Integrating Important Shark and Ray Areas into Marine Protected Area Network Design in the Australian Exclusive Economic Zone

Helena Verbruggen

Prof. Dr. Tom Van der Stocken - Vrije Universiteit Brussel

Prof. Dr. Anthony J. Richardson - University of Queensland



MSc thesis submitted in 2026 as partial fulfilment of the requirements for the degrees of:

Master en Biologie des Organismes et Écologie, Finalité EMJMD in Tropical Biodiversity and Ecosystems, ULB

Master in Biology, Specialisation EMJMD in Tropical Biodiversity and Ecosystems, VUB

Master de Sciences, Technologies, Santé, Mention Biodiversité, Écologie et Évolution, Parcours EMJMD en Biodiversité et Écosystèmes Tropicaux, UdG

Université de Guyane TROPIMUNDO ULB VUB UQ

Suggested Citation:

Verbruggen, H. (2026). Integrating Important Shark and Ray Areas into Marine Protected Area network design in the Australian Exclusive Economic Zone. Msc. Thesis Erasmus Mundus Joint Master Degree in Tropical Biodiversity and Ecosystems, Université Libre de Bruxelles – ULB (Belgium), Vrije Universiteit Brussel – VUB (Belgium), Université de Guyane – UdG (French Guiana). 49 + vii pp

Contact Details:

Helena Verbruggen
E-mail: helena.verbruggen@telenet.be

Supervisors:

Prof. Dr. Tom Van der Stocken
E-mail: Tom.Van.Der.Stocken@vub.be

Department of Biology - Vrije Universiteit Brussel (VUB), Brussels, Belgium
Ecology, Evolution & Genetics Research Group (bDIV)
Website: https://bdiv.research.vub.be

NASA-Caltech Jet Propulsion Laboratory, California Institute of Technology, California, United States

Prof. Dr. Anthony Richardson
E-mail: a.richardson1@uq.edu.au

School of Mathematics & Physics - The University of Queensland (UQ), Brisbane, Australia
Unit: Mathematical Marine Ecology Lab
Website: https://mathmarecol.github.io

Commonwealth Science and Industrial Research Organisation (CSIRO) Environment, Brisbane, Australia

Word Count: 4334 (core) + 1985 (methodology)

Number of References: 87

Frontpage Credit:
Stegostoma tigrium (Zebra Shark) by Emilie Ledwidge – Ocean Image Bank

PERSONAL ACKNOWLEDGEMENTS

The past two years have been an unforgettable experience. My younger self would never have imagined that this would become my future. I have had the opportunity to live in beautiful places, meet wonderful people, and create memories that I will carry with me for the rest of my life. Along the way, I have also grown both personally and professionally. Completing this thesis has been the perfect way to conclude this beautiful journey, and I am deeply grateful to everyone who helped make it possible.

First, I would like to thank my supervisors, Tom and Anthony, for guiding and advising me throughout the entire process. I have learned so much from both of you, and this project would not have been possible without your support. Tom, thank you for showing me that it is possible to continue believing in ambitious and idealistic goals. Anthony, thank you for introducing me to the world of spatial planning and for making my time in Australia possible. It has been a truly unforgettable experience that helped me better understand what I hope to do in the future. I would also like to give special thanks to Chris, whose expertise in shark and ray conservation was invaluable throughout the project.

I am also very grateful to everyone in the lab. Daniel, thank you for helping me set up my project. Angela, thank you for opening your doors to me. Jaime, thank you for always taking the time to listen and give guidance whenever I needed it. Tin and Alvise, thank you for answering my questions whenever I felt uncertain or lost. Jase, thank you for your help with the AquaX data.

I would also like to thank everyone in the Steele Building who welcomed me with open arms. Whether we were grabbing coffee, playing badminton, discussing how we would change the world, or going frogging on campus, those moments provided the best possible breaks from thesis work. Etienne, thank you for being my “fellow student-in-crime” and for always being willing to explore Brisbane together.

I am deeply grateful to the TROPIMUNDO Board for making this experience possible. I would also like to thank the Tropifam, who played such an important role in making these two years so memorable.

Finally, I would like to thank my boyfriend, Alex, as well as my family and friends, for their constant support, encouragement, and for always helping me recharge whenever I needed it.

TABLE OF CONTENTS

ABSTRACT ____ **IV**

LIST OF ABBREVIATIONS ____ **VII**

INTRODUCTION ____ **- 1 -**

METHODOLOGY ____ **- 3 -**

1 Study Area ____ **- 3 -**

2 Spatial Datasets ____ **- 3 -**
2.1 Marine Protected Areas ____ - 3 -
2.2 Important Shark and Ray Areas ____ - 4 -
2.3 Species Distributions ____ - 4 -

3 Current Protection Status ____ **- 5 -**

4 Systemic Conservation Prioritization ____ **- 5 -**
4.1 Conservation Features ____ - 5 -
4.2 Conservation Targets ____ - 5 -
4.3 Conservation Problem Formulation ____ - 6 -
4.4 Evaluation Importance of Planning Units ____ - 7 -

RESULTS ____ **- 8 -**

1 Current Protection of Chondrichthyans and ISRA Coverage ____ **- 8 -**

2 Conservation Outcomes Under Australian 30×30 Commitments ____ **- 12 -**
2.1 Conservation Prioritization Performance ____ - 12 -
2.2 Representation of Chondrichthyan Species in Prioritizations ____ - 13 -
2.3 Representation of No-Movement Important Shark & Ray Areas ____ - 15 -
2.4 Distribution of Irreplaceable Planning Units ____ - 16 -

DISCUSSION ____ **- 18 -**

1 MPA Coverage Masks Protection Gaps ____ **- 18 -**

2 Existing MPA Boundaries Limit 30×30 Outcomes ____ **- 19 -**

3 ISRAs Can Guide Targeted Action ____ **- 20 -**

4 Conservation Contributions Are Unevenly Distributed ____ **- 20 -**

5 Limitations and Future Directions ____ **- 21 -**

REFERENCES ____ **- 23 -**

SUPPLEMENTARY ____ **- 32 -**

ABSTRACT

Marine Protected Areas (MPAs) are expanding under the global goal to protect 30% of the ocean by 2030. However, conserving biodiversity depends not only on how much ocean is protected, but also on whether protection covers where vulnerable species and important habitats occur. Sharks, rays, and chimaeras (chondrichthyans) are among the most threatened marine vertebrates, primarily due to fishing. This study assessed how well Australia's no-take MPAs, where fishing is prohibited, protect chondrichthyan distributions and Important Shark and Ray Areas (ISRAs). ISRAs identify habitats used for reproduction, feeding, resting, and movement. We also compared two spatial planning scenarios to increase no-take protection to 30% of Australian waters: one strengthened protection within existing MPAs, while the other also allowed new no-take areas outside current boundaries. Despite Australia's extensive MPA network, existing no-take areas overlapped poorly with chondrichthyan biodiversity and ISRAs. Species richness was highest in areas where fishing was permitted and outside MPAs. Strengthening protection within existing MPAs improved species representation and ISRA coverage but left many conservation targets unmet. Allowing new no-take areas outside current MPA boundaries more than doubled the number of targets achieved and reduced average target shortfall from 18.9±29.8% to 3.4±6.4%. Irreplaceable areas were concentrated on the continental shelf and slope, where species richness and ISRA coverage were highest, whereas most existing no-take MPAs occurred in the deep sea. These findings show that area-based protection targets alone are insufficient. Combining species distributions with ecologically important habitats can help design more representative and strategically located protection for chondrichthyans.

Keywords: biodiversity conservation; chondrichthyans; Important Shark and Ray Areas (ISRA); Marine Protected Areas; systematic conservation planning; spatial prioritization

RÉSUMÉ

Les aires marines protégées (AMP) se développent dans le cadre de l'objectif mondial visant à protéger 30% des océans d'ici 2030. La conservation de la biodiversité dépend toutefois non seulement de la superficie protégée, mais aussi de la capacité des AMP à couvrir les zones où se trouvent des espèces vulnérables et des habitats importants. Les requins, les raies et les chimères, regroupés sous le terme de chondrichthyens, comptent parmi les vertébrés marins les plus menacés, principalement en raison de la pêche. Cette étude a évalué dans quelle mesure les AMP australiennes sans prélèvement, où la pêche est interdite, protègent la répartition des chondrichthyens et les Important Shark and Ray Areas (ISRA). Les ISRA correspondent à des sites essentiels aux chondrichthyens, notamment pour la reproduction, l'alimentation, le repos et les déplacements. Deux scénarios de planification spatiale ont également été comparés afin d'évaluer comment étendre la protection sans prélèvement à 30% des eaux australiennes. Le premier renforcait la protection au sein des AMP existantes, tandis que le second permettait également de sélectionner de nouvelles zones sans prélèvement au-delà de leurs limites actuelles. Malgré l'étendue du réseau d'AMP, les zones sans prélèvement correspondaient peu à la répartition des chondrichthyens et des ISRA. La richesse spécifique était la plus élevée dans les zones où la pêche était autorisée et en dehors du réseau d'AMP. Le renforcement de la protection au sein des AMP existantes améliorait la représentation des espèces et la couverture des ISRA, mais de nombreux objectifs de conservation restaient néanmoins inatteints. Autoriser la sélection de nouvelles zones sans prélèvement au-delà des limites actuelles des AMP a plus que doublé le nombre d'objectifs atteints et réduit le déficit moyen par rapport aux objectifs de 18,9 ± 29,8% à 3,4 ± 6,4%. Les zones à forte irremplaçabilité se concentraient principalement sur le plateau et le talus continentaux, où la richesse spécifique et la couverture des ISRA étaient les plus élevées. À l'inverse, la majorité des zones existantes sans prélèvement se situait dans les eaux profondes. Ces résultats montrent que les objectifs de superficie ne suffisent pas à garantir une conservation efficace. Combiner les données de répartition des espèces avec les habitats écologiquement importants peut contribuer à concevoir une protection plus représentative et stratégiquement située pour les chondrichthyens.

SAMENVATTING

Mariene beschermde gebieden (MPA's) groeien door de wereldwijde doelstelling om tegen 2030 30% van de oceaan te beschermen. Biodiversiteitsconservatie hangt echter niet alleen af van de totale beschermde oppervlakte, maar ook van de mate waarin zij kwetsbare soorten en belangrijke leefgebieden omvatten. Haaien, roggen en draakvissen – samen de kraakbeenvissen – behoren tot de meest bedreigde groepen mariene gewervelden, voornamelijk door visserijdruk. Deze studie onderzocht hoe doeltreffend Australische *no-take*-MPA's – waar visserij verboden is – de verspreiding van kraakbeenvissen en Important Shark and Ray Areas (ISRA's) beschermen. ISRA's zijn belangrijke gebieden voor onder meer voortplanting, foerageren, rust en verplaatsing. Daarnaast werden twee ruimtelijke planningsscenario's vergeleken waarin *no-take*-bescherming werd uitgebreid tot 30% van de Australische wateren. Het eerste scenario versterkte de bescherming binnen bestaande MPAs, terwijl het tweede ook nieuwe *no-take*gebieden buiten de huidige MPA-grenzen toeliet. Ondanks het uitgebreide Australische MPA-netwerk overlapten bestaande *no-take*gebieden slechts beperkt met de verspreiding van kraakbeenvissen en ISRAs. De soortenrijkdom was het hoogst in gebieden waar visserij was toegestaan en buiten MPA's. Hogere bescherming binnen bestaande MPA's verbeterde de vertegenwoordiging van soorten en ISRA's, maar veel conservatiedoelstellingen bleven onbereikt. Bescherming buiten bestaande MPA's verdubbelde het aantal behaalde doelstellingen en verlaagde het gemiddelde tekort van 18,9 ± 29,8% naar 3,4 ± 6,4%. Onvervangbare gebieden concentreerden zich op het continentale plat en de continentale helling, waar de soortenrijkdom en ISRA-dekking het hoogst waren. Het grootste deel van de bestaande *no-take*-gebieden lag daarentegen in de diepzee. De resultaten tonen dat oppervlaktedoelstellingen alleen niet volstaan. Door verspreidingsgegevens te combineren met ecologisch belangrijke leefgebieden, kunnen kraakbeenvissen representatiever en strategischer beschermd worden.

LIST OF ABBREVIATIONS

CR	Critically Endangered
DD	Data Deficient
EEZ	Exclusive Economic Zone
EN	Endangered
ISRA	Important Shark and Ray Area
IUCN	International Union for Conservation of Nature
LC	Least Concern
MPA	Marine Protected Area
NT	Near Threatened
PU	Planning Unit
VU	Vulnerable
WDPA	World Database on Protected Areas

INTRODUCTION

Biodiversity underpins the functioning of ecosystems and provides essential ecological, social, and economic goods and services (CBD, 2022; WHO & CBD, 2015). Marine ecosystems and biodiversity are facing increasing cumulative human pressures, which are expected to intensify (Halpern *et al.*, 2019; Jouffray *et al.*, 2020). Sharks, rays, and chimaeras (collectively chondrichthyans) are the most threatened group of marine vertebrates (IUCN Red List, 2026), with a reduction of global abundance by half since 1970 (Dulvy *et al.*, 2024). Approximately 38% of assessed species are threatened with extinction, primarily because of targeted fishing and incidental bycatch (Dulvy *et al.*,2021). Their slow growth, late maturity, and low reproductive output make them particularly vulnerable to overexploitation and limit their capacity to recover from population declines (Giménez *et al.*, 2020). As apex and mesopredators, they play key ecosystem roles through top-down effects on the abundance, distribution, and behavior of smaller prey species (Dedman *et al.*, 2024; Flowers *et al.*, 2021). Population declines may therefore alter food-web interactions and ecosystem functioning, making their conservation important both for preventing extinctions and maintaining ecosystem resilience (Baum & Worm, 2009; Heithaus *et al.*, 2008).

In response to the accelerating biodiversity loss, the Kunming-Montreal Global Biodiversity Framework commits 196 signatory nations to protect 30% of their marine waters by 2030 (the '30 by 30' agreement) and reduce extinctions by 90% by 2025 (CBD, 2022). Marine Protected Areas (MPAs) are an important tool for achieving these objectives, but their effectiveness depends on their location, regulations, and management (Pike *et al.*, 2024; Watson *et al.*, 2023). Although approximately 10% of the global ocean is currently designated within MPAs, only about 3% is assessed as fully or highly protected (MPAtlas, 2026). Fully protected or no-take areas prohibit extractive activities and generally produce stronger conservation outcomes than MPAs in which substantial fishing or damaging activities remain permitted (Sala & Giakoumi, 2018; Turnbull *et al.*, 2021). Without appropriate design and effective management, MPAs risk becoming ineffective "paper parks" that are politically easy to establish but provide little protection (Devillers *et al.*, 2015; Relano & Pauly, 2023).

