tropical and warm-temperate species that occurs worldwide in all temperate and tropical waters (Figure 51), predominantly found at temperatures >21°C (Compagno 2001; Rowat and Brooks 2012). Although previously thought to be absent from the Mediterranean Sea, their presence there has now been confirmed (Turan et al. 2021).

Whale sharks are filter feeders and are predominantly solitary, although they form seasonal aggregations (defined as more than 10 individuals in less than 1 km^2) at around a dozen mostly coastal locations across the globe to exploit seasonal productivity, e.g. fish spawning events (Rowat and Brooks 2012). Juveniles feed near the coast unlike larger individuals which are more oceanic (Ketchum et al. 2013). Most aggregation sites are dominated by males - the GMR is the only known location almost completely comprised of large adult females (Norman et al. 2017), which appear seasonally from July through November at Darwin Island, and sporadically elsewhere in the reserve throughout the year (Hearn et al. 2016).



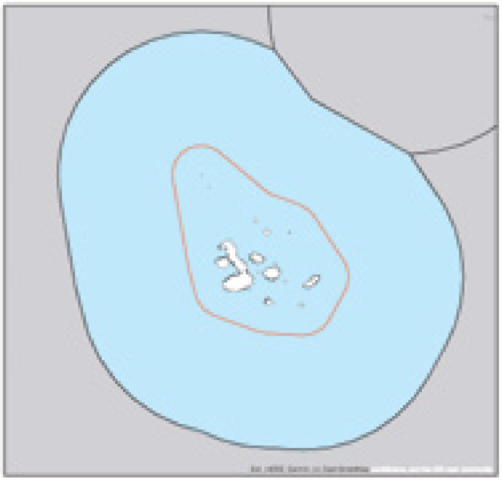


Figure 51. Global range of the whale shark (left) and distribution within the Galápagos EEZ (right). Source: Pierce and Norman (2016).

Whale sharks fitted with satellite tags at Darwin Island moved rapidly away from the GMR at average rates of 27 km per day (Hearn et al. 2016). In July, these movements were mostly offshore, towards the Equatorial Front, where they tracked tropical instability waves westward for over 1,000 km (Ryan et al. 2017), before returning along a similar pathway, through Galápagos and towards mainland South America. Most individuals reach the shelf break of Ecuador or northern Peru by the end of the year (Hearn et al. 2016). One individual moved near Cocos Island and eventually to Malpelo in 2012 (Figure 52), while another individual was recently tracked to inside the Cocos Island National Park in 2020 (Turtle Island Restoration Network 2020).

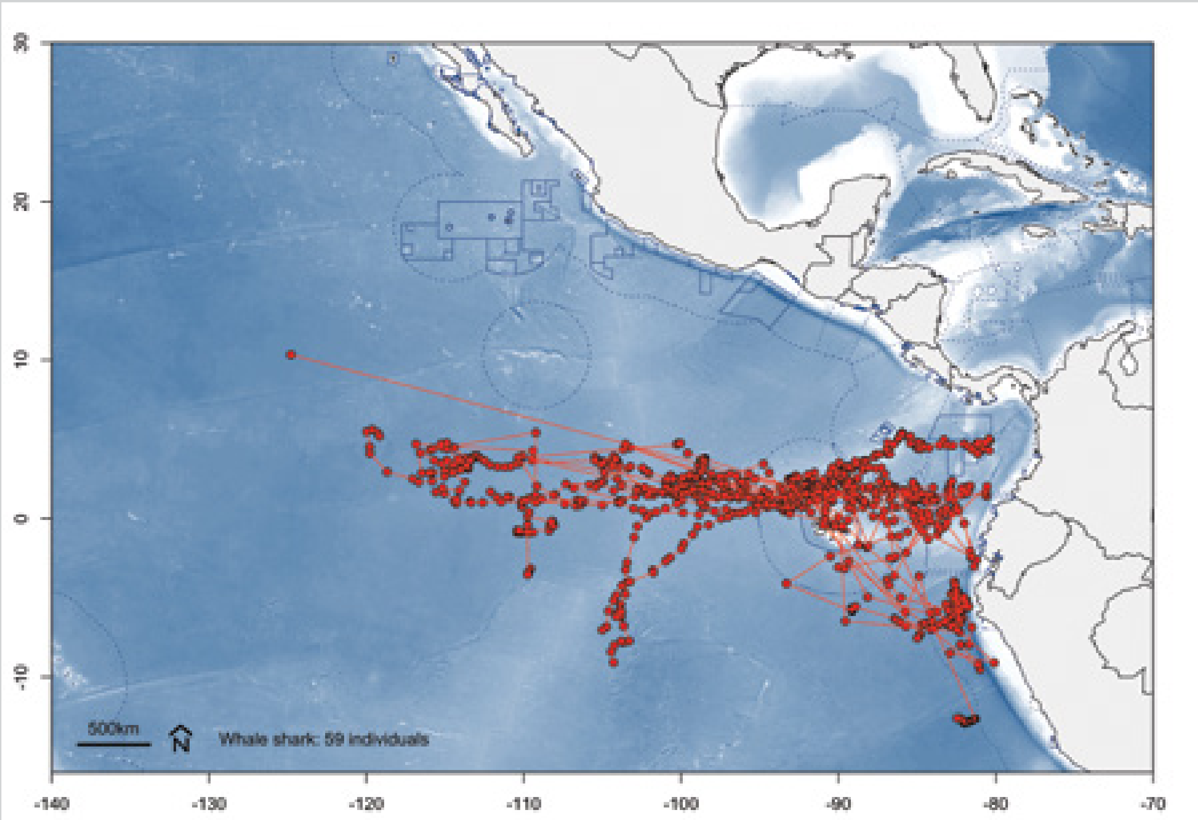


Figure 52. Whale shark tracks based on 59 individuals tagged in Darwin Island, Galápagos Marine Reserve, 2011-16 (average track length 70 days). Source: Galápagos Whale Shark Project (unpublished data), Hearn et al. (2016) and Hearn et al. (2017).

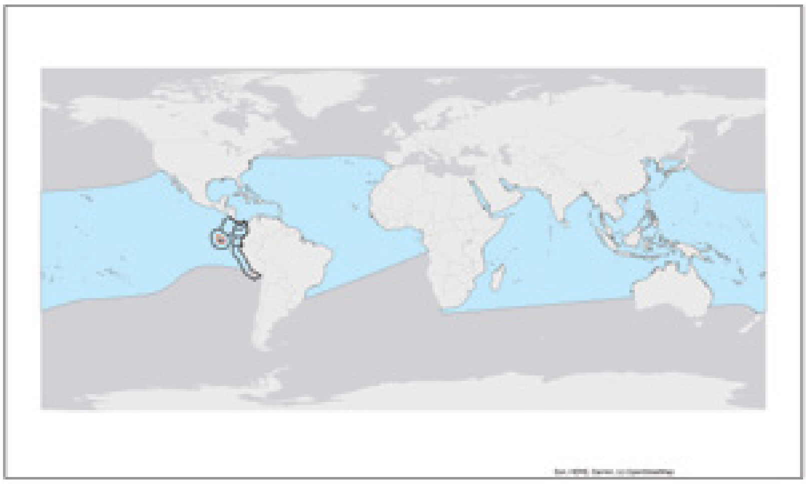
There may be at least two populations, with little mixing between the Indo-Pacific and the Atlantic oceans (Vignaud et al. 2014). According to Pierce and Norman (2016) approximately 75% of the global *R. typus* population occurs in the Indo-Pacific, and 25% in the Atlantic. For the Atlantic subpopulation, a trend analysis showed a decline of ≥30% over the last three generations (75 years). For the Indo-Pacific subpopulation, a trend analysis showed a decline of 63% over 75 years. Overall, there is a decline of whale shark population by ≥50% over the last 75 years. Despite this, the apparent abundance of whale sharks has remained relatively stable, both in the GMR over the last three decades (Peñaherrera-Palma et al. 2018b;) and at Cocos Island over the past two decades (White et al. 2015)

Whale sharks are sometimes caught incidentally in net fisheries, and are also vulnerable to vessels strikes (Pierce and Norman 2016). Tropical tuna purse-seine fisheries often use whale sharks as an indicator of tuna presence (Capietto et al. 2014). "The long-term survivorship of whale sharks released from nets has not been examined. Shipping lanes, where they are placed close to whale shark feeding areas, can create a serious risk of vessel strikes" (Pierce and Norman 2016). The active fishery in Chinese waters is almost certainly unsustainable (Li et al. 2012). In mainland Ecuador there are records of bycatch aboard surface gillnet fishing vessels (Martínez-Ortiz and García-Domínguez 2013), and a whale shark was also found on board the Chinese reefer vessel detained inside the GMR in 2017 (Bonaccorso et al. 2021).

Whale sharks are listed on Annex I of UNCLOS (Fowler 2014). In 1999, they were included in Appendix II of the CMS, and later in 2010 in Annex I Sharks MOU. In 2017 they were added to Appendix I of the CMS (Pierce et al. 2021). They were included on Appendix II of CITES in 2002 (Pierce et al. 2021). RFMOs have banned the setting of purse seine nets around whale sharks in the Eastern Pacific, Western and Central Pacific and Indian Oceans (IATTC 2019a; IOTC 2013b; WCPFC 2012b). In Ecuador, any whale shark captured incidentally must be returned to the sea (INP 2005).

Giant manta ray

The giant manta ray *(Mobula birostris)* is the largest living ray, reaching a maximum size of 910 cm. Its conservation status was recently updated to Endangered on the IUCN red list (Marshall et al. 2020). It is found globally at latitudes between latitudes 40° north and south (Figure 53). This planktivore mostly inhabits open waters and around islands (Last et al. 2016) at depths between the surface and 150 m (Stewart et al. 2016). Mantas have a lifespan of at least 40 years, and attain sexual maturity at sizes of 410-470 cm in females and 375-400 cm in males (Last et al. 2016; Marshall et al. 2018; Martínez-Ortiz and García-Domínguez 2013). Their gestation period is 10-14 months and they tend to give birth to one pup (and rarely two). Ecuador hosts one of the largest aggregation sites for this species globally, at Isla de La Plata, in Machalilla National Park, where mantas are the main attraction for scuba divers (Guerrero and Hearn 2017).



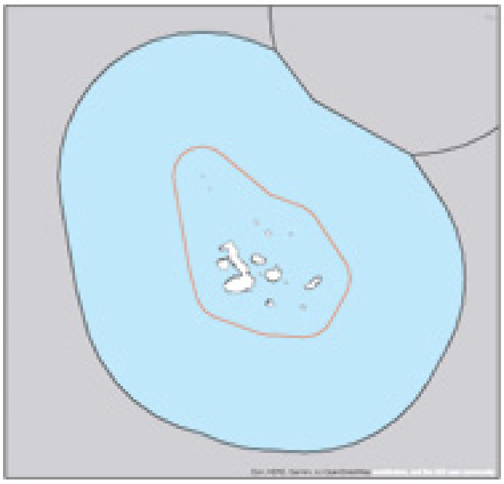


Figure 53. Global range of the giant manta ray (left) and distribution within the Galápagos EEZ (right). Source: Marshall et al. (2020).

Giant mantas are known to make movements in excess of over 1,000 km, across national jurisdictions (Marshall et al. 2018). Many of their reported movements appear to be related to foraging (Graham et al. 2012). Satellite tracks have shown that there is evidence of individuals moving between coastal Ecuador and the GMR (Andrzejaczek et al. 2021; Hearn et al. 2014), however many individuals remain, at least temporarily, on the continental shelf, moving between Ecuadorian and Peruvian coastal waters (Andrzejaczek et al. 2021; Palomino et al. 2020).

The estimated rate of population reduction over the last three generations (87 years) globally is thought to be 50-79% (Marshall et al. 2020). In Cocos Island there has been an 89% decline in diver sighting records of giant manta rays over a 21-year period (White et al. 2015). Sustained pressure from fishing has been isolated as the overwhelming cause of these declines (Marshall et al. 2020). According to Marshall et al. (2011), this species has a high value in international trade and directed fisheries exist that target this species unsustainable numbers. In some places, artisanal fisheries target this species for food and medicine e.g. the gill rakers (Essumang 2010; Marshall et al. 2011; White et al. 2006). Other threats include mooring line entanglement and boat strikes (Deakos et al. 2011), habitat degradation, climate change, pollution, ingestion of micro-plastics and irresponsible tourism practices (Marshall et al. 2018). Furthermore, as a migratory species, they do not remain in protected waters (Graham et al. 2012). In Ecuador, manta rays around Isla de la Plata "show damage received from fishing equipment, which occurs when artisanal fishermen use trawling tackle illegally within the Machalilla National Park boundaries to fish for seasonal aggregations of wahoo *(Acanthocybium solandri)* which coincide with the seasonal aggregation of giant manta rays" (Marshall et al. 2018).

In 2011, the giant manta ray was included on Appendices I and II of the CMS (UNEP-CMS 2012). In 2016 it was listed on Annex I Sharks MOU of the CMS (CMS 2016). In 2013, it was listed on Appendix II of CITES (CITES 2014).

In 2015, the IATTC prohibited *Mobula* species caught by large-scale fisheries in the IATTC Convention Area from being retained or sold, and mandated prompt, careful release (IATTC 2019a). In Ecuador, the giant manta ray has been protected since 2010, and individuals caught incidentally must be returned to the sea alive or dead, whole or in part, nor can they be kept for human consumption or owned, sold or transported (MAGAP 2010b).

Leatherback turtle

The leatherback turtle *(Dermochelys coriacea)* is the largest of the marine turtles, and is mostly pelagic, except when coming ashore to nest. Globally, its conservation status is Vulnerable, but the East Pacific population is Critically Endangered (Wallace et al. 2013b). It has a circumglobal distribution, with nesting sites on sandy tropical beaches and a foraging range that extends into temperate and subpolar latitudes (Figure 54). It is the reptile with the widest geographic range, and it nests on all continents except Europe and Antarctica, as well as the Caribbean and Indo-Pacific Islands (Eckert et al. 2012). The East Pacific population is distributed from Baja California, Mexico to the central zone of Chile (Wallace et al. 2013b).

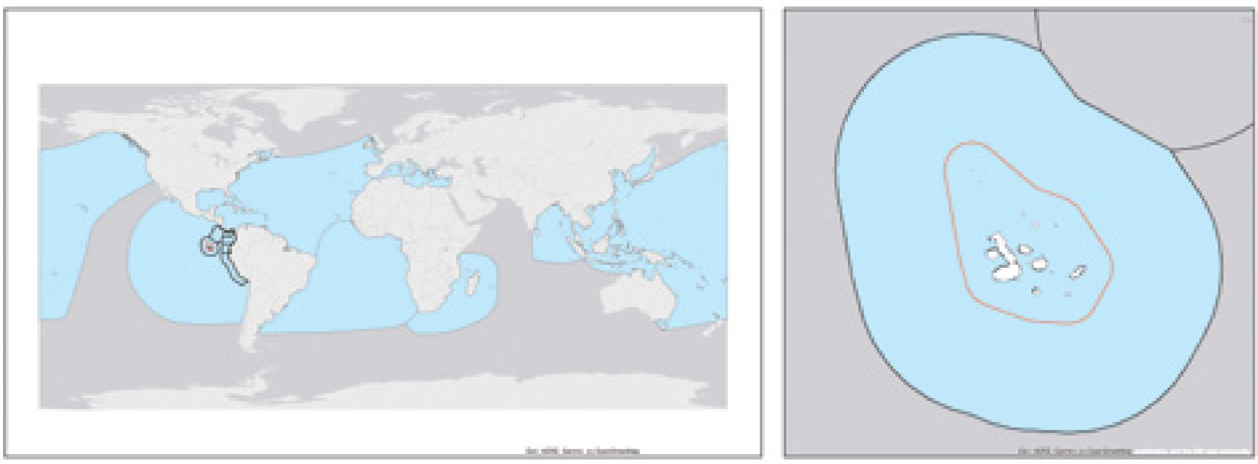


Figure 54. Global range of the leatherback turtle (left) and distribution within the Galápagos EEZ (right). Source: (Wallace et al. 2013b).

Its diet consists mainly of cnidarians and tunicates (Wallace et al. 2013b). Generation length is about 30 years (Wallace et al. 2013b). Age at sexual maturity is not known exactly but, based on mean size at first nesting in the western North Atlantic Ocean, may be 24.5-29 years (Avens et al. 2009), or based on population trend analyses, may be 12-14 years (Dutton et al. 2005). A recent genomic promoter cytosine-phosphate-guanine (CpG) study suggested that it may live around 90.4 years (Mayne et al. 2020). Leatherback turtles nest on beaches along the coast of central and South America, laying between 29-116 eggs in each nest, and nesting multiple times in a season (Quiñones et al. 2007). The East Pacific leatherback is genetically distinct from other leatherback populations (Dutton et al. 1999). No nests have been reported for Galápagos, but nests are occasionally reported on the coast of mainland Ecuador (The Jakarta Post 2020).

East Pacific leatherback turtles nest from December to March, and then migrate offshore from the nesting beaches of Mexico and Costa Rica to the pelagic waters of the eastern south Pacific (Figure 55) (Benson et al. 2011, Shillinger et al. 2008). This species uses Ecuadorian waters during the migration to Chile, there is also data on secondary capture and interaction with fisheries near the Galápagos Islands and the Ecuadorian continental area (Miranda 2019).

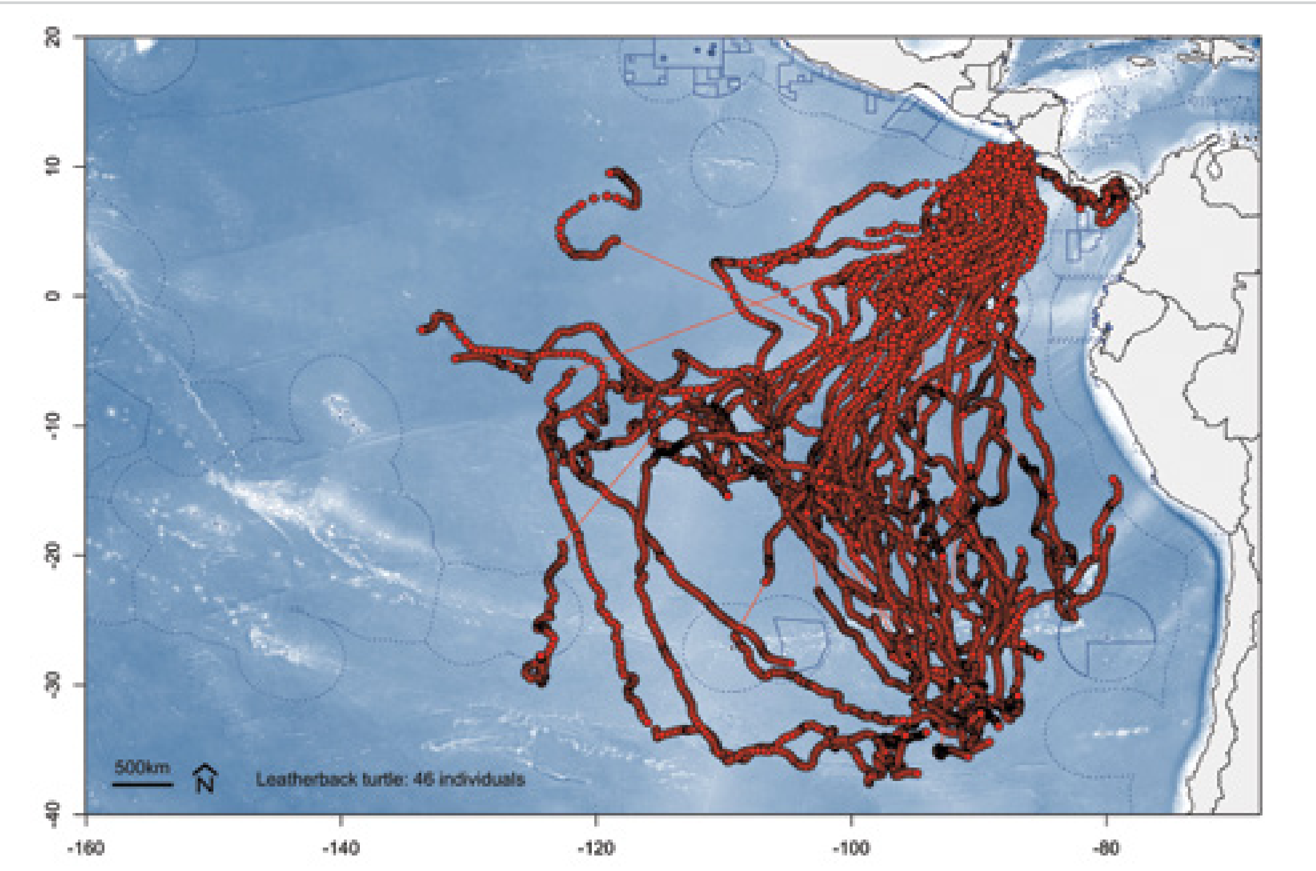


Figure 55. East Pacific leatherback turtle movements based on 46 post-nesting individuals fitted with satellite tags on beaches in Costa Rica in 2004-2008 (average track length 239 days). Source: Shillinger et al. (2008).

The East Pacific leatherback population is estimated to have declined by up to 90% from 1988 to 2000 (Spotila et al. 2000) and there is a high risk that this population will be extinct within the next generation. The ongoing threats to these turtles include egg harvesting on nesting beaches and fisheries bycatch. According to a study from 1990-2011, the use of driftnets has a greater impact on the decline of the eastern Pacific subpopulation, followed by longline fishing (Wallace et al. 2013a). This species registers the highest rate of bycatch among sea turtles in Chile, for example, between 2001-2005, the Chilean industrial longline fleet, captured a total of 363 sea turtles, of which 284 were leatherback turtles (Donoso and Dutton 2010). A similar situation occurred between 2001 and 2013 where a total of 337 leatherback turtles were caught (SUBPESCA 2014). In Ecuador, there are few reports of this species in the Ecuadorian Fisheries Agency observer program (2008-12), mostly in central coastal Ecuador and south to the GMR (Figure 56).

Other problems associated with anthropogenic actions include coastal development (constructions and beach dredging) (Miranda 2019). According to Wallace et al. (2013b), climate change increases the temperature of the sand on the beaches, thus affecting the sex ratio of the offspring, while increasing sea levels can reduce suitable nesting habitat availability.

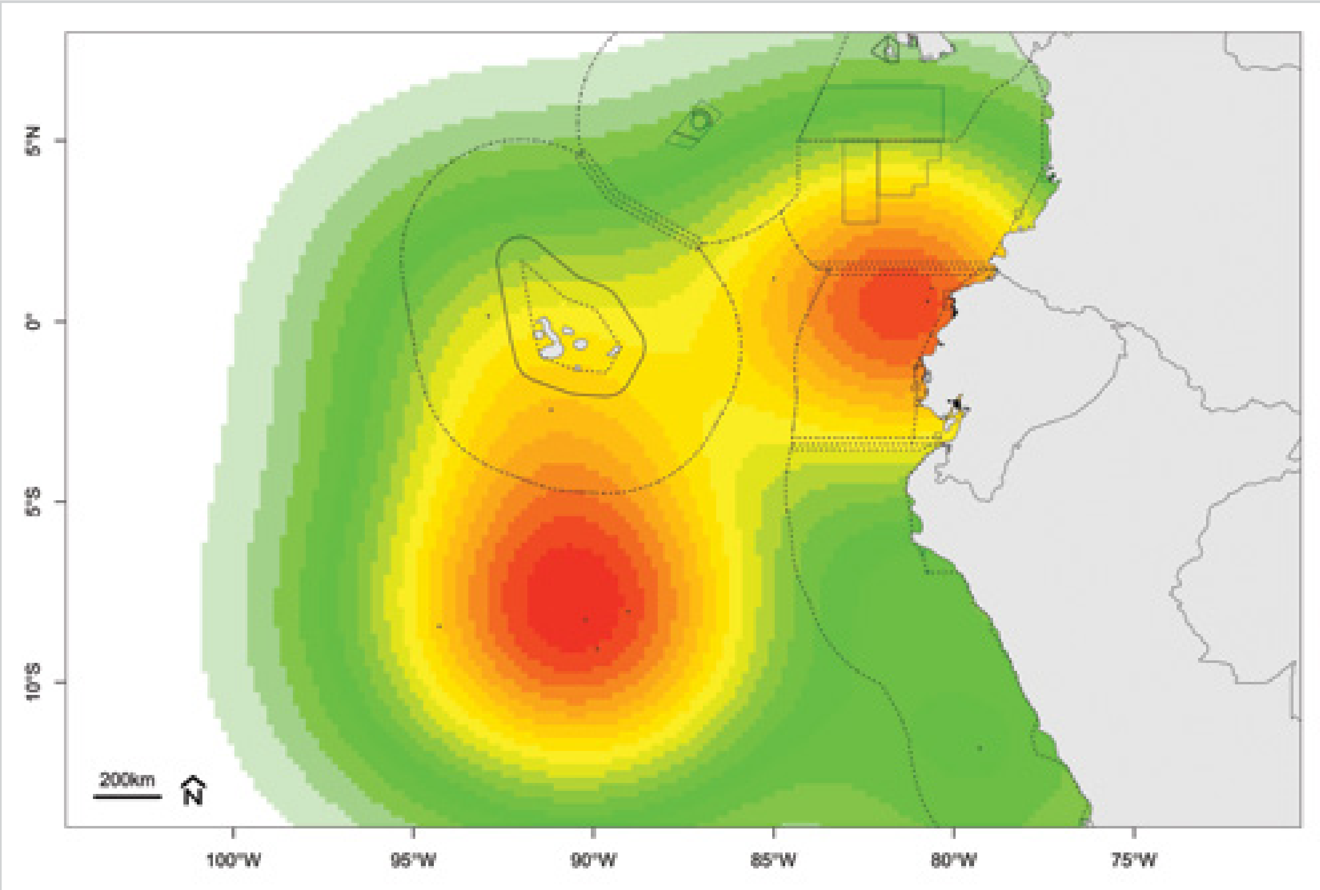
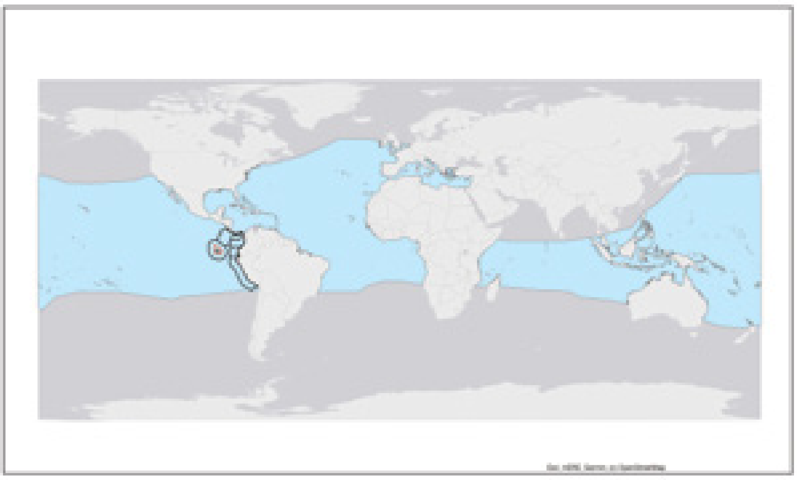


Figure 56. Location of catches of leatherback turtles as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

The leatherback turtle is listed on Appendix I CITES, and Appendices I and II of the CMS (Wallace et al. 2013b). The decline of the leatherback turtle has provided an impetus for the development of conservation initiatives throughout the ETP. The Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC) was created, which establishes regional agreements for the conservation and management of sea turtles (Eckert et al. 2012).

Green sea turtle

The green sea turtle *(Chelonia mydas)* is classified as Endangered by the IUCN. It is found in tropical and subtropical waters across the world (Figure 57) (Seminoff 2004). Among the most important nesting sites is Tortuguero beach in Costa Rica, several beaches of Mexico, Suriname, Venezuela and the Galápagos archipelago (Lara-Uc and Mota-Rodríguez 2015). In mainland Ecuador, the most important aggregation site for this species is the Isla de La Plata, where between 2008 and 2013 a total of 403 individuals were identified through capture-recapture (Miranda 2019). The Galápagos Archipelago represent one of the most abundant green turtle sites in the Eastern Pacific (Parra et al. 2011), the most important nesting and foraging areas for green turtles in the archipelago are Quinta Playa and Bahía Barahona (Isabela Island), where between 2,000 and 2002 a total of 1,384 turtles were captured and tagged (Zárate and Dutton 2002) .



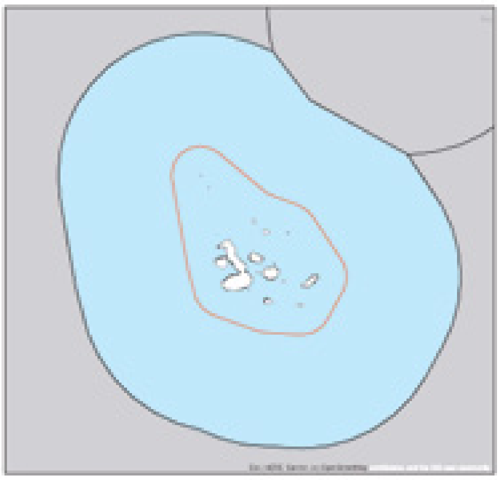


Figure 57. Global range of the green sea turtle (left) and distribution within the Galápagos EEZ (right). Source: Seminoff (2004).

Its diet mainly consists of algae species *Ulva lactuca, Polysiphonia* sp., *Hypnea* sp. and *Dictyota* sp., and the red mangrove *Rhizophora mangle* (Carrión-Cortez et al. 2010), and to a lesser extent, cnidarians (Lara-Uc and Mota-Rodríguez 2015). Being herbivorous, they play a very important ecological role by helping to distribute nutrients and stabilize marine ecosystems (Lara-Uc and Mota-Rodríguez 2015). Sexual maturity occurs between 25 and 30 years, (Monzón-Argüello et al. 2011). Generation length (age at sexual maturity plus one half the reproductive longevity) is thought to be 35.5-49.5 years (Seminoff 2004). The number of hatchlings produced by a female each year varies from 67 to 138 (Hirth 1980). After hatching, the neonate turtles swim into the open ocean in search of food (Luschi et al. 2003). Once they have reached sexual maturity they migrate, approximately every three years, from their feeding area to the nest at the beach where they were hatched (Eckert et al. 2000).

A conventional tagging study in the 1970s showed that green turtles perform long-distance movements from Galápagos (approximately 1,250–2,000 km) throughout the ETP, mainly to Costa Rica and Panama, with 10 individuals also recovered from Peru (Green 1984). Three types of movement patterns have been identified within the nesting green turtles of the Galápagos Islands: Residents, migration to Central America, and migration to the oceanic southwest (Figure 58) (Seminoff et al. 2008). A green turtle tagged at Cocos Island in 2014 traveled to the GMR over a 14-day period (Turtle Island Restoration Network 2014). Through genetic analysis, a migratory connection has been identified between the Galápagos Islands and Machalilla National Park in mainland Ecuador (Chaves et al. 2017).

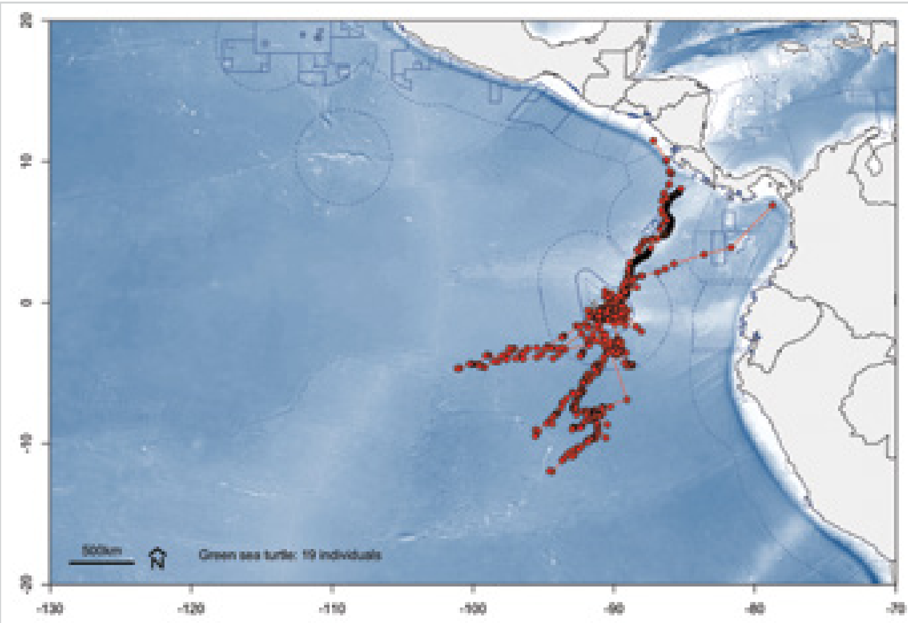


Figure 58. Satellite tracks of 19 green turtles tagged at Cocos and Galápagos Islands, 2003-2013 (average track length 46 days) (Source: Seminoff et al. 2008, Parra unpublished, Steiner & Arauz unpublished).

There is some uncertainty about the current status of the green turtle. According to the Colombian red list, the green turtle population in the EPO has declined by 95% over the preceding 20 years (Páez et al. 2015). Studies at key nesting sites across its distribution between 1976 and 2001 showed that "the mean annual number of nesting females has declined by 48% to 67% over the last three generations" (Seminoff 2004, Parra et al. 2011). Historically the most important nesting site for *C. mydas* was Michoacán, Mexico. In the Golfo Dulce in Costa Rica between 2010 and 2013 a total of 253 green turtles were captured. In addition, it was determined that the annual CPUE gradually decreased from 0.45 to 0.19, which may be as a result of the capture of turtles in 2013 (Chacón-Chaverri et al. 2015). There is no reliable information on the population trends of green turtles in the GMR.

Green turtles are threatened by illegal egg trafficking, collection and capture of adults, fishery bycatch, pollution, disease, and coastal development (Seminoff 2004). In the GMR despite efforts to protect sea turtles, there are still reports of green turtle mortality due to anthropogenic interactions, including the collision of boats and entanglement with fishing gear (Parra et al. 2011). For example, one of the most important sites is Drake Bay, which is located inside the Machalilla National Park; however, the nests are threatened by the rise in sea level on such a narrow beach. Nests must be moved to a hatchery each season (Miranda 2019). On other beaches outside protected areas, nesting activity is exposed to a variety of threats, including habitat destruction from sand removal and coastal development, predation by domestic animals, and commercialization of turtle meat and derivatives (MAE 2014).

Based on the Ecuadorian Fisheries Agency observer program (2008-12), green sea turtles interactions with the small-scale artisanal and semi-industrial fisheries are common, and occur mostly in the areas west to the Galápagos, within the north area of Ecuador's EEZ, and in international waters off the coast of Peru and Ecuador (Figure 59).

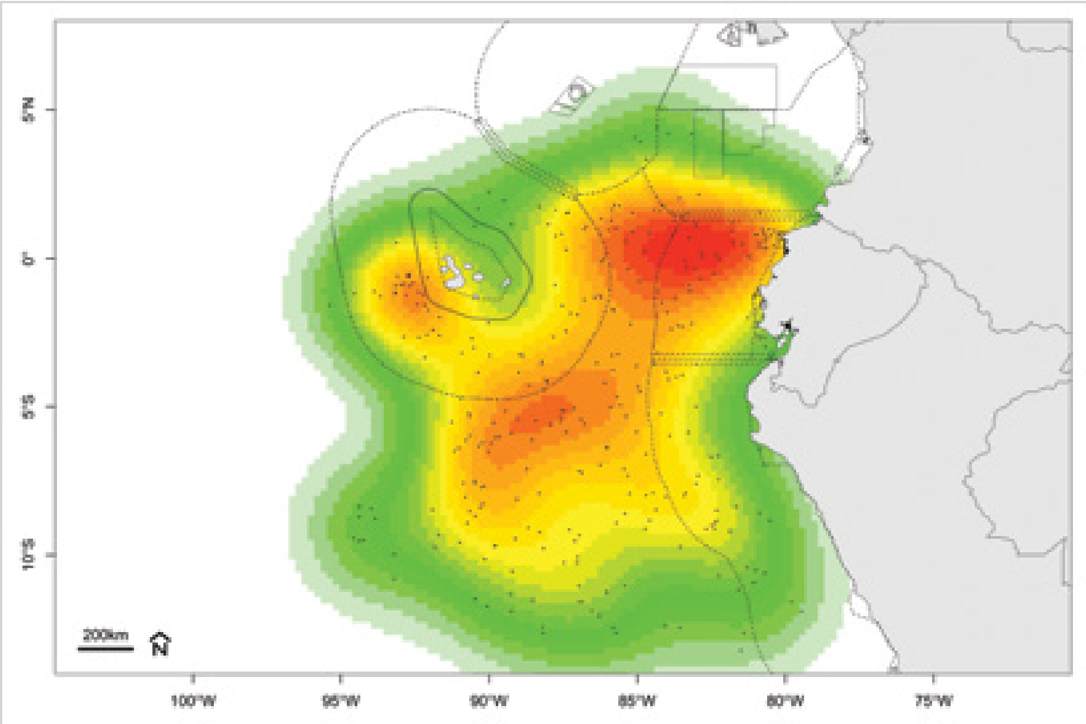


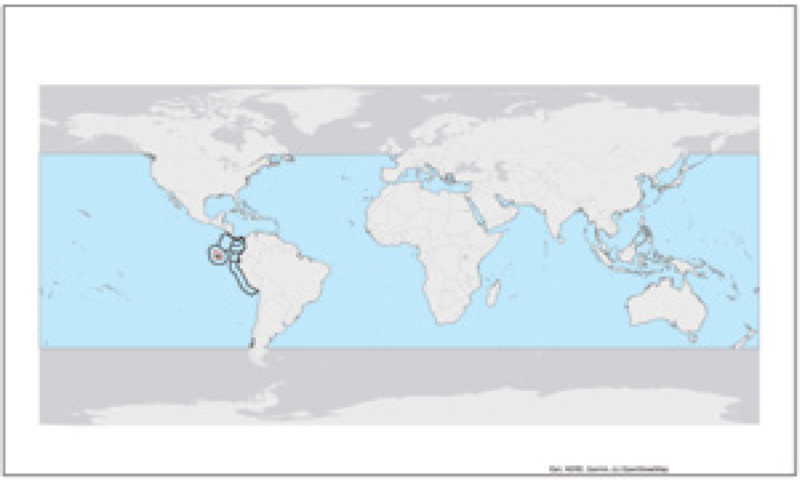
Figure 59. Location of catches of green sea turtles as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Green sea turtles are listed on CITES Appendix I, and on Appendices I and II of CMS (Seminoff et al. 2004). In 2014, Ecuador implemented a National Plan for the Conservation of Sea Turtles in an effort to protect and conserve coastal marine biodiversity (MAE 2014).

Hawksbill turtle

The hawksbill turtle *(Eretmochelys imbricata)* is a mainly coastal species that inhabits warm (25–30°C) (Gaos et al. 2012a), shallow tropical and subtropical seas worldwide (Figure 60), often associated with coral reefs. This species has been reported in more than 60 countries around the world, although in low numbers due to the intense exploitation to which it has been exposed (Vilaça et al. 2013). It is listed as Critically Endangered by the IUCN (Mortimer and Donnelly 2008). In the Eastern Pacific Ocean it is found from Baja California, Mexico, to northern Chile. The diet of the hawksbill turtle is mainly sponges (Meylan 1988; von Brandis et al. 2014). Juvenile hawksbill turtles in Costa Rica fed mostly on sponges and tunicates (Carrión-Cortez et al. 2013). Longevity is thought to be 30 to 55 years (Zolgharnein et al. 2011), and a recent genomic promoter cytosine-phosphate-guanine (CpG) study suggested that they may live around 53.2 years (Mayne et al. 2020). Hawksbill turtles reach sexual maturity at 4 years and in each nest they can place between 70 and 200 eggs every 2 to 4 years (Santisteban et al. 2015; Zolgharnein et al. 2011). The beaches in

Bahía de Jiquilisco in El Salvador and the Estero Padre Ramos in Nicaragua are very important sites for hawksbill nesting, as they represent 40% of the entire population in the Eastern Pacific (Santisteban et al. 2015). In Ecuador, hawksbill turtles historically nested along much of the coast, mainly between Manta and Cojimíes, while the GMR is considered to be a foraging site (Mortimer and Donnelly 2008).



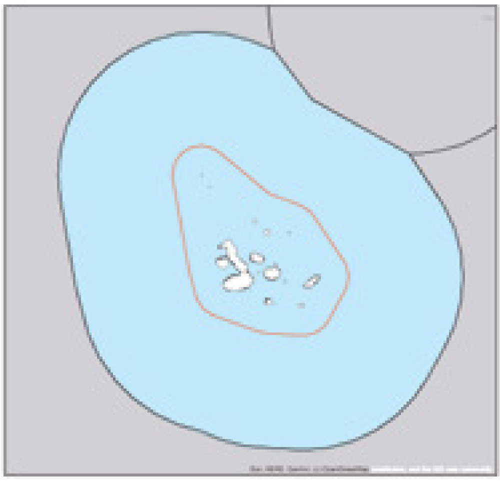


Figure 60. Global range of the hawksbill sea turtle (left) and distribution within the Galápagos EEZ (right). Source: Mortimer and Donnelly (2008).

On mainland Ecuador, La Playita in Machalilla National Park was identified in 2008 as a key nesting site (Miranda 2019). Since then, a total of 14 nesting beaches have been identified in mainland Ecuador, two of which have been designated index beaches (Miranda 2019). These two beaches are La Playita in the Machalilla National Park with an average of nearly 30 nests per year (Miranda 2019) and Playa Rosada (including the small adjacent Chipi-Chipi beach in the El Pelado Marine Reserve with an average of 41 nests per year) (Gaos et al. 2017, Miranda 2019). "A total of 54 nesting females have been identified in Ecuador, 44 from Machalilla National Park, and 10 from El Pelado, with around 5 nesting each year in Machalilla National Park" as of 2019 (Miranda 2019). In 2015, the first hawksbill turtle hatchlings were registered in the GMR, at San Cristóbal Island (Alarcón-Ruales et al. 2016).

Tracking studies have in the ETP showed that hawksbill turtle movements and habitat use are highly neritic and migratory (although post-nesting movements were shorter than those of other turtle species), mainly along the coasts of El Salvador, Honduras and Ecuador (Gaos et al. 2012b). Hawksbill feeding ground ranges appear to be larger than their inter-nesting range (Cuevas et al. 2008). Based on limited satellite and ultrasonic tracking at both Cocos and Galápagos it appears that hawksbill turtles at these island locations are fairly residential (Arauz & Steiner, unpublished; Muñoz et al. unpublished), and remain for the most part in restricted foraging grounds (Figure 61), although some connectivity has been established: one adult male was tracked to Clipperton Island (Muñoz-Perez et al. in prep.). Further, two hawksbill turtles with metal flipper tags were reported from mainland Ecuador: a female tagged in San Cristóbal in 2014 was reported from Cayapes Mataje in Esmeraldas province 411 days later, in 2015; and a male that had been tagged in the GMR as a juvenile in 2004 was captured 13 years later in Machalilla National Park (Muñoz-Pérez et al. 2018).

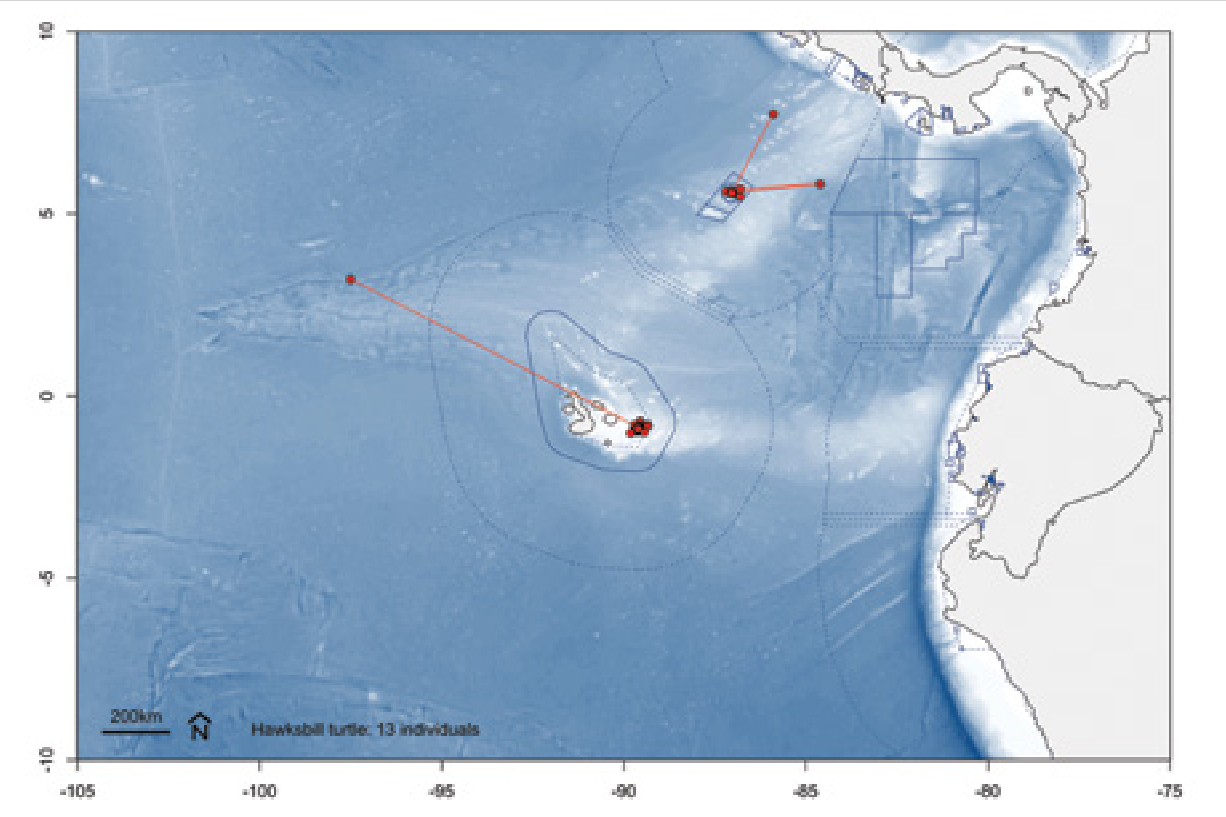


Figure 61. Satellite tracks of hawksbill turtles tagged at Cocos and Galápagos Islands, 2009-2020 (average track length 79 days). Source: Arauz & Steiner (unpublished), Muñoz & Alarcón (unpublished).

It is estimated that over the past three generations, the there has been a global decline of >80% in the number of mature female hawksbill turtles nesting (Mortimer and Donnelly 2008). Today, there are less than 10 large nesting sites worldwide where more than 1,000 females nest annually (Spotila 2004). El Salvador is thought to host most of the known hawksbill turtle population in the eastern Pacific, with 79.6% of all known nesting observation records for this species (Gaos et al. 2010).

Hawksbill turtles are targeted or retained (both illegally), to sell their meat or derivatives on the black market (Santisteban et al. 2015). Only a small number of individuals have been reported by the Ecuadorian longline fleet, mostly in international or Peruvian waters (Figure 62).

Hawksbill nesting beaches outside protected areas are exposed to threats such as sand extraction, vehicle traffic on the beach, artificial lighting, and illegal predation and collection of nests (MAE 2014). Even on those beaches within protected areas such as Playa Rosada in the El Pelado Marine Reserve, nesting habitat has been altered by the construction of tourist facilities, the lighting network or the destruction of vegetation. At many of these sites there is the threat of invasive species such as domestic and wild dogs which destroy nests (Luzuriaga 2019). As with other sea turtles, hawksbills are vulnerable to climate change through a range of impacts, from sea level rise affecting viability of the nesting habitat, and temperature changes affecting nesting success, sex ratio and malformations in neonates (Glen and Mrosovsky 2004; Hawkes et al. 2009). Hawksbill turtles are listed on Appendix I of CITES, and on Appendices I and II of CMS (Mortimer and Donnelly 2008).

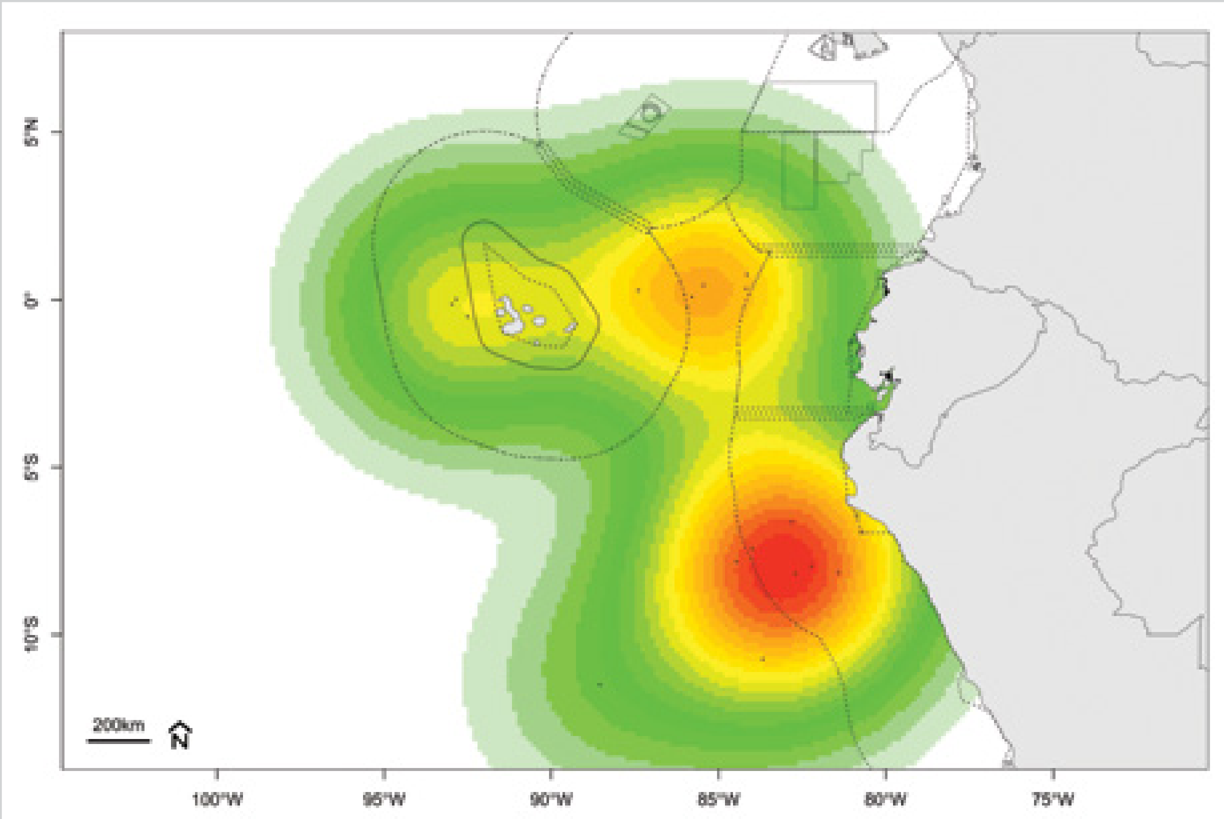


Figure 62. Location of catches of hawksbill turtle as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Olive ridley sea turtle

The olive ridley sea turtle *(Lepidochelys olivacea)* is found throughout the world's tropical oceans (Figure 63), with the exception of the Gulf of Mexico (Abreu-Grobois and Plotkin 2008). This species is mostly solitary and epipelagic, except for in breeding seasons (Zug et al. 1998). Olive ridley turtles are the most abundant of the sea turtles (Ariano-Sánchez et al. 2020). They were listed as Endangered during successive red list assessments from 1982-1996, but their status was amended to Vulnerable in 2008 (Abreu-Grobois and Plotkin 2008).

Olive ridley turtles are nomadic opportunistic omnivores that are thought to feed in both benthic and pelagic habitats (Peavey et al. 2017, Plotkin 2010). A genomic promoter cytosine-phosphate-guanine (CpG) study suggested that the olive ridley sea turtle may live around 54.3 years (Mayne et al. 2020), reaching maturity at 13 years (Abreu-Grobois and Plotkin 2008), from which age they nest every 1.7-2 years (Hinestroza and Páez 2000). To nest they look for sandy beaches with high levels of humidity (Arzola-González 2007), and lay 100-110 eggs in each nest (Abreu-Grobois and Plotkin 2008). Olive ridley turtles can nest in a solitary fashion but in some locations, they perform mass nestings, known as "arribadas" (Abreu-Grobois and Plotkin 2008) although there are no reports of these mass nestings in Ecuador. In the eastern Pacific, these include beaches in Guanacaste in northern Costa Rica, and in Oaxaca in Mexico (Zug et al. 1998). No nesting of this species has been reported in the Galápagos Islands (Zárate 2006).

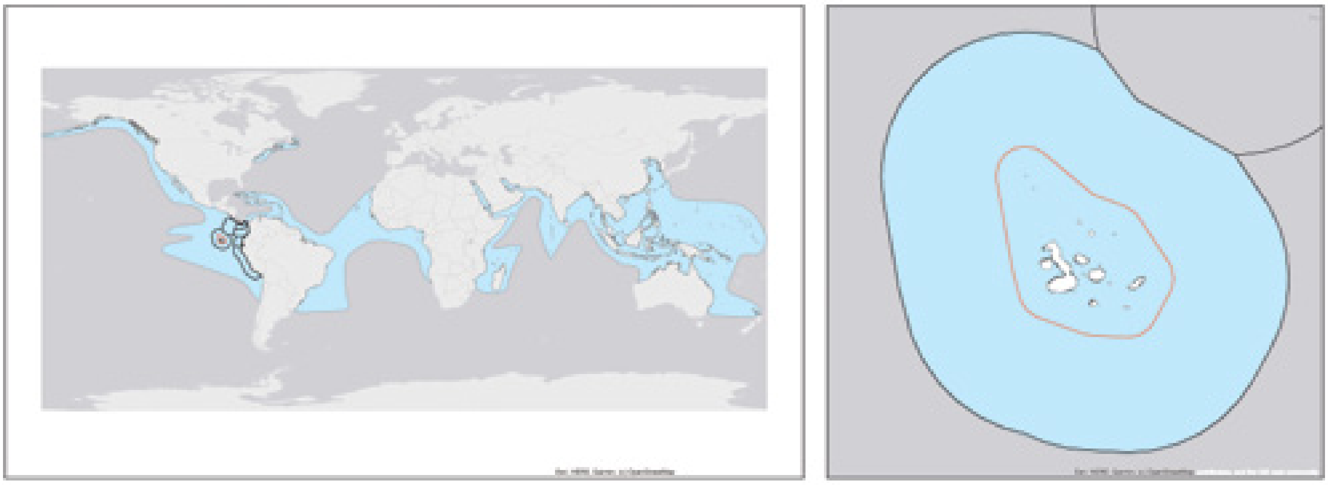


Figure 63.Global range of the olive ridley sea turtle (left) and distribution within the Galápagos EEZ (right). Source: Abreu-Grobois and Plotkin (2008).

In the ETP, satellite tagging studies in Costa Rica showed broad movements within the EEZs of Mexico, Honduras, Nicaragua, Costa Rica, Colombia, Guatemala, El Salvador, Panama, Ecuador and Peru, and in international waters (Plotkin 2010). The low migration between ocean basins has given rise to genetic divergences between the oceanic regions of the ETP, Atlantic and Indo-Pacific (Bowen et al. 1998).

The estimated global rate of population decline ranges between 31-36% over two generations, and is thought to be a conservative estimate (Abreu-Grobois and Plotkin 2008). In Ecuador, even though it is the most abundant nesting species of sea turtle, there is no recent information on the number of females, remigration intervals, number of nests per female, etc. (Alava et al. 2007; Miranda 2019). Nests are reported at 40 beaches along the coast. The most important nesting beaches are in Manabí, in the Pacoche Wildlife Refuge with an average of 127 nests per year in San Lorenzo, followed by La Botada beach with 95 nests per year (MAE 2014; Miranda 2019). In Esmeraldas, the most outstanding beaches are Portete and Las Palmas with an abundance of 77 and 88 nests per year respectively (Coello and Herrera 2011).

Olive ridley turtles risk entanglement with fishing gear (Figure 64) and potentially also vessel strikes. According to Miranda (2019), during a bycatch study of the Ecuadorian artisanal longline fishery between 2009 and 2010, 92 olive ridley

turtles were caught. Invasive species on nesting beaches are also cause for concern, as is the harvesting of eggs. In Portete – Esmeraldas, dogs destroyed 100% of the nests in 2010 (Herrera and Coello 2011). A similar case occurred in Las Tunas in the province of Manabí, where dogs destroyed 40% of the nests (Miranda 2019). Although the use and sale of meat and turtle derivatives is prohibited, cases have been reported on the beaches from the central coast (MAE 2014) and in Las Tunas and Playa Dorada beaches in Manabi (Miranda 2019).

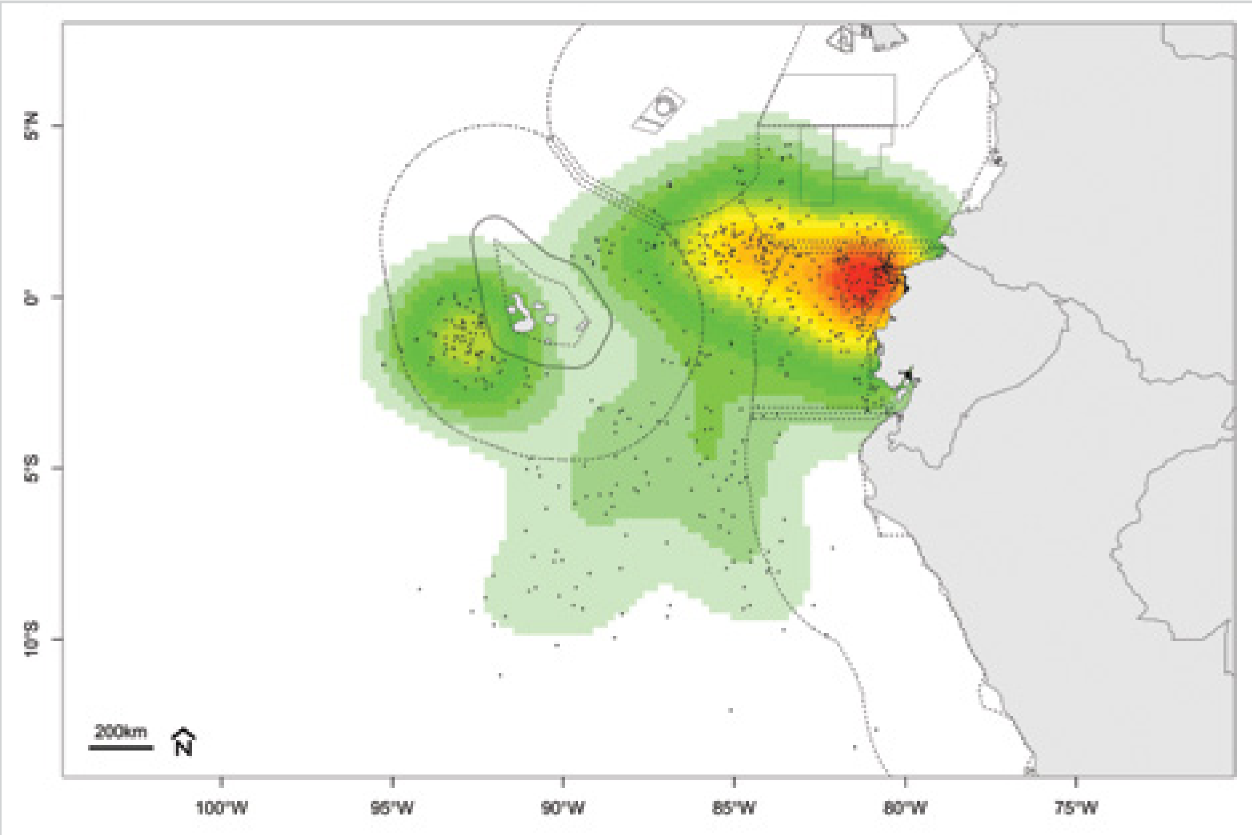


Figure 64. Location of catches of olive ridley sea turtles as reported by the Ecuadorian Fisheries Agency observer program (2008-12). Each dot represents the capture location, and the heat map-colored regions a simple kernel density analysis (Worton 1989) of capture locations. Green areas are less dense; yellow, middle dense; and red, highly dense.

Research and monitoring of beaches are recent for most of mainland Ecuador, especially for this species. Nevertheless, like other species of sea turtles, these are protected by Ecuadorian legislation. Olive ridley turtles are listed on CITES Appendix I and on Appendices I and II of CMS (Abreu-Grobois and Plotkin 2008).

Waved albatross

The waved albatross *(Phoebastria irrorata)*is the largest seabird in the Galápagos Islands, with a wingspan of 220–250 cm and weighing up to 4.0 kg. It is the only albatross species to nest and forage exclusively in the tropics (Figure 65) (Anderson et al. 2002, Suryan et al. 2008). Albatrosses in general inhabit temperate regions where average wind speeds are higher. Waved albatrosses (together with the short-tailed albatross) have one of the smallest breeding ranges in comparison with other species of albatross and rely on more wing flapping/active flight to cope with lower wind speeds over tropical waters (Suryan et al. 2008).

They are considered top marine predators but also opportunistic scavengers. As such, they are attracted to fishing baits used in long-line fisheries. Fishery bycatch is a major cause of mortality for albatrosses in general (Tuck et al. 2001) and waved albatross in particular (Awkerman et al. 2006).

They are long-lived - the oldest record is of an individual recaptured 40.8 years after banding (Jiménez-Uzcátegui et al. 2016); but have slow reproduction rates, which makes them susceptible to introduced species and colony disturbance (Anderson and Fortner 1988). Breeding begins at 4-6 years, and they lay a single egg per year. Waved albatross nest almost exclusively (<99%) on the island of Española, except for likely fewer than 10-20 pairs at Isla de la Plata, off mainland Ecuador (BirdLife International 2018b). This species nests along the rocky shores and the interior of the island. The breeding season is between April and January of each year. During breeding, waved albatross do short trip foraging within the GMR and long trips to forage in the Humboldt upwelling system of the coast off Ecuador and Peru (Figure 66). During the nonbreeding season, between January and March, birds migrate from the Galápagos to the Humboldt upwelling system, presumably to molt and recover for the next breeding season.

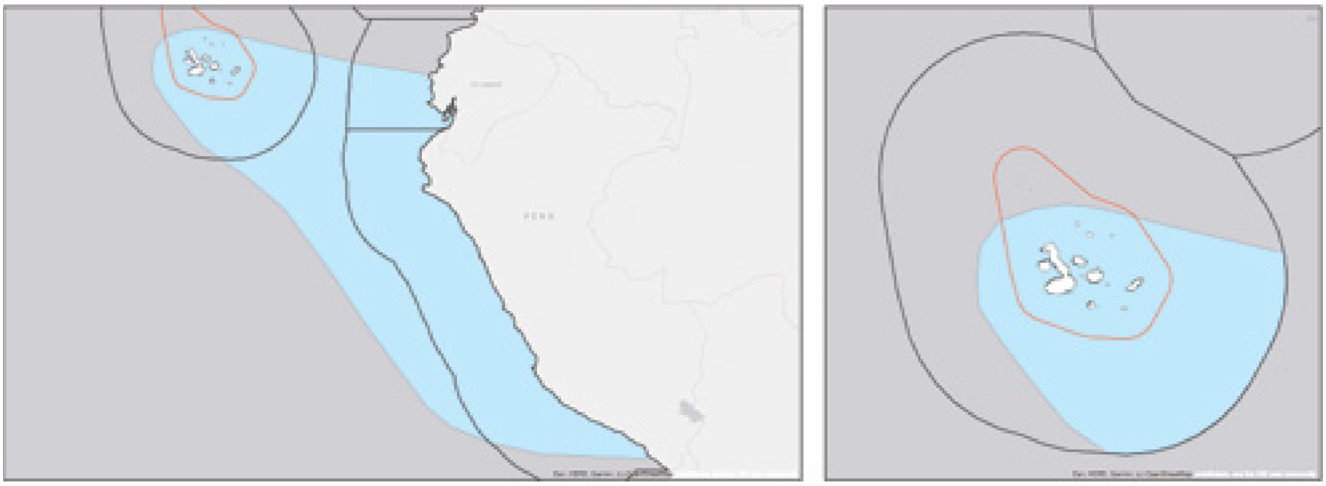


Figure 65. Global range of the waved albatross (left) and distribution within the Galápagos EEZ (right). Source: BirdLife International (2018b).

The foraging distribution of the waved albatross varies with breeding stage. During the chick-brooding period (in June-July) birds mostly occupy waters on the Galápagos platform within 100 km of their breeding site (Awkerman et al. 2005). Alternatively, during incubation and chick rearing when one or both parents are free to forage for multiple days, birds travel to the coasts of Ecuador and Peru to feed in the rich waters of the Humboldt upwelling system (Awkerman et al. 2014).

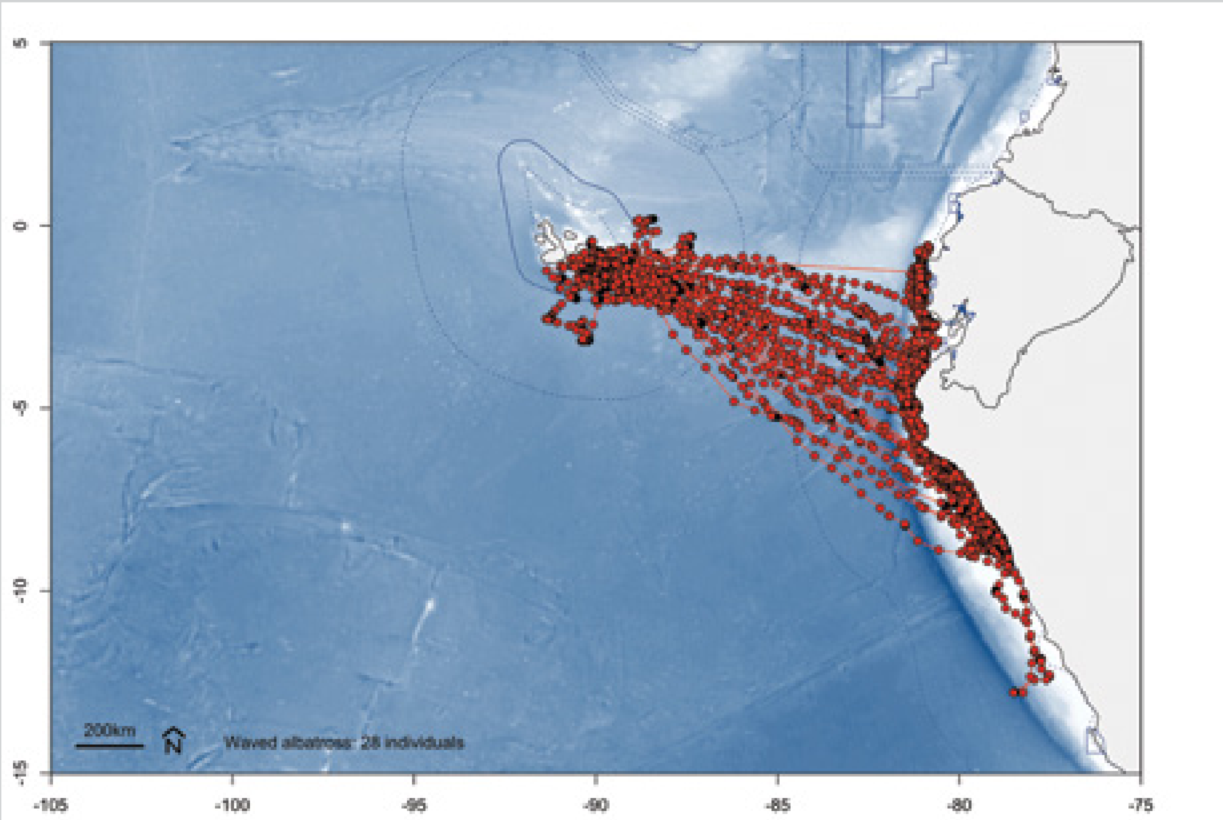


Figure 66. Satellite tracks for 28 waved albatross tagged in 2008 (average track length 37 days). Adapted from Dodge et al. (2013), Anderson et al. (2003) and data from Galápagos Movement Consortium, data repository www.movebank.org.

Waved albatross are listed as Critically Endangered across their range (BirdLife International 2018b). The first complete census of waved albatrosses on Española was carried out in 1970-1971; it estimated 12,000 pairs (Douglas III 1998; Harris 1973). A second census in 1994, with improved methods, estimated the global population of waved albatrosses to be at least 18,200 pairs (Douglas III 1998). A population survey in 2001 estimated between 31,818 to 34,694 adult birds on Española Island (Anderson et al. 2002). Annual adult survival, a measure of the trend of a population, was reduced between 1999–2005 when compared with historical estimates (Awkerman et al. 2006). In 2006, Awkerman reported that the population growth rate was less than 1, indicating a declining population. Studies suggest that the breeding population has continued to decline between 1994-2007 (Figure 67) (Anderson et al. 2008). At the two main study sites, Punta Cevallos and Punta Suárez, the number of breeding pairs were estimated at 6,045 breeding pairs, 88.1% of that in 2001 (Anderson et al. 2008).

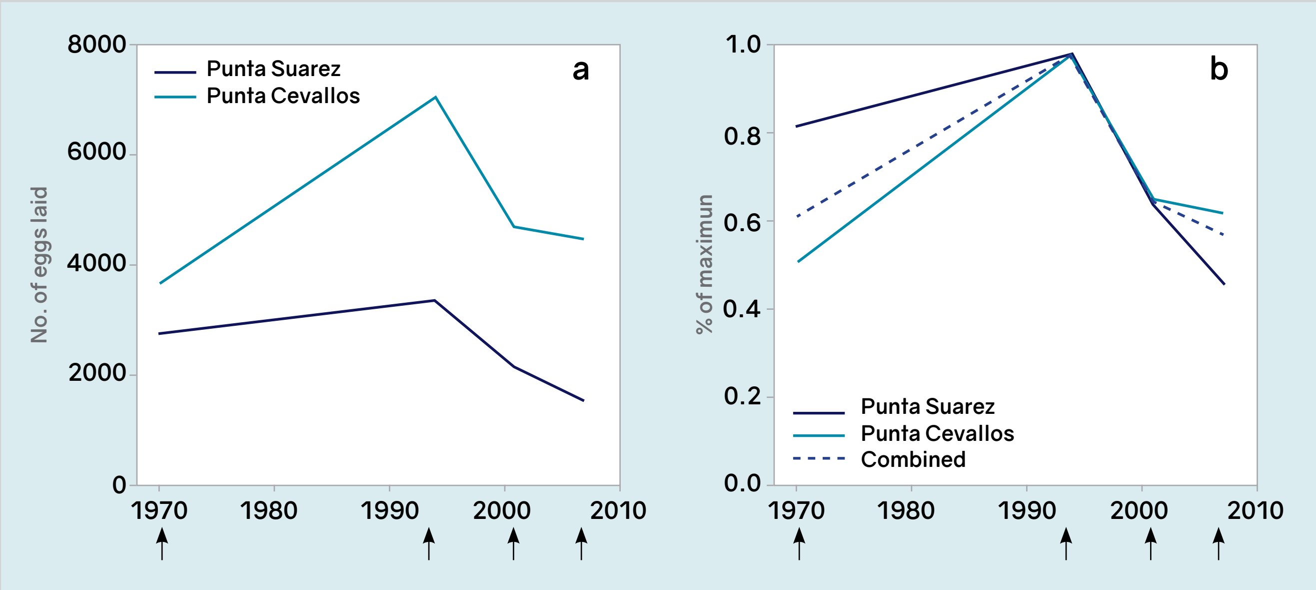


Figure 67. Trend in size of the breeding population of waved albatrosses at two principal breeding sites on Isla Española, Galápagos. (a) Estimate of number of eggs laid in each breeding season corrected for egg loss and gain. (b) Number of eggs laid per season scaled to the maximum number observed. Arrows in (a) indicate timing of the 4 population counts Source: Anderson et al. (2008).

The waved albatross population has undergone a severe decline, which might be linked to incidental and intentional capture in the artisanal long-line fisheries of Peru (Awkerman et al. 2006). Waved albatross forage in this heavily fished zone despite the fact that they reproduce on the Galápagos Islands. Because albatrosses are long-lived animals with delayed breeding and slow reproductive rates, they are especially vulnerable to extrinsic sources of mortality (Awkerman et al. 2006). "Banding data and recovery information also suggest that capture by fisheries is male-biased, which should reduce fecundity in this species with obligate bi-parental care" (Awkerman et al. 2006). It is thought that increasing vegetative cover on Española due to the decline of giant tortoise *Geochelone hoodensis* populations prior to 1900, and the 1978 eradication of feral goats *Capra hircus*, "have restricted breeding habitat generally Douglas III 1998). In 2017 a study was published that reported the detection of avipoxvirus in 14 waved albatross chicks (Tompkins et al. 2017). Climate change may also pose a threat to waved albatross, given that there are indications of increased adult mortality and interactions with fishing activities during El Niño events (Rechten 1986, Awkerman *et al.* 2006).

Ecuador and Peru are both members of ACAP (Agreement on the Conservation of Albatrosses and Petrels), a legally binding international agreement, which entered into force in 2004 (ACAP 2018, 2021). It was created in order to halt the drastic decline of albatross and petrel populations. Española is a designated ACAP breeding site, due to its importance to waved albatross reproduction. Several meetings have taken place to reduce bycatch of waved albatross in the artisanal long line fisheries of both countries. The IATTC introduced measures to reduce seabird mortality on longlines (IATTC 2011a). The Peruvian NGO Pro Delphinus (https://www.prodelphinusperu.org) has conducted several campaigns with fishermen to eliminate intentional catches of waved albatross. Scientists have an ongoing capture-mark-recapture program on Española to monitor population trends.

Galápagos petrel

The Galápagos petrel *(Pterodroma phaeopygia)* is a long-lived (30+ years), endemic bird that breeds exclusively in the Galápagos archipelago (Browne et al. 1997), and whose foraging grounds are within the Eastern Tropical Pacific (Figure 68). Galápagos petrels breed on four of the major islands in Galápagos archipelago, Santa Cruz, Floreana, Santiago, San Cristóbal and potentially also on Isabela. Unlike other seabirds in the Galápagos, nesting colonies are located in the highlands, typically above 200-300 meters above sea level (Cruz and Cruz 1996). Large colonies are restricted to protected sites managed by the Galápagos National Park. Although nests are found within private farmlands, they are few and far apart.

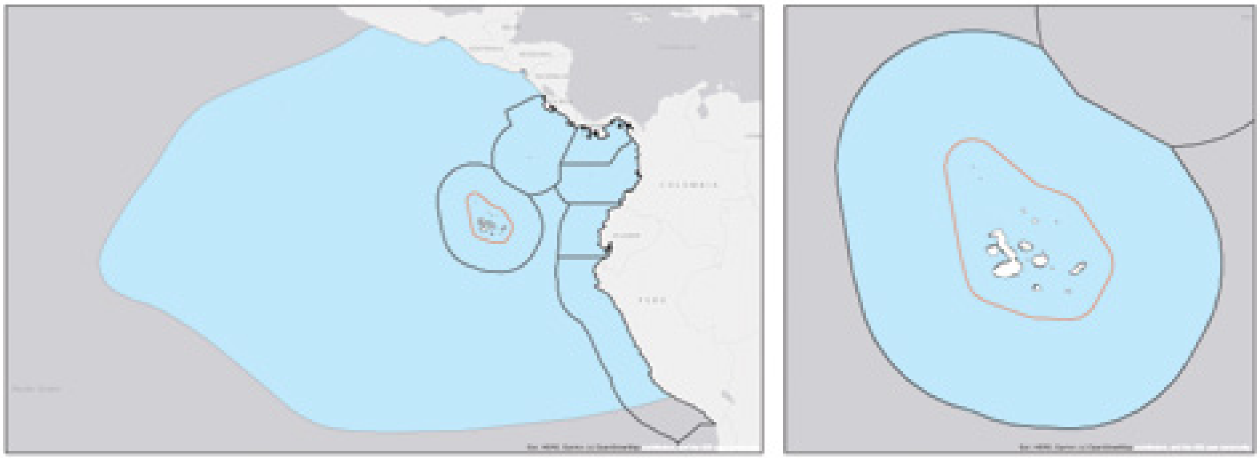


Figure 68. Global range of the Galápagos petrel (left) and distribution within the Galápagos EEZ (right). Source: (BirdLife International 2018c).

This species is nocturnal at breeding colonies, arriving after sunset and leaving before dawn. Galápagos petrels exhibit extreme philopatry, returning to the colony in which they were born when reaching adulthood. Breeding begins at age 3-5 years. Breeding pairs form stable bonds and will use the same burrow throughout their reproductive life (Schreiber and Burger 2001). They have an extended breeding season that lasts 5-6 months (Coulter et al. 1982). They lay a single egg per season. Petrel chicks will stay in their burrow without ever seeing the ocean, which can be tens of kilometers away until they fledge at ~120 days of age (Imber et al. 1992).

Galápagos petrel colonies are highly vulnerable to habitat destruction because they overlap with the agricultural zone on populated islands. Most of their breeding habitat was destroyed for use as pasture for cattle and plantations (Harris 1977). Furthermore, because eggs and chicks are on the ground, they are easily preyed upon by introduced predators such as rats, cats and feral pigs (Cruz and Cruz 1990; Cruz and Cruz 1987).

At sea, Galápagos petrels travel over large expanses of ocean search of food. They are fast moving top marine predators with a highly developed sense of smell to detect prey. They feed on squid, fish and fish eggs. Foraging trips during reproduction occur to the west, east and south of the archipelago. Petrels can forage over shallow coastal waters, seamounts, continental shelves and in deep, blue water. Petrels forage in looping trips to maximize the area they cover in search of prey. During the breading season birds regularly travel 1,000 km from their nest and cover approximately 3,000-4,000 km in a single trip (Figure 69).

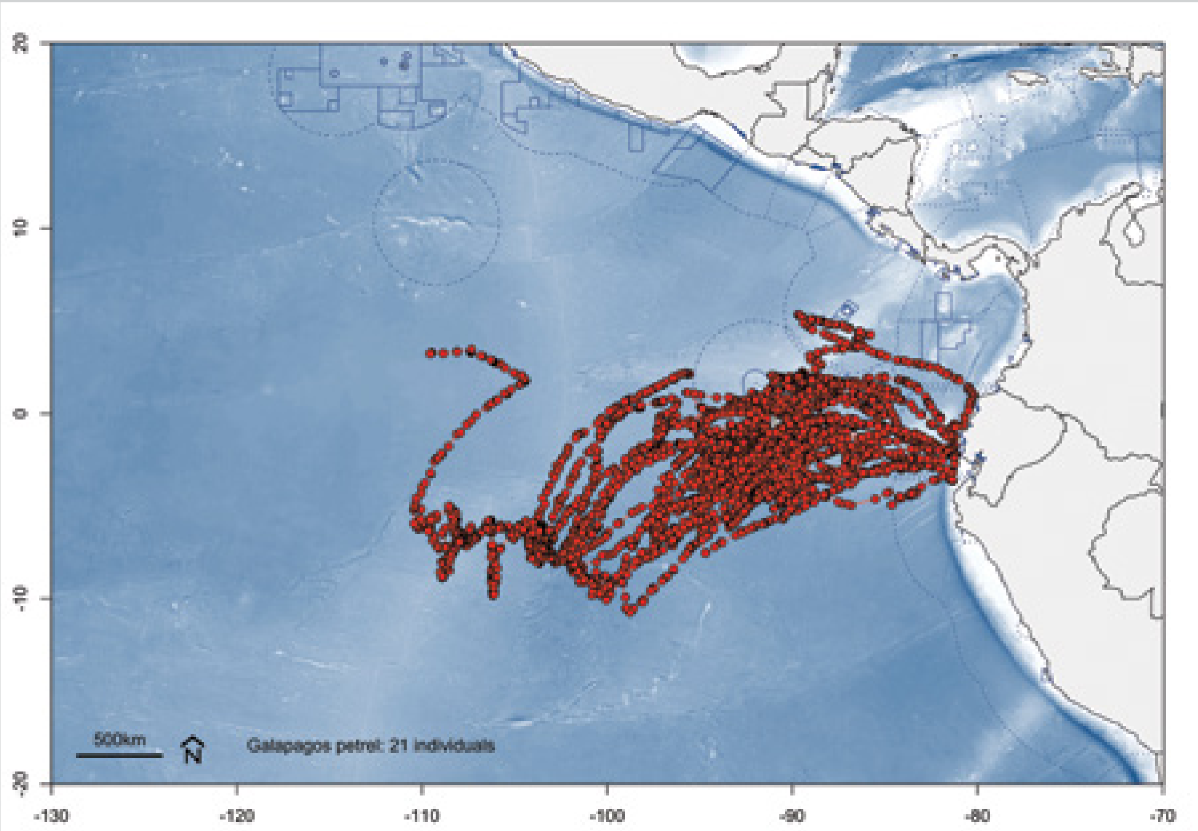


Figure 69. Satellite tracks for 21 Galápagos petrels tagged in 2009-2011 (average track length 82 days). Source: Proaño C, unpublished data (accessed via Galápagos Movement Consortium, data repository www.movebank.org).

Estimates of the historical population size of Galápagos Petrels, prior to the 1980s, range from 11,000 breeding pairs on Santiago, 9,000 on Santa Cruz and 2,000 on Floreana (Cruz and Cruz 1987). The population size and reproductive success of this species plummeted in the early 1980s, with an estimated ~30% annual decrease in active burrows, and unless immediate conservation measures were taken it would become extinct (Coulter et al. 1982). Programs to reduce predation through poisoning and hunting demonstrated that breeding success could be improved significantly by controlling predators in and around petrel nesting sites (Cruz and Cruz 1987). Based on GNP internal reports there are currently four colonies that are actively managed by the GNP service, with annual and monthly control of rodents, cats and invasive plants such as blackberry. The largest of these is Cerro Pajas (Floreana) with over 1,000 active nests; followed by the Media Luna colony (Santa Cruz) with 500 active nests and Cerro Los Helechos (Santa Cruz) with 242 active nests. On Santiago Island, the only unpopulated island with petrels, there are 300 active nests at Cerro Jaboncillo. Nonetheless, it is important to note that Galápagos petrel colonies were far larger prior to human settlement. Thus, these current numbers are significantly reduced, and colonies rely on active management.

The Galápagos petrel is listed as Critically Endangered (BirdLife International 2018c). Galápagos petrels face a multitude of threats on all of the five nesting islands. The most pervasive and severe threat to this endemic petrel are non-native mammalian predators, including feral cats, rodents and pigs (Cruz and Cruz 1996). Nonetheless, farming and agriculture have destroyed much of their nesting habitat. Invasive blackberries were identified by the IUCN as a threat to Galápagos petrels. National Park personnel have been controlling this invasive plant, which has already caused many problems to the island's ecosystems. This plant grows so densely that is covers nesting sites completely preventing birds from accessing their burrows, furthermore birds attempting to enter burrows or fledglings departing can become entangled in the thorny brambles and subsequently die. Petrels regularly feed on squid; there are concerns that the increase in the number of squid fisheries in the foraging distribution of this species could have a negative impact on their survival (unpublished data).

