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Shortfalls in the protection of Important Shark and Ray Areas undermine shark conservation efforts in the Central and South American Pacific

Théophile L. Mouton [a], Adriana Gonzalez-Pestana [a,b], Christoph A. Rohner [a,c], Ryan Charles [a], Emiliano García-Rodríguez [a], Peter M. Kyne [a,d], Amanda Batlle-Morera [a], Giuseppe Notarbartolo di Sciara [a,e,f], Asia O. Armstrong [a,g], Enzo Acuña [h], Joanna Alfaro-Shigueto [a,b,i], Randall Arauz [j,k], Cristopher G. Avalos-Castillo [a,l], Ely Augustinus [a], Sandra Bessudo [k,m], Enrique Barraza [n], Carlos Bustamante [a,o], Elpis J. Chávez [k,p], Eduardo Ramon Espinoza [k,q,r], Mario Espinoza [a,k,s,t], Ana Hacohen-Domené [a,u], Alex R. Hearn [a,k,v], Grettel M. Hernández [w], Felipe Galván-Magaña [x], José A. Gonzalez-Leiva [y], James T. Ketchum [k,z,aa], Felipe Ladino [m], Frida Lara-Lizardi [k,ab], Jorge Manuel Morales-Saldaña [a,ac,ad], Naití Morales Serrano [ae], Jeffry Madrigal-Mesén [p,af], Paola A. Mejía-Falla [a,ag,ah], Andrés F. Navia [a,ag], Gabriela M. Ochoa [ai,aj], Marta D. Palacios [x,z,ak,al], César R. Peñaherrera-Palma [k], Francisco Polanco-Vásquez [a,am], Yehudi Rodríguez-Arriatti [an], Luz E. Saldaña-Ruiz [ao], Oscar Sosa-Nishizaki [a,ao], Javier Tovar-Ávila [ap,aq], Ángel J. Vega [ap,aq], Ximena Velez-Zuazo [a,ar], Melany Villate-Moreno [as], Ilena Zanella [at], Rima W. Jabado [a,au,av,*]

[a] International Union for Conservation of Nature Species Survival Commission Shark Specialist Group, Dubai 29588, United Arab Emirates
[b] Facultad de Biología Marina, Universidad Científica del Sur, Lima, Peru
[c] Marine Megafauna Foundation, West Palm Beach, USA
[d] Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, NT 0909, Australia
[e] Tethys Research Institute, Milano 20121, Italy
[f] IUCN Joint Species Survival Commission (SSC)/World Commission on Protected Areas (WCPA) Marine Mammal Protected Areas Task Force, Gland, Switzerland
[g] School of Science, Technology and Engineering, University of the Sunshine Coast, Qld, Australia
[h] Departamento de Biología Marina and Center for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Facultad de Ciencias del Mar, Universidad Católica del Norte, Casilla, Coquimbo 117, Chile
[i] ProDelphinus, Miraflores, Lima, Peru
[j] Marine Watch International, 2440 16th Street #305, San Francisco, CA 94103, USA
[k] MigraMar, 2099 Westshore Rd, Bodega Bay, CA 94923, USA
[l] Centro de Estudios del Mar y Acuicultura, Universidad de San Carlos de Guatemala, Ciudad Universitaria, zona 12, ciudad de Guatemala, Mexico
[m] Fundación Malpelo y Otros Ecosistemas Marinos, Bogotá, Colombia
[n] Dirección de Ecosistemas y Vida Silvestre, Ministerio de Medio Ambiente y Recursos Naturales, Col. y Calle Las Mercedes, San Salvador, El Salvador
[o] CHALLWA, Laboratorio de Biología Pesquera, Instituto de Ciencias Naturales Alexander von Humboldt, Facultad de Ciencias del Mar y Recursos Biológicos, Universidad de Antofagasta, Antofagasta, Chile
[p] Centro Rescate de Especies Marinas Amenazadas (CREMA), San José, Costa Rica
[q] Dirección del Parque Nacional Galápagos, Av. Charles Darwin, Puerto Ayora, Galápagos, Ecuador
[r] Instituto Nacional de Biodiversidad (INABIO) Quito, Ecuador
[s] Escuela de Biología, Universidad de Costa Rica, San José, Costa Rica
[t] Centro de Investigación en Ciencias del Mar y Limnología, Universidad de Costa Rica, San José, Costa Rica
[u] Biology Department, Universidad del Valle de Guatemala, Guatemala
[v] Universidad San Francisco de Quito USFQ, Colegio de Ciencias Biológicas y Ambientales COCIBA, Galapagos Science Center, Diego de Robles sn y Pampite, Cumbaya, Quito, Ecuador

* Corresponding author at: International Union for Conservation of Nature Species Survival Commission Shark Specialist Group, Dubai 29588, United Arab Emirates.

E-mail address: rimajabado@hotmail.com (R.W. Jabado).

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[w] Instituto Nicaragüense de la Pesca y Acuicultura, Km 3, 5 Carretera Norte, Managua 11032, Nicaragua
[x] Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz 23096, Mexico
[y] Centro de Investigaciones Marinas y Limnológicas, Universidad Francisco Gavidia (CIMARyL-UFG), El Salvador
[z] Pelagios Kakunjá A.C., La Paz 23060, Mexico
[aa] Centro de Investigaciones Biológicas del Noroeste (CIBNOR), La Paz 23096, Mexico
[ab] ORGCAS, La Paz 23060, Mexico
[ac] Smithsonian Tropical Research Institute, Balboa 0843-03092, Panama
[ad] Department of Biology, McGill University, Montreal, Quebec H3A 1B1, Canada
[ae] Center for Ecology and Sustainable Management of Oceanic Islands (ESMOI), Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Chile
[af] Mantas Costa Rica, San Ramón, Alajuela, Costa Rica
[ag] Fundación colombiana para la investigación y conservación de tiburones y rayas, SQUALUS, Calle 10A No. 72-35, Cali, Colombia
[ah] Wildlife Conservation Society, WCS Colombia, Av. 5N No 22N-11, Cali, Colombia
[ai] Institute of Environment, Department of Biological Sciences, Florida International University (FIU), 3000 NE 151st Street, North Miami, FL 33181, USA
[aj] Ilili, 500 Half Moon Bay Rd., Roatan, Bay Islands, Honduras
[ak] Mobula Conservation, La Paz 23075, Mexico
[al] The Manta Trust, Catemwood House, Norwood Lane, CorscombeDorset DT2 0NT, UK
[am] Wildlife Conservation Society, Guatemala
[an] Shark Defenders, Ciudad de Panamá, Panama
[ao] Departamento de Oceanografía Biológica, Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California (CICESE), Mexico
[ap] National Fisheries and Aquaculture Institute (INAPESCA), Mexico
[aq] Centro de Capacitación, Investigación y Monitoreo de la Biodiversidad en el Parque Nacional Coiba (CCIMBIO-CRUV-UP), Universidad de Panamá, Santiago, Veraguas, Panama
[ar] Center for Conservation and Sustainability, Smithsonian National Zoological Park and Conservation Biology Institute,Washington, DC, USA
[as] Fundación MarAdentro, Bahía Solano, Chocó, Colombia
[at] Asociación Conservacionista Misión Tiburón, Carrillo de Guanacaste 50503, Costa Rica
[au] College of Science and Engineering, James Cook University, Townsville, Qld 4811, Australia
[av] Elasmo Project, Dubai 29588, United Arab Emirates

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A B S T R A C T

Global biodiversity targets require nations to designate 30 % of their marine waters as protected areas by 2030. Sharks, rays, and chimaeras (hereafter 'sharks') are key components of aquatic ecosystems; however, over a third are globally threatened with extinction. Across the Central and South American Pacific Ocean region, we (i) assessed trends in Marine Protected Area (MPA) expansion and extent across the 12 nations of the region; (ii) quantified the spatial overlap between MPAs and Important Shark and Ray Areas (ISRAs); and (iii) evaluated the effectiveness of the current MPA governance structure at protecting sharks and their critical habitat. There has been a recent rapid increase in the establishment of MPAs with 90 % of current MPAs designated since 2010. Yet, El Salvador, Guatemala, Peru, and Honduras still protect less than 10 % of their waters. We find that ISRAs overlap with all MPAs by only 15.6 % and with no-take MPAs by 7.3 %. This raises concerns about the low level of protection afforded to critical shark habitats in the region. Of 182 MPAs identified, 41.8 % do not have a management plan, comprising 39.8 % of the total MPA surface area. Mexico, Costa Rica, and Colombia have relatively strong governance frameworks in place and, along with Panama, Honduras, and Ecuador, represent the highest overlap between MPAs and ISRAs. However, the contribution of the remaining six countries to shark protection via MPAs is low based on limited spatial overlap with ISRAs (<2 %). As countries mobilise to meet the 30×30 target, we propose considering ISRAs as a key component of spatial planning when designing new MPAs, designating existing partially protected areas as no-take zones, or reshaping the boundaries of existing MPAs.

1. Introduction

The current global biodiversity crisis results from anthropogenic activities, particularly overexploitation, habitat modification, and climate change [1,2]. These activities impact 87–90 % of the global ocean surface [3,4] and marine defaunation rates are expected to rapidly intensify as human use of the oceans further industrialises [5]. Some marine species are more at risk than others due to extrinsic (e.g., selective harvesting or incidental catch) and intrinsic factors (e.g., low reproductive potential) [6,7]. The most recent global IUCN Red List of Threatened Species™ (hereafter 'IUCN Red List') assessment estimated that one-third (37 %) of sharks, rays, and chimaeras (hereafter 'sharks') are at risk of extinction [8] and one species is already Extinct [9]. Overfishing is the primary threat to all shark species and is confounded with other threats such as loss and degradation of habitat [8]. Many sharks play key roles in aquatic ecosystems and dominate high trophic levels through direct predation effects (i.e., prey consumption) or indirectly through risk effects (e.g., prey behaviour; [10,11]). Declines in shark populations can lead to changes in the functioning of ecosystems and the services they provide [12,13]. Considering that sharks are the second most threatened group of vertebrates on the planet after amphibians, action is urgently needed to recover populations.

To halt the global biodiversity crisis, protecting places with high conservation value is crucial [14,15]. Area-based protection is increasingly advocated as a key tool to revert current declining biodiversity trends and reduce species extinction risk [16]. Marine Protected Areas (MPAs), if well designed and managed, can be an effective and viable tool to reduce biodiversity loss, increase resilience to human and climate-induced threats, reduce fishing mortality, rebuild fish populations, and deliver essential ecosystem services [17,18]. Despite some MPAs benefiting shark conservation (e.g., [19-22]), most are considered ineffective at conserving migratory and/or wide-ranging species (e.g., [23]). Spatial planning approaches, including the extent of protection afforded, often fail to consider and incorporate biological, behavioural, and ecological attributes that determine habitat use for different shark species across different life-stages [24-26]. For highly migratory species, which can move long distances across a wide range of environments [27], MPAs often need to be large or dynamic to sufficiently protect them. However, many existing MPAs are too small or have limited overlap with critical habitats to effectively conserve sharks (e.g., [23, 24]). The effectiveness of MPAs also depends on their ability to limit anthropogenic activities, especially unsustainable fishing practices, within their boundaries [28]. Further, the presence of other anthropogenic threats (e.g., mining) in the vicinity of these MPAs may also diminish their effectiveness. Considering that most MPAs can have multiple conservation objectives, including some socio-economic ones, it can be difficult to have a standardised measure of the effectiveness of each protected area [29].

Rapid gains in MPA extent were seen following the adoption of the Aichi Biodiversity Targets in 2010, which included a commitment to conserve 10 % of coastal and marine areas through effective and equitably managed networks of protected areas and sustainable management of marine living resources (Aichi Target 11; [30,31]). With the adoption of the Kunming-Montreal Global Biodiversity Framework (GBF) in 2022, Target 3 'to protect and conserve 30 percent of land and sea areas through well-connected systems of protected areas and other effective area-based conservation measures by 2030' must now be achieved (30×30 target; [31]). In 2023, United Nations (UN) member states also agreed on a legal framework through the High Seas Treaty, a legally binding instrument under the UN Convention on the Law of the Sea, on the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction [28]. Achieving these global conservation goals with area-based management approaches will help to mitigate ongoing biodiversity loss, build climate resilience, and ensure food security [32,33].