This effectiveness challenge is particularly relevant for chondrichthyans. Due to their often wide-ranging distributions and movement ecology, chondrichthyans have been largely overlooked in the designation of MPAs globally (Davidson & Dulvy, 2017; Giménez *et al.*, 2020; Pimiento *et al.*, 2023). Nevertheless, many species depend disproportionately on specific locations for reproduction, feeding, resting, aggregation, or movement (Fleury *et al.*, 2024; Heupel *et al.*, 2015). To address this gap, the IUCN Species Survival Commission Shark Specialist Group developed Important Shark and Ray Areas (ISRAs). ISRAs are discrete, three-dimensional portions of habitat identified as important for one or more chondrichthyan species using standardized scientific criteria and regional expert review (Hyde *et al.*, 2022; IUCN SSC Shark Specialist Group, 2024). Integrating ISRAs into MPA design and conservation planning could enhance the quality of protected areas for chondrichthyans (Cochran *et al.*, 2026; Mouton *et al.*, 2025; Rohner *et al.*, 2025).

Australia provides an important setting in which to evaluate this potential. Its waters support approximately one quarter of global chondrichthyan diversity, high levels of endemism, and several globally threatened species that remain comparatively secure nationally (i.e., lifeboat species) (Kyne *et al.*, 2021; C. Simpfendorfer *et al.*, 2019). Australia also manages one of the largest MPA systems globally. Although the network already exceeds the global 30% area target (~50%), only about one quarter of Australian waters are highly protected no-take areas (~24%). Australia has consequently committed to increasing highly protected MPAs to 30% of its marine environment by 2030 (Commonwealth of Australia, 2024). The recent delineation of ISRAs across Australia and the Southeast Indian Ocean provides a timely opportunity to assess whether this expansion can better represent the conservation needs of chondrichthyans (Jabado *et al.*, 2026). However, the extent to which chondrichthyans' distributions and ISRAs are represented within existing no-take areas, and the degree to which current MPA boundaries constrain further improvement, remain unclear.

This study evaluates how chondrichthyan distributions and ISRAs can inform no-take conservation planning across the Australian Exclusive Economic Zone (EEZ). First, it quantifies their representation within existing no-take MPAs, take-permitted portions of MPAs, and waters outside the MPA network. Second, systemic conservation prioritization is used to compare two conservation planning scenarios for reaching a 30% no-take area budget: strengthening protection within existing MPA boundaries and allowing new no-take areas to be selected across the full planning region. Species distributions and no-movement ISRAs (i.e., ISRAs not delineated under the 'Movement' criterion) are included as conservation features. Finally, Ferrier irreplaceability scores quantify how strongly individual planning units contribute to finding a solution to the conservation problems and how these contributions vary among depth zones. Together, these analyses examine whether the location and level of protection, rather than protected extent alone, determine the effectiveness of Australia's MPA network to conserve chondrichthyans and their critical habitats.

METHODOLOGY

1 Study Area

The study area was the Australian EEZ, covering ~9 million km^2. It includes mainland Australia and its external territories, including the Cocos (Keeling), Christmas, Norfolk, Heard and McDonald, and Macquarie Islands. The EEZ spans tropical, temperate, and subantarctic waters, extending from shallow continental shelf environments to deep-ocean basins >4000 m in depth. It encompasses a diverse range of habitats, including coral reefs, mangroves, seagrass meadows, kelp forests, estuaries, and offshore environments associated with continental shelves, submarine canyons, seamounts, and deep-ocean basins. Major marine regions include the Timor and Arafura Seas, the Coral Sea, the Tasman Sea, the Great Australian Bight, and parts of the Indian and Southern Oceans.

2 Spatial Datasets

All data preparation and analyses were performed in R version 4.5.3 (R Core Team, 2026). Spatial datasets were projected to the GDA94 Australian Albers equal-area projection (EPSG:3577). All layers were clipped to the Australian EEZ and transformed to the common coordinate reference system before analysis. The Australian EEZ boundary was obtained using the *mregions2* R package (Fernández Bejarano & Phol, 2024).

2.1 Marine Protected Areas

Marine Protected Area boundaries were obtained from the World Database on Protected Areas (WDPA), the most comprehensive global database of officially recognized protected areas (UNEP-WCMC & IUCN, 2026). The database was accessed in February 2026 using the *wdpar* R package (UNEP-WCMC, 2019). We excluded proposed and non-implemented MPAs, and records considered to have limited conservation value. Point records were converted to polygons based on on their reported areas. Only MPAs with a status of "Designated", "Established", or "Inscribed" were retained, representing areas with formal legal recognition or equivalent long-term conservation commitment (UNEP-WCMC, 2019). Definitions of all WDPA status categories are provided in **Supplementary Table 1**.

Because fishing mortality, including bycatch, is the principal threat to chondrichthyans, MPAs were further classified according to the level of fishing protection (Dulvy *et al.*, 2021). Following Arnold *et al.* (2026), the WDPA "No-take Status" attribute was used to distinguish between fully no-take MPAs ("All"), partially no-take MPAs ("Part"), take-permitted MPAs ("None"), and MPAs with unreported no-take status (UNEP-WCMC, 2019). In many other studies, MPA protection levels are instead classified using IUCN protected area management categories. Categories Ia, Ib, II and III are generally considered highly protected, and categories IV, V and VI allow varying degrees of resource extraction (Day *et al.*, 2012). However, these management categories do not always reflect the level of fishing protection. For example, some Australian IUCN II (National Park) MPAs permit commercial and recreational fishing (Fitzsimons, 2011; Turnbull *et al.*, 2021). Therefore, the WDPA no-take status was a more appropriate indicator of fishing protection for this study. Furthermore, MPAs with an unreported no-take status accounted for only 0.30% of the Australian EEZ, minimizing uncertainty associated with this classification (**Supplementary Table 2**).

2.2 Important Shark and Ray Areas

ISRAs were obtained from the IUCN Species Survival Commission Shark Specialist Group in February 2026 (https://sharkrayareas.org). To achieve complete coverage of the Australian EEZ, the study combined 157 ISRAs from the Australian and Southeast Indian Ocean region (Jabado *et al.*, 2026), 2 ISRAs from the New Zealand and Pacific Islands region (Jabado, García-Rodríguez, Armstrong, *et al.*, 2024), and 2 ISRAs from the Polar Waters region (Jabado, García-Rodríguez, Kyne, *et al.*, 2024). River sections extending beyond the EEZ were subsequently removed to restrict the dataset to the marine study area, while retaining estuarine and other coastal habitats within the EEZ.

ISRAs designated exclusively under the "Movement" criterion (C4) were analyzed separately because they represent connectivity pathways between critical habitats rather than discrete life-history areas. They encompass a range of temporal and spatial scales, including seasonal coastal migrations, trans-oceanic and trans-equatorial movements, and vertical migrations through the water column (IUCN SSC Shark Specialist Group, 2024). Consequently, they typically span much larger spatial extents and require a different approach (13.1% of Australian EEZ; **Supplementary Table 2**). In contrast, all remaining ISRAs, representing life-history functions such as reproduction, feeding, resting, etc., were grouped as no-movement ISRAs (2.2% of EEZ). Definitions of all ISRA criteria are provided in **Supplementary Table 3**.

2.3 Species Distributions

Species distribution data were obtained from AquaX, a global marine species distribution database that builds upon AquaMaps by combining occurrence records, environmental variables, and expert knowledge to generate high-resolution (0.05°) habitat suitability maps (Reygondeau *et al.*, 2026). Global binary distribution maps for all chondrichthyan species were intersected with the Australian EEZ to identify species occurring within the study area.

The resulting species list was cross-referenced with the *Australian Shark Action Plan 2021* (Kyne *et al.*, 2021), which provides a comprehensive assessment of sharks, rays, and chimaeras occurring in Australian waters. Nine species assessed in the *Shark Action Plan* lacked AquaX distribution maps for Australian waters and were therefore excluded from subsequent analysis (**Supplementary Table 4**). Species not included in the *Shark Action Plan* were retained when at least 5% of their global distribution occurred within the Australian EEZ, whereas species with only marginal occurrence (<5%) were excluded. This threshold was determined following visual inspection of species distribution maps. The final dataset consisted of 335 species. Each species was subsequently assigned an IUCN Red List category using the *rredlist* R package (Gearty & Chamberlain, 2025). Because global IUCN assessments may not accurately reflect extinction risk within Australian waters, national conservation assessments from the *Australian Shark Action Plan* were used where available (Kyne *et al.*, 2021).

3 Current Protection Status

A gap analysis quantified the representation of chondrichthyan biodiversity and ISRAs within Australia's existing MPA network. Following Arnold *et al.* (2026), spatial intersections were used to calculate the proportion of each species' distribution overlapping fully no-take, partly no-take, take-permitted, and unprotected areas outside MPAs. Species representation was then expressed as the percentage of each species' Australian distribution occurring within each MPA category and summarized by IUCN Red List status. Overlap with movement and non-movement ISRAs was also assessed. Finally, species richness was calculated as the number of species whose distributions overlapped each raster cell and summarized across MPA categories to characterize the spatial distribution of chondrichthyan biodiversity within the current MPA network.

4 Systemic Conservation Prioritization

4.1 Conservation Features

The Australian EEZ was subdivided into 103,790 equal-area 10 km hexagonal planning units (PU) using the *spatialgridr* R package (Flower, 2026). Two conservation feature types (i.e., elements of conservation interest) were included in the prioritization: (1) no-movement ISRAs and (2) chondrichthyan species distributions. Like Rohner *et al.* (2025), movement ISRAs were excluded from the main prioritization because of their large extent and because they are corridors. Species distributions and no-movement ISRAs were subsequently converted to the PU grid using *spatialgridr* (Flower, 2026). A species was considered present within a PU when at least 50% of the PU overlapped its binary AquaX distribution. For ISRAs, a 0.01% overlap threshold was applied to retain small polygons. Despite this lower threshold, 9 ISRAs did not overlap any PU and were excluded from the analysis. In total, the prioritization analysis included 473 features.

4.2 Conservation Targets

The primary analysis applied a uniform conservation target (i.e., the minimum proportion of a conservation feature to be included in the solution) of 30% for all species. This reflects both Australia's commitment to highly protect 30% of its EEZ by 2030 and the global 30×30 target. No-movement ISRAs were assigned a 100% representation target (i.e., forcing into solution) because they represent discrete ecological areas of recognized conservation importance. A sensitivity analysis for the species' targets was subsequently conducted using range-scaled representation targets based on species' IUCN Red List category, global range size, and the degree of endemism. Maximum and minimum representation targets were assigned according to threat status and endemism, following Faure-Beaulieu *et al.* (2023) (**Table 1**). Near-endemic species were defined as species with at least 50% of their global distribution within the Australian EEZ.

To avoid disproportionately favoring widespread species, conservation targets declined with increasing global range size using a log-linear interpolation adapted from Rodrigues *et al.* (2004). The targets were rescaled following the methodology adapted by Rohner *et al.* (2025). Species with global ranges of ≤200,000 km^2 were assigned the maximum target, whereas species with ranges equal to or exceeding the Australian study area (~9 million km^2) were assigned the minimum target.

The lower threshold was based on the IUCN Shark Specialist Group's definition of range-restricted species used for ISRA identification, whereby species restricted to 1 or 2 adjacent Large Marine Ecosystems are considered range-restricted (Hyde *et al.*, 2022). Given that Large Marine Ecosystems cover ~200,000 km^2 (Sherman & Alexander, 1986), this value was adopted as the upper threshold for assigning maximum representation targets. Intermediate values were interpolated on a log10 scale (**Supplementary Figure 1**).

Table 1: Maximum and minimum conservation targets (%) assigned to chondrichthyan species by IUCN Red List category and endemism class *(following Faure-Beaulieu et al., 2023). Near-endemics were defined as species that have ≥50% of their global range within the Australian Exclusive Economic Zone.*

IUCN Status	Non-endemic max target	Near-endemic max target	Endemic max target	Minimum target
Critically Endangered	40	50	60	30
Endangered	40	50	60	30
Vulnerable	30	40	50	30
Near Threatened	30	30	40	20
Data Deficient	30	30	40	20
Least Concern	30	30	30	10

4.3 Conservation Problem Formulation

Systematic conservation prioritization was performed using the *prioritizr* R package, which formulates conservation planning objectives as integer linear programming problems to identify optimal solutions (Hanson *et al.*, 2024). All optimization problems were solved using the Gurobi algorithmic solver with an optimality gap of 0.01%, ensuring solutions were within 0.01% of the mathematical optimum (Gurobi Optimization & LLC, 2026).

To define optimization goals in *prioritizr*, an objective function (i.e., the metric to minimize/maximize) needs to be specified (Hanson *et al.*, 2024). All prioritizations used the minimum shortfall objective, which minimizes the weighted relative shortfall across all conservation features while ensuring that the total cost of the PUs does not exceed a predefined budget. Relative shortfall represents the proportion of each conservation target that remains unmet. Each PU was assigned a uniform cost of one so that a solution was proportional to the number (and therefore area) of selected PUs. Consistent with Australia's commitment to highly protect 30% of its EEZ by 2030, the total budget was fixed at 30% of the EEZ, meaning that solutions could include PUs covering a maximum of 30% of the Australian EEZ.

Planning units containing existing MPAs were classified according to their WDPA no-take status (Section 2.1). Fully no-take MPAs were assigned to Category 1, while partially no-take and take-permitted, and unreported MPAs were assigned to Category 2. Those outside of the existing MPA network were defined as Category 3. These categories formed the basis for the spatial constraints applied during optimization. Planning units could be constrained either by locking them into the solution (i.e., forcing their selection) or locking them out (i.e., preventing their selection) (Hanson *et al.*, 2024).

Three conservation scenarios were evaluated (**Table 2**). All scenarios assumed that existing no-take MPAs would remain unchanged, reflecting a low likelihood that established no-take protected areas would be removed or relocated. The current scenario quantified species and no-movement ISRA representation within the existing no-take network and served as a baseline. For further optimization scenarios, the existing no-take MPA network (Category 1) was retained, locking 25.6% of all PUs into the solution. The remaining 4.4% of the 30% budget was then allocated either within the existing MPA network (S1) or across the entire PU network (S2). The *S1 Within-MPA* improvement scenario restricted additional selections to Category 2 PUs by locking out Category 3 PUs. This scenario quantified the conservation gains achievable through upgrading protection levels within the existing MPA network. In contrast, the *S2 Outside-no-take* scenario allowed both Category 2 and 3 PUs to be selected. This scenario assessed the additional conservation gains achievable when conservation planning was not forced to stay within the current MPA network, while still building on the current no-take MPA network.