The Galápagos National Park Directorate (GNPD) has for the past four decades kept an ongoing campaign to control rodents, cats, pigs and dogs in key breeding colonies of Galápagos petrels on four islands. The numbers of active nests and reproductive success of Galápagos Petrels have increased with the conservation measures implemented by the GNP in the breeding colonies that are managed on Santa Cruz (Media Luna, Los Helechos), Floreana (Cerro Pajas) and Santiago (Jaboncillo) islands.


Sebastián Cruz

Great frigatebird

Great frigatebirds *(Fregata minor)* are one of the two frigatebird species that nest on the Galápagos Islands. They are widely distributed throughout the world's tropical seas mainly between 25°N and 25°S (Birdlife International 2020b) (Figure 70). Great frigatebirds soar and glide over large expanses of the ocean looking for surface-feeding predators, such as tuna and dolphins, that bring prey fish up to the surface (Weimerskirch et al. 2004). They are very light with a large wingspan (Rattenborg et al. 2016) and unique among marine birds for lacking a waterproof plumage (Weimerskirch et al. 2017). For this reason, they are unable to rest on the water's surface. They are opportunistic kleptoparasites (Gilardi 1994). During this period, they are completely airborne and capable of sleeping during flight for brief periods of time (Rattenborg et al. 2016). Showcasing this species extreme aerial lifestyle a study found that through the annual cycle, including both breeding and nonbreeding periods, adult great frigatebirds in Galápagos spend an estimated 85.8% of their time in flight (Weimerskirch et al. 2017). Great frigatebirds are vulnerable to extrinsic sources of mortality because they are long-lived (up to 44 years) animals with delayed and slow reproduction (Juola et al. 2006). Females breed every other year. Great frigatebirds have one of the longest rearing stages of any seabird, and they reproduce once they reach an age of 8-9 years (females) or 10-11 years (males) (Nelson 1967, Valle et al. 2006).

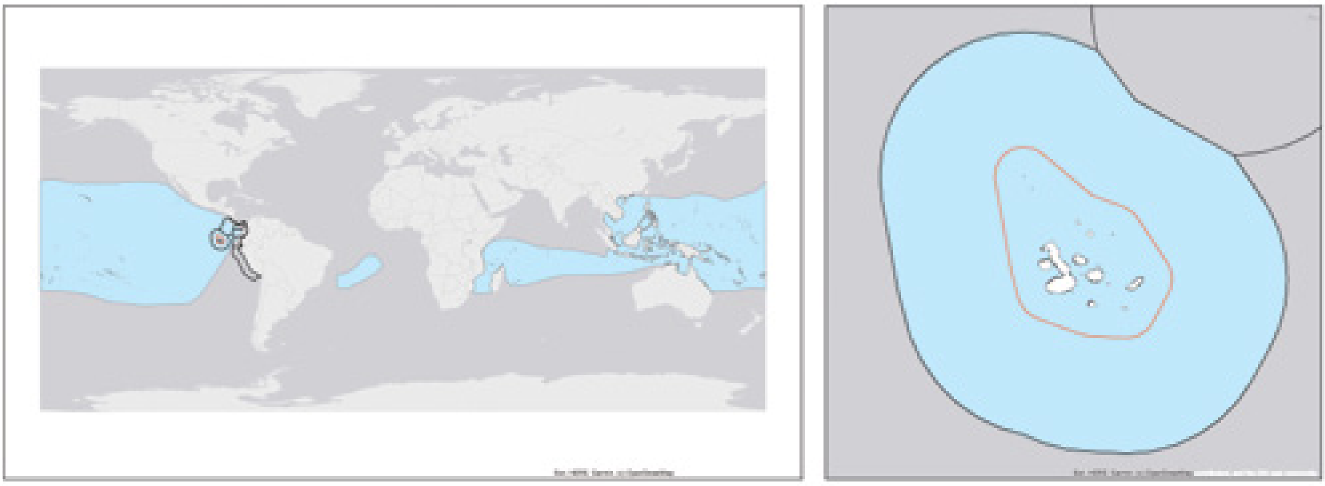


Figure 70. Global range of the great frigatebird (left) and distribution within the Galápagos EEZ (right). Source: BirdLife International (2020b).

Great frigatebirds nesting on Genovesa Island engaged in trips over the ocean lasting up to 10 days and spanning up to 3,000 km (Rattenborg et al. 2016). Most birds completed a roughly clockwise loop over the ocean northeast of the Galápagos Islands (Figure 71). The birds spent less time flapping at night than during the day. The frigatebirds' altitude peaked in the hour before sunset and decreased across the night. On average, "the birds' altitude did not differ between the day (137.9±4.7 m) and night (136.5±3.8 m)" (Rattenborg et al. 2016).

Post-breeding adults remained within the Galápagos Archipelago but moved to sites away from the Genovesa colony (Figure 72) (Weimerkirch et al. 2017). They also differ to the non-breeding movements of this species in the rest of its distribution. Galápagos birds were resident within the archipelago year-round.

This is starkly different to great frigates elsewhere in their distribution, which undertake large-scale migrations. The migratory behavior at Europa Island. (Seychelles) and New Caledonia resulted in "complete separation of foraging grounds between breeding adults, non-breeding adults, and juveniles, whereas in the Galápagos the overlap was complete" (Weimerskirch et al. 2017).

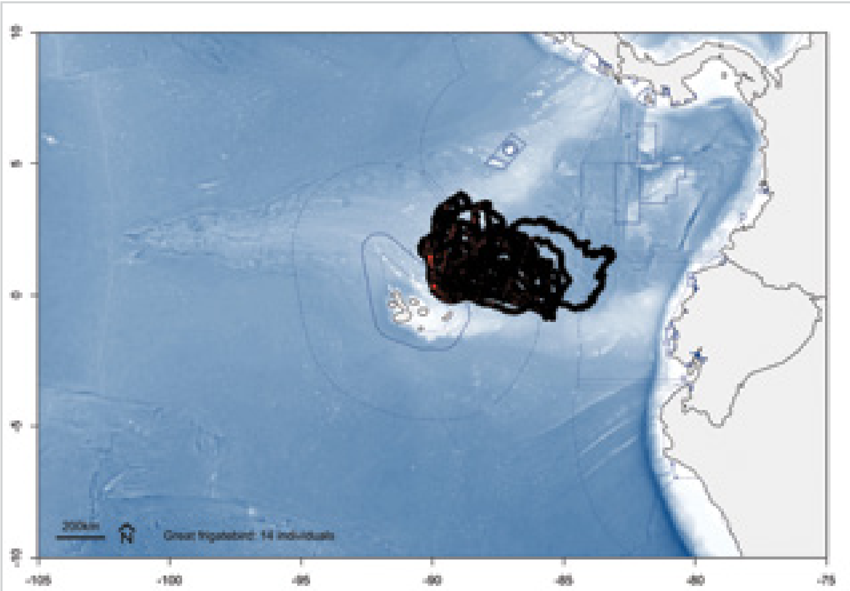


Figure 71. Satellite tracks for 14 great frigatebirds (average track 8 days) tagged in 2014 at Genovesa Island during breeding season. Source: Galápagos Movement Consortium, data repository www.movebank.org.

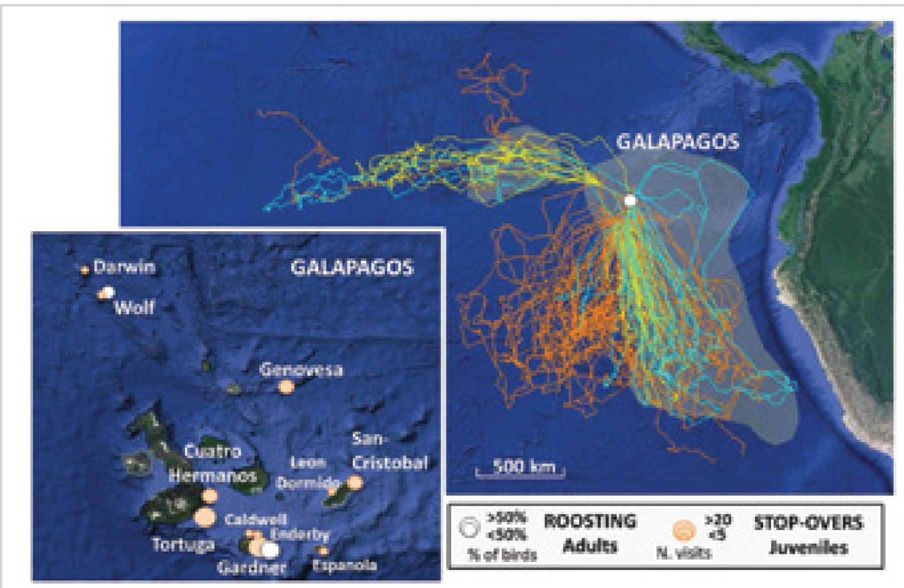


Figure 72. Non-breeding foraging movements of males (blue) and females (yellow) adult Galápagos great frigatebirds from the roosting sites in the eastern equatorial Pacific, with the movements of juveniles (orange). Insert: (Galápagos archipelago showing the breeding site – Isla Genovesa – and the roosting sites and stop-overs). Source: Weimerskirch et al. (2017).

The conservation status of the great frigatebird is Least Concern (BirdLife International 2020b), but there are indications of global population declines, possibly affected by climate change (Birdlife International 2020b). Information on the population trends of great frigates in Galápagos is not available. Great frigatebirds are sensitive to human disturbance when breeding, and roosting sites are usually in areas without human presence (Weimerskirch et al. 2017). Reductions in the number and activity of tuna, dolphins and other pelagic fish could have adverse effects on great frigatebirds. One great frigatebird died as bycatch in a pilot study (2012-2013) to examine the feasibility of long-line fishing in Galápagos (Cerutti-Pereyra et al. 2020).

Magnificent frigatebird

Figure 73. Global range of the magnificent frigatebird (left) and distribution within the Galápagos EEZ (right). Source: Birdlife International (2020a).

Magnificent frigatebirds *(Fregata magnificens)* nest on islands throughout the Caribbean, and in tropical areas of both coasts of Central and South America (Birdlife 2020a). Its range overlaps that of the great frigatebird in the Galápagos Islands and Central America (Figure 73).

They are exceptional aerial acrobats and can take advantage of thermals to glide for extended periods of time. Like great frigatebirds, they are opportunistic kleptoparasites. Males are known for their bright red inflatable gular sac, which they use to attract females during courtship. In the Galápagos Islands, both magnificent and great frigatebirds coexist. In general, magnificent frigates are more common, present in ports and harbors and more coastal than great frigatebirds. Remarkably, Galápagos magnificent frigatebirds are genetically distinct from all conspecifics, molecular data suggests that this population has been isolated for several hundred thousand years (Hailer et al. 2011). This discovery was contrary to expectations for such a highly mobile species.

The world population of magnificent frigatebirds is estimated at 130,000 mature adults, but this population is displaying some declines (Partners in Flight 2019). The Atlantic population is now feared extinct (Orta et al. 2018). It is possible that some of the lesser known colonies in the Caribbean may no longer exist, as a result of human disturbance (Lindsey et al. 2000). At least 10 nesting sites in the Caribbean are known to have been abandoned in the twentieth century dueo human disturbance (Diamond and Schreiber 2020). In the Galápagos Islands the estimated population is approximately 1,000 pairs, distributed across four islands (Diamond and Schreiber 2020).

Blue-footed booby

The blue-footed booby *(Sula nebouxii)* is one of the three Sulidae species that nest on the Galápagos Islands (Harris 1984). As a species, its range extends throughout the ETP (Figure 74) (Taylor et al. 2012). Blue-footed boobies are highly charismatic seabirds, recognized by their distinctive blue feet, plunge diving near seashores and for their flashy courtship displays (De Roy 2019). The blue-footed booby usually lays one to three eggs at a time (Harris 1977). This species has asynchronous hatching, which results in a growth inequality and size disparity between siblings, leading to facultative siblicide if parents are unable to secure enough food (Drummond et al. 1986).

Researchers and naturalist guides have reported for several years the decline and disappearance of blue footed booby colonies on several islands. In 2012, a complete coastal survey of the Galápagos revealed a drastic reduction of the population due to a chronic lack of breeding (Anchundia et al. 2014). The decrease in the reproductive success has been associated with the disappearance of their preferred prey: sardines (Anchundia et al. 2014).

As a specialized fish eater, the blue-footed booby showcases the interrelationship between predators and their prey in the marine environment (Anchundia et al. 2014). ENSO events can affect blue-footed booby reproduction, for example, during the 1982-83 and 1986-87 El Niño, reproductive attempts failed throughout the archipelago and colonies were deserted with the rise of sea surface temperatures (Anderson 1989).

The blue-footed booby forages at sea, searching for aggregations of shoaling fish, on which it feeds by plunge-diving from great heights (Ballance and Pitman 1999, Schreiber and Burger 2001). Their foraging movements are characteristically coastal, especially when compared to the Nazca and red-footed boobies, although tracking studies have shown movements at least to the limits of the Galápagos EEZ (Figure 75) (Anderson and Ricklefs 1987, Anchundia et al. 2017).

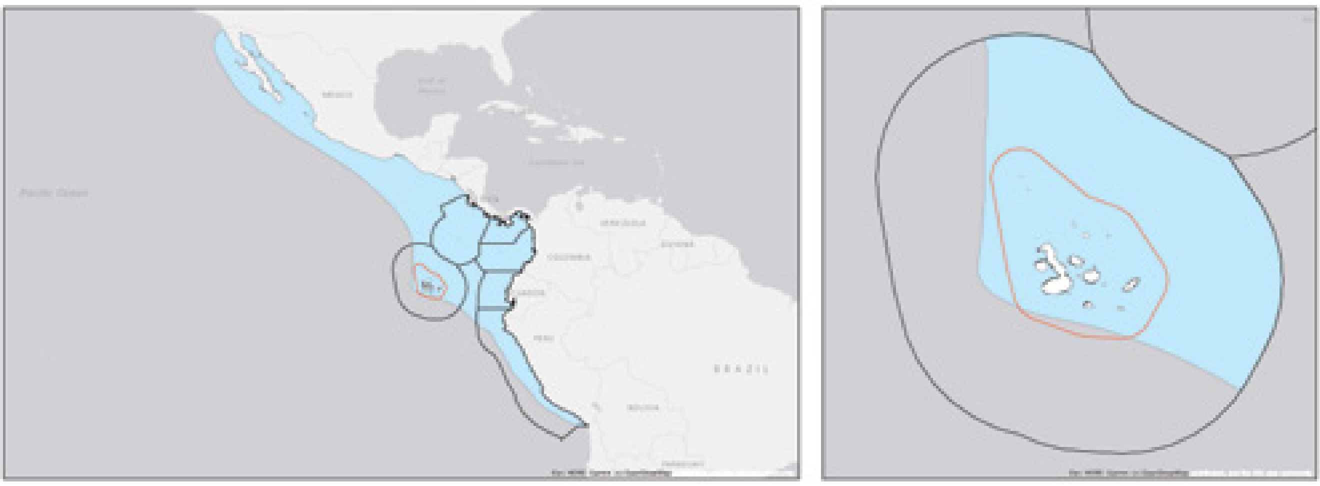


Figure 74. Global range of the blue-footed booby (left) and distribution within the Galápagos EEZ (right). Source: BirdLife International (2018e, 2021a).

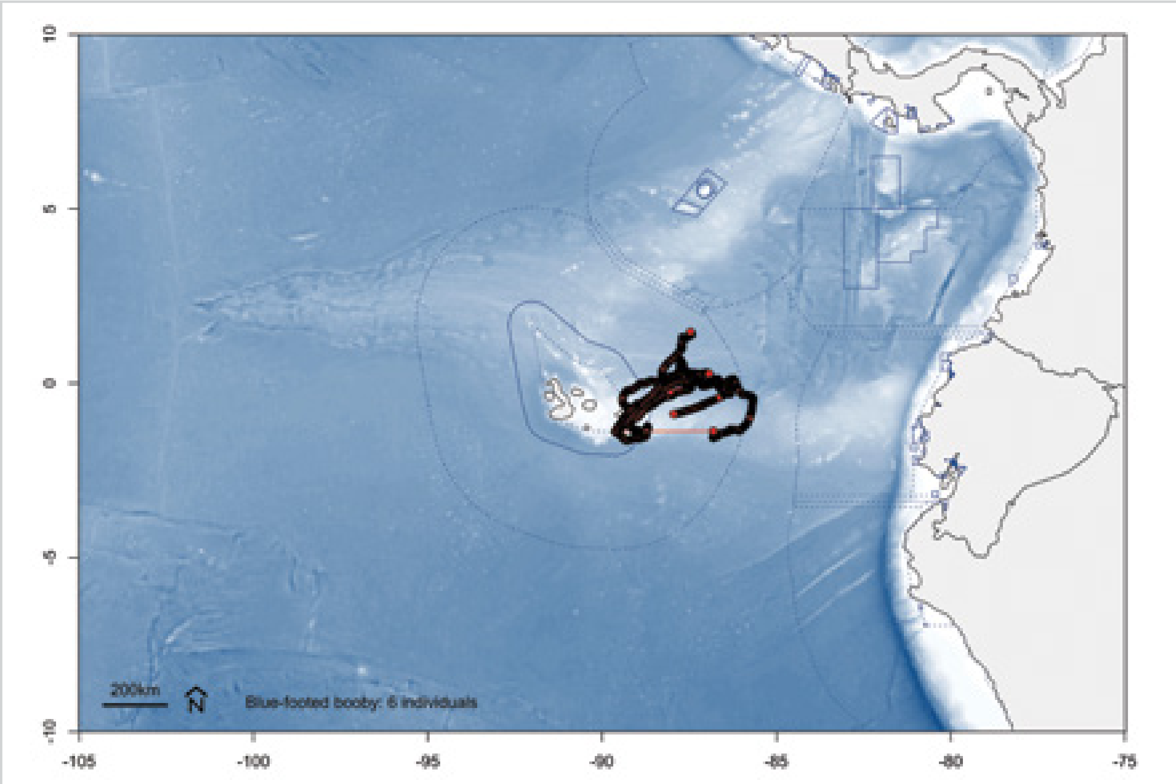


Figure 75. Satellite tracks for 6 blue-footed boobies tagged in 2009 (average track length 6 days). Source: Galápagos Movement Consortium, data repository www.movebank.org.

Due to its large range and population size, despite a decreasing population trend, the IUCN currently lists blue-footed boobies as Least Concern (IUCN 2018). There is no information available on global population trends. The population size of the endemic subspecies *(Sula nebouxii excisa)* in Galápagos was first estimated in the 1960s at approximately 10,000 pairs (Nelson 1978), at which point it was considered one of the largest populations of the species in the world (Anchundia et al. 2014). A robust survey was carried in 2012 throughout its range in Galápagos. It found ~6,400 adults and two juvenile birds, indicating a significant population decline associated with chronic lack of breeding (Anchundia et al. 2014). Monitoring found that few pairs bred in 2011-2013 (Anchundia et al. 2014). "Long-term data suggest that poor breeding began in 1998. Lack of recruitment over this period would mean that the current population is mostly elderly and experiencing senescent decline in performance" (Anchundia et al. 2014). Anchundia et al. (2014) suggest that the reduction in the reproductive rate of boobies is associated with sardines becoming less available throughout the archipelago since the 1997-98 ENSO event. Sardines appear to be crucial in chick-rearing, which would explain the high rate of nest abandonment. The cause of sardine decline is unclear, could be related to periodic shifts in their abundance in the Pacific. A population of older birds, that display actuarial and reproductive senescence, may accelerate the decline in the population of this iconic seabird (Anchundia et al. 2014). A second coastline survey was carried out in 2017, and preliminary results suggested that the population decline was continuing (Anderson 2018). Nonetheless, several hundred juveniles were observed, indicating a substantial increase in reproductive success (Anderson 2018).

Blue-footed boobies are threatened by introduced predators, namely cats and dogs, at certain sites on the Galápagos, although these predators likely have not driven the population decline, which is observed throughout the islands, even where the predators are absent (Harris 1977, Anchundia et al. 2014).

Nazca booby

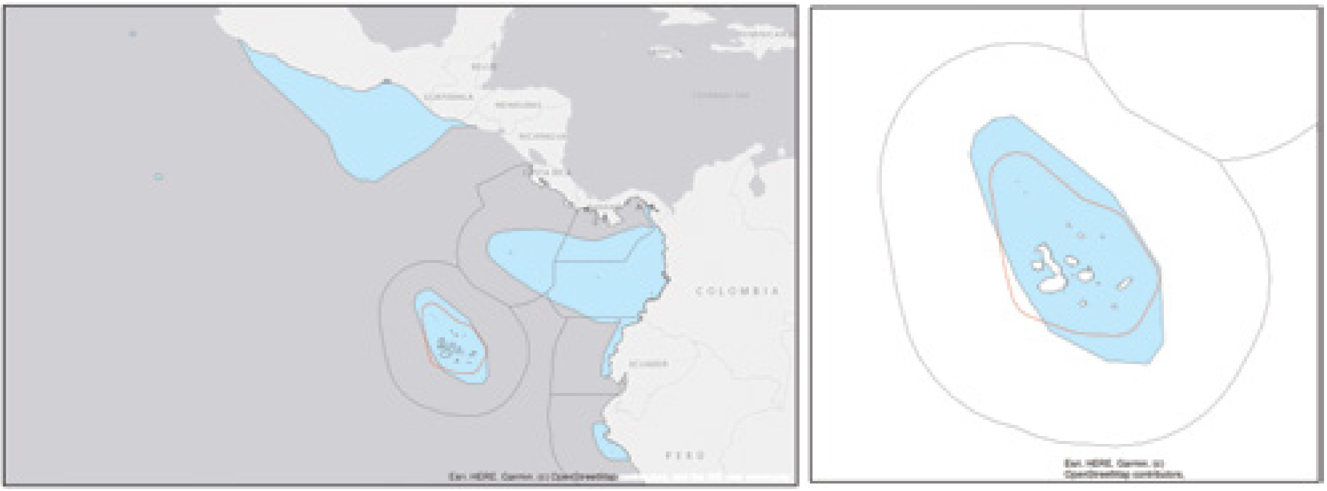


Figure 76. Global range of the Nazca booby (left) and distribution within the Galápagos EEZ (right). Source: (BirdLife International 2018d, 2021b).

Nazca boobies *(Sula granti)* are the largest of the three Sulidae species that nest on the Galápagos Islands (Harris 1984). They are native to the eastern Pacific, nesting on the islands of Baja California, Malpelo, Isla de la Plata and the Galápagos (Figure 76). They breed throughout the Galápagos Archipelago, but colonies are concentrated on the southern and northern islands and less in the central islands (Brinkhuizen, 2020).

Nazca boobies have a low annual reproductive rate, a monogamous mating system, and biparental care (Apanius 2008). They display obligate siblicide, the unconditional killing of the smaller chick when a nest has a two-egg clutch (Anderson 1989, Birdlife International 2021b). This behavior is explained by the insurance-egg hypothesis, the production of a second egg as insurance against the first egg's failure (Anderson 1989b, 1990).

The population size of Nazca boobies in Galápagos is approximately 20,000 birds (Huyvaert and Anderson 2004), with the largest colony at Punta Cevallos on Española (Figure 77). On Malpelo island the estimated population is approximately 24,000 individuals (Pitman 1995, García and López-Victoria 2007). There is a colony established on La Plata Island off the coast of mainland Ecuador (Ridgeleny 2001). Nazca boobies are vulnerable to ocean warming in the tropical Pacific during El Niño events (Anderson 1989a). Rising sea surface temperatures can cause a reduction in the number of prey available to Nazca which result in reduced reproduction or even increased mortality due to lack of food (Tompkins et al. 2017). Between 1983-1997, sardines were the main prey of the boobies, but these were replaced by less nutritious flying fish from 1997 onwards (Tompkins et al. 2017). Breeding success under the poor diet fell dramatically (Tompkins et al. 2017).

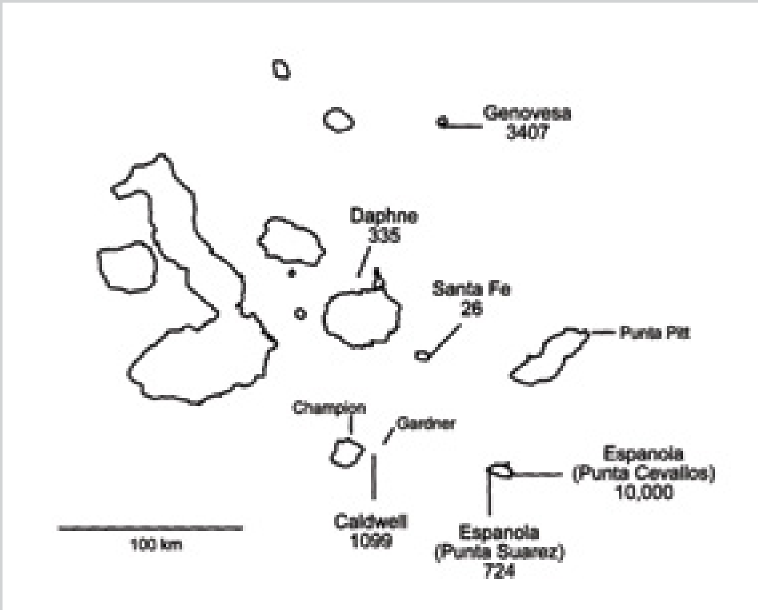


Figure 77. Nazca booby colonies in the Galápagos Islands. Island names with estimated population sizes beneath were searched for ringed birds. Approximate population sizes of other islands: Champion, <50; Gardner and Punta Pitt, 100–200 each; Culpepper (Darwin) and Wenman (Wolf), 1,000 to several thousand each. Source: Huyvaert and Anderson (2004).

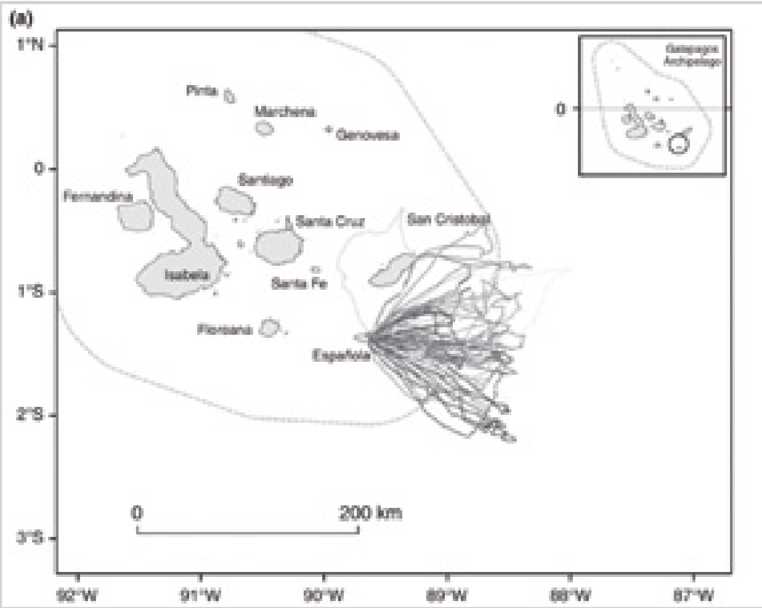


Figure 78. Tracks of chick-rearing Nazca boobies from Punta Cevallos, Isla Española, as determined by GPS dataloggers. Source: Zavalaga et al. (2012).

Nazca boobies tracked with radio telemetry in the 1980s foraged around 65 km from the colony during a single day (Anderson and Ricklefs 1987). Several decades later GPS tracking of foraging Nazca boobies undertook trips several times longer in distance (Figure 78) and time (Tompkins et al. 2017; Zavalaga et al. 2012). The increase in the foraging range of Nazca boobies coincides with a dietary shift from sardines to flying fish. The latter are less nutritional and widely dispersed, requiring Nazca boobies to fly further and longer in search of food (Tompkins et al. 2017).

The IUCN red list status of the Nazca booby is Least Concern. Although populations are thought to have decreased to some extent, this decline is not strong enough to require classification in a threat category. Ongoing long-term monitoring program occurs annually at Punta Cevallos, Española (Tompkins et al. 2017).

Red-footed booby

The red-footed booby *(Sula sula)* is a pantropical seabird and the smallest of all Sulidae species worldwide (Weimerskirch 2005). Red-footed boobies are polymorphic – the color of their plumage varies between morphotypes, mainly white and brown morphs (Brinkhuizen 2020). They are easily recognizable by their distinctive red feet, which gives them their name. Unlike all other boobies and gannets this species is a colonial tree-nester, of up to several thousand pairs (Schreiber et al. 2020). They have a pantropical distribution in the Caribbean Sea, Atlantic, Pacific, and Indian Oceans, and seas north of Australia (Figure 79) (Harrison et al. 2021). The main nesting site in the Galápagos is on Genovesa (Harris 1977, Brinkhuizen 2020). Two smaller colonies have formed in the past ~120 years at Punta Pitt, the eastern tip of San Cristóbal island and Gardner near Floreana (Brinkhuizen 2020). The local extinction of Galápagos hawks *(Buteo galapagoensis)* by human hunting (San Cristóbal and Floreana are populated) is thought to have enabled the establishment of the new colonies (Anderson 1991). Red footed boobies may be less vulnerable to ocean warming and ENSO events than other seabirds (Ainley et al. 1988).

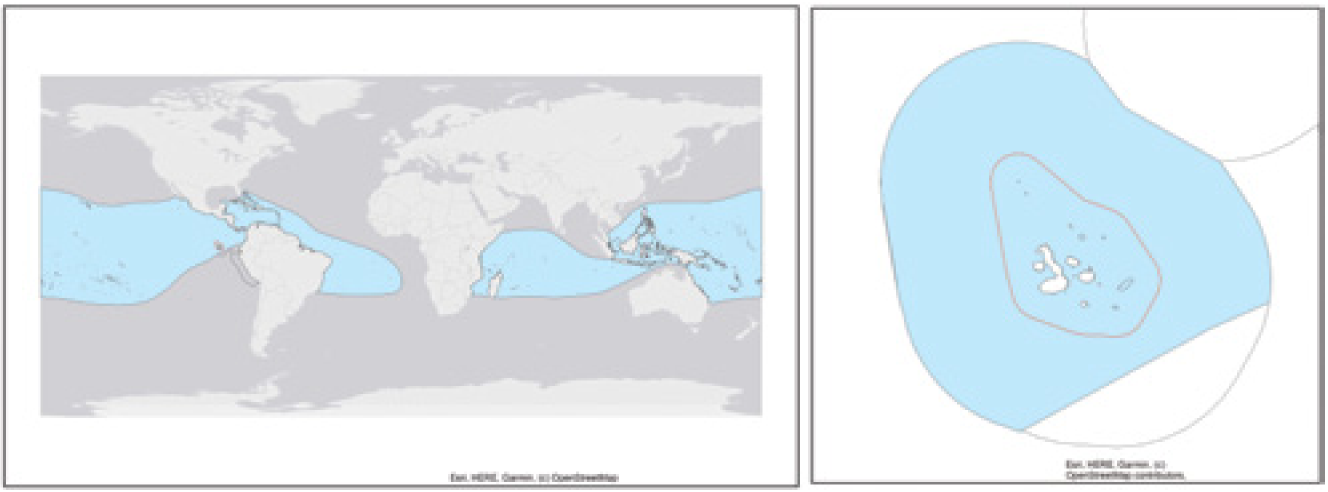


Figure 79. Global range of the red-footed booby (left) and distribution within the Galápagos EEZ (right). Source: (BirdLife International 2018f, 2021c).

Red-footed boobies are wide-ranging, strong fliers that forage the pelagic zone (Figure 80) (Nelson 1978, Weimerskirch 2005). Birds tracked with GPS from Genovesa Island had a generally eastern direction from the colony, covering the area between the Carnegie and Cocos ridges (Mendez 2017). Overnight trips were common at Genovesa, with a mean duration of 22 h and range of 122 km in 2009, and higher values in 2014 (37 h and 176 km). The furthest distance from the colony recorded was 472 km away from the colony (Mendez et al. 2017).

The largest known population of red-footed boobies is in the Galápagos Islands, approximately 250,000 birds, mostly on Genovesa (Nelson 1969). The red-footed booby is classified as Least Concern by the IUCN (BirdLife International 2018f, 2021c).

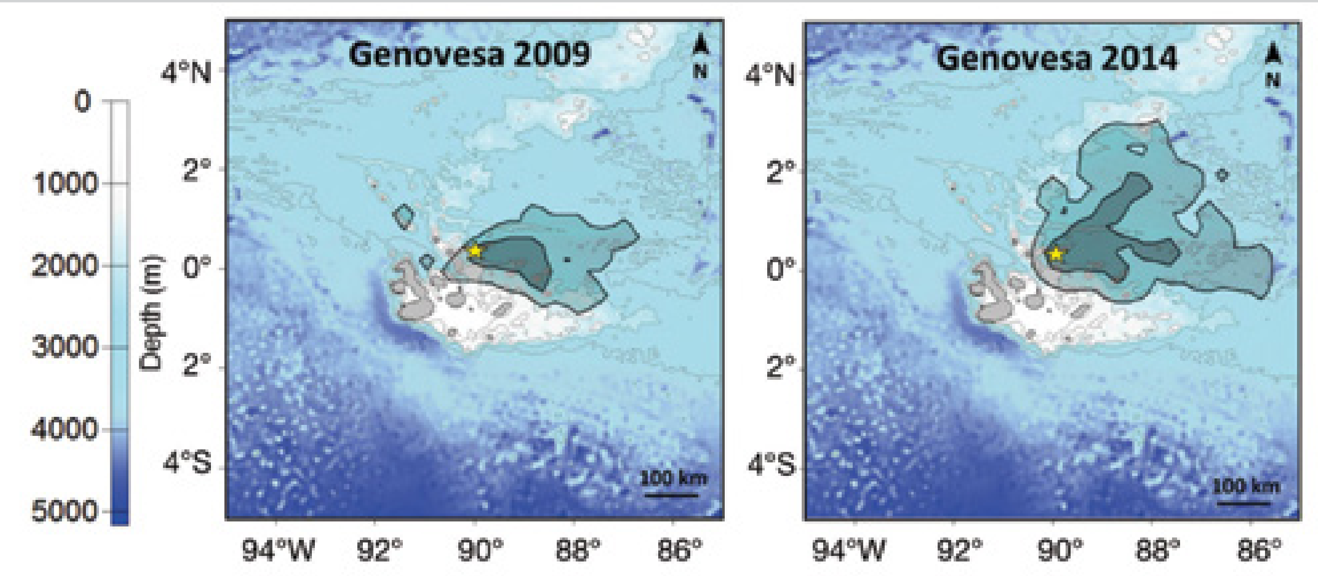


Figure 80. General (95% kernel density estimation, light shading) and core (50% kernel density estimation, dark shading) foraging areas of red-footed boobies Sula sula from Genovesa island, Galápagos, superimposed on bathymetric maps. Source: Mendez et al. (2017).

Swallow-tailed gull

The swallow-tailed gull *(Creagrus furcatus)* is one of the two species of gull that nest in Galápagos (Harris 1977). It reproduces on several of the islands in Galápagos but is noticeably absent from the west of the archipelago (Nelson 1968). Swallow-tailed gulls also breed on Malpelo Island (McMullan et al. 2018). When not breeding, they travel along the offshore waters of South America's Pacific coast from central Colombia to central Chile (Figure 81) (Harrison et al. 2021).

Their life history traits make them one of the most unusual and unique species of the Laridae family (Hailman 1965). Firstly, they are pelagic, foraging in the open ocean several kilometers from land, while most other gulls are coastal scavengers (Harris 1977). Nonetheless, they are mostly recognized for being obligate nocturnal foragers, with adaptations such as large eyes (largest in relation to cranium size of any gull) and lack of a circadian rhythm (Hailman 1964; Wikelski et al. 2006). Their adaptations to the nocturnal niche are so pronounced that foraging varies with lunar phase (Cruz et al. 2013). Foraging activity is highest during darker periods of the lunar cycle, which coincides with the cycle of the diel vertical migration, which is strongest during new moons, transporting large amounts of prey to the sea surface at night (Cruz et al. 2013). The breeding cycle of swallow-tailed gulls is also peculiar for two reasons: first, they have an asynchronous breeding cycle which results, at the population level, in year-round reproduction across several colonies in Galápagos; second, they have a sub-annual breeding cycle of 9-10 months (Harris 1969). Furthermore, they are the only gull species with a single egg clutch, most larids lay 2-4 eggs per clutch (Agreda and Anderson 2003).

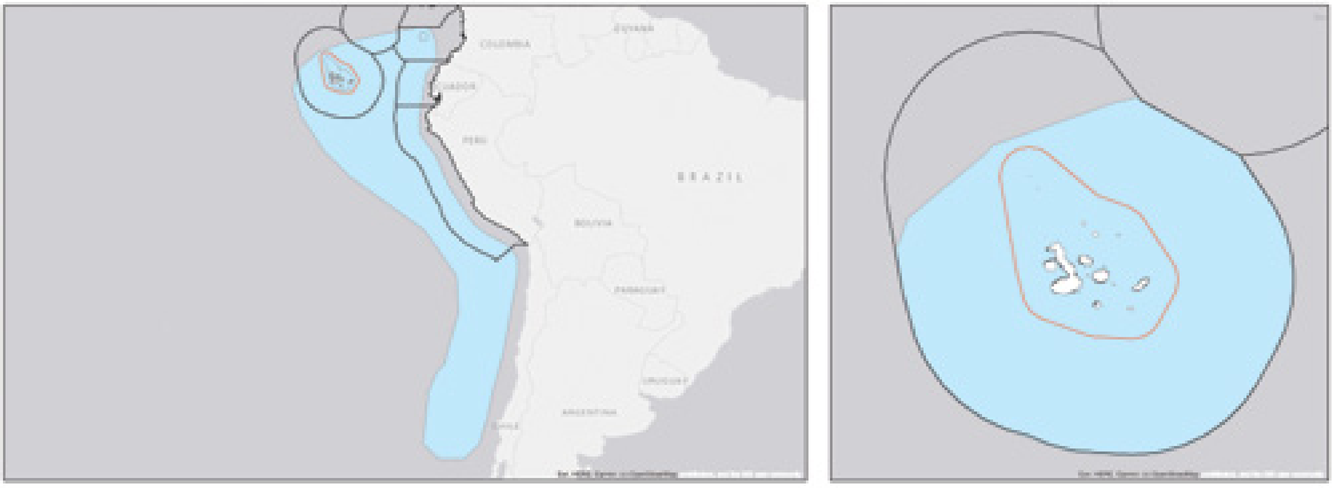


Figure 81. Global range of the swallow-tailed gull (left) and distribution within the Galápagos EEZ (right). Source: (BirdLife International 2018a).

At dusk, swallow-tailed gulls go directly to their foraging areas. The average foraging trip duration of birds breeding on Punta Cevallos was 6.9 hours, and average distance travelled was 105.3 km. The average trip duration of birds nesting on Genovesa was 3.04 hours, and average distance travelled was 41.7 km (S Cruz, unpublished data). After breeding, swallow-tailed gulls migrate to the coast of South America, to the Humboldt upwelling system (Figure 82) (Harrison et al. 2021). They spent up to three months in this area presumably recovering from the previous breeding period and preparing for the next (S Cruz, unpublished data).

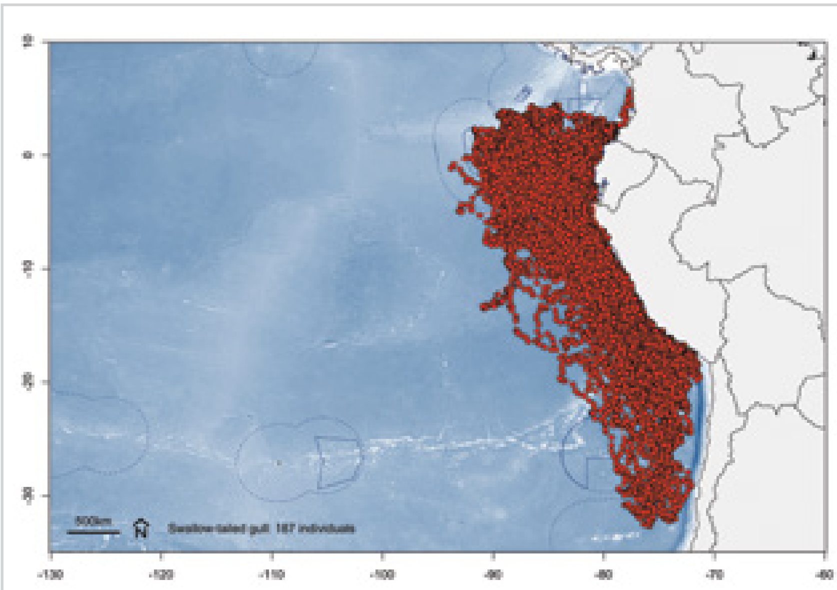


Figure 82. Overall tracks for 187 swallow-tailed gulls tagged in 2008-2011 (average track 2 days for 142 breeding individuals, 296 days for 45 non-breeding individuals), use of the Galápagos EEZ by swallow-tailed gulls (right). Source: Galápagos Movement Consortium, data repository www.movebank.org.

Their population size in Galápagos was suspected to be around 10,000 pairs, but there is no information on population trends (Harris 1970). Some patchy information is available on survival rates, which are higher than 95% (Harris 1970). Swallow-tailed gulls are currently listed as Least Concern by the IUCN (BirdLife International 2018a).

Galápagos fur seal

The Galápagos fur seal *(Arctocephalus galapagoensis)* is one of two endemic pinniped species of the Galápagos Islands (Figure 83), and is classified as Endangered by the IUCN (Salazar 2002, Trillmich 2015a). It is the smallest eared pinniped in the world and is adapted to equatorial climatic conditions (Félix et al. 2007b). Its habitat is characterized by steep coastlines or cliffs, on rocky coasts adjacent to areas of intense outcrop, close to deep waters (Salazar 2002). Galápagos fur seal colonies are distributed only in the western and northern part of the archipelago (Alava and Salazar 2006), likely linked to localized upwelling of the cold, nutrient rich Cromwell undercurrent. Genetic evidence has shown that the Galápagos fur seal population is sub-structured through strong female natal site-fidelity, despite the comparably close spatial proximity of breeding colonies (Lopes et al. 2015).

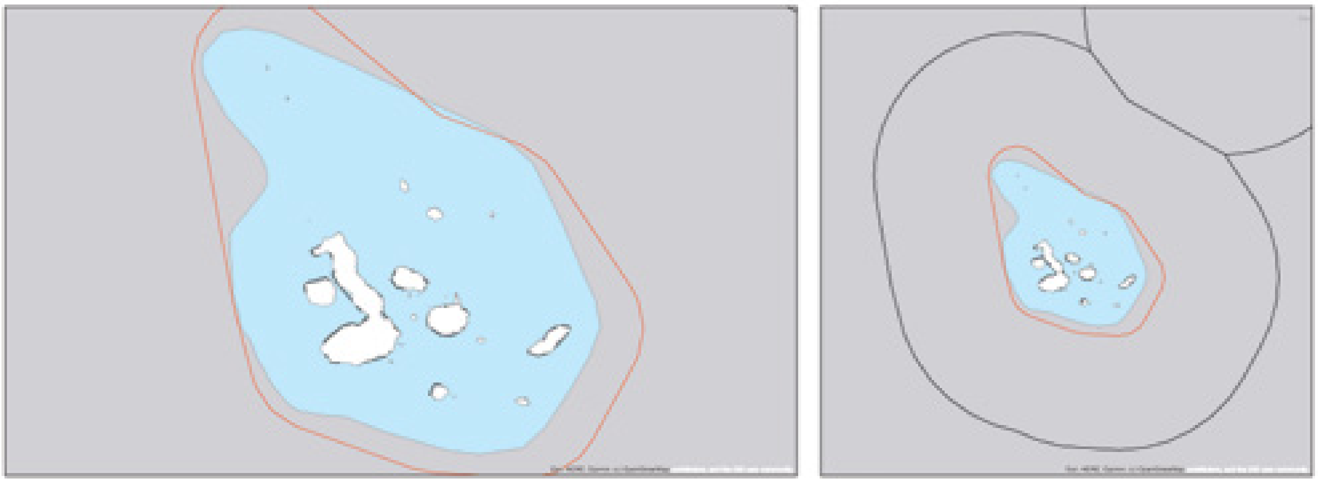


Figure 83. Global range of the Galápagos fur seal (left) and distribution within the Galápagos EEZ (right). Source: Trillmich (2015a).

The species is non-migratory, but rare migrants have been recorded off the Mexican, Colombian and mainland Ecuadorian coast (Aurioles-Gamboa et al. 2004; Félix et al. 2007b). A total of 10 individuals have been reported on the Ecuadorian continental coast between 1991-7 (Félix et al. 2001). Two other individuals were recorded in southwestern Mexico between 1997 and 1998 (Aurioles-Gamboa et al. 2004). A similar pattern was reported in Colombia between 1970 and 2001 with the sighting of 12 individuals of this species more than 2,400 km from their home (Capella 2001). In 2004, the birth of an individual outside the Archipelago was registered for the first time, in the province of Esmeraldas, and the second birth occurred in 2005 in Posorja. On both occasions the pups died by starvation due either to abandonment or death at sea of the mother (Félix et al. 2007b). This species has been reported from the Pacific coasts of Guatemala, Peru, Costa Rica and Mexico (Ibarra et al. 2016; Montero-Cordero et al. 2010; Quintana et al. 2017). All the organisms recorded outside their geographic range were individuals are thought to have migrated mostly due to changes in environmental conditions, prey migration or simply got lost during feeding trips (Félix et al. 2001; Páez-Rosas et al. 2017a).

Galápagos fur seals use the pelagic waters to the west of the archipelago (though note that tracking studies have been limited to juveniles and adult females with pups), traveling a maximum of 69 km away from their colonies (Figure 84, Jeglinski et al. 2013). The trip duration and distance from the colony increase in the warm, less productive season. The preferred foraging areas of female Galápagos fur seals were deeper locations, and locations both close to the coast as well as further from the coast (Ventura et al. 2019). Galápagos fur seal females generally forage within the Galápagos marine reserve (Jeglinski et al. 2013; Villegas-Amtmann et al. 2013), but one individual ventured beyond the boundary in the warm season (Ventura et al. 2019). The movements of immature animals and adult males are unknown, but it is likely that these groups are less constrained by the need to return to the breeding colonies and spend much more time at sea.

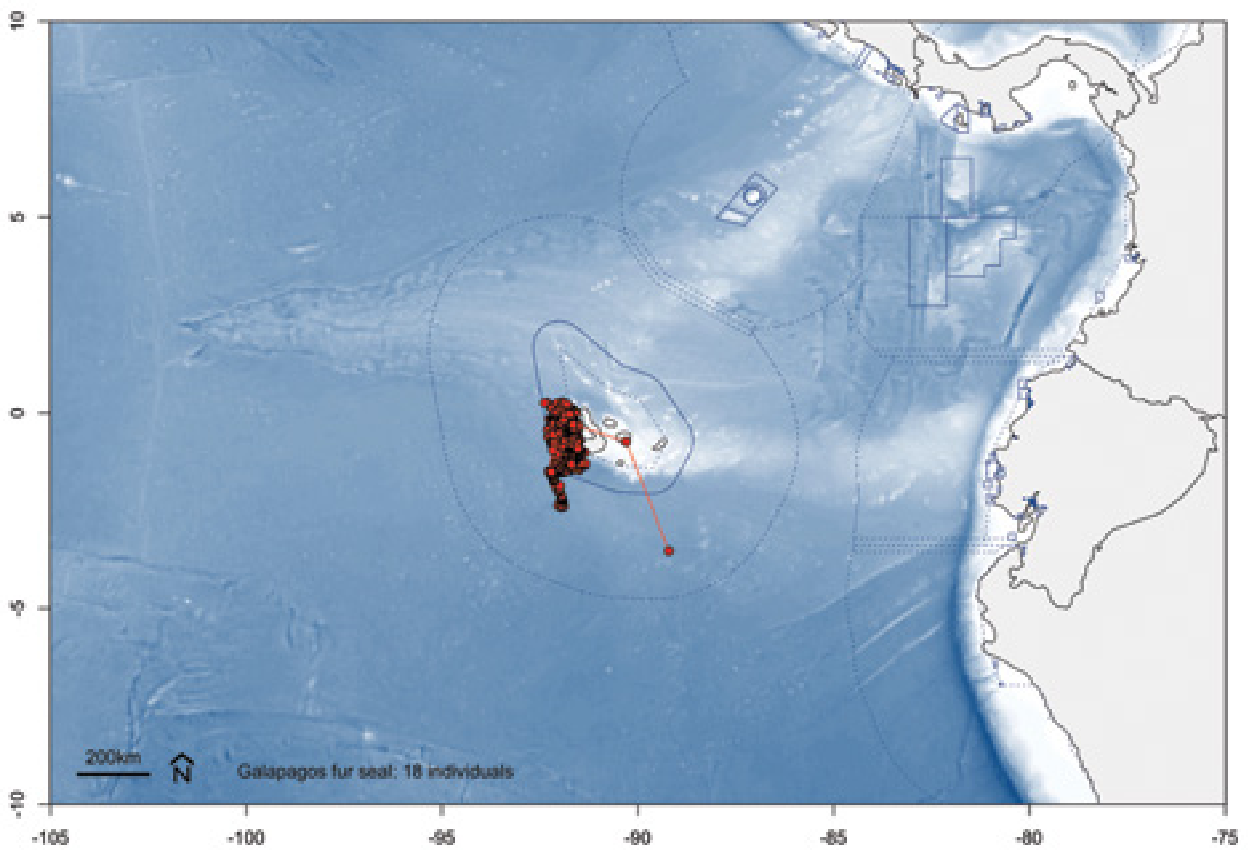


Figure 84. Tracks of 18 Galápagos fur seals tagged in the western bioregion of Galápagos in 2009-2010 (average track length 23 days). Adapted from Jeglinski et al. (2013) and Galápagos Movement Consortium, data repository www.movebank.org.

Galápagos fur seals live in an unpredictable habitat, with seasonal and annual fluctuations in productivity that have likely shaped the unique life history traits of the species. They can live around 20 years (Trillmich 2015a). Young fur seals depend on their mother for up to two years and if females give birth to a younger pup whilst feeding an older still dependent offspring the pup generally dies – in rare cases females manage to suckle both offspring forming a so-called 'trio' (Trillmich and Wolf 2008).

Galápagos fur seals forage almost exclusively at night, targeting prey from the deep scattering layer such as myctophids, bathylagids and squid that rise to the surface at night (Clarke and Trillmich 1980; Dellinger and Trillmich 1999). Their foraging behavior is strongly influenced by the lunar cycle, with very limited diving activity at full moon (Horning and Trillmich 1999; Trillmich and Mohren 1981). Female Galápagos fur seals forage at fairly shallow depth, on average 32 m, with a maximum of 97 m (Jeglinski et al. 2013).

Historically, Galápagos fur seals have been persecuted to the extent that no distinguishable colonies remained (Trillmich 1987) but the population recovered since protection in 1959. During the El Niño events of 1982 and 1983, approximately 30% of adult females and non-territorial males disappeared from Fernandina Island (Trillmich and Limberger 1985). High temperatures deepen the thermocline, decrease productivity, which subsequently produces a depressive effect on higher trophic levels (Salazar and Denkinger 2010). El Niño not only acts as a mechanism of natural selection but also leads to the migration and colonization of new sites (Aurioles-Gamboa et al. 2004).

There are no recent population estimates and the population size has only been quantified twice (using complete haul out and colony counts throughout the whole archipelago): in 1977-1978 a total of 30,000-40,000 individuals were estimated and in 2001 a total of 6,000–8,000 individuals – suggesting a 80-85 % decline in population size over that time period (Alava and Salazar 2006). The population might have recovered somewhat since then, with recent abundance estimated very roughly at 15,000, but the population is classified as decreasing (Trillmich 2015a).

The Galápagos fur seal population will always be vulnerable due to its restricted breeding distribution (Trillmich 2015a). As mentioned above, the species is particularly vulnerable to unpredictable El Niño events, which drastically reduce the marine productivity and increase fur seal mortality, particularly of pups, yearlings and adult males (Trillmich and Dellinger 1991) – these events might increase in strength and frequency due to climate change.

Galápagos fur seals might also be at risk of entanglement in fishing gear and pollution from oil spills and pollutants (Trillmich 2015a). Galápagos fur seals are listed as Endangered on the IUCN Red list and are listed on CITES Appendix II (Trillmich 2015a).


Tui de Roy

Galápagos sea lion

The Galápagos sea lion *(Zalophus wollebaeki)* is an endemic pinniped (Figure 85) that breeds on almost all the islands of the archipelago (Drago et al. 2016). One of the smallest sea lion species, it is also the only tropical sea lion and occurs right on the equator. Genetic analyses suggests that Galápagos sea lions diverged from the California sea lion *(Zalophus californianus)* 2.3 ± 0.5 million years ago (Wolf et al. 2007). Sea lions from colonies in the western archipelago (Fernandina, western Isabela) are genetically distinct from the remaining population (Wolf et al. 2008), likely as a consequence of foraging specialization (Jeglinski et al. 2015), potentially influenced by the unique marine ecology of the western bio-region (Edgar et al. 2004) and perhaps as a consequence of niche segregation with sympatric Galápagos fur seals *(Arctocephalus galapagoensis)*, who only co-occur with sea lions in some of the western colonies (Jeglinski et al. 2013; Villegas-Amtmann et al. 2013).

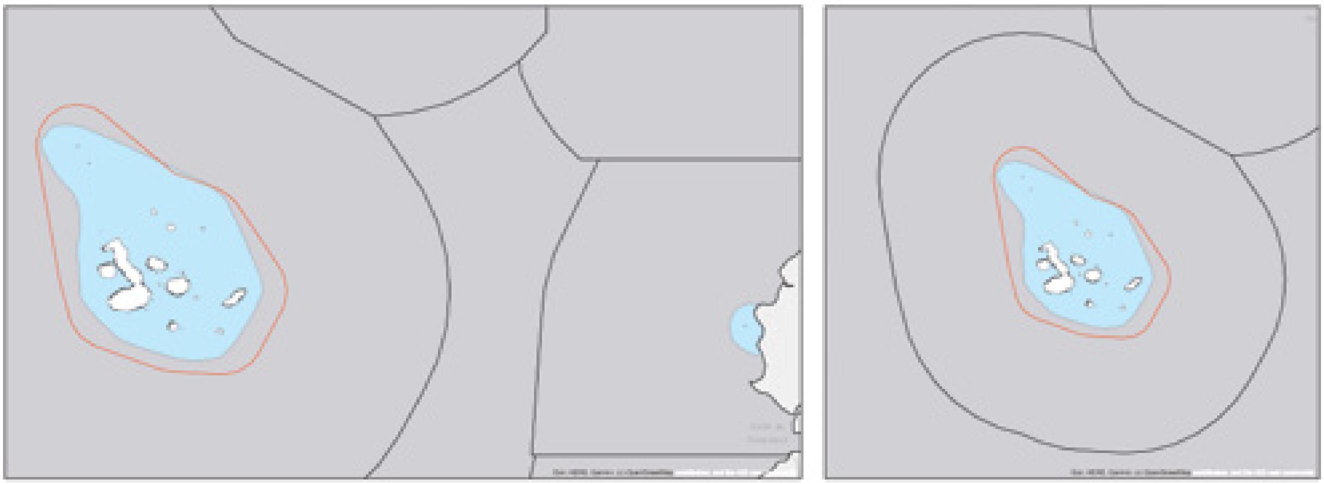


Figure 85. Global range of the Galápagos sea lion (left) and distribution within the Galápagos EEZ (right). Source: Trillmich (2015b).

Z. wollebaeki is the most recognized marine mammal of the archipelago, is an important tourist resource of the islands, also important for the transport of marine nutrients to terrestrial ecosystems (Fariña et al. 2003). Galápagos sea lions are colonial breeders, with colonies distributed on most of the islands in the archipelago, with the most numerous populations located in the central islands (Salazar 2005). The species is non-migratory, but rare migrants have been recorded off the Mexican, Colombian and mainland Ecuadorian coast (Palacios et al. 1997, Trillmich et al. 2014). Galápagos sea lions have been reported sporadically in Costa Rica at Cocos Island since 1983 - most of the individuals were found in poor condition, possibly due to malnutrition (Montoya 2008). In 2015, an individual was reported for two months off the coast of El Salvador (Pineda et al. 2019).

Galápagos sea lions live in an unpredictable habitat, with seasonal and annual fluctuations in productivity that have likely shaped the unique life history traits of the species. For example, unpredictably occurring strong El Nino events drastically reduce food availability and increase the mortality rate, with adult males and juveniles most affected (Trillmich and Dellinger 1991). The development of juveniles to independence starts late and is exceptionally slow: only when around 18 months juvenile sea lions forage independently, and this was further delayed in a mild El Niño year (Jeglinski 2012). Females start reproducing late, with about 5-6 years, and produce offspring only every 2-3 years, likely due to the long dependence of their offspring (Müller 2011). With an estimated life span of about 20 years (Trillmich 2015b), the average lifetime reproductive success is low compared to other species. As all otariids, Galápagos sea lions display sexual size dimorphism with much larger males than females, and a polygynous mating system where males hold territories during the breeding season to monopolize access to mating opportunities, but in Galápagos sea lions this system is exceptionally weak, alternative mating strategies and female choice might play a much higher role than in other species (Pörschmann et al. 2010; Trillmich et al. 2014). Interestingly, colonies seem to be sub-structured into communities of related females with offspring (Wolf and Trillmich 2007), while males might form long-lasting social relationships amongst themselves (Meise et al. 2013).

Tracking studies have been limited to juveniles and females with pups, and these show that the habitat use of Galápagos sea lions is strongly associated with the shelf edge and the coastal area in the west and the central shelf in the central part of the archipelago (Jeglinski et al. 2015; Ventura et al. 2019). Adult females travel a maximum of 50.5 km away from their colonies, while juveniles cover maximum distances of less than 15 km (Figure 86, Jeglinski et al. 2013). The preferred foraging habitat of female western Galápagos sea lions were colder locations close to the coast with higher productivity (Ventura et al. 2019). Based on the available tracking data, there is no evidence that Galápagos sea lion females or juveniles venture beyond the boundary of the Galápagos marine reserve (Jeglinski et al. 2013; Páez-Rosas et al. 2017b; Schwarz et al. 2021; Villegas-Amtmann et al. 2008) but our understanding of the movements of immature animals, females without young pups and adult males is very limited.

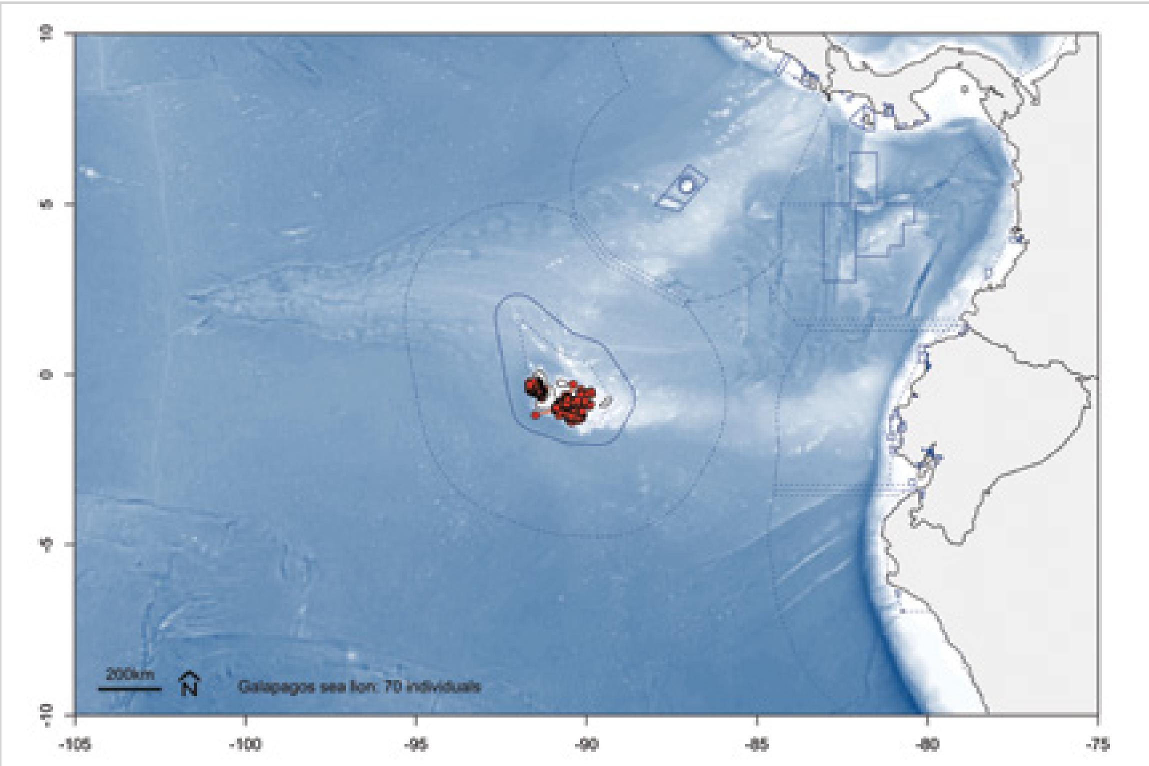


Figure 86. Tracks of 70 Galápagos sea lions tagged in Galápagos Marine Reserve in 2005-2010 (average track length 22 days). Data: Jeglinski et al. (2013) and Galápagos Movement Consortium, data repository www.movebank.org.

Despite their small size, Galápagos sea lions can dive exceptionally deeply: the deepest recorded dive of an adult female was 584 m, and 367 m for a one year old juvenile (Jeglinski et al. 2013; Jeglinski et al. 2012). Galápagos sea lion females display distinct foraging strategies, either benthic, pelagic or night time diving (Schwarz et al. 2021; Villegas-Amtmann et al. 2008; Villegas-Amtmann et al. 2013), while young sea lions dive predominantly at night (Jeglinski et al. 2013; Jeglinski et al. 2012). Galápagos sea lions feed on a wide range of benthic and pelagic prey (Jeglinski et al. 2013; Páez-Rosas et al. 2020; Páez-Rosas et al. 2014; Páez-Rosas et al. 2017b) with distinct differences in diet between the western and the central archipelago (Dellinger and Trillmich 1999; Jeglinski et al. 2015).

The population size has only been quantified twice (using complete haul out and colony counts throughout the whole archipelago): a total of 40,000 individuals were estimated by Trillmich (1979) and in 2001 a total of 14,000–16,000 individuals (Alava and Salazar 2006)–suggesting a >50% decline in population size over that time period. There are no recent population estimates, but colony size estimates from the centrally located colony Caamaño, where a long-term monitoring study was established in 2003, suggests that the colony size has fluctuated around a steady mean between 2003 and 2013 (Trillmich et al. 2016)–potentially indicating that the Galápagos sea lion population has not recovered from the decline (Trillmich 2015b). The underlying causes of the population decline are only partly understood, with two major El Niño events in close succession likely playing a major role (Trillmich et al. 2014).

The key threat to the species is its small population size and small distributional area, coupled with the unpredictable environment of the Galápagos ecosystem and unpredictable occurrence of El Niño events that either directly kill pups, yearlings and substantial numbers of adults, or indirectly reduce productivity and survival (Trillmich et al. 2014). Climate change might exacerbate the impact of El Niño on the population if these events become more frequent and more extreme and could reduce the small population below sustainable levels (Trillmich et al. 2014). Some of the largest sea lion colonies are close to or within human settlements, which puts sea lions into direct contact with dogs, rats and cats as well as sewage and potentially harmful pollutants and increases the risk for infectious disease transmission such as canine distemper (Brock et al. 2013; Denkinger et al. 2017; Trillmich 2015b). Sea lions, predominantly in the central archipelago, are also likely to be threatened by increasing anthropogenic pressures, including vessel traffic and the associated risk of pollution and oil spills. In 2001, 600 tons of diesel were spilled in Naufragio Bay, San Cristóbal, which caused deaths, high incidence of conjunctivitis and burns among Galápagos sea lions (Salazar 2003).The synergy between multiple effects likely pose the largest threat with the potential to critically endanger the small population (Trillmich et al. 2014). Over the years, there has also been evidence of deliberate killing of sea lions, or to provide genitalia to the illegal trade in wildlife products (Dalton 2001).

Galápagos sea lions are listed as endangered in the IUCN Red list (Trillmich 2015b) and listed as a species under 'special protection' under the Law of Forestry and Conservation of Natural Areas and Wildlife of Ecuador (Páez-Rosas and Guevara 2017).

Blue whale

The blue whale *(Balaenoptera musculus)* is the largest animal on the planet, reaching lengths greater than 30 m (Mizroch et al. 1984). A baleen whale, it feeds almost exclusively on euphausiids (krill) available in cold upwellings (Reilly and Thayer 1990). Blue whales are widely distributed in both hemispheres (Figure 87), inhabiting mostly oceanic waters but occasionally venturing into coastal waters when with calves or foraging (CPPS/PNUMA 2012). Blue whales are thought to live to at least 80-90 years, reaching sexual maturity between 5 and 15 years (Sears and Perrin 2008). Females give birth every 2 to 3 years in winter (Sears and Perrin 2008). Four subspecies are recognized: the northern hemisphere subspecies *(B. m. musculus)*, the Antarctic subspecies *(B. m. intermedia)*, the pygmy blue whale *(B. m. brevicauda)* in the Indian Ocean, and South Atlantic (and possibly South Pacific, although this may be a fifth subspecies), and the northern Indian Ocean subspecies *(B. m. indica)* (CPPS/PNUMA 2012). In the northern Pacific, blue whales can be found from Alaska to Mexico and Costa Rica in winter (Sears and Perrin 2008). In the South Pacific, the Chilean blue whale was found to be distinct from the Antarctic population (Torres-Florez et al. 2014) and it ranges as far north as the Eastern Tropical Pacific, including the Galápagos Islands (Hucke-Gaete et al. 2018).

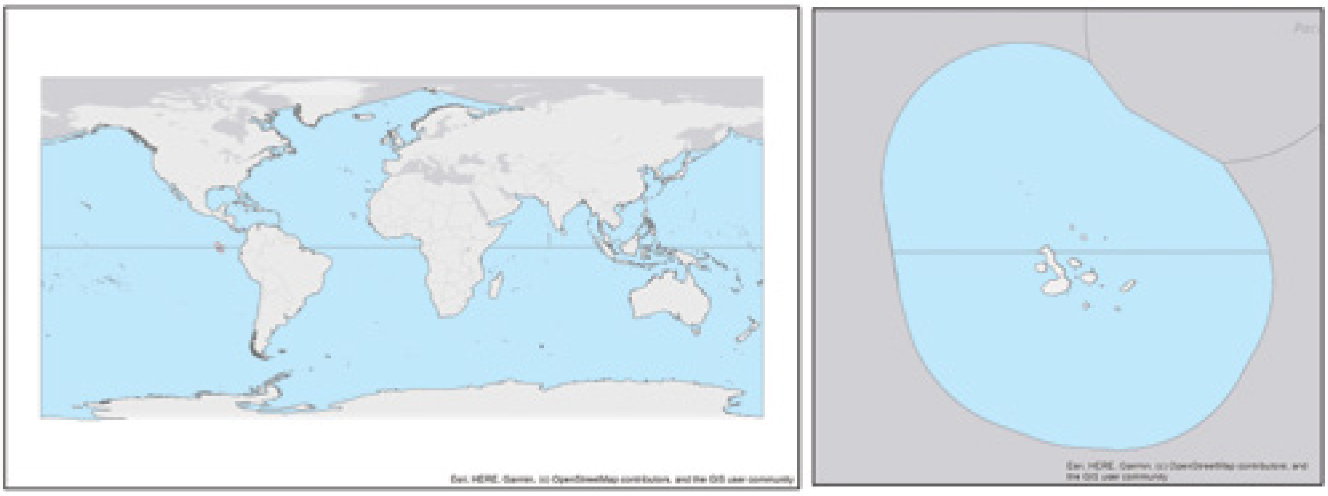


Figure 87. Global range of the blue whale (left) and distribution within the Galápagos EEZ (right). Source: Cooke (2018a).

Blue whales migrate from their summer grounds in Arctic or Antarctic waters to spend winter in tropical waters (Cummings and Thompson 1971). The northeast Pacific population aggregates seasonally in foraging grounds off the coasts of Oregon, Washington, and Vancouver Island (Burtenshaw et al. 2004). Satellite tracking studies in southern California showed whales moving south to Baja California, Mexico, with one individual tracked over a distance of 2,959 km to within 450 km of the Costa Rica Dome, which has been suggested to be a breeding and calving area as well as a key foraging ground (Mate et al. 1999). In the South Pacific there is evidence of movements from the Corcovado Gulf in Chile to the south-central Galápagos Islands in Ecuador (Figure 88) (Hucke-Gaete et al. 2018). The waters around Galápagos would correspond to a key wintering location and could provide foraging opportunities during the breeding season (Hucke-Gaete et al. 2018). In surveys carried out around the GMR (Denkinger et al. 2013), most of the blue whales were seen in the south and west of Floreana and Isabela islands, and were more common in the cool season.

Given their size and commercial value, blue whales were hunted relentlessly from the early 19th century to the first half of the 20th century: in the South Pacific, the Antarctic population is thought to have declined to 1% of its original size, while the Chilean population is thought to have declined to 7.2-9.5% of its original size (Torres-Florez et al. 2014). In the South Pacific, photo-identification data estimates a population of 450 whales, although there is a fair degree of uncertainty in the estimate, given that both resident and transient individuals were included (Cooke 2018a). The blue whale is classified as Endangered on the IUCN Red List (Cooke 2018a).

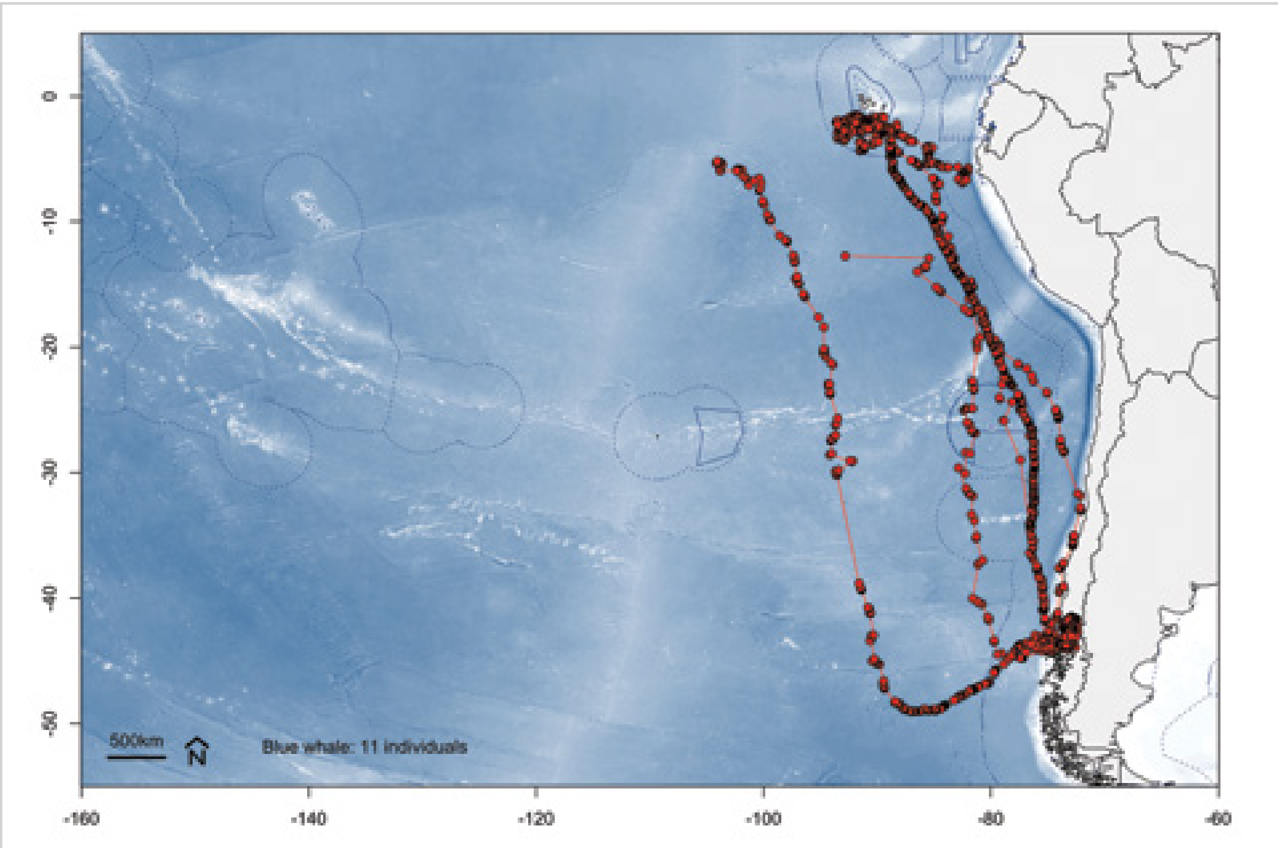


Figure 88. Satellite tracks of 11 blue whales tagged in Chile, 2013-2016 (average track length 66 days). Source: Hucke-Gaete et al (2018, Hucke-Gaete, (unpublished data).

Present-day threats to blue whales include vessel collision (Berman-Kowalewski et al. 2010), which can cause significant injuries and even death (Australian Government 2015). Increasing anthropogenic noise and contact with fishing gear can be an obstacle within their migratory routes. Contaminants such as polychlorinated biphenyls (PCBs) can have negative impacts on the reproduction and population recovery of this species (Sears and Perrin 2008). The movements of those individuals tracked to Galápagos displayed a high overlap with both industrial and artisanal fishing effort in the EEZ, yet there are no reports of collisions, and it is thought that fishing activity here does not pose a significant risk to this species (Fernando Félix, Pontificia Universidad Católica del Ecuador, pers comm). The blue whale is protected in all oceans by the International Whaling Commission (IWC). This species is listed on Appendix I of CITES, and Appendix 1 of the CMS (Cooke 2018a).

Humpback whale

The humpback whale *(Megaptera novaeangliae)* has an average length of 15 m for females and 14 m for males (Medrano 2002). Humpback whales can reach ages of 48 years (Chittleborough 1965), and reach sexual maturity at at an average age of 5 years (Clapham 2018). They reproduce every 2-3 years, generally giving birth to a single calf (Clapham 1992). They have a generalist diet, feeding on euphausiids and various species of small schooling fish such as: *Clupea spp., Mallotus villosus, Ammodytes spp. and Scomber scombrus.* (Clapham 2018). This species has a particular technique for capturing its prey – forming a curtain of bubbles under the shoals, then lunging with its mouth open to the center of the bubble structure (Miklosovic et al. 2004).

Humpback whales are found throughout the world's oceans (Figure 89). They are divided into are several geographic populations and subpopulations: in the southern hemisphere, two major populations comprising ten subpopulations around Antarctica, with differing migratory routes up the Atlantic and Pacific, and in the northern hemisphere, three populations in the north Pacific, five in the north Atlantic and a potentially resident population in the Arabian Sea (Rodriguez 2004). Estimates of abundance of humpback whales in the Pacific Ocean include 21,000 for the North Pacific (Barlow et al. 2011) and 6,504 individuals for the southeastern Pacific in 2005-2006 (Félix et al. 2011a). Humpback whales perform annual migrations from summer feeding grounds in polar regions to tropical and subtropical regions in the winter (Curtice et al. 2015; Trudelle et al. 2016). During migration, they move into warm (average 28.6 °C) shallow waters, often near islands or reefs (Rasmussen et al. 2012). Humpback whales are commonly observed off the coast of mainland Ecuador from June to September, mainly near Salinas, Puerto Lopez and Esmeraldas in Galera San Francisco (Félix et al. 2018; Narváez Caicedo 2015; Scheidat et al. 2004). A photo-identification study reported 3 whales in Antarctica that had previously been recorded off the coast of Salinas, one of which was re-identified after 12 years (Félix et al. 2018). Records in Galápagos suggest that the species is not common in these waters, however sightings have been reported throughout the islands, in particular around Floreana and Isabela (Félix et al. 2011b).

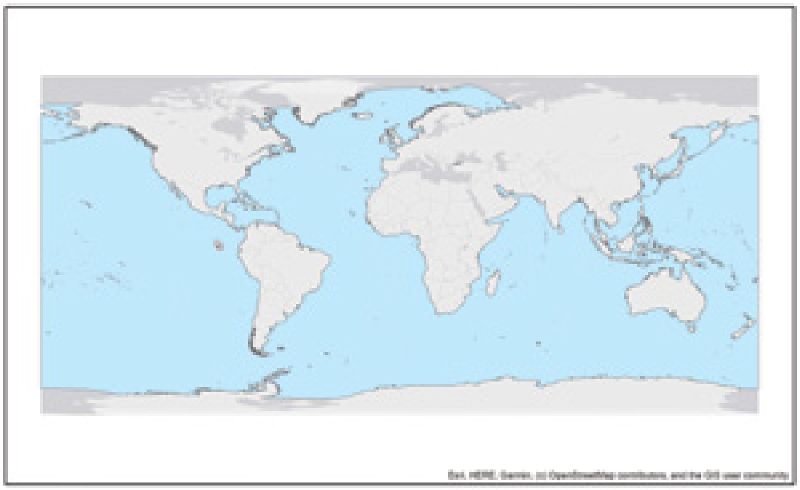


Figure 89. Global range of the humpback whale (left) and distribution within the Galápagos EEZ (right). Source: Cooke (2018b).

Humpback whales, after Bryde's whales, are among the most common whales to be seen in the GMR, in particular in the cool season, which coincides with the winter migration of the Southeast Pacific population (Denkinger et al. 2013). They are commonly observed in the central region of the archipelago, and east to San Cristóbal Island. Galápagos may be a breeding area, or a stepping-stone for whales migrating to the Panamanian/Colombian breeding grounds (Félix et al. 2011b).

Humpback whales in the eastern North Pacific breed in two geographically distinct areas: 1) Baja California, coastal mainland Mexico and Revillagigedo, and 2) Central American coastal waters from southern Mexico to Costa Rica (Titova et al. 2018). In the southeastern Pacific they migrate between feeding grounds in Antarctica and their breeding area, mainly in the waters of Ecuador and Colombia (Acevedo et al. 2006), with individuals traveling between 920 and 8,670 km (Félix and Guzmán 2014).

Humpback whales may be affected by anthropogenic noise, collisions with boats, and entanglement with fishing gear and marine debris (Cooke 2018b). A study on bycatch in Ecuador showed an annual mortality of 0.53% equivalent to 15 or 33 humpback whales, (Alava et al. 2012). Humpback whales are listed on Appendix I of CITES and Appendix I on the CMS (Flórez-González et al. 2007). They are classified as Least Concern by the IUCN (Cooke 2018b).

Sperm whale

The sperm whale *(Physeter macrocephalus)* is the largest toothed predator on the planet (Cantor et al. 2019). It is a cosmopolitan species distributed from the poles near the ice edges, to the tropics, mainly in the Pacific Ocean (Figure 90). Males occupy the entire range, especially at high latitudes, while females and juveniles are more restricted latitudinally to waters where surface temperatures exceed 15°C (Whitehead 2018). There is no significant differentiation in DNA sequence variations between ocean basins, suggesting that there is no subdivision except for isolated basins such as the Mediterranean and the Gulf of Mexico (Drouot et al. 2004; Richard et al. 1996; Taylor et al. 2019).

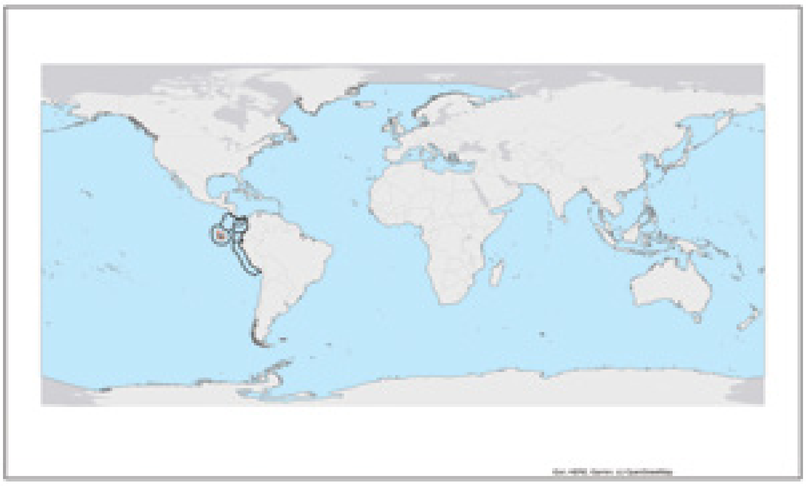


Figure 90. Global range of the sperm whale (left) and distribution within the Galápagos EEZ (right). Source: Taylor et al. (2019).

The most distinctive feature of the sperm whale is its huge nasal complex, packed with spermaceti, which enables the whale to echolocate prey during hunting (Cantor et al. 2019), and may also play a role in buoyancy (Clarke 1970). Sperm whale diet is varied: the females feed on cephalopods such as the giant squid *Architeuthis* spp. and squids *Dosidicus gigas*. Males will eat larger individuals of the same prey but also feed on higher latitude prey such as the colossal squid *Mesonychoteuthis hamiltoni* and demersal fish such as sharks, rays, and gadoids (Clarke et al. 1993; Whitehead 2018). Sperm whales play an important ecological role in mesopelagic food webs, carbon cycle and carbon consumption (Eguiguren et al. 2020).

Sperm whales may leave at least 50 years, with females reaching sexual maturity at around 9 years, while males undergo prolonged puberty between the ages of 10-20 years (Whitehead 2018). Females give birth to a single calf every five years (Best 1979). Adult males are mostly solitary (although they sometimes form bachelor groups (Best 1979), but females and juveniles form near-permanent social units, several of which may sometimes join to form temporary social groups (Cantor et al. 2019). Sperm whales generally travel at around 4 km/h (Whitehead 2018). Their migrations are not as clear or regular as whales, and they are considered more nomadic than migratory. However, in mid-latitudes there seems to be a seasonal migration that goes from north to south according to food availability (Whitehead 2002).

Sperm whales sometimes concentrate in restricted areas of high productivity. The cool, productive waters west of the Galápagos Islands were targeted by whalers in the 18th and 19th centuries (Whitehead and Hope 1991), with over 5,000 individuals removed from this region from 1830-1850 alone (Whitehead et al. 1997). Further, in the latter half of the 20th century, intensive commercial whaling took place off Peru, which contributed to continued declines in the abundance of sperm whales in the region, in particular in the case of males, due to a bias towards hunting large males (Whitehead et al. 1997). A recent habitat suitability model (Eguiguren et al. 2020) for sperm whales around the Galápagos Islands suggested that while their distribution has remained broadly consistent over long time scales (tending to occur in deep, cool waters in the western bioregion), they display fine scale variability on a year-to-year basis (Figure 91). The sperm whales followed during this study spent a significant portion (up to 30%) of their time in the unprotected waters outside the GMR, where they may interact with longline and purse seine fisheries.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Current threats to sperm whales include anthropological effects such as fishing (bycatch), collisions with boats, ingestion of solid waste, chemical pollution, disturbance associated with industrial noise and climate change (Notarbartolo Di Sciara 2014). Historical data from 1880 suggest that the global sperm whale population was around 1,100,000 prior to whaling, but that by the 1990s the population had declined by 67% with approximately 360, 000 individuals globally (Taylor et al. 2019). Sperm whales are classified as Vulnerable by the IUCN (Taylor et al. 2019), and are listed on Appendix I of CITES and Appendix I and II of CMS (Taylor et al. 2019).