In designing effective MPAs, the development and implementation of robust management plans is pivotal to their success [17,34]. Specific to sharks, management plans should recognize their Conservation Value [35] and account for the varied processes that are essential for the survival of these species. Since overfishing is the primary cause of population declines in sharks, global shark mortality needs to be drastically reduced to rebuild depleted populations and restore marine ecosystems with functional predators [8]. By tailoring conservation measures to address the specific needs of different shark species, MPAs can ensure a more comprehensive and tailored approach to shark protection (e.g., as suggested for climate resilience; [34]). Management plans should therefore encompass measures to regulate fishing activities, mitigate potential threats such as habitat degradation, and protect critical habitats.

The Important Shark and Ray Area (ISRA) approach was designed to contribute robust ecological information to area-based management. This expert-driven approach has the potential for wide-ranging policy and conservation outcomes [36]. The ISRA framework identifies discrete, three-dimensional portions of habitat important for one or more shark species, that are delineated and have the potential to be managed for conservation [36,37]. The ISRA Criteria consider the vulnerability, range restriction, diverse life histories, and distinct attributes of sharks and can be applied to all environments where these species occur. ISRAs can therefore be used to identify priority areas where spatial planning approaches can improve shark conservation and to evaluate if existing spatial approaches provide sufficient protection. All ISRAs are publicly available via an online atlas (www.sharkrayareas.org). Thirteen ISRA regions, covering the world's marine and inland waters, have been delineated and are being assessed. In 2022, ISRAs were delineated in the Central and South American Pacific region, though their overlap with MPAs and the robustness of existing governance frameworks at protecting these areas has yet to be assessed.

Here, we investigate MPAs in the Central and South American Pacific region to (1) assess temporal trends in MPA extent and expansion and evaluate country-level progress in meeting global protection targets, specifically Target 3 of the GBF; (2) examine and quantify the spatial overlap between MPAs and ISRAs; and (3) evaluate the existing governance framework across the regional MPA network using a Shark Management Robustness Index. Finally, we provide recommendations on how ISRAs can be integrated into marine spatial planning by decision-makers and resource managers.

2. Materials and methods

2.1. Study area

The Central and South American Pacific region covers the Food and Agriculture Organization of the United Nations (FAO) Fishing Area 87 and the eastern part of FAO Fishing Area 77. It encompasses a large area of the Eastern Tropical Pacific Ocean, spanning from the Gulf of California, Mexico to southern Chile. It also includes the oceanic islands of Revillagigedo Archipelago (Mexico); Clipperton (a French state property); Cocos Island (Costa Rica); Coiba (Panama); Malpelo (Colombia); Galápagos (Ecuador); Rapa Nui, Salas y Gómez, Juan Fernández, and Desventuradas (Chile); along with large expanses of high seas. We acknowledge that Mexico is generally considered part of North America, however, due to the biogeography and distribution of sharks in this region, Mexico was divided into various regions with the Gulf of California and southern coast included within the Central and South America Pacific region. This region is considered one of the most productive and highly dynamic oceanic regions in the world and is influenced by major ocean currents, wind-driven upwellings, and diverse climatic conditions [38]. Within this region, 188 shark species have been reported to occur, comprising 95 shark, 82 ray, and 11 chimaera species [39].

2.2. Important Shark and Ray areas

A regional expert workshop was held in Bogotá, Colombia, from 3–7 October 2022 [40]. All Central and South American Pacific countries were represented, with 55 experts attending the hybrid meeting. Country representatives proposed areas they considered critical for the survival of sharks, rays, and chimaeras (hereafter 'sharks') based on available data. Details of the ISRA process can be found in Hyde et al. [36] and the ISRA Guidance on Criteria Application [41]. Briefly, the ISRA Criteria allow the delineation of an area according to the known regular or predictable presence and/or activities of sharks. Four criteria incorporating seven sub-criteria are considered: Vulnerability (i.e., species listed as threatened [Critically Endangered, Endangered, or Vulnerable] on the IUCN Red List, or listed as threatened with extinction by national regulatory and legal frameworks that assess the extinction risk of species), Range Restricted (i.e., where a species' distribution is entirely limited to one Large Marine Ecosystems (LME) or two adjoining LMEs), Life-History (i.e., Reproductive Areas, Feeding Areas, Resting Areas, Movement, or Undefined Aggregations), Special Attributes (i.e., Distinctiveness [related to distinct biological, behavioural, or ecological characteristics] and Diversity [i.e., species richness]). Species meeting one or several of the aforementioned criteria are considered Qualifying Species. Overall, after undergoing review by an independent panel of experts [36], 65 ISRAs were delineated in the region [40], and their boundaries were considered for this study.

2.3. Marine protected areas

To obtain the most recent set of MPAs from countries in the Central and South American Pacific region, we considered MPAs that have been Designated (i.e., established or recognized by law or other authoritative rulemaking) with defined boundaries and did not include those that have been Proposed/Committed but have not been officially designated [17]. We downloaded MPAs from the World Database on Protected Areas (WDPA - https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA) in March 2023. Moreover, we examined official government websites while consulting with experts from each country to determine whether additional MPAs should be included that have been designated by the government and have a published MPA polygon with clear boundaries (Table A1). Spatial data for the Atlantic Ocean were also downloaded for those seven countries in the region that possess an Exclusive Economic Zone (EEZ) in the Atlantic. For Mexico, MPAs in the north-eastern Pacific outside the Central and South American Pacific region were also downloaded. Boundaries were verified by comparing the information available in the WDPA with those provided in MPA management plans and official government websites. We considered two groups of MPAs according to their level of protection: no-take MPAs (where any type of extractive activity is forbidden; i.e., those aligning with IUCN categories I, II, or III; following [42]) and partial MPAs [also referred to as multiple-use MPAs]; those aligning with IUCN categories IV, V, VI, and other types of classification). IUCN categories are reported in the WDPA, however, if national experts and/or management plans provided updated information on the type of MPA (no-take or partial/multiple-use) that differed from information available on the WDPA, the updated information was used. Our final set comprised 65 no-take MPAs and 117 partial/multiple-use MPAs (Table A1). We include some discussion of proposed areas not included in our analysis or proposed management changes in the context of our results based on expert knowledge at the country level.

Protected areas can have multiple zones where only parts of the MPA are designated as a no-take zone, while extractive activities are allowed in others. The WDPA considers this type of MPA as a category IV MPA or above, without specifying which area inside the MPA is designated as a no-take zone. To accurately identify all no-take zones in our MPA dataset, we checked for potential zoning within each MPA, by comparing the information provided by the WDPA with MPA management plans. Detailed shapefiles for each zoned MPA were requested from government organisations, MPA managers, and researchers in each country. If the boundaries of the zoning were described with sufficient details in official documents, we created shapefiles using standard GIS protocols in ArcGIS Desktop 10.8 (ESRI Inc.). Overall, we compiled zoning information for 16 MPAs accounting for 27.2 % of all MPA extent in the region.

To assess the extent of MPAs in each nation and expansion required to meet the 30×30 target, we examined the extent of both no-take MPAs and partial MPAs as the percentage of EEZ covered by MPAs. For those countries with coastlines on the Pacific and Atlantic Oceans, we report MPA expansion and extent as a percentage of their EEZ for both bodies of waters. Finally, we assessed progress against Aichi Target 11 (10 % protection) by measuring MPA expansion (for both no-take and partial MPAs individually; defined as increases in areas designated as MPAs) for the period 2010–2023 (i.e., post-Aichi Target 11 period; [43]).

2.4. Overlap between MPAs and ISRAs

We measured the percentage area of ISRAs overlapping with MPAs in the Central and South American Pacific region at two different spatial scales (all ISRAs in the region combined and ISRAs within the EEZ of each country) and two designations levels (all MPAs [i.e., regardless of management type] and no-take MPAs only). Because some ISRAs overlapped each other, overlap analysis between ISRAs and MPAs were all performed after dissolving the boundaries of our ISRA polygons (i.e., merging into a single multi-polygon). For Mexico, three Pacific coast MPAs were not included in the analysis as those are located outside the boundaries of the ISRA Central and South American Pacific ISRA region, on the west coast of the Baja California peninsula (i.e., El Vizcaíno, Islas del Pacífico de Baja California, and Isla Guadalupe). Measuring overlap at different spatial levels allows us to identify national variations in MPA overlap with ISRAs. Measuring overlap at different designation levels identifies potential conservation gains that could be obtained if partial MPAs were to become no-take MPAs. We measured the extent of delineated ISRAs within each country's EEZ in the region using the *st_area* function from the sf package v.1.0–10 [44]. We did this after intersecting our spatial layer of ISRAs with a spatial layer of EEZs from the Central and South American Pacific region using the *st_intersection* function in sf. We repeated the same analysis for ISRAs and MPAs at each spatial level and for both protection levels.

2.5. Shark Management Robustness Index

We assessed the governance structure in place that would allow protected areas to contribute to shark conservation through a Shark Management Robustness Index. Here, governance was defined as the measures in place to conserve or reduce mortality of sharks within MPAs as defined in their management plans. For this, existing management plans were thoroughly reviewed against specific criteria that assessed the design and planning of the MPA in relation to shark conservation. Management plans were retrieved from official government or legally mandated organisations and agencies (Table A1). Further, we define Conservation Values as those species that are conservation targets within an MPA, require management actions, and are therefore key elements of the planning and monitoring of a protected area [45]. Conservation Values is a tool that allows the prioritisation of conservation efforts and indicators of endangerment [35]. Each MPA was then scored according to seven criteria (Table 1). The first criterion evaluated the existence of a management plan. If a plan was not published, then the other criteria were not considered (i.e., score of 0). This is because the first stages in the establishment of an MPA (i.e., Designated and Implemented) requires an approved management plan [17]. We did not assess the validity of management plans (i.e., updated or outdated). The second criterion evaluated the key management measures that protect sharks (e.g., fishing bans). The third criterion assessed whether sharks were included in the objectives of the MPA, as a Conservation Value. Criteria four to six were aligned with the ISRA Criteria to determine whether vulnerability, range restriction, life-history, and special attributes were taken into consideration [36].

We adopted a binary coding approach and assigned 'No' a score of 0, and 'Yes' a score of 1 for each question posed to assess these criteria. Here, zoned MPAs were considered as two separate MPAs because the no-take and multi-use zones within them can differ widely in size and age. We then summed individual MPA scores for each MPA to calculate the Shark Management Robustness Index for each [50,51].

To understand variations in the index's total score in relation to the year of MPA establishment and MPA size (km^2), we used a generalised linear mixed effect model (GLMM) fitted by maximum likelihood estimation with a Poisson distribution and using countries ($n = 11$) as random effects. The country list excluded France since it has a single MPA (i.e., Clipperton Island - Île de la Passion). Marine protected area size was log-transformed prior to model computation and both predictor variables standardised to zero, with one unit variance to allow comparison of estimates. Visual examination of residual diagnostic plots did not reveal obvious deviations from homoscedasticity, and analyses of the residuals indicated a notable tendency for the residuals to conform to a normal distribution. We ran the GLMM using the *glmer* function in the lme4 R package v.1.1–33 [52]. We tested for model parsimony by modelling all combinations of predictor variables and comparing model fits using the correction for small samples of Akaike's Information Criterion (AICc; [53]), using the *dredge* function in the MuMIn package v.1.47.5 (Bartón, 2023). Model performance (i.e., marginal and conditional r-squared: R^2m and R^2c, respectively) was assessed with the *model_performance* function in the performance package v. 0.7.0 [54], and marginal and random effects visualised with the sjPlot package v.2.8.9 [55].

2.6. Sensitivity of Shark Management Robustness Index results

We assessed the sensitivity of the Shark Management Robustness Index results to variations in the number and type of questions used to calculate the total score. We re-ran the GLMM with the total score of the index using: (1) questions 1–3, and (2) questions 1–3 in combination with the cumulative sum of questions 4, 5, 6 and 7, respectively. Therefore, five models were computed in total, with the index's total score gradually ranging from 3 to 7. In the first model, the first three questions were used because the current goal of MPAs should be to

Table 1
The seven questions and their rationale used to assign scores to calculate the Shark Management Robustness Index.