Table 2: Overview of the conservation scenarios used in the conservation prioritization analysis. *Planning units (PUs) were classified according to the no-take status of overlapping Marine Protected Areas (MPAs) into Category 1 (fully no-take), Category 2 (partially no-take, take-permitted, or unreported), and Category 3 (outside of existing MPA network). "Locked in" indicates that PUs were forced into the solution, "selectable" indicates that they were available for selection, and "locked out" indicates they were excluded from selection.*

Scenario	Category 1 *= No-take MPA*	Category 2 *= Partially no-take, take-permitted, unreported MPA*	Category 3 *= Outside MPA*	Purpose
Current No-Take Network	Existing no-take network	Not included	Not included	Baseline – No optimisation
S1 Within-MPA	Locked in	Selectable	Locked out	Assess gains through upgrading protection within current MPA network
S2 Outside-no-take	Locked in	Selectable	Selectable	Assess gains through expansion beyond existing no-take MPA network

4.4 Evaluation Importance of Planning Units

Following optimization, solutions were evaluated using Ferrier irreplaceability scores, which assess the relative contribution of each selected PU to meeting the conservation targets (Ferrier *et al.*, 2000). Ferrier irreplaceability scores were calculated with a function within the *prioritizr* R package. For further analysis, selected PUs were separated into (i) locked-in no-take MPA PUs, and (ii) newly selected PUs. To compare the distribution of irreplaceability across major marine environments, PUs were assigned to three bathymetric zones: continental shelf (0-200 m), continental slope (200-1000 m), and deep sea (>1000 m). Within each group, the proportion of PUs and summed Ferrier irreplaceability score were calculated for each depth zone.

RESULTS

1 Current Protection of Chondrichthyans and ISRA Coverage

MPAs are distributed throughout the Australian EEZ (**Figure 1**). Large no-take MPAs are primarily located in Australia's external territories, including the Macquarie, Cocos (Keeling), and Christmas Islands. Around mainland Australia, extensive no-take areas generally occur beyond the continental shelf in deeper waters. An exception is the Great Barrier Reef Marine Park, along the east coast within the Coral Sea, where no-take zones are smaller and more fragmented. In contrast, relatively few no-take MPAs occur across northern Australia, including the Timor Sea, Arafura Sea, Gulf of Carpentaria, and northern Indian Ocean. Similarly, along the south-east coast in the Tasman Sea, no-take MPAs are relatively sparse.

ISRAs were concentrated predominantly in coastal and shelf waters (**Figure 1**). The 148 no-movement ISRAs and 13 movement ISRAs cover 2.2% and 13.1% of the EEZ, respectively, with a combined extent of 14.5% after accounting for spatial overlap (**Supplementary Table 2**). Notably, most spatial overlap between movement and no-movement ISRAs was along the eastern Australian coastline, extending from the southern Coral Sea through the Tasman Sea to Tasmania. The level of protection differed between ISRA types (**Figure 2**). Approximately 60% of the area of no-movement ISRAs overlapped the existing MPA network, although there was only 19.5% within no-take MPAs. In contrast, movement ISRAs were substantially less represented, with 71.5% of their area outside of the MPA network and only 8.3% within no-take MPAs.

At the species level, a mean of 56.2-74.1% of the range of Australian chondrichthyans occurred outside the current MPA network (**Figure 2**). Mean representation within no-take MPAs remained below 10% for all IUCN Red List categories, except Data Deficient species (14.1%). The Near Threatened category had the lowest mean representation in no-take MPAs (6.3%), followed by the Critically Endangered category (7.6%). For all categories, a larger proportion of the mean range of species was found within take-permitted or partly no-take MPAs than within strictly protected no-take areas. Species-specific representation values are provided in **Supplementary Table 5**.

Species richness (i.e., number of species per grid cell) was highest along northern Australia, the north-west shelf, and the Great Barrier Reef, while offshore and southern areas generally supported fewer species (**Figure 3**). Mean species richness also varied among MPA categories. Cells within no-take MPAs contained an average of 10.5±18.0 species. Conversely, within the take-permitted MPAs, the mean species richness was 37.0±26.6 and 14.7±16.1 for partly no-take MPAs. Outside the current network, a mean species richness of 32.2±28.7 was observed. Lastly, areas classified as "not reported" showed the highest mean richness (69.9±7.7), although these MPAs represent only 0.3% of the EEZ (**Supplementary Table 2**). Overall, species richness was lower in no-take MPAs than in take-permitted or unprotected areas.

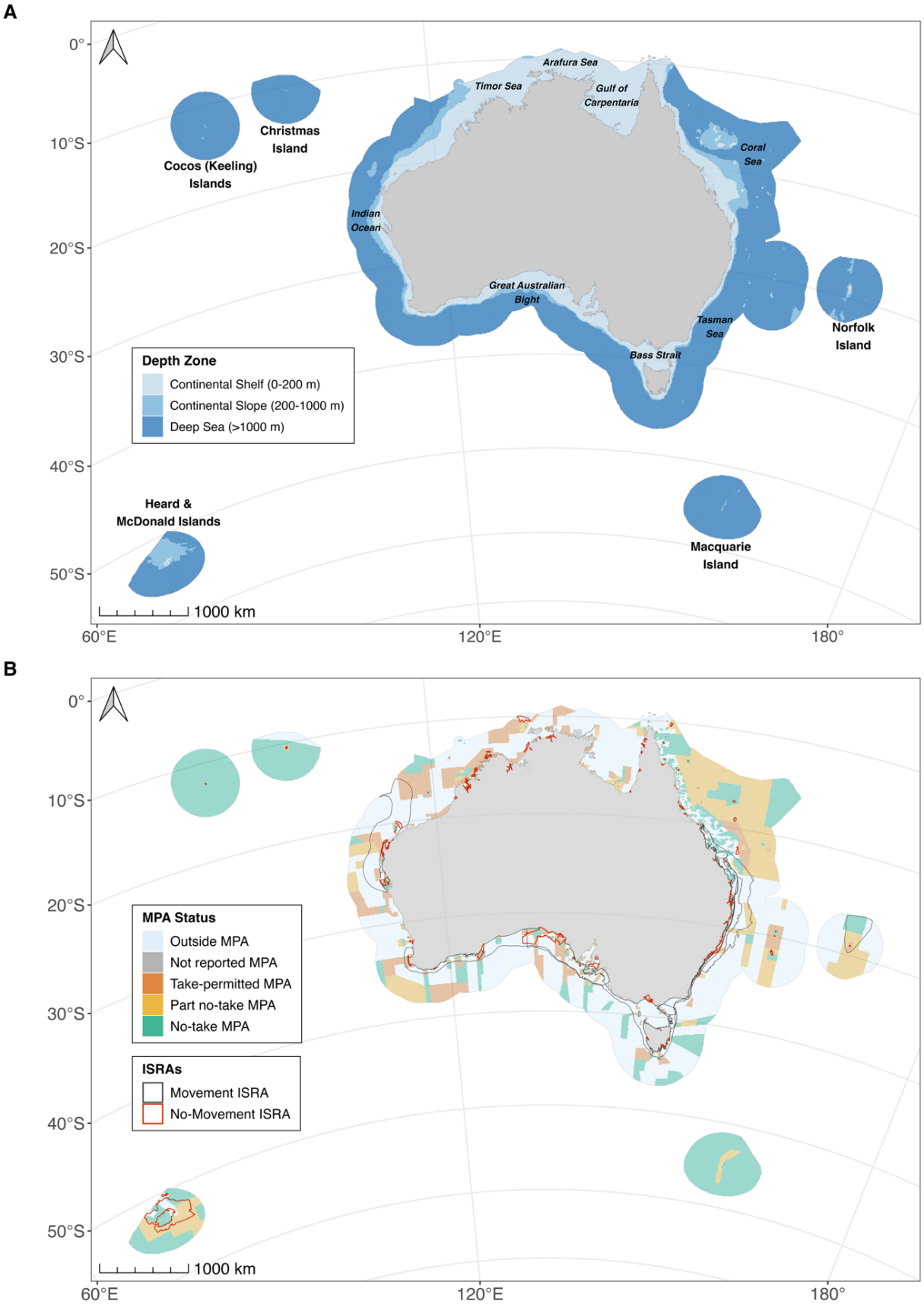


Figure 1: Study area and spatial distribution of Marine Protected Areas (MPAs) and Important Shark and Ray Areas (ISRAs). *(A) Bathymetric zones of the Australian EEZ, classified as continental shelf (0-200 m), continental slope (200-1000 m), and deep sea (>1000 m). (B) Australian MPAs (n=812) by no-take status and distribution of movement (n=13) and no-movement ISRAs (n=148).*

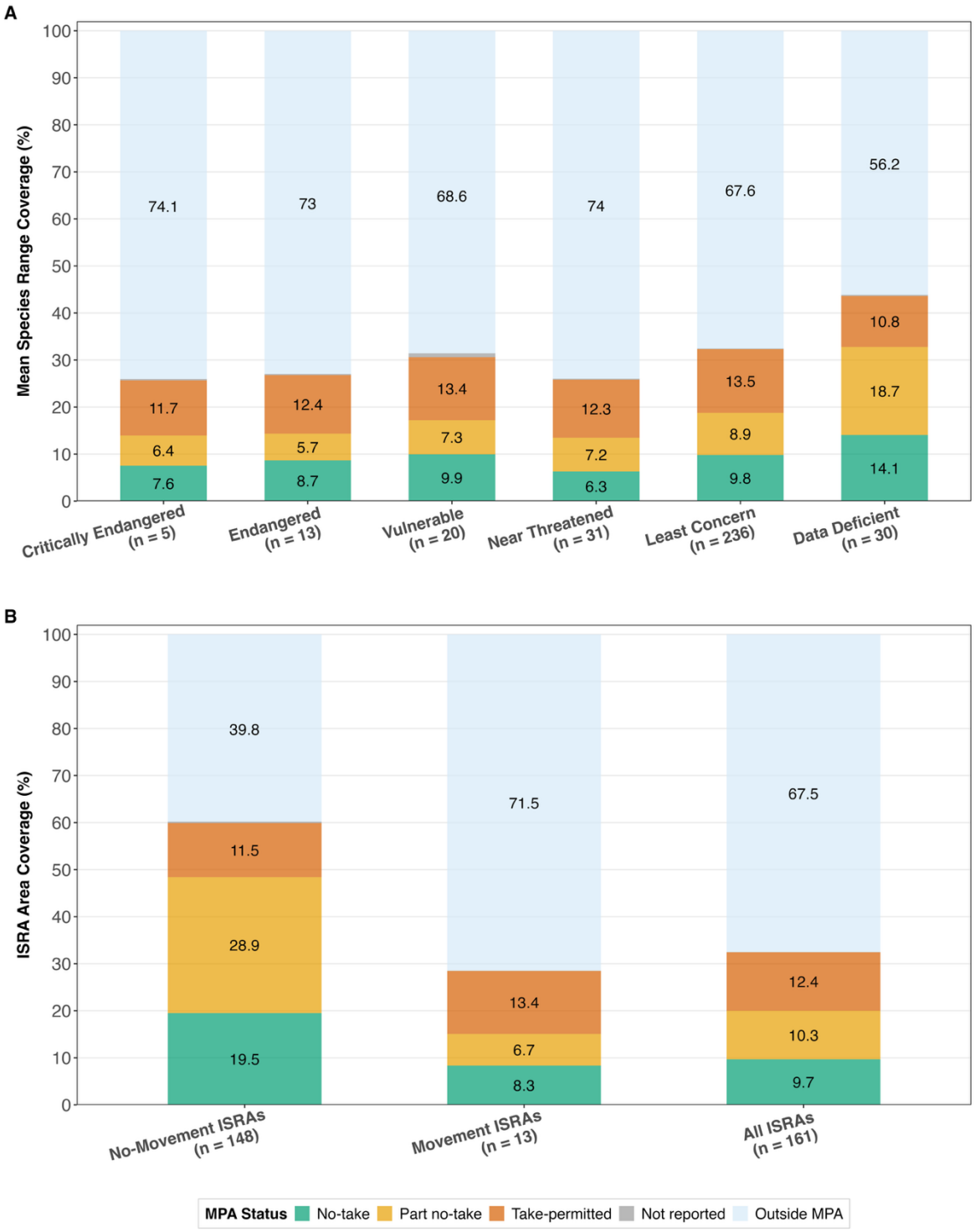


Figure 2: Current representation of chondrichthyan species and Important Shark and Ray Areas (ISRAs) within the Australian Marine Protected Area (MPA) network. *(A) Mean species range coverage (%) by MPA no-take status across IUCN Red List threat categories. (B) ISRA coverage (%) by MPA no-take status for no-movement, movement, and all ISRAs combined. The light blue represents the proportion of species range or ISRA area falling outside any MPA.*