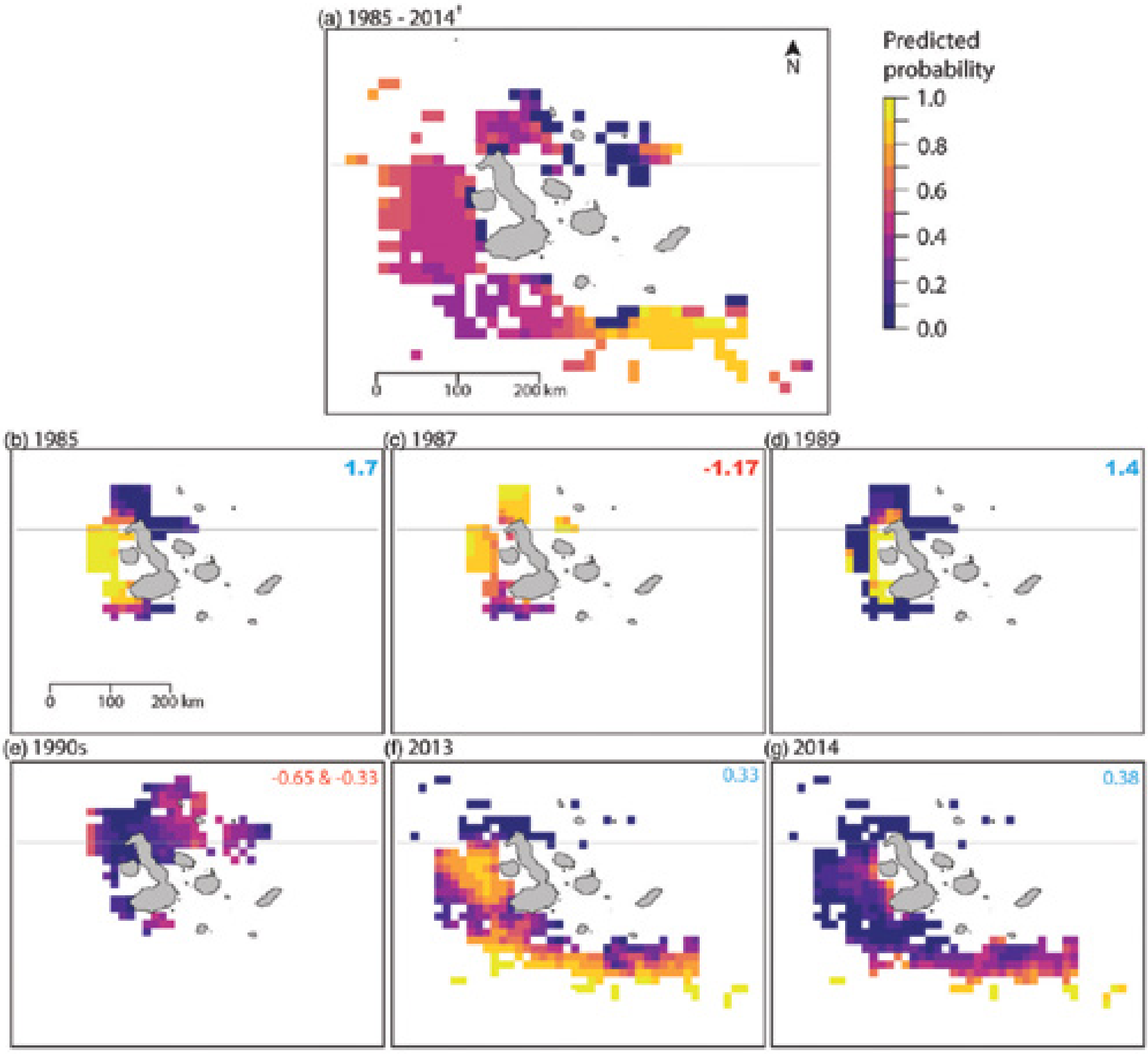

Figure 91. Predicted annual probability (0–1) of sperm whale presence as a function of geographic, topographic, and oceanographic variables for all decades (a) 1980s (b-d), 1990s (e) and 2010s (f, g) from final models. Southern Oscillation Index annual averages – obtained from https:// www.cpc.ncep.noaa.gov/data/ indices/soi – are shown in red (El Niño) and blue (La Niña). Bold numbers indicate strong El Niño and La Niña conditions. Includes data collected in 1985, 1987, 1989, 1995, 2013, and 2014. From: Eguiguren et al. (2020).

Habitat

Seamounts

Seamounts are volcanic in nature, and present in all ocean basins, in particular near ocean spreading centers and over geological hotspots (Wessel 2007). Definitions of seamounts vary between studies and disciplines (e.g. see Staudigel et al. 2010), but can generally be considered as isolated topographic elevations with summit depths at least 100 m above the surrounding seafloor (Rogers 2018). Seamounts may be classed as "shallow" or "deep", depending on whether or not they extend into the photic zone (Genin 2004). Given that they occupy a large geographical area with similar physical attributes and similar biotic assemblages, Etnoyer et al. (2010) proposed that seamounts be considered a marine biome. It is estimated that there may be anywhere from 150,000 to more than 25 million seamounts globally (Rogers 2018).

Like oceanic islands, seamounts provide structural complexity to both ocean bathymetry and current patterns, which results in "hotspots" characterized by a greater diversity and abundance of pelagic species (Worm et al. 2003) particularly with respect to apex predators such as sharks (Stevenson et al. 2007). Seamounts interact with the aquatic surrounding in several ways (Barton 2001): in stratified, enclosed seas with significant tidal oscillations but weak mean flow, the tide "moves water back and forth and the island or seamount serves as a stirring rod to cause vertical mixing and disrupt the pycnocline" (Richert et al. 2017). Where there is a strong mean flow past the seamount, eddies and a wake of disturbed flow can extend several seamount-diameters downstream. Persistent wake structures are present at both large and small oceanic islands and seamounts. The spatial scale of eddies is usually close to the diameter of the feature and the temporal scale can vary from days for larger islands to hours at smaller islands and seamounts with flows produced by tides. In addition to island wakes, bow-wave effects are expected along the upstream face of a seamount or island. Doty and Oguri (1956) have noted upstream effects where the current stalls as it splits to flow around the obstacle. Finally, in addition to specific small-scale habitats in downstream-wake and upstream-blocking locations, one expects to see locations on the flanks where plankton fluxes are highest due to maximum flow speeds (possibly combined with a high plankton concentration that developed in the upstream blocking location). Fixed benthic organisms or fish that can easily hold position by sheltering behind small reef features can take advantage of this high rate of food delivery and allow high local concentrations of fish to develop.

Dietary studies of benthic and pelagic fish at seamounts have shown migrating zooplankton to be important components of the diet of resident fish (e.g. Fock et al. 2002; Seki and Somerton 1994). The "divergence of the current due to upstream blocking creates a zone of weak currents, can also lead to entrapment and accumulation of plankton (Hamner and Hauri 1981). (Hamner et al. 2007; Hamner et al. 1988) suggest that planktivorous fishes on the upstream reef face form a "wall of mouths" that removes most of the zooplankton from the water near the reef face before that water physically impinges upon the reef surface" (Hearn et al. 2010). They conclude that zooplankton as a source of nutrition for reef communities has been underestimated.

Biological enhancement may also occur due to an increase in the horizontal flux of suspended food particles as a result of increased current speed on the sides of the seamount. This may promote high densities of resident fish both indirectly by augmenting growth and recruitment of the members of the benthic communities, on which pelagic fishes feed, or through direct feeding of planktivorous fish in these locations. The structural complexity of reef habitat on the seamounts might additionally provide shelter for fish (McFarland and Levin 2002). In the "rest-feed" hypothesis, fish are quiescent while in shelters and emerge to feed when conditions are right, thus avoiding the need to swim actively in open water to seek prey. This mechanism has been suggested as the cause of large aggregations of orange roughy *(Hoplostethus atlanticus)* at seamounts (Lorance et al. 2002). This might not directly pertain to larger biota (e.g., sharks) as they may not be able to find adequate small-scale shelter and would need to move between current-exposed sites on the side of the island and current-protected sites on the downstream side of the island. For example, Klimley and Nelson (1984) showed that the schools did not move from one side to the other of a seamount in response to changing current conditions as would be expected under this scenario.

A third "explanation for the aggregations of some species at seamount or oceanic hotspots, from which they make diel migrations away at night, is that the island or seamount may serve as a landmark. Providing a perceptible physical property, such as the local magnetic field intensity, they could be used for guidance during daily and seasonal migrations. Species making diel foraging movements away from seamounts or fish aggregating devices are skipjack tuna (Yuen 1970), yellowfin tuna (Holland et al. 1992), and hammerhead sharks (Klimley 1993)" (Hearn et al. 2010).

Seamounts have increasingly attracted the attention of artisanal and industrial fishing fleets, due to the abundance and concentration of commercial species, including tuna (Pitcher et al. 2010). Seamounts in the Eastern Pacific host aggregations of blue and bigeye thresher sharks (Litvinov 2007). Scalloped hammerhead sharks were also among the species found to aggregate at seamounts between Cocos and Galápagos (Cambra et al. 2021).

In addition to isolated seamounts, two underwater ridge systems converge near the Galápagos platform – the Cocos Ridge, linking the islands with Costa Rica to the northeast; and the Carnegie Ridge, connecting Galápagos with mainland Ecuador to the east (Figure 92). The different peaks along these ridges may function as a series of stepping-stones, providing connectivity through movements of individuals or through dispersal of populations (Cambra et al 2021, Clark et al. 2010). Seamounts around the Galápagos and the ecosystem services that they provide (e.g. biodiversity and habitat conservation, fisheries, mining) are poorly studied, although a 2017 study found that tourists visiting the Galápagos Islands may be willing to pay on average an extra US$48.98 on top of the entry fee at that time of US$100 for seamount conservation (Ison et al. 2021).

For the purposes of this study, we obtained locations of known seamounts from 30 arc-sec resolution satellite bathymetry data (Yesson et al. 2011) and overlaid these on bathymetric maps of the region from GEBCO *(The General Bathymetric Chart of the Oceans)*, using gridded bathymetry data from 2020 (GEBCO Compilation Group 2020), to provide an overview of where seamounts and underwater ridges occur near Galápagos (Figure 93). Shallow-water seamounts are mostly limited to the Galápagos platform and occur inside the GMR. Most of the seamounts outside the GMR occur along one of the two ridges, although isolated deep-water seamounts are reported to the southeast of the Galápagos EEZ and along the Galápagos spreading center in the high seas to the west of the EEZ. The cluster of seamounts just outside the eastern boundary of the GMR range from 120-600 m at their shallowest points, and thus extend into the photic zone, as do some of the seamounts on the northwestern margin of the Cocos Ridge, which range from 200-1,200 m (Figure 92).

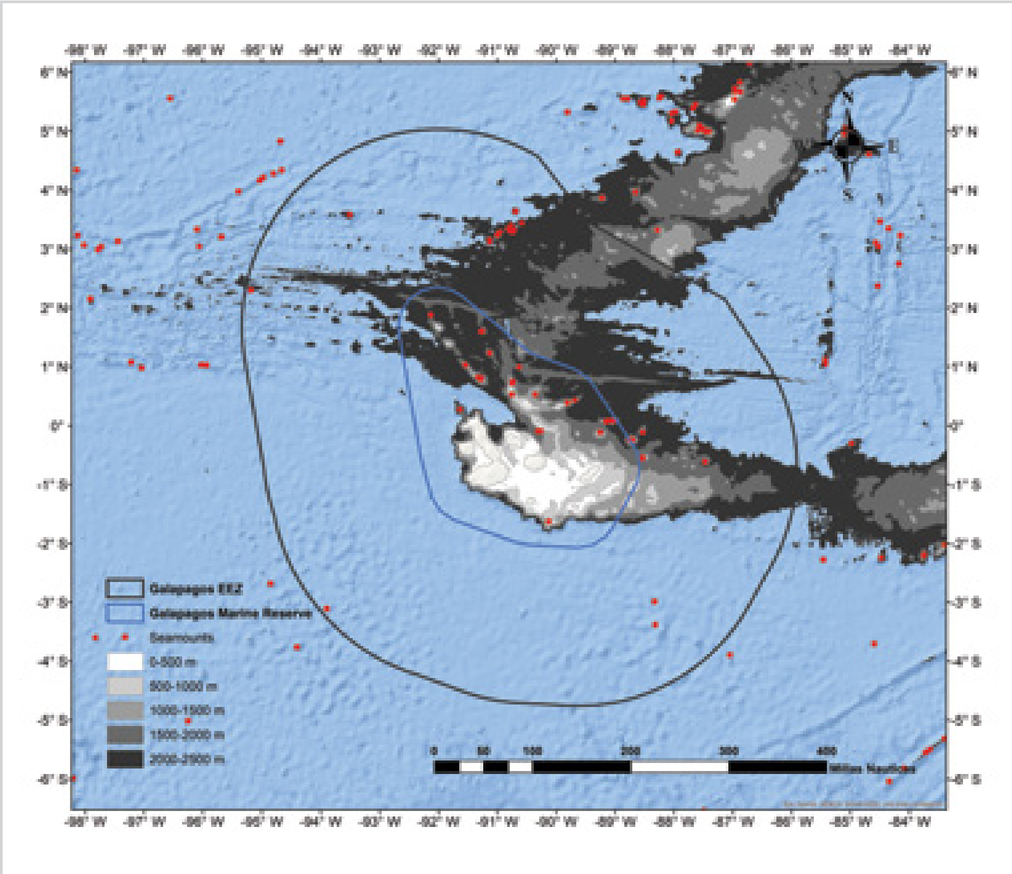

Figure 92. Seabed features surrounding the Galápagos Islands, showing location of mapped seamounts and bathymetry to 2500m. Source data: GEBCO Compilation Group (2020).

Hydrothermal vents

Hydrothermal vents are hot springs that occur on the seafloor, generally close to spreading centers and hotspots (Fisher et al. 2007). Seawater percolates into the seabed where it is heated under pressure to temperatures which may reach 400°C (Fisher et al. 2007). The superheated fluid dissolves minerals in the substrate, which precipitate out when the fluid is emitted, forming chimney-like structures over fissures in the seabed. The liquid is rich with sulfides and CO2, which are metabolized by chemosythetic microbes (Van Dover 2000). In turn, these form the basis of a unique ecosystem that is not reliant on photosynthesis.

The first hydrothermal vents were discovered in 1977 northeast of the Galápagos Islands (Corliss et al. 1979), in international waters (see Galápagos Mounds in Figure 93). Since then, several more have been identified in the region, including five systems within the boundaries of the GMR, and a string of vents along the Galápagos rift system in the far western area of the EEZ (Figure 93).

Hydrothermal vents have provided scientists with a unique opportunity to study the potential origins of life on Earth and potentially on other planets (Martin et al. 2008, Menini and Van Dover 2019). They may also be rich in valuable minerals – for example, deposits in active vent systems in Papua New Guinea contained sufficient concentrations of gold and silver to prompt interest in mining, sparking conservation concerns (Halfar and Fujita 2007; Van Dover et al. 2018).

Hydrothermal vents are included as potentially vulnerable habitats that may be designated as Vulnerable Marine Ecosystems (VMEs) by the FAO (FAO 2009). In terms of conservation measures, some hydrothermal vents fall within MPAs designated for other reasons, as is the case with the five vents occurring within the GMR (Figure 94). However, a small but growing number of MPAs specifically address the protection of hydrothermal vents, for example the Offshore Pacific Seamounts and Vent Closure (OPSVC) in Canada (Menini and Van Dover 2019).

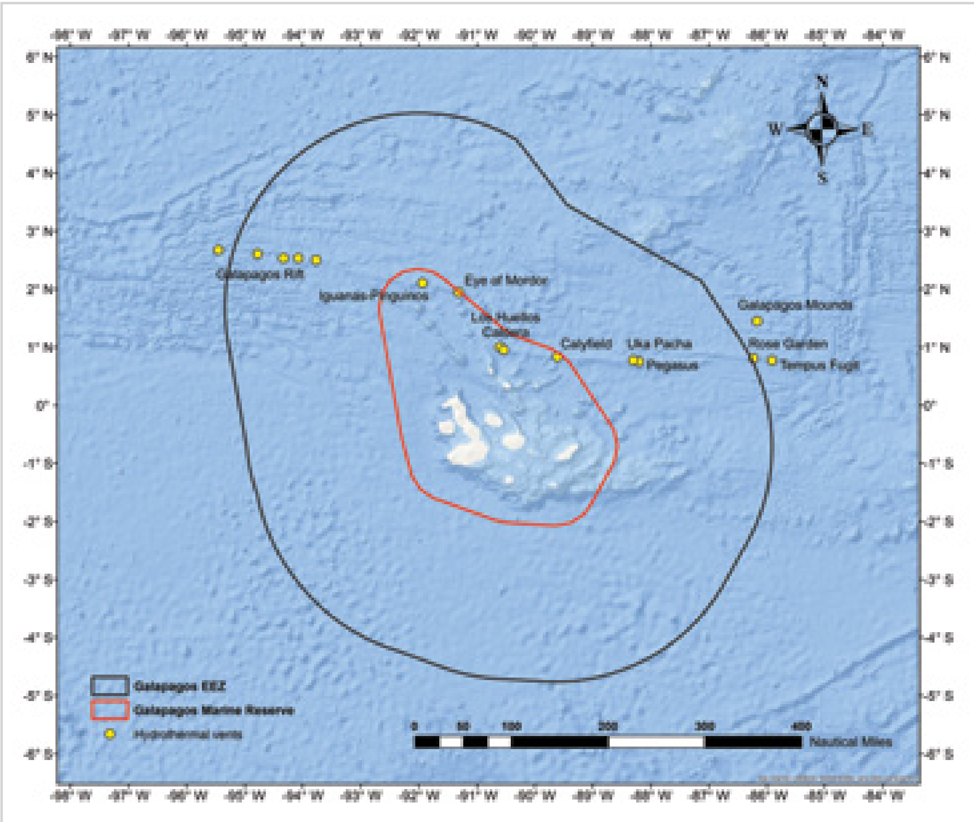

Figure 93. Location of hydrothermal vents in and around the Galápagos Islands Source: InterRidge Vents Database (2011).

Key processes

Persistent upwelling

Large and meso-scale upwelling processes largely drive the exceptionally rich and diverse ecosystem around the islands (Edgar et al. 2004; Palacios 2002). These processes have a strong seasonal signal and are located along the western margins of some of the islands, and in the western bioregion of the Galápagos EEZ in general. The oceanography of the Galápagos Islands has been described in a previous section, as has the influence of the El Niño Southern Oscillation (ENSO). The current and past links between ENSO and climate change have been a subject of research to help forecast potential climate scenarios in the future (Lu et al. 2018; Sandweiss et al. 2020).

We used a biogeochemical oceanographic circulation model developed by the University of Southampton (Forryan et al. 2021; Naveira-Garabato et al. unpublished) to identify areas of persistent upwelling under three different climatic conditions: El Niño year (2015), a La Niña year (2008) and a neutral year (2012) (Figure 94).

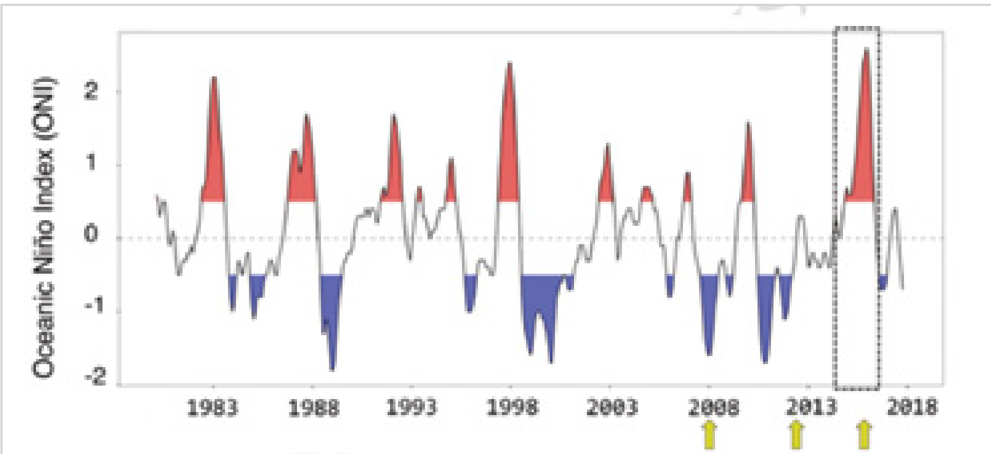

Figure 94. Time-series of Oceanic Niño Index (ONI), showing El Niño (red) and La Niña (blue) conditions. Yellow arrows depict years chosen to model thermocline depth in the Galápagos EEZ. Source: Lamb et al. (2018).

The model provides daily averages of all oceanographic fields (e.g. temperature, salinity and velocity). It was constructed using a general circulation model from MIT (Marshall et al. 1997) with bathymetry from General Bathymetric Chart of the Oceans (GEBCO_14) Grid (Weatherall et al. 2015). Model grid resolution is 4 km in the horizontal (0.03334°) between ± 5° latitude stretching out to ~ 12 km (0.03333°) in latitude at the model boundaries with 840 grid points in X and 600 in Y and a grid origin at 17.8°S 105°W. The vertical grid comprised 75 depth levels. Vertical resolution varied with depth from 5 m over the first 50 m, 9.8 m to 164 m depth and 13.7 m to 315 m depth, with a maximum cell height of 556 m below 3,000 m. The model domain was extended southwards to improve resolution of the Chilean coastal current system. The model was run with three completely open boundaries (North, South and West), using periodic boundary forcing for temperature, salinity, and velocity fields and a 15-grid box thick sponge layer (Figure 95 dashed red line) for velocity (Forryan et al. 2021).

Initial conditions and monthly boundary forcing were taken from the Mercator ocean reference model (https://www.mercator-ocean.fr/), a global ocean model based on 1/12 (0.083) degree NEMO (https://www.nemo-ocean.eu/). Wind stress, evaporation and precipitation were taken from ERA-Interim reanalysis (Dee et al. 2011) at a 3 hour temporal resolution for all fields and radiation (shortwave and longwave) forcing from Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA2; Global Modeling and Assimilation Office (GMAO) (2015)) at hourly temporal resolution.

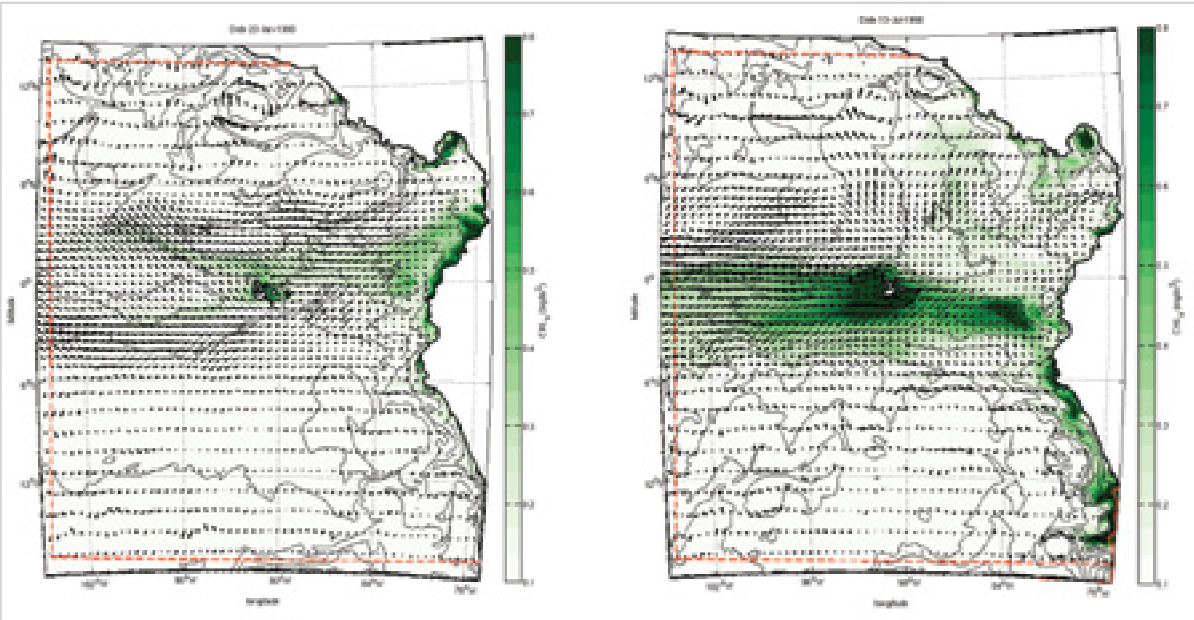

Figure 95. Model boundary (dotted red lines) and chlorophyll a concentration (green shading) for two different dates in 1998: el Niño conditions in January (left) and la Niña conditions in December (right). Arrows show direction and strength of surface flow.

We used the depth of the 20°C isotherm relative to the annual mean depth of the 20°C isotherm as a proxy measure for the seasonal strength of upwelling, with a positive 20°C isotherm anomaly indicative of stronger upwelling (displacement of isopycnals towards the surface). An empirical orthogonal function (EOF) analysis was conducted on a box encompassing the Ecuadorian EEC on depth-integrated chlorophyll-a concentration, sea surface temperature, and 20°C isotherm depth anomaly to determine persistent patterns in the variability of these quantities (Bretherton et al. 1992; Palacios 2004). In essence, this analysis shows the patterns in the depth of the thermocline across the study area and how these patterns vary over time. We carried out this analysis for 2008 (La Niña), 2012 (neutral) and 2015 (El Niño), and for each analysis, the variance is shown in relation to the mean for that year. For each year, three panels are shown – the maximum EOF, which shows the variation in thermocline depth with respect to the average on the date when the strength is greatest; the minimum EOF, which is the inverse pattern, displaying the variation when the strength is lowest; and a graph showing how the amplitude of the variance changed throughout the year (Figures 96, 97 and 98). Note that the scales are different in each panel, and that positive numbers denote shallower depths, i.e. that the thermocline is closer to the surface than the annual mean for that year.

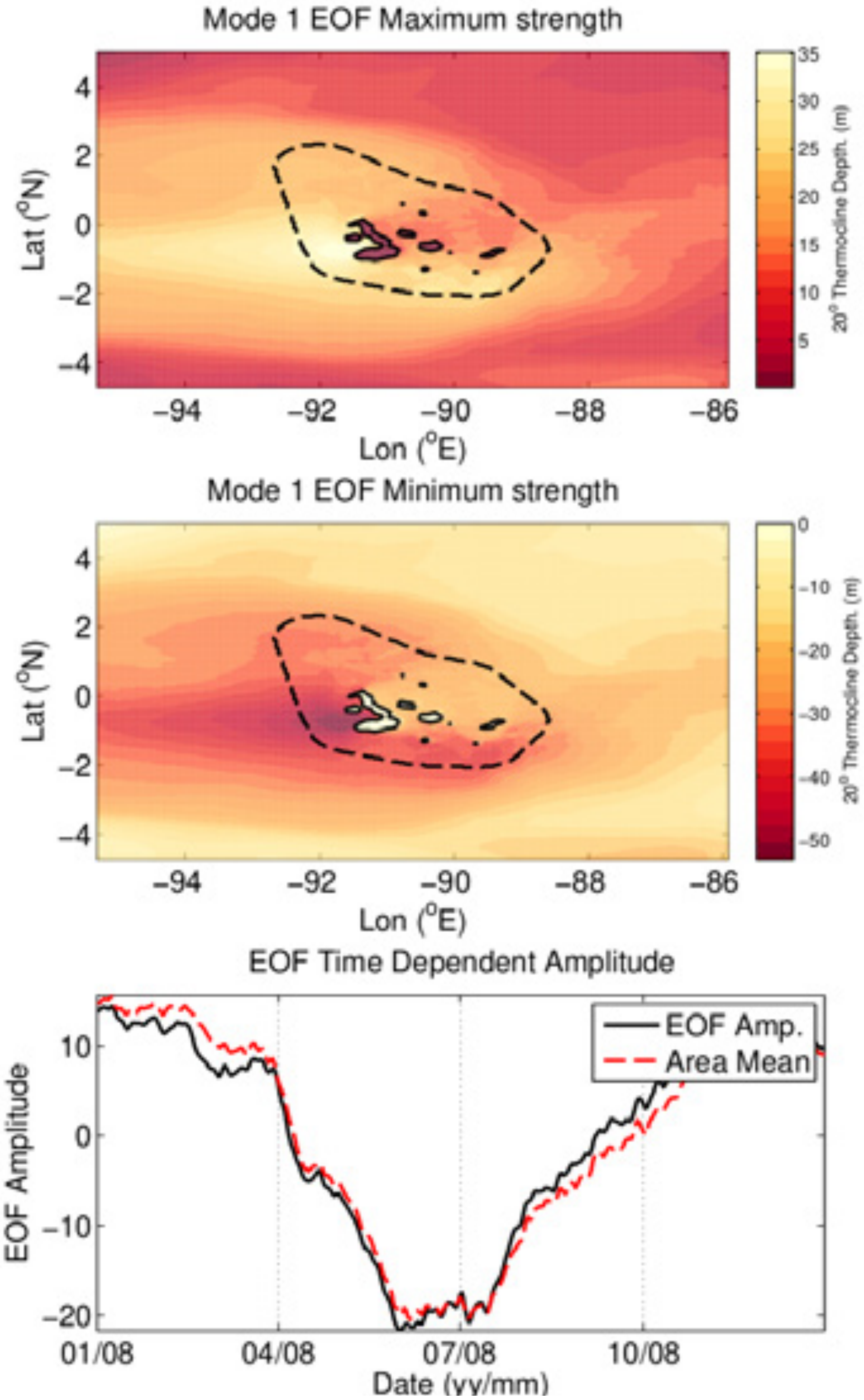

Figure 96. Empirical orthogonal function (EOF) analysis for 2008 (La Niña conditions) showing how the depth of the 20oC isotherm varied across the region and throughout the year. The top panel shows the position of the thermocline relative to the average on the date of maximum amplitude (January). The middle panel shows the position of the thermocline relative to the average on the date of minimum amplitude (June). The bottom panel shows how the amplitude varied over the year.

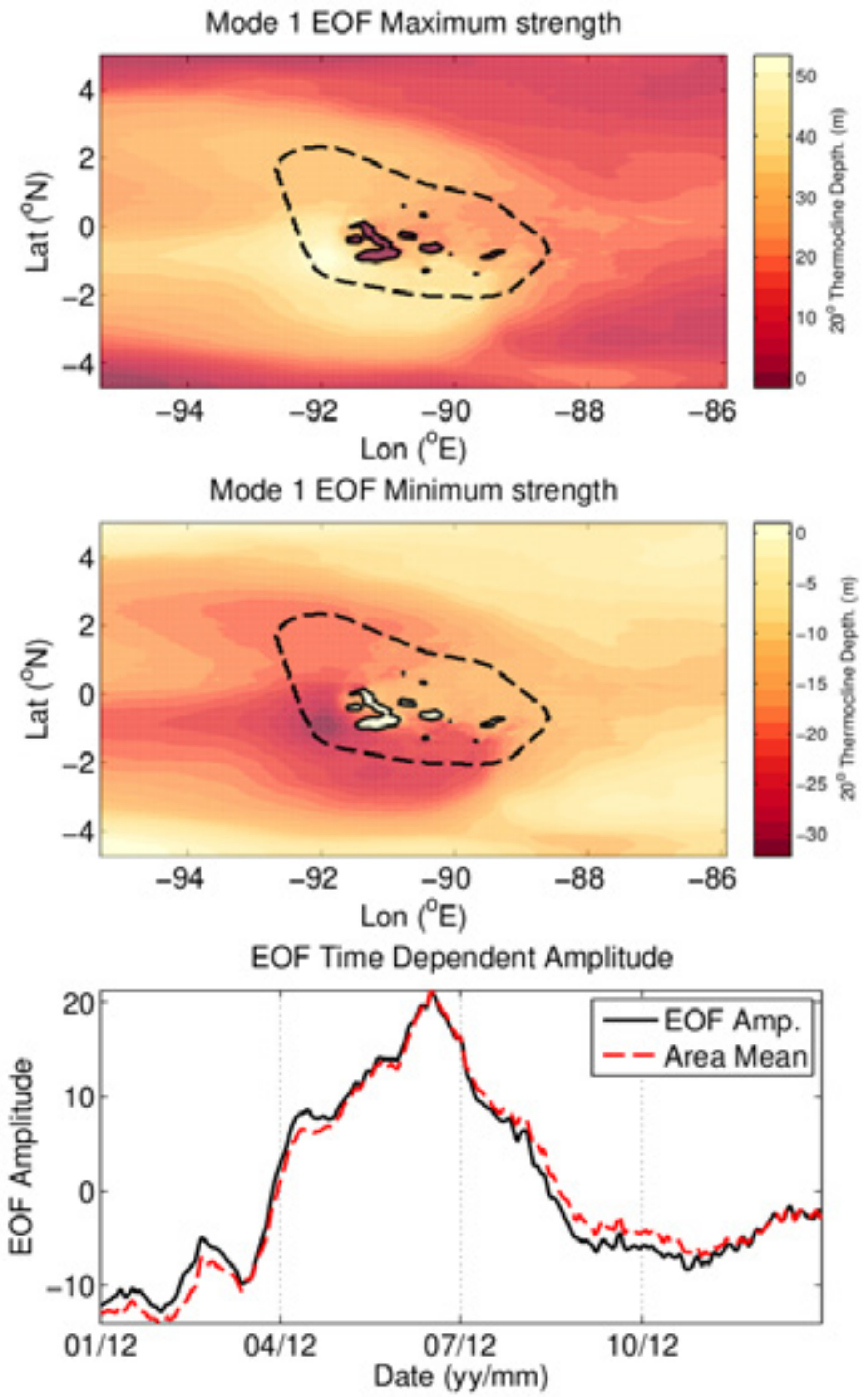

Figure 97. Empirical orthogonal function (EOF) analysis for 2012 (neutral conditions) showing how the depth of the 20oC isotherm varied across the region and throughout the year. The top panel shows the position of the thermocline relative to the average on the date of maximum amplitude (June). The middle panel shows the position of the thermocline relative to the average on the date of minimum amplitude (February). The bottom panel shows how the amplitude varied over the year.

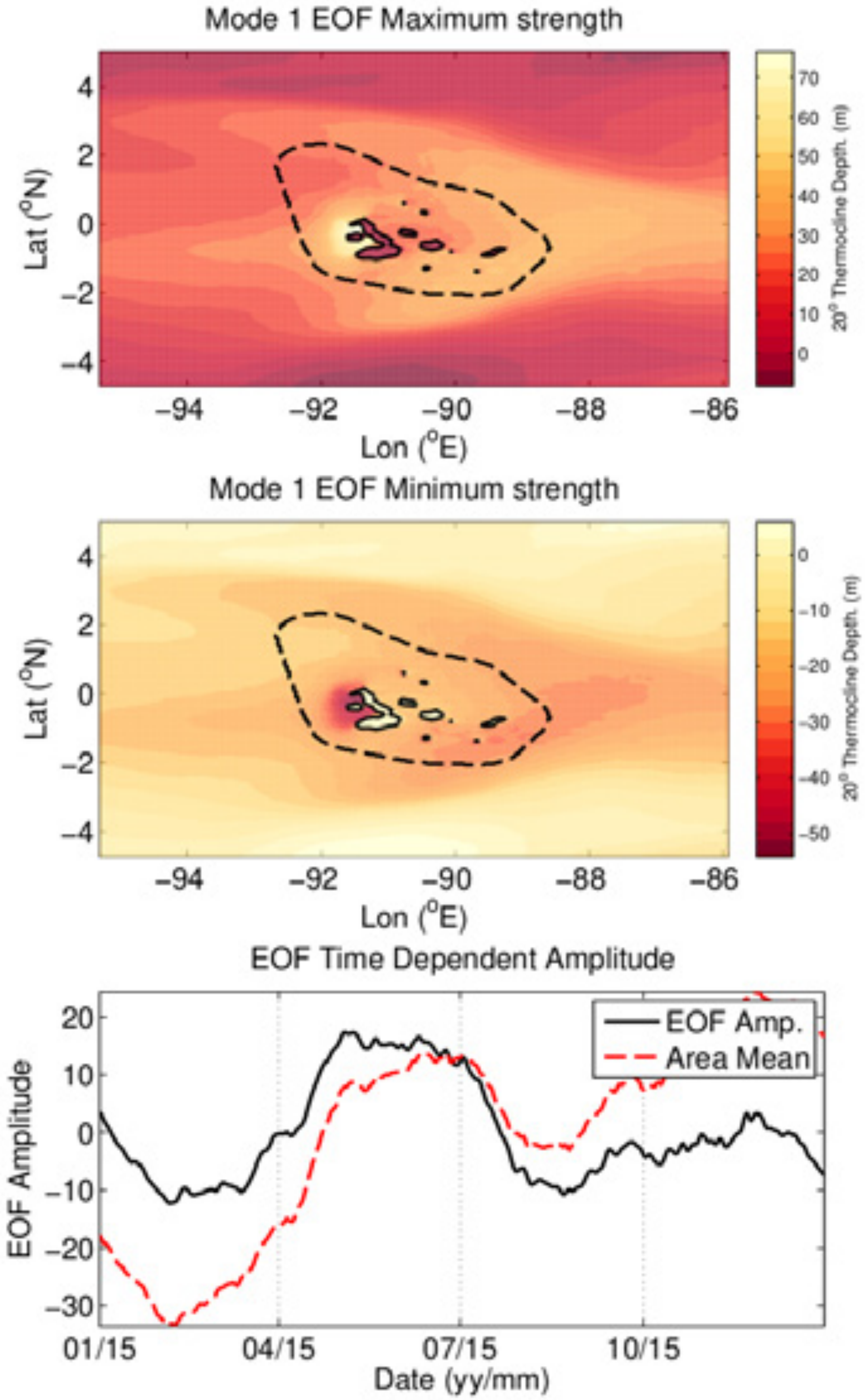

Figure 98. Empirical orthogonal function (EOF) analysis for 2015 (El Niño conditions) showing how the depth of the 20oC isotherm varied across the region and throughout the year. The top panel shows the position of the thermocline relative to the average on the date of maximum amplitude (May). The middle panel shows the position of the thermocline relative to the average on the date of minimum amplitude (February). The bottom panel shows how the amplitude varied over the year.

The results showed a highly seasonal variation in the depth of the thermocline, which is an indicator of a persistent core of seasonally highly productive waters immediately west of Isabela and Fernandina under all conditions. During 2008 and 2012, this extended along the southern margin of the GMR boundary and west beyond the EEZ, but not in 2015.

Ecosystem Services

The world's ecosystems provide a variety of services that are essential for the survival and well-being of humans. Ecosystem services (ES) can be broadly classified into four main types: a) *provisioning services*, which refer to the products obtained directly from ecosystems (e.g. food, fuel, water); b) *regulating services*, which are the benefits obtained from regulating ecosystem processes (e.g. climate regulation, carbon storage, water purification); c) *cultural services*, which comprise the non-material benefits derived from ecosystems (e.g. educational, recreational and spiritual values) and d) *supporting services*, which include all the processes required to produce the services previously mentioned (e.g. photosynthesis, nutrient cycling) (MEA 2005, TEEB 2009).

The ocean provides a wide range of ES that contribute to humans' survival, well-being and health (Table 6). However, a lot of attention has been brought to the services provided by coastal ecosystems, which account only for 7% of the total area of the global ocean (Nellemann et al. 2009). The services provided by coastal ecosystems like coral reefs, seagrass meadows and mangroves are widely studied and recognized (e.g. Martínez et al. 2007), while those provided by the open ocean are much less understood. However, research in the open ocean has increased over the past decade and many authors have highlighted their importance and the services they offer (Table 5, Rogers et al. 2014, Thurber et al. 2014).

Provisioning Services: Fisheries & Food Security

Fishery resources are the main goods provided by the world's oceans. Population growth, as well as dietary and socioeconomic changes over the past half-century, have led to an increase in the demand for seafood (defined here as food harvested from marine and freshwater systems) at a global scale. According to FAO (2020), fish consumption has been increasing in developed and developing countries, reaching 24.4 kg and 19.4 kg per capita respectively in 2017. Currently, fish consumption represents 17% of the global population's intake of animal protein, making marine fisheries direct contributors to global food security, which is the condition where all people have access (economic, social and physical) to "sufficient, nutritious and safe foods" (FAO, 2020). Seafood is an excellent source of macro and micronutrients and is particularly important in developing countries that mainly rely on wild-caught fish to survive (Hicks et al. 2019; Hall et al., 2013). Additionally, fisheries resources can contribute indirectly to food security by providing livelihood opportunities to millions of people as well as income to purchase food (García and Rosenberg 2010).

Over the past seven decades, marine fishing effort increased to meet the growing demand for seafood. In 2018, global capture fisheries reached their highest level at 96.4 million tons, of which 84.4 million tons corresponded to marine capture fisheries (FAO 2020).

Marine small-scale fisheries operate almost exclusively inshore and contribute between one quarter and one-third of the total marine catch (Chuenpagdee et al. 2006). However, the depletion of coastal fishing resources as well as the improved fishing and storage technologies has allowed the geographical expansion of industrial fishing fleets towards the open ocean (Swartz et al. 2010). Currently, it is estimated that industrial fishing occurs in over 55% of the global ocean area (Kroodsma et al. 2018). Around 90% of the world's fisheries take place within countries' EEZs (FAO 2020), while high seas fisheries (in international waters) contributed approximately 4.3% of the annual marine catch between 2009 and 2014 (Schiller et al. 2018).

Table 6 | Summary of ecosystem services provided by the high seas (Rogers et al. 2014).

Ecosystem Service (ES) Category	Definition
Provisioning Services	
1. Sea Food	All available marine fauna and flora extracted from the high seas for the specific purpose of human consumption as food.
2. Raw Materials	The extraction of any biologically mediated material from the high seas (excluding material covered by ES 5).
3. Genetic Resources	Any material that is extracted from the high seas for use in non-marine, non-medicinal contexts (excluding the research value associated ES 15).
4. Medicinal Resources	Any material that is extracted from the high seas for its ability to provide medicinal benefits (excluding the research value associated ES 15).
5. Ornamental Resources	Any material extracted from the high seas for use in decoration, etc.
Regulating Services	
6. Air Purification	The removal from the air of natural and anthropogenic pollutants by the high seas.
7. Climate Regulation	The contribution of the biotic elements of the high seas to the maintenance of a favorable climate via its production and sequestration of climate-influencing substances.
8. Waste Treatment	The bioremediation by the high seas of anthropogenic pollutants.
9. Biological Control	The contribution of the high seas to the maintenance of natural, healthy population dynamics that support ecosystem resilience by maintaining food webs.
Habitat Services	
10. Lifecycle Maintenance	The contribution of the high seas to migratory species' populations through the provision of essential habitat for reproduction and juvenile maturation.
11. Gene Pool Protection	The contribution of the high seas to the maintenance of viable gene pools through natural selection/evolutionary processes.
Cultural Services	
12. Recreation and Leisure	The provision of opportunities for recreation and leisure that depend on the state of the high seas.
13. Aesthetic Information	The contribution that the high seas make to the existence of a surface or subsurface landscape. This includes informal Spiritual Experiences but excludes that which is covered by ES 12, 14, and 15.
14. Inspiration for Culture, Art and Design	The contribution that the high seas make to the existence of environmental features that inspire elements of culture, art, and/or design (this excludes that which is covered by ES 5, 12, 13, and 15).
15. Information for Cognitive Development	The contribution of the high seas to education, research, and learning. This includes contributions of the high seas to the research into ES 3, ES 4.

Regulating Services: Carbon Sequestration

The world's oceans play a crucial role in the global carbon cycle by capturing and storing carbon. By doing so, the oceans regulate the concentrations of CO_2 in the atmosphere, a greenhouse gas that contributes directly to climate change and influences the global climate, thus providing an important regulating ES. Oceans are thought to capture and store one-third of the total anthropogenic CO_2 through two main processes (Figure 99): a) a geophysical process where atmospheric CO_2 dissolves into the surface layer of the ocean (>200 m), and then it is transported to the deep seabed (>1000 m) and b) a biological process (also known as the biological pump) that involves the 'fixation' of carbon by phytoplankton located in the surface layer of the ocean. Phytoplankton use CO_2 for photosynthesis and growth. When phytoplankton die, they decay and some particles sink to the seabed, where carbon can be stored over long periods of time (Rogers et al. 2014, Metz et al. 2005). Additionally, carbon can be transported along the water column through active transport by the vertical migrations of zooplankton (e.g. Steinberg et al. 2000). Phytoplankton in the high seas have been estimated to capture approximately 23 billion tons of carbon (which account for 49% of the total carbon fixed by the oceans) and to store around 0.448 billion tons of carbon per year. This service of the high seas amounts to US$148 billion per year (in 2010 dollars) (Rogers et al. 2014). Carbon sequestration is not just limited to planktonic species. Fish and other marine megafauna that die and sink to the seabed also play an important role, which has been affected by human activities – fisheries are thought to have released at least 0.73 billion metric tons of CO_2 since 1950 (Mariani et al. 2020). Commercial whaling has similarly reduced the carbon sequestration impact of large whales (Pershing et al. 2010). Rebuilding fish and cetacean stocks may be comparable to other carbon management schemes (Pershing et al. 2010).

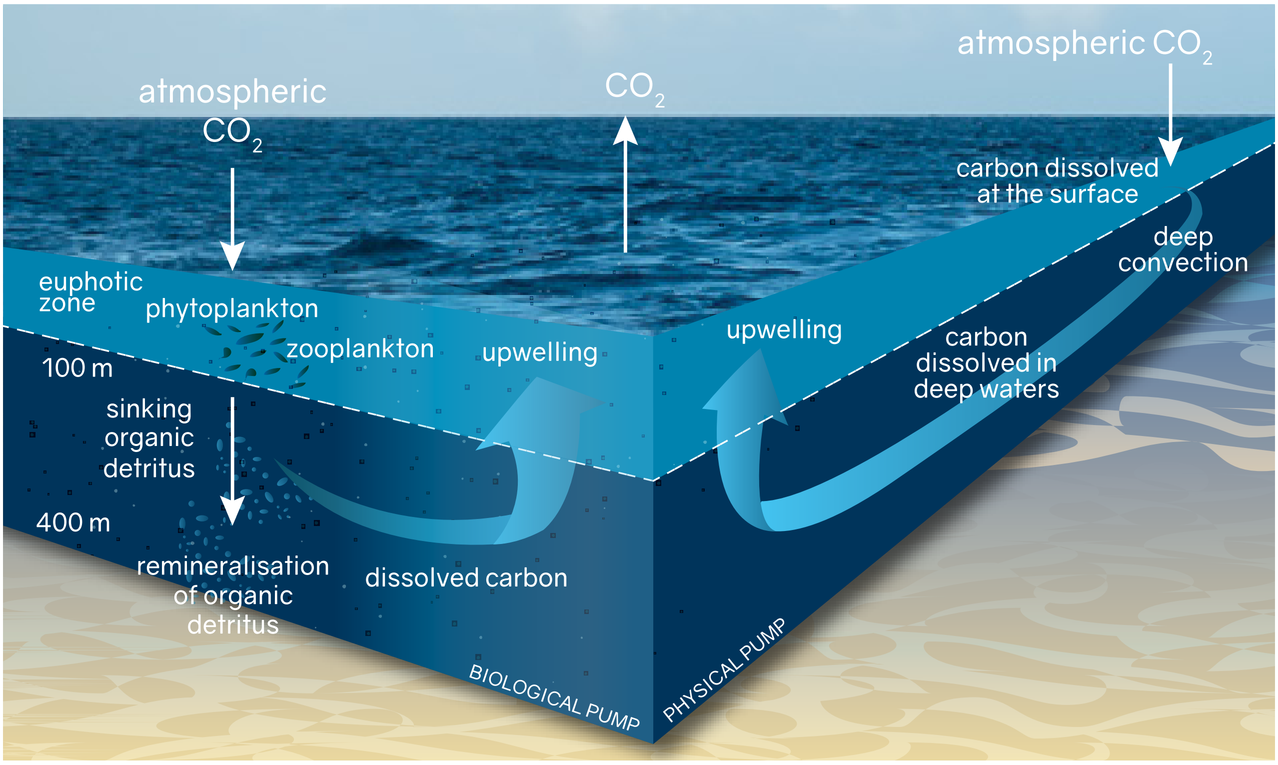

Figure 99. Representation of the physical and biological processes through which the oceans capture and store carbon (from Bopp et al. 2015).

Supporting Services: Biodiversity

Biodiversity encompasses living organisms, including richness, abundance and composition of species, populations and communities as well as functional types, landscape units and their interactions in a given system. Biodiversity is considered a key supporting ES, since it is necessary for the production and maintenance of the more direct provisioning, regulating and cultural services. Marine biodiversity plays an important role in maintaining the services obtained from the oceans, some of which have been described in the sections above. For example, biodiversity losses, such as reductions of local populations or extinctions negatively impact the oceans' provisioning services. The removal of large quantities of certain species, such as top predators, can lead to range contractions, reduce their influence on ecosystem processes, and ultimately alter the naturally occurring interactions between species (Chapin III et al. 2005). Overall, preserving the interactions among marine species and allowing individuals to complete their life cycles is pivotal for maintaining the long term production of commercially important species and ecosystem functioning (Cardinale et al. 2012, Chapin III et al. 2005). Biodiversity is also linked to ecosystem resilience. Theoretically, high biodiversity contributes to community resilience because it results in functional redundancy among its members, thus creating insurance towards disturbances such as biological invasions or disease outbreaks (Chapin III et al. 2005).

Cultural Services: Coastal and Marine Recreation

The ocean provides diverse benefits to people through recreation and aesthetic experiences; inspirational and spiritual enrichment opportunities, as well as educational and research development. Among these cultural services, coastal and marine recreational opportunities connect humans with ocean ecosystems. Coastal and marine tourism includes sailing, recreational boat-tours, cruises, swimming, kayaking, snorkeling, diving, surfing, and recreational fishing. The majority of recreational opportunities and activities relate to coastal and nearshore environments. However, high seas-based recreation is part of the growing tourism sector, and includes cruise tourism, sailing and even deep-sea tourism to hydrothermal vent fields (Rogers et al. 2014). Futhermore, coastal and marine tourism are interconnected; one such example is whale-watching, an activity taking place in some coastal areas but highly dependent on open-ocean ecosystems. Coastal and marine tourism is one of the fastest increasing segments of the global tourism industry (Hall 2001, Dwyer 2018, Tegar and Gurning 2018, Leposa 2020). Based on the study *"The Ocean Economy in 2030"* carried out by the Organization of Economic Cooperation and Development, the global value added by the marine and coastal tourism industry in 2010 was estimated to be US$390 billion (OECD, 2016). By 2030, marine and coastal tourism is estimated to show the largest share (26%) in the global ocean economy and to employ 8.5 million people (OECD, 2016).

Ecosystem Services in the ETP

The ETP is widely recognised for its productive tuna fisheries (e.g. Bucaram et al. 2018). In a recent study, Martin et al. (2016) applied an ES approach to identify the major ES provided by the pelagic waters of the ETP. Commercial fisheries were defined as the main provisioning service. Using IATTC observer data for 10 commercially important species from 1918 to 2011, they found that commercial fisheries caught an estimated 28,281,645 MT in the ETP, and 65% of this was captured by purse-seine fishing fleets. Yellowfin tuna was the most fished species over time, representing around 46% of the cumulative catch, followed by skipjack and bigeye tuna. In general, significant increases in annual catch and catch value (from 1975 to 2010) were identified for yellowfin, albacore, dolphinfish and swordfish while bonito was the only species with decreases in both annual catches and catch value. Overall, commercial fisheries in the ETP yield an estimated US$ 2.7 billion per year.

The upwelling processes that generate high fisheries productivity may also play a role in carbon uptake. However, carbon uptake is not the same as carbon storage, since ocean transport and circulation move the carbon captured from the atmosphere to other areas (Sabine & Tanhua, 2010). In the ETP, the captured carbon is transported from the equatorial region towards the subtropical gyres, where it is stored (Sarmiento and Orr 1992). To estimate the value of carbon storage services in the oceanic ETP, Martin et al. (2016) defined three main processes: the geophysical transport of atmospheric CO_2 into the ocean, the biological transport of carbon to the deep seabed and carbon storage in marine animal populations. For their calculations, they included only the latter two, as the first process is not directly affected by human activities in the ocean. They calculated the carbon export from the surface to the seabed and transformed the result into CO_2 trading units to estimate its potential market value. They found that the carbon storage service of the ETP is valued at US$12.9 billion per year. Additionally, the population declines of megafauna such as dolphins, which are common bycatch species, and large amounts of tuna, reduce the total amount of carbon stored in the ocean (Martin et al. 2016).

The high levels of productivity in some regions of the ETP allows this region to harbour high biodiversity and support a variety of native, endemic and migratory species. By analysing long-term survey data in the ETP, Martin et al. (2016) found that one-third of all cetacean, seabird and sea turtle species occur in the ETP and identified areas of the ETP with a high cetacean, seabird, ichthyoplankton richness and areas with a large number of sea turtle sightings. Although the authors did not calculate the potential market value of biodiversity in the ETP, assuming that one third of the world's cetacean, seabird and turtle species occur in the region, and that ecotourism in Galápagos was generated over US$418 million per year (Epler, 2007), they estimated that ecotourism alone could be valued at US$1 billion per year in the future, plus research and conservation initiatives related to marine biodiversity could also generate millions of dollars (Martin et al. 2016).

The oceanic archipelagos in the ETP: Galapagos, Cocos and Malpelo, are not only hotspots of marine biodiversity but also hotspots of marine and coastal tourism in the region. A diverse array of recreational activities, including scuba diving, snorkelling, live-aboard cruises, generate annually important economic benefits. Tourism at all three locations is wildlife-focused and marine megafauna species are considered charismatic species, which are the main tourist attractions. In the case of Galapagos, the majority of tourism value is dependent on the marine environment: as 58% of tourist expenditures in 2014, approximately US$154 million, was directly dependent on marine-based tours, activities and experiences (Lynham et al. 2015, using expenditure data from Epler, 2007). If a multiplier effect is considered throughout the economy of the islands, the economic impact rises to US$236 million per year (Lynham et al. 2015). A 2019 study in the Cocos Island National Park found that 98% of tourists go diving to observe sharks; 56% indicated that their main motivation of their visit was to enjoy marine resources, particularly sharks; and, 67% of the latter indicated that they would not visit this national park again if the marine resources declined or disappeared in the future (Moreno et al. 2021). These studies emphasize the importance of conserving healthy populations of key marine species and the whole marine environment in the region to guarantee the long-term economic benefits from marine and coastal tourism.


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Anthropogenic Activities and Pressures in the Galápagos EEZ

Human activities in the GMR (in particular fishing, tourism and scientific research) may be affected by a variety of processes operating across scales including human activity. It is also important to note, however, that certain user groups directly interact with these waters. The following section describes the different relevant stakeholder groups and then focuses on the activities and potential threats that they pose. In addition, we consider the indirect threats posed by humans through climate change and ocean plastics.

Industrial Fishing Sector

According to Ecuador's Organic Law for the Development of Aquaculture and Fisheries Article 7, Official Register 187, (Government of Ecuador, 2020), the definition of an industrial fishery encompasses those fishing activities that are carried out by vessels with mechanized, hydraulic fishing gear. The industrial fishing sector is comprised of several fleets (MAGAP 2010a) including:

1. Large pelagics (tuna) purse seine fleet
2. Large pelagics (tuna) longline or pole-and-line fleet
3. Small pelagics purse seine fleet
4. Shrimp trawl fleet
5. Whitefish purse seine
6. Demersal trap fishery

Tuna fleet

The industrial tuna fleet is comprised of those vessels pertaining to the large pelagics purse seine fleet and those pertaining to the large pelagics longline or pole-and-line fleet. According to FAO FishStatJ database (FAO 2019), Ecuador is the second-largest tuna producer in the world and the first in the Eastern Pacific Ocean. According to the Ministry of Foreign Trade of Ecuador, across the whole tuna value chain, the tuna sector provides an average of 24,000 direct employment and 120,000 indirect jobs, while women make up at least 53% of those working in tuna processing factories (Ministerio de Comercio Exterior, 2017).

The Ecuadorian industrial tuna fishing sector has a high degree of organization, leadership and entrepreneurial capacity (FAO 2019). The most relevant organizations that represent this sector are the Cámara Nacional de Pesquería (CNP), Cámara Ecuatoriana de Industriales y Procesadores Atuneros (CEIPA), Asociación de atuneros de Ecuador (ATUNEC) and the Tuna Conservation Group (TUNACONS) (see Castrejón (2020a) for further details). Access to the fishery is regulated by the Inter-American Tropical Tuna Commission (IATTC), whose Resolution C-02-03 requires vessels to be on the IATTC Regional Vessel Register to fish for tunas in the Eastern Pacific Ocean (EPO). Vessels are authorized to fish by their respective flag governments, and only duly authorized vessels are included in the register. This requirement does not apply to small artisanal vessels that also target tunas and tuna-like species in coastal waters of the EPO, whose numbers, effort, and catches are incomplete or unavailable.

In the EPO, tuna are caught mainly by purse seine and longline vessels (with some pole-and-line fishing also occurring) (IATTC 2019c). The five countries with the highest number of tuna vessels operating in the EPO include the United States, followed by Chile, China, Mexico, and Costa Rica (Table 7). The tuna fleets of these five countries represents approximately 68% of the total number of tuna vessels operating in the EPO. Ecuador occupies eighth place with 218 boats (Table 7). Of these, 53.7% are purse-seine vessels, while 45.4% are longline vessels. The remaining 0.9% corresponds to a pole and line and multi-purpose vessels. The fleet is of Asian origin, now nationalized by Ecuadorian companies. The main transshipment and landings ports are Manta and La Libertad.

Table 7 Fishing vessels with authorization to fish for tuna and tuna-like species in the IATTC Convention Area. Source: IATTC vessel database, Accessed 29 Jun 2020 https://www.iattc.org/VesselRegister/VesselList.aspx?Lang=en.

Ranking	Country	Fishing gear	Vessels	Percentage
1	United States	Harpoon, pole and line, troll, longline, recreational fishing, purse seine, gillnet, multiple-purpose	1,911	35.65
2	Chile	Harpoon, longline, gillnet, multiple-purpose	651	12.14
3	China	Longline	413	7.70
4	Mexico	Pole and line, longline, Purse seine, gillnet, Multiple-purpose	362	6.75
5	Costa Rica	Longline	308	5.75
6	Canada	Troll, multiple-purpose	257	4.79
7	Japan	Pole and line, longline	230	4.29
8	Ecuador	Pole and line, longline, Purse seine, multiple-purpose	218	4.07
9	Korea	Longline	191	3.56
10	Panama	Longline, purse seine	170	3.17

Purse seine vessels are classified into two categories and six classes, according to their carrying capacity and fish hold volume (Table 8). Over the years, there has been an increase in the number of large, Class 6 vessels in the Ecuadorian fleet (Bucaram et al. 2018). To address the problem of excess capacity in the tuna purse-seine fleet operating in the EPO, a target level of 158,000 m^3 was discussed in August 2000 for this fleet, based on the level of the stocks of tuna and other relevant factors (Arenas 2006) and included in resolution C-02-03 (IATTC 2002). However, according to the IATTC register of active purse seine vessels, the current capacity of the fleet is over 250,000 m^3 (IATTC (2021), accessed April 23rd, 2021).

Tabla 8 | Class size of purse seine, according to IATTC. Source: IATTC vessel database, accessed 29 Jun 2020. https://www.iattc.org/VesselRegister/VesselList.aspx?Lang=en.

Category	Class size	Carrying capacity (mt)	Fish hold volume (m³)
Small	1	< 46	< 54
	2	46-91	54-107
	3	92-181	108-212
Large	4	182-272	213-318
	5	273-363	319-425
	6	> 363	> 425

The main target species are the yellowfin *(Thunnus albacares)*, bigeye *(Thunnus obesus)*, and skipjack tuna *(Katsuwonus pelamis)*, which are caught within and beyond Ecuador's EEZ, including the waters surrounding the GMR. According to the Cámara Nacional de Pesquería de Ecuador, 80% of tuna production (cans and loins) is exported, mainly to European Union and United States, producing a total value of US$ 854 156.9 million in 2019 and making this industry a strategic sector for the economy of Ecuador (Ministerio de Comercio Exterior 2017; Anastacio 2020). Dolphinfish or mahi-mahi *(Coryphaena hippurus)*, locally known as "dorado", is caught incidentally by tuna purse-seine fisheries. However, this species is also targeted by Ecuador's artisanal longline fishery for large pelagics (Martínez-Ortiz et al. 2015). In this region, purse-seining for tuna use three fishing methods or set types (Bucaram et al. 2018):

- **Dolphin (DOL) sets:** the net is set around schools of tuna associated with dolphins. This fishing method is used to catch large quantities of yellowfin tuna, mostly large-size fish. Dolphin sets require a permit and 100% onboard observer coverage, and are rarely employed by the Ecuadorian fleet.

- **Floating objects (OBJ) sets:** the net is set around schools of tuna associated with logs or fish-aggregating devices (FADs) which catch mainly skipjack but also bigeye and yellowfin tuna. Most tuna caught are small-size fish. FADs are usually man-made of wood, nets or PVC.

- **Unassociated (NOA) sets (called "brisas"):** the net is set around unassociated schools of tuna, which catch skipjack, yellowfin, and bigeye tuna, mostly small and medium-sized fish.

The number of floating-object sets by both small and large purse-seine vessels has increased since 2005 (Roman et al. 2016). Nowadays, over 90% of sets on objects are on FADs rather than on natural objects. This trend is hypothesized to be correlated with a declining abundance of bigeye stocks in the EPO (Roman et al. 2016). Natural floating objects are detected by helicopters, satellites, and radar. However, in the case of FADs, these are equipped with satellite transmitters to locate them or with sonar equipment that indicates the amount of fish aggregated below the FAD. In the EPO, purse seiners usually place 100 or more FADs at a time (Morgan 2011). Sets on FADs usually take place at "night or very close to sunrise to catch the fish when they come up through the water column and to hide the purse seine from fish. In contrast, most sets on unassociated schools occur during the day" (Morgan 2011).

The industrial longline vessels are classified into two categories: deep-set longline (DSLL) ranging around 101-300 m, and shallow-set longline (SSLL) which operate at depths less than 100 m. Vessels with DSLL gear target bigeye tuna, although yellowfin and skipjack tuna may be caught as well, along with other incidentally caught species. In contrast, vessels with SSLL target swordfish, but catch a small number of tropical tunas incidentally. According to the IATTC, longline vessels less than 24 m in length are considered artisanal and, therefore, not managed with measures under IATTC tropical tuna resolutions.

The Ecuadorian purse seine fleet operates mainly in the EPO and around the Galápagos Marine Reserve. The number of purse seine vessels increased from 73 in 1999 to 117 in 2019 (Figure 100). The main homeports are Manta, Monteverde, Posorja, and Guayaquil. The Ecuadorian industrial longline vessels target yellowfin, bigeye, and skipjack tuna. The fleet is of Asian origin, now nationalized by Ecuadorian companies. According to the IATTC vessel database, there are 99 industrial longline vessels, one pole-and-line vessel and one multi-purpose vessels reported for the fleet in 2019 (IATTC 2020a). The main transshipment and landings ports are Manta and La Libertad.

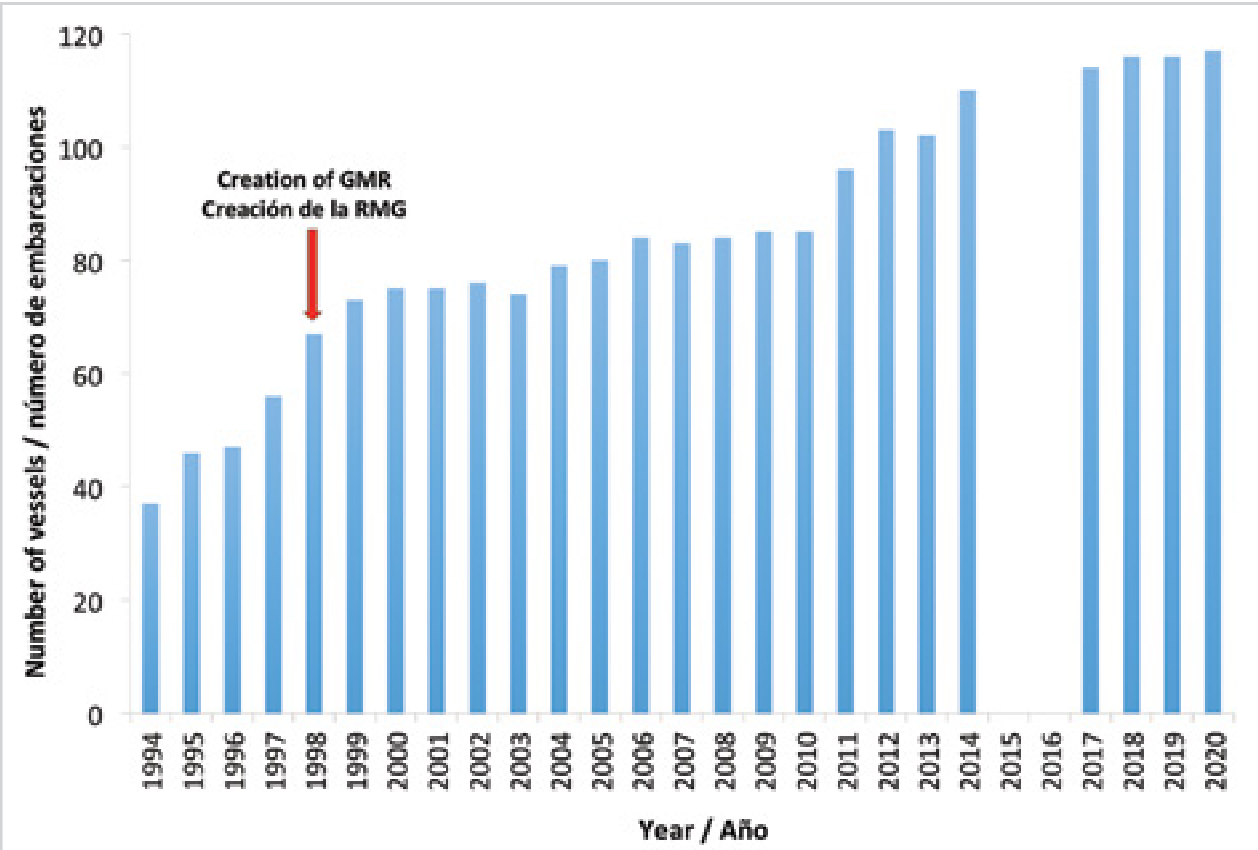

Figure 100. Number of vessels pertaining to Ecuador's tuna fleet from 1994-2020. Arrow denotes the year that the GMR was created (1998). Data for 2015 and 2016 were not available. Sources: (Bucaram et al. 2018; Cámara Nacional de Pesquería 2016; Ministerio de Comercio Exterior de Ecuador 2017).

Logbook and observer data for 2007-2010 for the purse seine fleet show how its fishing area covers over 29 million km^2, spanning from the coastal waters of mainland Ecuador to 170° E, and as far as 10° N and 20° S (Figure 101). However, there are also some clear areas where activity is concentrated, for example in the southwestern area of the Galápagos EEZ along border of the GMR and along the continental shelf off mainland Ecuador.

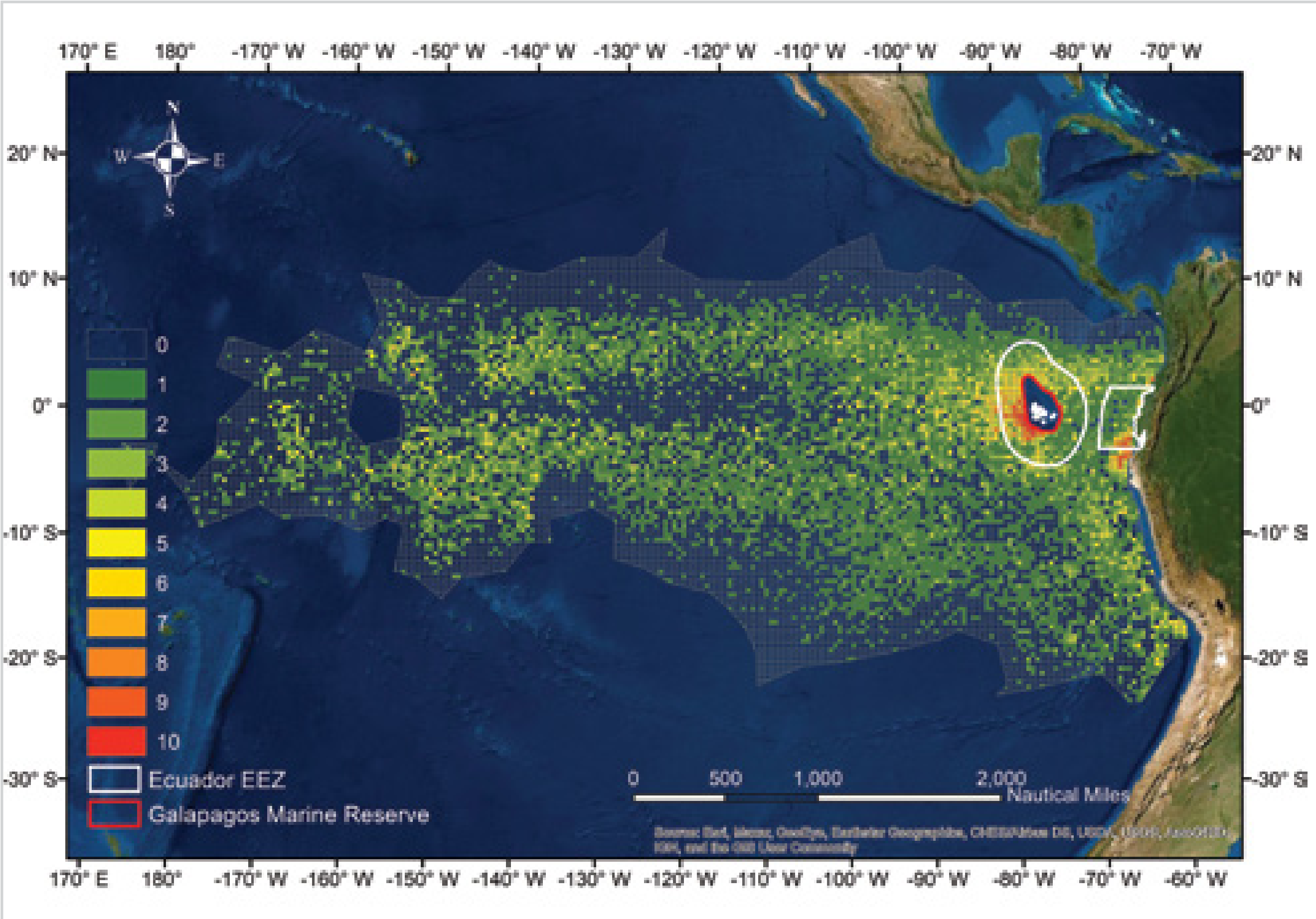

Figure 101. Area of operation of the Ecuadorian purse seine fleet 2007-2010, showing relative fishing importance (scaled from 0-10) based on the value of the catch per 25 NM pixel. Source: IATTC logbook and observer data 2007-10.

Given that the larger, Class 6 vessels are mandated to have 100% observer coverage, logbook reports are likely to be more representative of the smaller vessel sizes. By plotting sets by method (FAD vs unassociated) and by source (observer vs logbook) for the same period (2007-10), it is possible to appreciate how the smaller vessels have a much more restricted area of action (Figure 102). In addition, unassociated sets in the Galápagos EEZ are concentrated in the southwest, between the border of the GMR and that of the EEZ, while FADs extend in a band across the EEZ and (in the case of class 6 vessels), out across the Pacific. It was not possible to obtain more recent data on fishing effort and catches, or data pertaining to the industrial longline fleet.

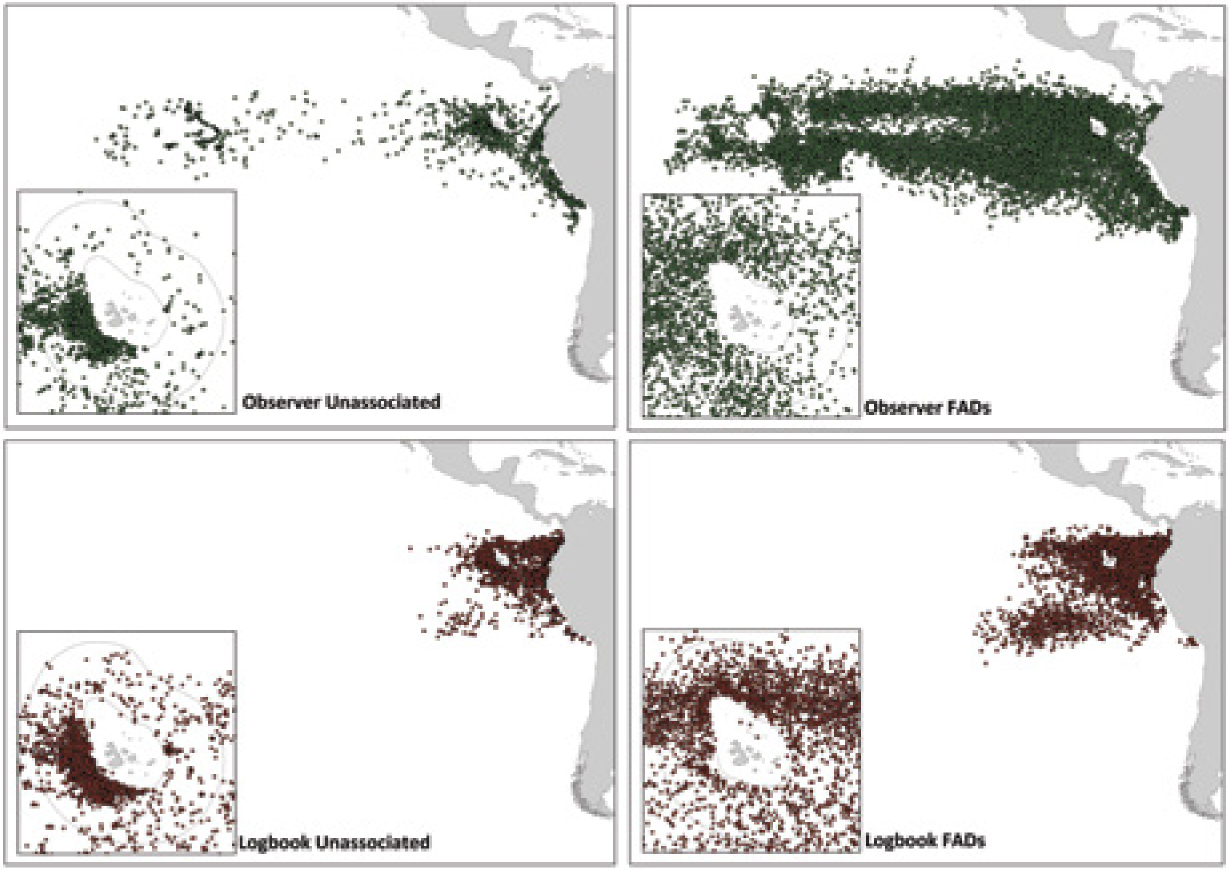

Figure 102. Fishing grounds of the tuna fleet, by method (unassociated vs FADs) and report type, used as a proxy of vessel size, assuming that observer data corresponds largely to Class 6 vessels, and logbook data to smaller vessels. Source: IATTC logbook and observer data 2007-10.

Landings

The IATTC compiles catch data for purse seine, longline, trolls, harpoons, gillnets, pole and line, and recreational fisheries. For purse seine and longline fisheries, catch data have been collected since 1931 and 1954, respectively. Catch time series for yellowfin and skipjack range from 1918 to 2018, while for bigeye tuna they range from 1954 to 2018. All Class 6 purse seine vessels have had aboard observers since 1993, who record thorough statistics on catches, both retained and abandoned at sea. Most of the catch (78% in 2018) is obtained from the purse seine fleet, while the longline fleet contributes around 17%. The three main target tuna species and the main retained bycatch species (dolphinfish) make up approximately 85% of the catch, with the remaining 15% comprised of 18 taxonomic groups, including other tuna species, sharks and billfish (IATTC 2019).

According to the FAO FishStatJ database (FAO 2019), worldwide production of yellowfin, bigeye, and skipjack tuna was approximately 4,777,437 MT in 2017 (Table 9). The top five tuna producers are Indonesia (15.0%), Ecuador (6.8%), Papua New Guinea (6.4%), Japan (6.2%), and Korea (6.1%).

Table 9 | Worldwide production (in metric tons) of yellowfin, bigeye, and skipjack tuna in 2017. Source: FAO FishStatJ database (FAO 2019).

Ranking	Country	Bigeye	Skipjack	Yellowfin	Total	%
1	Indonesia	106,143	451,109	161,176	718,428	15.0
2	Ecuador	66,520	199,810	56,904	323,234	6.8
3	Papua New Guinea	6,865	189,288	107,626	303,779	6.4
4	Japan	37,871	197,020	59,195	294,086	6.2
5	Korea	20,841	204,122	66,513	291,476	6.1
6	Spain	33,296	161,790	69,082	264,168	5.5
7	Taiwan Province of China	44,160	131,616	69,393	245,169	5.1
8	United States of America	11,820	159,648	34,409	205,877	4.3
9	Philippines	5,126	111,086	83,873	200,085	4.2
10	Kiribati	7,439	120,365	29,395	157,199	3.3
	Rest of the world	132,853	901,908	739,175	1,773,936	37.1
	Total	472,934	2,827,762	1,476,741	4,777,437	100.0

During 2014-2018 the total annual landings (retained catch) of mahi-mahi, skipjack, yellowfin, and bigeye tuna averaged 674,526 t in the EPO. The total landings of these three species have increased steadily since 1918, reaching a maximum historic peak of 807,105 t in 2003 (Figure 104). Since then, tuna production has decreased, reaching a value of 655,557 t in 2018.

Yellowfin tuna landings reached a maximum historic peak of 439,319 t in 2002 (Figure 103). Since then, the yellowfin tuna production has decreased, reaching a value of 251,054 t in 2018. The skipjack tuna landings reached a maximum peak of 338,493 t in 2016, declining to 289,066 t in 2018. Bigeye tuna landings increased steadily from 1954 until reaching a maximum historic peak of 143,141 t in 2000. Since then, bigeye tuna landings have decreased by 34.3% until reaching a value of 93,990 t in 2018. Finally, dolphinfish landings increased steadily from 1971 until reaching a maximum historic peak of 70,386 t in 2010. Since then, landings have decreased by 69.5%, equivalent to 21,447 t in 2018.


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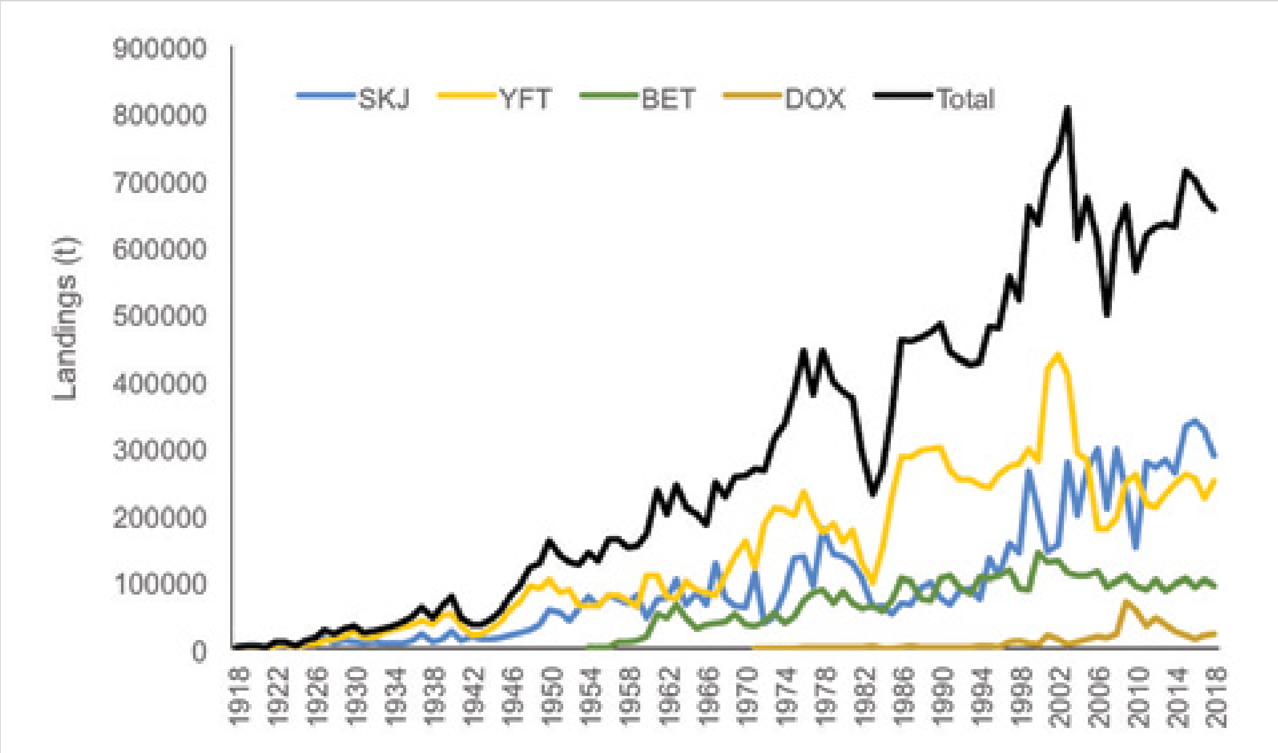


Figure 103. Total annual landings of skipjack, yellowfin and bigeye tuna and mahi-mahi in the EPO from 1918 to 2018. Source: IATTC public domain datafiles, https://www.iattc.org/PublicDomainData/IATTC-Catch-by-species1.htm. Accessed 29 Jun 2020.

The spatial distribution of Ecuadorian tuna catches from 2000 to 2019 is described by Pacheco (2020). Based on logbook data collected by the National Fisheries Institute of Ecuador (INP) and IATTC's observers onboard data, Pacheco (2020) estimated that approximately 86.2% of tuna catches reported by the Ecuadorian purse seine fleet in 2019 were caught in areas beyond national jurisdiction (ABNJ), while 11.6% and 2.2% were caught outside the Galápagos Marine Reserve (GMR) boundary in the Galápagos EEZ and within Ecuador's mainland EEZ, respectively (Table 9).

Catches in ABNJ increased steadily since 2006, reaching a maximum historic peak of 215,834 t in 2019 (Table 8, Figure 104). In contrast, the contribution of the GMR to the Ecuadorian tuna catches reported by the purse seine fleet has been quite variable. A maximum historic peak of 62,984 t was reached in 2008, ten years after the creation of the GMR in March 1998. In 2008, the contribution of the GMR to tuna catches was 27.9%, declining to a minimum historic of 9% in 2016 with 25,816 t (Table 8, Figure 104). Finally, the contribution of Ecuador's mainland EEZ to tuna catches has decreased steadily from a maximum historic value of 37,397 t in 2006, equivalent to 19.2% of total tuna catches, to 6,910 t in 2019, equivalent to 2.2% of total tuna catches (Table 10, Figure 104).