N	Question	Rationale
1	Does the MPA have a management plan?	MPA management plans are essential for achieving and maintaining conservation goals, ensuring sustainable use of marine resources, and fostering cooperation among stakeholders involved in managing the protected area [17,34].
2	Is the MPA a no-take zone?	No-take zones are instrumental for the conservation of shark populations by creating areas where shark fishing and mortality can be reduced, especially since overfishing is the primary cause of population declines in sharks [8]. These zones contribute to broader marine conservation efforts, benefitting not only sharks but the ecosystems on which sharks depend (e.g., [46,23,22]).
3	Are sharks included as a Conservation Value?	Recognizing the importance of sharks in MPAs contributes to prioritising their conservation, the overall success of conservation efforts, and benefits the species and the communities that depend on it [35].
4	Has the extinction risk of species been recognized in the MPA design?	It is crucial for MPAs to be strategically located in areas hosting threatened shark species because these regions serve as critical habitats for the survival and recovery of these populations [47].
5	Is the regular and predictable occurrence of range-restricted shark species considered in the MPA design?	Establishing MPAs in areas where range-restricted species occur is essential for preserving unique biodiversity. This conservation approach ensures the survival of species with limited geographic distributions and maintains the ecological integrity of specific regions [19,48].
6	Have life-history attributes of sharks (i.e., reproduction, feeding, resting, movement, aggregations) been acknowledged?	MPAs that consider the life history of species are crucial for the intrinsic value of those species. By protecting their essential habitats and life stages, networks of connected MPAs contribute directly to the well-being, survival, and resilience of sharks within their ecosystems [25].
7	Have areas of special attributes (i.e., hotspots of shark diversity or areas of distinct behaviour) been considered in the MPA design?	Preserving hotspots of shark diversity and areas of distinct behaviour is vital for maintaining biodiversity, supporting ecosystem stability, and ensuring the health and resilience of aquatic ecosystems. Such areas are critical for the conservation of a variety of shark species and contribute to the broader objectives of marine protection and sustainability [49].

reduce shark mortality. In the subsequent models, we tested the sensitivity of the results to the cumulative addition of each question from 4 to 7.

2.7. Congruence among indicators of protection

To understand the relative rank of each country and based on their scores for all indicators measured, we mapped countries in a two-dimensional space using Principal Component Analysis (PCA). There were eleven indicators in total within three categories: (1) MPA expansion and extent (four indicators: no-take MPA expansion 2010–2023, no-take MPA extent in 2023, all MPA expansion 2010–2023, and all MPA extent in 2023); (2) MPA overlap with ISRAs (two indicators: no-take MPAs, all MPAs); (3) MPA governance (index scores, as predicted random effects, using the five different total scores to account for sensitivity of the index as indicators). Because the three different categories had a different number of indicators, we weighted the scores of the indices in the PCA by the number of indicators in their respective category (i.e., 1/4, 1/4, 1/4, 1/4, 1/2, 1/2, 1/5, 1/5, 1/5, 1/5, 1/5). All indices were standardised prior to PCA computation. PCA was computed using the *dudi.pca* function from the Ade4 R package v.1.7–22 [56]. We further classified countries into clusters based on their position on the first two axes of the PCA. The first two axes of the PCA were used because these accounted for the majority (>85 %) of the variation in the data, with the other axes representing low variation (<8 %). We used the NbClust function in the NbClust R package v. 3.0.1 [57], using euclidean distances and Ward's D2 clustering method. This function provides a comprehensive framework for determining the optimal number of clusters in a dataset based on consensus among a large set of different clustering indices.

3. Results

3.1. Important Shark and Ray Areas

The 65 ISRAs of the Central and South American Pacific region covered 5,732,266 km^2 (min = 0.1, median = 915, mean = 79,717, max = 3,021,320 km^2, representing 15.6 % of the region) and occupied both national waters (64 % of the area) and waters beyond national jurisdiction (36 %; representing 7.5 % of the high seas in this region). These ISRAs were delineated for 96 species encompassing 47 shark (49 % of shark species reported from the region), 47 ray (57 % of ray species reported from the region), and two chimaera (18 % of chimaera species reported from the region) species from 12 orders and 33 families. Of these, 59 species (63 %) are threatened with extinction.

3.2. Marine protected areas

The first MPA of the Central and South American Pacific region was created in 1935, in the Archipelago Juan Fernandez, Chile (52 km^2; Fig. 1 **A & B**). From 1945–1969, six MPAs were created across the region (10,035 km^2). Marine protected area expansion rapidly increased from 1970 to 2010 with the creation of 111 MPAs (253,946 km^2; Fig. 1 **A & B**). Between 2010–2023, an additional 53 MPAs were created (2,557,863 km^2), which accounted for 90.4 % of the total MPA network area in 2023. As a consequence, marine protected areas cover 7.7 % of the Central and South American Pacific region, with only 3.7 % of the region covered by no-take MPAs.

There were contrasting patterns of recent MPA expansion among countries (Fig. 2 A). Between 2010–2023, expansions represented more than 18 % of the waters of Panama, Chile, Colombia, Mexico, and Costa Rica; 6–8 % of waters in Honduras, Peru, and Ecuador; and less than 1 % in Nicaragua, El Salvador, and Guatemala (Fig. 2 **A**). By March 2023, Panama, Chile, and Colombia had met the 30 % protection target (Fig. 2 **B**) while Costa Rica, Mexico, Ecuador, and Nicaragua had only met Aichi Target 11 (i.e., 10 % protection) (Fig. 2 **B**).

Countries with noteworthy no-take MPA expansion during the 2010–2023 period included Chile (23.5 %), Panama (13.7 %), and Mexico (10.3 %; Fig. 2 **A**). Notable no-take MPA extents (i.e., ≥7 %) were noted for Chile, Panama, Mexico, Costa Rica, Colombia, and Ecuador. In the remaining countries, no-take MPA extent was less than 3 % (Fig. 2 **B**).

3.3. Overlap between MPAs and ISRAs

All Central and South American Pacific ISRAs overlapped with country EEZs within this region to some extent (minimum overlap = 8.9 %, mean = 61.3 %, max = 100 %; Table A2, A3). The highest

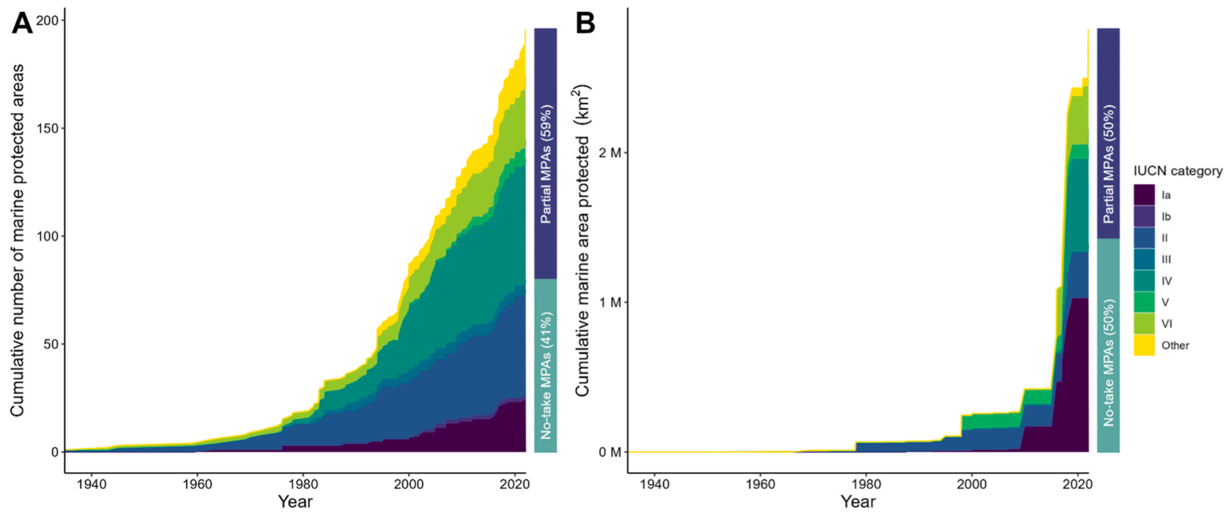

Fig. 1. **A**: Cumulative number and **B:** area, covered by marine protected areas (MPAs) in the Central and South American Pacific region over time. Bars on the right of the plots show the percentage of MPAs that are considered no-take or partial MPAs. No-take zones within partial MPAs were considered IUCN Category II.

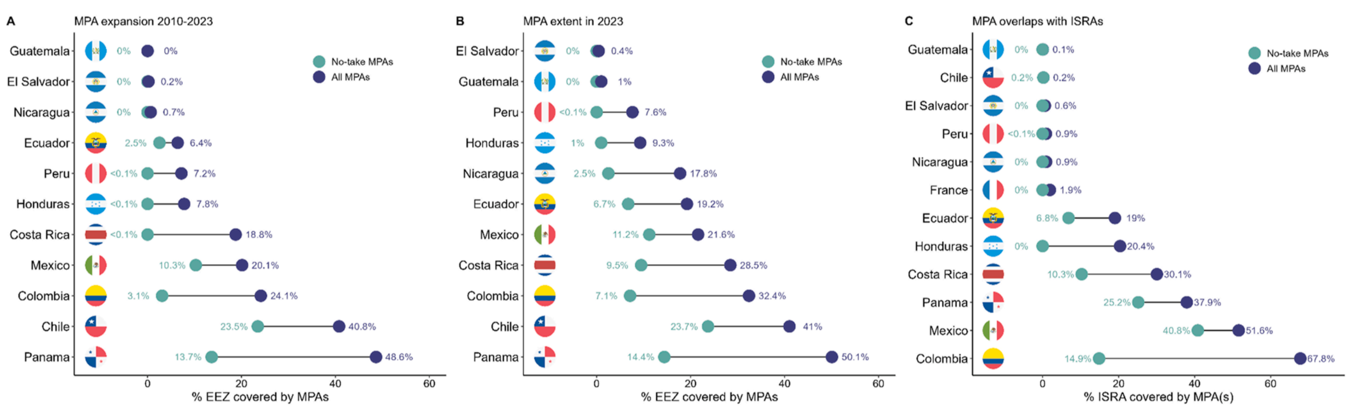

Fig. 2. **A & B.**: The percentage of waters covered by MPAs for each country in the Central and South American Pacific region. For those countries with a coastline on the Pacific and Atlantic Ocean, MPAs established on both coasts were considered for this analysis, providing an overall picture of the country's MPA expansion during the 2010–2023 period and extent in 2023. Dots show: **A:** (1) no-take MPA expansion from 2010 to 2023, and (2) all MPA expansion from 2010 to 2023. **B:** (1) no-take MPA extent in 2023, and (2) all MPA extent in 2023. **C:** Percentage ISRAs overlap with MPA(s) by country of the Central and South American Pacific region. Values are given both for all MPAs (blue) and no-take MPAs (green). The two dots are connected by a black line to emphasise the difference between no-take and all MPAs.

national level overlap between ISRAs and MPAs was in Colombia (67.8 %), Mexico (51.8 %), Panama (37.9 %), Costa Rica (30.1 %), Honduras (20.4 %), and Ecuador (19 %; Fig. 2 **C**). In all other countries, the overlap between ISRAs and MPAs was <2 %. When considering no-take MPAs only, overlap was highest in Mexico (40.8 %), Panama (25.2 %), Colombia (14.9 %), Costa Rica (10.3 %), and Ecuador (6.8 %). However, in each of the remaining seven countries, the overlap with all MPAs was ≤0.2 %. Finally, at the scale of the combined area of all ISRAs, 15.6 % overlapped with all MPAs, while 7.3 % overlapped with no-take MPAs (Fig. 3).