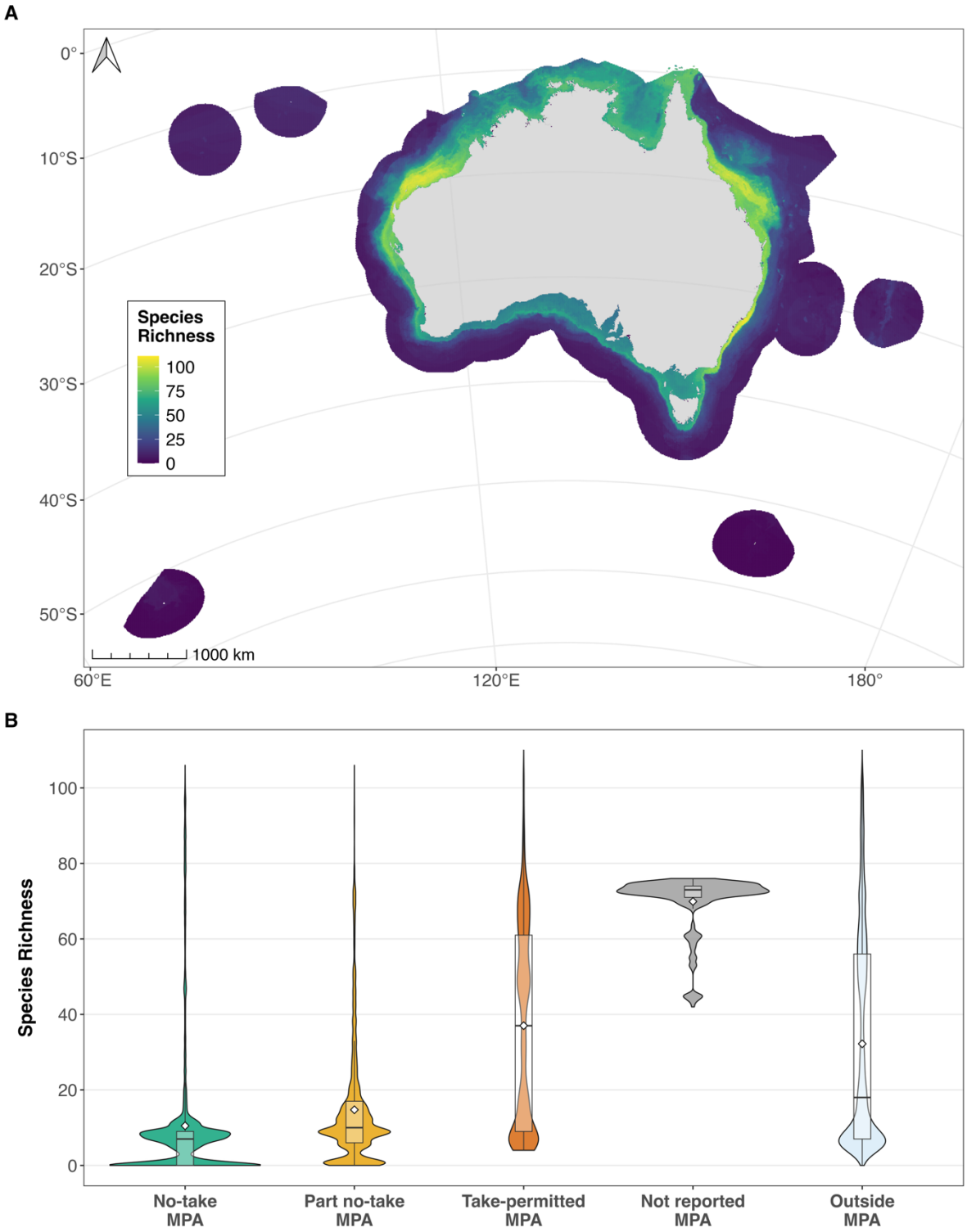


Figure 3: Distribution of chondrichthyan species richness (n=335) within the Australian Exclusive Economic Zone and across Marine Protected Area (MPA) categories. *(A) Spatial distribution of species richness, expressed as the number of chondrichthyan species per grid cell. (B) Distribution of species richness within no-take, part no-take, take-permitted, and unreported MPAs, and outside MPAs. The white diamonds denote the mean species richness.*

2 Conservation Outcomes Under Australian 30×30 Commitments

2.1 Conservation Prioritization Performance

Despite operating under the same 30% area budget, *S1 Within-MPA* and *S2 Outside-no-take* selected largely different sets of additional PUs (**Figure 4**). Excluding the locked-in no-take MPAs, the overlap between both solutions was limited (marginal Jaccard similarity = 0.13). Within the existing MPA network, additional PUs selected under *S1 Within-MPA* were distributed across multiple regions, including the Great Australian Bight, the west coast, and northern Australia from the Timor Sea to the Arafura Sea. In contrast, *S2 Outside-no-take* concentrated additional selections primarily along the west coast, between the Timor and Arafura Sea, and around the Bass Strait and the Tasman Sea.

Across all conservation features (i.e., chondrichthyan species and no-movement ISRAs; n = 473), *S1 Within-MPA* achieved 123 conservation targets (26.0%) with a mean coverage of 33.0±28.6%, whereas *S2 Outside-no-take* increased target attainment to 266 features (56.2%) with 49.6±33.5% mean coverage. Mean shortfall across all conservation features declined from 33.6±32.4% under the current network to 18.9±29.8% in *S1 Within-MPA* and to 3.4±6.4% in *S2 Outside-no-take*. This indicates greater feature representation when conservation actions were allowed beyond existing MPA boundaries.

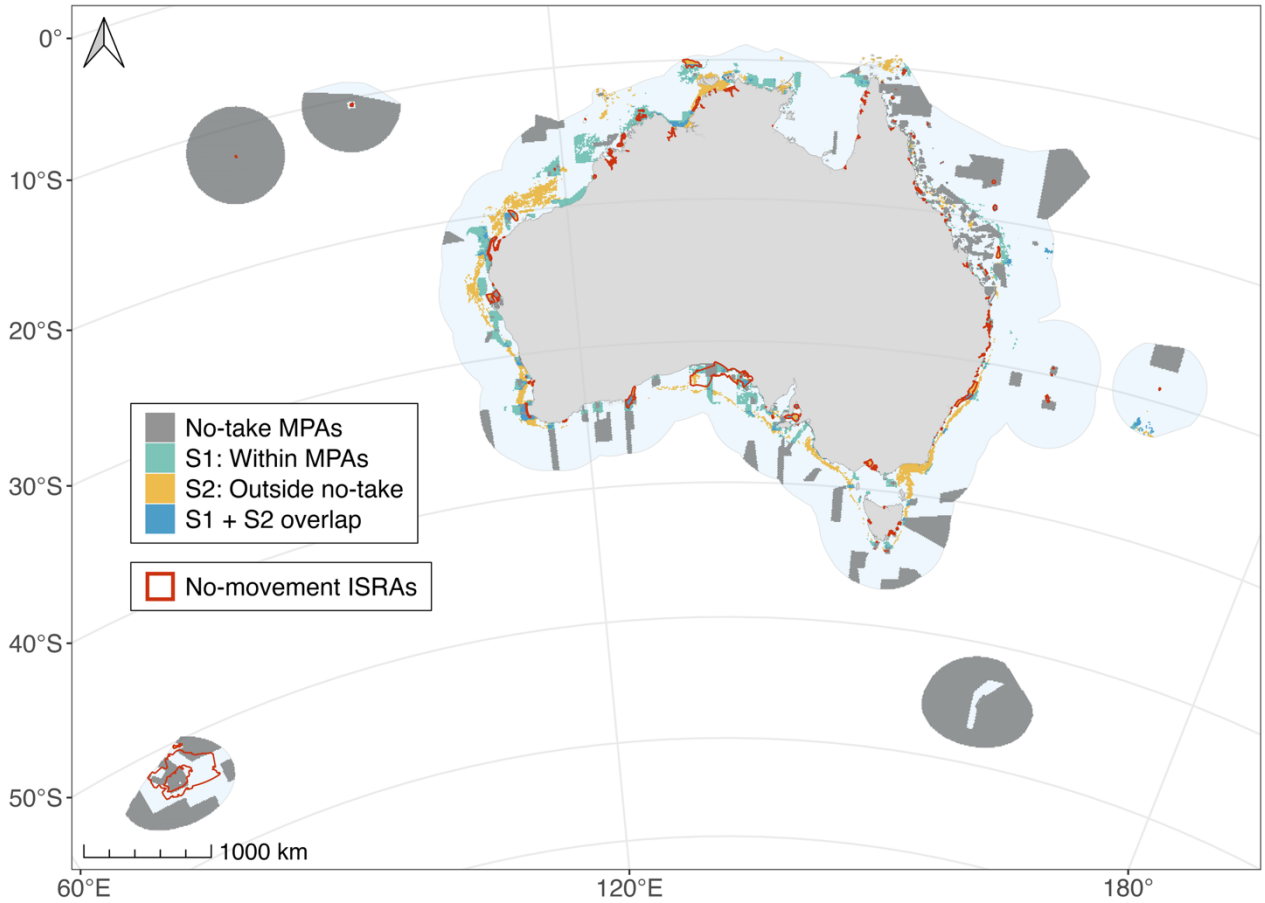


Figure 4: Spatial distribution of planning units (PUs) selected under the two conservation prioritization scenarios. *Existing no-take MPAs (locked into both solutions) are shown in grey. PUs selected only in S1 Within-MPA are shown in green, those selected only in S2 Outside-no-take in yellow, and PUs selected in both scenarios in blue. Red outlines indicate no-movement ISRAs.*

2.2 Representation of Chondrichthyan Species in Prioritizations

Under both prioritization scenarios, coverage shifted consistently towards higher representation across all IUCN categories. Accordingly, mean shortfall from the 30% representation target declined across all categories (**Figure 5**). Largest reductions in shortfall, and corresponding increases in coverage, occurred when conservation actions were allowed beyond existing MPA boundaries (*S2 Outside-no-take*). Across all IUCN categories, approximately half of the remaining shortfall in *S1 Within-MPA* was covered by extending conservation beyond the existing MPA network. Although mean species range coverage increased under *S1 Within-MPA* relative to the current no-take network, it remained below 30% across all IUCN categories. In contrast, mean coverage exceeded 30% for Endangered (EN), Vulnerable (VU), and Data Deficient (DD) species under *S2 Outside-no-take*, while Least Concern (LC) species approached the target with a mean coverage of 29.0±11.3%.

The greatest improvement was observed for VU species, where mean shortfall declined from 17.2±9.9% under the current no-take network to 5.8±6.7% in *S1 Within-MPA* and 2.3±4.4% in *S2 Outside-no-take*. In contrast, Critically Endangered (CR) species remained the least represented under both scenarios, with mean coverage increasing from 9.3±9.2% under the current no-take network to 18.7±8.1% in *S1 Within-MPA* and 23.6±6.8% in *S2 Outside-no-take*. Nevertheless, *S2 Outside-no-take* recovered a mean of 72.5±27.0% of the initial conservation shortfall for CR species, compared with 54.9±29.8% under *S1 Within-MPA* (see **Supplementary Table 6** for detailed prioritization metrics).

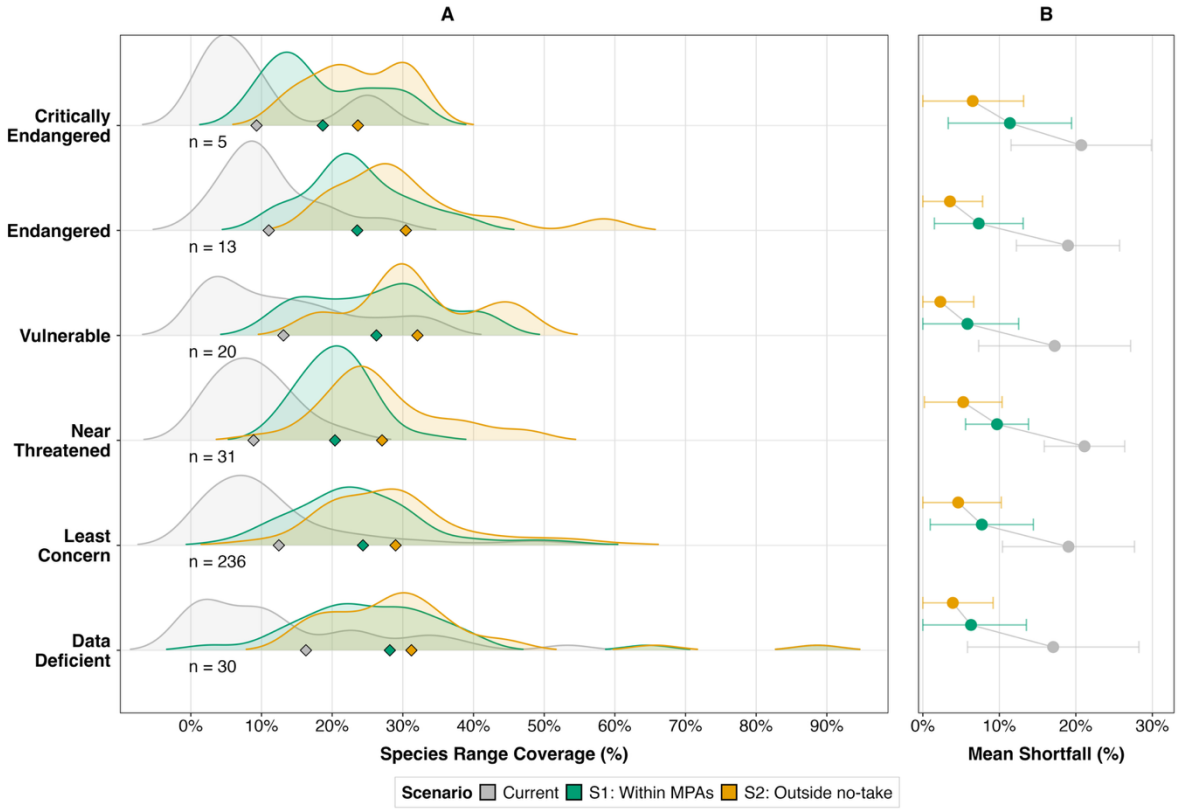


Figure 5: Australian range coverage of chondrichthyan species (n=335) under the three scenarios across IUCN Red List categories. *(A) Ridge density plots showing the percentage of each species' Australian range represented under the current no-take MPA network (grey), within-MPA improvement scenario (S1; green), and the outside no-take MPA expansion scenario (S2; yellow). Diamonds indicate mean range coverage. (B) Mean conservation shortfall (%) by IUCN category under each scenario. Points represent means and horizontal error bars indicate ± standard deviation.*

Representation varied considerably among individual threatened species (**Figure 6; Supplementary Table 7**). Many species increased in coverage under both prioritization scenarios. However, several remained below the 30% conservation target, whereas others only exceeded the target when conservation actions were possible beyond existing MPA boundaries (*S2 Outside-no-take*). Only two threatened species, the endemic VU Estuary Stingray (*Hemitrygon fluviorum*) and Colclough's Shark (*Brachaelurus colcloughi*), already met the 30% target under the current no-take MPA network. Three additional species, the CR Oceanic Whitetip Shark (*Carcharhinus longimanus*), the EN Whale Shark (*Rhinocodon typus*), and the VU Longfin Mako (*Isurus paucus*), were already close to the target. In contrast, few species achieved higher representation under the *S1 Within-MPA* scenario compared with *S2 Outside-no-take*, including the CR Green Sawfish (*Pristis zijsron*), the endemic EN Coastal Stingaree (*Urolophus orarius*), and the VU Spotted Shovelnose Ray (*Aptychotrema timorensis*).