Table 10 Annual tuna catches, in metric tons, caught by the Ecuadorian purse seine fleet from 2000 to 2019. EEZ: Economic Exclusive Zone; GMR: Galápagos Marine Reserve; ABNJ: Areas beyond national jurisdiction. Source: Pacheco (2020).

Year	Mainland EEZ	%	Galápagos EEZ	%	ABNJ	%	Total
2000	18,380	11.3	43,359	26.7	100,449	61.9	162,188
2001	5,586	4.0	15,907	11.3	118,727	84.7	140,220
2002	10,833	8.4	15,295	11.9	102,404	79.7	128,532
2003	35,121	19.9	26,395	15.0	114,585	65.1	176,101
2004	18,335	13.1	23,261	16.7	98,032	70.2	139,628
2005	16,316	10.4	24,491	15.6	115,812	73.9	156,619
2006	37,397	19.2	48,704	25.0	109,019	55.9	195,120
2007	3,843	2.6	19,105	13.0	123,814	84.4	146,762
2008	12,688	5.6	62,984	27.9	149,686	66.4	225,358
2009	6,238	3.3	41,755	22.1	141,123	74.6	189,116
2010	4,684	2.9	15,682	9.8	140,262	87.3	160,628
2011	7,069	2.9	44,924	18.7	187,639	78.3	239,632
2012	7,373	3.0	41,880	16.9	199,185	80.2	248,438
2013	7,582	3.0	39,783	15.7	206,378	81.3	253,743
2014	7,513	2.8	46,755	17.3	215,834	79.9	270,102
2015	12,808	4.1	53,654	17.3	243,474	78.6	309,936
2016	7,900	2.8	25,816	9.0	253,229	88.3	286,945
2017	6,923	2.3	46,874	15.8	243,021	81.9	296,818
2018	8,259	2.9	69,711	24.3	209,073	72.8	287,043
2019	6,910	2.2	36,002	11.5	268,907	86.2	311,819

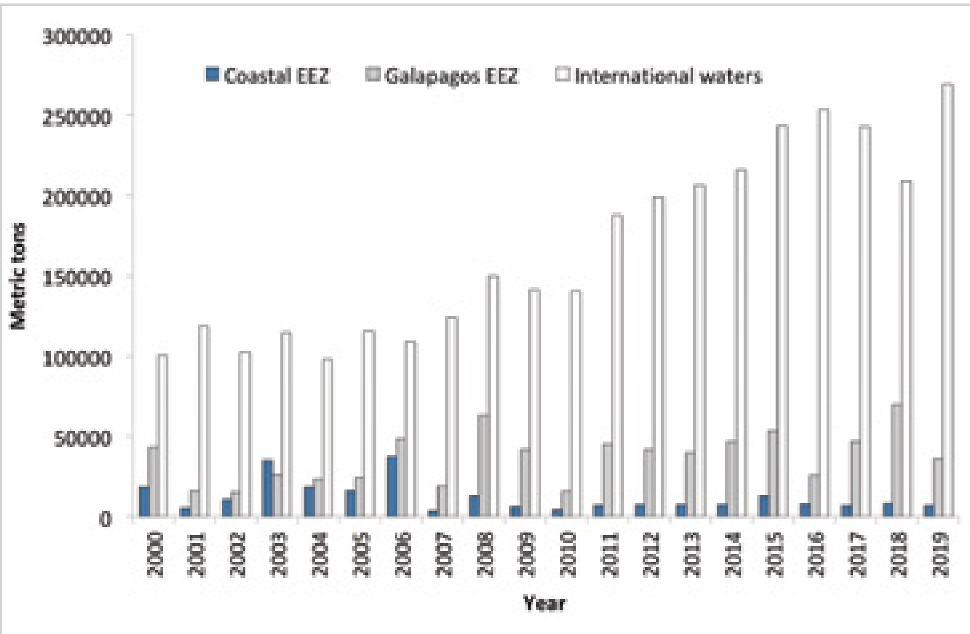
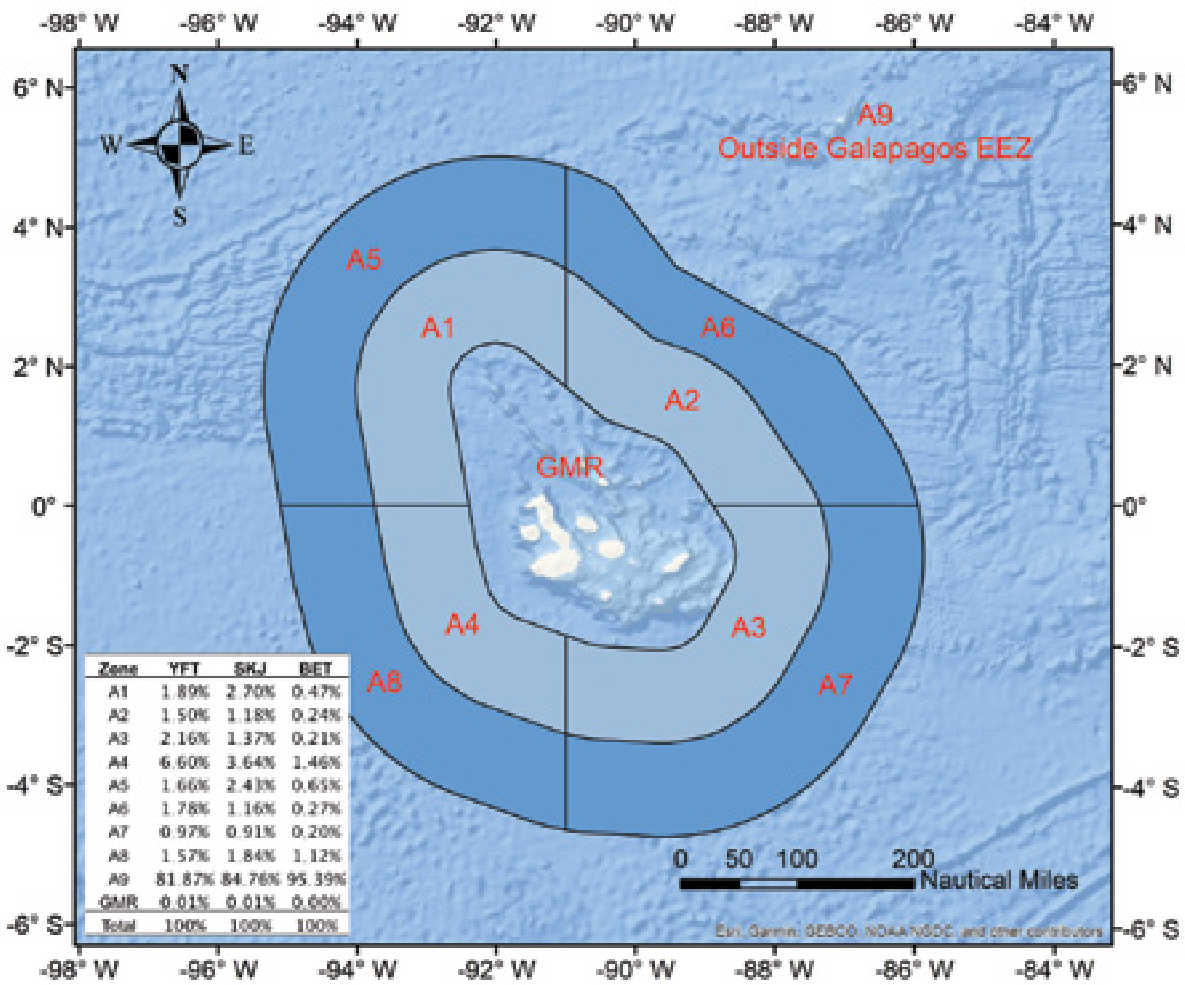


Figure 104. Annual tuna catches, in metric tons, caught by the Ecuadorian purse seine fleet from 2000 to 2019. EEZ: Economic Exclusive Zone; GMR: Galápagos Marine Reserve; ABNJ: Areas beyond national jurisdiction. Source: Pacheco(2020).

These data coincide broadly with coarse-scale catch data published by the IATTC, which suggests that 18% of yellowfin tuna, 15% of skipjack tuna and 5% of bigeye tuna are caught within the Galápagos EEZ, and much of this is concentrated in the southwestern portion (sections A4 and A8 in Figure 105).



Zone	YFT	SKJ	BET
A1	1.89%	2.70%	0.47%
A2	1.50%	1.18%	0.24%
A3	2.16%	1.37%	0.21%
A4	6.60%	3.64%	1.46%
A5	1.66%	2.41%	0.65%
A6	1.78%	1.16%	0.27%
A7	0.97%	0.91%	0.20%
A8	1.57%	1.84%	1.12%
A9	81.87%	84.76%	95.39%
GMR	0.01%	0.01%	0.00%
Total	100%	100%	100%

Figure 105. Percentage of purse seine landings of the three main tuna resources from different portions of the Galápagos EEZ, 2014-19. Source: IATTC public database, accessed June 18th 2020.

Stock Status

Yellowfin tuna are managed and assessed as a single stock throughout the region. The most recent stock assessment conducted in 2018 (Minte-Vera et al. 2019), determined that the spawning biomass (S) and the biomass of fish aged 3 quarters and older (B) were estimated to be below the maximum sustainable yield (MSY) (Srecent/S_{MSY}=0.76; Brecent/B_{MSY}=0.84), indicating that the stock may be overfished (Figure 106). However, it also found an increase in the average size of the fish, so there is a fair level of uncertainty around these results.

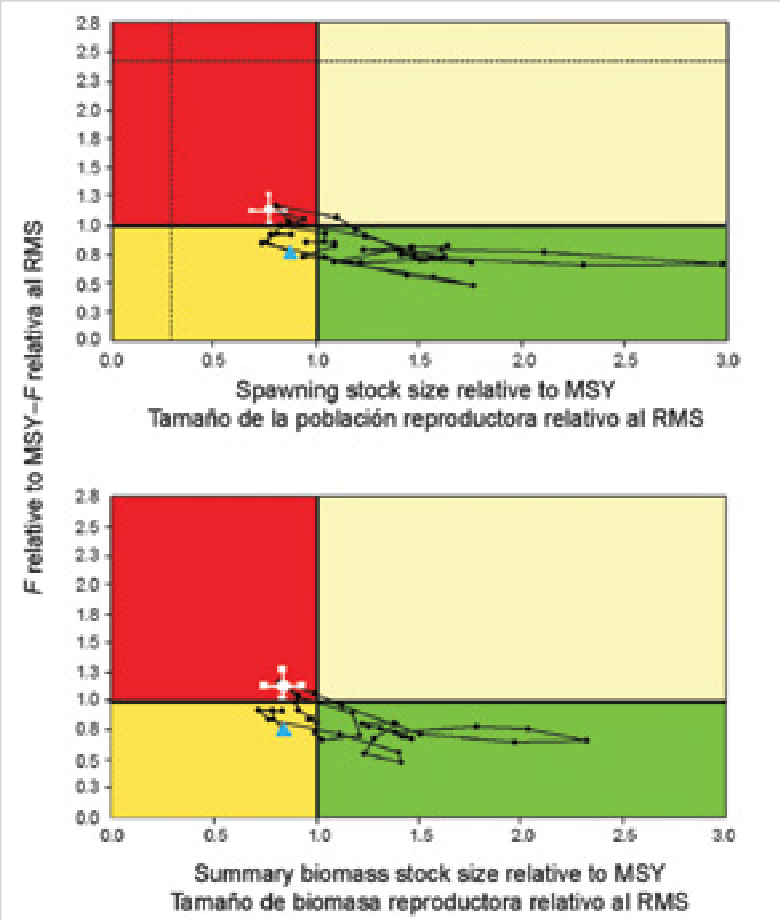


Figure 106. Kobe (phase) plot of the time series of estimates of yellowfin tuna stock size (left: spawning biomass; right: total biomass of fish aged 3 quarters and older) and fishing mortality relative to their MSY reference points. Panel colors represent the level of risk to the stock: red (overfished and overfishing phase), beige (overfishing is occurring), yellow (stock is overfished), green (no risk). The panels represent target reference points (S_{MSY} and F_{MSY}). The dashed lines represent the interim limit reference points of 0.28*S_{MSY} and 2.42*F_{MSY}, which correspond to a 50% reduction in recruitment from its average unexploited level based on a conservative steepness value (h = 0.75) for the Beverton-Holt stock-recruitment relationship. Each dot is based on the average exploitation rate over three years; the large white dot indicates the most recent estimate. The squares around the most recent estimate represent its approximate 95% confidence interval. The triangle represents the first 3-year period (1975-1977). Source: Minte-Vera et al. (2019).

The average annual fishing mortality (F) has been increasing for all age classes since 2009 (Minte-Vera et al. 2019). However, the highest F has been on fish aged 11-20 quarters (2.75-5 years). In contrast to the previous assessment, which estimated recent fishing mortality rates around the level corresponding to MSY, the ratio F_{recent}/F_{MSY} is estimated to be 1.12, indicating that overfishing is occurring (Minte-Vera et al. 2019).

Historically, dolphin-associated and unassociated purse-seine fisheries generate the greatest impact on the spawning biomass of yellowfin tuna. However, the impact of the floating-object fisheries has increased and exceeded that of unassociated fisheries and dolphin-associated fisheries (Minte-Vera et al. 2019). This recent trend could negatively impact fishing mortality of juvenile fish.

The increasing number of sets in the floating object fishery suggests that the yellowfin stock in the EPO may be under increasing fishing pressure and that measures additional to the current seasonal closures, such as limits on the number of floating-object sets, are required.

MSY is estimated to be 255,000 t (Minte-Vera et al. 2019). According to Minte-Vera et al. (2019), the MSY calculations indicate that theoretically at least, catches could be increased if the fishing effort were directed toward longlining and purse-seine sets on yellowfin associated with dolphins. This would also increase SBR_{MSY}.

However, as noted in previous full assessments, these interpretations are uncertain and highly sensitive to the assumptions made. These results are "more pessimistic if a stock-recruitment relationship is assumed, if a higher value is assumed for the average size of the older fish, and if lower rates of natural mortality are assumed for adult yellowfin" (Minte-Vera et al. 2019). Alternatively, a more recent risk assessment (Figure 107), based on a suite of 48 reference models, carried out found only a 9% probability that the fishing mortality corresponding to the maximum sustainable yield (FMSY) had been exceeded, and only a 12% probability that the spawning stock biomass corresponding to the maximum sustainable yield (SMSY) had been breached, with a zero probability that the limit reference points for F and S had been exceeded (Aires-da-Silva et al. 2020). The authors of this more recent document conclude that the yellowfin tuna stock in the EPO is healthy.

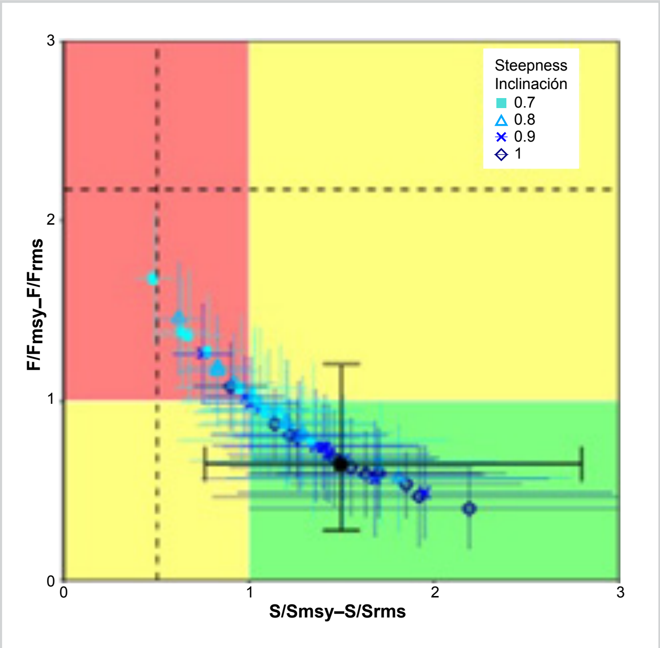


Figure 107. Kobe (phase) plot of the time series of estimates of spawning stock size (S) and fishing mortality (F) of yellowfin tuna relative to their MSY reference points. Panel colors represent the level of risk to the stock: red (overfished and overfishing phase), yellow (intermediate phases: either stock is overfished or overfishing is occurring), green (no risk). The colored panels are separated by the target reference points (S_{MSY} and F_{MSY}). Limit reference points (dashed lines), which correspond to a 50% reduction in recruitment from its average unexploited level, based on conservative steepness (h) of 0.75 for the Beverton-Holt stock-recruitment relationship, are merely indicative, since they vary by model and are based on all models combined. The center point for each model indicates the current stock status, based on the average fishing mortality over the last three years. The solid black circle represents all models combined. The lines around each estimate represent approximate 95% confidence intervals. Source: Aires-da-Silva et al (2020).

For bigeye tuna, there appears to be more uncertainty as to the stock status. The most recent IATTC assessment of bigeye tuna in the EPO conducted in 2018 (Xu et al. 2018), determined that the current ratio of spawning biomass $SSB_{current}/SSB_{MSY}$ is estimated at 1.02, which indicates that the stock is not overfished (Figure 108). However, the ratio of $F_{current}$/FMSY is estimated at 1.15, indicating that overfishing is occurring (Figure 108).

The IATTC estimated the MSY of bigeye to be 95 000 t (Xu et al. 2018). This MSY was reduced to about half its level in 1993, due to the expansion of the floating-object fishery, including FADs that did not differentiate between juvenile and adult tuna. Since bigeye tuna can grow close to 200 cm, catching them when they are small results in a loss of potential yield (ISSF 2019). Therefore, reducing the catch of juvenile bigeye tuna will increase the MSY (Xu et al. 2018).

Several uncertainties have been identified in the updated assessment of bigeye tuna conducted in 2018 due to the high levels of uncertainty in the assessment model's assumptions, the reliability of the recent longline data, and other issues that need to be improved in the assessment (Xu et al. 2018). Additional to this uncertainty, there are concerns regarding the increasing fishing capacity of the purse seine fishery fleet in the EPO, as does the number of purse seine sets on floating objects (ISSF 2019).

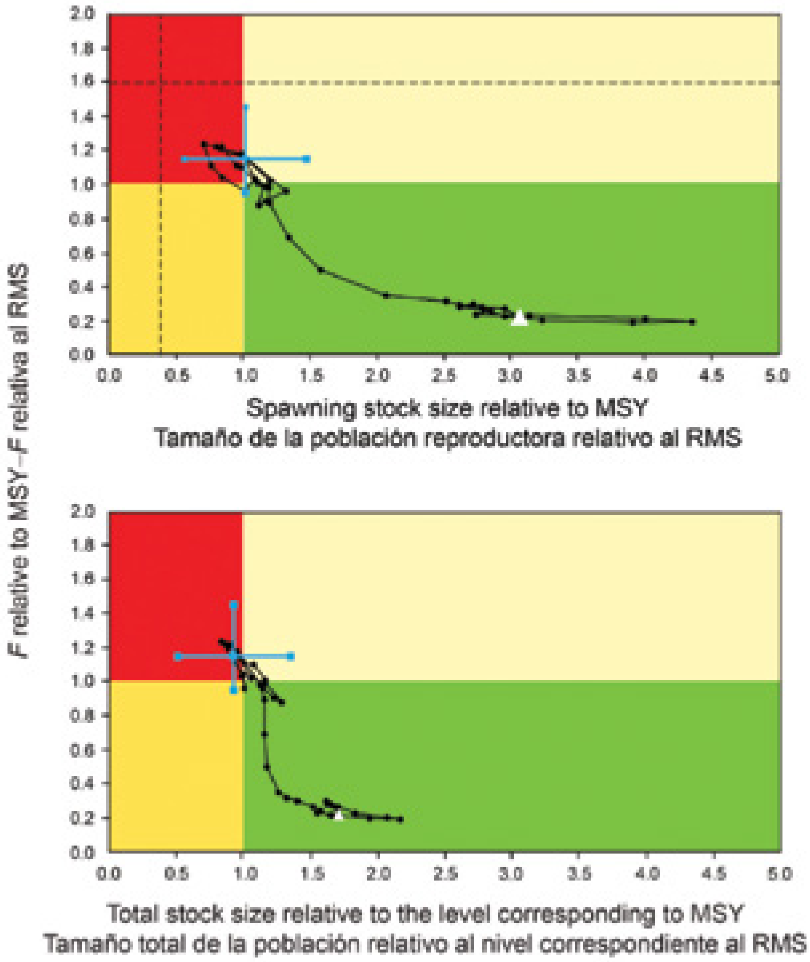


Figure 108. Kobe (phase) plot for bigeye tuna of the time series of estimates of spawning stock size (top panel: spawning biomass; bottom panel: total biomass aged 3+ quarters) and fishing mortality relative to their MSY reference points. Panel colors represent the level of risk to the stock: red (overfished and overfishing phase), beige (overfishing is occurring), yellow (stock is overfished), green (no risk). The colored panels represent target reference points (S_{MSY} and F_{MSY}; solid lines) and limit reference points (dashed lines) of 0.38 SMSY and 1.6 F_{MSY}, which correspond to a 50% reduction in recruitment from its average unexploited level based on a conservative steepness value (h = 0.75) for the Beverton-Holt stock-recruitment relationship. Each dot is based on the average fishing mortality rate over three years; the large dot indicates the most recent estimate. The squares around the most recent estimate represent its approximate 95% confidence interval. The triangle represents the first estimate (1975). Source: Xu et al. (2018).

A risk analysis similar to the one outlined above for yellowfin tuna, on 44 models, found a combined, overall probability of exceeding F_{MSY} to be around 50%, although the probability of exceeding the limit reference point for fishing mortality was extremely low (Aires-da-Silva et al. 2020). Similarly, in terms of the spawning stock biomass, the probability of being below that corresponding to MSY was 53%, although the probability of being below the limit reference point was only 6% (Figure 109).

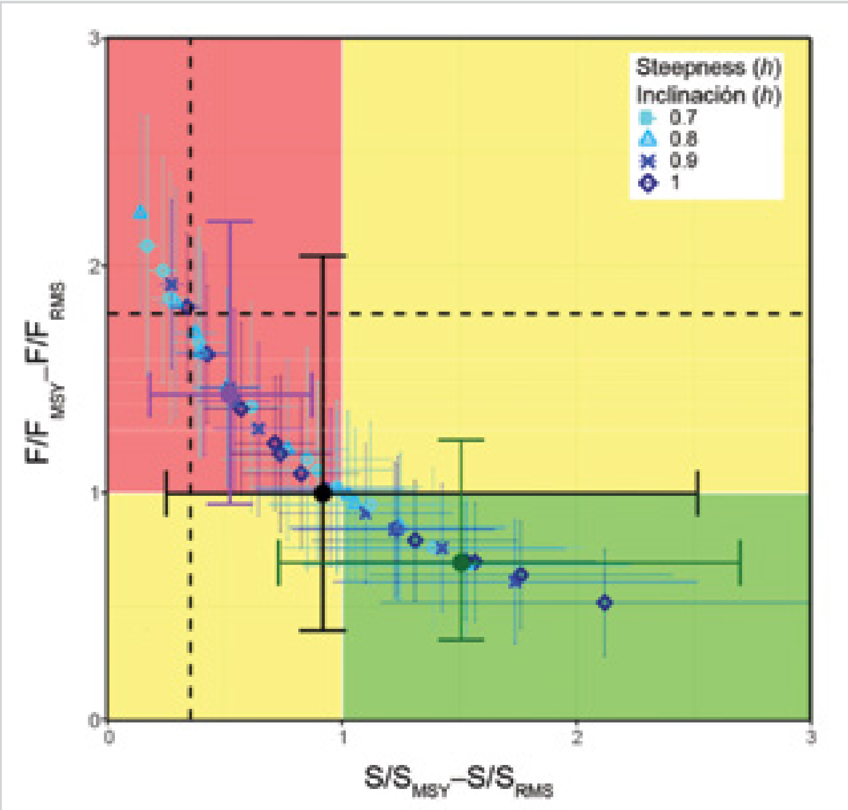


Figure 109. Kobe (phase) plot of the time series of estimates of spawning stock size (S) and fishing mortality (F) of bigeye tuna relative to their MSY reference points. Panel colors represent the level of risk to the stock: red (overfished and overfishing phase), yellow (intermediate phases: either stock is overfished or overfishing is occurring), green (no risk). The colored panels are separated by the target reference points (S_{MSY} and F_{MSY}). Limit reference points (dashed lines), which correspond to a 50% reduction in recruitment from its average unexploited level, based on conservative steepness (h) of 0.75 for the Beverton-Holt stock-recruitment relationship, are merely indicative, since they vary by model and are based on all models combined. The center point for each model indicates the current stock status, based on the average fishing mortality (F) over the last three years. The solid black circle represents all models combined. The lines around each estimate represent approximate 95% confidence intervals (Source: Aires-da-Silva et al. (2020)).

The stock status of skipjack in the region is uncertain. The last assessment for skipjack tuna was conducted in 2012, and was based on four alternative types of analyses (ISSF 2019). However, it has not been possible to detect the effect of fishing on the skipjack tuna stock with standard fisheries data and stock assessment methods due to its high and variable productivity, the lack of age-composition data, and especially tagging data, and the uncertainty as to whether the catch per unit of effort (CPUE) of the purse-seine fisheries is an appropriate index of abundance for skipjack, particularly when the fish are associated with FADs (Maunder 2019). Therefore, it has not been possible to estimate either the biomass or fishing mortality-based reference points nor the indicators to which they are compared, for skipjack in the EPO (Maunder 2019). In this case, there are also concerns over the substantial increase in the number of sets on floating objects in recent years (ISSF 2019).

In 2016, an exploratory stock assessment of mahi-mahi in the southeastern Pacific Ocean was conducted by Aires-da-Silva et al. (2016), which is the "core region" of the mahi-mahi stock in the EPO. The assessment was implemented in the Stock Synthesis (SS) modeling platform with a monthly time step from July 2007 to June 2015. The SS model was fitted to sex-combined length-composition data from Peru artisanal fisheries and purse-seine bycatch and sex-specific length-composition data and CPUE from artisanal fisheries from Ecuador. The monthly time step allows depletion caused by catch and measured by the CPUE to inform estimates of absolute abundance. This assessment synthesized knowledge about the population dynamics of mahi-mahi and its history of exploitation in the EPO. However, Aires-da-Silva et al. (2016) were unable to conclude stock status, because no reference points, target or limit, have been defined for mahi-mahi in the EPO. Nevertheless, preliminary results showed that "recent mahi-mahi catches were near the estimates of maximum sustainable yield (MSY) from the stock assessment and that the yield per recruit (YPR) curve was very flat, with the fishing mortality required to achieve MSY poorly defined" (Minte-Vera et al. 2019).

The sustainability of tuna and tuna-like fisheries in the EPO is threatened by an increasing number of anthropogenic and climate change drivers, including signs of overfishing, El Niño–Southern Oscillation (ENSO), and long-term and large-scale changes in sea conditions generated by climate change (Bertrand et al. 2020; FAO 2020). On the other hand, climate change is expected to disrupt the spatial distribution of yellowfin, bonito *(Sarda chiliensis)*, and mahi-mahi in the Eastern Tropical Pacific. According to Bertrand et al. (2020), the stocks of these three species will move into the coastal waters from northern Chile to northern Peru–south Ecuador. Shifts in the migratory patterns of tuna and mahi-mahi will have an impact on the economy and food security of Ecuador. However, the nature and magnitude of these socioeconomic impacts are uncertain due to a lack of long-term studies about the impact of climate variability and change on these two migratory species within the EEZ of Ecuador.

Bycatch

To adopt an ecosystem approach to fisheries (EAF) in its management decision, the IATTC evaluates the impact of tuna fisheries in the EPO on non-target species (bycatch and discards) and marine ecosystems. Even though there is relatively good information for catches of tuna and billfishes across the entire tuna fishery, this is not the case for bycatch species (Griffiths and Fuller 2019). Comprehensive information exists for large purse-seine vessels, which carry on-board observers. However, "detailed information on retained and discarded bycatch by the smaller purse-seine fleet and much of the longline fleet is limited, while virtually no information exists on bycatches and discards by fishing vessels that use other gear types (e.g., gillnet, harpoon, and recreational gear)" (Griffiths and Fuller 2019).

Several species of sharks, marine turtles, marine mammals, sea birds and large fishes are caught as bycatch or targeted catch in EPO tuna longline and purse–seine fisheries as well as multi–species and multi–gear artisanal fisheries. Among the seabirds, in this region, the Critically Endangered waved albatross was found to be particularly vulnerable to Ecuadorian and Peruvian longline fishing vessels (Jiménez-Uzcátegui et al 2006). Seabirds appear not to be particularly vulnerable to entanglement with purse seine gear (Gilman et al. 2011, Baker and Hamilton 2016).

The most common species of shark and rays caught in the purse-seine fishery are silky sharks *(Carcharhinus falciformis)*, oceanic whitetip shark *(C. longimanus)*, hammerhead sharks *(Sphyrna spp.)*, thresher sharks *(Alopias spp.)*, mako sharks *(Isurus spp.)*, blue sharks *(Prionace glauca)*, manta rays (Mobulidae) and pelagic stingrays (Dasyatidae) (Table 11). Most sharks are caught in sets on floating objects (mainly silky and hammerhead sharks) followed by unassociated sets and, at a much lower level, dolphin sets (Table 11). In contrast, the bycatch rates of manta rays and stingrays occur mostly in unassociated sets, followed by dolphin sets and floating-object sets, although catches by set type can be variable (Griffiths and Fuller 2019). Until 2007, thresher sharks occurred mostly in unassociated sets, while oceanic white-tip sharks were commonly caught in sets on floating objects. However, this species became much less common after 2005. Here is important to note that Resolution C-11-10, which entered into force in January 2012, prohibits the retention of oceanic whitetip sharks. Since then, catch data for this species corresponds to bycatch and discards.

Table 11 Preliminary catches, in tons, of sharks and rays in the EPO by large purse seine vessels, by set type, 2018, and by longline vessels, 2017. *Longline sample data should be considered minimum catch estimates due to incomplete data reporting. Source: Griffiths and Fuller (2019).

Species	Purse seine				Longline*
	OBJ	NOA	DEL	Total	
Blue sharks	-	-	-	-	6,908
Silky shark	400	11	20	431	2,626
Mako sharks	1	<1	<1	2	1,606
Other sharks	31	4	1	36	1,430
Thresher sharks	<1	4	2	7	724
Oceanic whitetip shark	3	-	<1	3	202
Hammerhead shark	24	<1	<1	26	186
Manta rays	16	20	13	49	-
Pelagic Stingrays	<1	<1	<1	1	-

Blue and mako shark catches increased remarkably after 2008 (Figure 110). Catches of blue shark reached a maximum peak in 2013 with more than 10,000 t, while catches of mako shark peaked in 2014 at about 2,500 t (Figure 110). Silky shark catches peaked at about 4,200 t in 2013. Catches of oceanic whitetip shark reached nearly 300 t in 2009 (Figure 110), then decreased because its capture has been prohibited since 2012 under Resolution C-11-10. These estimations must be taken with caution because due to limitations in data reporting requirements for non-target species caught in the longline fishery (Griffiths and Fuller 2019).

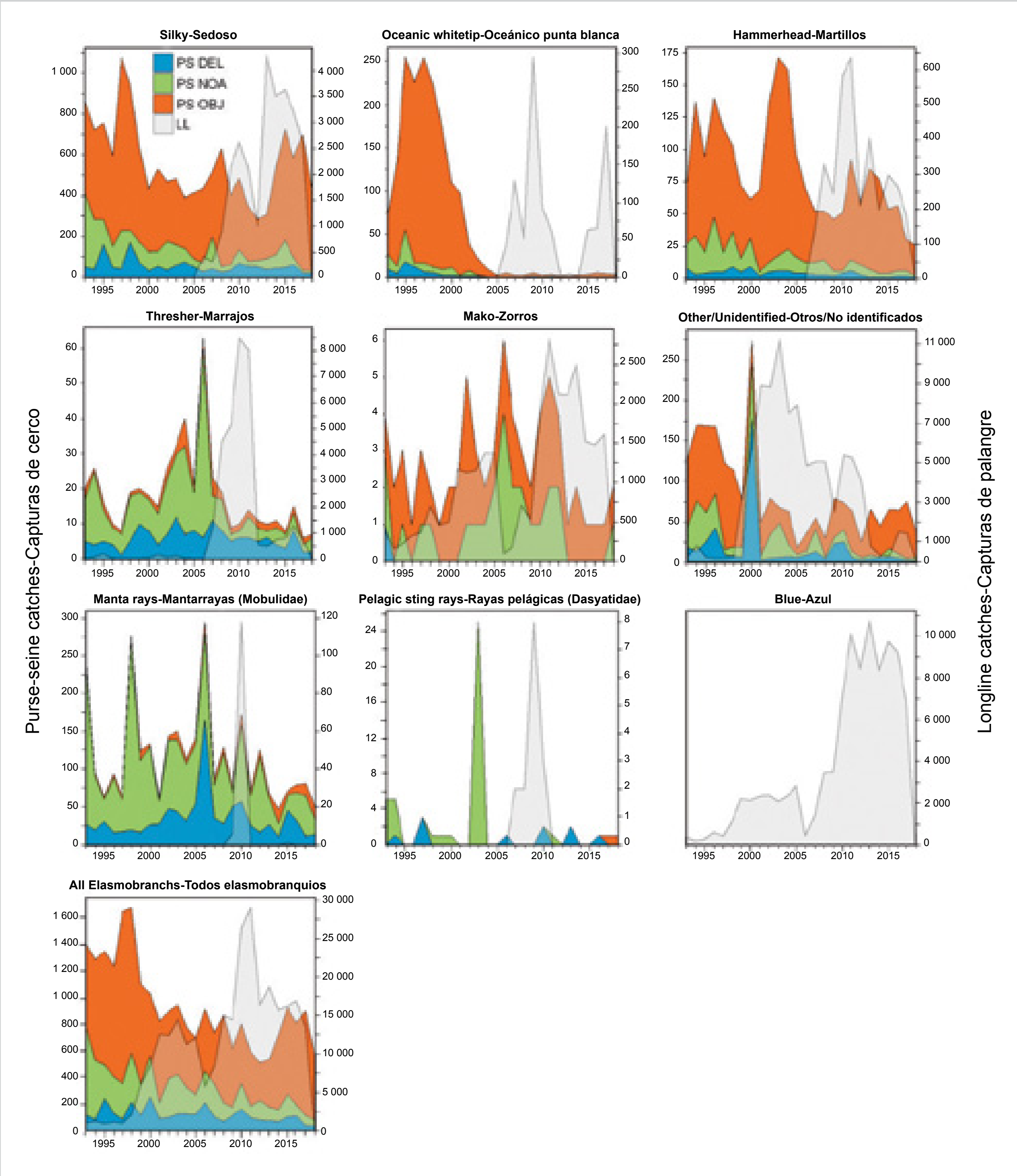


Figure 110. Retained and discarded catches of sharks and rays, in tons, reported by observers aboard large purse-seine vessels in the EPO between 1993 and 2018, by set type (left y-axis). DEL: dolphin set; NOA: unassociated set; OBJ: floating object set. Longline data (right y-axis) are considered to be minimum catch estimates. Data for the past two years should be considered preliminary; longline data for 2018 not currently available. Source: Griffiths and Fuller (2019).

The incidental mortality of marine mammals by purse seines, especially of spotted dolphins *(Stenella attenuata)*, spinner dolphins *(S. longirostris)*, and common dolphins *(Delphinus delphis)* has decreased remarkably since the 1990s (Figure 111). The incidental mortality of dolphins and other marine mammals caused by the purse seine fishery in the EPO was about 819 individuals, equivalent to 47.5 t, in 2018 (Figure 111). Other marine mammals include Central American spinner dolphin *(Stenella longirostris centroamericana)*, bottlenose dolphin *(Tursiops truncatus)* and unidentified dolphins. No information is reported by IATTC about the incidental catch of marine mammals by longline fisheries.

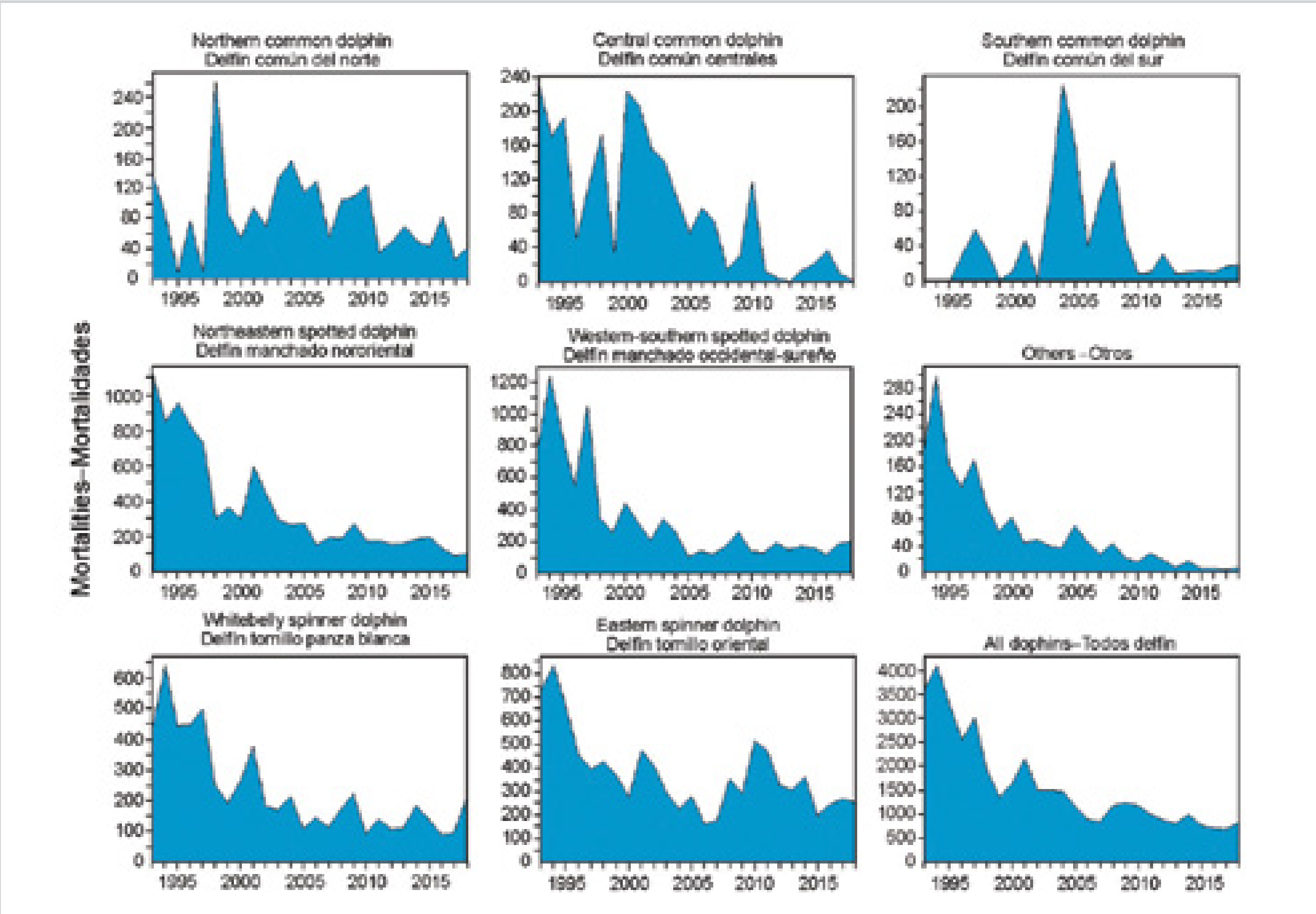


Figure 111. Incidental dolphin mortalities, in numbers of animals by purse-seine vessels, in the EPO between 1993 and 2018. Source: Griffiths and Fuller (2019).

Sea turtles are caught incidentally by longline and purse-seine vessels. There are few estimates of incidental mortality of sea turtles due to industrial and artisanal longlines. According to Griffiths and Fuller (2019), the mortality rates of sea turtles in the EPO by the industrial longline fishery are likely to be lowest in "deep" sets (around 200-300 m) targeting bigeye tuna, and highest in "shallow" sets (<150 m) for albacore and swordfish.

In the EPO, sea turtles are caught by purse seines usually in sets on floating objects, or in sets on unassociated tunas or tunas associated with dolphins. Sea turtles sometimes "become entangled in the webbing under fish-aggregating devices (FADs) and drown, or they are entangled by the fishing gear and may be injured or killed" (Griffiths and Fuller 2019).

The most common species of sea turtles caught by purse seines are the olive ridley turtle *(Lepidochelys olivacea)*, followed by green sea turtles *(Chelonia mydas)* and, very occasionally, by loggerhead *(Caretta caretta)* and hawksbill *(Eretmochelys imbricata)* turtles (Figure 112).

The mortality of olive ridley turtles is higher in sets on dolphins, while interactions are higher in sets on floating objects. The mortality of all species of turtles by purse seines has decreased remarkably since 2002, as have the frequency of interactions (Figure 112). No information is provided by IATTC regarding sea turtle interactions or mortality by industrial and artisanal longlines. However, these estimations are expected to be available in future due to improvements in data reporting (Griffiths and Fuller 2019).

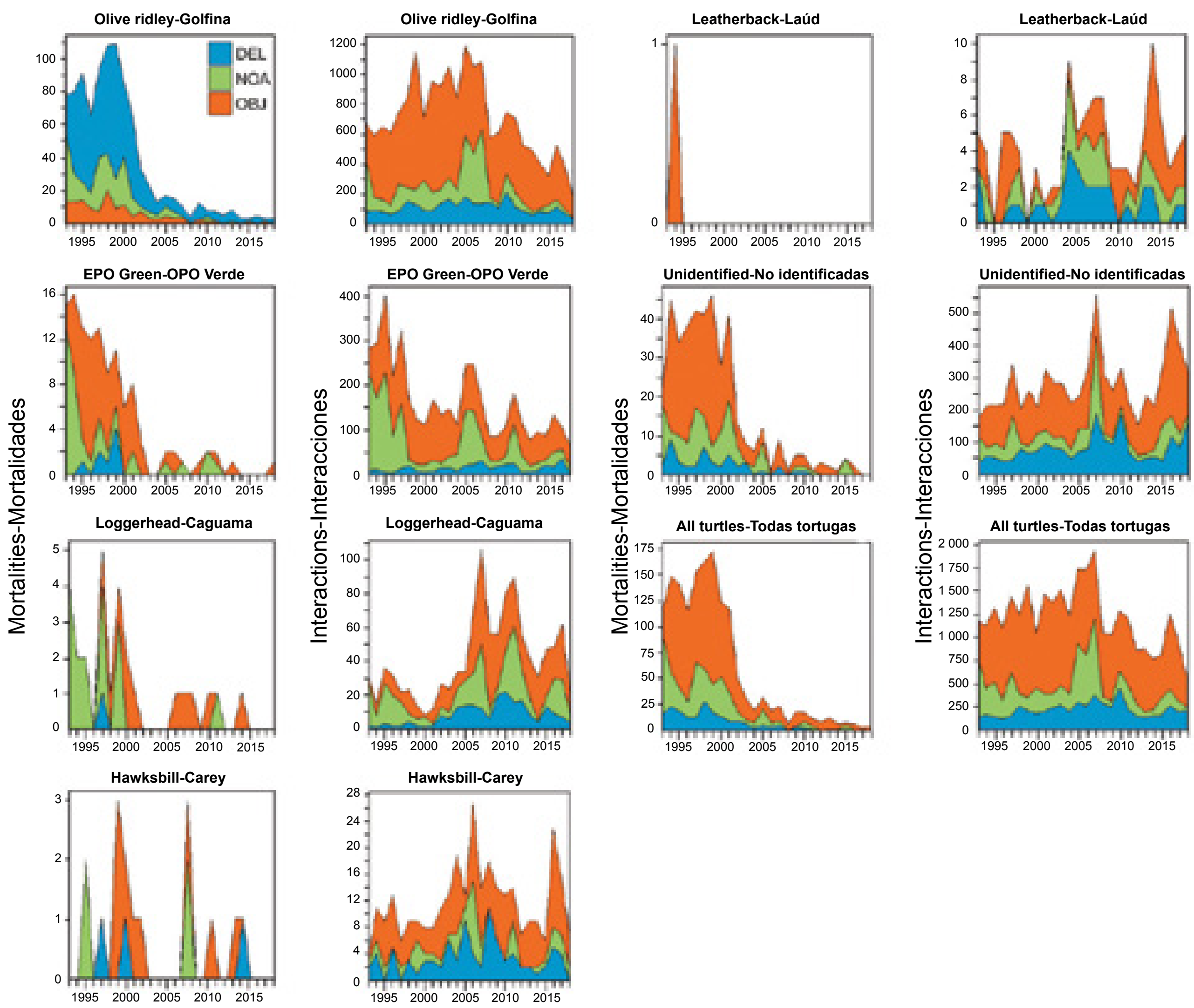


Figure 112. Sea turtle interactions and mortalities, in numbers of animals, for large purse-seine vessels in the EPO between 1993 and 2018, by set type. DEL: dolphin set; NOA: unassociated set; OBJ: floating object set. Source: Griffiths and Fuller (2019).

Risks Posed by Fish Aggregation Devices

The use of Fish Aggregation Devices (FADs) in the region has increased dramatically from less than 2,000 deployments at the turn of the century to almost 15,000 deployments in 2015 (Hall and Román 2016). This has raised concerns about the potential to overfish stocks of yellowfin and bigeye tuna, given that they target small individuals (e.g. (Bucaram et al. 2018; Griffiths et al. 2019) and about their levels of bycatch, in particular silky sharks and to a lesser extent two species of hammerhead shark (Hall and Román 2016). FADs attract and aggregate commercially important fish species such as tuna as well as protected species like silky sharks. In general, FADs do not increase productivity, but rather concentrate fish and intensify their capture. Because of this, if not used responsibly, FADs can lead to overfishing. Indeed, modeling studies in the western and central Pacific suggested that a reduction of FAD effort by 50% would increase tuna and shark biomass to pre-industrial fishing levels within 10 years (Griffiths et al. 2019). Although the percentage of bycatch obtained by fisheries using FADs has decreased from 15-20% in the 1990s to 2-3% at present (Hall and Roman 2013), the volume of bycatch is still significant given the large and targeted fishing effort that FADs facilitate. In other words, percentage of bycatch is not an appropriate indicator of the impact of fishing on a species or group of species, because the impact will depend rather on the proportion of the population of each species caught.

Recent studies have also shown that lost FADs may pose problems in MPAs (Escalle et al. 2019; Phillips et al. 2019). In Galápagos, naturalist guides, field scientists and fishers commonly find FADs drifting at sea or entangled on reefs (Figure 113). No official register of these reports exists, but they are common enough that some restaurants display collections of FADs as ornaments, and a local fisher explained that a middle-man in Galápagos buys the transmitters from lost FADs for US$40 and sells them back to the tuna fleet on mainland at $200.

By deploying FADs to the east of the GMR, there is a strong likelihood that they will drift with the South Equatorial Current across the reserve, essentially expanding the scale of fisheries capture for the schools of fish attracted to the FADs which subsequently drift outside the reserve.

Figure 113. Left: Divers retrieving a FAD at Darwin Island (Galápagos Whale Shark Project 2012). Right: FAD entangled on reef at Wolf Island in 2020 (photo: Sofia Green).

This practice could be negatively affecting the catches of locally important species such as wahoo and yellowfin tuna. Additionally, it could affect resident populations of threatened sharks that associate with FADs. Further, FADs may pose a collision risk to Galápagos fishers, especially when operating at night.

We used offline particle tracking (Döös et al. 2017) in the biogeochemical oceanographic circulation model described earlier, developed by the University of Southampton (Forryan et al. (2021), Naveira-Garabato et al. unpublished) to estimate the effects of deploying drifting FADs at three locations upcurrent from the GMR – on the eastern boundary of the current GMR; 40 NM further east of the border but still within the Galápagos EEZ; and in international waters 200 km from the current GMR boundary (Figure 114). To provide an understanding about how dispersal patterns might change under different climatic conditions, we ran our simulations for an El Niño year (2015), a La Niña year (2008) and a neutral year (2012).

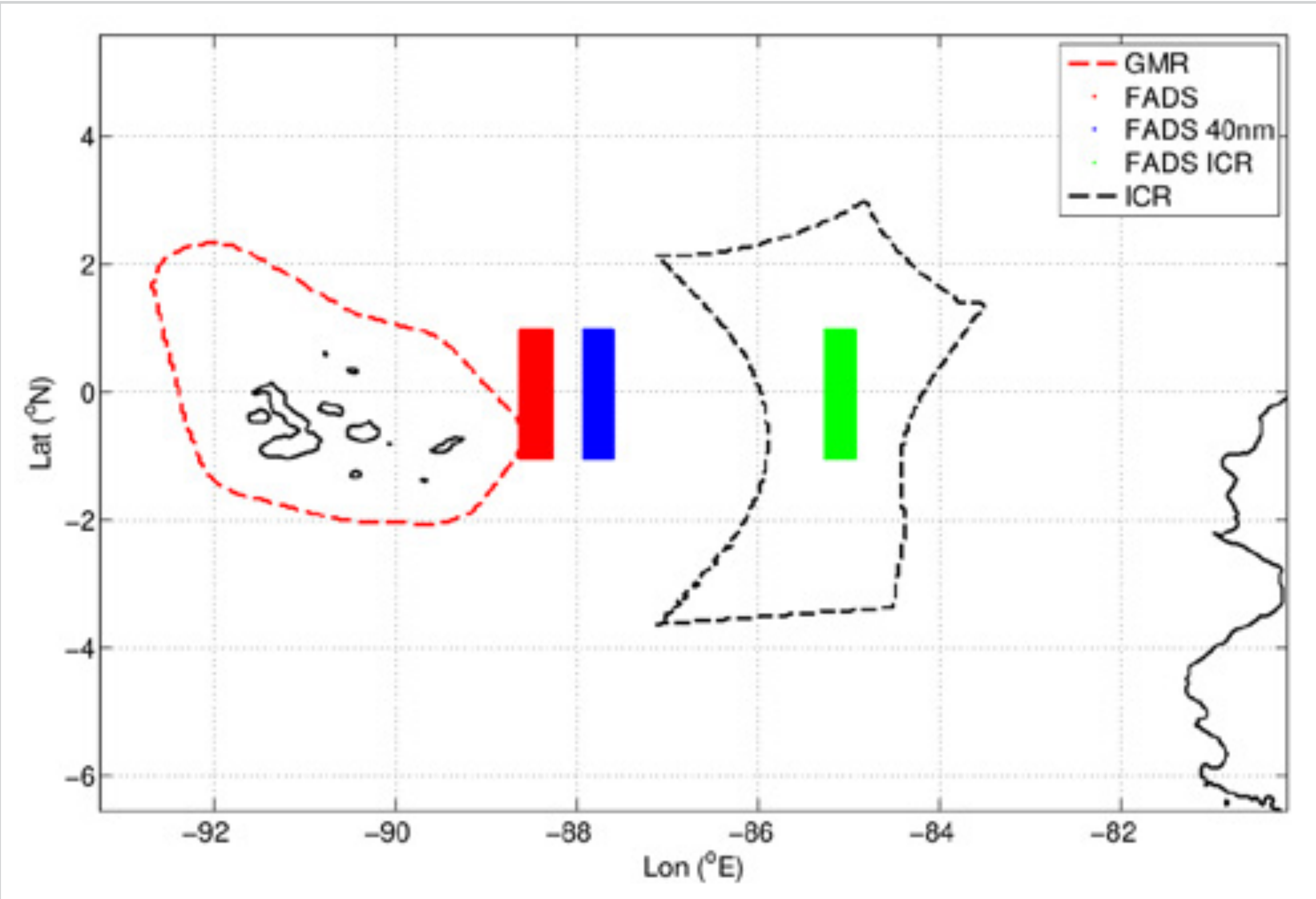


Figure 114. Simulated release location of FADs: along the eastern margin of the Galápagos Marine Reserve (red), 40 NM outside the GMR (blue) and in the international waters between Ecuador's two EEZ zones (green). Red dotted line delineates the GMR; black dotted line shows limits of EEZs.

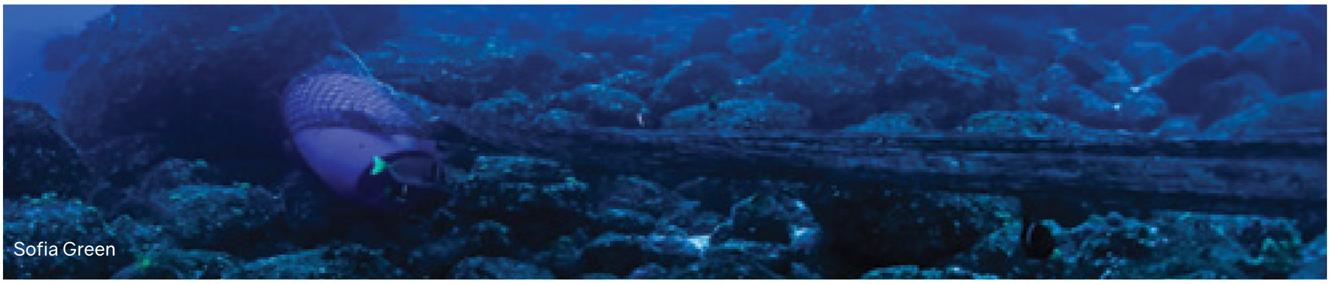
Given the average depth of the tail of the FADs, we integrated the current vectors of the top 20 m of the water column to provide a mean surface water flow. For each year and each release location, we deployed approximately 61,000 FADs on the first day of each month with an even distribution of approximately 8 FADs/km^2. Each individual FAD was tracked for 25 days. We assumed that a residency of >25 days implied that the FAD was washed ashore or entangled in shallow water. We calculated the residency time within the GMR for each FAD (a value of 0 implies that the FAD did not enter the GMR) then plotted these as monthly histograms. For each year we normalized the numbers of FADs relative to the number deployed per km^2, and used these values to map the likelihood of FAD presence on a scale of 0-1 (Figures 115, 116 and 117). Bar charts showing the residency (in number of days) per month under each scenario can be found in Appendix A.

In 2008, under La Niña conditions, the only months with significant avoidance (residency of zero days) for deployments both on the GMR border and 40 NM to the east, were February (0.644) and March (0.831), and to a lesser extent, June (0.246), whereas by deploying in international waters, the GMR was avoided altogether in February-April, with significant avoidance in all other months except August (Figure 115). Overall, approximately 50% of FADs deployed at the border or at 40 NM outside, spent 4-8 days within the GMR, in comparison to only 18% of those deployed in international waters. Interestingly, over 50% of the FADs deployed in April at 40 NM from the GMR spent 18-20 days inside the protected waters. Areas where there was a higher probability of FAD presence included the southeastern part of the reserve, between San Cristóbal and Española (which are important fishing grounds for the local fleet), and the three northern islands of Pinta, Marchena and Genovesa.

In 2012, under neutral conditions, for deployments on the border of the GMR, all FADs entered the reserve except in the month of April, when the proportion of avoidance was 0.68 (Figure 116). The pattern was similar for deployments at 40 NM, with an avoidance of 0.3. Significant levels of avoidance throughout the year were only achieved once deployments occurred in international waters. In all cases, residency mostly fell between 3-8 days.

In 2015, under El Niño conditions, deployments on the border of the GMR avoided entry into the reserve entirely in the month of April, and significantly (0.65) in May, while deployments 40 NM avoided the reserve entirely in April and May, and significantly in March (0.65). Deployments from international waters were able to avoid the reserve in these months and those of June and September. In all cases, the residency of those FADs entering the reserve, mostly fell in the 3-8 day range (Figure 117).

In summary, unsurprisingly, deployment of FADs upstream of the GMR has the effect of a large proportion of FADs drifting across the reserve, thus confirming the concerns voiced by local fishers. In order to reduce the overall probability of this occurring, FADs would either need to be deployed downstream, or in the international waters east of the islands, however in the latter case, the risk of entry into the reserve is diminished but still significant under all modeled conditions.


Sofia Green

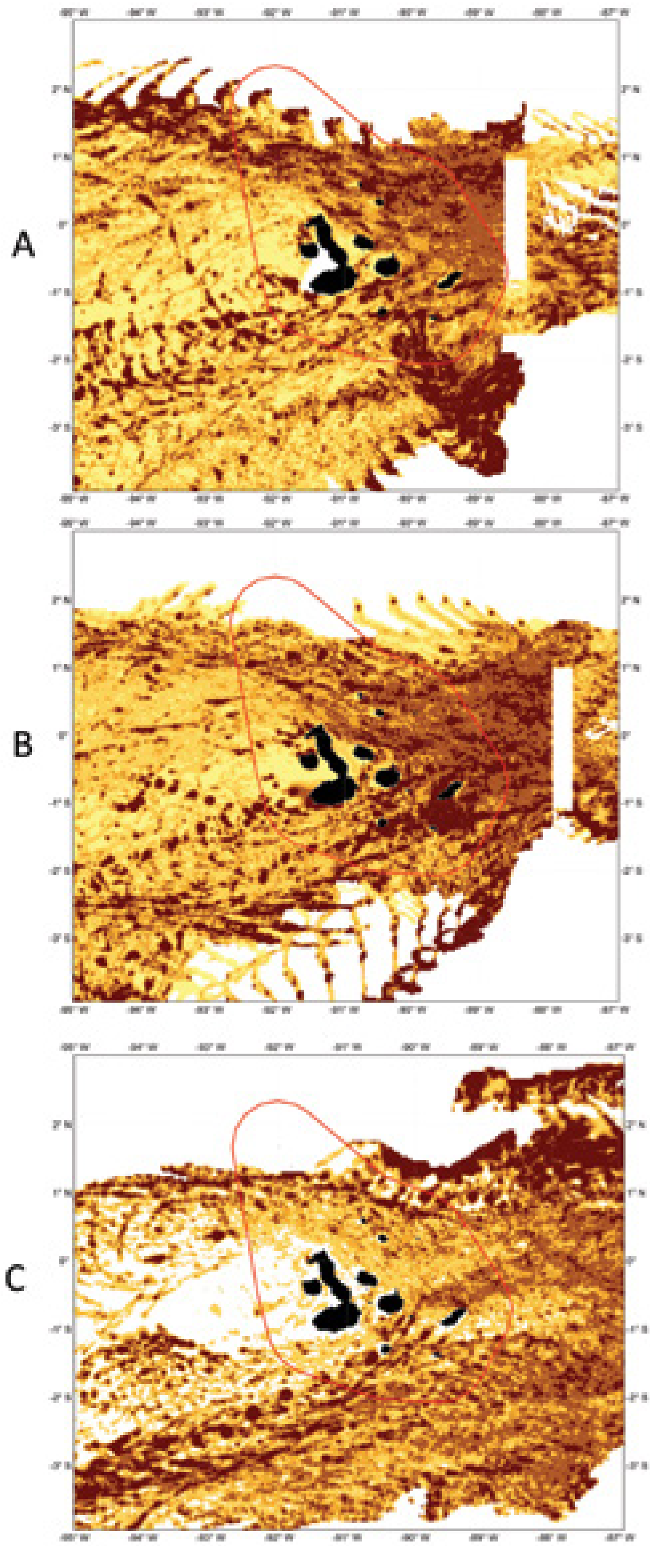


Figure 115. Modeled movements and residency time of drifting FADs deployed outside the eastern border of the GMR (A), 40 NM to the east of the current GMR boundary (B) and in international waters between mainland Ecuador and Galápagos (C) for 2008 (La Niña conditions). The panels show the relative likelihood of a FAD being found at each location, on a quartile scale from low (yellow) to high (dark brown).

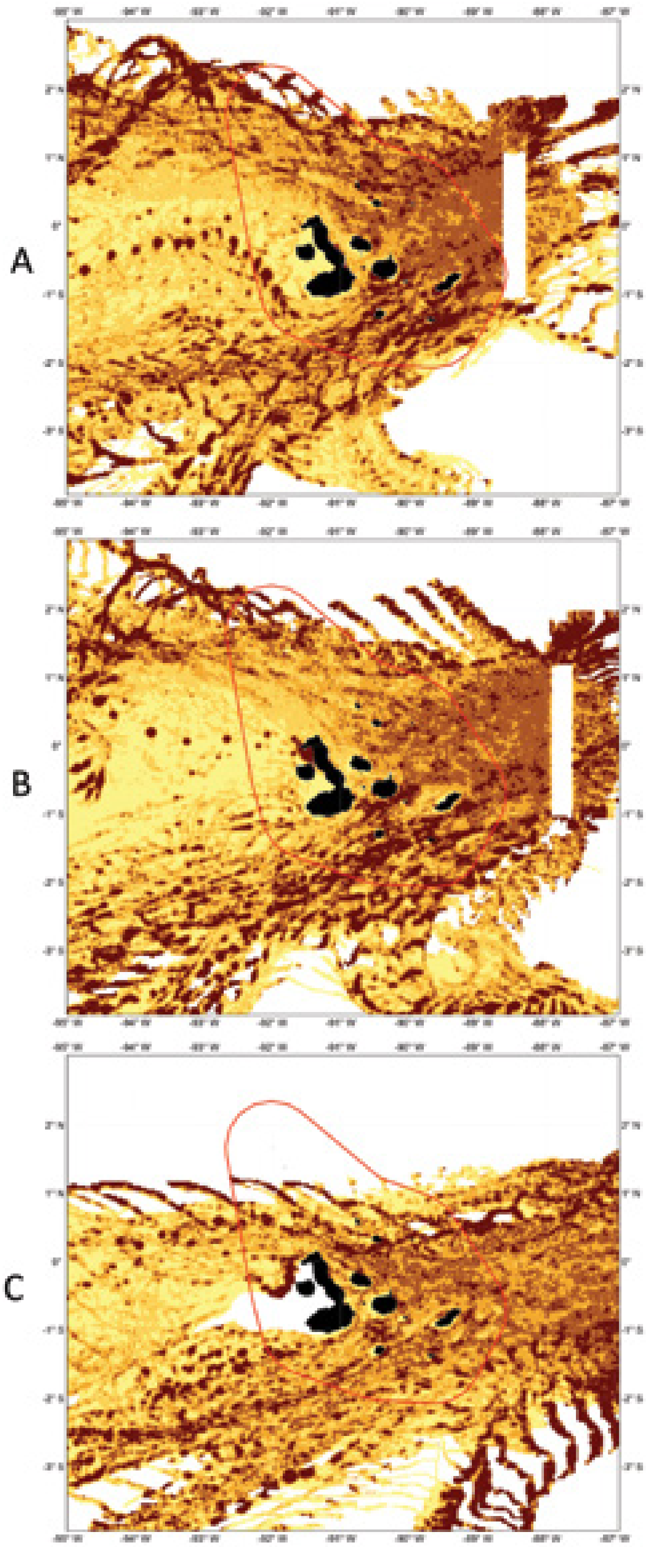


Figure 116. Modeled movements and residency time of drifting FADs deployed outside the eastern border of the GMR (A), 40 NM to the east of the current GMR boundary (B) and in international waters between mainland Ecuador and Galápagos (C) for 2012 (neutral conditions). The panels show the relative likelihood of a FAD being found at each location, on a quartile scale from low (yellow) to high (dark brown).

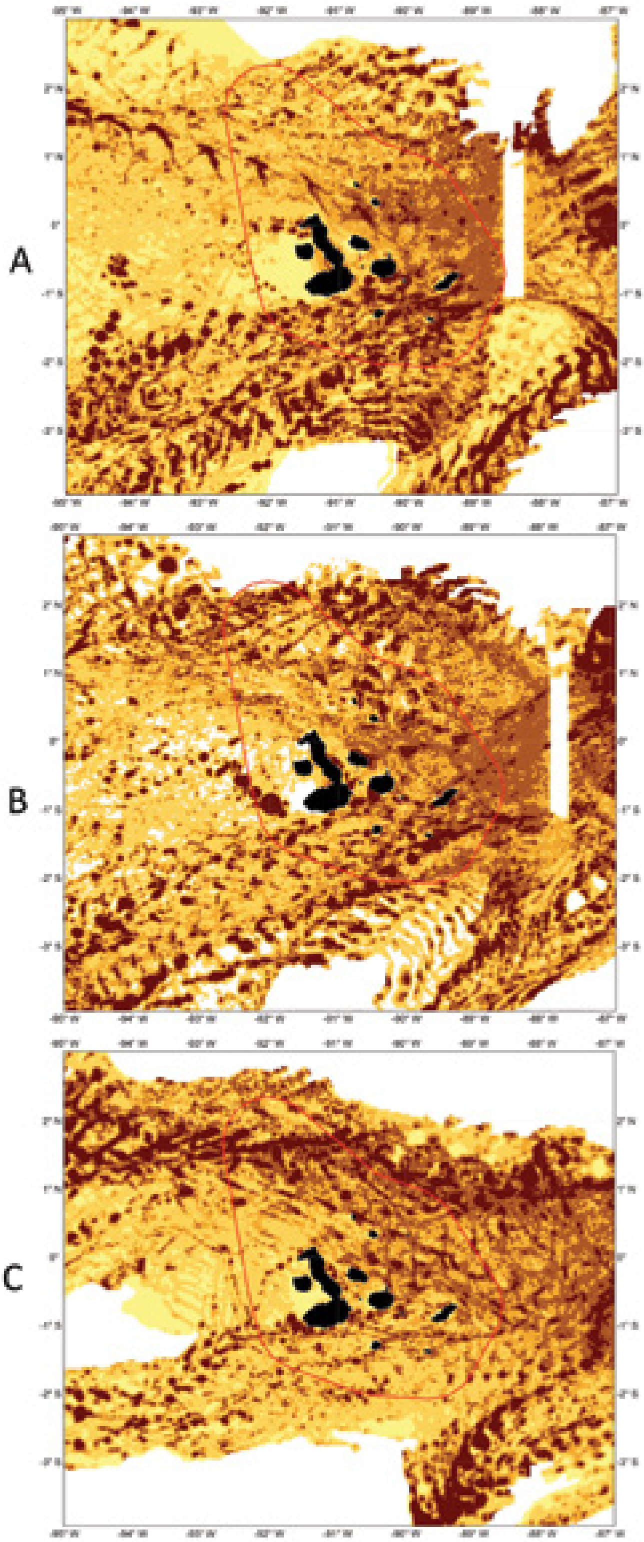


Figure 117. Modeled movements and residency time of drifting FADs deployed outside the eastern border of the GMR (A), 40 NM to the east of the current GMR boundary (B) and in international waters between mainland Ecuador and Galápagos (C) for 2015 (El Niño conditions). The panels show the relative likelihood of a FAD being found at each location, on a quartile scale from low (yellow) to high (dark brown).

The fishing industry has taken some steps to address some of the concerns with FADs (IATTC 2017b). FADs cannot be deployed within 15 days of closure periods, and must be recovered. The number of active FADs at any given time is limited by vessel size:

- Class 6 (1,200 m^3 and greater): 450 FADs
- Class 6 (< 1,200 m^3): 300 FADs
- Class 4-5: 120 FADs
- Class 1-3: 70 FADs

In 1999, the Costa Rican Institute of Fisheries and Aquaculture (INCOPESCA) prohibited the use of FADs within the EEZ of Costa Rica. In Ecuador, the National FADs management plan was approved in 2018 (SRP Agreement MAP-SRP-2018-0176-A). The objective of the National FADs management plan is to strengthen the sustainable management and responsible use of FADs in the purse-seine tuna fishery, maintaining the operational efficiency of the Ecuadorian purse-seine tuna fleet through the implementation of standards, actions and new technologies. The specific objectives of this plan are the following:

- Establish a registry of floating objects with their characteristics.
- Improve the collection of information by implementing technological platforms.
- Contribute to the knowledge of the species composition of the catch in the sets of FADs and its spatial and temporal variability.
- Deepen knowledge about the possible impacts of FADs on ecosystems and species.
- Establish information exchange mechanisms between shipowners, scientists, and administrations.
- Design prototypes of FADs that cause less impact on the marine ecosystem through non-entangling and degradable materials.

Furthermore, the group TUNACONS (https://tunacons.org) have developed non-entangled and biodegradable FADs, to reduce their ecological impacts, which last from 6 to 12 months in the waters before their biodegradation (TUNACONS 2020). No nets are utilized in the Eco-FADs' flotation or raft structures, in the submerged structure or tail. Neither are synthetic materials of any sort (save in the satellite buoy and tiny markings required for FAD identification), nor chemicals that may be hazardous to the environment. The Eco-FADs are made from materials that originate from a sustainable manufacturing system and do not disintegrate into harmful or damaging elements

Mainland Ecuador Artisanal Sector

The new Organic Law for the Development of Aquaculture and Fishing, approved in April 2020, defines artisanal fishing as *"the activity of fishing and harvesting that is carried out individually, autonomously or collectively, by men or women, family groups or settled in coastal, riparian communities and inland and insular waters, carried out predominantly manually, to improve their quality of life and contribute to food sovereignty, with or without the use of an artisanal vessel"* (Art. 7, Official Register 187, 2020). In this sense, the fishery described below is included within this description, although it is also true that it includes components that are large-scale, commercial ventures mainly oriented towards international export. Indeed, the total value of the main large pelagic species (mahi mahi, swordfish, yellowfin and bigeye tuna) exported to the USA by these artisanal fisheries was valued at approximately US$364 million for the period 2008-12 (Martínez-Ortiz et al 2015). The most relevant organizations that represent the interest of the artisanal fishing sector, including the tuna and mahi-mahi fisheries, are the Federación Nacional de Cooperativas Pesqueras del Ecuador (FENACOPEC) and the Asociación de Exportadores de Pesca Blanca del Ecuador (ASOESPEBLA).

Ecuador's two main artisanal fisheries include the longline fishery targeting large pelagic fishes (dorado, tuna, billfishes, and sharks), and the coastal gillnet fishery for surface and bottom gillnets targeting a wide range of epipelagic fish, from medium water and demersal, crustaceans and mollusks (Martínez-Ortiz et al. 2015).

Large Pelagics Oceanic Fleet

The Ecuadorian large pelagic artisanal fishing fleet is divided into two components: coastal and oceanic (Martínez-Ortiz et al. 2015). The coastal component is made up of fiberglass boats (known as "*fibras*") with a dimension of 7.5 to 9.0 m in length with autonomy for two to three days at sea. This fleet operates in coastal waters located within a range of 40 to 200 NM from the shoreline. There is no accurate estimate of the exact proportion of *fibras* that are part of the coastal component of the Ecuadorian large pelagic artisanal fishing fleet (Martínez-Ortiz et al. 2015). However, according to the last national fishing census carried out in 2013, there were 21,798 *fibras* that operated in Ecuadorian artisanal fisheries at that time. According to Martínez-Ortiz et al. (2015), based on the number of fishing permits registered by gear type and by port, it is estimated that between 72% and 86% of the *fibras* registered in the ports of Esmeraldas, San Pablo de Manta and Santa Rosa de Salinas participate in the artisanal fishery for large pelagics, while 50% of the *fibras* registered in the ports of Puerto Daniel López and Anconcito participate in this fishery. The oceanic component of the artisanal fishery for large pelagics is made up of medium to large vessels called "*nodrizas*", or "motherboats", whose size varies from 7.6-25.9 m in length with an autonomy of up to 25 days (Martínez-Ortiz et al. 2015). According to the 2013 national fishing census, there are 317 motherboats, of which 90% are registered in the port from San Pablo de Manta, while the remaining 10% are located in Anconcito (9%) and Esmeraldas (1%). Motherboats can tow between one and 12 small *fibras* to offshore fishing grounds. The range of distribution of this fleet reaches the western limits of the Galápagos archipelago and southwards to the high seas off Peru (Martínez-Ortiz et al. 2015), covering an area of 2.57 million km^2 (Figure 118).

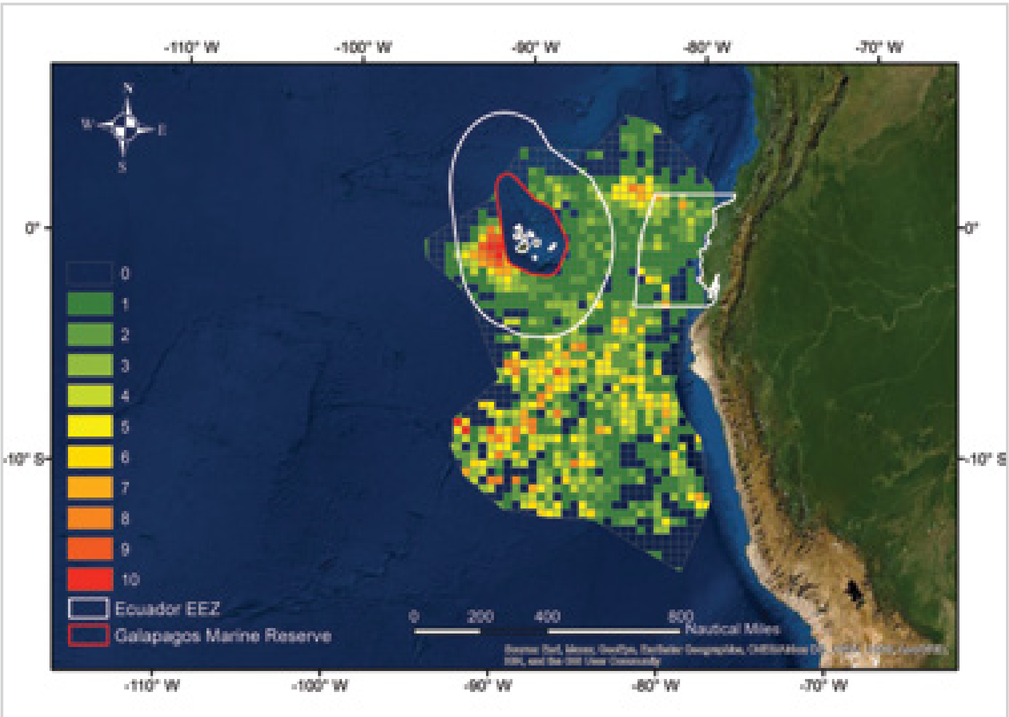


Figure 118. Relative spatial importance of fishing effort (scaled from 0-10) for the oceanic longline fleet from 2008-12, based on the value of the catch in each 25 NM pixel. Source: Martínez-Ortiz et al. (2015).

Landings

The large pelagics oceanic longline fleet engages in two seasonal fisheries. The longline dolphinfish (mahi mahi) fishery operates mainly from October to February, with very few catches of this species reported outside this period, while the tuna-billfish-shark fishery (which operates year round), is most important in the remaining months (Martinez-Ortiz et al. 2015). There are few available statistics regarding landings by this fleet, but a study in 2015 analyzed catch data from 106,963 trip records (including gillnet sets) from a fisheries monitoring program run by the Secretary of Fishery Resources under the Vice-Ministry of Fisheries and Aquaculture between 2008-12 (Martinez-Ortiz et al. 2015), and provides insights into the catch composition for this period, although they must be considered as incomplete estimates of total catch, due to sampling limitations. Mahi mahi (40.1%) and pelagic thresher shark (21.8%) were the two species making up the largest portion of the catch. Given that, despite what the name of the fishery suggests, Ecuador does not formally recognize a targeted shark fishery, shark landings will be discussed in the following section as bycatch. Bony fishes made up 67.6% of the catch by weight and 91.5% of the catch by number of individuals over this period. Yellowfin, bigeye and skipjack tuna, together with swordfish, striped marlin and sailfish, made up the bulk of the remainder of the bony fish catch, with small numbers of other fish occasionally landed (Martinez et al 2015, Table 12).

Table 12. Landings of bony fish species by Ecuadorian artisanal fleet reported by monitoring program 2008-12 (Martínez-Ortiz et al. 2015).

Species	Scientific Name	Total Weight (mt)	% Weight	Total Counts	% Counts
Mahi mahi	*Coryphaena hippurus*	53,945.4	40.1	10,036,226	64.7
Escolar	*Lepidocybium flavobrunneum*	1,011.3	0.8	103,321	0.7
Striped Marlin	*Kajikia audax*	1,561.6	1.2	46,894	0.3
Blue Marlin	*Tetrapturus angustirostris*	1.3	0.0	20	0.0
Shortbill Spearfish	*Istiophorus platypterus*	1,125.1	0.8	46,214	0.3
Sailfish	*Makaira nigricans*	9,805.8	7.3	139,090	0.9
Wahoo	*Acanthocybium solandri*	344.2	0.3	25,925	0.2
Black Skipjack	*Euthynnus lineatus*	17.1	0.0	16,026	0.1
Skipjack Tuna	*Katsuwonus pelamis*	7,226.3	5.4	2,871,461	18.5
Oriental Bonito	*Sarda orientalis*	11.3	0.0	6,026	0.0
Yellowfin Tuna	*Thunnus albacares*	9,151.2	6.8	712,433	4.6
Bigeye Tuna	*Thunnus obesus*	1577	1.2	36,829	0.2
Swordfish	*Xiphias gladius*	5,179.2	3.9	162,313	1.0
Total		**90,956.8**	**67.6**	**14,202,778**	**91.5**

Bycatch

One of the main environmental issues with the oceanic longline fleet is the level of bycatch incurred during the tuna-billfish-shark fishing season. Although Ecuador does not formally recognize the existence of a targeted shark fishery, sharks may be sold and used so long as they are landed whole (with their fins attached) and were caught as bycatch (Fowler 2005, Gobierno del Ecuador 2007). However, there is no definition of an acceptable level of bycatch, and so in reality, shark fishing appears to be a targeted, unmanaged fishery. At least 250,000 sharks are landed annually on the main fishing ports of mainland Ecuador (Table 13), (Hearn and Bucaram 2017; Martinez-Ortiz et al. 2015)

Seabirds can also be caught on baited hooks in pelagic longline fisheries, especially albatrosses and petrels. The waved albatross *(Phoebastria irrorata)* in particular is endemic to the EPO and, (with the exception of only a handful of individuals at Isla de la Plata off mainland Ecuador) nests only on Española Island in the Galápagos Archipelago. Although observer data from artisanal vessels have reported no interactions with this species in the EEZ surrounding Galápagos (Griffiths and Fuller 2019), observer coverage is limited, and bycatch is reported from longline fisheries along the coast of Peru (Awkerman et al. 2006).

In Ecuador, sea turtles are the species most affected by the mahi-mahi fishery. Based on information collected by on-board observers from 2008 to 2012, Pincay-Espinoza (2018) determined that in 137 out of 927 fishing sets, equivalent to 14.8%, there were interactions between longlines and sea turtles. Such interactions resulted in the capture of 153 turtles, mainly olive ridley (112 specimens) and green (32 specimens) sea turtles. Approximately, 88.59 % of these turtles were released alive, although some having minor injuries or still carrying hooks, while the remaining 11.41% of the specimens were released with serious injuries.

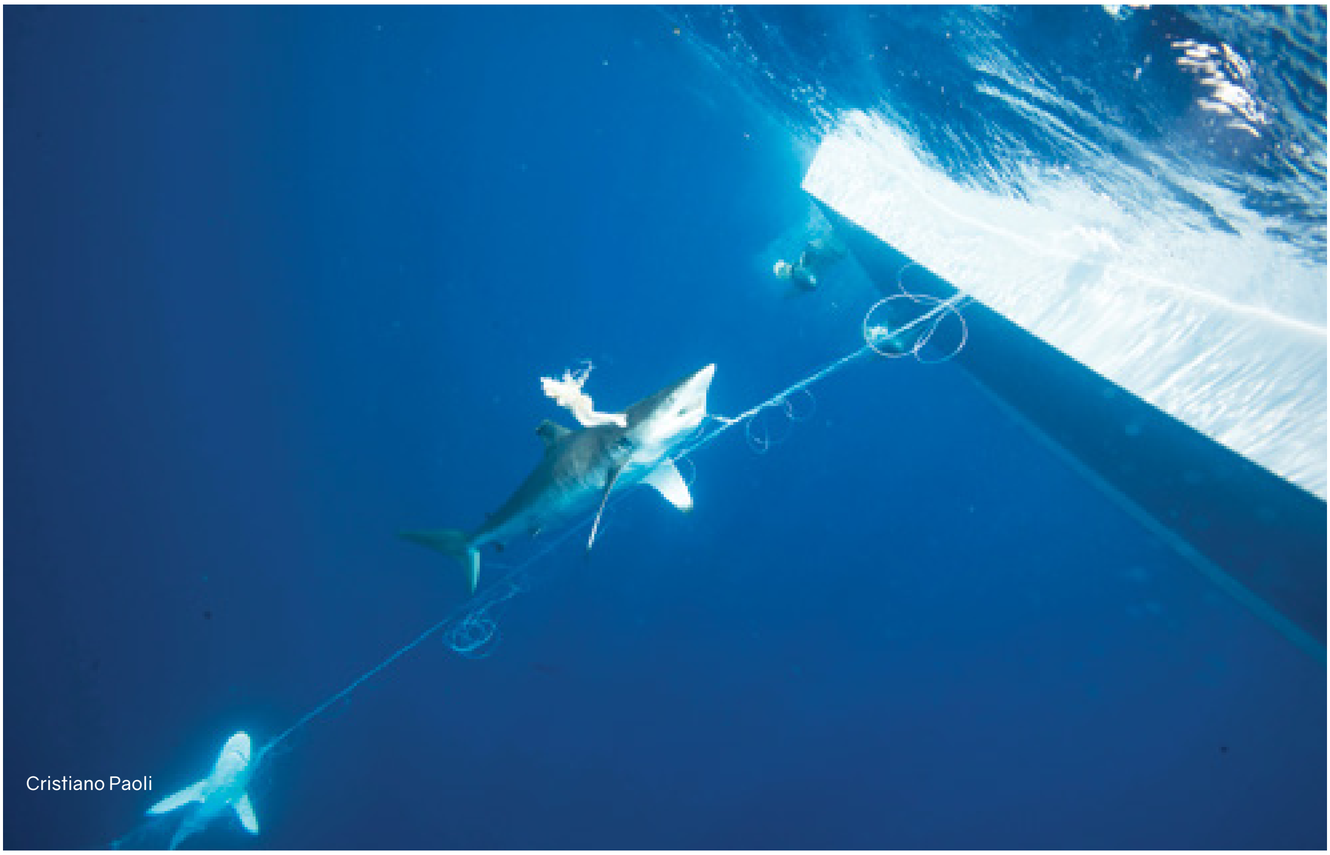

Cristiano Paoli

Table 13. Landings of shark and ray species by Ecuadorian artisanal fleet reported by monitoring program 2008-12 (Martínez-Ortiz et al. 2015).