3.4. Shark management robustness

Of the 182 MPAs designated in the Central and South American Pacific region, 106 (58.2 %; 45 no-take and 61 partial) had a management plan (60.2 % of the total MPA extent in the region). This varied widely between countries with Nicaragua having the lowest number of MPAs with a management plan (n = 1; 20 % of its MPAs) and Costa Rica the highest (n = 22; 85 %). Twenty MPAs (11.0 %; including eleven no-take) in six countries included sharks as a Conservation Value. Twenty-eight were mentioned at the species level (19 shark and nine ray species), including 20 species globally threatened with extinction (14 shark; 6 ray species), and three at the genus level (two shark and one ray species) (Fig. 4 **A;** Table A4). No MPA management plans mentioned chimaeras as a Conservation Value. These 28 species represent 14.9 % of the regional species richness and 29.2 % of the ISRA Qualifying Species in the region. Whale Shark *Rhincodon typus* and Scalloped Hammerhead *Sphyrna lewini* were the most frequently mentioned species, followed by the Pacific Eagle Ray *Aetobatus laticeps* (Table A4).

Seventeen (9.3 %) MPAs in six countries noted the extinction risk (i.e., Vulnerability) of sharks. Five MPAs (2.7 %) from three countries (El Salvador, Costa Rica, and Colombia) included six range-restricted species as a Conservation Value (Table A4). Eighteen (9.9 %) MPAs recognised the importance of considering habitats critical for the life-history of sharks (e.g., reproduction, feeding, movement). Two MPAs (1.1 %) recognised the importance of protecting shark diversity.

For each of the five models assessed, model comparison based on AICc consistently revealed that the model incorporating both predictor variables demonstrated the lowest AICc value (Table A5). All GLMMs converged towards similar results, suggesting low sensitivity of the index total score to question inclusion (Fig. 4). However, model fits increased gradually with the addition of questions in the index's total score, indicating better relationships with year of MPA establishment and MPA size as more questions were added (Fig. 4 **B;** inset plot). The

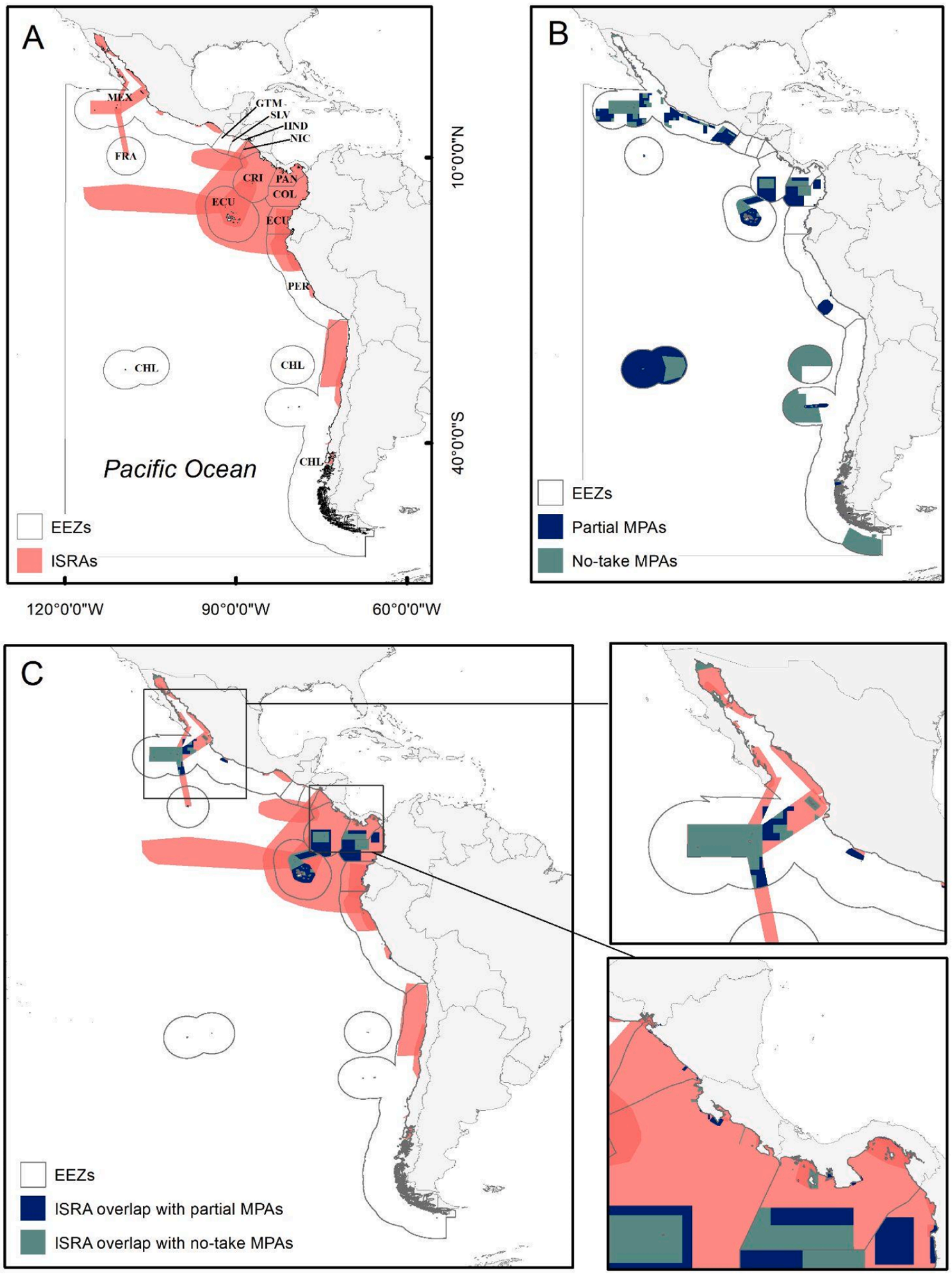

Fig. 3. Central and South American Pacific region (boundaries are indicated by the black box in maps A and B). **A**: Important Shark and Ray Areas (ISRAs; pink areas), and Exclusive Economic Zones (EEZs; grey lines). Three-letter codes inside the EEZs represent the corresponding jurisdictions. CHL, Chile; COL, Colombia; CRI, Costa Rica; ECU, Ecuador; FRA, France; GTM, Guatemala; HND, Honduras; MEX, Mexico; NIC, Nicaragua; PAN, Panama; PER, Peru; SLV, El Salvador. **B**: Marine Protected Areas (MPAs); **C**: Overlap between ISRAs and no-take MPAs (green), and with partial MPAs (blue).

Shark Robustness Management Index for MPAs in the region ranged from 0 to 6 (mean = 1.45, SD = 1.38), out of a maximum possible score of 7. Costa Rica, Mexico, Colombia, and Ecuador had the highest score (Fig. 4 **B**). Year of MPA establishment and MPA size were both significant predictors (Table A6). Year of MPA establishment was negatively related to Shark Robustness Management Index (Fig. 4 **C**), whereas MPA size was positively related (Fig. 4 **D**).

3.5. Congruence among indicators of protection

The first axis of the PCA (57.5 % of variation explained) ranked countries according to all three categories (MPA extent and expansion, MPA overlap with ISRAs, and MPA governance) with positive values having high scores and negative values low scores (Fig. 5 **A**). In contrast, the second axis (27.7 %) distinguished countries with higher MPA governance (positive axis 2 values) from those having high MPA extent and expansion (negative axis 2 values; Fig. 5 **A**). Consensus among the clustering indices suggested that there were three major groups of countries (Fig. 5 **B**). Mexico, Colombia, and Costa Rica (Group 1) had relatively high values of all three categories of indicators (positive axis 1 values; mid axis 2 values). Chile and Panama (Group 2) had high MPA extent and expansion but a low recognition of sharks in governance frameworks (negative side of axis 2). Ecuador, Peru, Guatemala, El Salvador, Honduras, and Nicaragua (Group 3) had the lowest values for all three categories (mid and negative axis 1 values; Fig. 5 **B**).

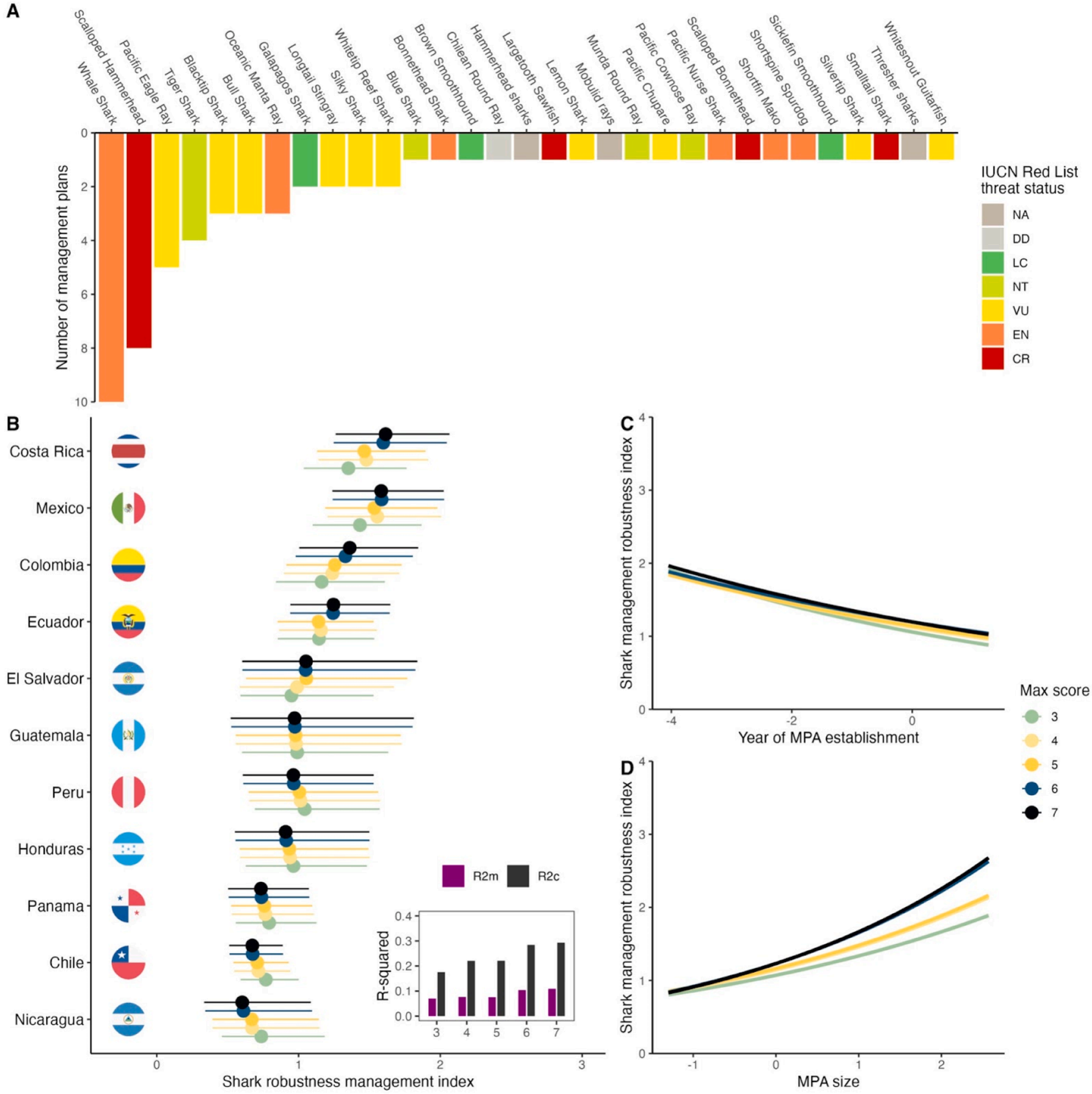

Fig. 4. A – The species considered of Conservation Value in MPA management plans and their global IUCN Red List threat status. 'NA' denotes a grouping of species without an IUCN Red List status. **B -D** Results of Shark Robustness Management Index for Central and South American Pacific region MPAs as obtained from Generalised Linear Mixed-effects Models. Models were computed with the maximum score of the index gradually increasing from 3 to 7 (as indicated by the legend; for further details refer to Methods). **B** - Estimates (black points) and 95 % confidence intervals (black lines) for each country (predicted random effects). The inset bar plot in the bottom right corner shows the R-squared values (marginal [R2m; purple] and conditional [R2c; black]) of each model. **C** - Marginal effects of year of MPA establishment to the index. **D** - Marginal effects of MPA size on the index.