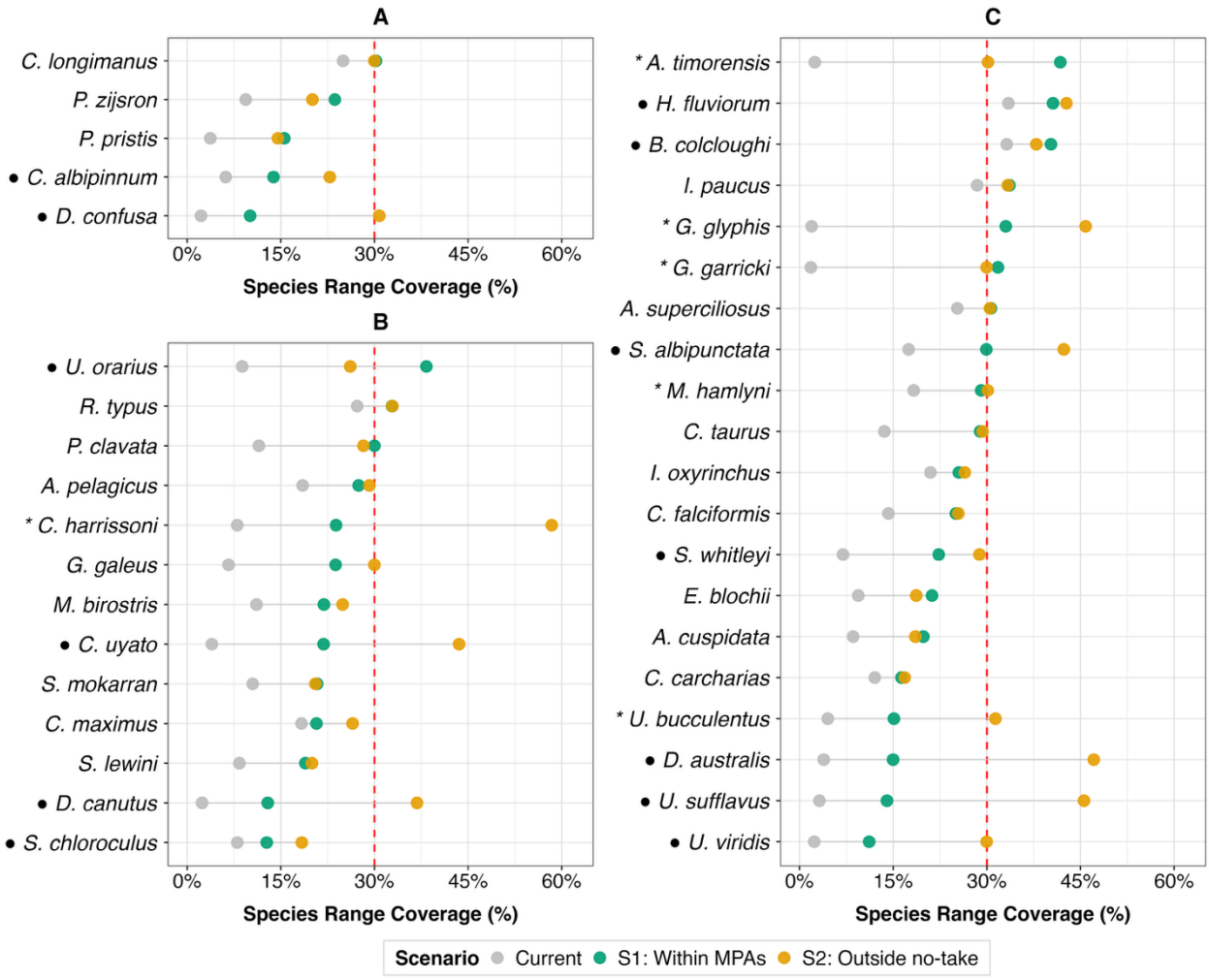


Figure 6: Australian range coverage of threatened chondrichthyan species (n=38) under the three scenarios. *Panels show (A) Critically Endangered, (B) Endangered, and (C) Vulnerable species. Points indicate the percentage of each species' Australian range represented under the current no-take MPA network (grey), the within-MPA improvement scenario (S1; green), and the outside no-take MPA expansion scenario (S2; orange). Species are ordered by decreasing representation in S1. The dashed line indicates the 30% conservation target, • Australian endemic species, and * near-endemic species. Full scientific and common names are provided in Supplementary Table 7.*

The two endemic CR species, Whitefin Swellshark (*Cephaloscyllium albipinnum*) and Australian Longnose Skate (*Dipturus confusa*), had among the lowest representation under the current no-take network and remained well below the 30% target under *S1 Within-MPA* (**Figure 6**). Similar patterns were observed for several endemic EN and VU species with low initial representation. Extending conservation beyond existing MPA boundaries (*S2 Outside-no-take*) substantially increased coverage for many of these species, often bringing them closer to or above the target, as illustrated by the EN Grey Skate (*Dipturus canutus*) and the VU Sydney Skate (*Dipturus australis*).

2.3 Representation of No-Movement Important Shark & Ray Areas

Representation of no-movement ISRAs increased consistently under both prioritization scenarios, although the magnitude of improvement varied (**Figure 7**). Mean ISRA coverage increased from 31±40.6% under the current no-take MPA network, to 53.9±43.6% in *S1 Within-MPA*, and 99.1±7.6% in *S2 Outside-no-take* (**Supplementary Table 6**). Correspondingly, the number of fully represented ISRAs (i.e., 100% target reached) increased from 28 (20.3%) under the current no-take MPA network to 51 (37.0%) in *S1 Within-MPA* and 136 (98.6%) in *S2 Outside-no-take*. Further, under *S1 Within-MPA*, 44 ISRAs (31.9%) gained partial representation, whereas 43 (31.1%) remained without any representation. Allowing selection beyond all existing MPA boundaries (*S2 Outside-no-take*) resulted in full coverage of nearly all ISRAs but two sites (**Supplementary Figure 2**). The two remaining ISRAs below the 100% representation target were the Great Australian Bight Shelf and Heard and McDonald Islands, both of which remained below 50% coverage.

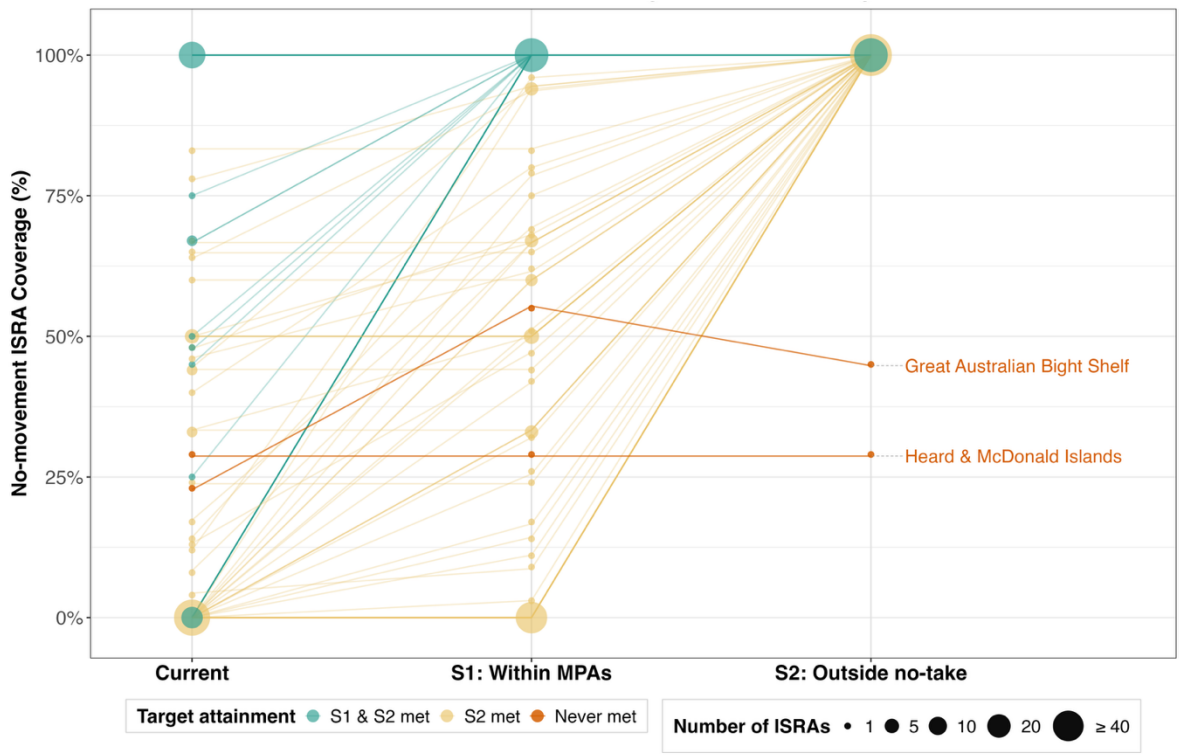


***Figure 7: Changes in no-movement ISRA (n=138) coverage under the three scenarios**. Each line connects the coverage percentage of an individual ISRA under the current no-take MPA network, the within-MPA improvement scenario (S1), and the outside no-take MPA expansion scenario (S2). Line colors indicate whether the 100% representation target was achieved under both scenarios (green), only under S2 (yellow), or under neither scenario (orange). Point size is proportional to the number of ISRAs sharing the same representation value*

2.4 Distribution of Irreplaceable Planning Units

Ferrier irreplaceability scores revealed substantial spatial variation among PUs selected under the *S1 Within-MPA* improvement scenario (**Figure 8**). High-scoring PUs were concentrated along the continental shelf, particularly along the western coastline, the Great Barrier Reef, and parts of southern Australia. Additional clusters occurred around several offshore island territories, including Norfolk Island and Heard and McDonald Islands. Ferrier scores generally decreased with increasing depth, although isolated high-scoring PUs also occurred in offshore regions.

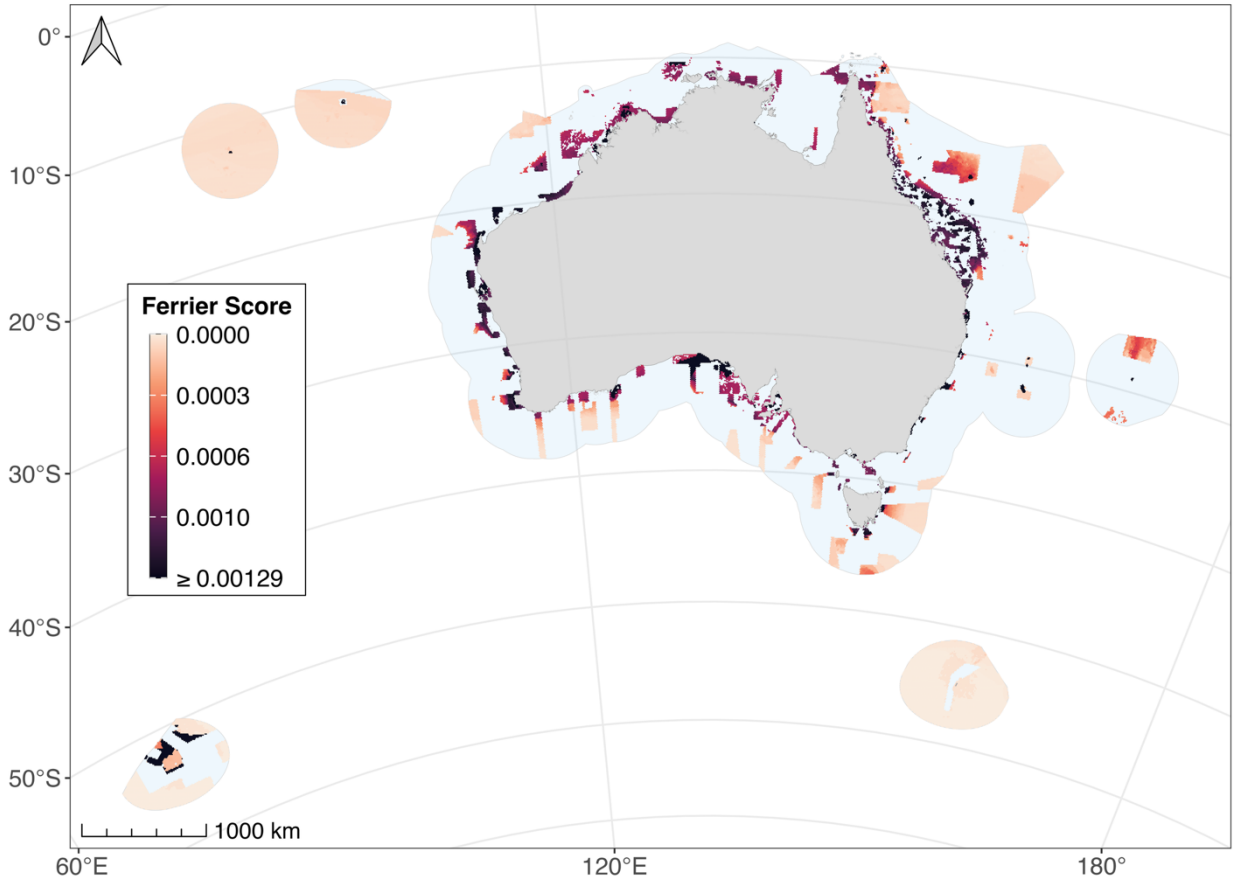


Figure 8: Spatial distribution of Ferrier irreplaceability scores for planning units (PUs) selected under the S1 Within-MPA improvement scenario. *Darker colors indicate higher Ferrier scores and therefore PUs with greater irreplaceability within the constrained S1 solution. The color scale is capped at the 95th percentile (≥0.00129) to improve visibility.*

The depth composition of the locked-in no-take MPA PUs and newly selected PUs differed markedly (**Figure 9**). Within the locked-in no-take MPA network, deep-sea PUs (>1000 m) accounted for 86.3% of all PUs but contributed only 10.8% of the total Ferrier score. In contrast, continental shelf (0-200 m) and continental slope (200-1000 m) PUs together represented only 13.7% of locked-in PUs but accounted for 89.2% of the total Ferrier score. Among newly selected PUs, continental shelf PUs made up 71.6% of all PUs and contributed 90.7% of the total Ferrier score. Continental slope PUs represented 16.6% of newly selected PUs and contributed 7.3% of the total Ferrier score, whereas deep-sea PUs represented 11.7% of the newly selected PUs but contributed only 2.0% of the total Ferrier score. Results for *S2 Outside-no-take* showed a broadly similar pattern (**Supplementary Figure 3**; **Supplementary Figure 4**).