Species	Scientific Name	Total Weight (mt)	% Weight	Total Counts	% Counts
Pelagic thresher Shark	*Alopias pelagicus*	292,77.7	21.8	744,027	4.8
Bigeye thresher Shark	*Alopias superciliosus*	1093.9	0.8	21,747	0.1
Common thresher Shark	*Alopias vulpinus*	30.6	0.0	278	0.0
Copper shark	*Carcharhinus brachyurus*	4.1	0.0	136	0.0
Silky shark	*Carcharhinus falciformis*	3,008.9	2.2	137,827	0.9
Galápagos shark	*Carcharhinus galapagensis*	5.1	0.0	122	0.0
Bull shark	*Carcharhinus leucas*	12.1	0.0	124	0.0
Blacktip shark	*Carcharhinus limbatus*	59.7	0.0	1,861	0.0
Oceanic whitetip Shark	*Carcharinus longimanus*	37.2	0.0	822	0.0
Dusky shark	*Carcharhinus obscurus*	11.9	0.0	234	0.0
Smalltail shark	*Carcharhinus porosus*	0.6	0.0	47	0.0
Tiger shark	*Galeocerdo cuvier*	12	0.0	453	0.0
Whitenose shark	*Nasolamia velox*	1.8	0.0	332	0.0
Lemon shark	*Negaprion brevirostris*	0.6	0.0	6	0.0
Blue shark	*Prionace glauca*	7,469.9	5.6	282,313	1.8
Prickly shark	*Echinorhinus cookei*	0.2	0.0	3	0.0
Nurse shark	*Ginglymostoma cirratum*	0.1	0.0	6	0.0
Broadnose sevengill shark	*Notorynchus cepedianus*	0	0.0	3	0.0
Shortfin mako	*Isurus oxyrhynchus*	846.6	0.6	27,864	0.2
Longfin mako	*Isurus paucus*	9.2	0.0	47	0.0
Bigeye sand tiger shark	*Odontaspis noronhai*	3.9	0.0	1	0.0
Crocodile shark	*Pseudocarcharias kamoharai*	0.8	0.0	290	0.0
Scalloped hammerhead shark	*Sphyrna lewini*	258.4	0.2	7,404	0.0
Great hammerhead shark	*Sphyrna mokarran*	-	0.0	-	0.0
Bonnethead shark	*Sphyrna tiburo*	3	0.0	28	0.0
Smooth hammerhead shark	*Sphyrna zygaena*	1,227.8	0.9	79,283	0.5
Pacific angel shark	*Squatina californica*	6.2	0.0	1,698	0.0
Tope	*Galeorhinus galeus*	0.2	0.0	93	0.0
Brown smooth-hound shark	*Mustelus henlei*	0.7	0.0	258	0.0
Sicklefin smooth-hound shark	*Mustelus lunulatus*	1.4	0.0	473	0.0
Longtail stingray	*Dasyatis longa*	9.1	0.0	626	0.0
Smoothtail mobula	*Mobula munkiana*	121.1	0.1	4171	0.0

Galápagos Artisanal Fishing Sector

The Galápagos fleet is a multi-specific sector that targets both coastal and open water resources, depending on the season (Hearn 2008). Although resource-specific licenses have been proposed as a solution to signs of overexploitation of several resources (Schiller et al. 2015), to date, all fishery resources continue to be available to all fishermen with an artisanal permit (Castrejón and Charles 2013). The coastal fisheries – in particular lobster and sea cucumber, have been well-documented over the years, and have posed challenges related to managing a local resource for a global market (e.g. Hearn 2008). These coastal fisheries are beyond the scope of this study, except to note that there may be an argument for developing offshore fisheries as a means of reducing pressure on overfished coastal resources.

The offshore component of Galápagos fisheries is known as "pesca blanca", although this includes demersal fish, often caught both along the coast and at offshore seamounts (Castrejón et al. 2014). The offshore Galápagos Fishery tends to concentrate around the "bajos" or seamounts on the Galápagos platform, especially those to the south and east of the main archipelago, where demersal fish such as the "brujo" (scorpionfish) and "bacalao" (sailfin grouper) are targeted, along with the main pelagic resources: yellowfin tuna and wahoo – the former increasingly for export, and around 100 vessels participate in this fishery (Ramirez and Reyes 2015; Burbano and Meredith 2020). Fishing methods are limited to manual gear including deep-set handlines for demersal fish (Zimmerhackel et al. 2015) and trolling or oceanic handlines for pelagic fish (Tejada 2006). A study of 22 fishing trips using demersal handlines found that 36 species were caught using this gear, of which 19 were discarded/released, including juvenile Galápagos and whitetip reef sharks, and two sea lions. Overall, 59.7% of the catch was landed and used or sold, with the remaining 40.3% discarded or used as bait (Zimmerhackel et al. 2015).

Longlines, despite being banned in the GMR, are used illegally; and over the years, experimental longlines have been authorized, largely aimed at yellowfin tuna and swordfish, all for export markets (Ramirez and Reyes 2015) longline experiments have generally been authorized in response to political pressure, and have been undertaken with different levels of observer coverage, gear composition and fishing areas (Table 14). However, each time, the decision based on the study has been either to ban the fishery or to conduct more studies. In 2020, a longline fishery was authorized in response to economic pressures due to the effects of COVID-19, raising concerns among the conservation sector (Izurieta and Green 2021).

We obtained fishing site locations for *pesca blanca* by combining fisheries landing data from the GNPD marine resources fisheries monitoring program and vessel position data from the GNPD AIS (Automatic Identification System) information system from 2017 and 2018. Position data from the AIS system were transformed to UTM 15°S for spatial analyses. This combined data set included 1,804 landing certifications from 222 registered Galápagos artisanal vessels to represent the movement in the GMR associated with each landing certification. This equates to approximately 73% of the total "pesca blanca" catch records in the GNPD monitoring data for 2017 and 2018. In order to estimate the location of fishing sites, a movement model was created to filter out segments of the tracks associated with vessels navigating rather than fishing (i.e. speeds > 1.6 knots), resulting in ~2,730 sites (Calenge 2006, 2011; WildAid-DPNG 2020). Geographic positions were summarized for each date to provide an estimate of unique visits to each site and plotted on a map of the GMR with the coastline and depth contour of 500 m (approximate depth of the Galápagos platform). This visualization provided a way to distinguish between fishing sites in offshore areas associated with seamounts, shoals and the shelf break, as well as coastal sites and those associated with the main ports and anchorages, while also showing that the fleet does not utilize the waters beyond the boundaries of the existing reserve, with the exception of an area of seamounts just outside the eastern border (Figure 119).

Table 14. Summary of longline experimental fisheries within the GMR.

Year	Study	Independent observers	Effort	Area	Bycatch	Gear Type	Notes on costs
1997	Luna and Vinueza (1997)	yes	1 trip	West	40%	22 m deep longline, 60-175 hooks	Not economical
2001	Revelo et al. (2001)	yes	12 fishing days Observers	West and South	60%	7 km longline, deep set 10-30m	NA
2003	Murillo et al. (2004)	yes	1 trip, 21 sets	Northwest and southwest Isabela	77%	3.6-18.9 km, 80-350 hooks, 8-21m depth	Not economical
			7 trips, 134 sets	Northwest and southwest Isabela	35%		
2013	Reyes et al. (2014)	Only 4 observers. Self reporting	16 vessels, 107 trips, 422 sets	Not reported	11.25% includes barrilete and miramelindo as bycatch so should reduce to 8.93%	100 hooks 10-30 m, 1-3 km length	Incomplete data
2017	CTI (2018)	Not all	15 vessels 57 trips. 179 sets	All over except far north	11.3% May-Oct, 4% Jan-Apr	Horizontal 50-hooks midwater longline – 30 m then 15 m leaders	Yes – generates benefits

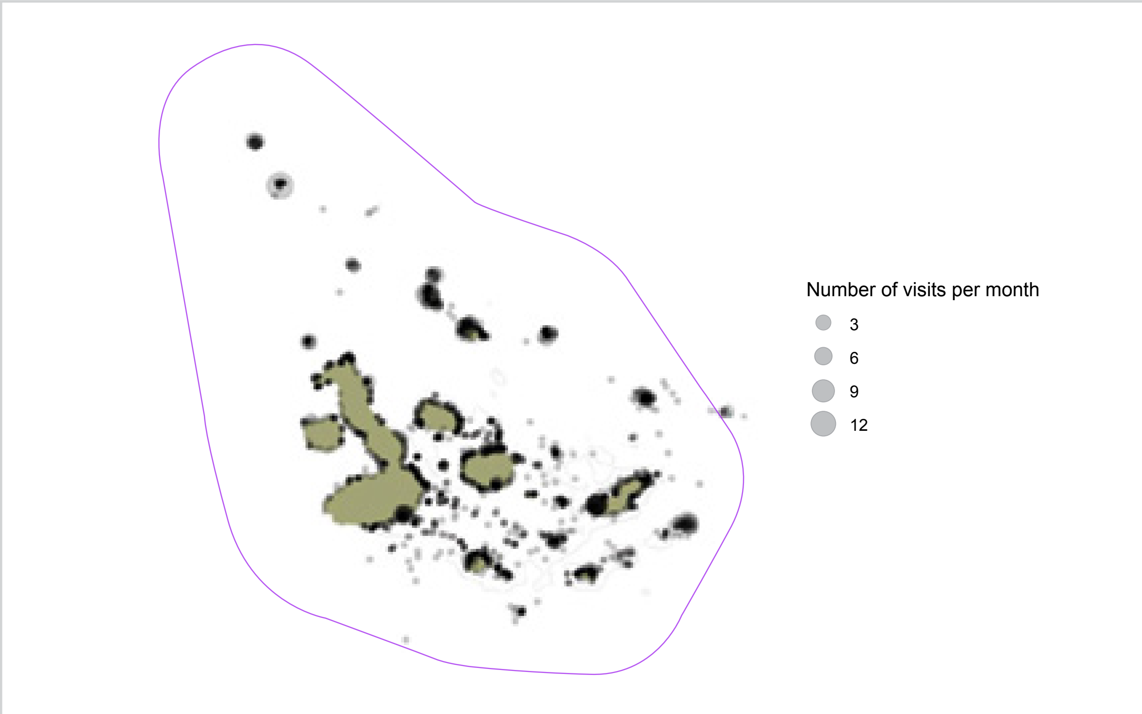


Figure 119. Main fishing grounds for the Galapagos artisanal fleet. Source: Galapagos National Park Directorate Fisheries Monitoring Program and WildAid, data from 2017 and 2018. Darker circles show overlapping points due to the scale of the map.

The relationship between local fishers and conservationists has always been uneasy, and has arguably become more difficult in recent years after a local and an international NGO by-passed a participatory process aimed at rezoning the marine reserve, and convinced the President of Ecuador to declare a large no-take "sanctuary" in the northern third of the marine reserve (Burbano and Meredith 2020). This led to pressure to allow experimental longlining in the rest of the reserve as a measure of appeasement, and eventually to the abandonment of the sanctuary idea. The rezoning process has been stalled ever since, but the mistrust remains (Burbano and Meredith 2020), and was reflected in some of the stakeholder discussions regarding concerns about fishery resources in and around Galápagos (Castrejón 2020b).

Certain members of the fishing sector expressed an interest in fishing outside the GMR (Castrejón 2021), however to date they do not do so, and it is unclear whether the costs incurred in traveling greater distances from port, and the productivity outside the GMR with respect to that of their current fishing grounds around the seamounts would make this worthwhile.

Some of the concerns expressed by local fishers, both in meetings with the technical team in this project, and at the Fishery Summit held in Puerto Ayora, Santa Cruz Island in January 2021, are that illegal fishing is a problem that needs to be resolved, and that conserving fishery resources is key to ensuring their sustainability in the long term (Castrejón 2021). Conversations with local fishers identified three key perceptions, which might be addressed by the current initiative:

1. Fishers expressed concerns that mainland-based longline skiffs were able to illegally enter the GMR undetected and access their fishing grounds to the south and east of the GMR within 1-2 hours.

2. Fishers expressed concern about the number of FADs detected in and around their fishing grounds, and there is the perception that these FADs to some extent attract their resources away as the FADs drift through the GMR.

3. There was some concern expressed about potential overfishing, the cause of which was attributed to excess fishing pressure from fleets outside the GMR.

International Vessels and IUU Fishing

A recent study of AIS (Automatic Identification System) data obtained from the Global Fishing Watch platform (www.globalfishingwatch.org) found that, between 2012 and 2015, vessels from 15 flag states undertook fishing activities within the EEZ surrounding Galápagos, and in some cases, within the GMR (Chinacalle-Martínez 2020). Apart from Ecuadorian vessels, which naturally made up the largest proportion of vessels, significant fishing effort by Panamanian, Taiwanese, Colombian, Venezuelan, Nicaraguan and Peruvian were recorded both inside the GMR and within the EEZ. Gear used included squid jigs, purse seines and longlines (Chinacalle-Martínez 2020). Some of these vessels may have permits to fish within Ecuadorian waters.

Outside the EEZ, fisheries in the region are managed through the IATTC (for tuna and tuna-like species) and through the SPRFMO (South Pacific Regional Fisheries Management Organization). The Ecuadorian tuna fleet and its activities are described above, and large international longline fleets have been reported along the western border of the Galápagos EEZ at least since 2017, raising concerns as to their impact on highly mobile resource species and endangered species (Alava et al. 2017). In July 2020, a large distant water industrial fleet was reported to the south of the Galápagos Islands, just outside Ecuador's EEZ (Figure 120). This fleet was mostly made up of Chinese squid jiggers, targeting the jumbo squid *Dosidicus gigas* (OCEANA 2020). The appearance of such a large fleet caused an outcry in mainland Ecuador and Galápagos alike, yet it was not a new phenomenon. China is the largest contributer to harmful subsidies globally, mainly in the form of tax exemptions (Sala et al. 2018, Sumaila et al. 2019), which allow its squid jigger and drifting longline fleets to travel further and stay at sea for months, using reefer vessels to deliver their catch back to China. In 2014, the Ecuadorian government expressed an official interest in developing its own squid fishery, and undertook some pilot surveys. Jumbo squid were found to be mostly distributed in the Gulf of Guayaquil and around the Galápagos Islands (Morales-Bojórquez and Pacheco-Bedoya 2016). To date, Ecuador has only reported a catch of 1,500 tons in 2015 (SPRFMO 2020), however, it is likely that this fishery will grow in the future.

Illegal, unreported and unregulated (IUU) fishing poses one of the greatest threats to the marine biodiversity and the sustainability of tuna fisheries in the Eastern Tropical Pacific (CMAR) (FAO 2019a; Bertrand et al. 2020; Castrejón 2020a; FAO 2020). IUU fishing involves different types of activities. According to FAO (2001), a national or foreign flag vessel operates illegally in jurisdictional waters if its fishing activities violate the regulations established by the country where the fishing activities are carried out or the regulations established by the Flag State to which the vessel belongs. Likewise, fishing activity is considered illegal if it contravenes the regulations established by a Regional Fishery Management Organization (RFMO) within the waters of its jurisdiction. In the EPO, the RFMO responsible for the conservation and management of tuna and other marine resources is the Inter-American Tropical Tuna Commission (IATTC). The magnitude of illegal fishing and bycatch of commercial and ETP species within and beyond GMR's boundaries are poorly known. Nevertheless, two recent incidents provide evidence of the magnitude of these threats around the GMR and the rest of the EEZ of Ecuador.

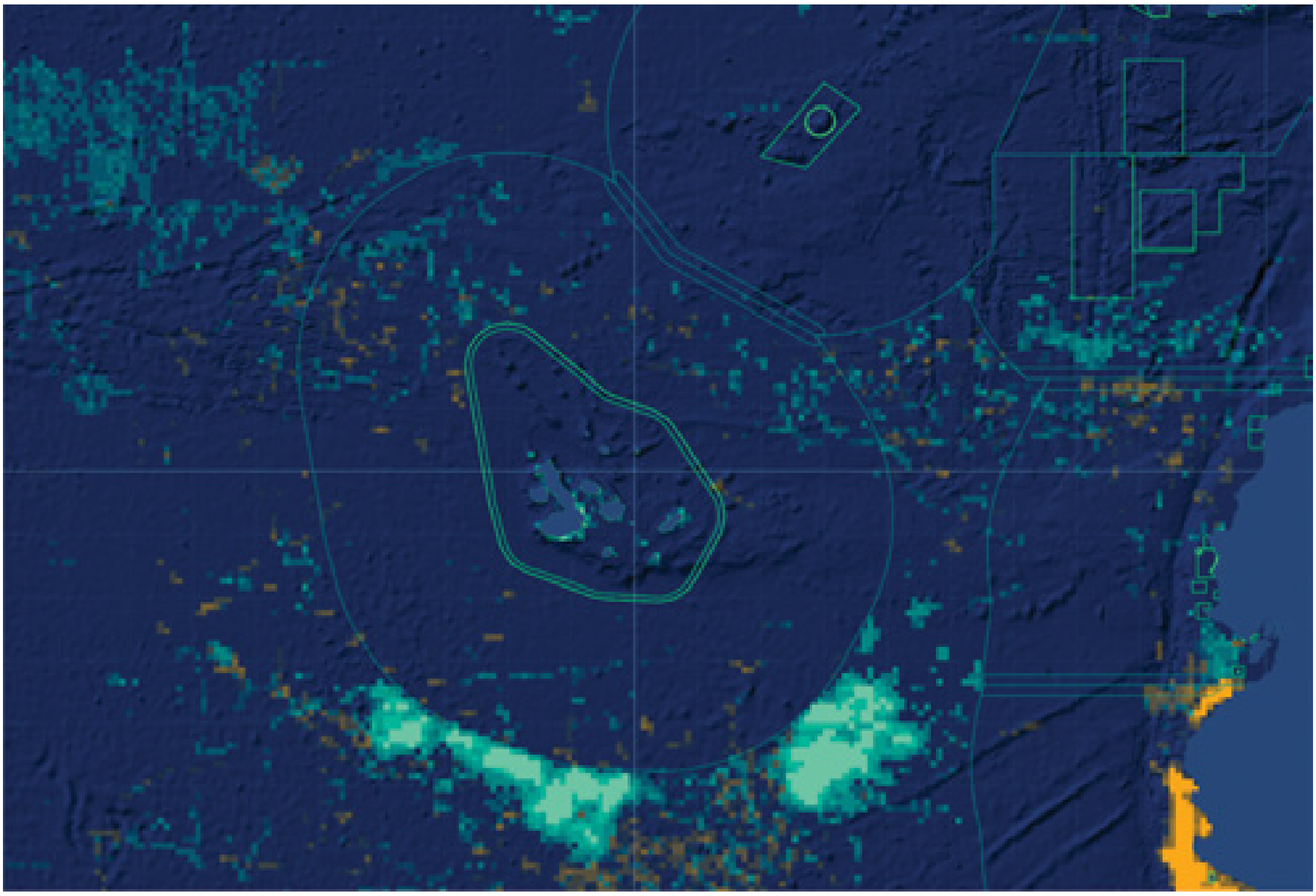


Figure 120. Fishing effort in the Eastern Tropical Pacific, 1 July-1 August 2020, based on satellite vessel tracking data available from Global Fishing Watch. Green pixels depict AIS positions; orange pixels depict VMS positions. Intense green areas to the south of the Galápagos EEZ correspond to the Chinese squid jigger fleet. Source: https://globalfishingwatch.org/map accessed 26 October 2021.

The first is the seizure of the Chinese-flagged vessel Fu Yuan Yu Leng 999 on August 13, 2017 (El Universo 2017). This boat entered and sailed illegally within the limits of the GMR transporting more than 572 t of commercial (tuna) and protected species, mostly sharks, whose capture, marketing, and transport is prohibited within this multiple-use MPA (Bonaccorso et al. 2021). Although the catch found inside the Fu Yuan Yu Leng 999 was caught outside the Galápagos EEZ, the species caught likely belonged to the same populations that the GMR is designed to protect. This case study highlights the need to establish regional and international agreements to regulate the fishing of commercial and ETP species in waters beyond national jurisdictions, not only to ensure the conservation of large pelagic species protected by MPA, but also to protect the food security of Ecuador and the remaining countries of the Eastern Tropical Pacific.

The second event was two seizures of shipments of shark fins from Ecuador, equivalent to 38,500 individuals (26 t), which occurred in Hong Kong in April 2020, representing the largest seizure of shark fins recorded in Hong Kong's history (El Comercio 2020b). This event has made clear that the surveillance and control capacity of Ecuador is insufficient to prevent and eradicate IUU fishing. Further, The Commissioner for Environment, Maritime Affairs and Fisheries of the European Commission, aware of this shortcoming, had already issued a "yellow card" to Ecuador in October 2019, urging this country to take stricter action against IUU fishing (El

Universo 2019). The Commission noted that Ecuador has not made the necessary efforts to ensure that fish entering the European market does not come from illegal fishing practices. This warning is before the red card, which, if applied, would prohibit the entry of Ecuadorian fishery products to the European Union, the most important tuna export market for Ecuador (Ministerio de Comercio Exterior 2017).

The events described have contributed to increasing the awareness of society, at the national and international level, about the ecological and economic impact produced by IUU fishing. In consequence, the Ecuadorian society and the European Union are demanding the Ecuadorian government and industrial tuna fishing sector to take action to prevent and eradicate IUU fishing within the EEZ of Ecuador, with emphasis on the boundaries of the GMR.

In response to the increasing evidence that IUU fishing is one of the main threats that put in risk the sustainability of tuna fisheries, the conservation of marine biodiversity, and the economy of Ecuador, concrete actions have been taken by the Government of Ecuador to combat IUU fishing. One of the most relevant is the approval of the Organic Law for the Development of Aquaculture and Fisheries in April 2020, which establishes a set of measures to combat IUU fishing within and beyond the jurisdictional waters of Ecuador (Coit and Spinrad 2021). Furthermore, the Ecuadorian fishing sector is implementing fishery improvement projects (FIP) for the tuna purse seine fishery and artisanal mahi-mahi fishery (FIP identification numbers 4176 and 90, respectively, at https://fisheryprogress.org) to be certified as sustainable fisheries by the Marine Stewardship Council (MSC). The effective implementation of these measures is a work in progress. However, they reflect the interest of the government and tuna fishing sector to prevent and eradicate IUU fishing in the EEZ of Ecuador and reduce the ecological impact of tuna fishing on the marine biodiversity of the GMR.

Illegal Fishing Inside Galápagos

Illegal fishing in the GMR occurs on several levels. First, local residents can engage in illegal activities such as fishing without permits, or fishing for resources out of season, fishing in no-take areas, or trading in protected species (such as sharks or sea horses). These issues with local stakeholders are linked with governance weaknesses and have been explored in the literature (e.g Hearn 2008, Castrejón and Charles 2013, Jones 2013, Schiller et al. 2015).

However, illegal fishing also includes the unauthorized entry of national and international fishing vessels to carry out fishing activities within the GMR. Local fishermen reported the presence of longlining skiffs at some of their key fishing grounds to the south and east of the GMR. These skiffs are part of the national large pelagics longline fleet, which operates by means of mother vessels *(nodrizas)* which can carry up to a dozen small skiffs as far as the western margin of the Galápagos EEZ, and which are described in more detail above (Martinez-Ortiz et al. 2015). The nodrizas remain outside the GMR, while the skiffs (which do not carry AIS systems, and therefore cannot be tracked) can cross into the GMR and reach the fishing grounds within two hours. The magnitude of this behavior is unknown and hard to quantify.

Larger vessels may be detected and intercepted by joint Navy and GNPD patrols, thanks to the surveillance capacity brought about by aerial patrols carried out by the GNPD's seaplane, by radar, and, more recently, by AIS tracking. Reyes and Murillo (2007) reported that from 1996-2004, the majority of incidents occurred in the southern part of the reserve, near the islands of Española and Floreana. Most were national purse seine and longline vessels, but Costa Rican vessels were also intercepted at that time (Carr et al. 2013). Many of these vessels were seized with shark bodies or fins on board.

Illegal fishing has continued in recent years. The Galápagos National Park Directorate reported that between 2018 and 2020, 136 unauthorized fishing vessels had been detected in the GMR (El Universo 2020b). A study carried out by WildAid (2020) using AIS data from the Global Fishing Watch platform, found that industrial fishing was more focused along the southwestern border of the GMR from October through March, similar to that reported by Bucaram et al (2018) and Boerder et al (2017), while in the remainder of the year there is less fishing pressure within the EEZ, but an increase of concentration of vessels in the high seas bordering the EEZ, in particular, of Chinese flagged vessels. They also reported that fishing effort within the EEZ by the national fleet seemed to concentrate in the east and west, with relatively little effort in the north and south (WildAid 2020). Based on vessel speed and movements, they found evidence of illegal fishing by at least eight foreign vessels within the EEZ. By comparing with radar and satellite imagery, they detected the presence of another 163 vessels that were not transmitting AIS data at the time. They concluded that the limits of the GMR tend to be observed by vessels transmitting AIS data, however, they assume that most vessels engaged in IUU fishing disconnect their tracking systems.

Tui de Roy

Climate Change

To understand the current state of knowledge regarding the impacts of climate change on the marine environment at a global scale, we reviewed the Intergovernmental Panel on Climate Change Report (IPCC 2019), and carried out literature searches which we then refined geographically using the terms "Pacific Ocean", "Eastern Pacific Ocean", "Ecuador" or "Galápagos". Additionally, we gathered information from peer-reviewed papers and grey literature that were referenced in the papers that resulted from our preliminary search. We assessed the potential risks of climate change in the EEZ surrounding the Galápagos Islands using a qualitative risk analysis.

Current state of knowledge

Anthropogenic climate change is primarily caused by the burning of fossil fuels (petroleum, coal, and natural gas), which releases carbon dioxide, the main greenhouse gas (GHG). These fuels are used for transportation, generation of electricity, heating and cooling, and for manufacturing (Tripati et al. 2009). The concentration of carbon dioxide in the atmosphere recently peaked about 418 ppm – by far the highest level in human history (Tanhua et al. 2021), although the average for 2020 was slightly lower – 412.5 ppm (NOAA 2021). Carbon dioxide and other greenhouse gases act like a blanket around the earth, re-emitting heat towards the earth's surface. Over 90% of that additional heat goes into the oceans (Gleckler et al. 2016), with some of the following results:

- **Ocean warming:** Oceans can naturally absorb and release heat over long periods. Rising greenhouse gas emissions are preventing heat radiated from the Earth to pass freely through the atmosphere and into space. This excess heat is absorbed by the ocean, and it has significantly increased its temperature over the last decades. There will likely be an increase in the mean global temperature of 1-4°C by 2100 (Laffoley and Baxter 2016).
- **Deoxygenation:** A reduction in the concentration of oxygen in seawater due to changes like increased water temperature and/or nutrient concentrations. Oxygen is fundamental to the survival of species ranging from microorganisms to large vertebrates, who use oxygen for respiration. Since the mid 20th century, oxygen in the ocean has declined between 1 to 2% and currently, low-oxygen or anoxic areas in the world's oceans are expanding (Laffoley and Baxter 2019).
- **Acidification:** Oceans have absorbed up to 33% of anthropogenic CO_2 emissions over the past decades. The massive increase in CO_2 emissions has changed the chemistry of seawater and increased its acidity (= reduction in pH) because when carbon dioxide mixes with saltwater, it forms a weak acid (Caldeira and Wickett 2003). This in turn affects calcifying organisms such as corals and oysters to form and maintain structures like their shells and skeletons (Feely et al. 2004). A recent review revealed that ocean acidification negatively impacts marine species' (both calcifiers and non-calcifiers) growth, survival, abundance and development, showing how this climate change effect has widespread consequences across marine life (Kroeker et al. 2013).
- **Increased stratification:** Ocean stratification is a natural layering process that occurs because of the different characteristics of ocean water like density, salinity and temperature. Ocean warming makes ocean water more stratified. As a result, there is reduced mixing and stronger layering of the ocean's surface which limits the transfer of essential nutrients from the deep ocean to shallower waters (Helm et al. 2011).

- **Reduced surface productivity:** Declines in the growth and abundance of the microscopic plants, known as phytoplankton, that constitute the base of the marine food web. Primary productivity is declining because of increased stratification, which limits the essential nutrients available to plankton needed for photosynthesis and growth (Bindoff et al. 2019).
- **Sea level rise:** An increase in the height of the ocean surface. Global sea level is influenced mainly by temperature changes that make the average ocean volume to expand or contract, melting of glaciers and ice sheets and changes in land water storage. Sea level rise mainly affects coastal habitats (Bindoff et al. 2019; Oppenheimer et al. 2019).
- **Increased storminess:** Warming ocean and air increase water vapour in the atmosphere that could increase the frequency and intensity of heavy rain and storms, including increase in the peak intensity of tropical cyclones.

The effects of climate change on marine populations, species, and ecosystems were reviewed in the recent IPCC Special Report on the Ocean and Cryosphere in a Changing Climate and numerous peer-reviewed articles (Burrows et al. 2011; Harley et al. 2006; Hoegh-Guldberg and Bruno 2010; Poloczanska et al. 2013). Because people are so dependent on healthy oceans for food, income, and countless other services, these impacts are already affecting our communities.

One notable effect of climate change globally is changing species distributions, a phenomenon that is occurring in both terrestrial and marine environments. In the latter, species that are adapted to cold waters are shifting towards higher latitudes or migrating to greater depths as the world's oceans become increasingly warmer (Poloczanska et al. 2016). Further, there is evidence of changes in the distribution and thermal ranges of top predators such as sharks, tunas and whales (Hobday et al. 2015a). Changes in ocean temperature can indirectly impact sea turtles, marine mammals and seabirds by altering the abundance and availability of their prey as well as affecting their breeding success and survival (Laffoley and Baxter 2016; Sydeman et al. 2015). Likewise, animals may modify their range to avoid oxygen minimum zones (OMZs). Deoxygenation causes metabolic stress in some species and increases their energetic demands (Breitburg et al. 2018; Poloczanska et al. 2016). For example, in the eastern tropical Atlantic, blue sharks modified their diving behavior to avoid the expanded OMZ, thus compressing their vertical habitat occupancy and potentially increasing their vulnerability to fishing gear (Vedor et al. 2021).

The effects of climate change often overlap and interact synergistically with one another. For example, ocean warming and acidification affect the structure of phytoplankton communities across all oceans. Phytoplankton growth and survival depend on factors like temperature, light, nutrients and UV radiation, yet, the responses of phytoplankton to the interaction of climate change effects are species-specific (Bindoff et al. 2019). Climate change has the potential to reduce the biomass of some phytoplankton species, but there is evidence of species that can adapt to new conditions, expand their ranges and others that could thrive under increased nutrient concentrations, lower water pH or warmer sea temperatures and become dominant within their communities (Bindoff et al. 2019; Dutkiewicz et al. 2015; Taucher et al. 2018). A recent meta-analysis found that the responses of phytoplankton are also region-specific: the biomass of non-calcifying phytoplankton species in temperate regions are likely to increase but in the tropics, primary production is likely to decline due to ocean acidification (Nagelkerken and Connell 2015). Other issues, such as ocean warming and acidification have the potential to increase the risk of harmful algal blooms, which are proliferations of phytoplankton that negatively impact marine ecosystems by reducing oxygen availability, disrupting food webs and causing large-scale mass mortality of marine animals (Anderson et al. 2017; Gobler et al. 2017; Riebesell et al. 2018).

Since climate change is causing negative consequences on ecosystem functioning, it also impacts fisheries and therefore, the economy of many countries around the world. It is estimated that by 2100, up to 30% of fish biomass will be reduced because of climate change, mainly due to reductions in marine primary production (Carozza et al. 2019). By 2050, under high CO_2 emission scenarios, global fisheries revenues could decrease by 10.4% (Figure 122), mainly affecting developing countries that are highly dependent on fisheries (Lam et al. 2016). Impacts to fisheries are expected to be disproportionately greater in the tropics than in temperate waters, with some areas projected to display up to 40% reductions in fisheries catch potential by the 2050s (Booth et al. 2018, Lam et al. 2020). In the Eastern Tropical Pacific, the waters in the Galapagos EEZ under climate change scenarios RCP 2.6 and RCP 8.5 are projected to undergo less reduction in fisheries potential than surrounding areas, although there is model disagreement (Figure 121). However, if this were the case, it may lead to increased fishing effort here, as vessels move away from more impacted areas. Under an open access system, this may pose challenges to sustainability and governance.

Additionally, uncertainty regarding shifts in species' distribution, especially of top predators which are often commercially important, is a challenge for efficient fisheries management (Hobday et al. 2015b). Clear evidence of the impacts of climate change on fisheries is that catch composition has been changing through time and it is being increasingly dominated by warm-water species (Cheung et al. 2013). In addition, increased storminess, an effect of climate change, can cause extensive disturbances in marine ecosystems like mangroves and coral reefs (Bindoff et al. 2019; Dutkiewicz et al. 2015; Taucher et al. 2018) and it has potential negative impacts for fisheries because it is a physical threat to fishers and their vessels, and can disrupt fishing effort (Sainsbury et al. 2018). Further, coastal hazards such as extreme and more frequent flooding events, enhanced coastal erosion, salinization of soils and impeded drainage can cause significant economic and biological losses (Oppenheimer et al. 2019).

The Eastern Tropical Pacific (ETP) is an important region that influences global climate variability. Therefore, it has been widely studied to understand the impacts of climate change and the effects of increased greenhouse gas emissions in the upcoming decades. The forecasted impacts of climate change in the ETP are uncertain and varied because of the different models and parameters that are used to make predictions (Brown et al. 2015, Figure 121). The ETP is characterized by a shallower thermocline in the east and an asymmetric sea surface temperature (SST) pattern along the equator, with a warm pool forming in the west and a cold tongue in the east. The Pacific cold tongue is one of the largest natural sources of atmospheric CO_2 and influences El Niño Southern Oscillation (ENSO). In the context of climate change, studies have found an increasing global ocean warming trend as a result of increased greenhouse gas emissions over the last century. Some models suggest that climate change will increase the frequency and amplitude of extreme El Niño events as oceans become warmer (Cai et al. 2014) while other models fail to consistently predict ENSO behavior in a warmer world (Brown et al. 2015; Collins et al. 2010). In the Tropical Pacific, climate change models (like CMIP5) show enhanced warming in the cold tongue. However, there are regions in the Tropical Pacific where cooling has occurred in the upper 700 m due to internal decadal variability associated with ENSO events (Bindoff et al. 2019).

In general, observed SST measurements show no evidence of a clear cooling or warming trend in the central and eastern equatorial Pacific (Coats and Karnauskas 2017) or in the Galápagos Islands in particular (Sachs and Ladd 2011). These SST discrepancies are likely caused by cold biases (a much cooler cold tongue), and biases in the thermocline asymmetry of the ETP included in climate models. A recent study that used a corrected model showed that increased CO_2 emissions cause more warming in the western tropical Pacific, causing stronger trade winds that shoal the thermocline and cools the cold tongue, strengthening the zonal SST gradient. This response favors colder La Niña-like climate trends around the world. The results of this model are in accordance with observed measurements that the ETP is not necessarily warming (Seager et al. 2019). However, predictions of climate change in the ETP must be interpreted carefully, as models are simplified representations of complex and dynamic systems. Therefore, climate change predictions in this region are highly uncertain. To understand the impact of climate change on ENSO events, it is necessary to collect more observations and measurements as well as testing new models (Bertrand et al. 2020).

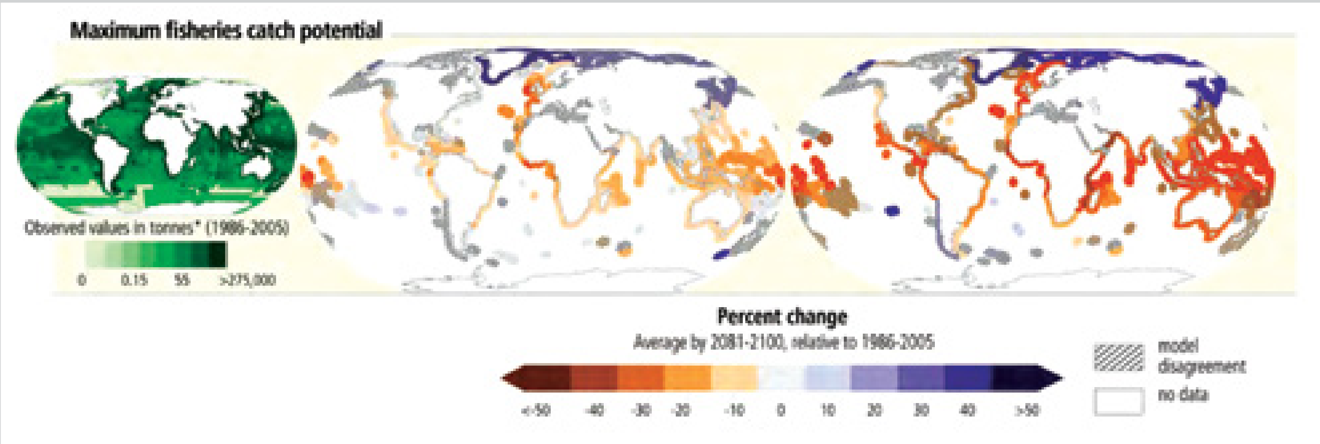


Figure 121. Global predicted changes in maximum fisheries catch potential, based on two climate change models: RCP 2.6 and RPC 8.5. Source: IPCC (2019).

ENSO events shape regional and global climate systems and influence weather patterns, oceanic conditions, productivity and consequently, marine fishery resources (Bertrand et al. 2020; Lehodey et al. 2006). Therefore, it is critical to understand the effects of ENSO on marine capture fisheries because of their economic importance and contribution to the world's food supply and nutrition (Costello et al. 2020; Golden et al. 2016). Due to the complexity of ENSO, it is difficult to predict the strength, frequency and amplitude of future events. Additionally, ENSO events are diverse and vary considerably from one event to another. For instance, El Niño or La Niña events can vary in terms of their intensity (e.g. extreme or moderate) and in terms of the location where their effects are stronger, such as the Central Pacific, Equatorial Pacific or Coastal region. As a result, each event has different impacts depending on its characteristics. However, at a global scale, fisheries landings tend to decline during El Niño years, compared to neutral years, because of the significant decreases in productivity that result from less upwelling and a deeper thermocline. On the other hand, fisheries landings tend to increase during la Niña years because of the colder and more productive conditions. This pattern is stronger in the Pacific Ocean, where fisheries landings records show a negative effect of 0.8 million tons less during El Niño and 1.1 million tons higher during La Niña, compared to landings under neutral conditions (Bertrand et al. 2020).

The effects of ENSO on marine capture fisheries in the ETP varies between types of ENSO events and the target species. In the Southeast Pacific region, that extends from Colombia to southern Chile, extreme and coastal El Niño cause warm ocean conditions and primarily affect the Humboldt Current System, which is linked to upwelling events. During these events, the region also experiences high precipitation and extreme flooding, which can severely impact coastal and small-scale fisheries because of infrastructure damages. In the Galápagos region, Equatorial Pacific and Coastal El Niño events can moderately increase ocean temperature, while Extreme El Niño events can cause moderate to strong increases in ocean temperature and moderate to strong decreases in primary productivity (Bertrand et al. 2020).

One effect of El Niño events is marine species may change their distributions. As the SST increases and the thermocline deepens, some species' distributions shift towards colder areas with higher food availability. Large pelagic predators like tuna are economically important to many countries in the ETP and their distribution also changes as a consequence of ENSO events (see Table 15). Tropical tuna have high energetic demands and foraging requirements, and their habitat is determined by factors like ocean temperature and dissolved oxygen concentrations. Therefore, changes in oceanic conditions due to ENSO can dramatically impact their movements and migrations as they seek favorable habitats (Lehodey 2001; Lehodey et al. 2006). During El Niño, tuna and other large pelagics like bonito and dolphinfish move towards the coast, increasing their susceptibility to fisheries. However, it seems that ENSO-related variability does not have long-term effects on the population dynamics of pelagic fish in the Southeast Pacific Region (Bertrand et al. 2020).

Because of Ecuador's high economic dependence on natural resources, climate change adaptation and mitigation, the Ecuadorian government and other institutions have developed climate change strategies. In 2012, the Ecuadorian government published a National Strategy for Climate Change that identifies key sectors where climate action must be prioritized. The document includes the possible effects of climate change on key sectors as well as adaptation and mitigation strategies. The general forecasted climate change impacts in Ecuador identified in this document include: increased intensity of climatic events such as El Niño, sea-level rise, increased transmission of dengue and other tropical diseases, increased risk of introduction of invasive species in fragile ecosystems such as the Galápagos Islands and overall biodiversity loss. Fisheries are identified as a key sector that will be impacted by climate change. Specifically, the threats to Ecuadorian fisheries in the context of climate change are ocean warming, sea level rise and increased frequency of ENSO events. Additionally, changes in currents and circulation patterns are likely to cause shifts in species' distributions and alter marine trophic dynamics. The adaptation strategies for the fishing sector include measures that guarantee the sustainability of marine resources for food security, the implementation of renewable energy and increased resilience. Other strategies to protect marine ecosystems are to increase protection of marine and coastal ecosystems as well as ensuring connectivity between protected areas to foster species' mobility and adaptation under different climate change scenarios (MAE 2012).

Potential climate change impacts on the Galápagos economy

Nature-based tourism is the main economic activity in the Galápagos Islands, accounting for 77% of the islands' economy (Epler 2007). Although tourism has changed over time, from specialized wildlife enthusiasts to more generalized tourists, the charismatic fauna of the Galápagos is still the main attraction for many, and the number of tourists that visit the islands each year keeps increasing (Quiroga 2013; Quiroga et al. 2011). The tourism sector could be negatively affected by climate change if populations of emblematic species significantly decline or become extinct. Under this scenario, it is expected that international tourism will decline, which will have negative consequences on the local economy as this sector generates the biggest revenues. However, despite the possible effects of climate change on biodiversity, it is unlikely that the tourism sector would collapse and there is the possibility of shifting towards non-nature tourism (Quiroga et al. 2011).

The local fishing sector in Galápagos is exclusively artisanal and although it is not as profitable as the tourism sector, fishing is an important activity that employs around 4% of local residents (Larrea Oña and Di Carlo 2011; Quiroga et al. 2011). In Galápagos, fishermen typically harvest pelagic fishes like yellowfin tuna, wahoo, swordfish, escolar, and to a lesser extent, mahi mahi and sailfish (Ramirez and Reyes 2015), inshore fish like the Galápagos grouper and invertebrates such as spiny lobsters, octopus and sea cucumbers (Quiroga et al. 2011). Some of these species (groupers, lobsters and sea cucumbers) have been overexploited over the last decades (Schiller et al. 2015). The combined effect of overfishing of commercially important species and climate change could lead to stock declines in the future and shifts in spatial distributions (Quiroga et al., 2011). Changes in upwelling could reduce the abundance of many species (Larrea Oña and Di Carlo 2011). Additionally, increased ocean warming could decrease the abundance of cold-water species of demersal fish and intertidal species like octopuses. Conversely, warm-water species like spiny lobsters and tuna species could benefit from increased ocean temperatures. However, significant increases in lobster abundance could lead to their overexploitation. It is unlikely that these changes in the fishing sector as a consequence of climate change effects will impact the economy of the Galápagos islands, however, it would negatively impact fishers that rely economically on fishing products (Quiroga et al. 2011).


Frida Lara

Climate change risk register

We created two risk register tables to organize the most current information regarding climate change in the Galápagos Islands and surrounding waters. The first table includes the main relevant climate change components that were identified in the literature review (see above). To rank the likelihood of each climate change component occurring in the Galápagos Islands, we designed a scale where 0=unlikely, 1=possible, 2=likely and 3=very likely. Additionally, we designed a different scale where, 0=low impact, 1=moderate impact, 2= high impact and 3= very high impact to rank the overall potential impact of each climate change component in the Galápagos Islands. Finally, we calculated the average between the likelihood and potential impact values to obtain the summary status of each climate change component (Table 15).

Key:

Score	Likelihood	Impact
0	Unlikely	Low
1	Possible	Moderate
2	Likely	High
3	Very Likely	Very High

Table 15. Risk register table for the climate change components that are relevant to the Galápagos Islands (for more details see description above).

Climate Change Component	Likelihood	Overall Potential Impact	Summary Status
Higher Sea Surface Temperature (SST)	2	2	2
Reduced amplitude of seasonality	3	2	2.5
Changed strength in currents	2	1	1.5
Increased amplitude of El Niño (EN)	1	3	2
Increased stratification and reduced upwelling	3	2	2.5
Reduced net primary productivity	2	2	2
Reduced dissolved oxygen	2	1	1.5
Reduced fish biomass	1	2	1.5
Sea level rise	2	2	2
Ocean acidification	1	2	1.5
Increased air temperature	3	2	2.5
Changed atmospheric circulation	1	2	1.5

In the second risk register table (Table 16), we categorized the likelihood and impact of different climate change components for each conservation target identified in this report (36). Therefore, we carried out a second literature search in Google Scholar using keywords like "Climate Change" AND the conservation target (e.g., skipjack tuna, whale shark, green turtle, etc.). To obtain information at regional and local levels, we added keywords like "Pacific Ocean" OR "East Pacific Ocean" OR "Galápagos". We also used information from peer-reviewed and grey literature referenced in the papers that resulted from our preliminary search. We used the same likelihood values for the climate change components as in the first risk register table and ranked the impact of each component on the conservation target using information from the literature search. We obtained the summary status for each conservation target by calculating the average between the likelihood and impact values of the climate change component that represented the "worst-case scenario", meaning, the component with the highest likelihood and impact. Additionally, we designed a confidence scale to rank the relevance of the gathered information to the Galápagos Islands, where 3= included peer-reviewed literature in the EPO or Galápagos, 2= included grey literature in the EPO or peer-reviewed papers elsewhere and 1=included literature of proxy species or expert opinion.

Table 16. Risk register table for each conservation object.

Key:

Score	Likelihood	Impact	Confidence
0	Unlikely	Low	
1	Possible	Moderate	Proxy species/Expert opinion
2	Likely	High	Grey literature EPO/ Peer review elsewhere
3	Very Likely	Very High	Peer review EPO or Galápagos

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Pelagic Ecosystem						
Upwelling	Increased amplitude of El Niño	1	In the EPO, strong El Niño events deepen the thermocline and cause inefficient coastal upwelling, bringing warm and low nutrient water to the surface (Bertrand et al. 2020).	3	2	3
	Changes in atmospheric circulation patterns	1	Upwelling is driven by the prevailing meridional winds along the western margins of the islands. If these winds are debilitated, it will impact upwelling processes (Forryan et al. 2021).	2		1
Offshore Seamounts			There are no studies on the effects of climate change on the physical structure and localized upwelling processes of offshore seamounts.		unknown	
Bony Fishes						
Skipjack tuna	Increased amplitude of El Niño	1	The higher SST associated to El Niño events expands the favorable habitat for this species throughout the Pacific and increases larval recruitment in the Western Pacific (Lehodey et al. 2020).	2	2.5	2
	Higher SST	3	Range expansion towards higher latitudes as SST becomes warmer. Models show that in the upcoming decades, the EPO will become a more favorable spawning and feeding habitat for this species (Lehodey et al. 2013).	2		3
Yellowfin tuna	Increased amplitude of El Niño	1	The higher SST associated to El Niño events result in favorable habitat for larval survival in the EPO (Lehodey et al. 2020). As the thermocline deepens during El Niño, this species follows the warm front towards the coast, where it is more susceptible to fisheries (Bertrand et al. 2020).	2	2.5	3
	Higher SST	3	Range expansion towards higher latitudes as SST becomes warmer, resulting in increased catches in the northern EPO (Mediodia et al. 2020).	2		3
	Ocean Acidification	2	Experiments show reduced larvwl survival and size with increasing acidification (Bromhead et al. 2015), as well as physiological damage (Frommel et al. 2016).	1		2

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Bigeye tuna	Increased amplitude of El Niño	1	The higher SST associated with El Niño events result in favorable habitat for larval survival in the EPO (Lehodey et al. 2020).	2	1.5	3
Dorado	Increased amplitude of El Niño	1	As the thermocline deepens during El Niño, this species follows the warm front towards the coast, where it is more susceptible to fisheries (Bertrand et al. 2020). In the EPO, there is evidence of increased parasitic infections following strong El Niño events (Santana-Piñeros et al. 2020).	2	2.5	3
	Higher SST	3	Models suggest a range expansion towards higher latitudes as SST becomes warmer (Salvadeo et al. 2020).	2		3
Wahoo	Increased amplitude of El Niño	1	Increased catch rates in Galápagos following strong 1982-1983 El Niño event (Merlen 1984)	2	2.5	3
	Higher SST	3	This species prefers warm waters (upper mixed layer) and spends less time at great depths than tunas because it is unable to elevate its body temperature (Sepulveda et al. 2011). Although there are no studies on the effects of climate change on this species, it is likely that its range will expand as SST becomes warmer and it can switch preys, as it is an opportunistic piscivore whose prey changes between seasons (Perelman et al. 2017).	2		2
Striped marlin	Higher SST	3	This species prefers warm waters (epipelagic layer) between 20-30°C (Acosta-Pachón et al. 2017) and dives to deeper colder waters to forage or to avoid predators (Lam et al. 2015). Although there are no studies on the effects of climate change on this species, it is likely that its range will expand as SST becomes warmer.	2	2.5	3
	Reduced net primary productivity	3	In the EPO, this species prefers coastal waters with high concentrations of chlorophyll a, which is a proxy of food availability (Acosta-Pachón et al. 2017). It is likely that a reduction in net primary productivity could influence this species' distribution in the Pacific Ocean.	2		3
	Increased stratification and reduced upwelling	3	In the EPO, this species is more abundant in the Humboldt Current region and its presence is associated to coastal upwelling areas (Acosta-Pachón et al. 2017). It is likely that reduced upwelling could influence this species' distribution in the Pacific Ocean.	2		2
Blue marlin	Increased amplitude of El Niño	1	Range expansion towards higher latitudes during El Niño events as SST becomes warmer in the EPO. The habitat becomes more suitable for this species during La Niña events (Farchadi et al. 2019).	2	2.5	3
Blue marlin	Reduced net primary productivity	3	In the EPO, the concentration of chlorophyll-a is an important predictor of suitable habitat for this species (Farchadi et al. 2019). It is likely that a reduction in primary productivity could impact this species' distribution in the Pacific Ocean.	2	2.5	3

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Sailfish	Increased amplitude of El Niño	1	In the EPO, catches of this species have increased in coastal waters during El Niño events. It is likely that this species' range expands during El Niño, following the warm pool in the Pacific Ocean (Martinez-Rincon et al. 2015).	2	2.5	3
	Higher SST	3	In the EPO, SST is the most important oceanographic variable that explains the presence of this species. It prefers warm waters and catches increase when SST is >26°C (Martinez-Rincon et al. 2015). Although there are no studies on the effects of climate change on this species, it is likely that its range could expand as SST becomes warmer.	2		3
	Reduced net primary productivity	3	Sailfish catches by purse-seine fisheries in the EPO are higher in areas with relatively low chlorophyll a concentrations (< 0.25 mg m^{-3}), possibly because phytoplankton makes water turbid, making it difficult for this species to find prey (Martinez-Rincon et al. 2015).	2		3
Swordfish	Higher SST	3	In the EPO, this species is more abundant (higher CPUE) in waters between 15-21°C (Espíndola et al. 2011). Its seasonal movements in the EPO are primarily driven by SST and latitude (Silva et al. 2015). This species' distribution is likely to change as SST becomes warmer (Sculley and Brodziak 2020). Climate models indicate that abundance (CPUE) of this species could decline in the future and that the Pacific stock is likely to shift poleward (Erauskin-Extramiana et al. 2020).	1	2	3
Sunfish	Higher SST	3	In the EPO, the presence of *Mola mola* is associated to cold SST (<17°C) (Hahlbeck et al. 2017). Although there are no studies on the effects of climate change on this species, it is likely that it will be negatively impacted by warmer SST.	2	2.5	2
	Increased stratification and reduced upwelling	3	In the EPO, *Mola mola* is more abundant in upwelling regions because they harbor large aggregations of gelatinous zooplankton, which is their preferred prey (Hahlbeck et al. 2017). It is likely that reduced upwelling could negatively impact this species.	2		2
Elasmobranchs						
Pelagic thresher shark	Increased amplitude of El Niño	1	During El Niño events, a portion of the stock in the EPO (Mexico) shifts northward as SST becomes warmer (Smith et al. 2008). Although there are no studies on the effects of climate change on this species, it is likely that its distribution could change as SST increases.	2	1.5	3
Bigeye thresher shark	Higher SST	3	Throughout its distribution, this species can tolerate colder temperatures than the pelagic thresher shark and can dive at greater depths (Smith et al. 2008). It is unknown how higher SST will affect this species.	1	2	3
Galápagos shark	Changed strength in currents	1	This species is more abundant in areas with strong currents (White et al. 2015). Although there are no studies on the effects of climate change on this species, it is likely that its distribution could be impacted by changes in current strength.	2	1.5	3

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Blue shark	Higher SST	3	Throughout its distribution, this species prefers cold water temperatures between 12-20°C (Nakano and Stevens 2008). In Australia, models suggest that its suitable habitat is likely to be reduced as SST increases (Birkmanis et al. 2020).	2	2.5	3
	Reduced net primary productivity	3	Reduction of suitable habitat in the North Pacific (Hazen et al. 2013).	2	2.5	3
Oceanic whitetip shark	Higher SST	3	Throughout its distribution, this species is most commonly found in shallow surface waters above 20°C (Bonfil et al. 2008). In Australia, models suggest that its suitable habitat is likely to be reduced as SST increases (Birkmanis et al. 2020).	1	2.5	2
Shortfin mako	Higher SST	3	The distribution of this species in the Western and Central Pacific follows seasonal changes in SST and prefers temperate waters between 15-25°C (Kai et al. 2017). In Australia, its suitable habitat is likely to increase as SST becomes warmer. However, as its preferred prey (e.g. tuna) moves towards the poles, this species is likely to follow (Birkmanis et al. 2020).	1	2	2
Longfin mako	Higher SST	3	In Australia, its suitable habitat is likely to increase as SST becomes warmer. However, as its preferred prey (e.g. tuna) moves towards the poles, this species is likely to follow (Birkmanis et al. 2020).	1	2	1
Great hammerhead shark	Higher SST	3	This species primarily occurs in shallow warm coastal waters (in the upper water column) but engage in offshore long-scale migrations (Gallagher and Klimley 2018). There are no studies on the effects of climate change on this species.	1	2	1
Scalloped hammerhead shark	Increased amplitude of El Niño	2	Abundance declines during El Niño events in Cocos Island, Costa Rica (White et al. 2015).	1	2	3
	Higher SST	3	This species prefers warm shallow waters between 23-26°C above the thermocline (Ketchum et al. 2014a). It is unknown how higher SST will impact this species.	1		3
	Changed strength in currents	2	In the EPO, this species is more abundant around islands (e.g. Malpelo, Galápagos), where the currents are strong (Bessudo et al. 2011) and prefers up-current habitats in offshore areas (Ketchum et al. 2014a), likely due to higher food availability). Although there are no studies on the effects of climate change on this species, it is likely that changes in current strength could negatively affect its distribution.	2		3
Smooth hammerhead shark	Higher SST	2	Throughout its distribution, this species prefers warm temperate and tropical waters, typically within the top 20 m of the water column, but evidence shows it can tolerate colder temperate waters as well (Gallagher and Klimley 2018). It is unknown how higher SST will impact this species.	1	1.5	3
Tiger shark	Higher SST	3	In Australia, there is evidence of distributional shifts towards colder coastal waters as SST increases (Payne et al. 2018).	2	2.5	2

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Silky shark	Higher SST	2	Abundance declines during El Niño in Cocos Island, Costa Rica (White et al. 2015). In Australia, models suggest that its suitable habitat is likely to be reduced as SST increases (Birkmanis et al. 2020).	2	2	3
	Changed strength in currents	2	This species is more abundant in areas with strong currents (White et al. 2015). Although the impacts of changed strength in currents will affect this species, it is likely that it can adapt to less productive environments because it is an opportunistic feeder (Bonfil 2008).	1	2	3
Whale shark	Increased amplitude of El Niño	2	Abundance declines during El Niño events in Cocos Island, Costa Rica (White et al. 2015).	2	3	3
	Higher SST	3	In the Galápagos, this species prefers areas with cold water temperatures between 24-25°C and it is more abundant during the cold season (Acuña-Marrero et al. 2014). Warmer SST conditions influence the distribution, composition and abundance of zooplankton, the prey of this species (Richardson 2008). Some models predict small changes of suitable habitats in the EPO under climate change scenarios (Sequeira et al. 2014).	3		2
	Changed strength in currents	1	Higher abundance in Galápagos during cold season, where Humboldt current increases its intensity (Acuña-Marrero et al. 2014). Although there are no studies on the effects of climate change on this species, it is likely that changes in current strength will negatively impact food availability and distributional changes could be expected.	2	3	
Giant manta	Increased amplitude of El Niño	1	Range expansion towards higher latitudes in the EPO due to warm ocean conditions during El Niño events (Moreno and Gonzalez-Pestana 2017). Reduction of manta sightings in continental Ecuador during EN events, likely due to decreases in food availability (Burgess 2017).	3	3	3
	Higher SST	3	Warmer ocean conditions influence the distribution, composition and abundance of zooplankton, the prey of this species (Richardson 2008).	3		3
	Increased stratification and reduced upwelling	3	Mantas are very dependent on upwelling events to feed (Burgess 2017). Therefore, it is likely that reduced upwelling could negatively impact this species.	3		3
Spinetail devil ray	Reduced net primary productivity	3	In the EPO, this species is more abundant in areas with high chlorophyll a concentrations (0.5-1 mg m^{-3}) and this oceanographic variable is the most important to explain its seasonal distribution (Lezama-Ochoa et al. 2019). Although there are no studies on the effects of climate change on this species, it is likely that reduced primary productivity will negatively impact this species.	2	3	3

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Spinetail devil ray	Reduced dissolved oxygen	3	In the EPO, this species is likely to be found at the surface, in areas with low oxygen concentrations (< 200 mg/l) (Lezama-Ochoa et al. 2019).	1	3	3
	Increased stratification and reduced upwelling	3	There are hotspots of this species in coastal upwelling areas across the EPO, like the Galápagos Islands and its movements are influenced by seasonal upwelling systems. Upwelling regions are considered a critical habitat for this species (Lezama-Ochoa et al. 2019).	3	3	3
Pelagic stingray	Higher SST	3	It is hypothesized that in the EPO, this species moves to higher latitudes closer to the coast during the summer, as SST becomes warmer (Neer 2008). Although there are no studies on the effect of climate change on this species, distributional shifts as SST increases are to be expected.	1	2	3
Sea Turtles						
Olive ridley turtle	Increased amplitude of El Niño	1	Moderate declines of hatching success due to increased nest temperatures following El Niño events. Nesting abundance seems unaffected by El Niño in Costa Rica (Atlantic) (Tomillo et al. 2020). In Guatemala (Pacific), decrease of buried eggs following strong El Niño events, but number of nesting females remained the same. It is likely these omnivorous sea turtles can adapt to changing environmental conditions and switch prey (Ariano-Sánchez et al. 2020).	1	1	3
Green turtle	Increased amplitude of El Niño	1	Declines in nesting abundance after the 2015 El Niño in Costa Rica (Tomillo et al. 2020). In Galápagos, green turtles switch from algae of the genuses *Ulva, Spermothamnium, and Centroceras* to less palatable brown algae that is more abundant in warm conditions (Palacios et al. 2011).	2	3	3
	Higher SST	3	Decrease in the number of nesting females after the 2015 El Niño event in the Caribbean, likely due to warmer conditions and declines in food availability (Bruno et al. 2020).	3		2
	Reduced net primary productivity	3	Declines in net primary productivity during strong El Niño events can result in moderate declines of hatchling success (Tomillo et al. 2020).	3		3
	Sea level rise	3	Nest flooding and increased hatchling mortality (Camargo et al. 2020).	2		3
Leatherback turtle	Increased amplitude of El Niño	1	Decreased foraging success due to patchiness of primary prey (gelatinous zooplankton), leading to smaller female sizes and decreased reproductive output of the Eastern Pacific population (Saba et al. 2008). It is likely that El Niño events reduce probability of females remigrating to nesting beaches (Saba et al. 2007).	2	2	2
	Sea level rise	3	Nest flooding and increased hatchling mortality (Patino-Martinez et al. 2014).	1		2
	Increased air temperature	3	Increased hatchling mortality and reduced emergence rates due to dry and warm beach conditions (Saba et al. 2012; Tomillo et al. 2020). Production of female hatchlings that could lead to female-biased sex ratios (Tomillo et al. 2014; Tomillo et al. 2009).	1		3

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Hawksbill turtle	Sea level rise	3	Nest flooding and increased hatchling mortality, although less so that for green turtles (Camargo et al. 2020).	1	2	3
	Increased air temperature	3	Decreases in hatchling success (Montero et al. 2018).	1		2
Seabirds						
Swallow-tailed gull	Increased amplitude of El Niño	1	Low reproductive rates in the main breeding colonies in Galápagos during the 1982-1983 strong El Niño event (Valle et al. 1987). Although there are no studies on the effects of climate change on this species, its response to climate change could be similar to those during El Niño conditions.	3	2	3
Great frigatebird	Increased amplitude of El Niño	1	Low reproductive rates in the main breeding colonies in Galápagos during the 1982-1983 strong El Niño event, as well as high juvenile mortality (Valle et al. 1987). Although there are no studies on the effects of climate change on this species, its response to climate change could be similar to those during El Niño conditions.	3	2	3
Magnificent frigatebird	Increased amplitude of El Niño	1	Reproduction in the main breeding colonies in Galápagos remained unaffected during the 1982-1983 strong El Niño event. However, high juvenile mortality was recorded likely due to food shortage and adults spent more time scavenging (Valle et al. 1987). Although there are no studies on the effects of climate change on this species, its response to climate change could be similar to during El Niño conditions.	2	2	3
Waved albatross	Increased amplitude of El Niño	1	Low reproductive rates in Galápagos during the 1982-1983 El Niño event and egg abandonment in Española Island (Valle et al. 1987). Although there are no studies on the effects of climate change on this species, its response to climate change could be similar to during El Niño conditions.	3	2	3
Galápagos petrel	Increased amplitude of El Niño	1	Lower chick growth rate and mass during 1982-83 El Niño event, but in later years, chicks fledged at similar size and mass (Valle et al. 1987). Thus, it is likely this species can adapt to periods of decreased ocean productivity. Although there are no studies on the effects of climate change on this species, its response to climate change could be similar to those during El Niño conditions.	3	2	3
Blue-footed booby	Increased amplitude of El Niño	1	High precipitation due to the 1982-1983 El Niño event in Galápagos resulted in dramatic increases of vegetation that did not allow boobies to breed or nest on much of the island (Valle et al. 1987). Low reproductive rates in Galápagos during moderate 1986-1987 El Niño event (Anderson 1989a).	3	2.5	3
	Lack of prey species	2	Breeding failure (Anchundia et al. 2014).	3		3
Red-footed booby	Increased amplitude of El Niño	1	Interruption of breeding patterns (Valle et al. 1987). Although there are no studies on the effects of climate change on this species, response to climate change could be similar to during El Niño conditions.	3	2	3

Conservation Object	Climate Change Component	Likelihood	Potential Consequences	Impact	Summary Status	Confidence
Nazca booby	Increased amplitude of El Niño	1	Declines in juvenile survival in Galápagos (Champagnon et al. 2018). Diet changes from sardines to less nutritious prey during El Niño events, which result in reduced hatching and breeding success (Tompkins et al. 2017). Although there are no studies on the effects of climate change on this species, its response to climate change could be similar to those during El Niño conditions.	2	2	3
Marine Mammals						
Galápagos fur seal	Increased amplitude of El Niño	2	Significant population declines and increases in pup and juvenile mortality due to starvation during strong 1982-1983 El Niño event in Galápagos (Trillmich and Dellinger 1991). Increased foraging times due to food availability and distributional shifts towards colder waters (Ventura et al. 2019).	3	2.5	3
	Higher SST	1	Warm conditions reduce prey availability and result in a long-distance displacement (Salazar and Denkinger 2010).	3		3
Galápagos sea lion	Increased amplitude of El Niño	1	Interruption of breeding patterns (Valle et al. 1987). Although there are no studies on the effects of climate change on this species, response to climate change could be similar to during El Niño conditions.	3	2.5	3
	Higher SST	2	Reduced prey availability (Alava 2017) and increased transmission of infectious diseases (Salazar and Denkinger 2010).	3		3
Sperm whale	Increased amplitude of El Niño	1	Decrease in reproductive success during El Niño events in Galápagos (Whitehead 1997). Overall distributional shifts due to declines in prey availability (jumbo squid) and are less abundant near the Galápagos during warmer years (Eguiguren et al. 2020) as well as decreased foraging success (Cantor et al. 2017).	3	3	3
	Higher SST	3	This species' distribution is strongly associated to changes in SST, as evidenced in the Ligurian Sea (Azzellino et al. 2008) and Atlantic Ocean, probably due to changes in the distribution of its main prey (Pierce et al. 2007). Overall, this species is one of the most vulnerable of cetaceans to climate change (Sousa et al. 2019).	3		2
Blue whale	Increased amplitude of El Niño	1	Decreased presence around Galápagos, if this is linked to cool, productive waters providing feeding opportunities during the breeding season (Hucke-Gaete et al. 2018).	2	3	3
	Higher SST	3	Reduced prey availability (krill and copepods) in the Southern Ocean due to warmer conditions, and increased interspecific competition, which may be mitigated somewhat if migration routes change (Tulloch et al. 2019). Reduction of suitable habitat in the North Pacific (Hazen et al. 2013).	3		2
Humpback whale	Higher SST	3	As SST becomes warmer due to oceanographic variability (e.g. PDO), this species can change its diet and switch from krill, which is more abundant in cold water, to sardines. This foraging flexibility may allow this species to adapt to changing ocean conditions (Fleming et al. 2016).	2	2.5	2


Tui de Roy

Threats posed by plastics

The presence of plastic leaking into the environment is a system failure of monumental proportions, which threatens the marine ecosystem and causes physical and chemical contamination on a global scale. Contamination of the terrestrial environment has led to detectable levels of plastic and microplastic (defined as plastic <5 mm in size) pollution in soils and freshwaters across continents (Boyle and Örmeci 2020), but it is the contamination of the marine environment that has raised global societal attention, estimated at up to 12 MT of plastic entering the oceans each year (Jambeck et al. 2015 based on 2010 data). The economic damage from marine plastic pollution amounts to around US$13 billion USD per annum (UNEP 2014), due to the environmental and social cost of polluted and degraded environments including the loss of revenue from tourism, and costs of clean up and repair (Beaumont et al. 2019). A Global Waste Management Outlook Report from UNEP estimates the costs to the economy and to society of inadequate waste management are up to ten-fold higher than the costs of implementing proper waste management systems (Wilson et al. 2015).

The Eastern Tropical Pacific is a region of emerging concern. "It is estimated that 45% of all plastic used along the Pacific coastline of South and Central America is inadequately managed" (Savino et al. 2018), generating around 1 million tons of mismanaged plastic waste, an annual figure that is predicted to double by 2025 if no action is taken. The increasing abundance of shoreline and floating litter in Eastern Pacific coastal waters is, as seen all over the world, a consequence of poor waste management in urban areas, intentional domestic waste dumping and subsequent transport by rivers, recreational and tourism activities on the shore, and aquaculture and fisheries activities (Figueroa-Pico et al. 2016; Lebreton and Andrady 2019; Gaibor et al. 2020). Whilst some litter is directly deposited on beaches or reaches the coastal zone via rivers and accumulates on shorelines (Gaibor et al., 2020), a large proportion of litter is being exported by the offshore transport in upwelling systems along the Eastern Pacific, as shown by field and modelling studies (Gennip et al. 2019; Thiel et al. 2018; van Sebille et al. 2019) meaning that plastics are often transported far from source making inputs hard to define and presenting risks to remote habitats.

Fisheries and tourism are central to the Ecuadorian economy and in particular to the economy of the Galápagos Islands. As observed by Beaumont et al. (2019), the "productivity, viability, profitability and safety of the fishing and aquaculture industry is highly vulnerable to the impact of marine plastic, particularly when coupled with broader factors including climate change and over-fishing". Nature based tourism destinations depend on the true or "perceived" health of the wildlife and aesthetic condition of the landscape (Krelling et al. 2017; Ruiz-Orejon et al. 2018).

Mestanza et al. (2019) found that beaches near the harbor and at tourist sites in Galápagos were generally very clean, a likely result of small population size, elevated environmental expectations of visitors and good provision of bins and awareness messaging. Galápagos National Park Guides and community groups also do regular cleans, but accessible sites are limited and do not generally include remote, east-facing beaches that require expensive, multi-day cleaning campaigns. It is important however to recognize that the amount of urban littering and dumping in the towns of Galapagos can be significant and local microplastic inputs are measurable around populated areas e.g. from wastewater and increased shipping activity indicating that local efforts are still required (Jones et al. 2021; Schofield et al. 2020).

Over 22 tons of plastic were cleared from beaches around Galápagos in 2018 alone, and periodic clean-up operations organized by the Galápagos National Park and Conservation International Ecuador over the last two years have resulted in at least 2 tons collected per trip (El Comercio 2021b). At an island scale, microplastics have been recorded at the sea surface (0.04–0.89 particles $^{m-3}$), in benthic sediments (6.7–86.7 particles kg-1), and on the beach (mean concentration by site 0–449 particles m^{-2}, highest concentration measured 808 particles per m^{-2} (Jones et al. 2021). Plastics pose a threat to fragile systems via physical habitat contamination, injury risk to animals and as a potential vector for sorbed chemicals, pathogens and invasive species (Figueroa-Pico et al. 2016, Lebreton and Andrady 2019). This is of particular concern in Galápagos where invasive species are considered one of the greatest threats to island biodiversity. Microplastics pose a substantial risk to marine life, with widespread evidence of consumption across trophic levels, potentially reducing feeding, growth, fecundity and increasing morbidity to fishery target species and a potential risk to human health (Cox et al. 2019; Haegerbaeumer et al. 2019; Savoca et al. 2021). There is already evidence of microplastic ingestion in the Galapagos marine food web, with 52% of marine invertebrates (123 individuals across 7 species) containing microplastics although the level of harm is currently unknown (Jones et al. 2021). All vertebrate taxa present in Galápagos are known to ingest plastic in other geographic areas and suffer from entanglement (Figure 122) but little is known of levels of interaction although anecdotally it appears severe and worsening, with at least 31 animal species observed to negatively interact with plastic in Galápagos (J.P. Muñoz, pers. obs.). This is further supported by a recent desk-based risk assessment, which identified 27 species of high importance for mitigation action with top scoring species including the waved albatross, Galápagos sea lion, Galápagos fur seal, Galápagos penguin and green turtle (Jones et al. 2021).

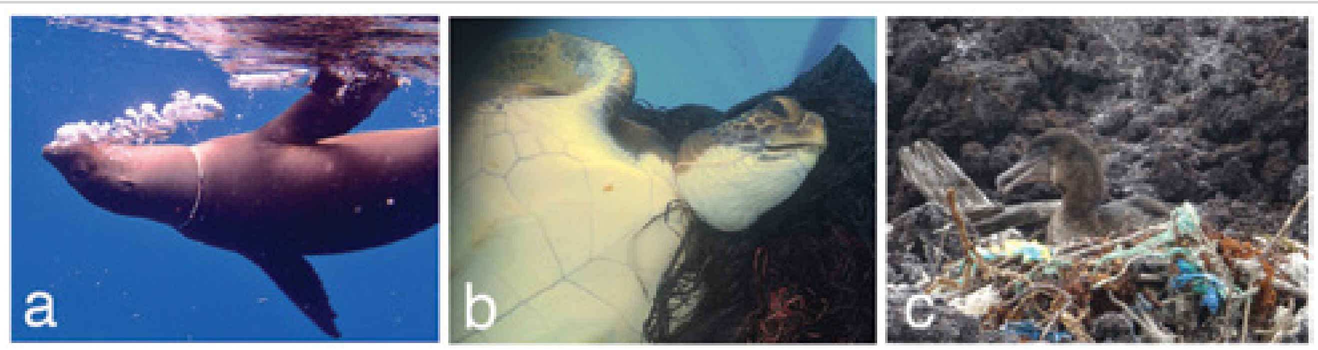


Figure 122. Photographic observations of Galapagos wildlife interacting with plastic items. (a) A Galápagos sea lion *(Zalophus wollebaeki)* with plastic sheeting wrapped around its neck (credit: Juan Pablo Muñoz-Pérez); (b) a green sea turtle *(Chelonia mydas)* entangled in fishing net (credit: Manuel Yépez-Revelo); (c) a flightless cormorant *(Phalacrocorax harrisi)* on its nest including many plastic items, predominantly ropes (credit: Catherine Hobbs). Source: Jones et al. (2021).

Modeling approaches have identified continental inputs as a major source of incoming plastic pollution to the Galápagos Marine Reserve, mostly from southern Ecuador and northern Peru where leaked plastic could arrive within a few months through riverine inputs and coastal waste mismanagement (van Sebille et al. 2019).

Action is already starting in Galápagos and in 2018, a series of bans of single use plastic items were introduced including a particular type of plastic carrier bag, straws, styrofoam takeaway containers and non-returnable soda bottles. This has largely been well accepted by local communities and tourists and has provided a platform for alternative products and outreach campaigns to highlight the issues of plastics. Although highly commendable, these targeted items are only a tiny fraction of plastic pollution in the environment however (< 1% of 2,240 items categorized across 17 beaches around San Cristobal Island, see Figure 123, after Jones et al. 2021) and therefore policy interventions are required to tackle more common items through bans and taxes and through the implementation of improved waste management protocols particularly for ocean industries of fisheries and tourism.

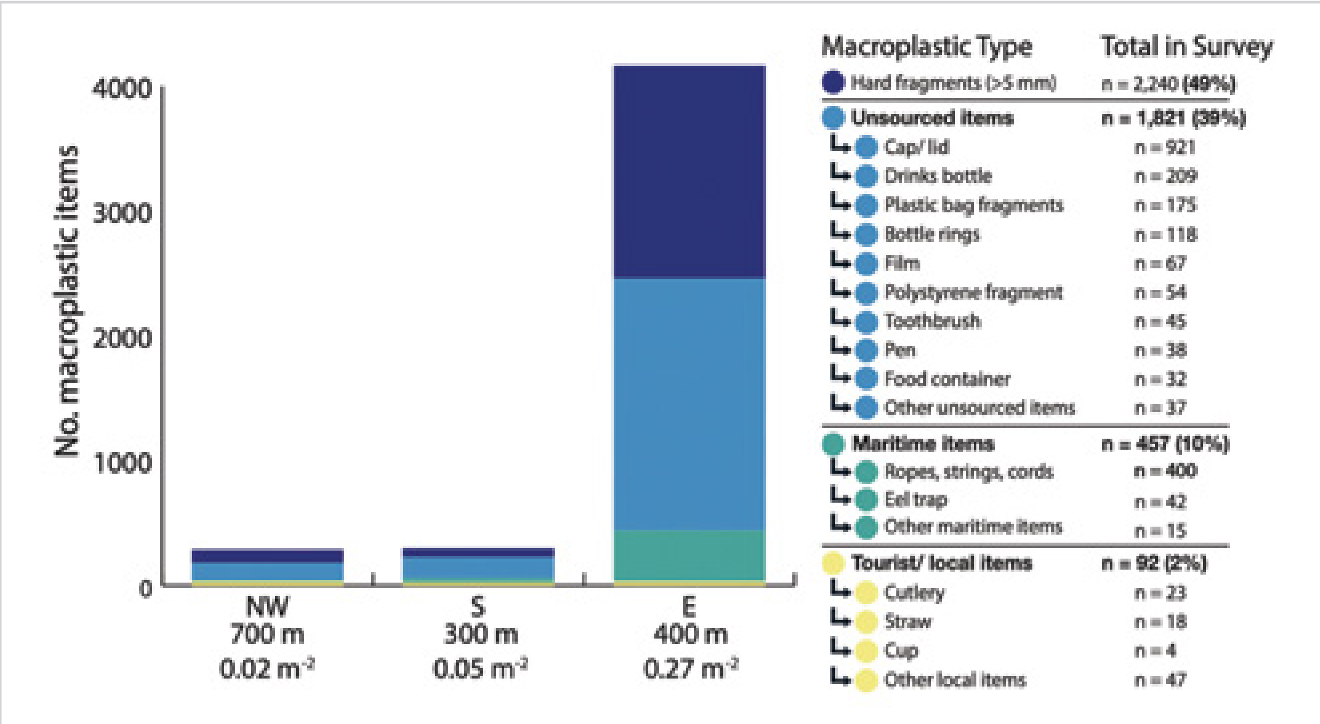


Figure 123. Composition of beach macroplastics found on San Cristobal Island, Galápagos, Ecuador. Items recovered from the beach surface across 14 north/west, south and east facing beaches (NW, S, E) with total distance surveyed (m) and mean litter density (items·m^{-2}) labeled for each group. Totals and percentage of each item source type are reported across the full 1.4 km surveyed coastline in the key along with a breakdown of major contributing items. Source: Jones et al. (2021).

Globally, coastal clean up data suggest that 28% of plastic pollution is from maritime sources (fishing, aquaculture and shipping) but at sea observations may yield a greater estimated input from these sources (Lebreton et al. 2018). In the Galápagos Marine Reserve, models suggest that only a small amount of plastic is entering from known industrial fishing grounds but this does not reconcile with unpublished coastal clean-up data or archaeological analysis of macroplastic items (Schofield et al. 2020; van Sebille et al. 2019). In San Cristobal, 10% of macroplastic found along shorelines was from fishing gear, primarily polypropylene and nylon ropes and lines (Jones et al., 2021). Due to the small size of the artisanal fishery, the majority of this litter is likely floating in from outside the Marine Reserve boundary. Connectivity with the continental fisheries is clear with the regular occurrence of eel traps, a gear not used in Galápagos. Every survey done by the authors of this contribution to date (> 10) has reported the occurrence of floating or beached Fish Aggregation Devices, that not only have negative consequences for fishery exploitation, but also represent a major ghost-fishing risk whilst in the water, an entanglement risk on the beach and a major future source of microplastics.

Fishery sources are also responsible for domestic waste including drinks-related debris that is very common including bottles, caps and sealing rings (53% of unsourced items recorded in the San Cristobal study, N = 1,821). Packaging with Chinese lettering was recorded at several eastern sites but oceanography dictates that these items could not have come from mainland Asia pointing to release from maritime sources (van Sebille et al. 2019; Alarcón and Alvardo Proaño 2022). This suggests potential violation of the regulations of the 'International Convention for the Prevention of Pollution from Ships' (MARPOL), as highlighted by previous littering studies on Inaccessible Island in the South Atlantic where domestic litter from ships is commonly found (Ryan et al. 2019).

To fix the problem of increasing plastic waste washing up in remote islands such as Galápagos, a regional approach is needed to understand polluting sources, to understand ecological and social impacts and to develop mitigation interventions at an effective scale. Pacific Plastics: Science to Solutions is an initiative with 18 organizations from Ecuador, Chile, Peru and Europe that launched in 2021 aiming to collect the evidence needed to support progressive plastics and pollution prevention policies, to improve waste management in the continent and fisheries and to strengthen laws prohibiting littering at sea (https://www.pacificplasticssciencetosolutions.com).


Sofia Green

Marine Traffic

Marine traffic can include the movements of fishing, leisure/passenger, military, oil and gas, and commercial ships. With the exception of vessels delivering fuel to the islands, the presence of oil tankers near Galápagos is not permitted since the designation of the GMR and a surrounding buffer zone as a PSSA in 2005 (IMO 2020), following the Jessica oil spill (Edgar et al. 2003). Fishing activities in the Galapagos EEZ are addressed elsewhere in this document. Cruise boats are all permanently based in Galapagos, so the only large vessels that may operate in the area are commercial transport ships.

Commercial shipping may pose a range of risks to marine biodiversity (Erbe et al. 2020), including physical strikes (Pirotta et al. 2019), noise – in particular to marine mammals (e.g. Williams et al. 2015), pollutants from voluntary or involuntary discharges (Pirotta et al. 2019, Walker et al. 2019), and risk of transport of invasive species (Toral-Granda et al. 2017). Globally, shipping accounts for approximately 80% of transportation of international trade goods (UNCTAD 2019), and the total volume of goods has increased fourfold in the last half-century (Erbe et al. 2020). To identify any major shipping routes in the Galapagos EEZ, we accessed the World Bank global shipping traffic density database, which provides hourly AIS positions reported by ships globally between January 2015 and February 2021, in grid cells of 0.005° x 0.005°. This corresponds to and area of approximately 500m x 50m at the equator (https://datacatalog.worldbank.org/search/dataset/0037580). We plotted this information at global and local scales (Figure 124).

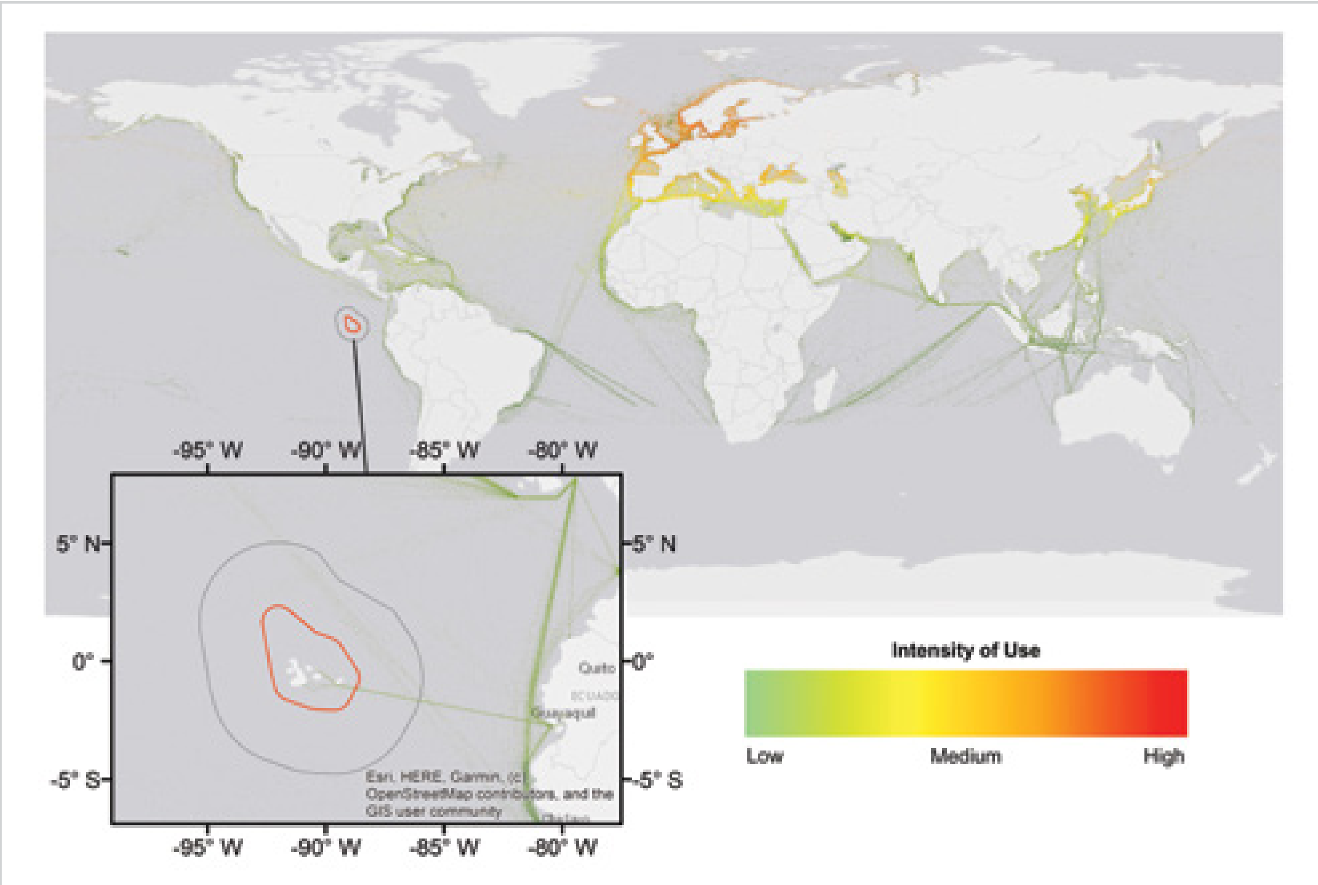


Figure 124. Commercial shipping traffic intensity between January 2015 and February 2021. Source: World Bank 2021, https://datacatalog.worldbank.org/search/dataset/0037580).