4. Discussion

Our results highlight a rapid expansion in MPAs designation in the Central and South American Pacific region from 2010 to 2023. This trend varied significantly between countries that are at diverging stages of reaching global biodiversity targets. Over 40 % of designated MPAs do not have management plans with shortcomings also identified in existing governance frameworks with regards to shark, ray, and chimaera (hereafter 'shark') conservation. Further, in most countries, there is a clear mismatch between no-take MPAs and identified critical shark habitats (i.e., ISRAs) highlighting that current MPAs are likely to offer limited protection for sharks and the habitats they depend on. Here, we consider and discuss: (1) the expansion of MPAs in the region and mismatch with ISRAs; (2) the governance structure of MPAs in relation to shark conservation; and (3) the use of ISRAs in marine spatial planning. Our findings provide an opportunity to ensure shark-specific needs are incorporated into future MPA design and establishment in the region.

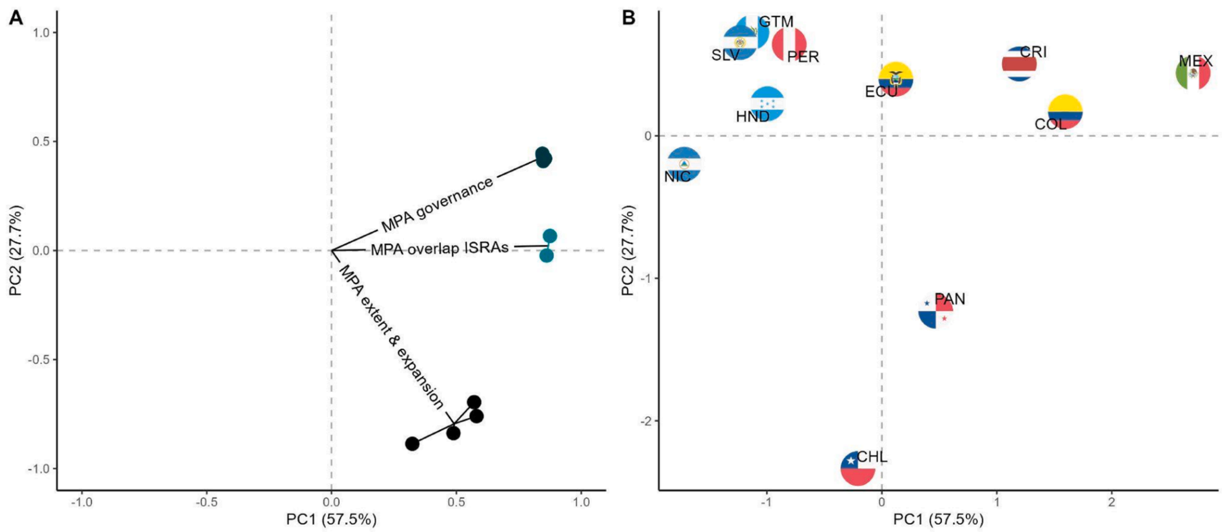

Fig. 5. Principal Component Analysis (PCA) of all indicators of protection (eleven indicators in total, belonging to three categories: MPA extent and expansion (black), MPA overlap with ISRAs (blue) and MPA governance in relation to shark conservation (green). **A**: Indicators' scores in the PCA. Indicators are coloured by their respective category and the black segments point to the centroid of the index scores by category. **B**: Countries' scores in the PCA.

4.1. MPA expansion and mismatch with ISRAs

Commitments to Aichi Target 11 prompted countries to establish MPAs in the region, which resulted in a nine-fold increase in their extent between 2010–2023. Still, despite Panama, Chile, and Colombia having protected over 30 % of their waters, several countries have yet to achieve global conservation goals. In fact, Guatemala, El Salvador, Honduras, and Peru have also yet to reach the 10 % stipulated under Aichi Target 11. If we consider the current pattern of MPA expansion to assess likely performance against Target 3 of the GBF (30 % protected), many countries in this region are unlikely to meet this target without dedicated effort and action.

While MPAs are a key mechanism for preserving marine and coastal biodiversity, those that allow fishing cannot maintain all levels of biodiversity in a natural condition [46]. Even with the rise in MPA establishment over the last decade, no-take MPAs coverage in the Central and South American Pacific region has remained low. Overall, with 7.7 % of waters covered by MPAs, only 3.7 % have been designated as no-take MPAs. Notwithstanding potential fisheries measures in place in each country, this leaves 96.3 % of the region subject to fishing. With overfishing being the main threat to sharks [8], this low coverage is a significant concern for their conservation. Our results suggest that sharks in this region would likely receive twice as much spatial protection if existing MPAs did not allow fishing within their boundaries (i.e., 15.6 % of ISRAs overlapped with MPAs, while only 7.3 % overlapped with no-take MPAs) and were well monitored and enforced, without the need to establish new MPAs. El Salvador and Guatemala have yet to establish no-take MPAs, while others have few (e.g., Honduras, Nicaragua, and Peru). Delineated ISRAs in these countries therefore provide an opportunity for countries to expand the protection level of existing partial MPAs to ensure that critical shark habitat can be preserved. This is especially important since we also found a high degree of mismatch between MPAs and ISRAs with 84.4 % of critical shark habitat not overlapping with designated MPAs. Only Mexico, Panama, Colombia, Costa Rica, and Ecuador had designated no-take MPAs that markedly overlap (range 6.8–40.8 %) with ISRAs within their EEZs. The remaining countries had less than 0.2 % of ISRAs under full protection. While no-take MPAs have been shown to support the protection and recovery of reef shark populations (e.g., [22,58]), there remains considerable uncertainty on how no-take Central and South American Pacific MPAs might be benefiting shark conservation when factors such as protected area size, age, remoteness, and enforcement [23,50], along with the life-history and movement ecology of species [27] are considered. This is especially the case since almost half of MPAs in the Central and South American Pacific do not have management plans. For instance, while Chile and Panama have already protected over 40 % of their waters, only about 30 % of their MPAs have published management plans. While an MPA declaration is a start, implementation and effective management is required to achieve species recoveries. Without management plans, MPAs are essentially 'paper parks' that offer limited protection to biodiversity ([17]; [59]).

With 36 % of ISRAs occurring in the high seas and no overlap with existing MPAs, these areas do not currently benefit from any area-based management. Habitats and ecosystems in the high seas are often overlooked and generally some of the least protected on Earth [4]. The identification of ISRAs in oceanic and/or areas beyond national jurisdiction has the potential to guide the design of large, offshore, dynamic, or mobile MPAs that can ensure shark protection requirements are met [60]. Some countries have moved away from focusing only on conserving coastal habitats and increased protection by designating oceanic MPAs (e.g., the Galapagos Marine Reserve in Ecuador, Revillagigedo Archipelago in Mexico, and Rapa Nui and Salas y Gómez in Chile). This has ensured protection is 'representative' of different habitats while countries inched closer to meeting their global targets [61]. This trend of designating oceanic MPAs within EEZs and in the high seas is likely to continue increasing due to political and ecological reasons [4]. Four transboundary MPAs encompassing high seas waters have already been established globally, including the Pelagos Sanctuary for marine mammals in the Mediterranean Sea [62,63]. Costa Rica, Ecuador, Panama, and Colombia have committed to join their marine reserves to form one interconnected area known as the Eastern Tropical Pacific Marine Corridor [64], where there is evidence of ecological connectivity for sharks [21], also confirmed through the ISRA process [40]. The impending ratification of the High Seas Treaty now offers a legal framework for the designation of protected areas in international waters which can conserve biodiversity [28]. There are no guarantees that MPAs established in the high seas will be designed to regulate fisheries and this mandate might remain with existing Regional Fisheries Management Organizations [28]. Nevertheless, having ISRAs delineated in the high seas provides an opportunity to ensure that shark conservation is considered in two-thirds of the ocean and offers some hope for threatened populations of species that can migrate across entire ocean basins. Ocean governance needs to be considered and multilateral cooperation will be critical to ensure the establishment and enforcement of these MPAs.

Our findings provide insights into the overlap of known critical shark habitat with MPAs, but we recognise that they only constitute a starting point. It is important to note that using designated marine protected areas only for analysis may conceal and lead to the omission of locally important conservation areas (e.g., [43]). Other area-based management conservation tools, which may or may not have management priorities directly related to biodiversity conservation, can also provide broader benefits [17,61] and contribute to reducing shark mortality. For example, Golfo Dulce in Costa Rica, which overlaps with an ISRA, has been designated as a Responsible Marine Fishing Area where some fishing gears have been banned (I. Zanella, pers. obs.). Honduras has been declared a Shark Sanctuary where targeted shark fisheries are banned across EEZ waters (G. Ochoa, pers. obs.). While noting that in most situations there are still challenges with implementation and dealing with the incidental catch of sharks, a comprehensive overview of the overlap of management areas (e.g., shark sanctuaries, areas with seasonal fishing closures, or where gear restrictions are enforced) with ISRAs is needed to fully understand the contribution of various area-based management approaches to shark conservation.

4.2. MPA governance structure

Our review of MPA management plans highlighted an overall low level of recognition of sharks with only 11 % of these highlighting sharks as a Conservation Value. Most ISRA Qualifying Species (70.8 %) are not considered as Conservation Value in MPAs of the Central and South American region. This focused primarily on a few charismatic species already protected nationally or listed on international conservation treaties (e.g., Whale Shark and Scalloped Hammerhead). The utilitarian value of these species was most highlighted in management plans and this pattern was also consistent with these species being those with the highest dive tourism value within these protected areas [64]. This biased prioritization undermines the protection of shark biodiversity. For MPAs to be effective at conserving sharks, management plans need to incorporate critical shark habitat and clearly identify the susceptibility of these species to extractive activities within the area and set objectives and strategies to reduce their impact. Readily available ISRA information can directly be used for the development of such management plans. Our results indicate that most MPAs in this region have been designed without considering the basic ecology of the species they are trying to protect (e.g., [65]). Management Robustness Index scores also decreased with increasing years of MPA establishment. This suggests that most recently established MPAs either were not designed to protect sharks or lack clear management plans addressing the protection of critical shark habitats. These scores underline a lack of political will and the need to develop, incorporate, and implement robust plans for shark management in current and future MPAs in the Central and South American Pacific region. In this sense, ISRAs are essential tools that can allow governments to take immediate steps to better incorporate sharks into MPA management and allow MPA practitioners to accelerate the development of objectives and strategies to reduce shark mortality, including monitoring indicators that can inform on the status of shark populations in relation to MPA boundaries.

The differences in MPA management plans are likely due to the various political climates across the region, legislative requirements, resource availability, and community acceptance. Even a clear political will to conserve and recover shark species requires overcoming significant monitoring and enforcement challenges. This is largely due to lack of coordination between government agencies, corruption, internal conflicts, and overall limited capacity to monitor and enforce fisheries regulation due to inadequate resources and limited public participation in decision-making [66,64,67,68]. Despite their legal designation, varying levels of illegal extractive activities often occur in MPAs with evidence that illegal, unregulated, and unreported (IUU) fishing activities persist [69-72]. For example, illegal fishing of large pelagic fish is known to occur within Costa Rica's largest MPA, the Isla del Coco National Park [73]. In Colombia, the declaration in 2021 of a blanket ban on all marine shark fishing in artisanal and industrial fisheries has been criticised for its potential to drive fishing and trade underground, fuel criminality, and marginalise fisher communities [66,68]. Sharks are vital components of livelihoods, economies, and food security in these countries [66] and therefore prohibiting shark fishing and implementing measures to reduce bycatch without considerations for the livelihoods of Indigenous and local communities can have significant impacts and exacerbate challenges in compliance and enforcement. This is especially true since there are very few programs across the region that provide economic alternatives to the shark artisanal fishers, such as ecotourism or aquaculture (e.g., [68]). Therefore, when planning and delineating new or existing MPAs, it is important to ensure ecological and socio-economic outcomes are considered so that nature, and the people that depend on it, can benefit from the establishment of the MPA (Manghbjai et al., 2015; [74]). Understanding the value and use of aquatic ecosystems by local communities is relevant to MPA design, as these factors can be opportunities or challenges to MPA success [75,76]. Overall, it appears that protected areas that ban fishing (i.e., no-take) are often perceived as leading to direct economic losses by displacing and reducing fishing effort (e.g., [77]). Critical to the success of MPAs is therefore consultation with local communities during the design phase and when developing regulations [78]. In Costa Rica, partially protected areas have more support than no-take MPAs by fishers and working with the fishing sector ensures their commitment and active participation in the establishment of new MPAs (M. Espinoza, pers. obs.). In the Colombian Pacific, partial MPAs declared with the active involvement of fishing communities have facilitated their participation in important processes such as control and surveillance and the establishment of management agreements (P. Mejía-Falla pers. obs.). In this context, delineated ISRAs can be used to design new partial/multiple-use MPAs that incorporate no-take zones or include resource use areas that prohibit or manage (e.g., temporal closures, use of deterrents, post-capture handling) the use of fishing gears that interact with sharks (e.g., gillnets, longlines, trawls) in consultation with fishing communities.