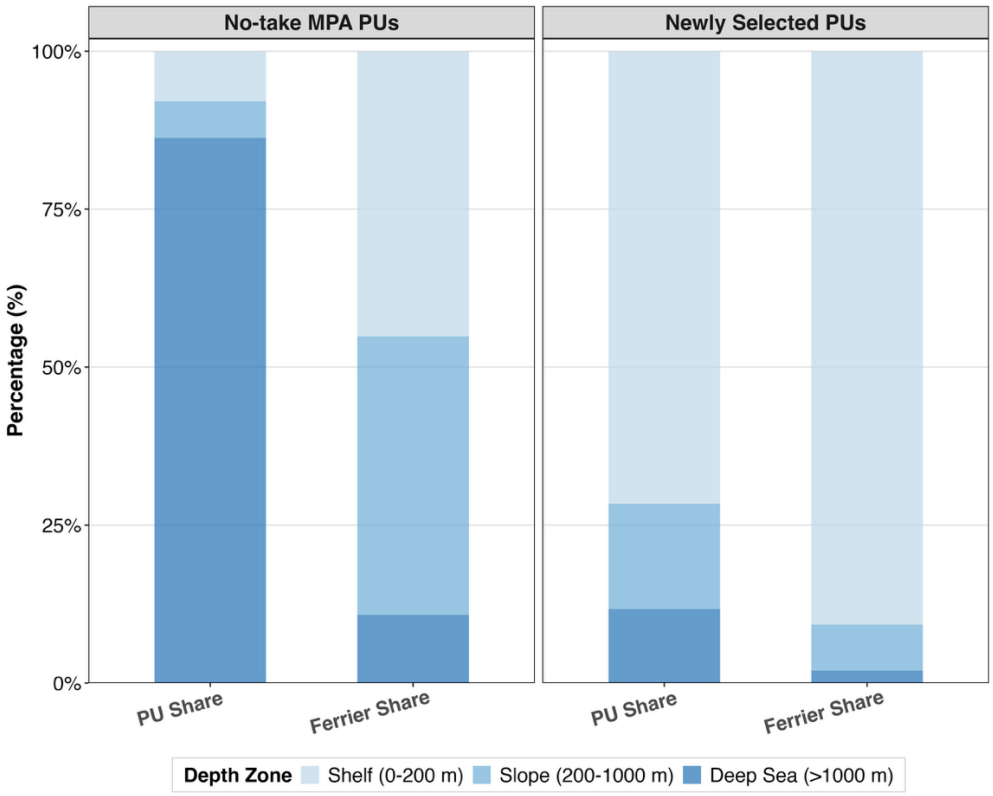


Figure 9: Comparison of the depth composition of locked-in no-take Marine Protected Area (MPA) planning units (PUs) and newly selected PUs under the within-MPA improvement scenario (S1). *Bars show the proportion of PUs (PU share) and the proportion of the summed Ferrier irreplaceability score (Ferrier share) contributed by each depth zone. Percentages are calculated separately for each panel and sum to 100%.*

DISCUSSION

Global commitments to protect 30% of the ocean by 2030 have accelerated MPA expansion, but greater protected extent does not necessarily produce greater conservation effectiveness (Klein *et al.*, 2015; Pike *et al.*, 2024). MPAs may provide limited biodiversity benefits when they are placed in areas of relatively low value for the features considered, permit activities driving population decline, or fail to represent critical habitats and ecological processes (Birkmanis *et al.*, 2020; Edgar *et al.*, 2014; Lester *et al.*, 2009; Turnbull *et al.*, 2021). Consequently, progress towards 30×30 should be evaluated not only by how much area is protected, but also by where protection occurs, which biodiversity it represents, and which pressures are restricted (Pike *et al.*, 2024).

Australia illustrates this distinction. Despite extensive MPA coverage, chondrichthyan distributions and ISRAs remained poorly represented in no-take areas. Rezoning within existing MPAs improved representation but left major shortfalls, whereas allowing selection of new no-take areas outside of the current MPA network produced substantially better outcomes under the same 30% area budget. Planning units contributing most towards conservation targets were concentrated on shelf and slope habitats, while the current no-take network was dominated by deeper offshore waters.

1 MPA Coverage Masks Protection Gaps

The Australian MPA network was poorly aligned with chondrichthyan distributions and critical habitats. Large proportions of species ranges and ISRAs occurred outside MPAs, while much of their overlap with the network remained open to fishing (**Figure 2**). Mean representation within no-take areas was therefore low across all IUCN Red List categories (~10.0%). Species richness and ISRAs were concentrated primarily in coastal and continental shelf waters, consistent with the high chondrichthyan diversity associated with Australia's shelf habitats (Kyne *et al.*, 2021) (**Figure 3**). In contrast, many large no-take MPAs occurred in deeper offshore waters and around external territories. Notably, species richness was higher within take-permitted MPAs and outside of the MPA network than within no-take areas. Similar mismatches have been reported in Australia and other ISRA regions (Birkmanis *et al.*, 2020; Cochran *et al.*, 2026; Mouton *et al.*, 2025; Rohner *et al.*, 2025).

Protection level is especially important because fishing mortality is the primary threat to chondrichthyans (Dulvy *et al.*, 2021). Fully protected Australian MPAs have supported greater fish abundance and biomass than partially protected areas, which showed no detectable ecological or social benefits relative to the areas open to fishing (Sala & Giakoumi, 2018; Turnbull *et al.*, 2021). Conversely, partially protected MPAs and shark sanctuaries may still benefit some populations, but they do not eliminate incidental capture (MacNeil *et al.*, 2020; Shea *et al.*, 2023; Vianna *et al.*, 2016; Ward-Paige & Worm, 2017). Bycatch mortality during capture or after release varies among species and fishing practices and can be especially consequential for species with low population growth rates (Ellis *et al.*, 2017; Gilman *et al.*, 2022).

These gaps are particularly important because Australia supports approximately one quarter of global chondrichthyan diversity, high endemism, and 45 “lifeboat species” that are globally threatened but remain comparatively secure nationally (Kyne *et al.*, 2021; C. Simpfendorfer *et al.*, 2019). Maintaining this conservation opportunity requires chondrichthyans and their critical habitats to be considered explicitly in future MPA design and rezoning.

2 Existing MPA Boundaries Limit 30×30 Outcomes

Strengthening no-take protection within existing take-permitted MPAs produced conservation gains. Under *S1 Within-MPAs*, the mean target shortfall declined from 33.6±32.4% to 18.9±28.8%, mean representation increased across all IUCN categories, and 37.0% of no-movement ISRAs achieved full representation (**Figure 5**; **Figure 7**). This indicates that take-permitted portions of Australia’s MPA network contain substantial unreleased value. Carefully targeted rezoning could improve conservation outcomes without immediately expanding the total MPA footprint.

The gains were evident for threatened species (**Figure 6**). For example, the no-take representation of the CR Green Sawfish (*Pristis zijsron*) more than doubled from 9.4% to 23.6%, although its 30% target remained unmet. This is important because Northern Australia supports some of the species’ last global viable populations despite continued fishing pressure (Harry *et al.*, 2022; Kyne *et al.*, 2021; Yan *et al.*, 2021). The endemic EN Coastal Stingaree (*Urolophus orarius*) and the VU Spotted Shovelnose Ray (*Aptychotrema timorensis*) also benefited because substantial portions of their distributions already overlapped take-permitted MPAs (**Supplementary Table 5**).

Nevertheless, current MPA boundaries showed a strong constraint. Mean species representation remained below 30% across all IUCN categories, and 43 no-movement ISRAs remained absent because they occurred wholly outside the network (**Figure 5**; **Figure 7**). Their protection could not be improved through rezoning alone. By contrast, *S2 Outside-no-take* allowed selection across the full planning region, doubled the proportion of conservation features reaching their targets to 56.2% and reduced mean shortfall to 3.4±6.4%. The principal limitation was therefore not only how much area could be selected, but where it could be located (**Figure 4**). This constraint was particularly evident for threatened species (**Figure 6**). For example, the endemic CR Australian Longnose Skate (*Dipturus confusa*) had the lowest current no-take representation, while more than 90% of its distribution occurred outside MPAs (**Supplementary Table 5**). Its 30% target was therefore unattainable through *S1 Within-MPA* rezoning alone.

Even under *S2 Outside-no-take*, the Great Australian Bight Shelf and the Heard and McDonald Islands ISRAs remained below their full-representation targets (**Figure 7**). Both were among the largest no-movement ISRAs (Jabado *et al.*, 2026; Jabado, García-Rodríguez, Kyne, *et al.*, 2024). Because retained no-take MPAs already occupied 25.6% of planning units, only an additional 4.4% could be selected before reaching the 30% budget. Rezoning is therefore a useful first step, but closing the main spatial gaps will also require conservation measures beyond existing MPA boundaries.

3 ISRAs Can Guide Targeted Action

The strong representation of no-movement ISRAs under *S2 Outside-no-take* demonstrates their practical value for Australian conservation planning (**Figure 7**). ISRAs could guide rezoning, targeted MPA expansion, or other effective area-based conservation measures. Because ISRAs do not prescribe a particular response, management should reflect the qualifying species, ecological function, and threats at each site (Hyde *et al.*, 2022). Depending on context, appropriate measures may include no-take designation, fisheries restrictions, seasonal closures, gear regulations, bycatch mitigation, enforcement, or monitoring (Cochran *et al.*, 2026; Mouton *et al.*, 2025).

Monitoring is needed to determine whether such measures reduce pressures and maintain the functions for which sites were identified. A "Pressure-State-Response" framework, as used for Important Bird and Biodiversity Areas, could support this assessment and reveal knowledge gaps concerning species' ecology and responses to environmental change (BirdLife International, 2006; Hyde *et al.*, 2022). ISRA information may also support targeted communication and non-lethal risk reduction where shark aggregations overlap human ocean use (Henriksen *et al.*, 2025; Riley *et al.*, 2022). However, interactions also depend on human exposure, species behavior, and environmental conditions and should be considered (Ryan *et al.*, 2019).

4 Conservation Contributions Are Unevenly Distributed

Ferrier irreplaceability scores further showed that protected areas are not interchangeable (**Figure 8**; **Figure 9**). Deep-sea planning units deeper than 1,000 m comprised 86.3% of those already protected within no-take MPAs but contributed only 10.8% of their cumulative Ferrier score. Shelf and slope planning units comprised only 13.7% of the network but contributed 89.2% of the score. The additional *S1 Within-MPA* selection showed the same pattern: 71.6% of newly selected planning units occurred on the shelf and contributed 90.7% of cumulative importance. This reflects the concentration of chondrichthyan richness and ISRAs in shallower waters, also reported by Rohner *et al.* (2025).

Large offshore no-take MPAs therefore contributed substantially to total protected extent but comparatively little to representation of the features assessed here. Similar concerns have been raised where large remote MPAs increase coverage without addressing biodiversity gaps in more heavily used waters (Devillers *et al.*, 2015; Jones & De Santo, 2016). This does not imply that deep-sea protection lacks ecological value. Ferrier scores are specific to the features, targets, and constraints included in the prioritization scenario (Ferrier *et al.*, 2000; Hanson *et al.*, 2024). Furthermore, deepwater chondrichthyans may have conservation needs not fully captured here (Finucci *et al.*, 2024). Rather, the results show that strategically located shelf and slope protection could generate greater representation gains for the assessed features than additional protection in already well-covered depth zones.

5 Limitations and Future Directions

The solutions identify spatial efficiency rather than direct economic or social feasibility. All planning units were assigned equal costs, and fishing effort, stakeholder preferences, enforcement capacity, other marine industries, and displacement of activities were not represented. This is important because public expectations and stakeholder participation can influence the legitimacy of MPAs, while well-established no-take areas can generate both ecological and human well-being benefits (Ban *et al.*, 2019; MacKeracher *et al.*, 2019; Raabe *et al.*, 2024). Furthermore, social aspects have often been overlooked within chondrichthyan conservation planning, confounding long-term outcomes (MacKeracher *et al.*, 2019; C. A. Simpfendorfer *et al.*, 2021). Future analyses should incorporate these factors and examine trade-offs among biodiversity, ecosystem services, and social and economic objectives through cross-sectoral or multiple-use planning (Dabalà *et al.*, 2023; Fourchault *et al.*, 2024; Neubert *et al.*, 2025).

The analysis was also two-dimensional and based on present-day distributions. Species differ in their use of the water column, making fishing impacts vary with gear, depth, and season (Clarke *et al.*, 2018; Cortés *et al.*, 2010). Three-dimensional approaches (e.g., *prior3D* R package) could incorporate depth-specific distributions, costs, and protection levels to better represent these differences (Doxa *et al.*, 2025). Seasonal distributions and fishing activity could similarly support dynamic or seasonal measures. Climate change was also not considered, although shifts in species distributions and environmental conditions may alter the future value of currently selected areas. Climate scenarios could therefore be incorporated into future scenarios to improve the long-term robustness of MPAs (Buenafe *et al.*, 2023).

Only no-movement ISRAs were included, as movement ISRAs are often extensive and cannot necessarily be managed through full-area protection (IUCN SSC Shark Specialist Group, 2024). Rohner *et al.* (2025) demonstrated that the inclusion of large movement ISRAs can influence costs and spatial solutions. Future studies could instead identify bottlenecks, high-use sections, and links among critical habitats and represent them through connectivity objectives, species-specific weights, or seasonal fisheries measures. Furthermore, the exclusion of the riverine portions of the ISRAs may have underestimated protection needs for species that depend on estuaries and rivers during part of their life cycle. Green and Largetooth Sawfishes (*Pristis zijsron* and *P. pristis*), for example, use riverine, estuarine, and mangrove habitats as important nurseries (Kyne *et al.*, 2021; Yan *et al.*, 2021). Planning for these species should connect marine, coastal, and freshwater management.

The analysis did not represent prey species, other taxa, or wider trophic interactions, and may therefore overlook ecological relationships needed for the long-term persistence of chondrichthyans and broader marine biodiversity. Future planning could integrate ISRAs with prey distributions and other taxon-specific approaches, such as Important Bird and Biodiversity Areas, Important Marine Mammal Areas, and Important Marine Turtle Areas. Together, these datasets could support more ecosystem-based planning and provide evidence for broader frameworks such as Key Biodiversity Areas (Boyd *et al.*, 2025; Butchart *et al.*, 2026; McGowan *et al.*, 2018; Plumptre *et al.*, 2023; Tetley *et al.*, 2022).

Uncertainty in species distributions represents an additional limitation. Besides the AquaX distributions used, IUCN maps are often implemented (i.e., expert-derived representations of known or inferred range). Both approaches are subject to uncertainty, and their agreement can depend strongly on environmental filtering and data availability (O'Hara *et al.*, 2017). Ten species were absent from the AquaX data, illustrating that conservation features may be omitted (**Supplementary Table 4**). This can be consequential for highly range-restricted species, such as the Maugean Skate (*Zearaja maugeana*), whose remaining population is confined to Macquarie Harbour and may not be adequately represented in a national-scale model (Moreno *et al.*, 2025). Future analyses should compare alternative distribution datasets, incorporate uncertainty explicitly, and validate priorities using monitoring and expert knowledge.

Finally, the sensitivity analysis showed little change when targets were scaled by IUCN status, endemism, and range size (**Supplementary Figure 5**). This may partly reflect the problem's limited flexibility given a small leftover budget. Nevertheless, representation targets are normative assumptions rather than direct estimates of the area required for species persistence (Jung *et al.*, 2021). Range size may also be an incomplete basis for setting targets for species like chondrichthyans with complex movements, uneven habitat uses, or concentrated life-history functions. Future work should compare policy-based targets with species-specific targets informed by population viability, habitat requirements, and threat exposure. Recent proposals to update representation standards provide a useful starting point, but marine and chondrichthyan-specific guidance is still required (Sreekar & Watson, 2026).