Globally, shipping activity is concentrated around Europe, China, both coasts of the USA, and the east coast of South America, and along the pathways that link these areas (Figure 124). Shipping in the Eastern Pacific is concentrated along pathways originating at the Panama Canal, south to Guayaquil and the rest of the South American coastline, or northwards towards Mexico. The only clearly distinguishable route to the Galapagos Archipelago is that of the cargo vessels from mainland Ecuador that supply the inhabitants of the islands, although some diffuse activity is registered across the north-east and south-west of the EEZ.

Tui de Roy

Spatial Planning

To address the open-water threats to the Galápagos ecosystem, we undertook a systematic spatial planning exercise across the Galápagos EEZ. We used the spatial planning program Marxan (Ball and Possingham 2000, Ball et al. 2009), which is a tool to prioritize areas to achieve area-based conservation targets while minimizing costs, and is the most widely used of several systematic conservation planning tools (Watts 2016). In Marxan, the area under consideration is divided up into cells or planning units. A list of conservation features is defined – which may include species distributions, key habitats among others, and then targets (in the form of the amount of coverage) are set for each feature. A cost value is assigned to each planning unit (in the case of this study this is based on the catch for longline and industrial tuna fishing fleets). Marxan then calculates a series of conservation scenarios based on the number of features included in each planning unit, minimizing the overall cost and fragmentation (Delavenne et al. 2012). If over a series of runs, particular planning units are selected more frequently than others, this can help to prioritize where protected areas might be placed.

Conservation Layers

Our conservation layers were based on the previous section of conservation objectives. We created four types of conservation layers (each of which were given the same weighting), for a total of 54 layers:

1. Key ecosystem processes: we created three layers, each based on the core upwelling areas in recent El Niño, La Niña and neutral years (as calculated in Figures 96-98). These layers provided us with guidance on how productivity may change inter-annually, and, in particular, where upwelling refugia may be located during El Niño conditions, which may provide insight on how climate change may affect the upwelling dynamics in and around Galápagos.

2. Key habitat: we created four bathymetric layers based on different seabed depths to show the presence of seamounts or ridge habitat off the Galápagos platform (500-1000 m, 1000-1500 m, 1500-2000 m, 2000-2500 m). These seamount and ridge areas provide connectivity with other regions, may also play an important role in carbon sequestration (e.g. Barnes et al. 2019) and are important themselves as areas of biodiversity aggregations and local upwelling (not captured by the meso-scale model described in the previous point).

3. Species distributions: we used the range maps of 31 species detailed in the previous section to provide a general distribution for each of these within the Galápagos EEZ. For some species, this is the best available information, although we acknowledge that these maps are coarse and do not reflect temporal variation in species distributions.

4. Species tracks: where available (for 16 species), we compiled existing tracking data to create core occupancy maps in addition to the distribution maps. We used Argos satellite Doppler-based positions (nominally with an error of less than 5 km) from tags placed on individuals to carry out a kernel density analysis for each species (Figure 125). We then applied a 90% threshold (which we equated to home range) to 12 species, where tracks were either few or did not display

consistent movement patterns, and a 50% threshold (which we equated to areas of high use) to four species where the datasets showed clear movement corridors (whale sharks, Galápagos petrels, waved albatross and leatherback turtles). Note that as a result of using species tracks, these species contributed two layers to the analysis – an overall distribution (see above) and a home range or high occupancy layer.

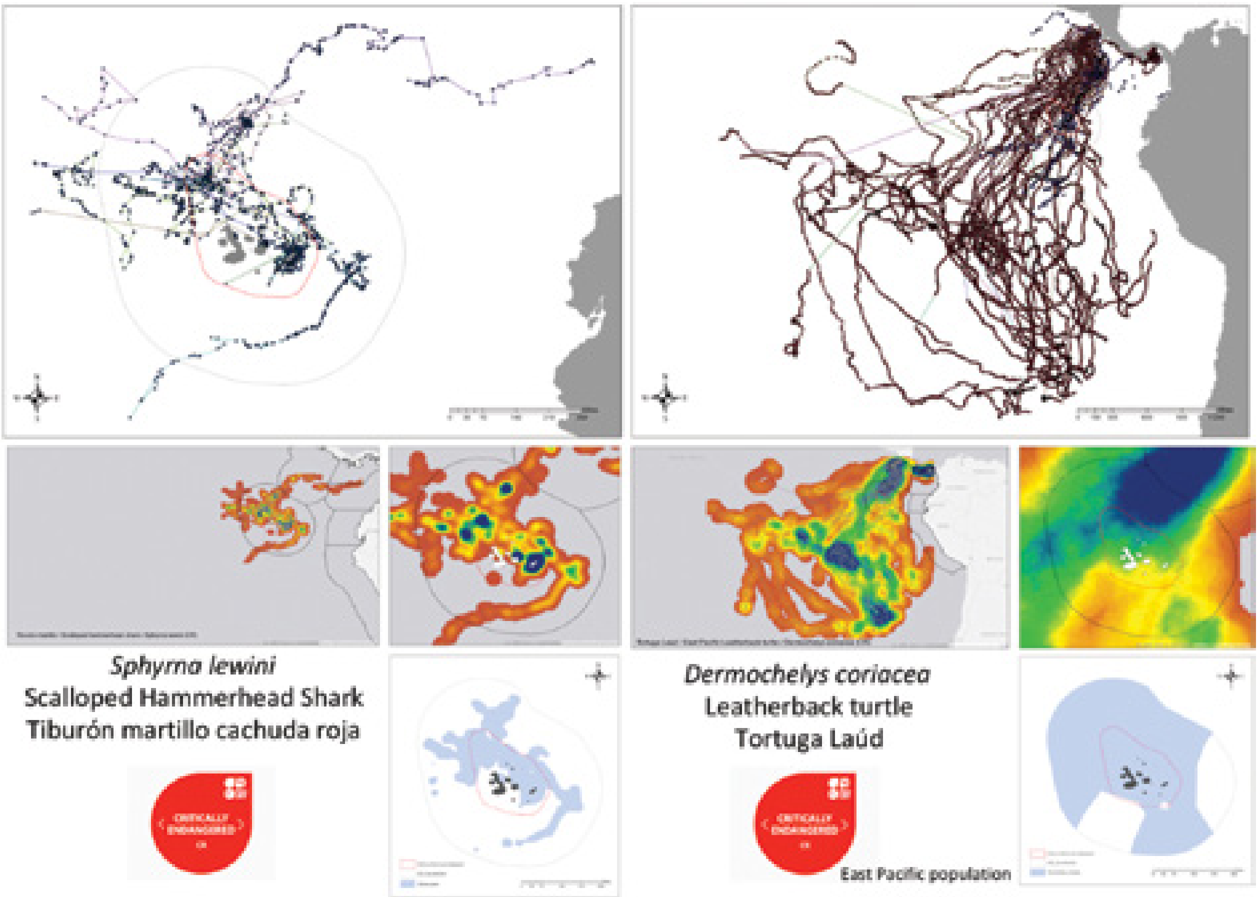


Figure 125. Two examples of how animal movements were used to generate conservation layers for Marxan exercise. Left panel: (top) positions and tracks from scalloped hammerhead sharks tagged in Galapagos (N=26) were used to carry out a kernel density analysis (middle left), showing the density distribution of all positions, with 50% of the positions concentrated in the green-blue areas. We clipped this map to the Galapagos EEZ (middle right) and then created a conservation layer from the entire track (bottom). Right panel: (top) positions and tracks from post-nesting leatherback turtles from Costa Rica (N=46) were used to carry out a kernel density analysis (middle left) showing the density distribution of all positions, with 50% of the positions concentrated in the green-blue areas. We clipped this map to the Galapagos EEZ (middle right) and then created a conservation layer from only the area in which 50% of the positions were concentrated (bottom).

Estimation of Fishing Costs

We obtained spatially explicit information from industrial tuna fishing published by Bucaram et al. (2018) and artisanal longline fishing published by Martínez-Ortiz et al. (2015). Industrial fishing catch and effort data were collected by the Inter-American Tropical Tuna Commission onboard observer program. According to Bucaram et al. (2018), this dataset covered all class 6 tuna purse-seine vessels that fished in the EPO from 1990 to 2009. "During the

1986–1991 period, coverage of the international fleet ranged between 30% and 60%; however, since then, it has been close to 100% for class 6 vessels" (Bucaram et al. 2018). In addition, class 5 vessels that fished for tuna associated with dolphins were also monitored from 1994 to 1997. This dataset comprises data only from yellowfin tuna *(Thunnus albacares)*, bigeye *(Thunnus obesus)* and skipjack *(Katsuwonus pelagicus)*, but does not include associated catch or discards. For more information on this dataset please review Bucaram et al. (2018).

For the industrial tuna fleet, we converted each individual net set into a total value in US dollars, based on the catch for the three main tuna species: yellowfin, skipjack and bigeye. It is important to note that sets sometimes contained associated species, which also have market value, but we were unable to access this information. However, because our final objective was to provide a relative, rather than an absolute, cost value across the EEZ, it is likely that the presence of associated species would have a small to negligible effect on the overall results. For each of the three tuna species, we obtained average annual value per ton for each species (Bucaram and Cardenas 2020) over the period 2007-10 (Table 17).

Table 17. Price (in US$) per ton for tuna landings in Ecuador 2007-10, used to calculate catch value for tuna fleet. Source: Cámara Nacional de Pesca.

Year	Yellowfin	Skipjack	Bigeye
2007	1,550	1,400	1,450
2008	1,800	1,600	1,700
2009	1,300	1,170	1,220
2010	1,600	1,480	1,520

The large pelagics longline fishery landings were monitored by the Monitoring Control System (Sistema de Control y Monitoreo) implemented by the Republic of Ecuador via the Subsecretaria de Recursos Pesqueros, Viceministerio de Acuacultura y Pesca (SRP-VMAP) in October 2007 (Martínez-Ortí et al. 2015). According to Martínez-Ortiz et al. (2015), a total of 115,487 fishing trips were monitored by the SCM program in the five main artisanal fishery ports of Ecuador from January 2008 to December 2012. The study excluded records from 2007 (considered as "training"), 71 trips where fleet category was unknown, and 17 trips from vessels pertaining to other fisheries. Species covered for this dataset are listed in Table 18. For more information on this dataset see Martínez-Ortiz et al. (2015).

As with the industrial tuna fishery, we converted catch per set into values in US dollars, using price references from target species, including shark meat (but not fins) – sharks are not legally recognized as a target group in Ecuador, but landings data clearly show that they make up a significant proportion of the catch for this fleet (Martínez-Ortiz et al. 2015). The prices used for this dataset were referential (Table 17), as it was not possible to find published ex-vessel prices for the majority of species, except for swordfish, which was US$ 5.50 per kilogram in 2011 (El Comercio 2011). We set a nominal value for all shark meat at US$ 0.50 per kilogram based on conversations with former staff at the Subsecretaría de Recursos Pesqueros. For other resources, we asked stall owners at the main artisanal fleet landing site at Tarqui Beach in Manta, what the current (2020) and past (2014) prices were.

For each dataset, we aggregated the catch records into 25 NM cells (corresponding to the planning units, or PUs, described below).

We then divided the values into ten equal interval groups, and assigned each cell a corresponding value from 0-10 (Figure 126, left and right). Finally, we summed the values for both fleets to generate an integrated relative cost layer from 0-20 (Figure 126, bottom).

Table 18. Market value (price) of a wet-pound of each of the assessed species in this study (Note: price does not include shark fins).

Scientific Name	Value 2015	Value 2020	Reference
Bony fish			
Acanthocybium solandri	3	3	At pier price
Coryphaena equiselis	2.25	2.5	At pier price
Coryphaena hippurus	2.25	2.5	At pier price
Euthynnus lineatus	1.6	2	At pier price
Istiompax indica	3	3.25	At pier price
Istiompax, Kajikia, Makaira	3	3.25	At pier price
Istiophorus platypterus	1	1.2	At pier price
Kajikia audax	3	3.25	At pier price
Katsuwonus pelamis	1.6	2	At pier price
Makaira nigricans	3	3.25	At pier price
Thunnus albacares	1.6	2	At pier price
Thunnus obesus	1.6	2	At pier price
Xiphias gladius	3	3.25	At pier price
Cartilaginous fish			
Alopias pelagicus	0.5	0.5	At pier price
Alopias spp.	0.5	0.5	At pier price
Alopias superciliosus	0.5	0.5	At pier price
Alopias vulpinus	0.5	0.5	At pier price
Carcharhinus albimarginatus	0.5	0.5	At pier price
Carcharhinus falciformis	0.5	0.5	At pier price
Carcharhinus galapagensis	0.5	0.5	At pier price
Carcharhinus limbatus	0.5	0.5	At pier price
Carcharhinus longimanus	0.5	0.5	At pier price
Carcharhinus obscurus	0.5	0.5	At pier price
Carcharhinus spp.	0.5	0.5	At pier price
Galeocerdo cuvier	0.5	0.5	At pier price
Isurus oxyrinchus	0.5	0.5	At pier price
Isurus paucus	0.5	0.5	At pier price
Lamna nasus	0.5	0.5	At pier price
Prionace glauca	0.5	0.5	At pier price
Pseudocarcharias kamoharai	0.5	0.5	At pier price
Sphyrna lewini	0.5	0.5	At pier price
Sphyrna zygaena	0.5	0.5	At pier price

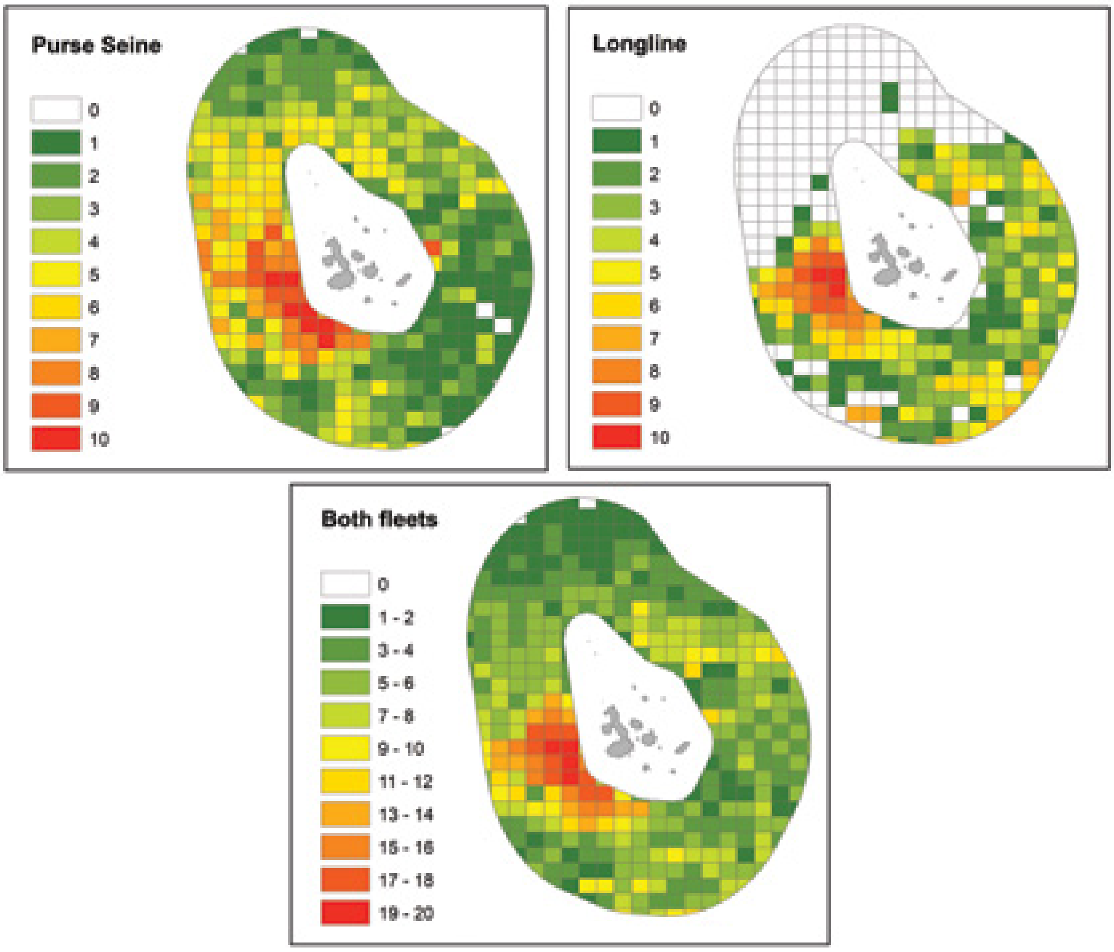


Figure 126. Division of Galápagos EEZ into relative cost layers (0-10) for tuna fleet, based on 2007-10 spatially explicit catch records (top left), and for large pelagics longline fleet, based on 2008-12 spatially explicit catch records (top right). Bottom: summed values (0-20) for both fleets combined.

Spatial Analysis

We initially carried out six modeling exercises for the full Galápagos EEZ, including the existing marine reserve. Using the cylindrical equal area world projection (EPSG 54034), the Galápagos EEZ was intersected using a 4 km^2 grid and each cell (hereafter referred to as "planning unit" or "PU") was assigned a unique ID number (n=211,819). Raster-based fishing costs were assigned to each PU using a mean of any overlapping features. Each raster was on a scale of 0-10, meaning that the cost layer was on a scale of 0-10 (for each individual fleet) or 0-20 for the scenarios where the fishing fleets were combined.

Each feature (N=54) was assigned a unique ID and intersected by the PU grid, calculating how much area of each feature is present in each PU. The status of each PU was set as either available or conserved. Any PU that was covered by 50% or more by the existing Galápagos Marine Reserve was marked as conserved. We created the base Marxan setup files using the QGIS plugin 'QMarxan Toolbox (v2.0.1)'. We clipped the area of each conservation feature to that of the GMR to calculate how well each feature was represented inside the GMR. We used this information as a baseline to understand how different scenarios might increase protection for each of the features (Table 19).

Table 19. Conservation features used in Marxan runs. In red, those for which ≥90% of the published range fell within the existing GMR and were therefore removed from consideration for the scenarios that excluded the GMR (for those species with asterisks, the data are limited and their range and movements likely extend beyond the GMR).

Processes and Habitats	General Distributions
High productivity areas 2008 (La Niña)	Pelagic thresher shark
High productivity areas 2012 (neutral)	Bigeye thresher shark
High productivity areas 2015 (El Niño)	Galápagos shark
Seamounts (2000-2500m)	Oceanic whitetip shark
Seamounts (1500-2000m)	Shortfin mako shark
Seamounts (1000-1500m)	Longfin mako shark
Seamounts (500-1000m)	Great hammerhead shark*
	Scalloped hammerhead shark
Species Tracks	Smooth hammerhead shark
Silky shark	Silky shark
Blacktip shark	Blacktip shark
Galápagos shark*	Tiger shark
Blue shark	Blue shark
Whale shark	Whale shark
Tiger shark*	Giant manta
Scalloped hammerhead shark	Olive ridley turtle
Green turtle	Green turtle
Leatherback turtle	Leatherback turtle
Hawksbill turtle*	Hawksbill turtle
Frigatebird	Swallow-tailed gull
Waved albatross	Frigatebird
Swallow-tailed gull	Waved albatross
Galápagos petrel	Galápagos petrel
Blue-footed booby	Blue-footed booby
Galápagos sea lion	Red-footed booby
	Nazca booby
	Galápagos fur seal
	Galápagos sea lion
	Sperm whale
	Blue whale

For each fleet (longline, purse seine and combined), in order to provide a range of results for discussion, we set minimum conservation feature coverage targets on an ad-hoc basis of 30% and 50% respectively. Each scenario was first run on a Boundary Length Modifier (BLM) of 0 and a Species Penalty Factor of 0. SPF was then increased incrementally by a value of 0.5 until all targets were met at 100 (Runs = 100, iterations = 1,000,000). Marxan was then run using the new SPF parameters and the summed solution of each PU (how many times each PU was selected) was assessed (Runs = 200, iterations = 1,000,000). Key areas were selected from each scenarios as being the areas selected in 90% or more of the runs. Key areas for both fisheries were compared to highlight any overlapping PUs.

Second, we re-ran the same six modeling exercises, but excluding the existing GMR, in order to assess how the GMR could be built upon in the pelagic region of the EEZ. This allowed us to focus on those species that are less centered inside the GMR. By removing the area inside the GMR, 177,392 planning units remained. As several of the ranges for the conservation features were largely found within the GMR and therefore have most of their range protected, any feature where ≥90% of the range was within the GMR was excluded from this scenario (N=11). The total number of remaining conservation features was 43.

In summary, we produced twelve scenarios: one for each combination of fleet (longline, purse seine, combined), area (full EEZ, EEZ excluding GMR), and conservation coverage target (30%, 50%).

Baseline: Current Performance of the GMR

Across the Galápagos EEZ, the maximum number of conservation features in a single PU was 44, while 18 features covered the whole EEZ. The average coverage was 45.5%, with 24 features met at 30% and 21 features met at 50%. Six features were fully protected inside the current Galápagos Marine Reserve – these included both endemic species of pinnipeds (Galápagos fur seal and Galápagos sea lion), the blacktip shark and the Galápagos shark (both of which mostly associate in coastal waters around the islands), and the hawksbill turtle – which has only been tracked in limited numbers and for short periods in the GMR. Finally, the core productivity area for 2015 (El Niño conditions) lay entirely within the current GMR boundaries (Figure 127). For coverage of each conservation objective, refer to Appendix B.

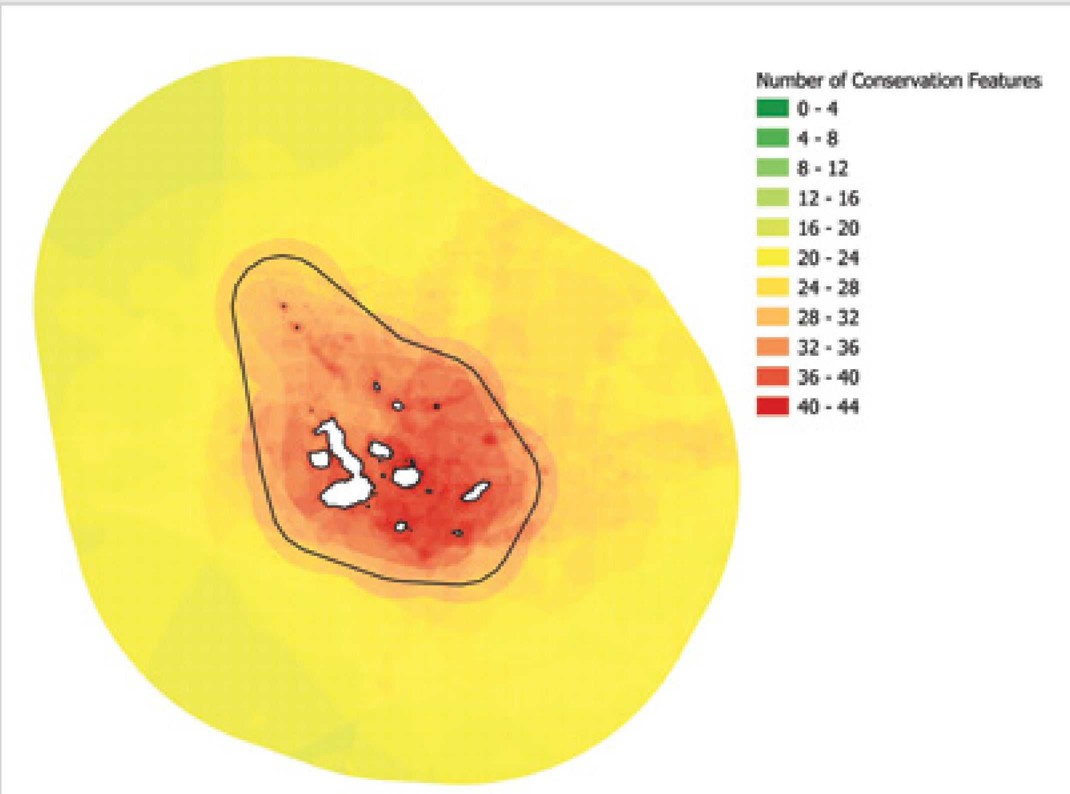


Figure 127. Distribution of conservation features (N=54) throughout the Galápagos EEZ, with 44 being the maximum number of features in any one planning unit (PU).

Marxan Outputs for Full EEZ

Due to the intensity of fishing in a relatively small area (to the southwest of the EEZ), Marxan outputs for both longline (Figure 128) and tuna (Figure 129) were largely driven by cost, rather than by the biodiversity value of the PUs. The outputs highlight the PUs that were selected in at least 90% of the 200 Marxan solutions. The frequently selected areas are those which are often selected for meeting biodiversity targets for minimal costs, and so may be useful areas to start consideration for protection. It is important to note that these areas do not meet biodiversity goals by themselves: other areas will need to be included, but as these areas are higher costs, they were selected less frequently in the Marxan solutions. In the case of the longline fleet, because the cost was concentrated in a relatively small area, there was a lot of flexibility in the summed solutions – there were large areas that were able to be selected for low cost, so only a few areas (to the east and southeast of the GMR) were selected very regularly (Figure 128). In the case of the industrial tuna fleet, Marxan also tended to select low-cost areas rather than high-biodiversity PUs, however with a marked tendency to the southeast quarter of the EEZ (associated with the Carnegie Ridge) and, to a slightly lesser extent, the northern area (associated with the Cocos Ridge) (Figure 129).

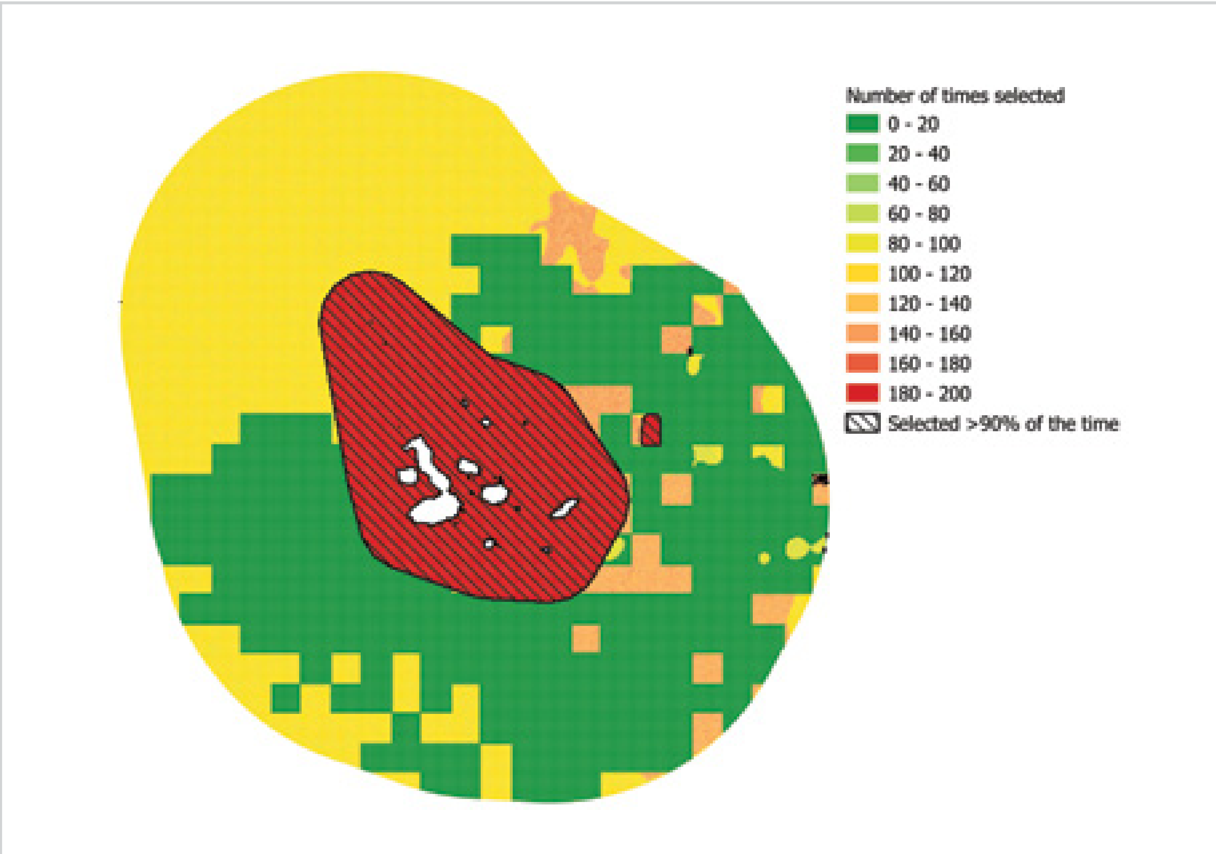


Figure 128. Summed solution Marxan outputs for 30% coverage of conservation features, using Ecuadorian large pelagics longline fleet as cost layer. Hashed areas were selected ≥90% of the time (the existing GMR was locked in, and thus selected on every run).

The summed solution for both fleets with a target coverage of 30% was driven largely by the tuna fleet scenario, and again, highlighted the region to the southeast and the north (Figure 130).

Increasing the conservation target from 30% to 50% increased the number of PUs selected ≥90% of the time in both individual fishery cost layers (Figures 131 and 132), to include some areas adjacent to the current GMR boundaries along the northeastern and southeastern edges, and further along the Carnegie Ridge, in particular for the tuna fishery. The combined runs highlighted some additional areas to the southwest of the EEZ (Figure 133).

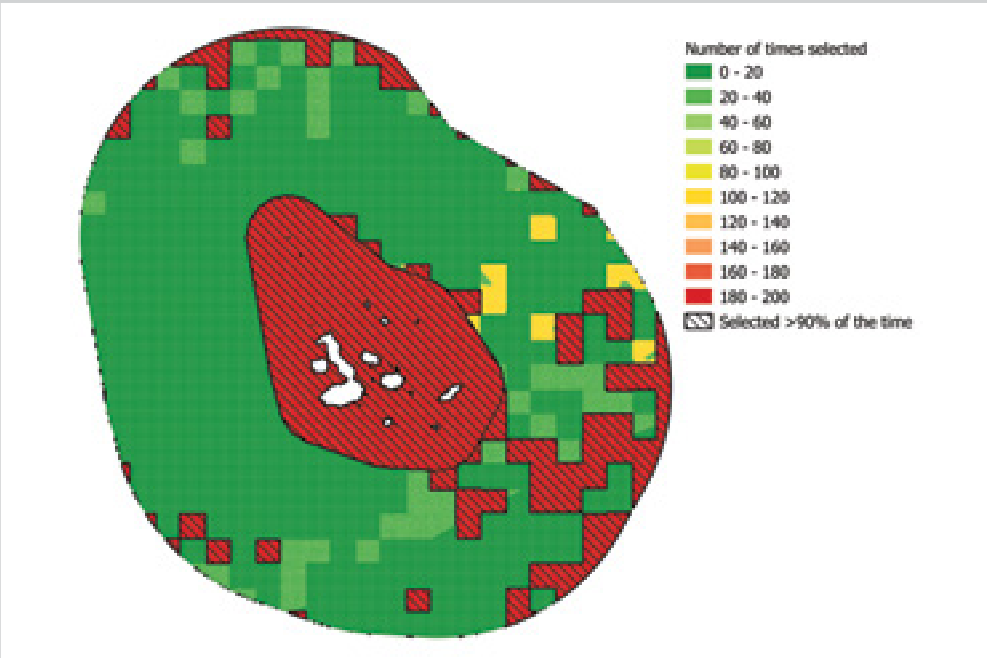


Figure 129. Summed solution Marxan outputs for 30% coverage of conservation features, using Ecuadorian industrial tuna fleet as cost layer. Hashed areas were selected ≥90% of the time (the existing GMR was locked in, and thus selected on every run).

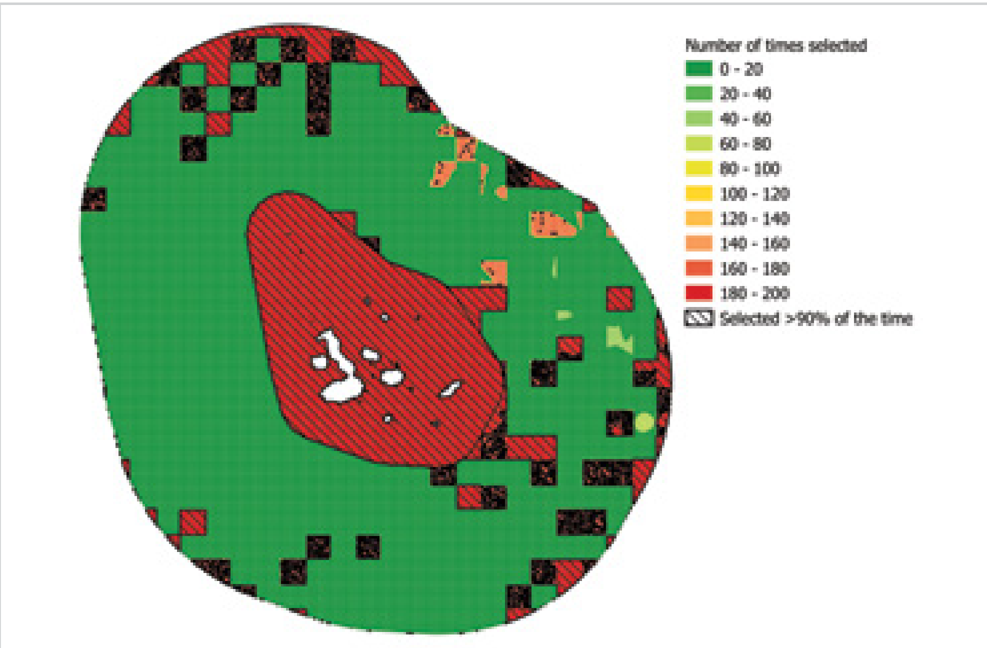


Figure 130. Summed solution Marxan outputs for 30% coverage of conservation features, using combined fleets as cost layer. Hashed areas were selected ≥90% of the time (the existing GMR was locked in, and thus selected on every run).

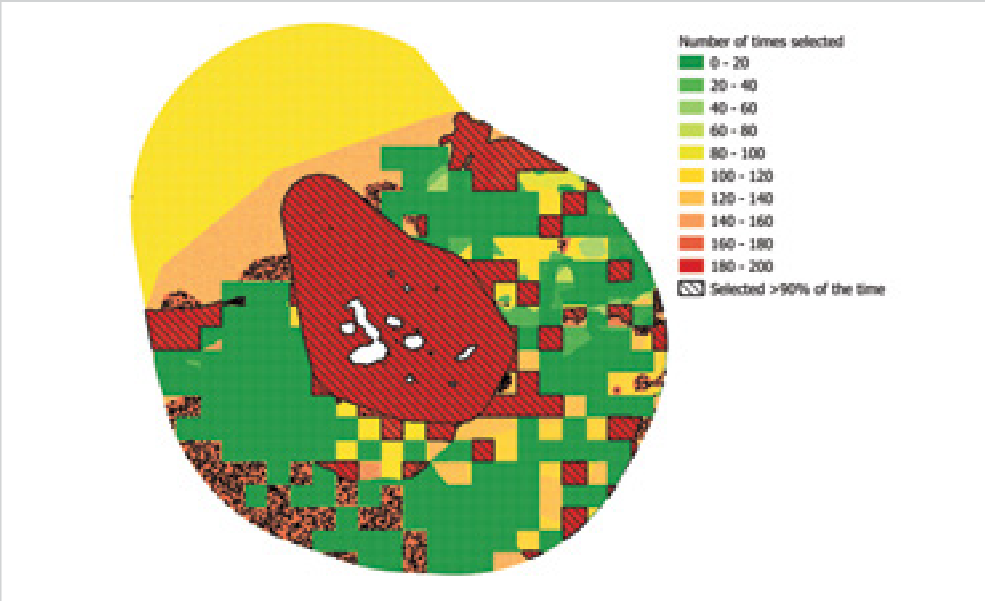


Figure 131. Summed solution Marxan outputs for 50% coverage of conservation features, using Ecuadorian large pelagics longline fleet as cost layer. Hashed areas were selected ≥90% of the time (the existing GMR was locked in, and thus selected on every run).

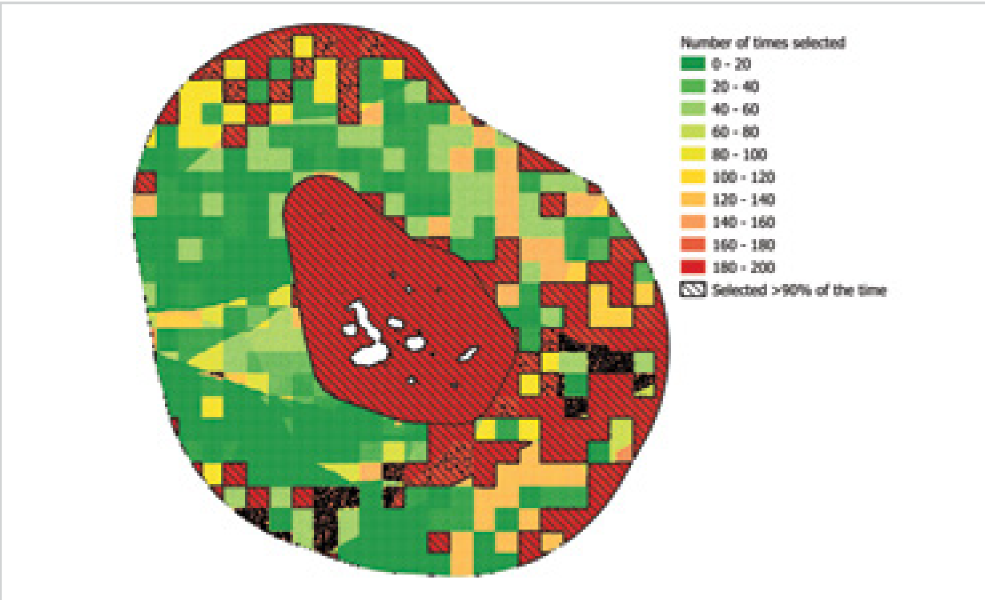


Figure 132. Summed solution Marxan outputs for 50% coverage of conservation features, using Ecuadorian tuna fleet as cost layer. Hashed areas were selected ≥90% of the time (the existing GMR was locked in, and thus selected on every run).

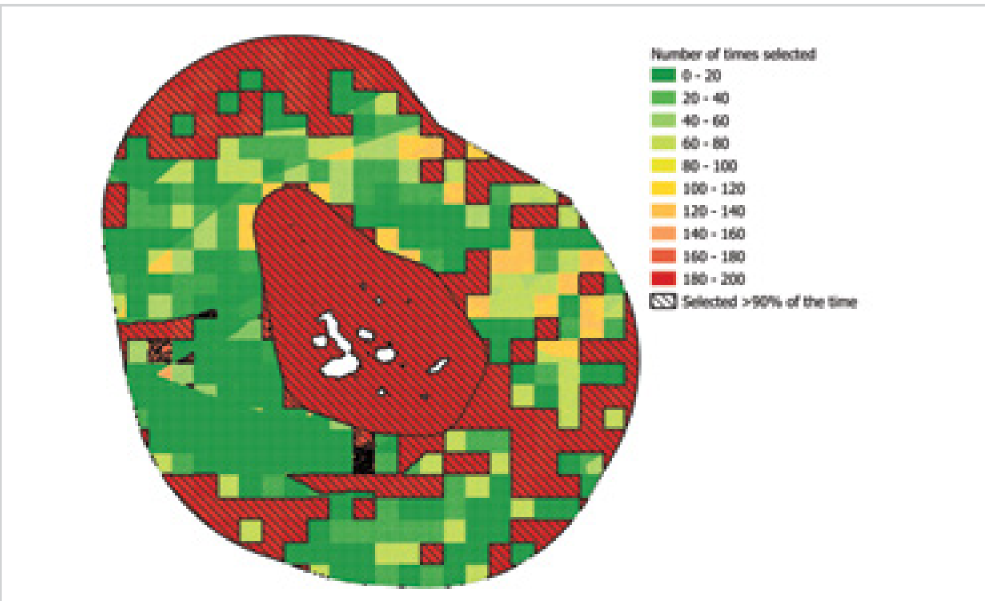


Figure 133. Summed solution Marxan outputs for 50% coverage of conservation features, using combined fleets as cost layer. Hashed areas were selected ≥90% of the time (the existing GMR was locked in, and thus selected on every run).

Marxan Outputs for EEZ Outside the Galápagos Marine Reserve

To assess how and where increased protection measures might be placed in the open waters outside the existing GMR, we ran Marxan scenarios on the area between the border of the GMR and that of the EEZ, excluding the GMR. In this manner, the conservation objectives became to protect 30% and 50% of the conservation features in addition to what is already protected, allowing us to focus on those species that are less centered within the GMR and to focus on pelagic protection. Under this scenario, by removing the GMR, our planning units (PUs) were reduced to 177,392, all of which were marked as available. We also removed all conservation features where ≥90% of the range was within the existing GMR (N=11). The total number of remaining features was 43 (Table 18), distributed across the areas as shown in Figure 134. The maximum number of conservation features in any PU was 29. As with the previous setup, the scenarios were run for each fleet independently, and then for both combined.

The outputs highlight which areas were selected ≥90% of the Marxan solutions. As with the previous example, these areas do not meet biodiversity targets by themselves – other areas need to be included, but as those other areas are a higher cost, they will have been selected less frequently in the Marxan solutions. Also as with the previous scenario, the outputs for the longline fleet were driven largely by cost than by the number of features present in each PU (Figure 135), and the industrial tuna fleet showed a similar pattern (Figure 136). However, in the case of the former, the most selected PUs were associated with the Cocos Ridge (Cocos-Galápagos Swimway), while in the latter, PUs associated with the Carnegie Ridge were selected more often. The combined cost layer did not show either pattern (Figure 137).

In order to achieve 50% coverage of the conservation features, a larger number of PUs were selected ≥90% of the time. In every case, the zone to the southwest of the GMR was rarely selected, and this reflects its importance to the longline fleet (Figure 138), the tuna fleet (Figure 139) and by extension, to the combined fleets (Figure 140).

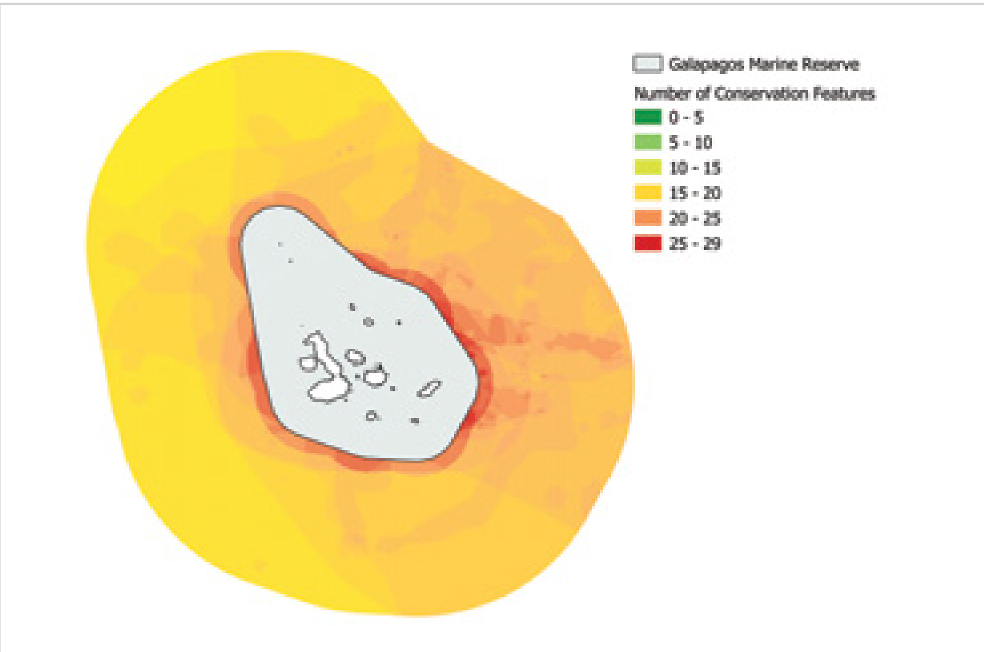


Figure 134.
Distribution of conservation features (N=43) throughout the Galápagos EEZ, with more features, with 29 being the maximum number of features in any one planning unit (PU).

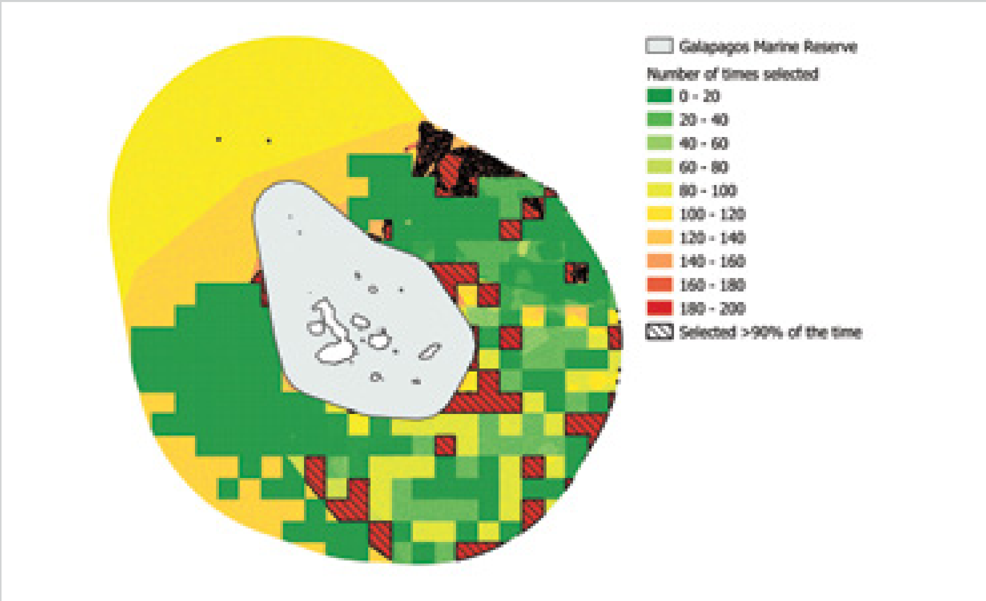


Figure 135. Summed solution Marxan outputs for 30% coverage of conservation features (excluding the GMR), using Ecuadorian large pelagics longline fleet as cost layer. Hashed areas were selected ≥90% of the time.

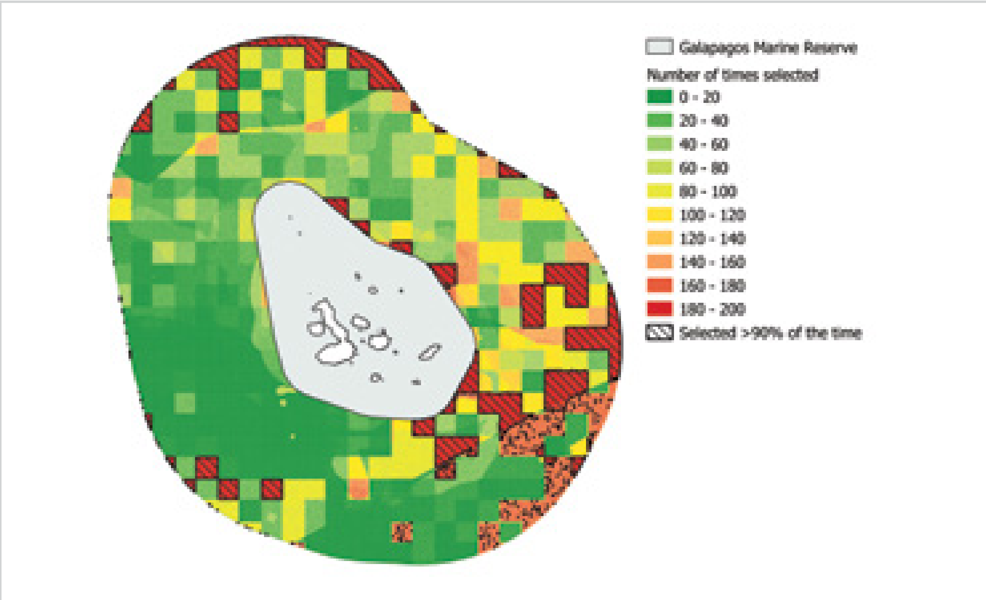


Figure 136. Summed solution Marxan outputs for 30% coverage of conservation features (excluding the GMR), using Ecuadorian tuna fleet as cost layer. Hashed areas were selected ≥90% of the time.

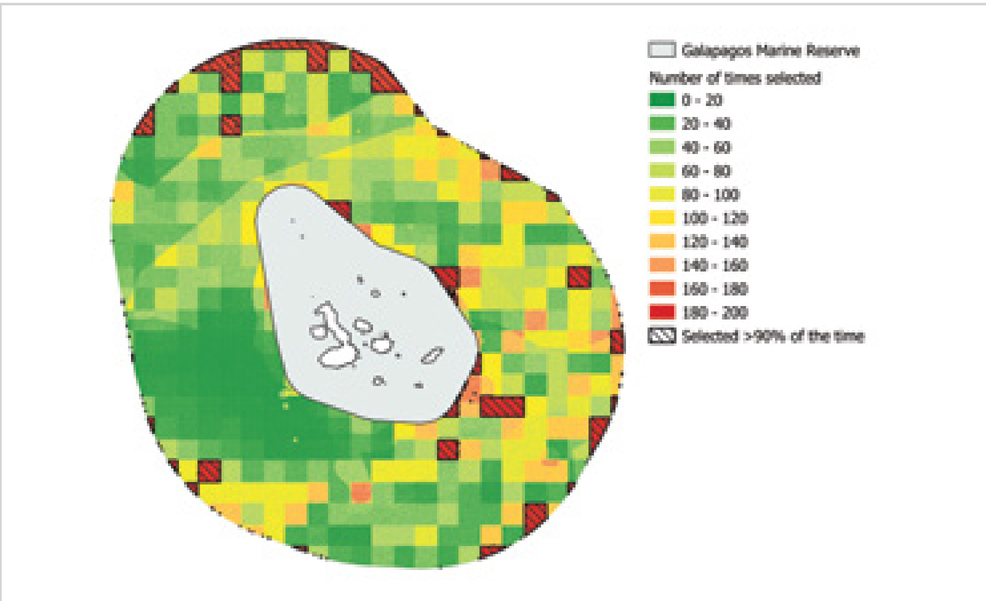


Figure 137. Summed solution Marxan outputs for 30% coverage of conservation features (excluding the GMR), using combined fleets as cost layer. Hashed areas were selected ≥90% of the time.

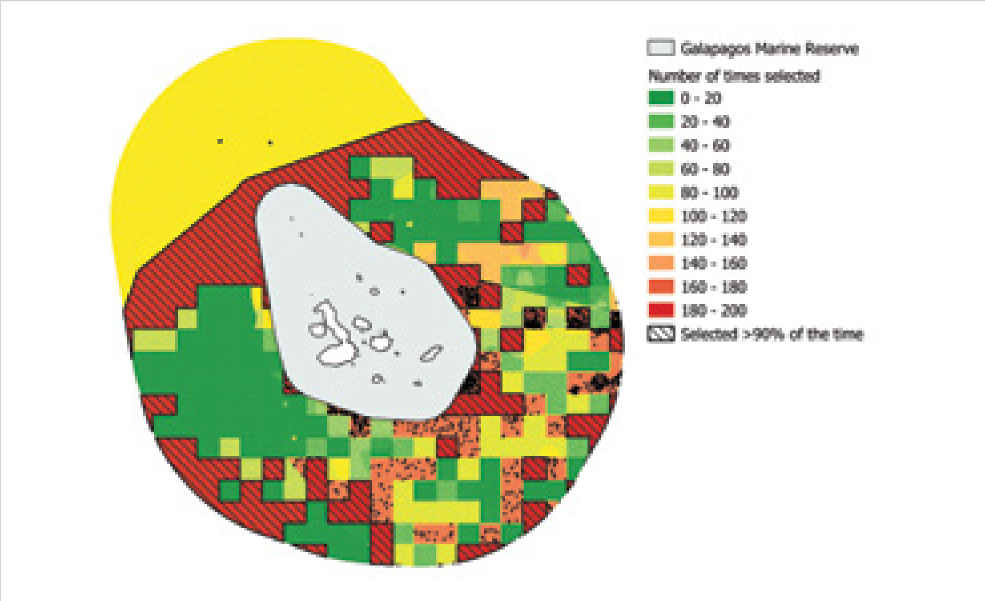


Figure 138. Summed solution Marxan outputs for 50% coverage of conservation features (excluding the GMR), using Ecuadorian large pelagics longline fleet as cost layer. Hashed areas were selected ≥90% of the time.

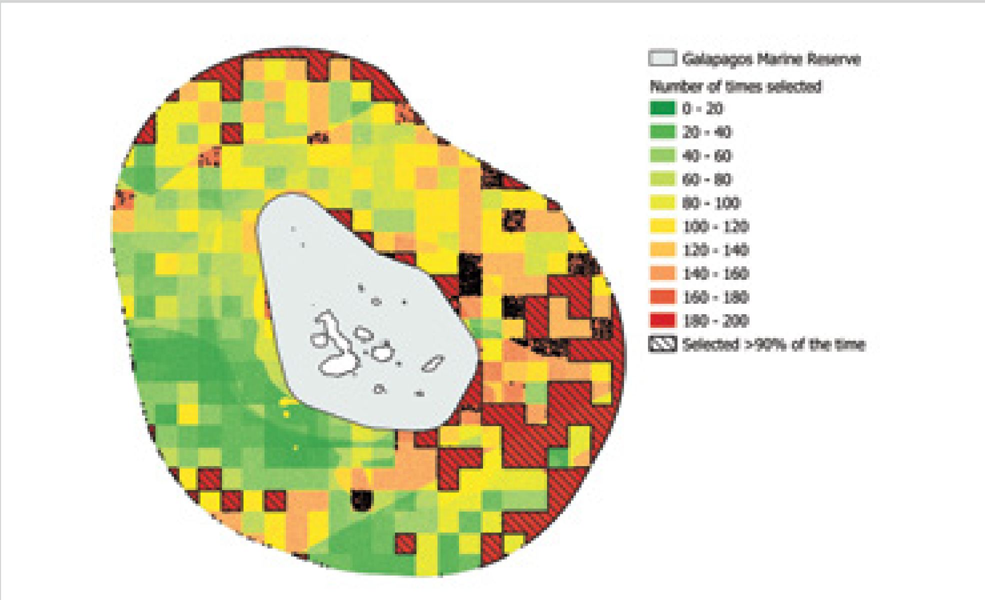


Figure 139. Summed solution Marxan outputs for 50% coverage of conservation features (excluding the GMR), using Ecuadorian tuna fleet as cost layer. Hashed areas were selected ≥90% of the time.

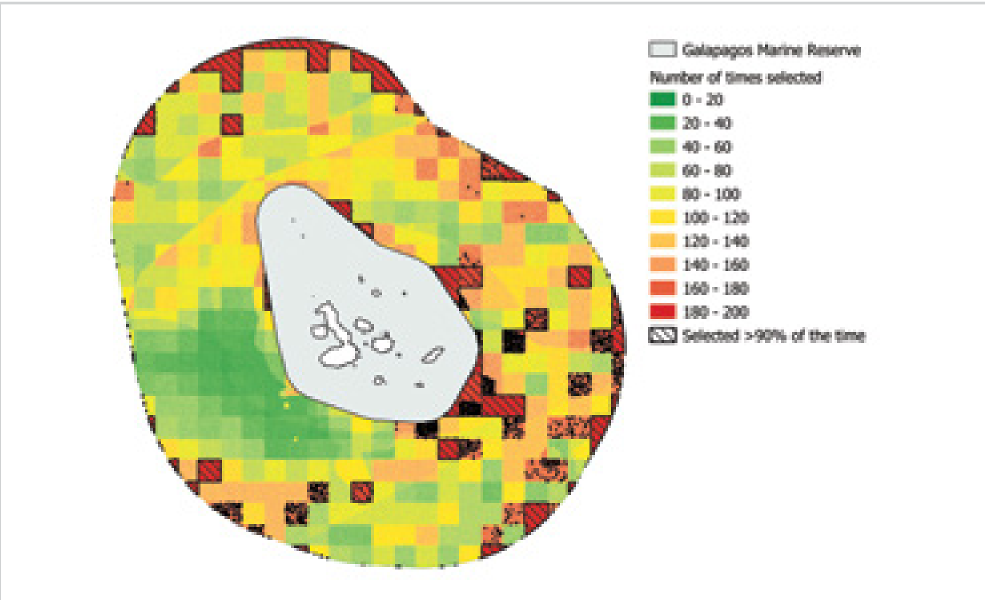


Figure 140. Summed solution Marxan outputs for 50% coverage of conservation features (excluding the GMR), using both fleets combined as cost layer. For each PU, the darker the shading, the more often it was selected. Hashed areas were selected ≥90% of the time.

Building Conservation Scenarios

The process of building conservation scenarios incorporated several key inputs:

- The Marxan outputs described in the previous section, based on spatially explicit information for 54 conservation features that include ecological processes, seamounts as critical oceanic habitats as well as the distribution and, where available, foraging areas and/or migratory routes of threatened marine species; and catches of commercial species.
- Distribution of bycatch intensity of the longline fishing fleet outside the GMR, as described for key vulnerable species in the section on the different species making up the conservation objectives.
- Information generated by other existing regional marine conservation initiatives as described in the earlier section on the overlap of different government and NGO initiatives throughout the region.
- Oceanographic modeling to estimate the effects of FADs in the EEZ surrounding Galápagos.
- Knowledge from local fishers about key areas in Galápagos for artisanal fishing that attract illegal fishing.
- Strategies that might help mitigate the impacts of ENSO events and climate change.


Alex Hearn

The conservation scenarios outlined in this section were designed to respond to the management objectives outlined in the Introduction and summarized below:

- Implement ecosystem-based management through marine spatial planning of the entire EEZ surrounding Galápagos, to ecologically connect and maintain the benefits of oceanic ecosystems and the services they provide.
- Ensure, through the creation of responsible fishing zones and control of illegal fishing, that national fleets have exclusive access to spillover effects arising from increased protection.
- Protect the current GMR from illegal fishing.
- Support measures to build economic and ecological resilience to mitigate the impacts of climate change on species of both commercial and conservation interests.
- Protect highly productive areas and cold-water refugia: upwelling events related to seamounts and persistent frontal zones, in particular during ENSO conditions.
- Maintain and protect the unique genetic resources of the GMR (for example, endemic species which may forage outside the current reserve) and maintain genetic diversity of highly migratory species.
- Protect migratory routes to maintain and strengthen connectivity of threatened marine species between biologically important areas (for example the Coco-Galápagos Swimway) across the ETP region.
- Support measures to reverse the declining population trends of migratory species and of species that forage in open waters around the GMR.
- Support Sustainable Development Goal 14 and its objectives to protect and sustainably utilize the oceans and marine resources in order to maintain ecosystem services and economic benefits in the long term.

Because of the objective to allow national fleets exclusive access to the benefits generated by spillover effects, a full no-take reserve covering the entire EEZ was not considered to be appropriate. For the scenarios described below, a spatial management involving different categories of areas within the entire EEZ is envisaged. Following the description of each scenario, we compare their relative coverage of the conservation features and their cost layers and discuss how each input led to its design.

Multiple spatial scenarios for stakeholder consideration

Maximum Conservation Scenario

The maximum conservation scenario is comprised of three main zones (Figure 141). It would increase the protected area coverage to 68.6% of the Galápagos EEZ (54.3% of Ecuador's combined EEZs) while maintaining access to the major fishing grounds for both fleets:

1. **A new marine reserve** extending over 444,470 km^2, where extractive activities are not permitted and that protects critical oceanic ecosystems as well as migratory routes and foraging areas of endangered marine species.
2. **Two Responsible Fishing Zones (RFZs)**, available to user groups through exclusive access-type agreements (such as territorial user rights), to be discussed and defined with user groups. It cannot be affirmed that current fishing levels in these zones are sustainable, however, there are significant levels of bycatch, so careful management and effective monitoring will be required in the RFZs. In both zones, there should be a commitment to move towards 100% observer

coverage (either physical or through technology), to release all bycatch species, and to contemplate the use of catch quotas. The vision for these two RFZs is to transition towards sustainable, certified fisheries. This should include a transition toward pole and line and FAD-free purse seine operations. Fisheries should be required to achieve 100% observer coverage (physical or supported by electronic monitoring) to document target and non-target species catch. Precautionary catch limits should be set based on the best available data, and adjusted through annual review of observer data and a tag-and-release programme. Licence conditions should include live release and safe handling of vulnerable non-target species and best practice bycatch reduction techniques should be incorporated in fishing operations.

a. Responsible fishing zone of 195,656 km^2 located west of the current GMR that includes the most important fishing areas for the purse-seine tuna fishing fleet and the semi-industrial longline fleet, as well as two spillover areas towards the north and south of the main fishing grounds.

b. Responsible fishing zone free of FADs that extends over 29,287 km^2. Scientific studies show that FADs placed east of the Galápagos have a high probability of entering the marine reserve, thus negatively affecting biodiversity and artisanal fishing operating inside the GMR.

3. **El Niño Buffer Zone** is an area of 33,805 km^2 that is included in the responsible fishing zone 2a, but during years when an El Niño event is declared, this will be a *de facto* No-Take Area here as a precautionary measure for endemic species that would not normally leave the GMR, but whose foraging ranges expand during these seasonal events.

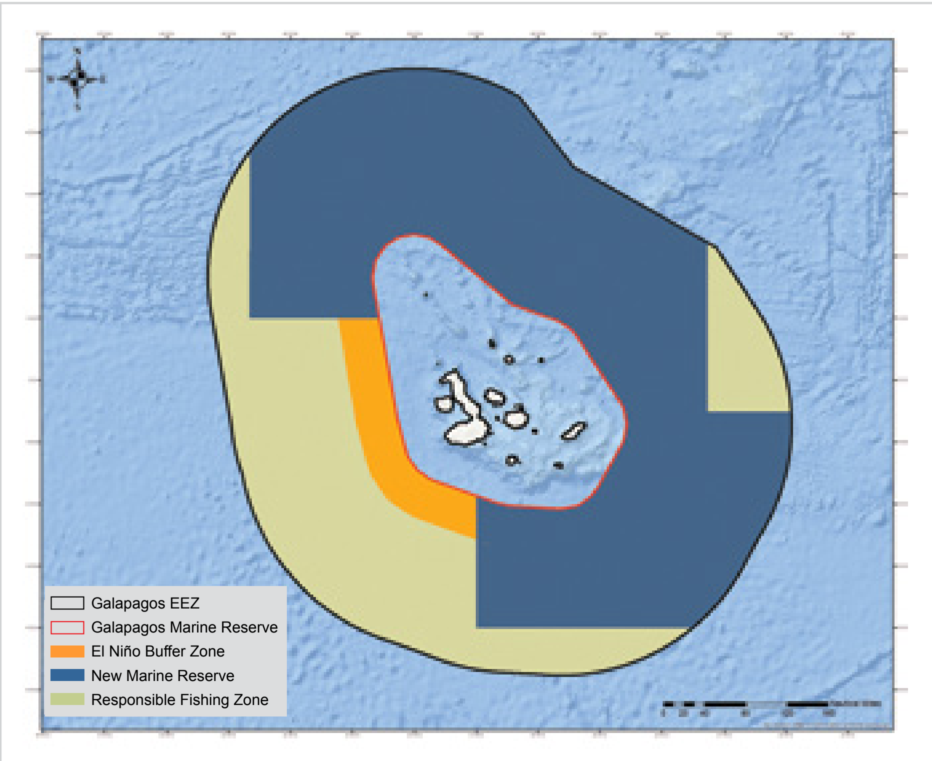


Figure 141. Maximum conservation scenario for the Galápagos EEZ, showing 444,470 km^2 No-Take area (blue), 195,656 km^2 and 29,287 km^2 Responsible Fishing Zones (olive green) and 33,805 km^2 El Niño Buffer Zone (orange).

Spillover and Migration Route Scenario

The optimized conservation and spillover scenario seeks to maximize the potential spillover benefits for the national fleets operating in the EEZ, whilst maintaining strict protection along key conservation areas associated with the Cocos and Carnegie Ridges (Figure 142). This scenario maintains access to the main fishing grounds for both fleets and, similar to the maximum conservation scenario described above, would implement a temporal no-take Buffer Zone around the southwestern corner of the GMR during El Niño Events. The RFZ to the east would be somewhat enlarged, while the western RFZ would extend along a 50 NM strip to the north around as far as the border in common with Costa Rica, which marks the beginning of the Cocos-Galápagos Swimway; and along an 80 NM strip to the southeast. The scenario would increase protected area coverage to 60.8% of the Galápagos EEZ (48.2% of Ecuador's combined EEZs):

1. **A new marine reserve** extending over 378,608 km^2, where extractive activities are not permitted and that protects critical oceanic ecosystems as well as migratory routes and foraging areas of endangered marine species.

2. **Two Responsible Fishing Zones (RFZs)**, of 259,618 km^2 and 34,869 km^2 respectively, which would be managed under the same conditions as explained in the previous scenario.

3. **El Niño Buffer Zone**, an area of 30,215 km^2 that, during years when an El Niño event is declared, will be a de facto No-Take Area here, as described in the previous scenario.

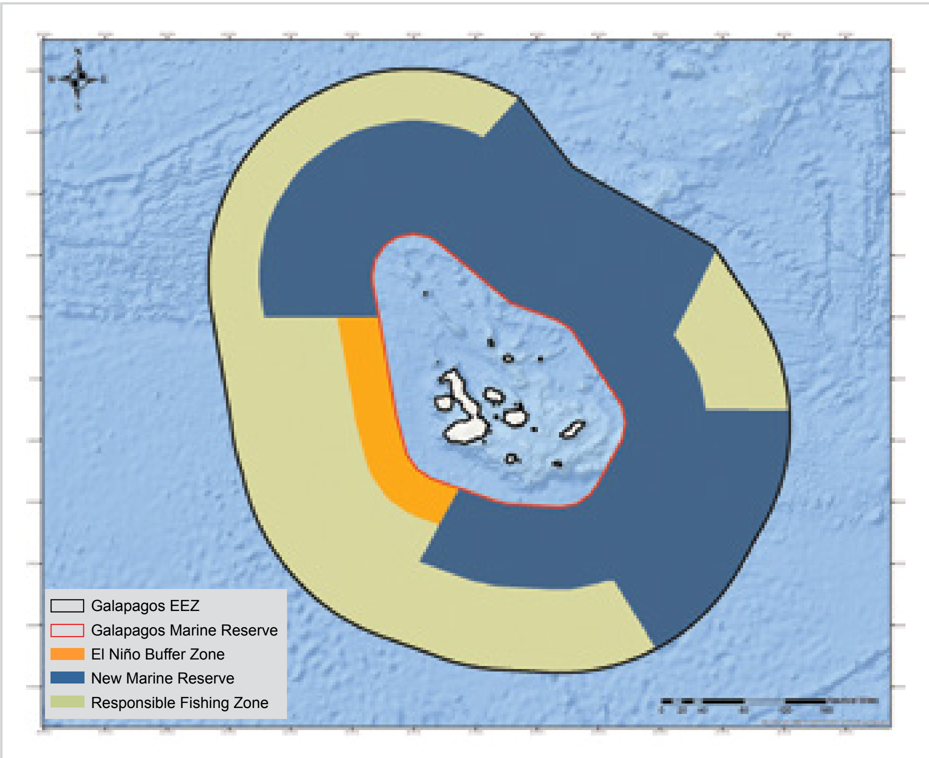


Figure 142. Spillover and migration route scenario for the Galápagos EEZ, showing 378,608 km^2 No-Take area (blue), 259,618 km^2 and 34,869 km^2 Responsible Fishing Zones (olive green) and 30,215 km^2 El Niño Buffer Zone (orange).

30 by 30 Scenario

The 30 by 30 scenario would allow Ecuador to make significant progress in attaining the goal of protecting 30% of its oceans by 2030, through the creation of a no-take area of 171,532 km^2, thus increasing the protected area coverage to 36.4% of the Galápagos EEZ and to 29.2% of Ecuador's EEZ as a whole (Figure 143). In order to complete the goal by 2030, the existing network of coastal MPAs might be expanded to approximately 15,000 km^2, a not unreasonable figure given the numerous existing and ongoing initiatives in mainland Ecuador. The four main zones in this scenario would be:

1. A new marine reserve extending 171,532 km^2, where extractive activities are not permitted and that focuses on protecting the migratory routes and foraging areas of endangered sharks and turtles.
2. **Two Responsible Fishing Zones (RFZs)**, of 399,323 km^2 and 55,036 km^2 which would be managed under the same conditions as explained previously.
3. **El Niño Buffer Zone**, an area of 33,805 km^2 that, during years when an El Niño event is declared, will be a de facto No-Take Area here, as described previously.
4. **A temporal Seabird Protection Zone** – an area of 43,185 km^2, where longlining activities would be banned from June through August.

This scenario would focus mainly on protecting Ecuador's portion of the Cocos-Galápagos Swimway, and on providing extra protection around a band of 40 NM from the east to the south of the GMR, in particular to protect artisanal fishing grounds in these areas that are subject to illegal incursions from outside the border, as identified as a key concern for local fishers. A temporary exclusion zone for longline

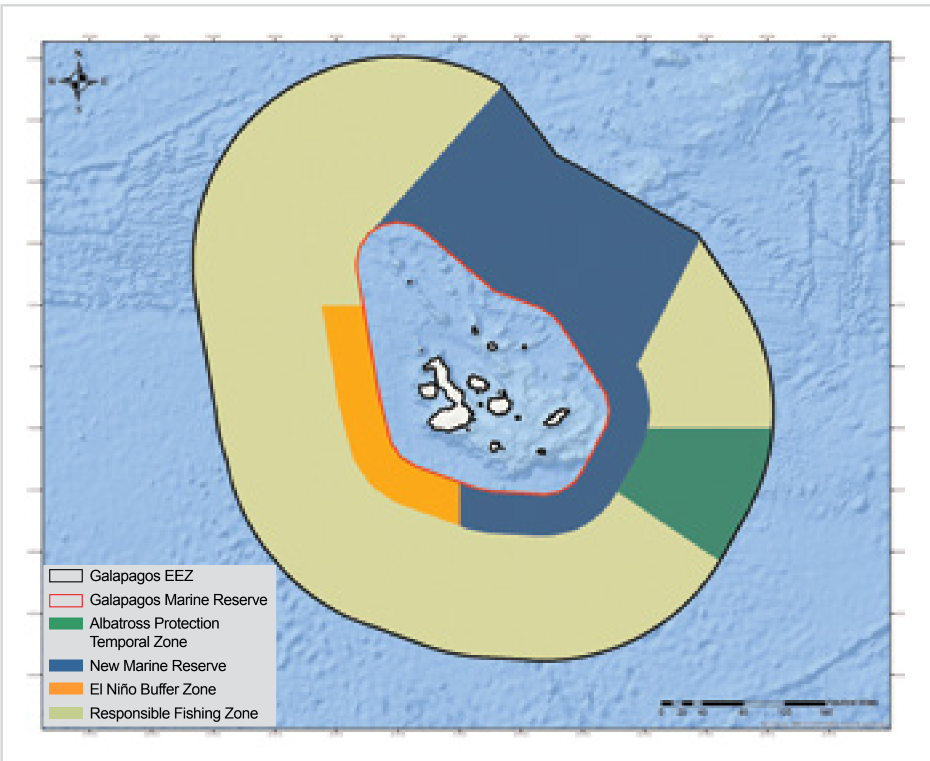


Figure 143. 30 by 30 scenario for the Galápagos EEZ, showing 171,532 km^2 No-Take area (blue), 399,323 km^2 and 55,036 km^2 Responsible Fishing Zones (olive green), a 43,185 km^2 temporal Seabird Protection Zone (dark green), and 33,805 km^2 El Niño Buffer Zone (orange).

vessels (but not purse seine vessels) would be created in the east of the EEZ to minimize the risk of seabird interactions in the months of June-August, when albatrosses in particular, forage as far as the coastal waters of Ecuador and northern Peru.

Cocos-Galápagos Swimway Scenario

The Cocos-Galápagos Swimway scenario focuses almost entirely on the area associated with the Cocos Ridge, where sharks and turtles have been shown to migrate between the GMR, Cocos Island and (in some cases) beyond (Figure 144). This would increase the protected area coverage of the Galápagos EEZ to 32.4%, and that of Ecuador's combined EEZs to 26.0%. Although the El Niño Buffer Zone remains, there is no increased protection around the existing GMR elsewhere, and seabird foraging and migratory routes are not covered for the most part. The artisanal fishing grounds in the east and south of the GMR would remain vulnerable to illegal fishing incursions, and other measures would need to be taken to reduce this risk. This scenario includes:

1. **A new marine reserve** extending over 137,439 km^2, where extractive activities are not permitted and that protects critical oceanic ecosystems as well as migratory routes and foraging areas of endangered marine species.
2. **One Responsible Fishing Zone (RFZ)**, together making up 531,650 km^2, which would be managed under the same conditions, as explained in the previous scenario.
3. **El Niño Buffer Zone**, an area of 33,805 km^2 that, during years when an El Niño event is declared, will be a de facto No-Take Area here, as described in the previous scenario.

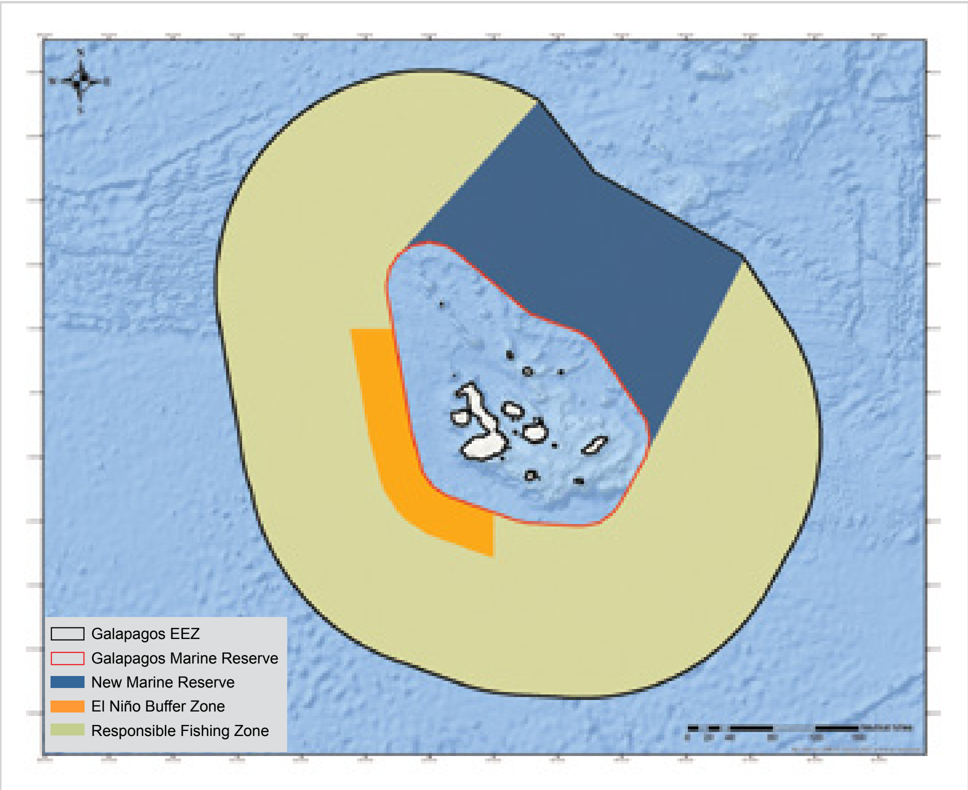


Figure 144. Cocos-Galápagos Swimway scenario for the Galápagos EEZ, showing 137,439 km^2 No-Take area (blue), 531,650 km^2 Responsible Fishing Zone (olive green) and 33,805 km^2 El Niño Buffer Zone (orange).

Minimum Scenario

The minimum protection scenario further combines management measures with spatial protection. In this scenario, a no-take zone of 112,748 km^2 would be created along the northern half of the Swimway area, where apparently greater movements of sharks and turtles are registered (Figure 145). This would increase protected area coverage of the Galápagos EEZ to 29.5% and that of Ecuador's combined EEZs to 23.7%. Part of the remaining Swimway area would be restricted to unassociated purse seine sets and pole and line fishing, with FAD sets and longline fishing prohibited. Both the El Niño Buffer zone and the temporal Seabird Protection zone described previously would be included in this scenario:

1. **A new marine reserve** extending 112,748 km^2, where extractive activities are not permitted and that focuses on protecting the migratory routes and foraging areas of endangered sharks and turtles.
2. **A longline and FAD exclusion zone** of 32,369 km^2 where these fishing activities are not permitted, but unassociated purse seine sets and pole-and-line fishing may be carried out.
3. **Two Responsible Fishing Zones (RFZs)**, of 399,324 km^2 and 81,713 km^2, which would be managed under the same conditions as explained previously.
4. **El Niño Buffer Zone**, an area of 33,805 km^2 that, during years when an El Niño event is declared, will be a de facto No-Take Area here, as described previously.
5. **A temporal Seabird Protection Zone** – an area of 43,185 km^2, where longlining activities would be banned from June through August.

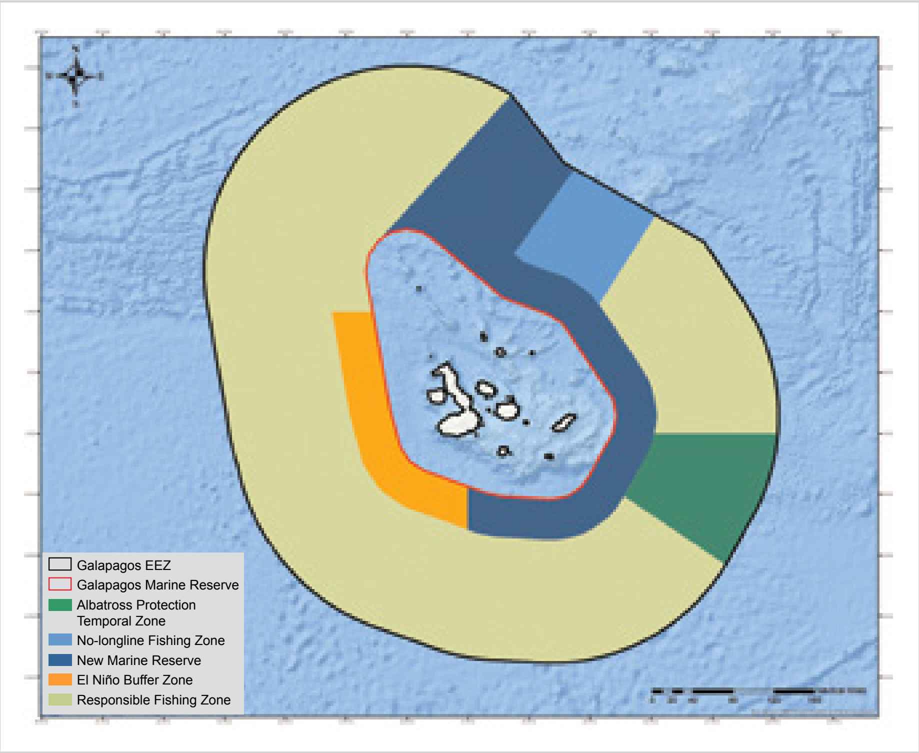


Figure 145. Minimum scenario for the Galápagos EEZ, showing 112,748 km^2 No-Take area (blue), 399,324 km^2 and 81,713 km^2 Responsible Fishing Zones (olive green), a 32,369 km^2 longline and FAD exclusion zone, a 43,598 km^2 temporal Seabird Protection Zone (dark green) and 33,805 km^2 El Niño Buffer Zone (orange).

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Swimway and Ring Scenario

The Swimway and ring scenario incorporates the Cocos-Galápagos Swimway as described above, but also includes a 10 NM ring around the remainder of the GMR (Figure 146). This would increase protected area coverage of the Galápagos EEZ to 34.6% and that of Ecuador's combined EEZs to 27.7%. The resulting El Niño buffer zone is applied beyond the ring, and is thus reduced to a width of 30 NM in comparison to that of other scenarios.

1. **A new marine reserve** extending over 155,627 km², where extractive activities are not permitted and that protects critical oceanic ecosystems as well as migratory routes and foraging areas of endangered marine species.
2. **One Responsible Fishing Zone (RFZ)**, together making up 521,423 km², which would be managed under the same conditions, as explained in the previous scenarios.
3. **El Niño Buffer Zone**, an area of 26,239 km² that, during years when an El Niño event is declared, will be a de facto No-Take Area here, as described in the previous scenarios.

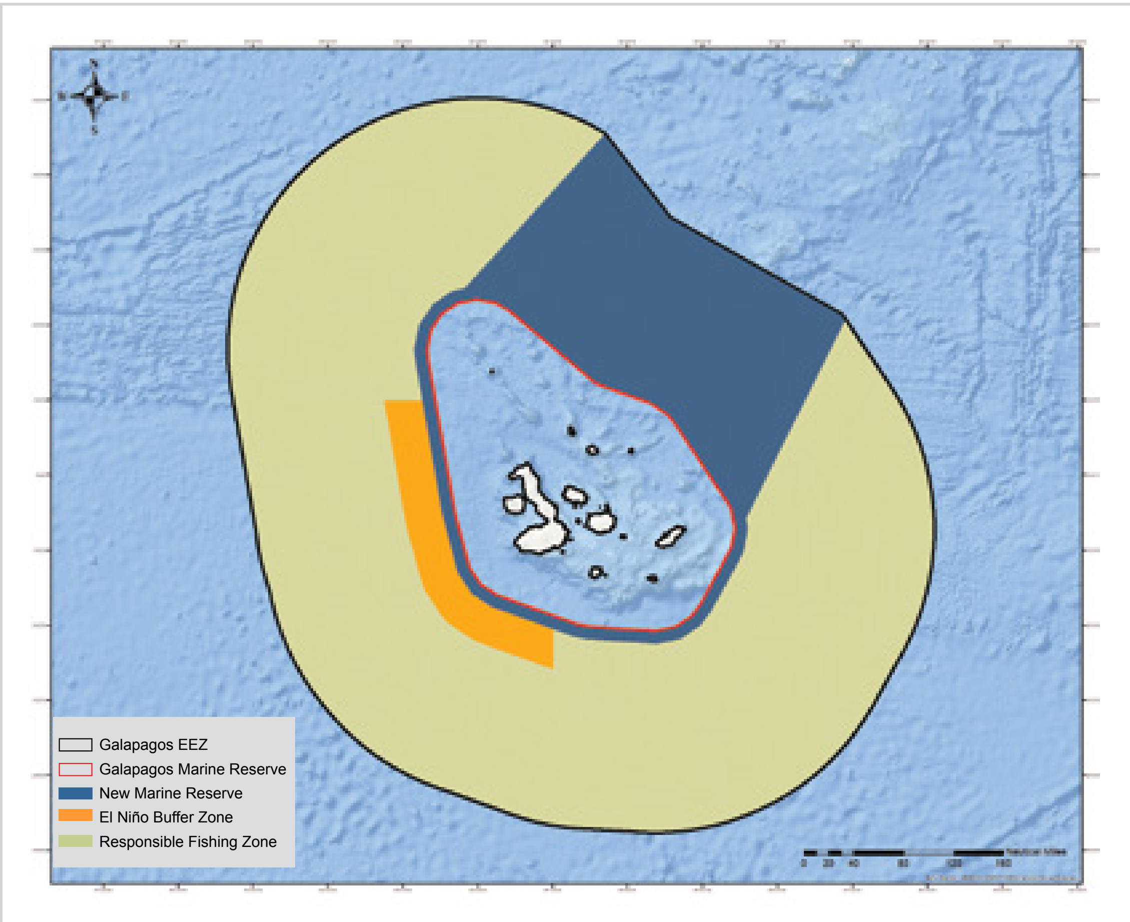


Figure 146. Swimway and simple ring scenario for the Galápagos EEZ, showing 155,627 km² No-Take area (blue), a 26,239 km² El Niño Buffer Zone (orange) and a 521,423 km² Responsible Fishing Zone.