Ecological factors are also a key consideration in MPA planning, as most MPAs aim to preserve marine biodiversity. Although this study focuses on sharks, this group of fishes can be used as indicators of ecological health, environmental quality, and biodiversity and abundance of other marine taxa [79], [80,81]). Therefore, sharks could be used as umbrella species whose presence or abundance provide information about the state of an ecosystem [82,79,81]. Umbrella species have been successfully used to select where protected areas should be established and to monitor the outcomes of their implementation [83, 84].

Albeit a relatively low percentage, the mention of sharks does indicate acknowledgment of the importance of sharks, and some political will to address issues related to their conservation that can be capitalised on (e.g., [85]). Across most countries in this region, shark species are often solely considered as a fishery resource and are not considered in national extinction risk assessments which is an important step towards designing conservation measures [86,87]. Still Colombia, Mexico, and Costa Rica, which have the highest scores in terms of governance framework in the region, have recognized the threatened status of sharks through a national extinction risk status. This may indicate commitment to increasingly consider sharks in the context of biodiversity conservation and eventually in the design and establishment of MPAs. Indeed, Ecuador has already designated MPAs based on available information on shark migration patterns (Hermandad Marine Reserve) and on the identification of reproductive areas (Puerto Cabuyal) (E. Espinoza, pers. obs.), although a management plan for the latter has yet to be published. Further, some of the countries with low performance on the Shark Robustness Management Index are showing signs of increasing marine protection for sharks. For example, the government of Guatemala is considering expanding current protected areas with a new proposed

MPA, Las Lisas. This proposed MPA overlaps with an ISRA and its draft management plan includes hammerhead sharks (Sphyrnidae) as species of Conservation Value (A. Hacohen-Domené and C. Avalos-Castillo, pers. obs.). The Ministry of Environment in Peru has also proposed a new MPA that overlaps with an ISRA where the Whale Shark is considered as a Conservation Value, representing the first time a shark is considered as a priority in Peruvian MPAs (A. Gonzalez-Pestana, pers. obs.).

Our study does not evaluate implementation and management effectiveness, but only the governance framework and representation of critical shark habitat by MPAs. Further research is needed to incorporate information on the validity of available management plans (i.e., whether they have been updated since they were developed), operational monitoring indicators and targets, and enforcement assessments of MPAs to allow for a critical evaluation of management effectiveness [88] and whether they are benefiting shark conservation.

4.3. Use of Important Shark and Ray Areas in marine spatial planning

Amidst the likely upcoming race to meet protected area coverage targets (i.e., 30×30), it is important for countries to have tools such as ISRAs available to make decisions on protecting areas that can contribute to shark conservation, rather than protecting areas opportunistically because of few competing interests [89]. The ISRA approach can help achieve conservation targets by defining which processes are most important for critical shark habitat protection and delineating these areas of importance. Our study revealed positive trends and shortfalls in MPA governance across the Central and South American Pacific region. These can be used by stakeholders to further design or improve MPA governance in the region. By assessing MPA overlap with critical shark habitat, we highlight where current MPA coverage gaps exist, which can inform future planning and evaluation of important biodiversity conservation measures [90,91]. The framework used in this study can also be used as a baseline for further research to model and identify drivers of MPA governance across nations. As countries mobilise to meet the 30×30 target, resource managers will strive to identify new MPAs, designate existing partially protected areas as no-take zones, or reshape the boundaries of existing MPAs. Considering ISRAs as a key component in spatial planning, along with the integration of other area-based or seascape of biodiversity importance approaches (e.g., Key Biodiversity Areas [KBAs; [92]]; Ecologically or Biologically Significant Marine Areas [EBSAs; [93]]; Important Marine Mammal Areas [IMMAs; [94,95]]) can further ensure that areas of high biodiversity are protected.

It is key that any future MPA expansions do not simply increase MPA size, but also perform effectively against the overarching goal of preserving biodiversity. This approach will avoid areas simply becoming 'paper parks'. We also note that expansions will need to be coupled with support from local communities. Sharks are commercially important species and potential impacts on industry and communities need to be considered. In partial MPAs that include sustainable fisheries objectives, ISRAs can provide a strong foundation for delineating robust and effective zoning for well-designed no-take or multi-purpose areas that can confer shark conservation benefits. Further, ISRAs should be considered when designing fisheries and other management strategies, such as regulating gear use or prioritising improved enforcement in delineated areas.

5. Conclusions

For the global 30×30 target to be met, recurrent assessments of protected area extent, governance, and coverage of biodiversity are necessary [96]. There are large disparities in MPA extent and overlap with ISRAs across countries in the Central and South American Pacific region. These results hold important management implications and provide opportunities for decision-makers and managers to evaluate the effectiveness of their current area-based management approaches for the conservation of sharks. Important Shark and Ray Areas are a new tool in biodiversity conservation that can benefit shark populations and will prove essential in informing which areas should be prioritised in spatial planning. Critical to these efforts is the incorporation of research and monitoring components to ensure that the impact and recovery of species (especially those considered threatened) can be measured and evaluated.

While a critical element of conservation, protected areas alone will not solve the shark biodiversity crisis. To optimise biodiversity conservation outcomes, we suggest that these should be used in conjunction with similar spatial-based initiatives to identify critical areas and to design and/or support networks of MPAs in national and international waters while taking into account factors such as connectivity and socioeconomic considerations. Effective shark conservation will further require a multi-pronged approach to recognize sharks as wildlife and a component of biodiversity rather than simply a fishery resource. The implementation and monitoring of fisheries and trade management measures is essential in this regard. However, the delineation of ISRAs now provides an opportunity to ensure that the most important sites for sharks are properly designated as we move closer to implementing our goal to conserve 30 % of the planet by 2030.

CRediT authorship contribution statement

Théophile L Mouton: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Adriana Gonzalez-Pestana:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Christoph Rohner:** Writing – review & editing. **Ryan Charles:** Writing – review & editing, Data curation, Conceptualization. **Emiliano García-Rodríguez:** Writing – review & editing, Data curation, Conceptualization. **Peter Kyne:** Writing – review & editing, Data curation, Conceptualization. **Amanda Batlle-Morera:** Writing – review & editing, Data curation, Conceptualization. **Giuseppe Notarbartolo di Sciara:** Writing – review & editing, Data curation, Conceptualization. **Asia Armstrong:** Writing – review & editing. **Enzo Acuña:** Writing – review & editing, Resources, Data curation. **Joanna Alfaro-Shigueto:** Writing – review & editing, Resources, Data curation. **Randall Arauz:** Writing – review & editing, Resources, Data curation. **Cristopher Avalos-Castillo:** Writing – review & editing, Resources, Data curation. **Ely Augustinus:** Writing – review & editing, Resources, Data curation. **Sandra Bessudo:** Writing – review & editing, Resources, Data curation. **Enrique Barraza:** Writing – review & editing, Resources, Data curation. **Carlos Bustamante:** Writing – review & editing, Resources, Data curation. **Elpis Chávez:** Writing – review & editing, Resources, Data curation. **Eduardo Espinoza:** Writing – review & editing, Resources, Data curation. **Mario Espinoza:** Writing – review & editing, Resources, Data curation. **Ana Hacohen-Domené:** Writing – review & editing, Resources, Data curation. **Alex Hearn:** Writing – review & editing, Resources, Data curation. **Grettel Hernández Fernández:** Writing – review & editing, Resources, Data curation. **Felipe Galvan-Magana:** Writing – review & editing, Resources, Data curation. **José González-Leiva:** Writing – review & editing, Resources, Data curation. **James Ketchum:** Writing – review & editing, Resources, Data curation. **Felipe Ladino:** Writing – review & editing, Resources, Data curation. **Frida Lara Lizardi:** Writing – review & editing, Resources, Data curation. **Jorge Morales-Saldaña:** Writing – review & editing, Resources, Data curation. **Naiti Morales Serrano:** Writing – review & editing, Resources, Data curation. **Jeffry Madrigal-Mesén:** Writing – review & editing, Resources, Data curation. **Paola Mejía-Falla:** Writing – review & editing, Resources, Data curation. **Andrés Navia:** Writing – review & editing, Resources, Data curation. **Gabriela Ochoa:** Writing – review & editing, Resources, Data curation. **Marta Palacios:** Writing – review & editing, Resources, Data curation. **Cesar Peñaherrera-Palma:** Writing – review & editing, Resources, Data curation. **Francisco Polanco-**

Vasquez: Writing – review & editing, Resources, Data curation. **Yehudi Rodríguez-Arriatti:** Writing – review & editing, Resources, Data curation. **Luz Erandi Saldaña Ruiz:** Writing – review & editing, Resources, Data curation. **Oscar Sosa-Nishizaki:** Writing – review & editing, Resources, Data curation. **Javier Tovar-Ávila:** Writing – review & editing, Resources, Data curation. **Angel Vega:** Writing – review & editing, Resources, Data curation. **Ximena Velez-Zuazo:** Writing – review & editing, Resources, Conceptualization. **Melany Villate-Moreno:** Writing – review & editing, Resources, Data curation. **Ilena Zanella:** Writing – review & editing, Resources, Data curation. **Rima Jabado:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors confirm there are no competing interests.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106448.