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisors, Tom Van der Stocken and Anthony Richardson, for their guidance, feedback, and support throughout this study. I am grateful to Chris Rohner for his invaluable expertise and assistance regarding Important Shark and Ray Areas. I also thank Daniel Dunn, Angela Liu, Jaime Restrepo, Kristine Buenafe, Peter Kyne, Alvise Dabalà, and Jason Everett for their advice and contributions. I gratefully acknowledge the Important Shark and Ray Areas and AquaX teams for providing access to the data used in this research. This study was undertaken as part of the Erasmus Mundus Joint Master Degree in Tropical Biodiversity and Ecosystems, TROPIMUNDO, funded by the European Commission.

REFERENCES

Arnold, A. E., Matsushiba, J. H., & Dulvy, N. K. (2026). Sharks, rays and MPAs: A global assessment of Marine Protected Area coverage in national waters across species ranges. *Conservation Letters*. https://doi.org/https://doi.org/10.1111/con4.70071

Ban, N. C., Gurney, G. G., Marshall, N. A., Whitney, C. K., Mills, M., Gelcich, S., Bennett, N. J., Meehan, M. C., Butler, C., Ban, S., Tran, T. C., Cox, M. E., & Breslow, S. J. (2019). Well-being outcomes of Marine Protected Areas. In *Nature Sustainability* (Vol. 2, Number 6, pp. 524–532). Nature Publishing Group. https://doi.org/10.1038/s41893-019-0306-2

Baum, J. K., & Worm, B. (2009). Cascading top-down effects of changing oceanic predator abundances. In *Journal of Animal Ecology* (Vol. 78, Number 4, pp. 699–714). https://doi.org/10.1111/j.1365-2656.2009.01531.x

BirdLife International. (2006). *Monitoring Important Bird Areas: a global framework: 1.2*.

Birkmanis, C. A., Partridge, J. C., Simmons, L. W., Heupel, M. R., & Sequeira, A. M. M. (2020). Shark conservation hindered by lack of habitat protection. *Global Ecology and Conservation*, *21*. https://doi.org/10.1016/j.gecco.2019.e00862

Boyd, C., Charles, R., García-Rodríguez, E., Gonzalez-Pestana, A., Kyne, P. M., Rohner, C. A., Notarbartolo di Sciara, G., & Jabado, R. W. (2025). Applying the Key Biodiversity Area standard to important sites for sharks. *Conservation Letters*, *18*(3). https://doi.org/10.1111/conl.13117

Buenafe, K. C. V., Dunn, D. C., Everett, J. D., Brito-Morales, I., Schoeman, D. S., Hanson, J. O., Dabalà, A., Neubert, S., Cannicci, S., Kaschner, K., & Richardson, A. J. (2023). A metric-based framework for climate-smart conservation planning. *Ecological Applications*, *33*(4). https://doi.org/10.1002/eap.2852

Butchart, S. H. M., Crowe, O., Scott, T., Plumptre, A. J., Eldred, M., McKee, E., Waliczky, Z., Hasani, I. Al, Azpiroz, A. B., Baisero, D., Barasa, F., Beresford, A. E., Bezeng, B. S., Boyd, C., Brooks, T. M., Buchanan, G., Bunting, G., Capellan, S., Cox, N., … Upgren, A. (2026). Extent, characteristics and policy applications of Key Biodiversity Areas. *Biological Reviews*. https://doi.org/10.1002/brv.70144

CBD. (2022, December 19). *Kunming-Montreal global biodiversity framework*. https://www.cbd.int/conferences/post20202CBD/WG8J/11/7,CBD/SBSTTA/23/9,CBD/SBSTTA/24/12andCBD/SBI/3/21,respectively.

Clarke, T. M., Espinoza, M., Romero Chaves, R., & Wehrtmann, I. S. (2018). Assessing the vulnerability of demersal elasmobranchs to a data-poor shrimp trawl fishery in Costa Rica, Eastern Tropical Pacific. *Biological Conservation*, *217*, 321–328. https://doi.org/10.1016/J.BIOCON.2017.11.015

Cochran, J. E. M., Charles, R., Temple, A. J., Kyne, P. M., García-Rodríguez, E., Gonzalez-Pestana, A., Batlle-Morera, A., Mouton, T. L., Armstrong, A. O., Rohner, C. A., Coker, D. J., Hardenstine, R. S., Kattan, A., McIvor, A. J., Peinemann, V. N., O'Toole, K. A., Palm, L., Richardson, E. B., Akhilesh, K. V., … Jabado, R. W. (2026). Only one percent of Important Shark and Ray Areas in the Western Indian Ocean are fully protected from fishing pressure. *Ecology and Evolution*, *16*(1). https://doi.org/10.1002/ece3.72690

Commonwealth of Australia. (2024). *Achieving 30 by 30 on land: National roadmap for protecting and conserving 30% of Australia's land by 2030, Commonwealth of Australia 2024*. www.dcceew.gov.au/about/contact

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M. N., Ribera, M., & Simpfendorfer, C. (2010). Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquatic Living Resources*, *23*(1), 25–34. https://doi.org/10.1051/alr/2009044

Dabalà, A., Dahdouh-Guebas, F., Dunn, D. C., Everett, J. D., Lovelock, C. E., Hanson, J. O., Buenafe, K. C. V., Neubert, S., & Richardson, A. J. (2023). Priority areas to protect mangroves and maximise ecosystem services. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-41333-3

Davidson, L. N. K., & Dulvy, N. K. (2017). Global Marine Protected Areas to prevent extinctions. *Nature Ecology and Evolution*, *1*(2). https://doi.org/10.1038/s41559-016-0040

Day, J., Dudley, N., Hockings, M., Holmes, G., Laffoley, D., Stolton, S., & Wells, S. (2012). *Guidelines for applying the IUCN protected area management categories to Marine Protected Areas*. www.iucn.org/pa_guidelines

Dedman, S., Moxley, J. H., Papastamatiou, Y. P., Braccini, M., Caselle, J. E., Chapman, D. D., Cinner, J. E., Dillon, E. M., Dulvy, N. K., Dunn, R. E., Espinoza, M., Harborne, A. R., Harvey, E. S., Heupel, M. R., Huveneers, C., Graham, N. A. J., Ketchum, J. T., Klinard, N. V., Kock, A. A., … Heithaus, M. R. (2024). Ecological roles and importance of sharks in the Anthropocene Ocean. In *Science* (Vol. 385, Number 6708). American Association for the Advancement of Science. https://doi.org/10.1126/science.adl2362

Devillers, R., Pressey, R. L., Grech, A., Kittinger, John. N., Edgar, G. J., Ward, T., & Watson, R. (2015). Reinventing residual reserves in the sea: Are we favouring ease of establishment over need for protection? *Aquatic Conservation: Marine and Freshwater Ecosystems*, (25), 480–504.

Doxa, A., Adam, C., Nagkoulis, N., Mazaris, A. D., & Katsanevakis, S. (2025). prior3D: An R package for three-dimensional conservation prioritization. *Ecological Modelling*, *499*. https://doi.org/10.1016/j.ecolmodel.2024.110919

Dulvy, N. K., Pacoureau, N., Matsushiba, J. H., Yan, H. F., VanderWright, W. J., Rigby, C. L., Finucci, B., Sherman, C. S., Jabado, R. W., Carlson, J. K., Pollom, R. A., Charvet, P., Pollock, C. M., Hilton-Taylor, C., & Simpfendorfer, C. A. (2024). Ecological erosion and expanding extinction risk of sharks and rays. *Science*, *386*(6726), eadn1477. https://doi.org/10.1126/science.adn1477

Dulvy, N. K., Pacoureau, N., Rigby, C. L., Pollom, R. A., Jabado, R. W., Ebert, D. A., Finucci, B., Pollock, C. M., Cheok, J., Derrick, D. H., Herman, K. B., Sherman, C. S., VanderWright, W. J., Lawson, J. M., Walls, R. H. L., Carlson, J. K., Charvet, P., Bineesh, K. K., Fernando, D., … Simpfendorfer, C. A. (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Current Biology*, *31*(21), 4773-4787.e8. https://doi.org/10.1016/j.cub.2021.08.062

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., Barrett, N. S., Becerro, M. A., Bernard, A. T. F., Berkhout, J., Buxton, C. D., Campbell, S. J., Cooper, A. T., Davey, M., Edgar, S. C., Försterra, G., Galván, D. E., Irigoyen, A. J., Kushner, D. J., … Thomson, R. J. (2014). Global conservation outcomes depend on Marine Protected Areas with five key features. *Nature*, *506*(7487), 216–220. https://doi.org/10.1038/nature13022

Ellis, J. R., McCully Phillips, S. R., & Poisson, F. (2017). A review of capture and post-release mortality of elasmobranchs. In *Journal of Fish Biology* (Vol. 90, Number 3, pp. 653–722). Blackwell Publishing Ltd. https://doi.org/10.1111/jfb.13197

Faure-Beaulieu, N., Lombard, A. T., Olbers, J., Goodall, V., da Silva, C., Daly, R., Jordaan, G., Kerwath, S. E., Kock, A., Mann, B. Q., Murray, T. S., Albano, P., Cliff, G., dos Santos, N. A., Gennari, E., Hammerschlag, N., Bester-van der Merwe, A. E., Watson, R., Andreotti, S., … Harris, J. (2023). A systematic conservation plan identifying critical areas for improved chondrichthyan protection in South Africa. *Biological Conservation*, *284*. https://doi.org/10.1016/j.biocon.2023.110163

Fernández Bejarano, S. J., & Phol, L. (2024). *mregions2: Access Data from Marineregions.org: Gazetteer & Data Products*. https://doi.org/10.32614/CRAN.package.mregions2

Ferrier, S., Pressey, R. L., & Barrett, T. W. (2000). A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. *Biological Conservation*, (93), 303–325. www.elsevier.com/locate/biocon

Finucci, B., Pacoureau, N., Rigby, C. L., Matsushiba, J. H., Faure-Beaulieu, N., Sherman, C. S., VanderWright, W. J., Jabado, R. W., Charvet, P., Mejía-Falla, P. A., Navia, A. F., Derrick, D. H., Kyne, P. M., Pollom, R. A., Walls, R. H. L., Herman, K. B., Kinattumkara, B., Cotton, C. F., Cuevas, J.-M., … Dulvy, N. K. (2024). Fishing for oil and meat drives irreversible defaunation of deepwater sharks and rays. *Science*, *383*(6687), 1135–1141. https://doi.org/10.1126/science.ade9121

Fitzsimons, J. A. (2011). Mislabeling Marine Protected Areas and why it matters-a case study of Australia. *Conservation Letters*, *4*(5), 340–345. https://doi.org/10.1111/j.1755-263X.2011.00186.x

Fleury, A. G., O'Hara, C. C., Butt, N., Restrepo, J., Halpern, B. S., Klein, C. J., Kuempel, C. D., Gaynor, K. M., Bentley, L. K., Richardson, A. J., & Dunn, D. C. (2024). Spatial and life history variation in a trait-based species vulnerability and impact model. *PLoS ONE*, *19*(6). https://doi.org/10.1371/journal.pone.0305950

Flowers, K. I., Heithaus, M. R., & Papastamatiou, Y. P. (2021). Buried in the sand: Uncovering the ecological roles and importance of rays. *Fish and Fisheries*, *22*(1), 105–127. https://doi.org/10.1111/faf.12508

Fourchault, L., Dahdouh-Guebas, F., Dunn, D. C., Everett, J. D., Hanson, J. O., Buenafe, K. C. V., Neubert, S., Dabalà, A., Yapa, K. K. A. S., Cannicci, S., & Richardson, A. J. (2024). Generating affordable protection of high seas biodiversity through cross-sectoral spatial planning. *One Earth*, *7*(2), 253–264. https://doi.org/10.1016/j.oneear.2023.12.006

Gearty, W., & Chamberlain, S. (2025). *rredlist: IUCN Red List Client*. https://doi.org/10.32614/CRAN.package.rredlist

Gilman, E., Chaloupka, M., Benaka, L. R., Bowlby, H., Fitchett, M., Kaiser, M., & Musyl, M. (2022). Phylogeny explains capture mortality of sharks and rays in pelagic longline fisheries: A global meta-analytic synthesis. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-022-21976-w

Giménez, J., Cardador, L., Mazor, T., Kark, S., Bellido, J. M., Coll, M., & Navarro, J. (2020). Marine Protected Areas for demersal elasmobranchs in highly exploited Mediterranean ecosystems. *Marine Environmental Research*, *160*, 105033. https://doi.org/10.1016/J.MARENVRES.2020.105033

Gurobi Optimization, & LLC. (2026). *gurobi: Gurobi Optimizer 13.0 interface*. https://www.gurobi.com

Halpern, B. S., Frazier, M., Afflerbach, J., Lowndes, J. S., Micheli, F., O'Hara, C., Scarborough, C., & Selkoe, K. A. (2019). Recent pace of change in human impact on the world's ocean. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-47201-9

Hanson, J. O., Schuster, R., Strimas-Mackey, M., Morrell, N., Edwards, B. P. M., Arcese, P., Bennett, J. R., & Possingham, H. P. (2024). Systematic conservation prioritization with the prioritizr R package. *Conservation Biology*, *39*(1). https://doi.org/10.1111/cobi.14376

Harry, A. V., Everett, B., Faria, V., Fordham, S., Grand, M. I., Haque, A. B., Ho, H., Jabado, R. W., Jones, G. C. A., Lear, K. O., Morgan, D. L., Philips, N. M., Spaet, J. L. Y., Tanna, A., & Wuerigner, B. E. (2022). Pristis zijsron. The IUCN Red List of Threatened Species 2022: e.T39393A58304631. In *IUCN Red List of Threatened Species*. https://doi.org/https://doi.org/10.2305/IUCN.UK.2022-2.RLTS.T39393A58304631.en

Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008). Predicting ecological consequences of marine top predator declines. *Trends in Ecology and Evolution*, *4*(23), 202–210. www.lenfestocean.org

Henriksen, M., Barnett, A., Butcher, P., Chin, A., Frisch, K., Green, M., How, J., McPhee, D., Mikitis, M., Scott-Holland, T., Simpfendorfer, C., Taylor, S., & Huveneers, C. (2025). Novel risk assessment framework to compare shark-bite mitigation strategies. *People and Nature*, *7*(7), 1559–1580. https://doi.org/10.1002/pan3.70054

Heupel, M. R., Simpfendorfer, C. A., Espinoza, M., Smoothey, A. F., Tobin, A., & Peddemors, V. (2015). Conservation challenges of sharks with continental scale migrations. *Frontiers in Marine Science*, *2*(FEB). https://doi.org/10.3389/fmars.2015.00012

Hyde, C. A., Notarbartolo di Sciara, G., Sorrentino, L., Boyd, C., Finucci, B., Fowler, S. L., Kyne, P. M., Leurs, G., Simpfendorfer, C. A., Tetley, M. J., Womersley, F., & Jabado, R. W. (2022). Putting sharks on the map: A global standard for improving shark area-based conservation. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.968853

IUCN Red List. (2026). *The IUCN red list of threatened Species*. https://www.iucnredlist.org

IUCN SSC Shark Specialist Group. (2024). *Important Shark and Ray Area (ISRA): Guidance on Criteria Application 3rd Edition*.