Comparing Scenarios: Conservation Objectives and Fishery Values

Protection Coverage of Conservation Features

Using the output from the Marxan spatial analysis, we evaluated the coverage of each of the conservation features under the new marine reserve proposed (no-take zone) in each scenario. Results showed the minimum, maximum, and average coverage among all features and the number of features that met at least 30% or 50% protection coverage (Annex 1). In building each scenario, we attempted to maximize the inclusion of PUs that had been selected most frequently based on the combined fleet model excluding the GMR with a target of 50% coverage of conservation features (Figure 140). The coverage of these PUs under each scenario is shown in Figure 147. Figures 148 to 151 and the upper section of Table 19 compare the protection coverage achieved for key pelagic habitat and critically endangered marine migratory species.

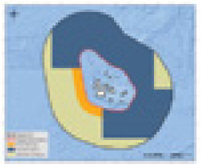
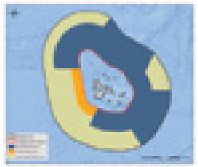
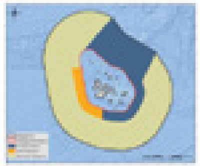
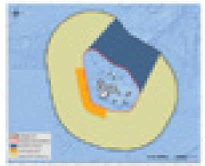
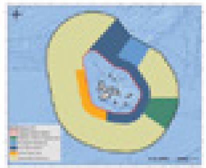
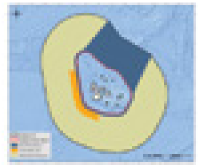
All conservation features are protected by at least 50% coverage under the first two scenarios, which were set up to this minimum protection target. All shallow seamounts, less than 500 meters depth fall mostly inside the current marine reserve, therefore additional protection in the EEZ increases their coverage by less than 0.1% in all scenarios. This is not the case for deeper pelagic seamounts that extend beyond the GMR (Figure 148). The layers of biophysical productivity due to upwelling processes have coverage ranging from 34% to 57%, in general these are low numbers because the main productivity areas in the Galápagos EEZ are located in areas open to fishing across all scenarios. For the key endangered marine migratory species, the two best scenarios for maximizing their protection, involve an area of more than 375,000 km^2. This effect is not equal among the species. The endangered green sea turtle is the only one that maintains a high level of coverage (> 90%) in all six scenarios. Both the scalloped hammerhead shark and the waved albatross gain high levels of protection only in the first two scenarios; protection is decreased significantly by 25% and 65% respectively, due to key areas at the southeast and northwest of the Galápagos EEZ that are not fully protected in the scenarios C, D, E and F (Figures 150 and 151). Because of their wider ranges, the leatherback sea turtle and the whale shark in general are less protected than the other key species included in the analysis. Overall, if all the conservation features are considered, scenarios with a new marine reserve of 171,000 km^2 or lower reduce by half the number of conservation features with over 50% coverage (25-27 features compared to 53 features from the maximum protection scenarios (Table 19, Appendix B).

Changes in Fishery Values

The spatial distributions of catch values for both the Ecuadorian purse seine and longline fleets, described previously, were overlaid with scenario layers to estimate the percentage catch value associated with the area proposed for new marine reserve in each case (Figures 152 and 153). The lower section of Table 19 summarizes these results. The southwestern part of the Galápagos EEZ is one of the most important zones for fisheries productivity as it represents approximately 71% and 82% of the purse seine and longline catch, respectively. Both scenarios A, maximum conservation, and b, Spillover and migratory routes, recognize the high productivity of this area and leave it open to fishing activities. Even though scenario B has a larger fishing area (approx. 66,000 km^2 more than A) the percent catch value for both fleets is the same.

Table 20. Summary of protection coverage for key conservation features (existing GMR + scenario) and percentage changes in fishery values under the six scenarios evaluated.

< 50%	>= 50% and <65%	>= 65% and <80%	>= 80% and <95%	>= 95%

	Scenario A Maximum Conservation	Scenario B Spillover + Migration Routes	Scenario C 30 by 30	Scenario D Coco-Galapagos Swimway	Scenario E Minimum Protection	Scenario F Swimway + 10 nm ring
						
CONSERVATION						
Area of new marine reserve (km^2)	444,470	378,608	171,532	137,439	112,748	155,627
% of available Galapagos EEZ	63%	54%	24%	20%	16%	22%
Conservation objectives met over 50% (total 54)	53	53	27	26	25	26
% Marine Protection reached at the country level	54.3%	48.2%	29.2%	26.0%	23.7%	27.7%
% Shallow Seamounts (< 500 mts)	100%	100%	100%	91.0%	100%	94.6%
% Deep Seamounts (> 500 mts)	99.4%	99.0%	82.0%	72.7%	68.5%	75.2%
% Upwelling, neutral year	51.7%	56.9%	44.3%	34.2%	44.3%	42.7%
% Leatherback turtle	76.8%	66.8%	46.0%	41.6%	41.9%	43.7%
% Green turtle	94.6%	93.3%	93.2%	93.2%	92.9%	93.3%
% Waved albatross	91.4%	90.1%	37.0%	22.9%	37.0%	25.6%
% Hammerhead shark	90.1%	87.5%	60.9%	59.1%	60.7%	62.1%
% Whale shark	76.2%	74.3%	58.3%	57.6%	52.2%	60.5%
FISHING						
Areas open to fishing (km^2)	258,979	324,841	531,917	566,010	590,701	547,822
% Value of purse seine catch in Galapagos EEZ	73.1%	71.4%	86.1%	89.0%	89.4%	80.3%
% Value of longline catch in Galapagos EEZ	81.2%	81.3%	91.9%	93.7%	95.7%	89.2%
% Total value of purse seine catch not in new reserve	94.2%	93.8%	97.0%	97.6%	97.7%	95.7%
% Total value of longline catch not in new reserve	95.6%	95.7%	98.1%	98.5%	99.0%	97.5%

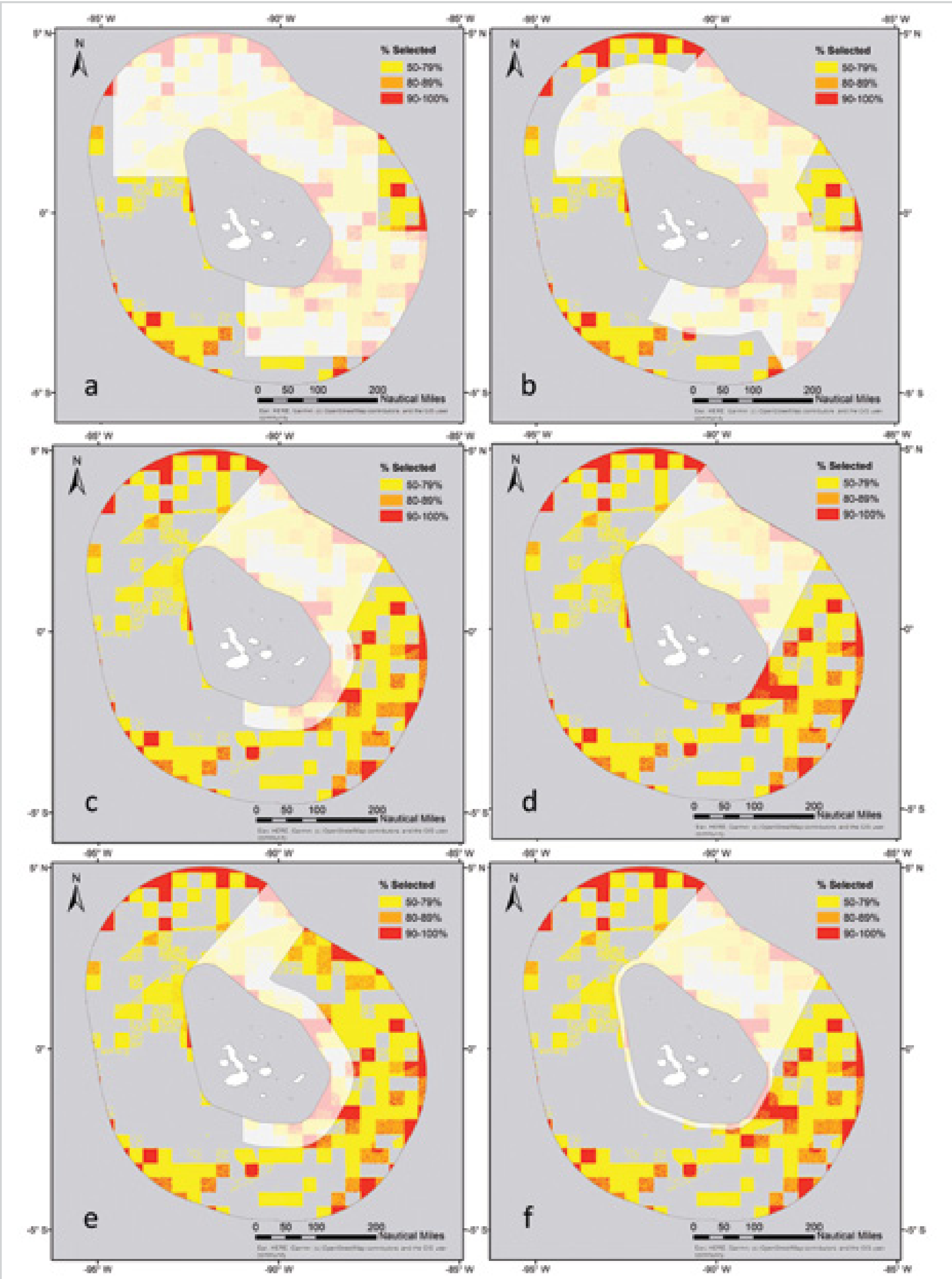


Figure 147. Protection coverage of planning units selected frequently by Marxan runs based on 50% protection of conservation features for both fleets combined, excluding the existing GMR. Scenarios are represented as white polygons. Panels: **a** - Maximum Conservation, **b** - Spillover and Migratory Routes, **c** - 30 by 30, **d** - Cocos-Galápagos Swimway, **e** - Minimum Protection, **f** - Swimway and ring.

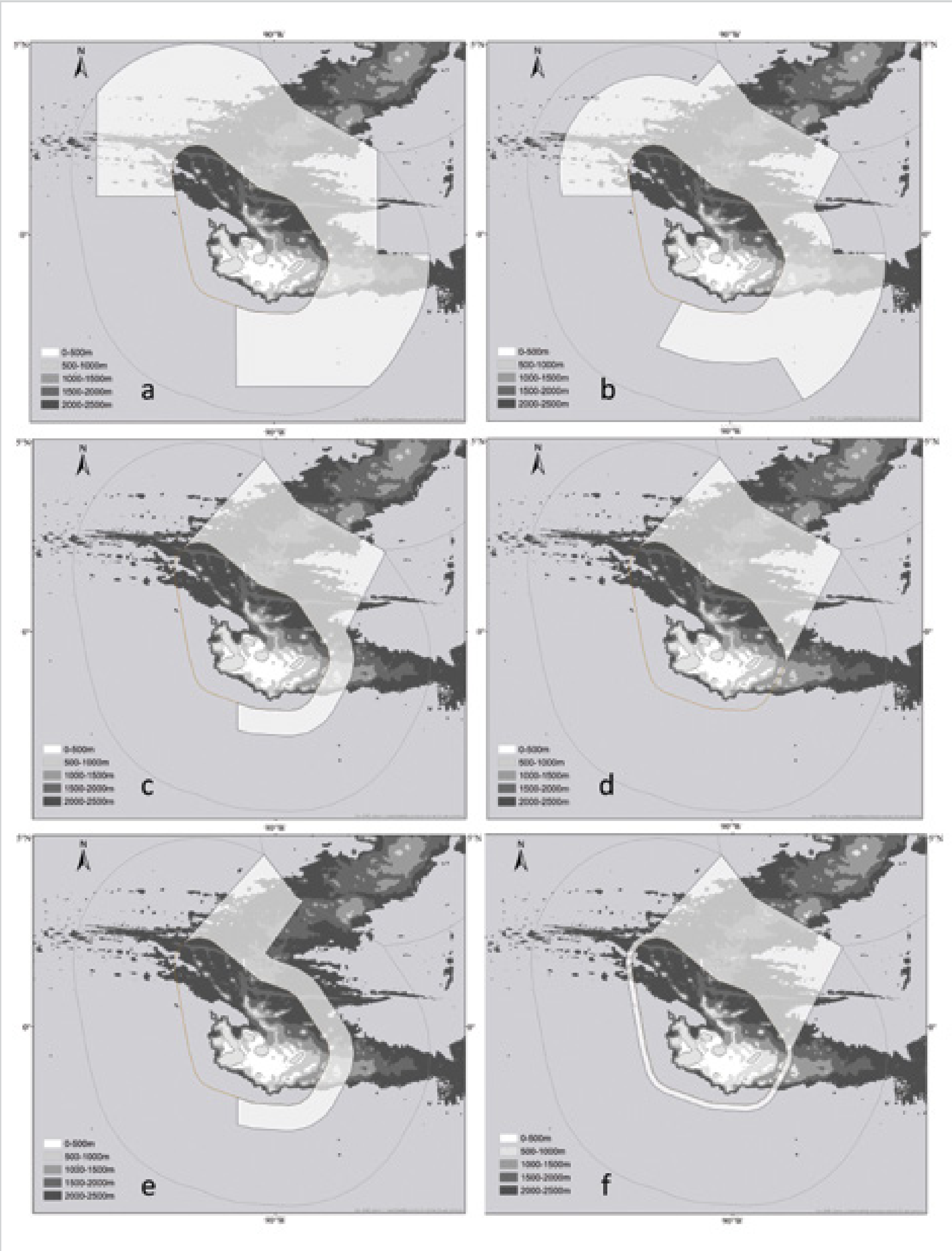


Figure 148. Protection coverage for seamounts as key pelagic habitats under each scenario. Scenarios are represented as white polygons. Panels: **a**- Maximum Conservation, **b**- Spillover and Migratory Routes, **c**- 30 by 30, **d**- Cocos-Galápagos Swimway, **e**- Minimum Protection, **f**- Swimway and ring.

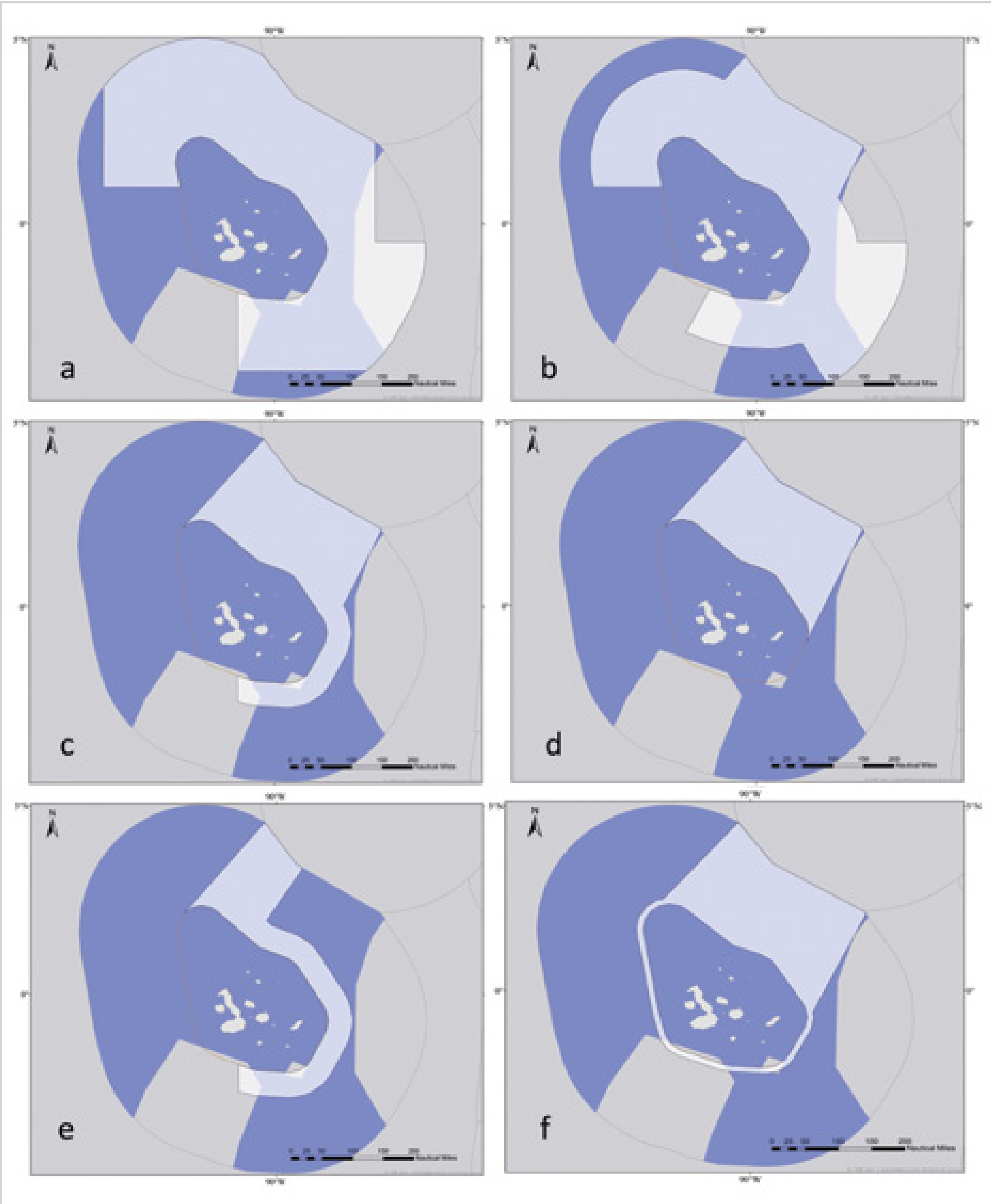


Figure 149. Protection coverage for the critically endangered leatherback sea turtle under each scenario. Scenarios are represented as white polygons. Panels: **a** - Maximum Conservation, **b** - Spillover and Migratory Routes, **c** - 30 by 30, **d** - Cocos-Galápagos Swimway, **e** - Minimum Protection, **f** - Swimway and ring.

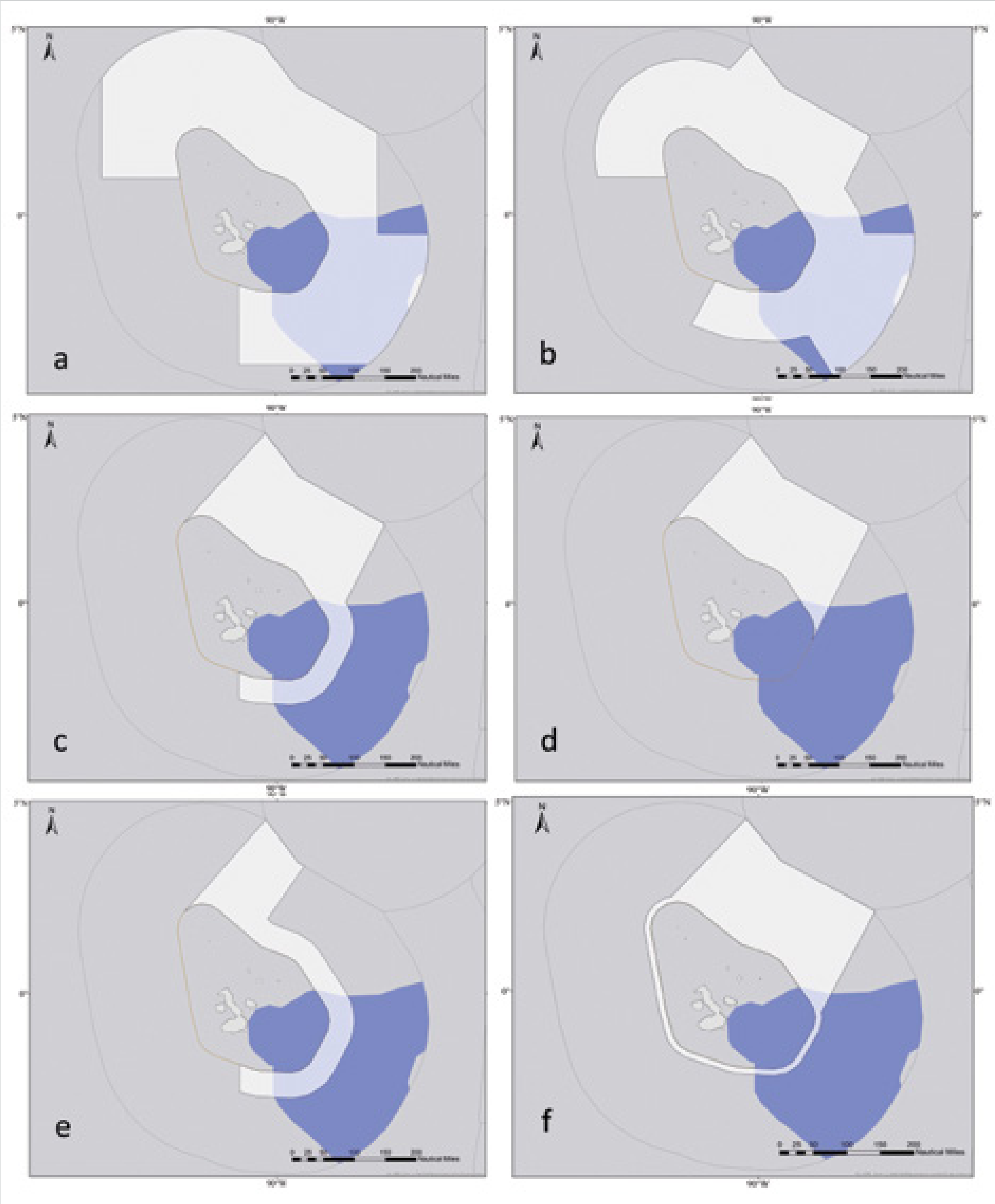


Figure 150. Protection coverage for the critically endangered Galápagos albatross under each scenario. Scenarios are represented as white polygons. Panels: **a** – Maximum Conservation, **b**- Spillover and Migratory Routes, **c** – 30 by 30, **d**- Cocos-Galápagos Swimway, **e** - Minimum Protection, **f** - Swimway and ring.

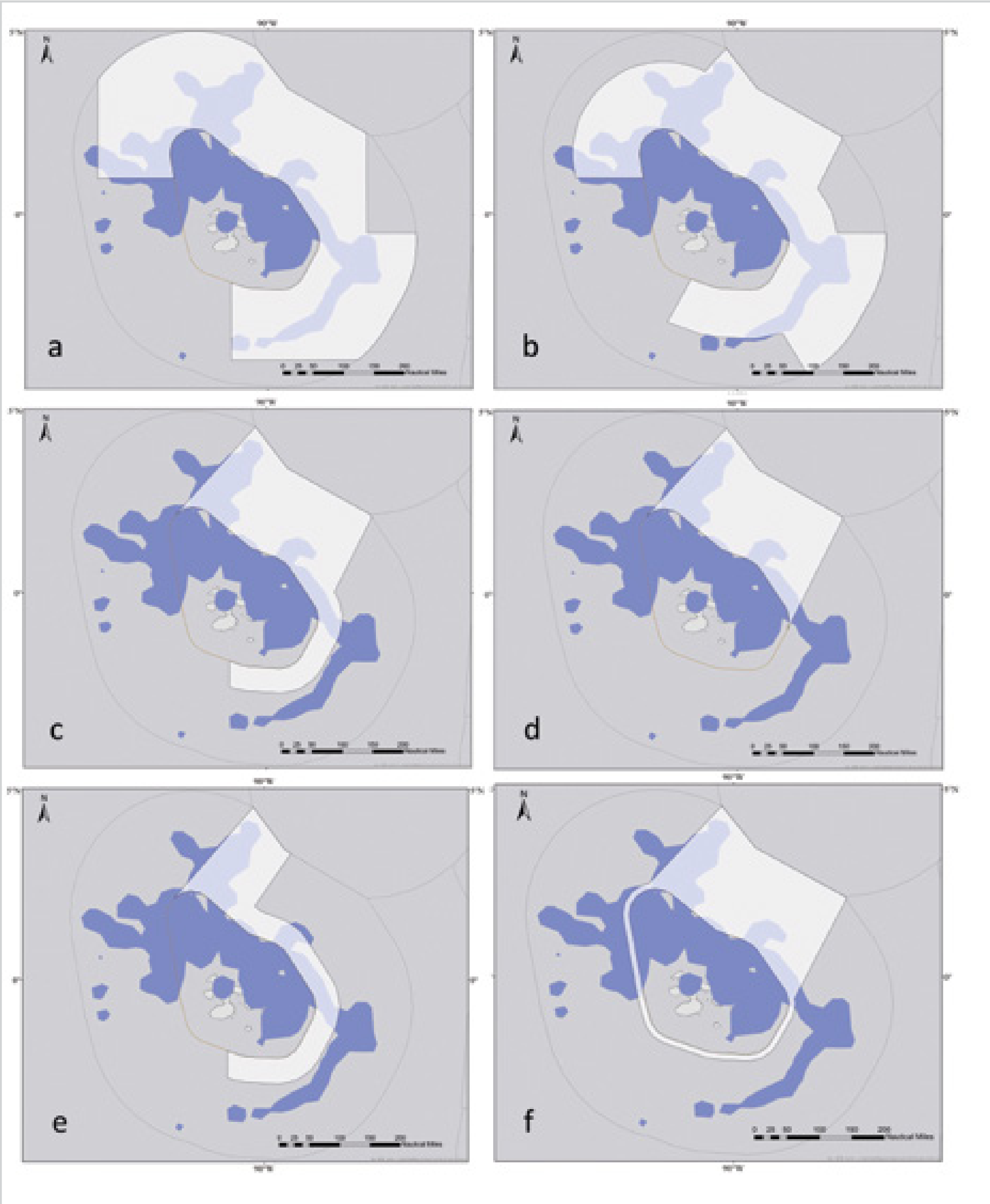


Figure 151. Protection coverage for the critically endangered scalloped hammerhead shark under each scenario. Scenarios are represented as white polygons. Panels: **a** – Maximum Conservation, **b**- Spillover and Migratory Routes, **c** – 30 by 30, **d**- Cocos-Galápagos Swimway, **e** - Minimum Protection, **f** - Swimway and ring.

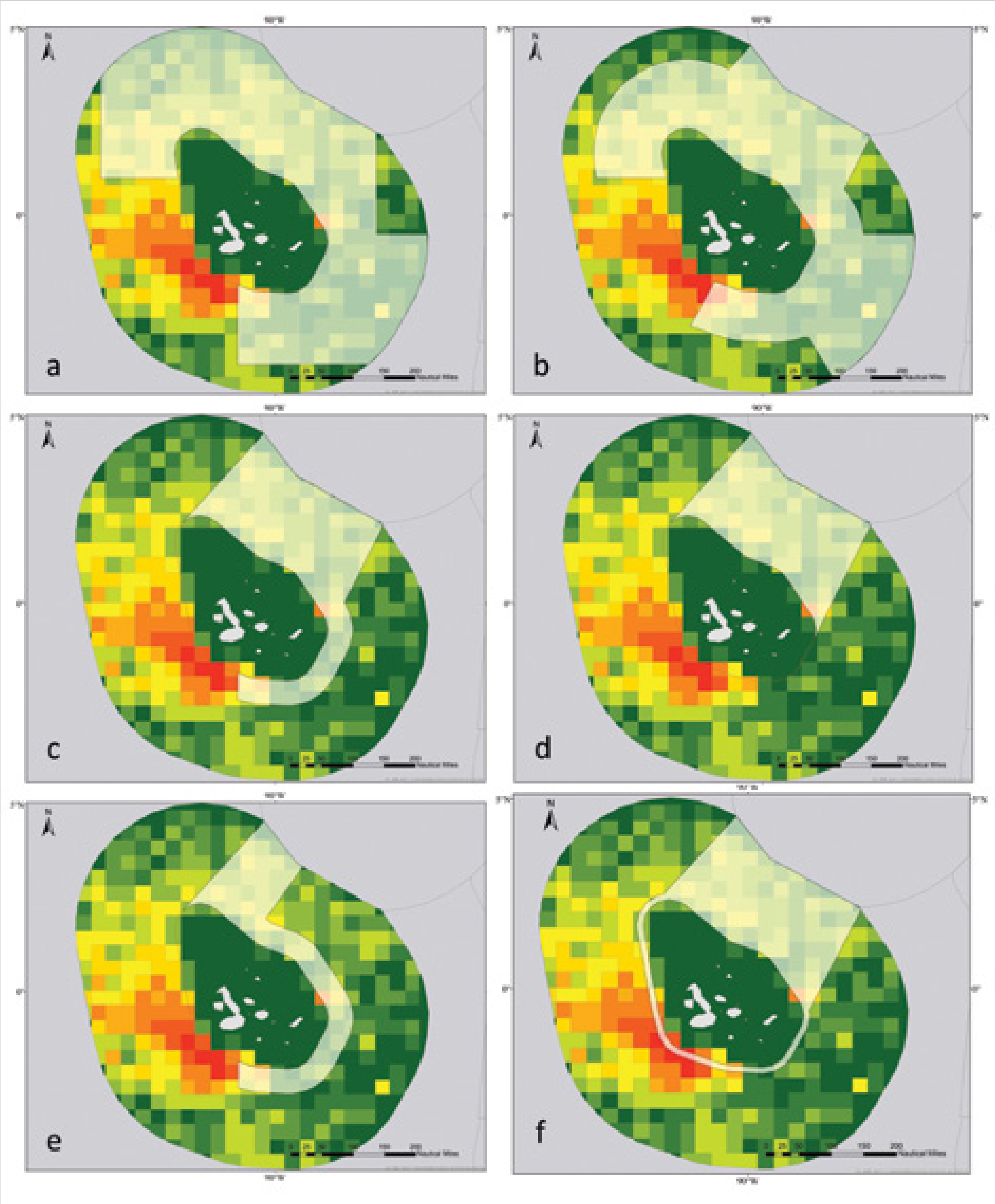


Figure 152. Spatial overlap of each scenario with the spatial distribution of catch value for the Ecuadorian purse seine tuna fleet. The value of the catch obtained for each 4 km^2 pixel is mapped on a scale of low-0 (green) to high-10 (red). Scenarios are represented as white polygons. Panels: **a** – Maximum Conservation, **b**- Spillover and Migratory Routes, **c** – 30 by 30, **d**- Cocos-Galápagos Swimway, **e** - Minimum Protection, **f** - Swimway and ring.

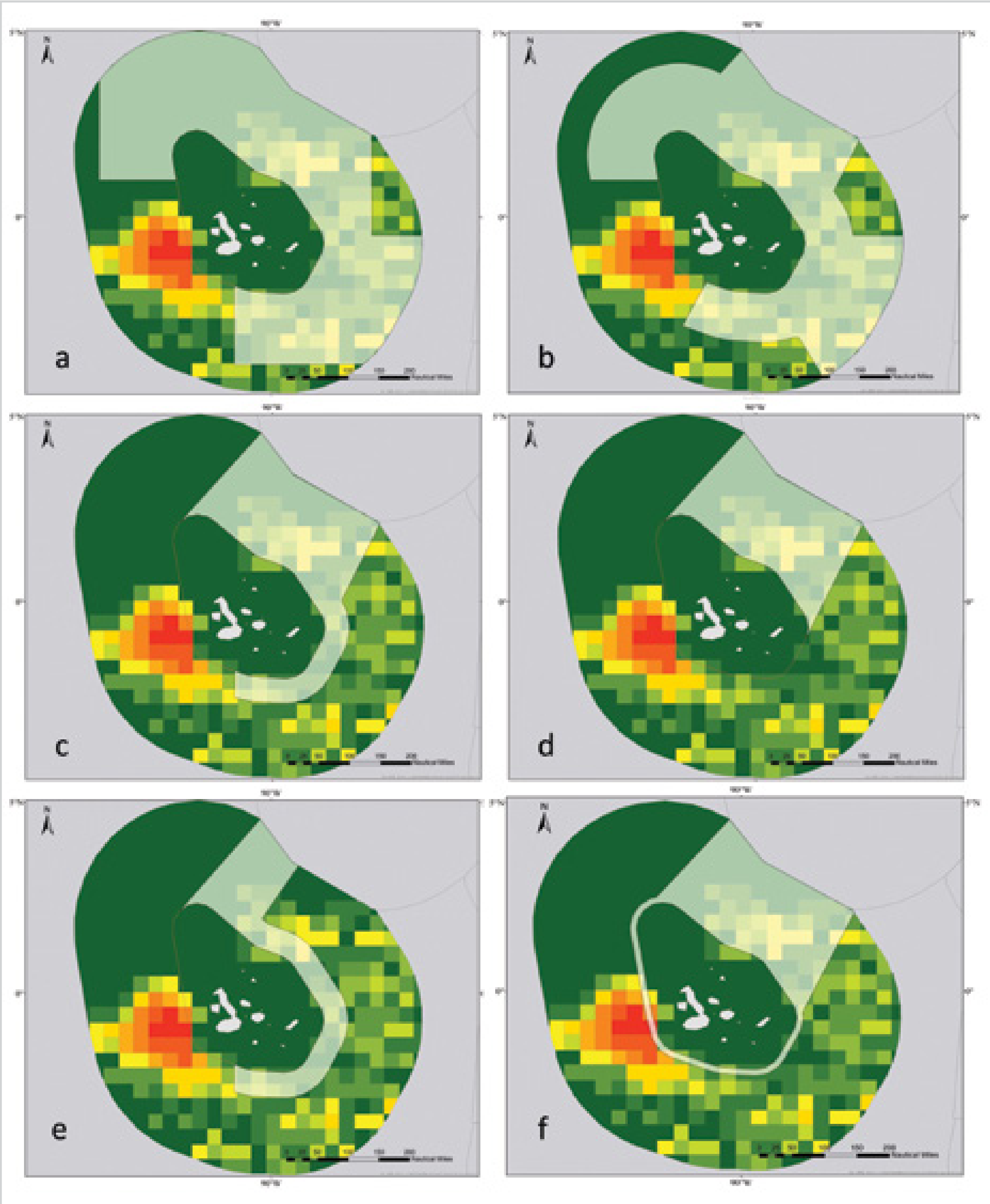


Figure 153. Spatial overlap of each scenario with the spatial distribution of catch value for the Ecuadorian artisanal longline tuna fleet. The value of the catch obtained for each 4 km^2 pixel is mapped on a scale of low (green) to high (red). Scenarios are represented as white polygons. Panels: **a** – Maximum Conservation, **b** - Spillover and Migratory Routes, **c** – 30 by 30, **d** - Cocos-Galápagos Swimway, **e** - Minimum Protection, **f** - Swimway and ring.

The other three scenarios focus protection mainly on the northeast, along the Cocos Ridge, and a 40 NM ring in the southeast of the Galápagos EEZ. Therefore, the no-take area reduces considerably while the fishing area more than doubles compared to the maximum protection scenario (Figures 152-153). Accordingly, the percent value of the catches increases for both fleets, although not proportionally: approximately 19-20%. In terms of direct impact on catch, the last three scenarios are very similar and imply a minimum relocation of fishing effort to account for 2-4% of the catch value considering the whole area of fishing grounds for both fleets.

All the fishing zones under each scenario require the implementation of responsible and adaptive management practices. These could include spatial and temporal measures to provide extra protection for fish stocks and also endangered migratory species if new or updated information on their status becomes available. Scenario E explicitly includes this type of measures. As shown in Figure 145, this scenario includes a longline exclusion zone in the east (light blue) and a temporal seabird protection zone in the southeast, where longline activities would be banned for 3-months each year. These measures would increase the protection coverage of key conservation features in these two zones and should be considered in the marine spatial planning process of the Galápagos EEZ. As an example, for this scenario E, the inclusion of the temporal seabird protection zone would increase the coverage of the waved albatross by 22% and the Galápagos petrel by 5%.

Trade-offs between Conservation Coverage and Fishery Values

Table 19 assesses the trade-offs among two ecosystem services in the Galápagos EEZ: biodiversity services represented by the percent coverage of key pelagic habitat and species, and provisioning services represented by the percent value of purse seine and longline catches. Green cells indicate higher level of services (>80% conservation coverage or value of catch), while orange cells lower level of services (<65%). As expected, conserving biodiversity increases with larger no-take areas for the new marine reserve, while showing medium-high level of provisioning services depending of the scale of fishing grounds. When considering the total area of fishing, percent value of catch represents only 4-6% in the new marine reserve. As the size of the proposed no-take areas increases, there is a corresponding increase in fishing revenue that would be affected, from 1% (longline) and 2.3% (purse seine) of total catch values coming from the no-take zone proposed in scenario E, to 4.4% (longline) and 5.8% (purse seine) respectively in scenario A. As the size of the no-take decreases, certain conservation features decrease up to 10-28% or even more for some endangered migratory species, including the waved albatross (90% to 35% protection coverage). As explained above, temporal closures could increase the protection of some conservation features.

Economic Impacts for Fisheries

For the 2007-2019 period, Ecuador's fishing industry contributed on average 1.36% to Ecuadorian gross domestic product (GDP), had an average growth rate of 3.45%, created about 52,328 direct jobs and generated 6.13 % of total exports (BCE 2020). In 2019, total exports reached US$1.62 billion, representing the 4th largest export generating industry for the country (BCE 2020).

The Ecuadorian fishing sector includes about 3,600 firms, participating in three main industries: marine fishing, fish processing and fish preservation. This sector also has 83 large companies, which are highly competitive in the fish processing business. Across the fisheries value chain, this industry interacts with 46 of the 69 industries within Ecuador's economy; it sells and buys, inputs to/from other industries, forming a complex grid in order to create value (Viteri-Mejía 2021).

As discussed in the previous section *"Comparing Scenarios: Conservation objectives and fishery values"*, the relative direct impacts of the proposed conservation scenarios on the fishing economy of Ecuador range between 2.3% to 6.2% of the total value for the purse seine fishery and 1% to 4.4% of the total value for the longline fishery. These numbers were applied in a study by Viteri-Mejía (2021), sumarized below, which used 2018 input-output matrix model simulator built by the Ecuadorian Central Bank (BCE 2020b) to examine economy-wide implications of these scenarios. The input-output matrix is a useful tool to assess connectivity among different industries that made up an economy and show the equilibrium between supply and demand. With this model, it is possible to analyze shocks that could affect a country's aggregated demand and measure their subsequent effects on the production, employment, and income of the whole economy in the short-term (but without considering dynamic behavior of the fishing fleets).

In this case, the model was used to calculate the effects of closing some fishing grounds located within the Galápagos EEZ, assuming that this is similar to a fall in the aggregate demand for the marine fishing industry. Besides the direct economic impacts on the industry, the model also assesses how an external shock is transferred to other sectors of the economy and estimates the broader effect over the whole economy. However, the model makes some basic assumptions that do not hold for this case, so the results must be interpreted with caution:

1. The model assumes that the resource is static – that is, the fish that are in the no-take area remain there and are lost to the fishers. Pelagic fish are highly mobile, and indeed it has already been shown with the current GMR, that they leave no-take areas, where they can be caught by fleets concentrated along the reserve borders "fishing the line" (Boerder et al. 2017, Bucaram et al. 2018).
2. The model assumes that the fishing effort expended in the area is lost once it becomes no-take. Again, it has already been shown in the case of the current GMR that effort did not decrease, rather it was displaced to other areas and increased (Bucaram et al. 2018). In addition, the model assumes relative prices do not change and production structures do not change either. This may not be true in the medium or long term due to the dynamic nature of the industry and the economy.
3. The model does not take into account the biology of the resource. In this case, while inside the no-take zone, fish may grow and reproduce, thus increasing the overall biomass of the stock. Depending on the size and mobility of the species, appropriately planned no-take zones may lead to a "spillover effect" whereby the population size in an area approaches a carrying capacity, inducing migration to unprotected areas.

In an ideal scenario, we would be able to either examine the behavioral adjustments by fishing fleets in response to the closure scenarios (e.g. Dépalle et al. 2020; Dépalle et al. 2021) or develop an integrated bioeconomic model to also consider the biology of the fisheries resources (e.g. Bastardie et al. 2014; Bastardie et al. 2015, Rybicki et al. 2021). Unfortunately, data limitations prevented our ability to do so within the scope of this study. While we cannot ascertain any specific trends, the likely behavioral adjustments by the fishing industry would indicate that the results below are an overestimate of likely economic impacts of the scenarios being assessed.

The results of the direct economic impact estimations are presented in Table 21. From larger to smaller protection scenarios, the direct economic impact varies from US$ 22.6 million, corresponding to the Maximum Conservation and Spillover and Migratory Routes scenarios, to US$ 10.2 million for the Swimway scenario.

Table 21. Short-term direct economic impacts (in tons and US$) of conservation scenarios in the Galápagos EEZ on the marine fishing industry (Source: Viteri-Mejía 2021).

Impact on Fisheries by type (based on entire fishing area per fleet)	Maximum Conservation/ Spillover and Migration Routes	Swimway + 10 NM ring	30 by 30	Cocos-Galapagos Swimway
% loss of purse seine fishing area	6%	4.1%	3.2%	2.7%
% loss of longline fishing area	4%	2.4%	2.0%	1.7%
Total short-term direct impact (in metric tons)				
Loss of catch of purse seine fishery	17,223	11,769	9,185	7,750
Loss of catch of longline fishery	973	584	486	413
Total	**18,195**	**12,352**	**9,672**	**8,164**
Decrease in value based on 2018 data (US$ In thousands)				
Loss of value of purse seine fishery	21,427.0	14,641.8	11,427.7	9,642.2
Loss of value of longline fishery	1,210.3	726.2	605.1	514.4
Total	**22,637.3**	**15,368.0**	**12,032.9**	**10,156.5**

Considering that the marine fishing industry has links with different industries as part of its value chain, the analysis also included estimation of the short-term impacts on the rest of the economy. For each conservation scenario, the input-output matrix simulation tool makes the comparative static analysis of how the negative effect on the marine fishing industry aggregate demand spreads across the other industries.

Table 22 shows the main results of this, in terms of changes in gross production, GDP, employment, income and taxes for both the marine fishing industry and the whole economy. For the case of the Swimway scenario, the results show that the marine fishing industry's gross production would decrease by US$ 10.16 million; the industry's GDP would decrease by US$ 10.2 million (a drop of 1.47%); the marine fishing industry labor force would lose 524 jobs; and there would be a decrease in revenue of about US$ 1.6 million. Taxes collected by the government from this industry would be only marginally affected by US$ 26,000, and the gross operating surplus of the industry (capital revenue) would fall by US$ 4.8 million.

The impacts of this protection scenario on the whole economy indicate a drop of US$ 14.9 million in gross production; a decrease in GDP of US$ 8.8 million (that is just 0.01% of Ecuador's entire GDP), a loss of 703 jobs, a total drop in revenue of US$ 2.4 million; government tax collection on the entire economy would be reduced by US$ 57,000, and the gross operating surplus would be reduced by US$ 6.3 million. For the scenarios with larger protection and conservation goals, the reduction in short-term gross production and GDP would approximately double.

Table 22. Marine fishing industry and short-term total economy impacts of the implementation of conservation scenarios in the insular EEZ, based on data from 2018. Monetary values are in US$ thousands. Source: Viteri-Mejía (2021), estimates obtained using the simulation tool of the 2018´s input-out matrix (BCE, 2020b).

Conservation Scenarios	Scope	Gross Production (US$)	%	Gross Domestic Product (US$)	%	Employement #	Income (US$)	Taxes (US$)	Gross Operating Surplus (US$)
Cocos-Galapagos Swimway	Marine Fishing	(10,160)	-1.47	(6,399)	-1.47	(524)	(1,589)	(26)	(4,783)
	Total economy	(14,895)	-0.01	(8,776)	-0.01	(703)	(2,432)	(57)	(6,287)
30 by 30	Marine Fishing	(12,037)	-1.74	(7,580)	-1.74	(621)	(1,883)	(31)	(5,667)
	Total economy	(17,646)	-0.01	(10,397)	-0.01	(833)	(2,881)	(67)	(7,449)
Swimway + 10 mn ring	Marine Fishing	(15,373)	-2.22	(9,681)	-2.22	(793)	(2,405)	(40)	(7,237)
	Total economy	(22,537)	-0.01	(13,279)	-0.01	(1,064)	(3,680)	(86)	(9,513)
Maximum conservation / Spillover & migratory routes	Marine Fishing	(22,644)	-3.27	(14,260)	-3.27	(1,168)	(3,542)	(58)	(10,660)
	Total economy	(33,197)	-0.02	(19,560)	-0.02	(1,566)	(5,420)	(127)	(14,013)

The static nature the analysis makes that these results are just reliable in the short-term (less than one year) as the model assumes relative prices do not change and production structures do not change either. This would likely not hold in the long term due to the dynamic nature of the industry and the economy, and it is expected that the economic agents adopt decisions to adapt and mitigate the impacts of the proposed polices, for instance, the fish processing industry can substitute fish coming from the Galápagos EEZ with fish from different origin, or fishing fleets can look for other fishing grounds. Hence, we cannot assert that the economic impacts estimated here will be maintained over time. According to the literature on fishing and how fleets perform their fishing activities, fleets are dynamic and constantly update their fishing grounds based on the movement of the target species (Dépalle et al. 2020; Wijermans et al. 2020; Dépalle et al. 2021).

Following this reasoning, it is likely that once some areas are closed, the fleets will adapt almost immediately to find alternative fishing grounds, thus mitigating the negative impacts of adopting the zoning alternatives. To illustrate these effects, three additional scenarios were modelled for each protection alternative, where different levels of adaptive behavior were assumed by considering that only 5%, 15% and 25% of the short-term direct impacts will occur in the short term, for high, medium and low adaptive behavior, respectively. This implies the fleets are able to adapt rapidly and avoid the negative effects on their catch. Assuming these partial direct impacts, the model evaluated the economic impacts on the marine fishing industry and the whole economy using the input-output matrix model (Table 23). The results show a clear inverse relationship between the adaptive capacity of the fleet and the impacts.

The input-output matrix model results suggest that the marine protection alternatives analyzed will have an impact on the GDP, employment, tax revenues and income of the marine fishing industry and Ecuador's economy as a whole. However, although the simplicity of this input-output model makes it convenient to have some short-term impact estimates, as mentioned earlier, these results have many caveats and limitations (Schuschny & UN, 2005). The most important of these is that the model is a static analysis that does not reflect the dynamics of the economic agents. Fishing fleets behave adaptively: after closures they seek out other fishing grounds, especially in the pelagic environment and with highly mobile commercial species such as tuna (Salas and Gaertner 2004). For this reason, a spatially-explicit dynamic economic study on fishing fleet behaviour would better capture the impacts of marine protection alternatives.

Table 23. Short-term marine fishing industry and total economy impacts of the conservation scenarios in the Galápagos EEZ, 2018; assuming high, medium and low adapting scenarios resulted in just 5%, 15% and 25% of direct impacts, respectively. Monetary values are in US$ thousands. Source: Viteri-Mejía (2021); estimates obtained using the simulation tool of the 2018´s input-out matrix (BCE, 2020b).

Conservation Scenarios	Adaptation Scenario	Scope	Gross Production (US$)	%	GDP (US$)	%	Jobs #	Income (US$)	Taxes (US$)	Gross Operating Surplus (US$)
Cocos-Galapagos Swimway	High	Marine Fishing	(508)	-0.07	(320)	-0.07	(26)	(79)	(1)	(239)
		Total economy	(745)	0.00	(439)	0.00	(34)	(122)	(3)	(314)
	Medium	Marine Fishing	(1,523)	-0.22	(959)	-0.22	(79)	(238)	(4)	(717)
		Total economy	(2,233)	0.00	(1,316)	0.00	(105)	(365)	(9)	(943)
	Low	Marine Fishing	(2,540)	-0.37	(1,599)	-0.37	(131)	(397)	(7)	(1,196)
		Total economy	(3,723)	0.00	(2,194)	0.00	(175)	(608)	(14)	(1,572)
30 by 30	High	Marine Fishing	(602)	-0.09	(379)	-0.09	(31)	(94)	(2)	(283)
		Total economy	(883)	0.00	(520)	0.00	(41)	(144)	(3)	(373)
	Medium	Marine Fishing	(1,806)	-0.26	(1,137)	-0.26	(93)	(282)	(5)	(850)
		Total economy	(2,647)	0.00	(1,560)	0.00	(124)	(432)	(10)	(1,117)
	Low	Marine Fishing	(3,009)	-0.43	(1,895)	-0.43	(155)	(471)	(8)	(1,417)
		Total economy	(4,411)	0.00	(2,599)	0.00	(208)	(720)	(17)	(1,862)
Swimway + 10 MN ring	High	Marine Fishing	(768)	-0.11	(484)	-0.11	(40)	(120)	(2)	(362)
		Total economy	(1,126)	0.00	(664)	0.00	(53)	(184)	(4)	(475)
	Medium	Marine Fishing	(2,306)	-0.33	(1,452)	-0.33	(119)	(361)	(6)	(1,085)
		Total economy	(3,380)	0.00	(1,992)	0.00	(159)	(552)	(13)	(1,427)
	Low	Marine Fishing	(3,843)	-0.55	(2,420)	-0.55	(198)	(601)	(10)	(1,809)
		Total economy	(5,634)	0.00	(3,320)	0.00	(265)	(920)	(22)	(2,738)
Maximum conservation / Spillover & migratory routes	High	Marine Fishing	(1,132)	-0.16	(713)	-0.16	(58)	(177)	(3)	(533)
		Total economy	(1,660)	0.00	(978)	0.00	(78)	(271)	(6)	(701)
	Medium	Marine Fishing	(3,397)	-0.49	(2,139)	-0.49	(175)	(531)	(9)	(1,599)
		Total economy	(4,980)	0.00	(2,934)	0.00	(235)	(813)	(19)	(2,102)
	Low	Marine Fishing	(5,661)	-0.82	(3,565)	-0.82	(292)	(885)	(15)	(2,665)
		Total economy	(8,299)	0.00	(4,890)	0.00	(391)	(1,355)	(32)	(3,503)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Discussion

The aim of this document was to describe and, where possible, quantify the threats facing the Galápagos EEZ and to propose scenarios that could mitigate these threats. When the process to create the GMR began in the mid 1990s, very little was known about the ecology of many of the wide-ranging species that the reserve was meant to protect. A quarter of a century on, this reassessment resulted from improved scientific knowledge about the species, habitats, ecosystem processes and human activities in and around the GMR, as well as the identification of new threats to the system.

Present-day threats to fisheries are very different from those of the 1990s. Currently, one of the main problems is illegal fishing by national, Ecuadorian vessels that enter the protected waters of the GMR. According to statistics from the Galápagos Park Directorate, between 2018 and 2020, 136 fishing vessels were intercepted inside the GMR (El Universo 2020b). Local fishermen have expressed their concern regarding the presence of smaller longline fishing vessels (which do not carry tracking devices) inside fishing zones within the GMR that are intended to support local economies. Likewise, illegal fishing by international vessels is another major concern for all countries in the ETP. According to data from Global Fishing Watch, between 2012-2018, vessels from at least 13 countries carried out fishing operations inside the Ecuadorian EEZ around Galápagos, although it is unclear how many of these were illegal (Chinacalle-Martinez 2020).

Since the mid-1990s, the national fleet has significantly increased its fishing capacity and intensity in the waters surrounding the GMR. In 2000, the IATTC established a regional maximum capacity of 158,000 m^3 for the purse-seine fishery. However, the current capacity is 253,000 m^3. Nationally, the industrial fishing fleet has grown from 47 vessels in 1997 to 116 vessels in 2019 (Bustamante 1999, Pacheco 2014). Likewise, tuna catches within the Galápagos EEZ have doubled since the start of the 21st century. The semi-industrial longline fleet has the capacity for 'motherboats' to tow up to 12 smaller vessels to Galápagos and beyond, in search of tuna, billfish and sharks (Martínez-Ortiz et al 2015). Furthermore, reports show that foreign vessels are fishing intensively in those international waters around the EEZ. This increase in fishing effort could negatively affect the sustainability of national marine resources today and in the future.

The use of Fish Aggregation Devices (FADs) in the ETP region has become widespread since the 1990s. FADs attract and aggregate commercially important fish species such as tuna as well as protected species like silky sharks. In general, FADs do not increase productivity, but rather concentrate fish and intensify their capture. Because of this, if not used responsibly, FADs can lead to overfishing. In the early 1990s, less than 5% of purse-seine sets used FADs while currently, around 70% of sets employ FADs (MAP 2018). The Ecuadorian tuna fishing fleet is one of the fleets that use the most FADs in the region. Although the percentage of bycatch obtained by fisheries using FADs has decreased from 15-20% in the 1990s to 2-3% at present (Hall and Roman 2013), the volume of bycatch is still significant given the large and targeted fishing effort that FADs facilitate. In other words, percentage of bycatch is not an appropriate indicator of the impact of fishing on a species or group of species, because the impact will depend rather on the proportion of the population of each species caught. This applies to several endangered species of sharks such as silky and hammerhead sharks.

The Galápagos artisanal fishing sector is concerned about the increased use of FADs around the GMR. They are also concerned that FADs are deployed in areas east of the GMR boundary, allowing them to drift with the South Equatorial Current across the reserve, essentially expanding the scale of fisheries capture for the schools of fish attracted to the FADs which subsequently drift outside the reserve. This practice could be negatively affecting the catches of locally important species such as wahoo and yellowfin tuna. Additionally, it could affect resident populations of threatened sharks that associate with FADs. Finally, FADs may pose a collision risk to Galápagos fishers, especially when operating at night. In this report, our modeling studies support these concerns, with FADs spending an average of 4-8 days in the GMR in most months, in ENSO neutral and La Niña years, with fewer incidences under El Niño conditions.

Fishing-related activities are not the only threats to Galápagos. According to the projections of the Intergovernmental Panel on Climate Change (IPCC), within the ETP region, fisheries productivity in the EEZ around Galápagos may be less affected than coastal areas, particularly the upwelling sites influenced by the Humboldt and Cromwell cold currents (IPCC 2019). This will likely result in increased fishing pressure in the waters around the Galápagos by vessels that, until now, have fished elsewhere. This pattern is already occurring on both national and international levels, as shown by the growing scale and presence of foreign vessels along the borders of the Galápagos EEZ in recent years. Thus, it will be imperative to safeguard national interests against this situation. For this reason, the IPCC identifies the ETP as an area that is at risk of facing complex fishing governance challenges.

Although at a regional scale the temperature of the ETP has increased by 0.4-0.8 °C in the last 40 years, there is no clear trend regarding the surface sea temperature in the waters surrounding Galápagos over the past 100 years (Banks et al. 2011). However, the expected oceanographic changes in the EEZ around Galápagos throughout this century are:

- Sea surface temperature rise
- Increased intensity and frequency of El Niño and La Niña events
- Sea level rise (several centimeters)
- Increased precipitation
- Reduction in surface pH (acidification)
- Reduced upwelling

Based on the observed behaviors in the past El Niño events, the foraging areas of endemic species (fur sea lions, sea lions, flightless cormorants, among others) are expected to expand as sea surface temperature rises and marine productivity decreases (Elorriaga-Verplancken et al. 2016), although in some cases climate change may create an 'ecological trap' when species, or particular life stages,

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are forced to shift their ranges to less suitable habitat – for these species, the outlook is bleak (Sherley et al. 2017). Similarly, the reproductive rates of these species could also decline, and the distributions of other oceanic species may shift over time. There are still major gaps in our knowledge of how climate change may affect the species and habitats out in the open ocean surrounding Galápagos.

Finally, plastics have emerged in recent years as a major threat to the world's ecosystems in general, and to the oceans in particular. Despite the isolation of the Galápagos Islands, plastic contamination levels of >800 microplastic particles per m^2 were recorded during recent surveys on beaches, placing them amongst the most plastic contaminated remote beaches in the world (Jones et al. in prep). Over eight tons of plastic has been cleaned annually during remote clean-up operations by the Galápagos National Park and Conservation International Ecuador over the last two years and the amount seems to be increasing (unpublished data). Models suggest that only a small amount of plastic is entering the GMR from known industrial fishing grounds but this does not reconcile with unpublished coastal clean-up data or archaeological analysis of macroplastic items (Schofield et al. 2020; van Sebille et al. 2019). Recent data (Jones et al. in prep) suggests that 10-30% of macroplastic found along the shores of Galápagos is from fishing gear, primarily polypropylene and nylon ropes and lines. Due to the small size of the artisanal fishery, the majority of this litter is likely floating in from outside the marine reserve boundary.

The direct results of these threats may be the continued population decline of a range of threatened and endangered migratory or highly mobile marine species, such as sharks, turtles and seabirds, and increasing challenges to sustainably manage commercial species such as yellowfin and skipjack tuna, both by local artisanal fishers within the GMR and national based semi-industrial and industrial fishers in the EEZ. The indirect effects across the marine food web in this region have only been studied under limited circumstances and are still poorly understood (Ruiz and Wolff 2011), although the transfer of microplastics through the food web by means of bioaccumulation and biomagnification is generally recognized as a threat, including to humans (Carbery et al. 2018).

Based on the management objectives proposed, we opted for a spatial management approach that would imply an inter-agency management of the entire EEZ and would provide for the creation of no-take areas along with areas where, by implementing management measures (such as gear restrictions or temporal closures), responsible fishing activities could be carried out. The no-take areas in each scenario are focused on the north and northeastern part of the EEZ, highlighting the importance of connectivity with Cocos Island, and the putative "swimway" associated with the Cocos Ridge.

This area is also described as "ocean wilderness" – small remaining areas of ocean (around 13% globally) where overall human impact is still low (Jones et al. 2018). Only 3.6% of the Eastern Tropical Pacific corresponds to ocean wilderness (most of which is in the Costa Rican EEZ, between Cocos Island and the border with Ecuador), and only 11.9% of this lies within MPAs. The cumulative impact of human activities in Ecuador's waters is increasing, albeit at a much lower rate than most other areas – a recent study based on changing levels of 14 stressors (including climate change, fisheries and shipping, among others) found that 59% of the ocean is experiencing significantly increasing cumulative impact, while only 5% was experiencing a decrease in impact (Halpern et al. 2019). Each of our proposed scenarios includes large areas of no-take in this wilderness area, all of which would fall under the category of a Large Scale MPA (LSMPA): a conservation area that is larger than 100,000 km^2 (Friedlander et al 2016, O'Leary et al 2018).

Benefits of Large MPAs

Since the beginning of the 21st century, there has been an emerging global trend towards the establishment of LSMPAs, often located in remote places within and beyond national jurisdictions and usually, as with smaller MPAs, with the goal of protecting pelagic ecosystems (Jones 2011; Leenhardt et al. 2013; O'Leary et al. 2018; Singleton and Roberts 2014). As with smaller MPAs, they have been defined as conservation areas that are larger than 100,000 km^2, although some authors have used larger sizes of 240,000 km^2 and above (Toonen et al. 2013, Wilhelm et al. 2014). LSMPAs can protect, conserve and restore marine habitats and processes that have been impacted by human activities. Additionally, LSMPAs have the potential to protect pelagic, highly mobile and migratory species that are threatened and/or commercially important (Smyth and Hanich 2019).

LSMPAs have a high conservation potential because they can protect and connect entire ecosystems that are not represented in smaller MPAs, such as pelagic realms, seamounts, ocean trenches and canyons (Davies et al. 2017; Game et al. 2009; Roberts et al. 2001; Smyth and Hanich 2019). In contrast to their small and coastal counterparts, LSMPAs can protect mobile and dynamic oceanographic features such as eddies and upwelling zones that are critical to sustain marine life (Fox et al. 2012).

Many marine migratory species are particularly vulnerable during certain life history stages such as breeding periods (Dunn et al. 2019). Further, they may undertake movements along predictable pathways, such as the post-nesting eastern Pacific leatherback turtles, which migrate along the Cocos Ridge from nesting sites in Costa Rica, past the Galápagos Islands, after which they disperse in the open ocean (Shillinger et al. 2008); or whale sharks, which move along the equatorial front from July through November each year in the eastern Pacific (Hearn et al. 2016). It is critical to consider migratory connectivity in the design of MPAs, and LSMPAs can address this by including critical habitats and their connecting pathways.

Additionally, LSMPAs can protect highly productive and diverse areas with low levels of anthropogenic impacts and prevent them from future exploitation. However, the benefits and ecological responses to LSMPAs are widely debated, mainly because most LSMPAs have been recently established and because many of them are located in remote locations, making long-term studies and ecological monitoring challenging. Some modelling studies have explored the ecological outcomes of LSMPAs (e.g Dueri and Maury 2013), but recent empirical studies have allowed further understanding of LSMPAs and the benefits derived from them.

For example, the Pacific Remote Islands Marine National Monument (PRIMNM) and Papahānaumokuākea Marine National Monument (PMNM) are part of an extensive LSMPA network in the Central Pacific. These LSMPAs cover the majority of the foraging habitat utilised by three species of boobies, which are highly mobile predators (Young et al. 2015). The British Indian Ocean Territory MPA (BIOT MPA) surrounds the Chagos Archipelago and was declared an entirely no-take LSMPA in 2010. This LSMPA provides some protection to pelagic predators like sailfish, blue marlin, silky sharks and yellowfin tuna because at least some individuals of these species have been observed remaining for extended periods of time within the MPA (Carlisle et al. 2019). Similarly, there is evidence of yellowfin tuna site fidelity within the Revillagigedo Islands Archipelago Biosphere Reserve (Schaefer et al. 2014) and a semi-resident population of yellowfin tuna in the waters surrounding Ascension Island Ocean Sanctuary (AIOS) (Richardson et al. 2018).

Therefore, protecting pelagic and commercially important species during these periods could benefit fisheries and the nations that rely on fishing resources. For example, the Phoenix

Islands Protected Area (PIPA), located in the Central Pacific, currently covers 11.3% of Kiribati's EEZ and has been entirely no-take since 2015. Kiribati is an island nation that relies heavily on selling fishing licenses to foreign industrial fleets that target skipjack, bigeye and yellowfin tuna. Thus, PIPA was established to meet conservation goals as well as a measure to protect tuna breeding stocks that could benefit fisheries. Using empirical data and larval backtracking, Hernández et al. (2019) found evidence that commercial tuna species spawned within PIPA, indicating the key role of this LSMPA in tuna conservation.

In theory, LSMPAs have the potential to provide refuges that are large enough to rebuild and maintain mobile stocks of commercially important species. As biomass increases inside a given LSMPA, adult or larval individuals can move to adjacent fishing grounds and benefit fisheries, a process also known as "spillover". Currently, there is limited empirical evidence of spillover in LSMPAs. However, there are few recent studies that help understand the ecological responses of pelagic species to LSMPAs and the effects on the fishing industry. For instance, before the establishment of the BIOT MPA in 2010, international industrial fisheries that targeted yellowfin and skipjack tuna operated in the waters near the Chagos Archipelago (Dunn and Curnick 2019). On one hand, census and tracking data indicate positive ecological responses of coral reefs and associated fauna, seabirds and sea turtles after the establishment of the BIOT MPA (Hays et al. 2020). Yet, the effects on the fishing industry are complex. For example, Curnick et al. (2020) analysed the temporal catch rates of yellowfin and bigeye at a regional scale (in the Equatorial Indian Ocean) before and after the establishment of the BIOT MPA. The study revealed increases in the average sizes of yellowfin (12.76% between 2009 and 2016) and bigeye tuna (21.56% between 2009-2017) within the BIOT MPA, and a similar trend was also observed across the equatorial Indian Ocean. However, the authors found no evidence of improved CPUE for both tuna species. In general, bigeye tuna CPUE remained stable through time but fishery data shows that yellowfin CPUE has been steadily declining since the 1960s in the BIOT MPA and surrounding areas. The persistent overfishing of the yellowfin tuna, and IUU fishing could be masking any positive effects and it is unlikely that the BIOT MPA alone is sufficient to benefit tuna stocks (Curnick et al. 2020; Hays et al. 2020).

Conversely, positive ecological responses have been recorded for LSMPAs that have been established for longer periods of time, such as the Galápagos Marine Reserve (GMR). Prior to the establishment of the GMR in 1998, the waters surrounding the Galápagos Islands were heavily fished by industrial tuna fleets. By 2002 when the GMR was effectively enforced, industrial fishing effort declined definitively within the GMR, such that within four years, fishing effort by the large industrial purse seiners was close to zero (Bucaram et al. 2018, Boerder et al. 2018). Spatial analyses reveal that the industrial fleets were 'fishing the line' – the border effect: a term used to describe the behaviour of fleets that fish along MPA boundaries. This response is often used as an indicator of spillover because it may show a higher productivity of targeted species within a given MPA that can benefit fisheries once they move outside. In the GMR, industrial fleets operate outside its boundaries and aggregate particularly at the southwest corner, indicating that this region is likely a tuna productivity hotspot. Over 20 years since its establishment, the GMR keeps benefiting Ecuadorian and international industrial tuna fleets by conserving key habitats for juvenile tuna species (Bucaram et al. 2018). Additionally, the GMR supports higher tuna catches and CPUE despite increases in fishing effort over time (Boerder et al. 2017).

Other studies have analysed the economic impact of LSMPAs on the fishing industry. The PMNM and PRIMNM, two of the United

States' largest MPAs located in the Central Pacific, underwent expansions in 2016 and 2014, respectively, with the aim of protecting biodiversity. During this period, concerns were raised regarding potential economic losses to the lucrative Hawaiian longline fishing industry that mainly targets big eye and yellowfin tuna. However, Lynham et al. (2020) found no observable declines in catch rates or revenue to the fishing industry. These results could be explained by the fact that over 90% of fishing occurred outside the expanded areas and that the fleets had access to unprotected fishing grounds in the high seas (Lynham et al. 2020). In a different study, Chan (2020) estimated changes in CPUE of high and low effort Hawaiian longline fishing fleets before and after the PMNM expansion, showing that 16 months after the expansion, fishing effort was displaced, CPUE decreased by 7% and revenue per trip decreased by 9%. It is likely that, during the time of the study, fishers had not adjusted to find fishing grounds as productive as those within the PMNM where they previously fished (Chan 2020).

Although empirical evidence on spillover effects from LSMPAs and the potential benefits to the fishing industry is limited, some studies reveal that LSMPAs have the potential of increasing catches in the long term without impacting fisheries productivity. Thus, LSMPAs could play a key role in global food security.

LSMPAs also play an important role in climate change adaptation and mitigation. Today, climate change is one of the main threats to the world's oceans because its effects are modifying ocean chemistry and interrupting natural processes that support marine life. Consequently, several marine species are projected to experience changes in their distributions as ocean conditions change (Bindoff et al. 2019). In a recent study, Davies et al. (2017) analyzed the conservation potential of LSMPAs (in this case, defined as areas larger than 30,000 km^2) under a climate change scenario (year 2100, IPCC SRES A2 scenario) by modelling future species distributions and LSMPAs coverage. They found that LSMPAs established until the time of the study covered approximately 4.4% of the ocean, yet they protected some portion of the range of 83.3% of the species assessed. Further, 26.9% of the species found within LSMPAs had at least 10% of their ranges represented and under the climate change scenario, in 2100, LSMPA coverage would increase for 40.1% of the species, considering distributional shifts.

Due to their extensive sizes, LSMPAs can protect entire ecosystems and act as buffers against the effects of climate change and other anthropogenic stressors. For example, LSMPAs can potentially protect genetic diversity, allow the recovery of ecosystems, maintain marine trophic linkages as well as protect keystone

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species and apex predators. Additionally, LSMPAs can act as refuges for many species and increase their resilience to extinction (Roberts et al. 2017). In general, well designed LSMPAs could be useful tools for climate change adaptation and provide conservation benefits for a variety of species (Smyth and Hanich 2019).

Addressing Criticisms of LSMPAs

A common criticism about LSMPAs is that they are often established to meet global percentage-based conservation targets: Jones and De Santo (2016) expressed concerns that by focusing on the Aichi 10% MPA coverage, the designation of LSMPAs might not allow the elements of effectiveness, representativeness, coherence and equity to be met. Similarly, some authors argue that governments and non-government organizations (NGOs) tend to prioritize quantity over quality and establish LSMPAs merely for political reasons (Singleton & Roberts, 2014). Additionally, they argue that some LSMPAs are designated in areas of low commercial interest to meet conservation targets, giving a false sense of progress (Wilhelm et al. 2014). Further, if countries create LSMPAs in a rushed fashion, they may alienate stakeholders and result in 'paper parks' that do not offer any real protection (Agardy et al. 2016), especially if there are inadequate resources for control and enforcement. However, other authors state that setting global conservation targets is useful because they are quantifiable and comparable metrics and work as simplified indicators of conservation progress (Boonzaier and Pauly 2016). Also, many authors agree that it is necessary for LSMPAs to have clear management plans that include enforcement and monitoring strategies and capacity to ensure their success and avoid turning into 'paper parks' (O'Leary et al. 2018).

Another criticism, related to the Aichi target of *effective* protection, is that it is costly and challenging to enforce and monitor LSMPAs due to their extensive sizes at often-remote locations (Jones and De Santo 2016). Because enforcement is a crucial factor for MPA effectiveness, concerns have been raised about enforcing MPA regulations over large areas and the costs of utilizing advanced monitoring technology (Leenhardt et al. 2013; Wilhelm et al. 2014). However, evidence shows that although the establishment of LSMPAs often involves higher initial investments than for small MPAs, the long-term maintenance costs tend to decrease as MPA size increases (McCrea-Strub et al. 2011). Additionally, vessel tracking data shows that it is possible to maintain low levels of fishing effort after the establishment of LSMPAs, as observed in the PMNM, PRIMNM, the PIPA, Pitcairn and Nazca-Desventuradas LSMPAs in the Pacific (White et al. 2020). Overall, cooperation between agencies and institutions is pivotal to ensure effective MPA management strategies regardless of their size (De Santo 2013; O'Leary et al. 2018; Wilhelm et al. 2014). In the case of the Galápagos EEZ, the existing infrastructure for control and enforcement of the GMR by both the Navy and the Galapagos National Park Directorate implies that many of the challenges for large-scale enforcement are already being met, and there may be economies of scale when expanding into a new reserve. For more details, see section below on *"Costs of patrolling and enforcement."*

A common misconception about LSMPAs is that they have negligible social impacts because they are located in remote places. However, many LSMPAs have some form of human use and a variety of stakeholders that are likely to be impacted by their designation. Evidence shows that managing LSMPAs involve trade-offs between ecological and social outcomes (Davies et al. 2018). Consequently, there are concerns about the lack of stakeholder participation in the establishment and implementation phases of LSMPAs. For example, there is controversy surrounding the BIOT MPA because its establishment generated a lot of opposition from the native people, who have requested to return to the archipelago (De Santo et al.

2011). Fishers are another important group to consider in the establishment of LSMPAs, as they can be displaced from their usual fishing grounds and experience negative economic impacts in the form of reduced catch or increased travel times (Wilhelm et al. 2014). Consequently, over the past few years, some authors have highlighted the importance of incorporating the human dimensions of LSMPAs into their management (Agardy et al. 2016; Christie et al. 2017). Stakeholder participation and engagement are considered to be pivotal to ensure people's support towards LSMPAs and engender trust between groups (Gruby et al. 2017). It is also recommended to include traditional knowledge into LSMPA management to preserve important cultural sites and practices (Leenhardt et al. 2013), which has proven to be successful in LSMPAs like the Great Barrier Reef Marine Park (Dale et al. 2018) and Papahānaumokuākea Marine National Monument (Kikiloi et al. 2017). Additionally, conflict resolution strategies, maintaining people's livelihoods and promoting institutional transparency as well as economic sustainability are necessary for the long-term success of LSMPAs (Christie et al. 2017).

Clearly, LSMPAs are not a panacea; they are simply one component of an array of conservation measures necessary to protect marine ecosystems and resources effectively (Toonen et al. 2013). Although there are some valid criticisms about LSMPAs, some authors argue that governments and other institutions should not choose between small or large MPAs because LSMPAs can complement small and coastal MPAs and that both of them have their own management challenges (Singleton and Roberts 2014; Toonen et al. 2013). Additionally, LSMPAs need to be complemented with other management strategies, as well as effective resource management in areas adjacent to the protected areas (O'Leary et al. 2018).

One additional management strategy that has been used successfully elsewhere, that incorporates fluidity in the use of temporal closures, is dynamic ocean management (DOM). In DOM, the stationary boundaries of MPAs are replaced by mobile boundaries that can be updated in near real-time to reflect the changing oceanographic conditions and distributions of marine species, and even changes in socio-economic conditions (Maxwell et al. 2015). This can allow for management of ocean resources across finer temporal and spatial scales than those addressed by static MPAs (Dunn et al. 2016). In eastern Australia, in order to reduce unwanted by-catch of southern Bluefin tuna by longliners, three different management zones (each with separate by-catch rules) were established and updated throughout the season as suitable habitat for the tuna varied with changes in oceanographic conditions (Hobday and Hartmann 2006). Habitat suitability was estimated by deploying electronic tags to look at SST preferences and then applied to satellite-based SST observations and sub-surface model temperatures. This system was implemented in 2003, resulting in 5 changes in measures in that season (of which only the last 3 included the habitat model). By 2008, 14 management actions were taken, and the model complexity and update frequency had increased (Hobday et al. 2010). However, most examples of DOM in practice relate to single-species avoidance, such as the case outlined above, the TurtleWatch program to reduce loggerhead turtle *(Caretta caretta)* by-catch by longline fishers in Hawai'i (Howell et al. 2008), and the US East Coast monitoring of the presence of North Atlantic right whales *(Eubalaena glacialis)* to reduce lethal ship strikes (Van Parijs et al. 2009). Given the technological, governance and data constraints in the ETP, we have not considered implementing DOM in this region, but it is a tool that may become feasible as these constraints are overcome in the future, and as multi-species approaches are developed.

Limitations of Study

This study was carried out using the best available information made available to the research team, and with the objective of addressing the threats to species and habitats in the open-water system and their impacts on the Galápagos community. It does not attempt to address other important issues and threats related to the existing Galápagos Marine Reserve, which should be the subject of other studies and, more importantly, other decision-making processes. These include concerns about the governance structure and effectiveness in the GMR (Hearn 2008, Jones 2013), the stalled process to re-zone the GMR (Burbano et al. 2019), ongoing attempts to legalize longlining inside the GMR (El Comercio 2020c), the risk of marine invasive species (Carlton et al. 2019), and the over-dependence on tourism and the need to diversify the employment portfolio of the islands (Burbano and Meredith 2020).

Notwithstanding the depth and extent of this study, we identified an overall lack of availability or existence of long-term trends and performance indicators for the Galápagos Marine Reserve. Decision-based indicators exist mostly for commercial species such as lobster (Hearn and Toral 2007, Hearn 2008) and sea cucumber (Shepherd et al. 2004, Ramirez et al. 2020), although their implementation has been intermittent (Hearn 2008, Jones 2013, Ramirez et al. 2020). However, there was very little information available pertaining to population trends of other species (particularly marine migratory species), despite this being a clear objective (Program 1.2: Ecosystems and Biodiversity Monitoring) of the Galápagos Management Plan (Galapagos National Park, 2014). As the Galápagos Marine Reserve approaches its silver jubilee, a robust monitoring plan that provides standardized indicators linked to management decisions must be a priority.

Further, we encountered difficulties in accessing information pertaining to the activities of the fishing fleets operating outside the GMR. Despite various requests, the Vice Ministry of Fisheries did not provide any datasets, and this eventually led to a public rebuke by the Special Commission appointed by the President of Ecuador to design a strategy to protect Galápagos (https://twitter.com/sevillaroque/status/1330582166032560129). As a result of the lack of transparency, we used the best available datasets, which were over a decade old, although we were able to compare the industrial tuna fleet dataset with more recent spatially aggregated catch data, and there did not appear to have been major changes in the spatial distribution of their catch. We have no reason to believe that the longline fleet has changed its spatial behavior either. Regardless, there is an urgent need to develop a process to monitor fishing activities across the Ecuadorian fishing sector, and to make this information available for analyses such as those undertaken in this report. In particular, as Ecuador moves forward in creating MPAs and passing regulatory measures to protect endangered marine wildlife, these data will be essential to evaluate the effectiveness of these actions, and their impact on the fishing sector. The mid- to long-term sustainability of the fishery and wider benefits of prescient management decisions will only be realized if there is rigorous and regular evaluation of the impacts of fishing in the responsible fishing zones (RFZs). This is especially true given the large overcapacity in even the current fleet. There needs to be a mechanism by which early evidence of declines in stocks are recognized (regardless of whether they are driven by climate change or fishing impacts), such that the maximum allowable fishing pressure is modified (i.e. it needs a management system with clear authority).

Further, we focused our analyses of human activities on two main fishing fleets – the industrial tuna fleet and the mainland-based longline fleet.

While we drew attention to international tuna and squid jigger fleets, it was not possible to measure their impact on the Galápagos EEZ, or forecast the potential impact of developing new fisheries, such as a national squid fishery (Morales-Bojórquez and Pacheco-Bedoya 2016). Other human activities that may require consideration in the future include offshore sports fishing, naval activities, exploration for seabed minerals, and shipping. We also did not include the Galapagos artisanal fleet, as they currently only fish within the current GMR.

The animal distribution layers used in the Marxan analyses were sourced from IUCN red listings, and in many cases were of a coarse scale nature that precluded meaningful analysis of association with particular habitats or ocean features. Further, when transforming these into conservation features for Marxan, data on the conservation benefits is a presence or absence (i.e., with no relative abundance data), so the Marxan approach will inevitably produce solutions that effectively avoid disturbance of the fishing fleets. This explains why the southwest area of the EEZ was rarely selected, as this is the area with the highest calculated costs for the fisheries.

While some tracking datasets were comprehensive in both their sample size and their duration and representation across seasons, for many of the species tracked in the region, unless the tracking sample is representative of the source population, interpretation must remain at the level of the individual. Thus, in these cases, the tracks are indicative of movements that animals tagged in Galápagos might make, rather than foraging grounds or migratory routes of the population as a whole.

For these reason, the outputs of the Marxan exercise should not be considered as fully-resolved solutions of the cost-benefit problem. To achieve these, more spatially and temporally explicit data on the abundance of each species per planning unit and a more refined modeling approach would be required.

Our climate change analysis was qualitative rather than quantitative, partly due to the lack of information on many of the key species or habitats, and also partly due to the model disagreement and uncertainty surrounding climate change impacts in the open waters around Galápagos (IPCC 2019).

Our economic model was a basic static model that did not account for the mobility of both the tuna, who will eventually leave the no-take area; and the fishers, who are likely to transfer their effort elsewhere rather than simply not fish. Neither does it take into account the potential spillover effect that has already been shown to occur in the GMR (Boerder et al. 2017, Bucaram et al. 2017). As such it is likely to grossly underestimate the true costs of creating a new no-take area to the fishing sector. Further work is required to more accurately model tuna dynamics and changes in fishing behavior.

Implementation: Key Steps

Successful implementation of this marine spatial planning proposal for the EEZ surrounding the Galápagos Islands will require additional steps to ensure that environmental, social and economic objectives are met. These include:

Active stakeholder participation: There should be a nationwide analysis and discussion of this proposal including participation of relevant authorities and stakeholders, including the national fishing sector, civil organizations and non-profit groups.

Design and implementation of management strategies: Appropriate co-management of the EEZ surrounding Galápagos will require a clearly defined strategy and regulations. In particular, to ensure application and compliance of regulatory measures in the RFZs (such as territorial user rights mechanisms, bycatch mitigation techniques, catch quotas, eliminating the use of FADs to the east of the islands, moving towards 100% observer coverage, among others) both fishery and environmental authorities will need to work closely with the fishing sector to construct a sound governance structure. Furthermore, as the capacity for spatially and temporally explicit resource monitoring and control is improved, components of dynamic spatial management could be incorporated in these zones.

Control and enforcement mechanisms: There will be a need to develop an integrated control and enforcement strategy for both the new protected area and the RFZs, and this may incorporate new tracking technologies. A study is currently underway to analyze the costs that would be incurred, and thus help to inform the decision-making process. Close coordination with user groups will be key to ensuring compliance, potentially in the form of a participatory group tasked with implementing the management plan and evaluating performance, similar to the original Participatory Management Board (PMB) of the GMR (DPNG 1998).

Sustainable financing mechanisms: A sustainable financing mechanism is key to the successful implementation of this proposal. Several initiatives to create Trust Funds or similar structures are currently being explored. Coordination and integration of these different initiatives will facilitate the development of a solid long-term financial base.

Long term monitoring and research: Effective implementation of this proposal requires the design and implementation of a long-term research and monitoring program. This should encompass both the new marine reserve and the RFZs, to establish whether the management practices adopted are securing increases in fish stocks and recovery of endangered species, and if these gains continue as climate change progresses. Long-term monitoring should identify the key species, habitats and processes that the new protection measures are designed to protect, include spatially explicit fisheries monitoring, and establish measurable indicators and threshold values that would trigger new measures or relax existing provisional measures. Research should be oriented to fill the gaps identified in this study, such as modeling climate change impacts on key species, habitats and processes and improving our knowledge on the spatial dynamics of migratory species, and estimating the true economic trade-offs among others. Research and monitoring priorities should be established in the management plan in consultation with users.

Costs of Patrolling and Enforcement

The creation or expansion of any MPA should address the costs incurred to enforce its implementation and monitor its performance over time. A recent study (WildAid 2020) of the presence and distribution of 1,335 fishing vessels in and around the Galápagos EEZ using AIS (Automatic Identification System) tracking from 2018-2020, identified two seasons:

- From October-March fishing vessels were concentrated in the western part of the EEZ.
- From April-September there is less fishing activity within the EEZ but a larger concentration of vessels along the southern and southeastern borders (this also coincides broadly with the long distance foraging movements of the waved albatross, and is therefore of concern).

However, the same study augmented with data from radar hosted at the Galápagos National Park Directorate, showed that during this period, a further 1,347 vessels did not use AIS – this may largely be accounted for by the number of artisanal vessels operating in the area that were not required by law to use AIS at that time (WildAid 2021).

In a subsequent analysis (WildAid 2021) identified three main fishing gear used in and around the Galápagos EEZ – longlines, purse seines, and squid jiggers. They pointed out that, although international fleets should not be directly affected by spatial measures taken within the Galápagos EEZ, given that they sometimes operate on the international border, they should be subject to surveillance, along with the national fleet which would require some changes in their activities. The three agencies that currently have jurisdiction over activities within the Galápagos EEZ are the Fisheries Subsecretariat, the Navy, and the Galápagos National Park Directorate, although the latter only has jurisdiction to the 40 NM border of the GMR. The responsibility of patrolling and surveillance in the EEZ outside the GMR lies with the Navy.