Data availability

All ISRA data are available freely online. The remaining data will be available upon request. All code associated with this work will be uploaded onto GitHub upon acceptance of the manuscript

References

[1] R. Dirzo, H.S. Young, M. Galetti, G. Ceballos, N.J. Isaac, B. Collen, Defaunation in the Anthropocene, Science 345 (6195) (2014) 401–406.
[2] S.T. Turvey, J.J. Crees, Extinction in the Anthropocene, Curr. Biol. 29 (19) (2019) 982–986.
[3] B.S. Halpern, M. Frazier, J. Potapenko, K.S. Casey, K. Koenig, C. Longo, J. S. Lowndes, R.C. Rockwood, E.R. Selig, K.A. Selkoe, Spatial and temporal changes in cumulative human impacts on the world's ocean, Nat. Commun. 6 (1) (2015) 1–7.
[4] K.R. Jones, C.J. Klein, B.S. Halpern, O. Venter, H. Grantham, C.D. Kuempel, N. Shumway, A.M. Friedlander, H.P. Possingham, J.E. Watson, The location and protection status of Earth's diminishing marine wilderness, Curr. Biol. 28 (15) (2018) 2506–2512, e2503.
[5] D.J. McCauley, M.L. Pinsky, S.R. Palumbi, J.A. Estes, F.H. Joyce, R.R. Warner, Marine defaunation: Animal loss in the global ocean, Science 347 (6219) (2015) 1255641.
[6] L.R. Lemke, C.A. Simpfendorfer, Gillnet size selectivity of shark and ray species from Queensland, Australia, Fish. Manag. Ecol. (2023), https://doi.org/10.1111/fme.12620.
[7] D. Pauly, V. Christensen, J. Dalsgaard, R. Froese, F. Torres Jr, Fishing down marine food webs, Science 279 (5352) (1998) 860–863.
[8] N.K. Dulvy, N. Pacoureau, C.L. Rigby, R.A. Pollom, R.W. Jabado, D.A. Ebert, B. Finucci, C.M. Pollock, J. Cheok, D.H. Derrick, Overfishing drives over one-third of all sharks and rays toward a global extinction crisis, Curr. Biol. 31 (21) (2021) 4773–4787, e4778.
[9] Constance, J., Ebert, D.A., Fahmi, Finucci, B., Simeon, B. & Kyne, P.M. 2023. *Urolophus javanicus*. The IUCN Red List of Threatened Species 2023: e. T60095A229337053.
[10] S. Dedman, J.H. Moxley, Y.P. Papastamatiou, M. Braccini, J.E. Caselle, D. D. Chapman, J.E. Cinner, E.M. Dillon, N.K. Dulvy, R.E. Dunn, Ecological roles and importance of sharks in the Anthropocene Ocean, Science 385 (6708) (2024) adl2362.
[11] K.I. Flowers, M.R. Heithaus, Y.P. Papastamatiou, Buried in the sand: Uncovering the ecological roles and importance of rays, Fish Fish 22 (1) (2021) 105–127.
[12] J.K. Baum, B. Worm, Cascading top-down effects of oceanic predators, J. Anim. Ecol. 78 (2009) 699–714.
[13] M.R. Heithaus, A. Frid, A.J. Wirsing, B. Worm, Predicting ecological consequences of marine top predator declines, Trends Ecol. Evol. 23 (2008) 202–210.
[14] J.R. Allan, H.P. Possingham, S.C. Atkinson, A. Waldron, M. Di Marco, S. H. Butchart, V.M. Adams, W.D. Kissling, T. Worsdell, C. Sandbrook, The minimum land area requiring conservation attention to safeguard biodiversity, Science 376 (6597) (2022) 1094–1101.
[15] R.T. Corlett, Safeguarding our future by protecting biodiversity, Plant Divers. 42 (4) (2020) 221–228.
[16] J.E.M. Watson, N. Dudley, D.B. Segan, M. Hockings, The performance and potential of protected areas, Nature 515 (2014) 67–73.
[17] K. Grorud-Colvert, J. Sullivan-Stack, C. Roberts, V. Constant, B.H.E. Costa, E. P. Pike, N. Kingston, D. Laffoley, E. Sala, J. Claudet, A.M. Friedlander, D.A. Gill, S. E. Lester, J.C. Day, E.J. Gonçalves, G.N. Ahmadia, M. Rand, A. Villagomez, N. C. Ban, J. Lubchenco, The MPA guide: A framework to achieve global goals for the ocean. Science 373 (6560) (2021) eabf0861, https://doi.org/10.1126/science.abf0861.
[18] Z.M. Topor, D.B. Rasher, J.E. Duffy, S.J. Brandl, Marine protected areas enhance coral reef functioning by promoting fish biodiversity, Conserv. Lett. 12 (4) (2019) e12638.
[19] P.S. Albano, C. Fallows, M. Fallows, O. Schuitema, A.T. Bernard, O. Sedgwick, N. Hammerschlag, Successful parks for sharks: No-take marine reserve provides conservation benefits to endemic and threatened sharks off South Africa, Biol. Conserv. 261 (2021) 109302.
[20] M.E. Bond, J. Valentin-Albanese, E.A. Babcock, D. Abercrombie, N.F. Lamb, A. Miranda, E.K. Pikitch, D.D. Chapman, Abundance and size structure of a reef shark population within a marine reserve has remained stable for more than a decade, Mar. Ecol. Prog. Ser. 576 (2017) 1–10.
[21] A.P. Klimley, R. Arauz, S. Bessudo, E.J. Chávez, N. Chinacalle, E. Espinoza, J. Green, A.R. Hearn, M.E. Hoyos-Padilla, E. Nalesso, Studies of the movement ecology of sharks justify the existence and expansion of marine protected areas in the Eastern Pacific Ocean, Environ. Biol. Fishes (2022) 1–21.
[22] C.W. Speed, M. Cappo, M.G. Meekan, Evidence for rapid recovery of shark populations within a coral reef marine protected area, Biol. Conserv. 220 (2018) 308–319.
[23] R.G. Dwyer, N.C. Krueck, V. Udyawer, M.R. Heupel, D. Chapman, H.L. Pratt, R. Garla, C.A. Simpfendorfer, Individual and population benefits of marine reserves for reef sharks, Curr. Biol. 30 (3) (2020) 480–489, e485.
[24] C.A. Birkmanis, J.C. Partridge, L.W. Simmons, M.R. Heupel, A.M. Sequeira, Shark conservation hindered by lack of habitat protection, Glob. Ecol. Conserv. 21 (2020) e00862.
[25] A. Chin, F.J. Molloy, D. Cameron, J.C. Day, J. Cramp, K.L. Gerhardt, M.R. Heupel, M. Read, C.A. Simpfendorfer, Conceptual frameworks and key questions for assessing the contribution of marine protected areas to shark and ray conservation, Conserv. Biol. 37 (1) (2023) e13917.
[26] R. Daly, M.J. Smale, S. Singh, D. Anders, M. Shivji, C.A.K. Daly, J.S. Lea, L.L. Sousa, B.M. Wetherbee, R. Fitzpatrick, Refuges and risks: Evaluating the benefits of an expanded MPA network for mobile apex predators, Divers. Distrib. 24 (9) (2018) 1217–1230.
[27] M.R. Heupel, C.A. Simpfendorfer, M. Espinoza, A.F. Smoothey, A. Tobin, V. Peddemors, Conservation challenges of sharks with continental scale migrations, Front. Mar. Sci. 2 (2015) 12.
[28] J. Claudet, C.M. Brooks, R. Blasiak, Making protected areas in the high seas count, Science 380 (6643) (2023) 353–354.
[29] D. Pelletier, Assessing the Effectiveness of Coastal Marine Protected Area Management: Four Learned Lessons for Science Uptake and Upscaling, 2020 |, Front. Mar. Sci. 7 (2020), https://doi.org/10.3389/fmars.2020.545930.
[30] H. Carr, M. Abas, L. Boutahar, O.N. Caretti, W.Y. Chan, A.S. Chapman, S.N. de Mendonça, A. Engleman, F. Ferrario, K.R. Simmons, The Aichi Biodiversity Targets: achievements for marine conservation and priorities beyond 2020, PeerJ 8 (2020) e9743.
[31] CBD) 2022. Kunming-Montreal Global biodiversity framework. Fifteenth meeting. Montreal, Canada. ⟨https://www.cbd.int/gbf/⟩.
[32] A. Arneth, P. Leadley, J. Claudet, M. Coll, C. Rondinini, M.D. Rounsevell, Y.J. Shin, P. Alexander, R. Fuchs, Making protected areas effective for biodiversity, climate and food, Glob. Change Biol. (2023).
[33] Y.J. Shin, G.F. Midgley, E.R. Archer, A. Arneth, D.K. Barnes, L. Chan, S. Hashimoto, O. Hoegh-Guldberg, G. Insarov, P. Leadley, Actions to halt biodiversity loss generally benefit the climate, Glob. Change Biol. 28 (9) (2022) 2846–2874.
[34] C. Lopazanski, B. Foshay, J.L. Couture, D. Wagner, L. Hannah, E. Pidgeon, D. Bradley, Principles for climate resilience are prevalent in marine protected area management plans, Conserv. Lett. (2023) e12972.
[35] V. Capmourteres, M. Anand, Conservation value: a review of the concept and its quantification, Ecosphere 7 (10) (2016) e01476.
[36] C.A. Hyde, G. Notarbartolo di Sciara, L. Sorrentino, C. Boyd, B. Finucci, S. L. Fowler, P.M. Kyne, G. Leurs, C.A. Simpfendorfer, M.J. Tetley, Putting sharks on

the map: A global standard for improving shark area-based conservation, Front. Mar. Sci. (2022) 1660.
[37] P.M. Kyne, G.N. di Sciara, A.B. Morera, R. Charles, E.G. Rodríguez, D. Fernando, A. G. Pestana, M. Priest, R.W. Jabado, Important Shark and Ray Areas: a new tool to optimize spatial planning for sharks, Oryx 57 (2) (2023) 146–147.
[38] J.T. Pennington, K.L. Mahoney, V.S. Kuwahara, D.D. Kolber, R. Calienes, F. P. Chavez, "Primary production in the eastern tropical Pacific: A review.", Prog. Oceanogr. 69 (2-4) (2006) 285–317.
[39] IUCN SSC Shark Specialist Group. 2022a. Inventory of Knowledge: Geographic Ranges of Sharks, Rays, and Chimaeras in the Central and South American Pacific, Important Shark and Ray Areas (ISRA) Region 12. August 2022. Dubai: IUCN SSC Shark Specialist Group.
[40] Jabado, R.W., García-Rodríguez E., Kyne P.M., Charles, R., Gonzalez-Pestana A., Priest, M., Battle-Morera, A., Notarbartolo di Sciara G. (2023). Central and South American Pacific: A regional compendium of Important Shark and Ray Areas. IUCN SSC Shark Specialist Group, Dubai, UAE.
[41] IUCN SSC Shark Specialist Group. 2022b. Important Shark and Ray Area (ISRA): Guidance on criteria application. Version 1, August 2022. Dubai: IUCN SSC Shark Specialist Group.
[42] J. Day, N. Dudley, M. Hockings, G. Holmes, D. Laffoley, S. Stolton, S. Wells, Guidelines for applying the IUCN Protected Area Management categories to marine protected areas, Wenzel (2019).
[43] M.S. Farhadinia, A. Waldron, Ż. Kaszta, E. Eid, A. Hughes, H. Ambarlı, H. Al-Hikmani, B. Buuveibaatar, M.A. Gritsina, I. Haidir, Current trends suggest most Asian countries are unlikely to meet future biodiversity targets on protected areas. Communications, Biology 5 (1) (2022) 1221.
[44] E. Pebesma, Simple Features for R: Standardized Support for Spatial Vector Data, R. J. 10 (1) (2018) 439–446, https://doi.org/10.32614/RJ-2018-009.
[45] Granizo, T., M. Molina, E. Secaira, B. Herrera, S. Benítez, O. Maldonado, M. Libby, P. Arroyo, S. Ísola and M. Castro (2006). Manual de Planificación para la Conservación de Áreas. PCA. Quito. TNC y USAID.
[46] M.J. Costello, B. Ballantine, Biodiversity conservation should focus on no-take Marine Reserves: 94% of Marine Protected Areas allow fishing, Trends Ecol. Evol. 30 (9) (2015) 507–509.
[47] L.N. Davidson, N.K. Dulvy, Global marine protected areas to prevent extinctions, Nat. Ecol. Evol. 1 (2) (2017) 0040.
[48] A.S. Rodrigues, S.J. Andelman, M.I. Bakarr, L. Boitani, T.M. Brooks, R.M. Cowling, L.D. Fishpool, G.A. Da Fonseca, K.J. Gaston, M. Hoffmann, Effectiveness of the global protected area network in representing species diversity, Nature 428 (6983) (2004) 640–643.
[49] C. Pimiento, C. Albouy, D. Silvestro, T.L. Mouton, L. Velez, D. Mouillot, A.B. Judah, J.N. Griffin, F. Leprieur, Functional diversity of sharks and rays is highly vulnerable and supported by unique species and locations worldwide. Nature, Communications 14 (1) (2023) 7691.
[50] G.J. Edgar, R.D. Stuart-Smith, T.J. Willis, S. Kininmonth, S.C. Baker, S. Banks, N. S. Barrett, M.A. Becerro, A.T. Bernard, J. Berkhout, Global conservation outcomes depend on marine protected areas with five key features, Nature 506 (7487) (2014) 216–220.
[51] S.M. O'Regan, S.K. Archer, S.K. Friesen, K.L. Hunter, A global assessment of climate change adaptation in marine protected area management plans, Front. Mar. Sci. 8 (2021) 711085.
[52] D. Bates, M. Maechler, B. Bolker, S. Walker, Fitting linear mixed-effects models using lme4, J. Stat. Softw. 67 (1) (2015) 1–48, https://doi.org/10.18637/jss.v067.i01.
[53] C.M. Hurvich, C.L. Tsai, Regression and time series model selection in small samples, Biometrika (1989) 297–307.
[54] Lüdecke, et al., performance: An R Package for Assessment, Comparison and Testing of Statistical Models, J. Open Source Softw. 6 (60) (2021) 3139, https://doi.org/10.21105/joss.03139.
[55] Lüdecke D. (2023). _sjPlot: Data Visualization for Statistics in Social Science_. R package version 2.8.14, <⟨https://CRAN.R-project.org/package=sjPlot⟩>.
[56] S. Dray, A.B. Dufour, The ade4 package: implementing the duality diagram for ecologists, J. Stat. Softw. 22 (2007) 1–20.
[57] M. Charrad, N. Ghazzali, V. Boiteau, A. Niknafs, NbClust: an R package for determining the relevant number of clusters in a data set, J. Stat. Softw. 61 (2014) 1–36.
[58] M.E. Bond, E.A. Babcock, E.K. Pikitch, D.L. Abercrombie, N.F. Lamb, D. D. Chapman, Reef sharks exhibit site-fidelity and higher relative abundance in marine reserves on the Mesoamerican Barrier Reef, PloS One 7 (3) (2012) e32983.
[59] V. Relano, D. Pauly, The Paper Park Index': Evaluating Marine Protected Area Effectiveness Through A Global Study of Stakeholder Perspectives, Mar. Policy 151 (2023) 105571.
[60] S.M. Maxwell, K.M. Gjerde, M.G. Conners, L.B. Crowder, Mobile protected areas for biodiversity on the high seas, Science 367 (6475) (2020) 252–254.
[61] M. Fernández, M. Rodríguez-Ruiz, S. Gelcich, L. Hiriart-Bertrand, J.C. Castilla, Advances and challenges in marine conservation in Chile: A regional and global comparison, Aquat. Conserv.: Mar. Freshw. Ecosyst. (2021) 1–12, https://doi.org/10.1002/aqc.3570.
[62] K. Gjerde, L. Reeve, H. Harden-Davies, J. Ardron, R. Dolan, C. Durussel, S. Earle, J. A. Jimenez, P. Kalas, D. Laffoley, N. Oral, Protecting Earth's last conservation frontier: scientific, management and legal priorities for MPAs beyond national boundaries, Aquat. Conserv.: Mar. Freshw. Ecosyst. (2016) https://doi.org/10.1002/aqc.2646.
[63] G. Notarbartolo di Sciara, T. Agardy, D. Hyrenbach, T. Scovazzi, P. Van Klaveren, The Pelagos Sanctuary for Mediterranean Marine Mammals, Aquat. Conserv.: Mar. Freshw. Ecosyst. 18 (2008) 367–391.
[64] S.R. Enright, R. Meneses-Orellana, I. Keith, The Eastern Tropical Pacific Marine Corridor (CMAR): The emergence of a voluntary regional cooperation mechanism for the conservation and sustainable use of marine biodiversity within a fragmented regional ocean governance landscape, Front. Mar. Sci. 569 (2021).
[65] N.A. Morales, M. Heidemeyer, R. Bauer, S. Hernández, E. Acuña, S.J. van Gennip, C.F. Gaymer, Residential movements of top predators in Chile's most isolated marine protected area: Implications for the conservation of the Galapagos shark, *Carcharhinus galapagensis*, and the yellowtail amberjack, *Seriola lalandi*, Aquat. Conserv.: Mar. Freshw. Ecosyst. 31 (2) (2021) 340–355.
[66] G.A. Castellanos-Galindo, P. Herron, A.F. Navia, H. Booth, Shark conservation and blanket bans in the eastern Pacific Ocean, Conserv. Sci. Pract. 3 (2021) e428, https://doi.org/10.1111/csp2.428.
[67] D.H. Guzmán, R.L. Mier, A. Vergara, C.B. Milanes, Marine protected areas in Colombia: A historical review of legal marine protection since the late 1960's to 2023, Mar. Policy 155 (2023) 105726.
[68] V. Puentes, P.A. Mejía-Falla, J.G. Ramírez, L.M. Manjarrés-Martínez, J. M. Rodriguez-Barón, L.A. Zapata, J. Tavera, F. Gómez-Delgado, C.G. Barreto, E. Zambrano, A.A. Villa, A.F. Navia, Analysis of sharks and marine batoids conservation measures in Colombia: implications for their populations and stakeholders, Mar. Policy 145 (2022), https://doi.org/10.1016/j.marpol.2022.105264.
[69] Arias, A., Pressey, R.L., Jones, R.E., Álvarez-Romero, J. and Cinner, J.E. (2014). Optimizando la coacción y el cumplimiento en áreas marinas protegidas oceánicas: el caso del Parque Nacional Isla del Coco, Costa Rica.
[70] A. Arias, R.L. Pressey, Combatting illegal, unreported, and unregulated fishing with information: a case of probable illegal fishing in the tropical Eastern Pacific, Front. Mar. Sci. 3 (2016) 13.
[71] B.J. Bergseth, A. Arias, M.L. Barnes, I. Caldwell, A. Datta, S. Gelcich, S.H. Ham, J. D. Lau, C. Ruano-Chamorro, P. Smallhorn-West, Closing the compliance gap in marine protected areas with human behavioural sciences, Fish Fish (2023).
[72] L.A. Carr, A.C. Stier, K. Fietz, I. Montero, A.J. Gallagher, J.F. Bruno, Illegal shark fishing in the Galápagos Marine Reserve, Mar. Policy 39 (2013) 317–321.
[73] Cristina González-Andrés, et al., Illegal fishing in Isla del Coco National Park: Spatial-temporal distribution and the economic trade-offs, Mar. Policy 119 (2020) 104023.
[74] S. Sarker, M.J. Rahman, M.M. Rahman, M. Akter, M.S. Rahman, M.A. Wahab, MPA zoning integrating socio-ecological data in the South East coast of Bangladesh, Mar. Policy 133 (2021) 104736.
[75] P.F.M. Lopes, S. Pacheco, M. Clauzet, R.A.M. Silvano, A. Begossi, Fisheries, tourism, and marine protected areas: conflicting or synergistic interactions? Ecosyst. Serv. 16 (2015) 333–340.
[76] T. MacKeracher, A. Diedrich, C.A. Simpfendorfer, Sharks, rays and marine protected areas: A critical evaluation of current perspectives, Fish Fish 20 (2) (2019) 255–267.
[77] B.S. Halpern, S.D. Gaines, R.R. Warner, Confounding effects of the export of production and the displacement of fishing effort from marine reserves, Ecol. Appl. 14 (4) (2004) 1248–1256.
[78] P. Guidetti, M. Milazzo, S. Bussotti, A. Molinari, M. Murenu, A. Pais, N. Spanò, R. Balzano, T. Agardy, F. Boero, G. Carrada, R. Cattaneo-Vietti, A. Cau, R. Chemello, S. Greco, A. Manganaro, G. Notarbartolo di Sciara, G.F. Russo, L. Tunesi, Italian marine protected area effectiveness: does enforcement matter? Biol. Conserv. 141 (2008) 699–709, doi:10.1016/j.biocon.2007.12.013.
[79] B.L. Gilby, A.D. Olds, R.M. Connolly, N.A. Yabsley, P.S. Maxwell, I.R. Tibbetts, D. S. Schoeman, T.A. Schlacher, Umbrellas can work under water: Using threatened species as indicator and management surrogates can improve coastal conservation, Estuar., Coast. Shelf Sci. 199 (2017) 132–140.
[80] H. Natsukawa, F. Sergio, Top predators as biodiversity indicators: A meta-analysis, Ecol. Lett. 25 (9) (2022) 2062–2075.
[81] G.J. Osgood, M.E. McCord, J.K. Baum, Chondrichthyans as an umbrella species-complex for conserving South African biodiversity, Afr. J. Mar. Sci. 42 (1) (2020) 81–93.
[82] E. Fleishman, R.B. Blair, D.D. Murphy, Empirical validation of a method for umbrella species selection, Ecol. Appl. 11 (5) (2001) 1489–1501.
[83] T.M. Caro, S. Girling, Conservation by Proxy: Indicator, Umbrella, Keystone, Flagship, and Other Surrogate Species, Island Press, Washington, DC, 2010.
[84] F.M. Pouzols, A. Moilanen, A method for building corridors in spatial conservation prioritization, Landsc. Ecol. 29 (2014) 789e801.
[85] A.M. Cisneros-Montemayor, E.E. Becerril-García, O. Berdeja-Zavala, A. Ayala-Bocos, Shark ecotourism in Mexico: Scientific research, conservation, and contribution to a Blue Economy, in: Advances in Marine Biology, 85, Academic Press, 2020, pp. 71–92.
[86] A. Gonzalez-Pestana, J. Alfaro-Shigueto, J.C. Mangel, A review of high trophic predator-prey relationships in the pelagic Northern Humboldt system, with a focus on anchovetas, Fish. Res. 253 (2022) 106386.
[87] J.T. Ketchum, M. Hoyos-Padilla, A. Aldana-Moreno, K. Ayres, F. Galván-Magaña, A. Hearn, F. Lara-Lizardi, G. Muntaner-López, M. Grau, A. Trejo-Ramírez, D. A. Whitehead, Shark movement patterns in the Mexican Pacific: a conservation and management perspective. In, Adv. Mar. Biol. 85 (1) (2020) 1–37.
[88] J. Geldmann, L. Coad, M. Barnes, I.D. Craigie, M. Hockings, K. Knights, F. Leverington, I.C. Cuadros, C. Zamora, S. Woodley, N.D. Burgess, Changes in protected area management effectiveness over time: A global analysis, Biol. Conserv. 191 (2015) 692–699.
[89] O. Venter, A. Magrach, N. Outram, C.J. Klein, H.P. Possingham, M. Di Marco, J. E. Watson, Bias in protected-area location and its effects on long-term aspirations of biodiversity conventions, Conserv. Biol. 32 (1) (2018) 127–134.

[90] S. Chan, S. Bauer, M.M. Betsill, F. Biermann, I. Boran, P. Bridgewater, H. Bulkeley, M.M. Bustamente, A. Deprez, F. Dodds, The global biodiversity framework needs a robust action agenda, Nat. Ecol. Evol. 7 (2) (2023) 172–173.

[91] M.A. MacNeil, D.D. Chapman, M. Heupel, C.A. Simpfendorfer, M. Heithaus, M. Meekan, E. Harvey, J. Goetze, J. Kiszka, M.E. Bond, Global status and conservation potential of reef sharks, Nature 583 (7818) (2020) 801–806.

[92] G. Eken, L. Bennun, T.M. Brooks, W. Darwall, L.D. Fishpool, M. Foster, D. Knox, P. Langhammer, P. Matiku, E. Radford, Key Biodiversity Areas as site conservation targets, BioScience 54 (2004) 1110–1118.

[93] CBD) (2008) Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Ninth Meeting UNEP/CBD/COP/DEC/IX/20, p. 12.

[94] G. Notarbartolo di Sciara, E. Hoyt, R. Reeves, J. Ardron, H. Marsh, D. Vongraven, B. Barr, Place-based approaches to marine mammal conservation, Aquat. Conserv.: Mar. Freshw. Ecosyst. 26 (2016) 85–100.

[95] M.J. Tetley, G.T. Braulik, C. Lanfredi, G. Minton, S. Panigada, E. Politi, M. Zanardelli, G. Notarbartolo di Sciara, E. Hoyt, The Important Marine Mammal Area network: a tool for systematic spatial planning in response to the marine mammal habitat conservation crisis, Front. Mar. Sci. 9 (2022) 841789, https://doi.org/10.3389/fmars.2022.841789.

[96] S.L. Maxwell, V. Cazalis, N. Dudley, M. Hoffmann, A.S. Rodrigues, S. Stolton, P. Visconti, S. Woodley, N. Kingston, E. Lewis, Area-based conservation in the twenty-first century, Nature 586 (7828) (2020) 217–227.