The WildAid (2021) report indicates that, given the nature of the proposal – in that it envisages a spatial management of the entire EEZ, control and surveillance should also cover the entire area, not just the new proposed no-take area. This implies that the costs of the operations will likely not vary substantially across the different scenarios proposed in the previous sections. Changes in the Ecuadorian Fisheries Law (2020), that now make the use of satellite tracking systems mandatory for all artisanal vessels, will facilitate remote surveillance.

A control program based on existing infrastructure, using the Galápagos Islands as a center for operations, would include the following levels:

- Electronic surveillance systems – a round-the-clock control center equipped with radar, Very High Frequency VHF-AIS, satellite-AIS, VMS and Long-Range Identification and Tracking (LRIT) detection systems.

- Air patrols (by airplane or Unoccupied Aerial Vehicle [UAV]) – with the capacity to identify incidents and report back to the control center in real time, carrying out patrols 3-7 days per week.

- Patrols and Interception – coastguard vessels would carry out long-distance patrols every 2-3 months, and be at the ready to intercept vessels detected by Levels 1 and 2.

A further level of monitoring would be required to implement the Responsible Fishing Zones (RFZs), which could be carried out using onboard vessel camera systems such as Shellcatch® (Bartholomew et al. 2018) which are currently being piloted in mainland Ecuador as part of a program to link fishers with sustainable markets (Revista Líderes 2021). As such, the traceability offered by this tool could be linked to the development of a "Galápagos" brand of responsibly caught fish, which could command higher market prices.

These activities would require an initial capital investment of US$ 436,000, plus a cost of around US$6 million for a medium altitude long endurance UAV, followed by annual operating costs of around US$ 6.5 million (Table 24).

Table 24. Summary of potential costs of control and enforcement for the Galápagos EEZ beyond the GMR (from WildAid 2021).

Item	2022	2023	2024	2025	2026	Total
Level 1	420,999	301,416	301,416	301,416	348,999	1,674,246
Level 2	2,772,000	9,178,540	3,178,540	3,178,540	3,178,540	21,486,160
Level 3	2,136,475	2,136,475	2,136,475	2,136,475	2,136,475	10,682,375
Fisheries Monitoring	1,083,338	826,400	826,400	826,400	826,400	4,388,938
TOTAL	6,412,812	12,442,831	6,442,831	6,442,831	6,490,414	38,231,719

Postdata: Declaration of the Hermandad Marine Reserve

On January 14th 2022, by means of Executive Degree 319 (Government of Ecuador 2022), the President of Ecuador, Guillermo Lasso Mendoza, ordered the creation of a new protected area called "Reserva Marina Hermandad" which will be integrated into the National System of Protected Areas and will cover a total area of 60,000 km^2.

The Hermandad Reserve is made up of two zones – a 30,000 km^2 no-take zone, and another 30,000 km^2 responsible fishing zone where longlining is not permitted but other fishing gear (including industrial purse seine) may be used. The stated priority objective of Hermandad is to protect the ranges of migratory species.

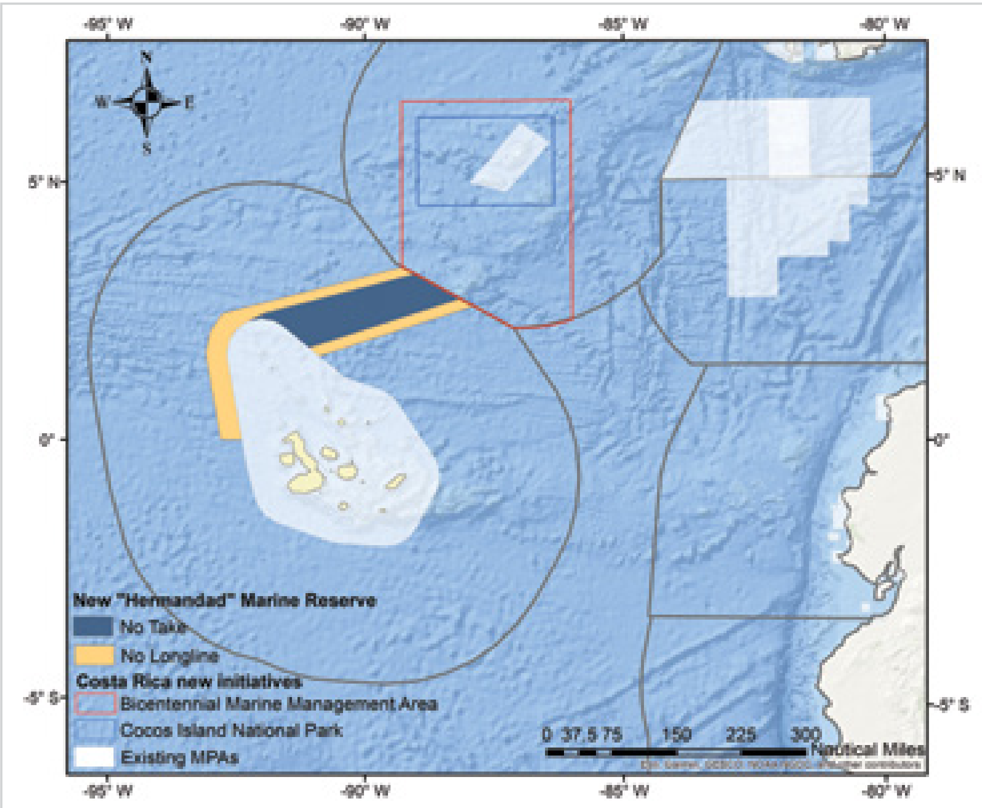


Figure 154. Location and zonation of the Hermandad Marine Reserve and its connectivity with protection initiatives in Costa Rica.

To this end, the Hermandad Reserve extends from the north of the existing Galapagos Marine Reserve (GMR) to the border of the EEZ (Figure 154). Its edge on the Costa Rican border was designed to coincide with the western edge of Costa Rica's Marine Seamount Management Area (AMMMS for its Spanish acronym), which is now known as the Bicentennial Marine Management Area. This extends over an area of 106,286 km^2 and surrounds the newly expanded Cocos Island National Park, which now covers an area of 54,844 km^2 (La Gazeta, 2022). The core no-take zone of Hermandad is approximately 290 km long and 100 km wide, and is bordered to the north and the south by two strips of 8,000 km^2 (approximately 25-30 km wide) responsible fishing zones where longlining is not permitted. The Hermandad

Reserve also includes a fringe of approximately 44 km width along the northwestern edge of the GMR, down to the equator. Based on equal earth projections, the total surface area of the no-take zone is 30,111 km², and that of the responsible fishing zone is 29,588 km².

The placement of the Hermandad alongside Costa Rica's conservation efforts is key to ensuring protection of endangered migratory species (in particular sea turtles and sharks) as they move between the Galapagos and Cocos marine reserves, apparently using the Cocos Ridge as a navigation aid. In this sense, although much smaller than the scenarios presented in this document, its placement follows the same logic as these, and is consistent with the Swimway initiative developed by the MigraMar network (Peñaherrera et al. 2018) and with the designation of the Coco-Galapagos Swimway as a Hope Spot by Mission Blue (see earlier section on regional conservation initiatives).

The creation of the Hermandad Reserve increases overall marine protection in Ecuador from 13.4% to 18.9% if we consider the entire 60,000 km² (note that if industrial fishing is permitted in the responsible fishing zone, this area may not be recognized by some organizations as a protected area – IUCN Category VI MPAs specifically consider low-level non-industrial use of natural resources). Inside the Galapagos EEZ, the new reserve covers 8.5% of the unprotected waters (i.e. those waters outside the GMR). For the industrial tuna fleet, 0.6% of the total value of their catch over this period came from the no-take area in the new Hermandad Reserve, which corresponds to 2.7% of what they caught inside the Galapagos EEZ. For the longline fleet, 0.23% of the total value of their catch over this period came from within the new reserve area (0.09% from the no-take zone, 0.14% from the responsible fishing zone), corresponding to 1% of the value of their catch within the Galapagos EEZ (Figures 155-7, Table 24).

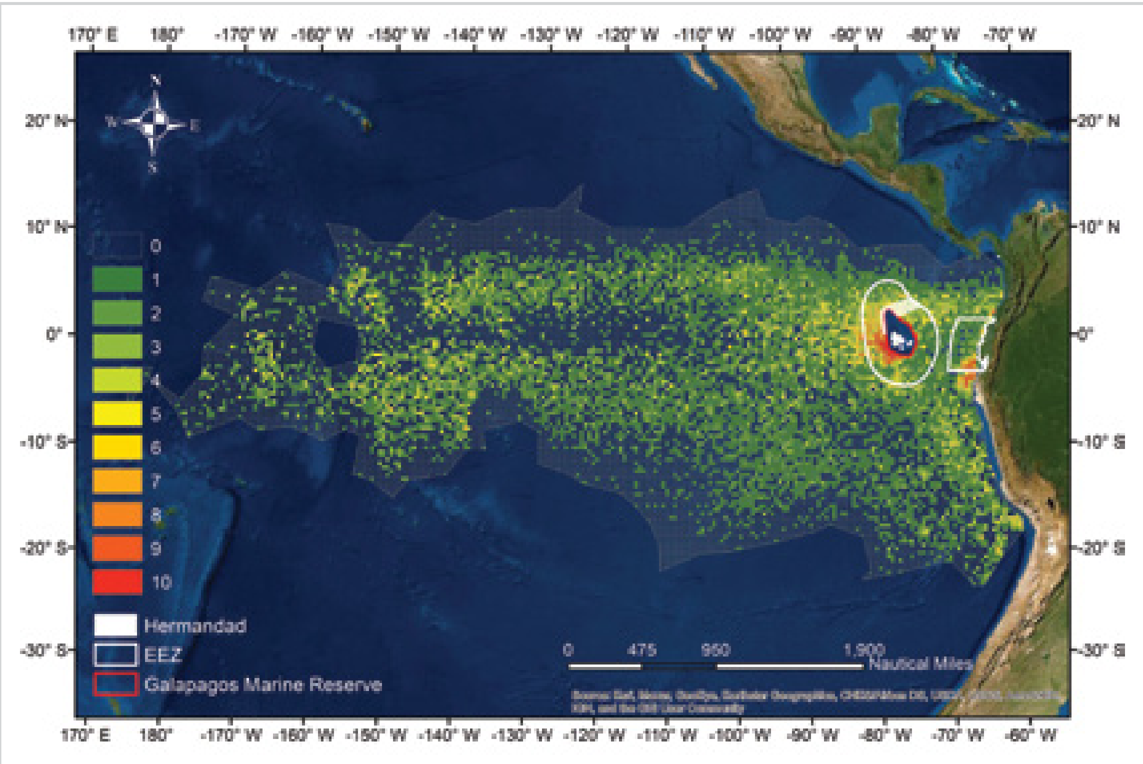


Figure 155. Extent of Ecuadorian purse seine fishing, ranked in relative value from 0-10 in 25 NM cells, based on georeferenced catch data 2007-10. The Hermandad Reserve is shown in semi-transparent white.

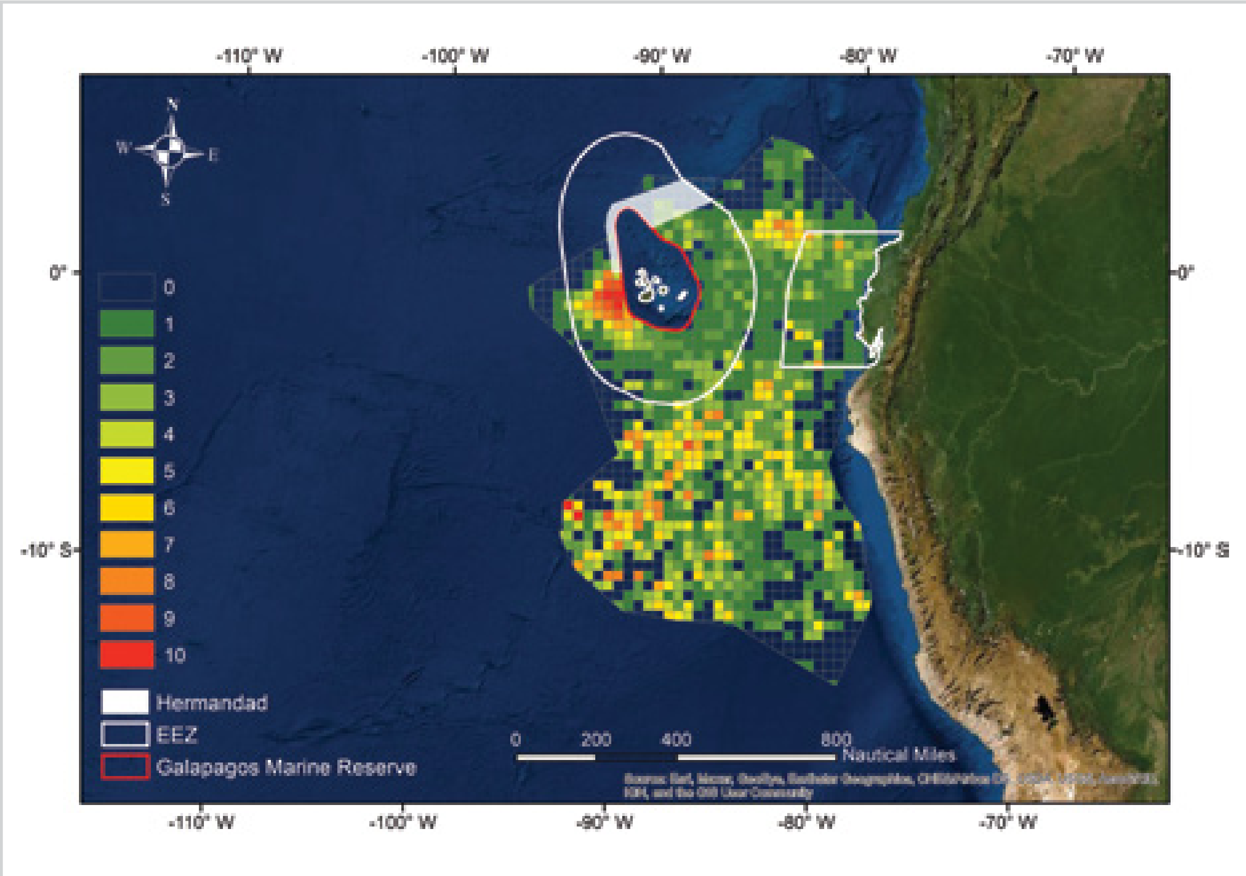


Figure 156. Extent of Ecuadorian longline fishing, ranked in relative value from 0-10 in 25 NM cells, based on georeferenced catch data 2008-12. The Hermandad Reserve is shown in semi-transparent white.

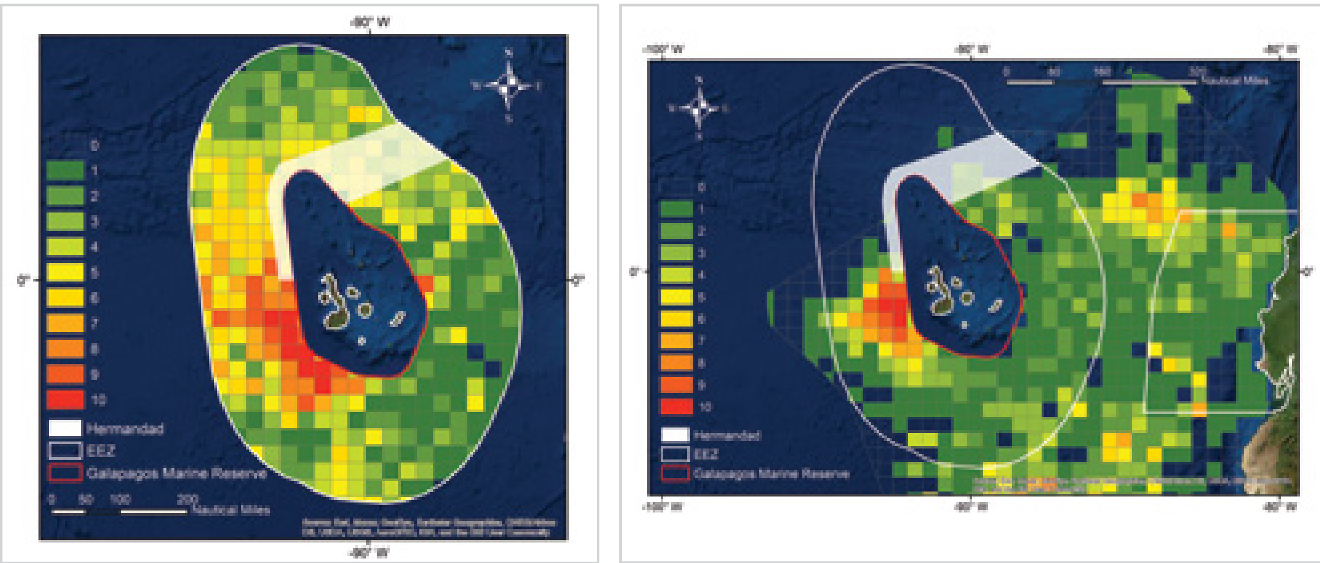


Figure 157. Relative values of catch inside the Galapagos EEZ for tuna fleet (left) and longline fleet (right), indicating the location of the Hermandad Reserve.

Of these 54 conservation objects, by adding the Hermandad Reserve to the existing GMR, 21 of them achieve at least 50% protection (Table 25). With the creation of the new reserve, protection of deep (>500m) seamounts increases to 50.2%, while that of shallow areas remains at 89.3%, given that most of these occur on the Galapagos platform within the existing GMR (Figure 158). There is no change in protection of highly productive upwelling areas in neutral years. Protection for green turtles increases to 68.6% and for critically endangered leatherback turtles to 29.7%, assuming that their risk of capture or entanglement is negligible in both the no-take and the responsible fishing zones. For sharks, which generally are vulnerable to purse seine gear, we assumed that there was still a risk of capture or entanglement in the responsible fishing gears (although we recognize that this will likely be significantly reduced due to the ban on longlines here). The protection estimated for these species is therefore likely an underestimate. For hammerhead sharks, the new marine reserve increases coverage of their movement pathways from 39.7% to 43.3%, while for whale sharks the increase is from 27.4% to 34.2% (Figure 159). It must be noted that Ecuador has implemented bans on landing and sale for both these species.

Table 25. Comparison of conservation and fishing coverage of the GMR and with the Hermandad Reserve. Note that all numbers and values are based on equal earth projection.

	Current GMR	Hermandad Reserve
CONSERVATION		
Area of new marine reservet (km^2)		30,111 (no-take)
		29,588 (no longline)
% of available Galapagos EEZ		8%
Conservation objectives met over 50% (total 54)	19	21
% Marine Protection reached at the country level	13.4%	18.9%
Main conservation features		
% Shallow Seamounts (< 500 mts)	89.3%	89.3%
% Deep Seamounts (> 500 mts)	38.4%	50.2%
% Upwelling, neutral year	34.2%	34.4%
% Leatherback turtle	20.6%	29.7%
% Green turtle	56.7%	68.6%
% Waved albatross	21.0%	21.0%
% Hammerhead shark	39.7%	43.2%
% Whale shark	27.4%	34.2%
FISHING		
Area open to fishing (km^2)	703,449	673,338 (purse seine)
		643,479 (longline)
% Value of purse seine catch in Galapagos EEZ	100%	97.3%
% Value of longline catch in Galapagos EEZ	100%	99.0%
% Total value of purse seine catch not in new reserve	100%	99.4%
% Total value of longline catch not in new reserve	100%	99.8%

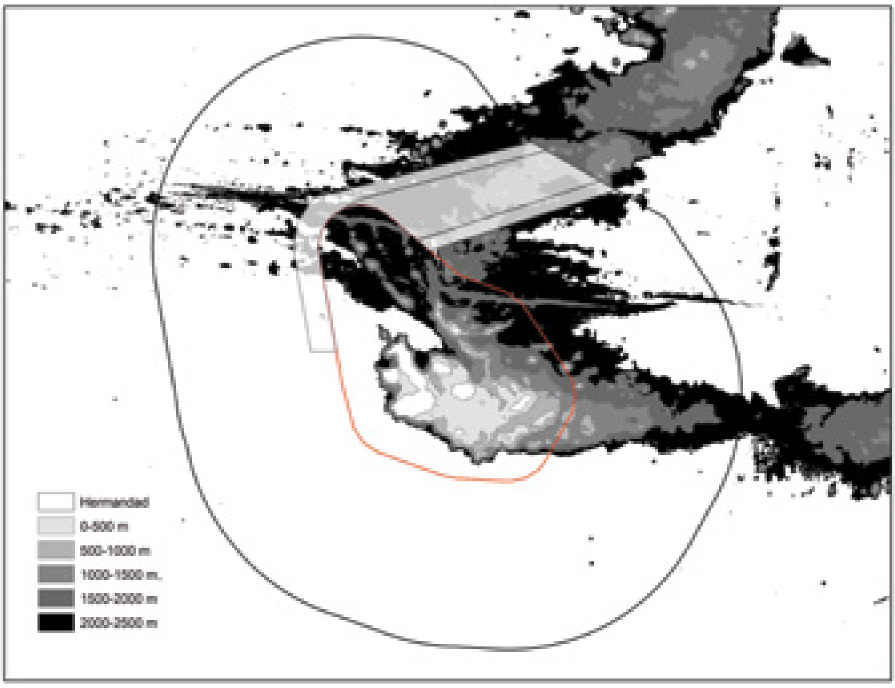


Figure 158. Ocean bathymetry in the Galápagos EEZ showing location of Hermandad Reserve.

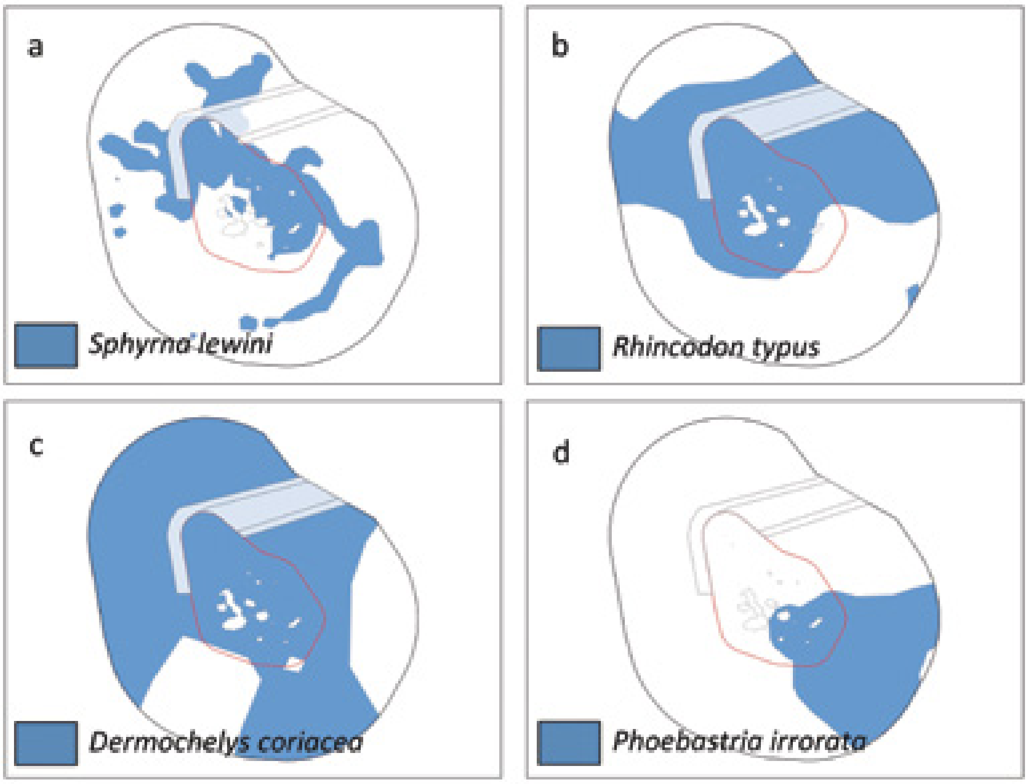


Figure 159. Hermandad Reserve (shown as a semi-transparent layer) showing coverage of different conservation features within the Galápagos EEZ. **a)** scalloped hammerhead shark movements, **b)** whale shark movements, **c)** post-nesting leatherback turtle movements, **d)** waved albatross foraging movements. The red line delimits the current GMR.

Edwar Herreno

Conclusion

The marine spatial planning proposal for the EEZ surrounding Galápagos, presented here is an investment that includes a combination of marine conservation, fishing and climate resilience strategies to provide benefits for all sectors with an integrative long-term perspective.

- The national fishing fleets, as the main user group of the Galápagos EEZ, will maintain access to their key fishing grounds in the most productive zones, and will be permitted to carry out their activities here under a responsible management approach that fosters long-term sustainable catches. Additionally, these fishing areas should benefit from enhanced levels of productivity through spillover effects caused by the new oceanic protected area, as occurred with the GMR.
- The Galápagos artisanal fishery will benefit from the reduction of illegal fishing inside the GMR, from the elimination of the risks posed by banning the use of FADs in the responsible fishing area to the east of the GMR, and by the spill-in effect of commercial species from the new no-take area into the GMR.
- Conservation of open water ecosystems encompassed by the proposed area will contribute to improving the protection of key oceanic habitats such as seamounts, of ecological processes such as upwelling that increase marine productivity and of endangered highly migratory species. All of these ecosystem elements will benefit from a new extension of protected critical habitats that will facilitate connectivity and recruitment between protected areas in the region and will generate resilience in the face of a highly changing environment.
- Tourism in marine protected areas of the Eastern Tropical Pacific, including Galápagos, is largely dependent on marine biodiversity, with highly mobile megafauna often the main attraction. By strengthening the protection of oceanic ecosystems and key migration routes for these species, their populations will be healthier and more abundant, indirectly benefiting the tourism activities in the Galápagos, and potentially throughout the region.
- Civil society, in general, will benefit through the conservation of biodiversity and marine habitats, as well as from the management of marine resources that ensure healthier and sustainable ecosystems in the region. These oceanic ecosystems around the Galápagos will not only contribute to food security but will also help build civic pride as Ecuador shows national and regional leadership in protecting a shared ecosystem.

Spatial management of the Galápagos EEZ through the creation of different zones will provide a significant contribution to the achievement of national, regional and global Sustainable Development Goals, through the protection and responsible management of marine resources. However, in order to ensure its successful implementation, it is vital to have tangible support from stakeholders, and the financial and management structure and capacity for adequate monitoring and enforcement. The creation of the Hermandad Marine Reserve was a direct result of the scientific information compiled in this document, and is an important first step towards achieving some of the objectives outlined here. However, the new reserve is focused on increasing protection for migratory species, and further measures will be required in order to address other key issues such as illegal incursions of longlining vessels into the GMR, drifting FADs entering the GMR, and strengthening resilience to climate change, among others. Further, regional coordination will be essential to ensure that appropriate spatial protection for migratory species is enacted in the future, both in Ecuador and across the Eastern Tropical Pacific.

Methods and Materials

Analysis of existing conservation measures in the region

The objective of this analysis was simply to visualize where in the region, different conservation initiatives related to the marine environment had been carried out. We accessed these files from online sources. We separated these into "UN-related or legally binding" and "NGO-related initiatives" – the latter being those that identify key biodiversity areas but do not afford them protection in themselves (such as the Mission Blue Hope Spots). We also included two fishery-management spatial tools – the purse seine exclusion zones designated by Costa Rica, and the temporal closure area known as the Corralito, within in which purse seine vessels may not fish for a short period each year. We used ArcGIS Pro2.8 (ESRI, 2021) to visualize each layer in Geographic Coordinates, Datum WGS 1984. We merged all the layers in polygons according to their type of initiative so that we can identify and count overlapping regions using the tool "Count Overlapping Features". We carried out the following steps:

1. Add all the separate polygon layers that show individual spatial initiatives
2. Merge the polygons in layers according to their type of initiative (i.e. Official including UN WHS, CMAR, PSSAs, EBSAs, and MPAs, as well as NGO that includes WWF Priority Areas, IBAs, CI Conservation Priorities, Alliance for Zero Extinction, Swimways, and Mission Blue Hope Spots).
3. Apply the tool Count Overlapping Features, part of the Overlay Toolset within the Analysis Toolbox of ArcGIS Pro.
4. Use the Count field of each resulting layer to symbolize the resulting features and create the output maps.

The result of this process was a series of overlay maps showing polygons within a 1-10 scale, according to their overlapping initiatives, which we also split between "Official UN-related or legally binding" and "NGO-related" initiatives.

Conservation Features

Species

We developed a list of conservation features based on a study of endangered marine species of the Galapagos Marine Reserve (Edgar et al 2008) and updated to show new red-listing statuses. To this list we added 9 species of local importance to the island ecosystem whose red-list status was not Vulnerable or above. For each of these species, we obtained general distribution maps from the IUCN Red List of Endangered Species website (www.redlist.org). Note that we corrected the range for scalloped hammerhead sharks, given that this did not include Cocos Island. All these maps are free to download. In our narrative for each species, we showed the global distribution and the distribution clipped to the Galapagos EEZ. The latter polygon was subsequently used in the Marxan analyses.

Catch and bycatch spatial information from catch and bycatch data published by Bucaram et al. (2018) and Martínez-Ortiz et al (2015). Heatmaps were created by calculating the probability utilization distribution (hereafter UD) using the simple kernel density estimator function (Worton 1989) implemented in the "adehabitatHR" family package (Calenge 2015, Calenge et al. 2009) within the R software environment (R Core Team 2021). The analysis was placed in a grid system consisting of 25 km^2 cells around the ETP. This analysis was run for every species in which catch spatial explicit data was available.

Movement information was obtained from satellite telemetry data from five marine birds, seven cartilaginous fish, and three marine mammals (Table 26). This information was gathered from different sources, and represents data collected via GPS or Argos satellite transmitters. To eliminate inaccurate Argos satellite location information, we filtered out data with poor quality locations and unrealistic speeds between successive relocations by using the package "trip" (Sumner and Luque 2015) implemented within the R software environment (R Core Team 2021). Data was filtered to eliminate spurious relocations by screening out values beyond sensor specifications (latitude and longitude), and unattainable speeds by animals greater than 2.25 ms^{-1}, following Weng et al. (2007) and Ketchum (2011).

Table 26. Tracked marine birds, turtles, mammals, and fish summary data.

Scientific name	English name	Spanish name	N	From	To	Mean track length (Days)	References
Marine bird							
Creagus furcatus	Swallow-tailed gull	Gaviota de Galápagos	142 (BM)	2008	2010	2 (min 0, max 2)	Galapagos Movement Consortium.
			45 (NBM)	2009	2011	296 (min 61, max 479)	Galapagos Movement Consortium.
Fregata minor	Great frigate bird	Fragata menor	14	2014	2014	8 (min 5, max 11)	Galapagos Movement Consortium, data repository Movebank.org
Pterodroma phaeopygia	Galapagos petrel	Petrel de Galápagos	21	2009	2011	82 (min 2, max 333)	Proaño C, unpublished data (accessed via Galapagos Movement Consortium, data repository www.movebank.org)
Sula nebouxii	Blue-footed booby	Piquero de patas azules	6	2009	2009	6 (min 2, max 17)	Galapagos Movement Consortium, data repository Movebank.org.
Phoebastria irrorata	Galapagos waved albatross	Albatros de las Galápagos	28	2008	2008	37 (min 0, max 147)	Anderson et al. (2003)
Pinniped							
Arctocephalys galapagoensis	Galapagos fur seal	Lobo peletero	18	2009	2010	23 (min 0, max 167)	Jeglinski et al. (2013).
Zalophus wollebaeki	Galapagos sea lion	Lobo marino de Galápagos	70	2005	2010	22 (min 0, max 165)	Jeglinski et al. (2013).

Scientific name	English name	Spanish name	N	From	To	Mean track length (Days)	References
Ray							
Mobula birostris	Giant manta	Manta gigante	4	2017	2017	92 (min 43, max 143)	Peñaherrera-Palma, unpublished; Hearn et al. (2014).
Sea turtle							
Chelonia mydas	Green sea turtle	Tortuga marina verde	19	2003	2013	46 (min 1, max 93)	Parra et al. (2013); Seminoff et al. (2008).
Dermochelys coriacea	Leatherback turtle	Tortuga laúd	46	2004	2008	239 (min 0, max 512)	Shillinger et al. (2011).
Eretmochelys imbricata	Hawksbill turtle	Tortuga carey	13	2009	2020	79 (min 0, max 281)	Arauz & Steiner (unpublished), Muñoz & Alarcón (unpublished).
Lepidochelys olivacea	Olive ridley turtle	Tortuga olivácea	32	2007	2011	91 (min 23, max 269)	Gaos et al. (2012).
Shark							
Carcharhinus falciformis	Silky shark	Tiburón sedoso	11	2006	2014	73 (min 16, max 155)	Hearn et al. (2014, 2017)
Carcharhinus galapagensis	Galapagos shark	Tiburón de Galápagos	4	2006	2012	40 (min 2, max 91)	Hearn et al. (2017)
Carcharhinus limbatus	Blacktip shark	Tiburón punta negra	19	2006	2015	10 (min 5, max 516)	Peñaherrera-Palma (2016)
Galeocerdo cuvier	Tiger shark	Tiburón tigre	4	2014	2014	197 (min 117, max 333)	Acuna-Marrero et al. (2017); Hearn et al. (2014).
Prionace glauca	Blue shark	Tiburón azul	5	2019	2019	29 (min 17, max 45)	Palomino Gaviria (2019)
Rhincodon typus	Whale shark	Tiburón ballena	59	2011	2016	70 (min 0, max 354)	Guzmán, no publicado, Hearn et al. (2013, 2016), Ryan et al. 2017)
Sphyrna lewini	Scalloped hammerhead shark	Tiburón cachuda roja	27	2007	2019	48 (min 0, max 148)	Hearn et al. (2017), Peñaherrera-Palma (2016)
Cetacean							
Balaenoptera musculus	Blue whale	Ballena azul	11	2013	2016	66 (min 17, max 201)	Hucke-Gaete et al. (2018)

We exported the resulting tracks into ArcMap and used the Kernel Density (KD) tool. Classification was done by equal intervals, using 5 intervals. We applied a 90% threshold (which we equated to home range) to 12 species (those that either included a small number of tracks, or whose movements did not display clear pathways), and a 50% threshold (which we equated to areas of high use) to four species where the datasets showed clear movement corridors (whale sharks, Galápagos petrels, waved albatross and leatherback turtles). We converted these kernel density maps into polygons for use in Marxan. Note that as a result of using species tracks, these species contributed two layers to the analysis – an overall distribution (see based on their range) and a home range or high occupancy layer, based on their tracks (Figure 125).

Habitat

We accessed a publicly available dataset showing the location of known hydrothermal vents, and then mapped these in the region using ArcMap (https://vents-data.interridge.org).

We obtained locations of known seamounts from 30-second bathymetry data (Yesson et al. 2011) and overlaid these on bathymetric maps of the region from GEBCO *(The General Bathymetric Chart of the Oceans)*, using gridded bathymetry data from 2020 (GEBCO Compilation Group 2020), to provide an overview of where seamounts and underwater ridges occur near Galapagos. We then used the Raster Calculator tool to classify depths in the region from 0-500 m, 500-1000 m, 1000-1500 m, 1500-2000 m and 2000-2500 m, and exported each one as a polygon for use with the Marxan analyses.

Processes

We used a biogeochemical oceanographic circulation model developed by the Southampton Oceanography Center (Forryan et al. 2021, Naveira-Garabato et al. unpublished) to identify areas of persistent upwelling under three different climatic conditions: El Niño year (2015), a La Niña year (2008) and a neutral year (2012).

The model provides daily averages of all oceanographic fields (e.g. temperature, salinity and velocity). It was constructed using a general circulation model from MIT (Marshall et al. 1997) with bathymetry from General Bathymetric Chart of the Oceans (GEBCO_14) Grid (Weatherall et al. 2015). Model grid resolution is 4 km in the horizontal (0.03334°) between ± 5° latitude stretching out to 12 km (0.03333°) in latitude at the model boundaries with 840 grid points in X and 600 in Y and a grid origin at 17.8°S 105°W. The vertical grid comprised 75 depth levels. Vertical resolution varied with depth from 5 m over the first 50 m, 9.8 m to 164 m depth and 13.7 m to 315 m depth, with a maximum cell height of 556 m below 3,000 m. The model domain was extended southwards to improve resolution of the Chilean coastal current system. The model was run with three completely open boundaries (North, South and West), using periodic boundary forcing for temperature, salinity, and velocity fields and a 15 grid box thick sponge layer for velocity.

Initial conditions and monthly boundary forcing were taken from the Mercator ocean reference model (https://www.mercator-ocean.fr/), a global ocean model based on 1/12(0.083) degree NEMO (https://www.nemo-ocean.eu/). Wind stress, evaporation and precipitation were taken from ERA-Interim reanalysis (Dee et al 2011) at a 3 hour temporal resolution for all fields and radiation (shortwave and longwave) forcing from Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA2; Global Modeling and Assimilation Office (GMAO) (2015)) at hourly temporal resolution.

We used the depth of the 20°C isotherm relative to the annual mean depth of the 20°C isotherm as a proxy measure for the seasonal strength of upwelling, with a positive 20°C isotherm anomaly indicative of stronger upwelling (displacement of isopycnals towards the surface). An empirical orthogonal function (EOF) analysis was conducted on a box encompassing the Ecuadorian EEC on depth-integrated chlorophyll a concentration, sea surface temperature, and 20°C isotherm depth anomaly to determine persistent patterns in the variability of these quantities (Bretherton et al. 1992; Palacios 2004). In essence, this analysis shows the patterns in the depth of the thermocline across the study area and how these patterns vary over time. We carried out this analysis for 2008 (La Niña), 2012 (neutral) and 2015 (El Niño), and for each analysis, the variance is shown in relation to the mean for that year. Each map was geo-referenced and clipped to the shape of the Galapagos EEZ and then exported as a polygon for use with Marxan.

Risks posed by Fish Aggregation Devices

We used offline particle tracking (Döös et al. 2017) in the biogeochemical oceanographic circulation model described earlier, developed by the Southampton University (Forryan et al. 2021, Naveira-Garabato et al. unpublished) to estimate the effects of deploying drifting FADs at three locations upcurrent from the GMR – on the eastern boundary of the current GMR; 40 NM further east of the border but still within the Galapagos EEZ; and in international waters 200 km from the current GMR boundary. To provide an understanding about how dispersal patterns might change under different climatic conditions, we ran our simulations for an El Niño year (2015), a La Niña year (2008) and a neutral year (2012).

Given the average depth of the tail of the FADs, we integrated the current vectors of the top 20 m of the water column to provide a mean surface water flow. For each year and each release location, we deployed approximately 61,000 FADs on the first day of each month with an even distribution of approximately 8 FADs/km^2. Each individual FAD was tracked for 25 days.

We assumed that a residency of >25 days implied that the FAD was washed ashore or entangled in shallow water. We calculated the residency time within the GMR for each FAD (a value of 0 implies that the FAD did not enter the GMR) then plotted these as monthly histograms. For each year we normalized the numbers of FADs relative to the number deployed per km^2, and used these values to map the likelihood of FAD presence on a scale of 0-1.

Climate Change Threats

To understand the current state of knowledge regarding the impacts of climate change on the marine environment at a global scale, we reviewed the IPCC (2019) Report, and carried out literature searches which we then refined geographically using the terms "Pacific Ocean", "Eastern Pacific Ocean", "Ecuador" or "Galapagos". Additionally, we gathered information from peer-reviewed papers and grey literature that were referenced in the papers that resulted from our preliminary search.

We assessed the potential risks of climate change in the EEZ surrounding the Galapagos Islands using a risk register. We created two risk register tables to organize the most current information regarding climate change in the Galapagos Islands. The first table includes the main climate change components relevant to the Galapagos Islands that were identified in the literature review (see above). To rank the likelihood of each climate change component occurring in the Galapagos Islands, we designed a scale where 0=unlikely, 1=possible, 2=likely and 3=very likely. Additionally, we designed a different scale where, 0=low impact, 1=moderate impact, 2= high impact and 3= very high impact to rank the overall potential impact of each climate change component in the Galapagos Islands. Finally, we calculated the average between the likelihood and potential impact values to obtain the summary status of each climate change component.

In the second risk register table, we categorized the likelihood and impact of different climate change components for each conservation target identified in this report (36). Therefore, we carried out a second literature search in Google Scholar using keywords like "Climate Change" AND the conservation target (e.g., Skipjack tuna, whale shark, green turtle, etc). To obtain information at regional and local levels, we added keywords like "Pacific Ocean" OR "East Pacific Ocean" OR "Galapagos". We also used information from peer-reviewed and grey literature referenced in the papers that resulted from our preliminary search. We used the same likelihood values for the climate change components as in the first risk register table and ranked the impact of each component on the conservation target using information from the literature search. We obtained the summary status for each conservation target by calculating the average between the likelihood and impact values of the climate change component that represented the "worst-case scenario", meaning, the component with the highest likelihood and impact. Additionally, we designed a confidence scale to rank the relevance of the gathered information to the Galapagos Islands, where 3= included peer-reviewed literature in the EPO or Galapagos, 2= included grey literature in the EPO or peer-reviewed papers elsewhere and 1=included literature of proxy species or expert opinion.

Fishing Effort

Although we made repeated requests for spatially explicit, recent fishery data, both directly and through the Presidential Committee led by Roque Sevilla and Yolanda Kakabadse, the Fisheries Vice-Ministry did not provide any data. We had access through prior contacts to the Fisheries Subsecretariat monitoring dataset of the artisanal mainland-based longline fleet (from 2008-12) and the industrial tuna purse seine fleet dataset, which includes both observer and logbook reports (from 2007-10).

For the tuna fleet, we plotted each purse seine set by fishing type (FAD vs Unassociated) and by report type (Observer vs Logbook) – Class 6 vessels have 100% observer coverage while the smaller vessels only 5%, so by separating out by report type, we were able to gain some insight into the spatial behavior of the larger vs smaller vessels.

We created a polygon around the datapoints for the purse seine and the longline fleets, using the Aggregate Points Tool with a minimum distance among points of 500 Km, to estimate the total area of their fishing grounds respectively (we subtracted the area of the GMR from this value.

Estimation of Fishing Costs

We obtained spatially explicit information from industrial tuna fishing published by Bucaram et al. (2018) and artisanal longline fishing published by Martínez-Ortiz et al. (2015). Industrial fishing catch and effort data were collected by the Inter-American Tropical Tuna Commission onboard observer program. According to Bucaram et al. (2018), this dataset covered all class 6 tuna purse-seine vessels that fished in the EPO from 1990 to 2009. During the 1986–1991 period, coverage of the international fleet ranged between 30% and 60%; however, since then, it has been close to 100% for class 6 vessels. In addition, class 5 vessels that fished for tuna associated with dolphins were also monitored from 1994 to 1997. This dataset comprises data only from on-board observers and for yellowfin tuna *(Thunnus albacares)*, bigeye *(Thunnus obesus)* and skipjack *(Katsuwonus pelagicus)*. For more information on this dataset please review Bucaram et al. (2018). The artisanal longline fishery landings were monitored by the Monitoring Control System (Sistema de Control y Monitoreo) implemented by the Republic of Ecuador via the Subsecretaria de Recursos Pesqueros, Viceministerio de Acuacultura y Pesca (SRP-VMAP) in October 2007. According to Martínez-Ortiz et al. (2015), a total of 115,487 fishing trips were monitored by the SCM program in the five main artisanal fishery ports of Ecuador from January 2008 to December 2012. Excluded data included records from 71 trips of unknown fleet category and 17 trips from vessels which were not part of the fishery for large pelagic species.

Catch data (in kilograms) for every species were further converted into catch value by using the at pier fish market value. Fishermen and fish sellers were interviewed during visits to fishing markets located in Manabí (Tarqui at Manta; and Puerto Lopez) on November 2020. Since both by Bucaram et al. (2018) and Martínez-Ortiz et al. (2015) datasets were collected before 2015, we required fishermen to state the wet-kilo of each of the assessed species for two timeframes: pre 2015 and post 2015. Following interviews, we prepared the information of the catch databases and add the value information to the geographic location data. For the artisanal database, records that only had number of individuals were converted into estimated weight by using the averaged measured weight per individual for those records that had weight data. This information was corroborated with the summary table found in Martínez-Ortiz et al. (2015). Catch records of protected species were not considered during this analysis.

Each georeferenced set of a purse seine or longline was converted into a monetary value based on the reported catch for that set. Note that for the purse seine catch we only had data pertaining to the three tuna species. For each fishery dataset, we created a "fishnet" of 25 NM cells using the Equal Earth Asia-Pacific projection (EPSG 8859), and summed the value of the catch for all the sets in each cell. Additionally, we defined the total area of catch using the Aggregate Points tool (using 500 km for Aggregation Distance). Each layer was then normalized on a scale of 0-10 dividing the data series using Jenks natural breaks classification methods, aiming to minimize the variance within each class and maximize the variance among classes– we used relative rather than absolute values because we do not have information regarding the sampling efficiency of the datasets. To combine the relative values of both fisheries, we simply added the values within the scale resulting on a 0-20 layer. We clipped each of the datasets to the Galapagos EEZ for use in the Marxan exercise, which was run on the nominal values for each fishery separately and combined.

We anticipated a certain amount of resistance from the fishing sector regarding the age of the datasets, and indeed, there has been some criticism from the sector, whilst simultaneously refusing to share more recent data. We used aggregated published data from the IATTC for the Ecuadorian fleet for 2014-2019 (IATTC public database, accessed June 18th 2020), to look at the relative catch by species outside the Galapagos EEZ and inside within 8 sections, split along the parallel 0° of latitude and the meridian 91°W of longitude, and each with a width of 80 NM. We plotted the points with the catch value for each of the tuna species t(i.e. bigeye, skipjack and yellowfin), and created a 1x1 degree fishnet around each of these points. We used the Spatial Join tool to assign each square the catch value for each fish species. Then, we calculated the amount of catch in each of the 8 sections, assuming that the catch was distributed evenly throughout each cell. A very small amount of the total catch value (<0.01%) fell inside the Galapagos Marine Reserve, so this was not counted in any of the gridded sections.

Spatial Analysis

We used the spatial planning program Marxan as a first input to the design of scenarios that achieve different levels of coverage of conservation features.

We initially carried out six modeling exercises for the full Galapagos EEZ, including the existing marine reserve. Using the cylindrical equal area world projection (EPSG 54034), the Galapagos EEZ was intersected using a 4 km^2 grid and each cell (hereafter referred to as "planning unit" or "PU") was assigned a unique ID number (n=211,819). Raster-based fishing costs were assigned to each PU using a mean of any overlapping features. Each raster was on a scale of 0-10, meaning that the cost layer was on a scale of 0-10 (for each individual fleet) or 0-20 for the scenarios where the fishing fleets were combined.

Each feature (N=54) was assigned a unique ID and intersected by the PU grid, calculating how much area of each feature is present in each PU. The status of each PU was set as either available or conserved. Any PU that was covered by 50% or more by the existing Galapagos Marine Reserve was marked as conserved. We created the base Marxan setup files using the QGIS plugin. We clipped the area of each conservation feature to that of the GMR to calculate how well each feature was represented inside the GMR. We used this information as a baseline to understand how different scenarios might increase protection for each of the features.

For each fleet (longline, purse seine and combined), we set minimum conservation feature coverage targets of 30% and 50% respectively. Each scenario was first run on a Boundary Length Modifier (BLM) of 0 and a Species Penalty Factor of 0. SPF was then increased incrementally by a value of 0.5 until all targets were met at 100 (Runs = 100, iterations = 1,000,000). Marxan was then run using the new SPF parameters and the summed solution of each PU (how many times each PU was selected) was assessed (Runs = 200, iterations = 1,000,000). Key areas were selected from each scenarios as being the areas selected in 90% or more of the runs. Key areas for both fisheries were compared to highlight any overlapping PUs.

Second, we re-ran the same six modeling exercises, but excluding the existing GMR, in order to assess how the GMR could be built upon in the pelagic region of the EEZ. This allowed us to focus on those species that are less centered inside the GMR. By removing the area inside the GMR, 177,392 planning units remained. As several of the ranges for the conservation features were largely found within the GMR and therefore have most of their range protected, any feature where ≥90% of the range was within the GMR was excluded from this scenario (N=11). However, as mentioned earlier, range maps are data limited and these may require revision as new data are collected.

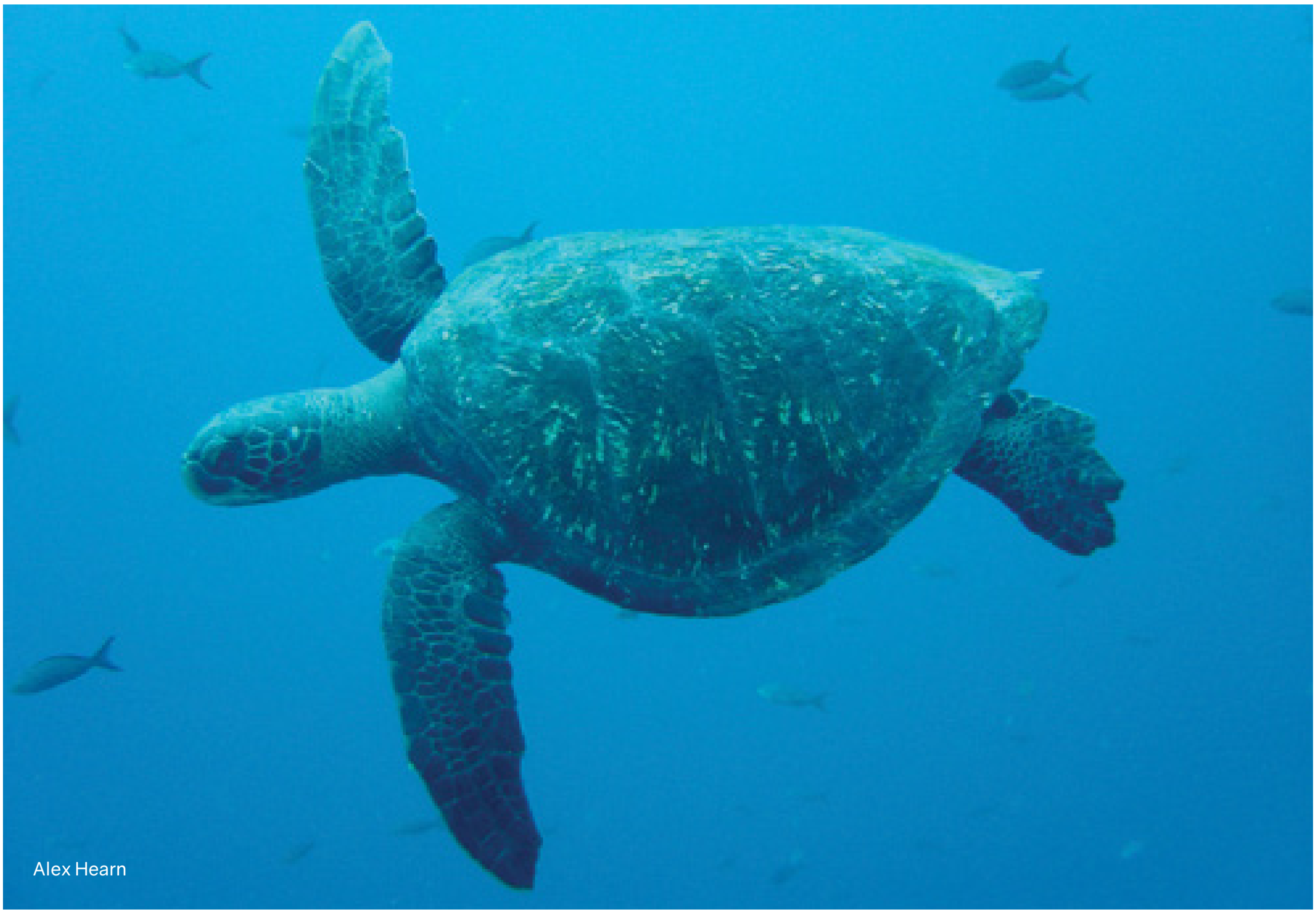
The total number of remaining conservation features was 43.

Building and Comparing Scenarios

Each protection scenario was designed using a combination of criteria:

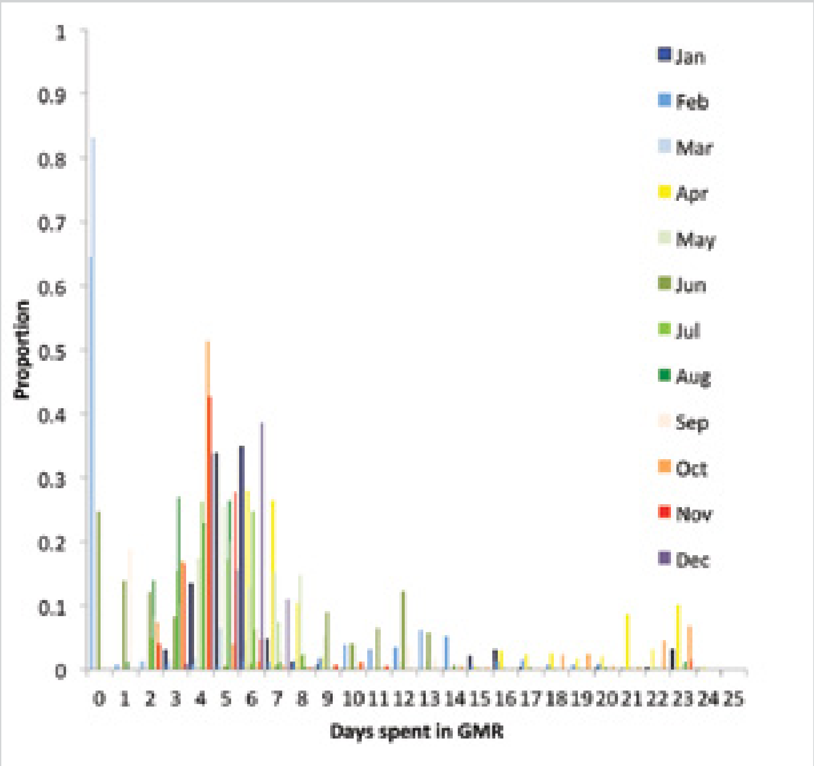
- Marxan Outputs
- Existing proposals
- Existing regional initiatives
- Non-tracking connectivity or habitat use knowledge
- Bycatch levels
- Climate change mitigation
- Local Ecological/Technical knowledge
- Spillover considerations and geopolitics
- Using straight lines versus curves to delineate borders

The scenarios were created as polygons and overlaid on the conservation and fishing layers to evaluate their performance. We used a model builder in ArcGIS to batch process this. The fishing costs were calculated by overlaying each cost layer (for each fishing fleet separately) with each scenario. We used the Spatial Join tool to calculate the sum of the cost in each scenario.

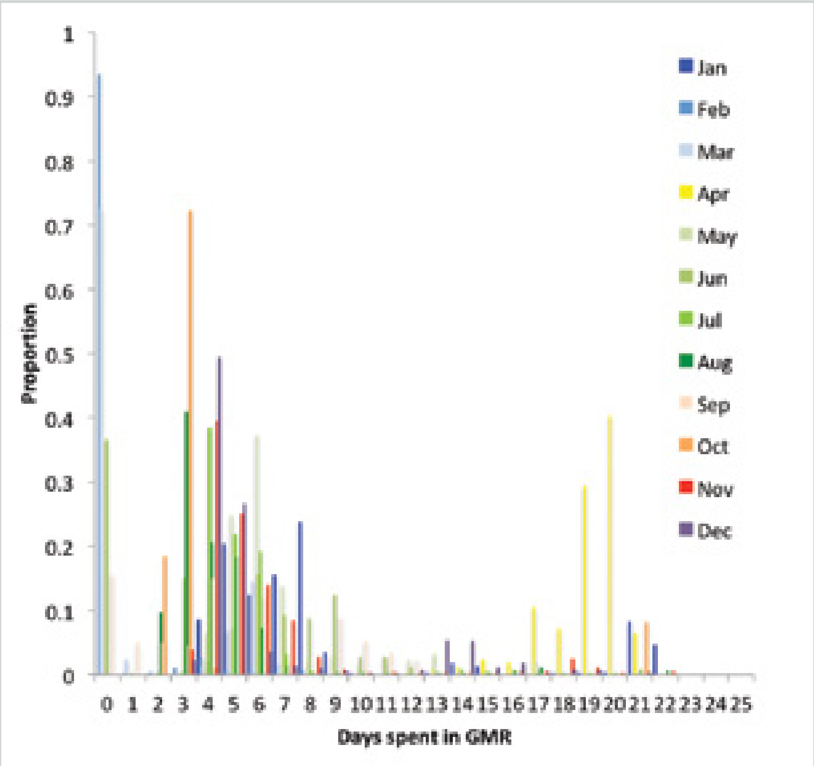


Alex Hearn

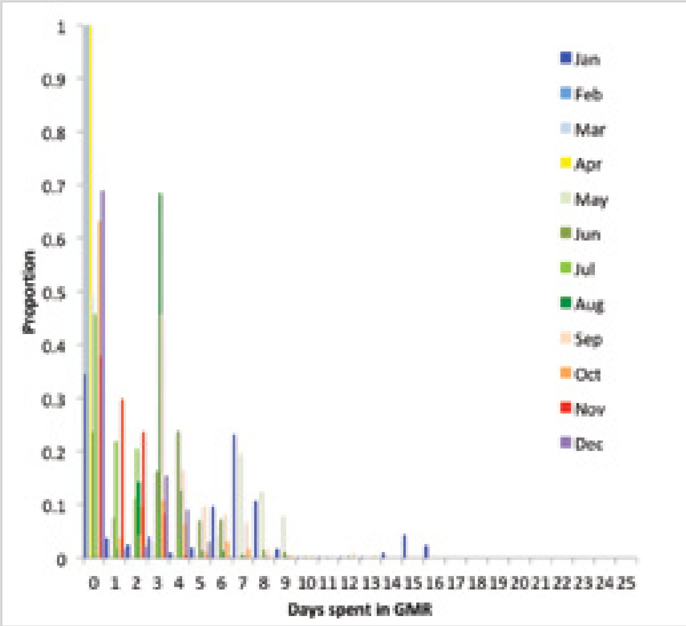
Appendix A. FAD Analysis: Time Spent in GMR Per Month



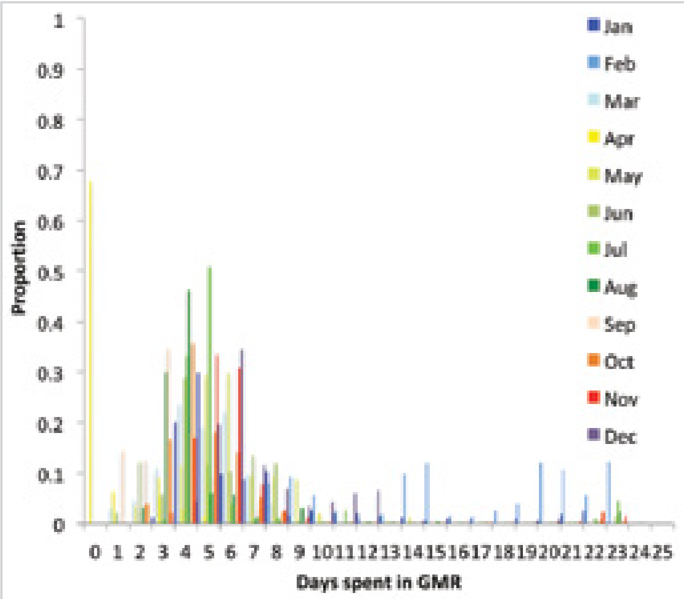
A1. Days spent in GMR, FADs released on eastern border of GMR in 2008 (La Niña conditions).



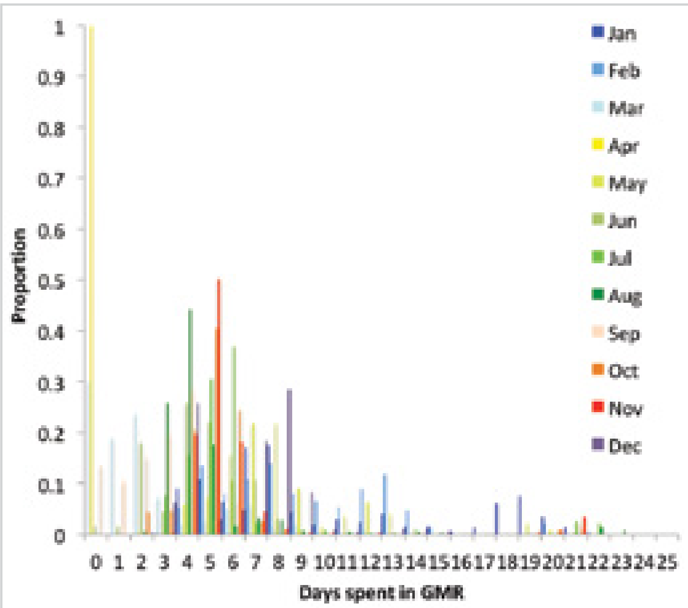
A2. Days spent in GMR, FADs released 40NM from eastern border of GMR in 2008 (La Niña conditions).



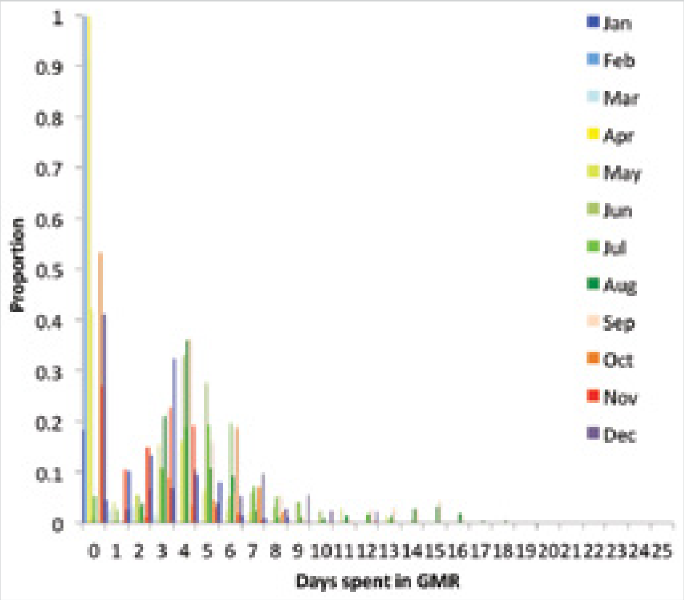
A3. Days spent in GMR, FADs released 200NM from eastern border of GMR in international waters, in 2008 (La Niña conditions)



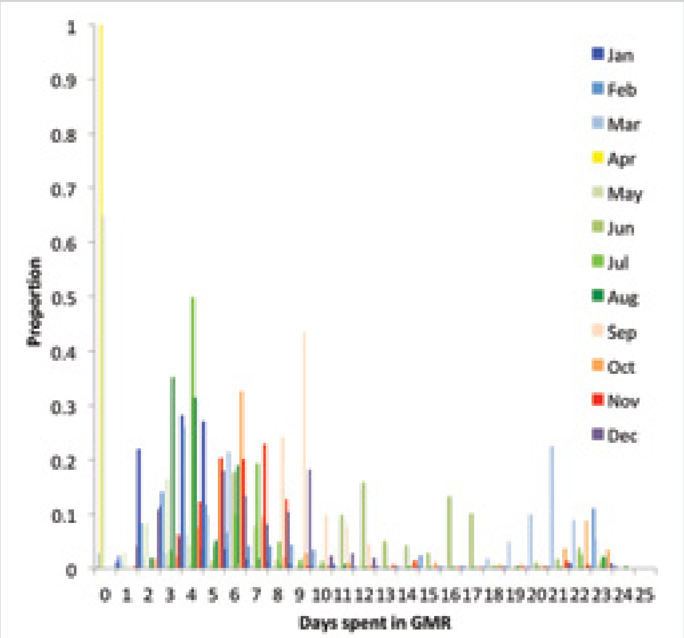
A4. Days spent in GMR, FADs released on eastern border of GMR in 2012 (neutral conditions).



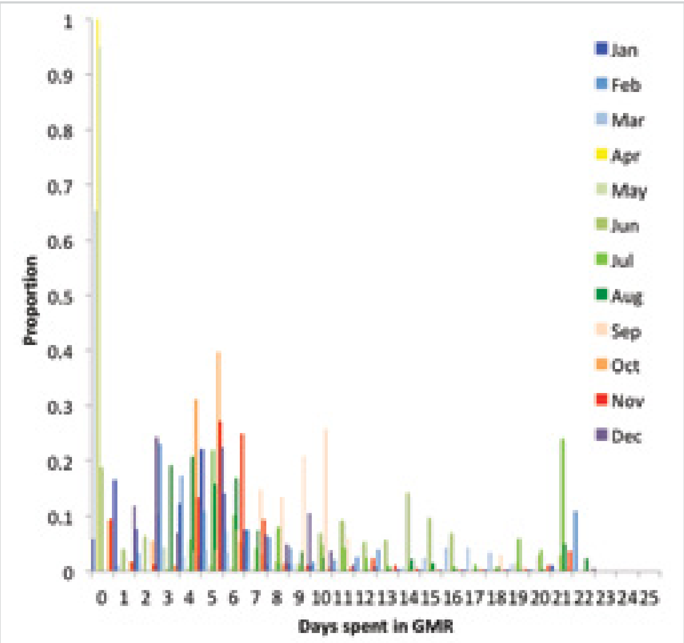
A5. Days spent in GMR, FADs released 40NM from eastern border of GMR in 2012 (neutral conditions).



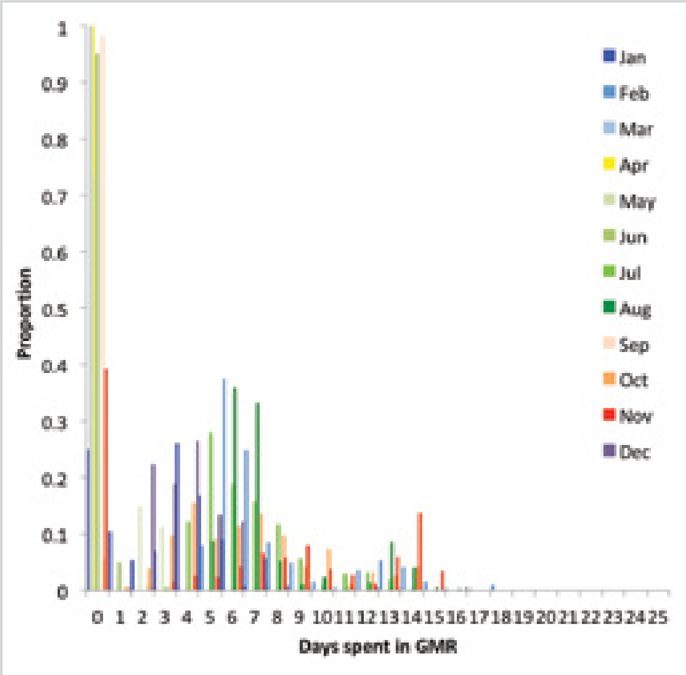
A6. Days spent in GMR, FADs released 200NM from eastern border of GMR in international waters, in 2012 (neutral conditions).



A7. Days spent in GMR, FADs released on eastern border of GMR in 2015 (El Niño conditions).



A8. Days spent in GMR, FADs released 40NM from eastern border of GMR in 2015 (El Niño conditions).



A9. Days spent in GMR, FADs released 200NM from eastern border of GMR in international waters, in 2015 (El Niño conditions).

Tui de Roy

Appendix B. Conservation Object Coverage Per Scenario

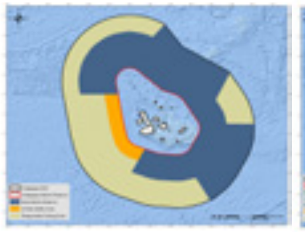
Color ramp

0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0

Map Legend

- No Take Zone
- No Longline Zone*
- Responsible Fishing Zone
- El Niño Buffer Zone

* Temporal or Permanent, depending on scenario

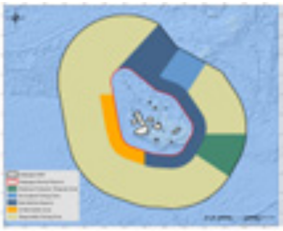


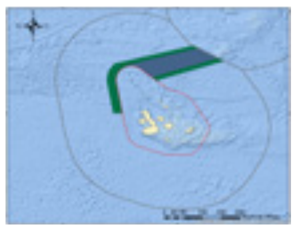
					Current status GMR		Maximum Conservation			Spillover and Migratory Routes		
Feature_ID	**Range Type**	**Common_Name**	**Area_km2**	**PC_EEZ**	**GMR_Area**	**% Protection**	**Area**	**%**	**% GMR + Scenario**	**Area**	**%**	**% GMR + Scenario**
FID_00	NA	Full EEZ	841,488.0	100.0	138,144.4	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_01	NA	Thermocline EOF 2015	10,106.2	1.2	10,106.2	100.0	0.0	0.0	100.0	0.0	0.0	100.0
FID_02	NA	Thermocline EOF 2012	102,236.0	12.1	34,916.5	34.2	17,974.7	17.6	51.7	23,263.3	22.8	56.9
FID_03	NA	Thermocline EOF 2008	73,557.8	8.7	24,310.6	33.0	413.0	0.6	33.6	413.0	0.6	33.6
FID_04	NA	Seamounts (2000-2500m)	156,022.3	18.5	37,147.0	23.8	116,197.91	74.5	98.3	114,322.2	73.3	97.1
FID_05	NA	Seamounts (1500-2000m)	52,850.5	6.3	17,704.0	33.5	35,121.76	66.5	100.0	35,120.7	66.5	100.0
FID_06	NA	Seamounts (1000-1500m)	22,135.0	2.6	12,810.9	57.9	9,324.41	42.1	100.0	9,324.1	42.1	100.0
FID_07	NA	Seamounts (500-1000m)	14,797.1	1.8	13,219.5	89.3	1,612.51	10.9	100.2	1,612.3	10.9	100.2
FID_08	Full	Pelagic thresher shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_09	Full	Bigeye thresher shark	841,288.9	100.0	137,945.4	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_10	Full	Galapagos fur seal	106,048.9	12.6	105,594.3	99.6	454.6	0.4	100.0	454.6	0.4	100.0
FID_11	Full	Galapagos shark	170,119.6	20.2	137,203.4	80.7	26,109.4	15.3	96.0	26,228.5	15.4	96.1
FID_12	Full	Oceanic whitetip shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_13	Full	Shortfin mako shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_14	Full	Longfin mako shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_15	Full	Olive ridley sea turtle	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_16	Full	Oceanic manta ray	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_17	Full	Sperm whale	841,289.6	100.0	137,945.9	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_18	Full	Great hammerhead shark	122,882.2	14.6	114,176.0	92.9	1,202.8	1.0	93.9	1,202.8	1.0	93.9
FID_19	Full	Smooth hammerhead shark	170,119.6	20.2	137,203.4	80.7	26,109.4	15.3	96.0	26,228.5	15.4	96.1
FID_20	Full	Silky shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_21	Full	Blacktip shark	170,119.6	20.2	137,203.4	80.7	26,109.4	15.3	96.0	26,228.5	15.4	96.1
FID_22	Full	Green sea turtle	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_23	Full	Swallow-tailed gull	684,939.9	81.4	138,144.4	20.2	310,813.4	45.4	65.5	295,478.3	43.1	63.3
FID_24	Full	Leatherback turtle	841,206.9	100.0	137,863.2	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_25	Full	Hawksbill sea turtle	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_26	Full	Great frigatebird	841,487.3	100.0	138,143.6	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_27	Full	Tiger shark	169,974.5	20.2	137,207.2	80.7	26,015.6	15.3	96.0	26,128.5	15.4	96.1
FID_28	Full	Waved albatross	362,611.0	43.1	107,577.8	29.7	178,335.8	49.2	78.8	168,099.3	46.4	76.0
FID_29	Full	Blue shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_30	Full	Galápagos petrel	841,287.4	100.0	137,943.7	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_31	Full	Whale shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_32	Full	Scalloped hammerhead shark	841,288.9	100.0	137,945.3	16.4	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_33	Full	Blue-footed booby	461,847.7	54.9	132,661.6	28.7	285,922.5	61.9	90.6	256,682.5	55.6	84.3
FID_34	Full	Galápagos sea lion	98,797.0	11.7	98,371.1	99.6	425.8	0.4	100.0	425.8	0.4	100.0
FID_35	Core	Silky shark	19,931.0	2.4	15,729.3	78.9	1,854.6	9.3	88.2	1,855.4	9.3	88.2
FID_36	Core	Blacktip shark	1,013.3	0.1	1,013.3	100.0	0.0	0.0	100.0	0.0	0.0	100.0
FID_37	Core	Green sea turtle	47,201.1	5.6	26,742.6	56.7	17,930.8	38.0	94.6	17,273.4	36.6	93.3
FID_38	Core	Swallow-tailed gull	398,143.7	47.3	93,125.3	23.4	254,859.0	64.0	87.4	238,849.8	60.0	83.4
FID_39	Core	Leatherback turtle	656,796.3	78.1	135,317.5	20.6	368,842.6	56.2	76.8	303,554.3	46.2	66.8
FID_40	Core	Hawksbill sea turtle	123.2	0.0	123.2	100.0	0.0	0.0	100.0	0.0	0.0	100.0
FID_41	Core	Great frigatebird	91,553.4	10.9	11,527.5	12.6	60,178.5	65.7	78.3	56,525.6	61.7	74.3
FID_42	Core	Tiger shark	2,677.2	0.3	2,537.8	94.8	139.4	5.2	100.0	139.4	5.2	100.0
FID_43	Core	Waved albatross	184,579.1	21.9	38,736.2	21.0	129,957.5	70.4	91.4	127,538.6	69.1	90.1
FID_44	Core	Blue shark	48,322.9	5.7	27,569.8	57.1	18,783.3	38.9	95.9	18,804.2	38.9	96.0
FID_45	Core	Galápagos petrel	458,414.7	54.5	117,552.2	25.6	177,851.8	38.8	64.4	164,120.7	35.8	61.4
FID_46	Core	Whale shark	438,911.6	52.2	120,167.5	27.4	214,124.8	48.8	76.2	205,986.8	46.9	74.3
FID_47	Core	Scalloped hammerhead shark	218,044.3	25.9	86,649.9	39.7	109,818.0	50.4	90.1	104,151.8	47.8	87.5
FID_48	Core	Blue-footed booby	17,810.5	2.1	2,211.7	12.4	10,715.0	60.2	72.6	8,837.7	49.6	62.0
FID_49	Core	Galápagos sea lion	10,666.2	1.3	9,975.9	93.5	0.0	0.0	93.5	0.0	0.0	93.5
FID_50	Core	Galapagos shark	6,950.9	0.8	6,950.9	100.0	0.0	0.0	100.0	0.0	0.0	100.0
FID_51	Full	Blue whale	840,798.5	99.9	137,454.9	16.3	446,566.2	53.1	69.5	378,554.4	45.0	61.4
FID_52	Full	Nazca booby	191,697.6	22.8	132,433.6	69.1	58,379.4	30.5	99.5	58,413.5	30.5	99.6
FID_53	Full	Red-footed booby	737,424.7	87.6	137,975.1	18.7	377,885.9	51.2	70.0	320,471.8	43.5	62.2
FID_54	Core	Red-footed booby	136,848.0	16.3	25,252.0	18.5	87,400.7	63.9	82.3	82,464.8	60.3	78.7
MIN			**123.2**	**0.0**	**123.2**	**12.4**	**0.0**	**0.0**	**33.6**	**0.0**	**0.0**	**33.6**
MAX			**841,487.3**	**100.0**	**138,144.4**	**100.0**	**446,566.2**	**74.5**	**100.2**	**378,554.4**	**73.3**	**100.2**
AVERAGE			**402,946.3**	**47.9**	**90,181.3**	**43.1**	**203,501.0**	**38.5**	**81.6**	**176,558.9**	**34.7**	**77.9**
COUNT			**54.0**	**54.0**	**54.0**	**54.0**	**49.0**	**49.0**	**54.0**	**49.0**	**49.0**	**54.0**

Appendix B shows the coverage of each of the six protection scenarios and the Hermandad Marine Reserve for the 54 conservation objects used in the Marxan analysis.

Note: Range type refers to the overall distribution of the species within the EEZ (Full) or the movements displayed by tracked individuals (Core).







30 by 30			Swimway			Minimum scenario			Swimway + 10 mn ring (full ring)			Hermandad Reserve		
Area	%	% GMR + Scenario	Area	%	% GMR + Scenario	Area	%	% GMR + Scenario	Area	%	% GMR + Scenario	Area	%	% GMR + Hermandad
171,725.51	20.4	36.8	138,891.69	16.5	32.9	145,393.08	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0
10,389.87	10.2	44.3	0.00	0.0	34.2	10,389.65	10.2	44.3	8,704.04	8.5	42.7	0.00	0.0	34.2
413.68	0.6	33.6	0.00	0.0	33.0	413.80	0.6	33.6	5,341.13	7.3	40.3	0.00	0.0	33.0
82,615.49	53.0	76.8	80,403.48	51.5	75.3	57,203.76	36.7	60.5	82,478.72	52.9	76.7	18,190.61	11.7	35.5
26,324.41	49.8	83.3	23,559.80	44.6	78.1	15,063.08	28.5	62.0	24,210.61	45.8	79.3	11,429.97	21.6	55.1
6,224.50	28.1	86.0	1,491.80	6.7	64.6	5,578.86	25.2	83.1	2,573.24	11.6	69.5	454.89	2.1	59.9
1,553.72	10.5	99.8	249.42	1.7	91.0	1,532.84	10.4	99.7	777.86	5.3	94.6	0.00	0.0	89.3
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
455.18	0.4	100.0	455.00	0.4	100.0	455.17	0.4	100.0	455.21	0.4	100.0	0.00	0.0	99.6
21,331.19	12.5	93.2	11,516.00	6.8	87.4	21,317.19	12.5	93.2	27,318.72	16.1	96.7	2,753.77	1.6	82.3
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
1,209.87	1.0	93.9	1,118.00	0.9	93.8	1,208.89	1.0	93.9	5,883.59	4.8	97.7	0.00	0.0	92.9
21,331.19	12.5	93.2	11,516.00	6.8	87.4	21,317.19	12.5	93.2	27,318.93	16.1	96.7	2,753.77	1.6	82.3
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
21,331.19	12.5	93.2	11,516.00	6.8	87.4	21,317.19	12.5	93.2	27,318.72	16.1	96.7	2,753.77	1.6	82.3
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
152,327.67	22.2	42.4	118,421.00	17.3	37.5	125,577.58	18.3	38.5	136,429.84	19.9	40.1	30,111.45	4.4	24.6
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
21,257.39	12.5	93.2	11,516.00	6.8	87.5	21,243.40	12.5	93.2	27,303.38	16.1	96.8	2,753.77	1.6	82.3
44,641.31	12.3	42.0	10,753.00	3.0	32.6	43,431.30	12.0	41.6	24,509.65	6.8	36.4	0.00	0.0	29.7
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
171,725.51	20.4	36.8	138,172.00	16.4	32.8	145,381.60	17.3	33.7	156,279.49	18.6	35.0	30,111.45	3.6	20.0
155,470.37	33.7	62.4	138,172.00	29.9	58.6	128,772.45	27.9	56.6	149,962.74	32.5	61.2	30,111.45	6.5	35.2
426.35	0.4	100.0	426.00	0.4	100.0	426.35	0.4	100.0	426.34	0.4	100.0	0.00	0.0	99.6
1,001.84	5.0	83.9	290.07	1.5	80.4	1,001.03	5.0	83.9	1,411.97	7.1	86.0	0.00	0.0	78.9
0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0
17,247.24	36.5	93.2	17,247.28	36.5	93.2	17,095.88	36.2	92.9	17,310.79	36.7	93.3	3,630.87	7.7	64.3
124,668.04	31.3	54.7	90,761.15	22.8	46.2	97,946.37	24.6	48.0	97,978.56	24.6	48.0	13,165.66	3.3	26.7
166,609.20	25.4	46.0	138,172.45	21.0	41.6	139,911.29	21.3	41.9	151,753.52	23.1	43.7	30,111.45	4.6	25.2
0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0
54,064.57	59.1	71.6	53,996.84	59.0	71.6	31,127.42	34.0	46.6	54,065.09	59.1	71.6	7,862.72	8.6	21.2
122.96	4.6	99.4	122.96	4.6	99.4	122.95	4.6	99.4	122.96	4.6	99.4	0.00	0.0	94.8
29,640.43	16.1	37.0	3,512.26	1.9	22.9	29,639.71	16.1	37.0	8,490.98	4.6	25.6	0.00	0.0	21.0
10,076.61	20.9	77.9	0.00	0.0	57.1	10,076.56	20.9	77.9	4,259.87	8.8	65.9	0.00	0.0	57.1
97,439.32	21.3	46.9	67,307.14	14.7	40.3	76,234.18	16.6	42.3	81,717.20	17.8	43.5	3,872.37	0.8	26.5
135,565.42	30.9	58.3	132,566.23	30.2	57.6	108,844.19	24.8	52.2	145,243.03	33.1	60.5	30,111.45	6.9	34.2
46,159.38	21.2	60.9	42,220.66	19.4	59.1	45,597.33	20.9	60.7	48,648.85	22.3	62.1	7,642.32	3.5	43.2
3,386.97	19.0	31.4	2,723.49	15.3	27.7	1,528.79	8.6	21.0	3,370.04	18.9	31.3	0.00	0.0	12.4
0.00	0.0	93.5	0.00	0.0	93.5	0.00	0.0	93.5	0.00	0.0	93.5	0.00	0.0	93.5
0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0	0.00	0.0	100.0
171,725.51	20.4	36.8	138,891.69	16.5	32.9	145,393.08	17.3	33.6	156,279.49	18.6	34.9		0.0	16.3
40,286.65	21.0	90.1	20,502.00	10.7	79.8	40,261.95	21.0	90.1	31,570.10	16.5	85.6	7,122.56	3.7	72.8
171,725.51	23.3	42.0	138,172.00	18.7	37.4	145,381.60	19.7	38.4	156,279.49	21.2	39.9	30,111.45	4.1	22.8
72,729.40	53.1	71.6	69,434.58	50.7	69.2	45,991.62	33.6	52.1	69,624.89	50.9	69.3	4,869.90	3.6	22.0
0.0	**0.0**	**31.4**	**0.0**	**0.0**	**22.9**	**0.0**	**0.0**	**21.0**	**0.0**	**0.0**	**25.6**	**0.0**	**0.0**	**12.4**
171,725.5	**59.1**	**100.0**	**138,891.7**	**59.0**	**100.0**	**145,393.1**	**36.7**	**100.0**	**156,279.5**	**59.1**	**100.0**	**30,111.5**	**21.6**	**100.0**
85,723.8	**19.0**	**62.2**	**68,258.5**	**14.6**	**57.7**	**71,905.4**	**15.6**	**58.7**	**78,442.4**	**17.5**	**60.6**	**14,183.2**	**3.0**	**46.1**
49.0	**49.0**	**54.0**	**46.0**	**46.0**	**54.0**	**49.0**	**49.0**	**54.0**	**49.0**	**49.0**	**54.0**	**37.0**	**36.0**	**54.0**

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