Jabado, R. W., García-Rodríguez, E., Armstrong, A. O., Rohner, C. A., Palacios, M. D., Gonzalez-Pestana, A., Bettcher, B. V., Charles, R., & Batlle-Morera, A. (2024). *New Zealand and Pacific Islands: A regional compendium of Important Shark and Ray Areas*. www.sharkrayareas.org

Jabado, R. W., García-Rodríguez, E., Kyne, P. M., Charles, R., Bettcher, B. V., Armstrong, A. O., Gonzalez-Pestana, A., Batlle-Morera, A., Palacios, M. D., & Rohner, C. A. (2024). *Polar Waters: A regional compendium of Important Shark and Ray Areas*. www.sharkrayareas.org

Jabado, R. W., García-Rodríguez, E., Kyne, P. M., Rohner, C. A., Palacios, M. D., Armstrong, A. O., Gonzalez-Pestana, A., Bettcher, B. V., Charles, R., & Batlle-Morera, A. (2026). *Australia and Southeast Indian Ocean: A regional compendium of Important Shark and Ray Areas*. www.sharkrayareas.org

Jones, P. J. S., & De Santo, E. M. (2016). Is the race for remote, Very Large Marine Protected Areas (VLMPAs) taking us down the wrong track? *Marine Policy*, *73*, 231–234. https://doi.org/10.1016/J.MARPOL.2016.08.015

Jouffray, J. B., Blasiak, R., Norström, A. V., Österblom, H., & Nyström, M. (2020). The blue acceleration: The trajectory of human expansion into the ocean. In *One Earth* (Vol. 2, Number 1, pp. 43–54). Cell Press. https://doi.org/10.1016/j.oneear.2019.12.016

Jung, M., Arnell, A., de Lamo, X., García-Rangel, S., Lewis, M., Mark, J., Merow, C., Miles, L., Ondo, I., Pironon, S., Ravilious, C., Rivers, M., Schepaschenko, D., Tallowin, O., van Soesbergen, A., Govaerts, R., Boyle, B. L., Enquist, B. J., Feng, X., … Visconti, P. (2021). Areas of global importance for conserving terrestrial biodiversity, carbon and water. *Nature Ecology and Evolution*, *5*(11), 1499–1509. https://doi.org/10.1038/s41559-021-01528-7

Klein, C. J., Brown, C. J., Halpern, B. S., Segan, D. B., McGowan, J., Beger, M., & Watson, J. E. M. (2015). Shortfalls in the global protected area network at representing marine biodiversity. *Scientific Reports*, *5*. https://doi.org/10.1038/srep17539

Kyne, P. M. ., Heupel, M. R. ., White, W. T. ., & Simpfendorfer, C. A. . (2021). *The action plan for Australian sharks and rays 2021*. National Environmental Science Program, Marine Biodiversity Hub.

Lester, S. E., Halpern, B. S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B. I., Gaines, S. D., Airamé, S., & Warner, R. R. (2009). Biological effects within no-take marine reserves: A global synthesis. *Marine Ecology Progress Series*, *384*, 33–46. https://doi.org/10.3354/meps08029

MacKeracher, T., Diedrich, A., & Simpfendorfer, C. A. (2019). Sharks, rays and marine protected areas: A critical evaluation of current perspectives. *Fish and Fisheries*, *20*(2), 255–267. https://doi.org/10.1111/faf.12337

MacNeil, M. A., Chapman, D. D., Heupel, M., Simpfendorfer, C. A., Heithaus, M., Meekan, M., Harvey, E., Goetze, J., Kiszka, J., Bond, M. E., Currey-Randall, L. M., Speed, C. W., Sherman, C. S., Rees, M. J., Udyawer, V., Flowers, K. I., Clementi, G., Valentin-Albanese, J., Gorham, T., … Cinner, J. E. (2020). Global status and conservation potential of reef sharks. *Nature*, *583*(7818), 801–806. https://doi.org/10.1038/s41586-020-2519-y

McGowan, J., Smith, R. J., Di Marco, M., Clarke, R. H., & Possingham, H. P. (2018). An evaluation of Marine Important Bird and Biodiversity Areas in the context of spatial conservation prioritization. In *Conservation Letters* (Vol. 11, Number 3). Wiley-Blackwell. https://doi.org/10.1111/conl.12399

Moreno, D., Tracey, S., Woolley, B., Semmens, J. M., & Semmens, J. (2025). *2014-2024 Macquarie Harbour Maugean skate population status and monitoring report*.

Mouton, T. L., Gonzalez-Pestana, A., Rohner, C. A., Charles, R., García-Rodríguez, E., Kyne, P. M., Batlle-Morera, A., di Sciara, G. N., Armstrong, A. O., Acuña, E., Alfaro-Shigueto, J., Arauz, R., Avalos-Castillo, C. G., Augustinus, E., Bessudo, S., Barraza, E., Bustamante, C., Chávez, E. J., Espinoza, E. R., … Jabado, R. W. (2025). Shortfalls in the protection of Important Shark and Ray Areas undermine shark conservation efforts in the Central and South American Pacific. *Marine Policy*, *171*. https://doi.org/10.1016/j.marpol.2024.106448

MPAtlas. (2026, June 19). *The Marine Protection Atlas*. Marine Conservation Institute. https://mpatlas.org

Neubert, S., McGowan, J., Metcalfe, K., Hanson, J. O., Buenafe, K. C. V., Dabalà, A., Dunn, D. C., Everett, J. D., Possingham, H. P., Stelzenmüller, V., Estep, A., Ervin, J., & Richardson, A. J. (2025). Multiple-use spatial planning for sustainable development and conservation. *Trends in Ecology & Evolution*, *40*(11), 1126–1142. https://doi.org/10.1016/J.TREE.2025.09.007

O'Hara, C. C., Afflerbach, J. C., Scarborough, C., Kaschner, K., & Halpern, B. S. (2017). Aligning marine species range data to better serve science and conservation. *PLoS ONE*, *12*(5). https://doi.org/10.1371/journal.pone.0175739

Pike, E. P., MacCarthy, J. M. C., Hameed, S. O., Harasta, N., Grorud-Colvert, K., Sullivan-Stack, J., Claudet, J., Horta e Costa, B., Gonçalves, E. J., Villagomez, A., & Morgan, L. (2024). Ocean protection quality is lagging behind quantity: Applying a scientific framework to assess real marine protected area progress against the 30 by 30 target. In *Conservation Letters* (Vol. 17, Number 3). John Wiley and Sons Inc. https://doi.org/10.1111/conl.13020

Pimiento, C., Albouy, C., Silvestro, D., Mouton, T. L., Velez, L., Mouillot, D., Judah, A. B., Griffin, J. N., & Leprieur, F. (2023). Functional diversity of sharks and rays is highly vulnerable and supported by unique species and locations worldwide. *Nature Communications*, *14*(1). https://doi.org/10.1038/s41467-023-43212-3

Plumptre, A. J., Butchart, S. H. M., von Staden, L., Smith, R. J., Matimele, H., Starnes, T., Brooks, T. M., Baisero, D., Costa, H., & Duarte, E. (2023). Key Biodiversity Areas are proving useful for spatial planning if the criteria are applied correctly. *Perspectives in Ecology and Conservation*, *21*(3), 263–264. https://doi.org/10.1016/J.PECON.2023.07.001

R Core Team. (2026). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Raabe, N. L., King, T. J., Cardilini, A. P. A., Miller, K. K., Bangay, S., & Singleton, A. (2024). Casting a wider net: A national survey of Australian attitudes to Marine Protected Areas. *Ocean and Coastal Management*, *251*. https://doi.org/10.1016/j.ocecoaman.2024.107100

Relano, V., & Pauly, D. (2023). The 'Paper Park Index': Evaluating Marine Protected Area effectiveness through a global study of stakeholder perceptions. *Marine Policy*, *151*. https://doi.org/10.1016/j.marpol.2023.105571

Reygondeau, G., Egorova, Y., Boerder, K., Tittensor, D. P., Kaschner, K., Kesner-Reyes, K., Bailly, N., & Cheung, W. W. L. (2026). AquaX: An enhanced and revised AquaMaps framework to model marine species distributions and biodiversity. *PLOS One*, *21*(2). https://doi.org/10.1371/journal.pone.0335823

Riley, M., Meagher, P., Huveneers, C., Leto, J., Peddemors, V. M., Slip, D., West, J., & Bradshaw, C. J. A. (2022). The Australian shark-incident database for quantifying temporal and spatial patterns of shark-human conflict. *Scientific Data*, *9*(1). https://doi.org/10.1038/s41597-022-01453-9

Rodrigues, A. S. L., Resit Akçakaya, H., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Chanson, J. S., Fishpool, L. D. C., Da Fonseca, G. A. B., Gaston, K. J., Hoffmann, M., Marquet, P. A., Pilgrim, J. D., Pressey, R. L., Schipper, J., Sechrest, W., Stuart, S. N., Underhill, L. G., Waller, R. W., … Yan, X. (2004). *Global gap analysis: Priority regions for expanding the global protected-area network* (Vol. 54, Number 12).

Rohner, C. A., Richardson, A. J., García-Rodríguez, E., Charles, R., Batlle-Morera, A., Bortoluzzi, J. R., Mouton, T. L., Notarbartolo di Sciara, G., Armstrong, A. O., Everett, J. D., Bakiu, R., Barash, A., Bariche, M., Başusta, N., Bousquet, C., Ćetković, I., Giovos, I., Guallart, J., Milazzo, M., … Jabado, R. W. (2025). Important Shark and Ray Areas can inform conservation planning in the Mediterranean and Black Seas. *IScience*, *28*(8). https://doi.org/10.1016/j.isci.2025.113192

Ryan, L. A., Lynch, S. K., Harcourt, R., Slip, D. J., Peddemors, V., Everett, J. D., Harrison, L. M., & Hart, N. S. (2019). Environmental predictive models for shark attacks in Australian waters. *Marine Ecology Progress Series*, *631*, 165–179. https://doi.org/10.3354/meps13138

Sala, E., & Giakoumi, S. (2018). No-take marine reserves are the most effective protected areas in the ocean. *ICES Journal of Marine Science*, *75*(3), 1166–1168. https://doi.org/10.1093/icesjms/fsx059

Shea, B. D., Gallagher, A. J., Bomgardner, L. K., & Ferretti, F. (2023). Quantifying longline bycatch mortality for pelagic sharks in western Pacific shark sanctuaries. *Science Advances*. https://www.science.org

Sherman, K., & Alexander, L. (1986). *Variability and management of large marine ecosystems*. Westview Press, Inc.,Boulder, CO. https://www.osti.gov/biblio/6958679

Simpfendorfer, C. A., Heupel, M. R., & Kendal, D. (2021). Complex human-shark conflicts confound conservation action. *Frontiers in Conservation Science*, *2*. https://doi.org/10.3389/fcosc.2021.692767

Simpfendorfer, C., Chin, A., Rigby, C., Sherman, S., & White, W. (2019). *Shark futures: A report card for Australia's sharks and rays*. www.frdc.com.au

Sreekar, R., & Watson, J. E. M. (2026). Updating species representation targets for protected and conserved area planning. *Nature Reviews Biodiversity*. https://doi.org/10.1038/s44358-026-00169-7

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

Turnbull, J. W., Johnston, E. L., & Clark, G. F. (2021). Evaluating the social and ecological effectiveness of partially protected marine areas. *Conservation Biology*, *35*(3), 921–932. https://doi.org/10.1111/cobi.13677

UNEP-WCMC. (2019). *User manual for the World Database on Protected Areas and world database on other effective area-based conservation measures: 1.6*. http://wcmc.io/WDPA_Manual

UNEP-WCMC, & IUCN. (2026). Protected Planet: The World Database on Protected Areas (WDPA). In *2026*. UNEP-WCMC and IUCN. https://www.protectedplanet.net/en

Vianna, G. M. S., Meekan, M. G., Ruppert, J. L. W., Bornovski, T. H., & Meeuwig, J. J. (2016). Indicators of fishing mortality on reef-shark populations in the world's first shark sanctuary: The need for surveillance and enforcement. *Coral Reefs*, *35*(3), 973–977. https://doi.org/10.1007/s00338-016-1437-9

Ward-Paige, C. A., & Worm, B. (2017). Global evaluation of shark sanctuaries. *Global Environmental Change*, *47*, 174–189. https://doi.org/10.1016/j.gloenvcha.2017.09.005

Watson, J. E. M., Venegas-Li, R., Grantham, H., Dudley, N., Stolton, S., Rao, M., Woodley, S., Hockings, M., Burkart, K., Simmonds, J. S., Sonter, L. J., Sreekar, R., Possingham, H. P., & Ward, M. (2023). Priorities for protected area expansion so nations can meet their Kunming-Montreal Global Biodiversity Framework commitments. In *Integrative Conservation* (Vol. 2, Number 3, pp. 140–155). Blackwell Publishing. https://doi.org/10.1002/inc3.24

WHO, & CBD. (2015). *Connecting global priorities: Biodiversity and human health a state of knowledge review*.

Yan, H. F., Kyne, P. M., Jabado, R. W., Leeney, R. H., Davidson, L. N. K., Derrick, D. H., Finucci, B., Freckleton, R. P., Fordham, S. V, & Dulvy, N. K. (2021). Overfishing and habitat loss drives range contraction of iconic marine fishes to near extinction. In *Sci. Adv* (Vol. 7). https://www.science.org

SUPPLEMENTARY

Supplementary Table 1: Definitions of the Marine Protected Area status categories used by the World Database on Protected Areas (UNEP-WCMC, 2019). *MPAs with a status of Designated, Established, or Inscribed were retained for this study. Proposed status was excluded. Adopted status does not apply to the Australian study area.*

Status	Definition
Adopted	Only applicable to protected areas designated as Specially Protected Area of Marine Importance under the Barcelona Convention.
Designated	The protected area is recognized or dedicated through legal/formal means. Implies specific binding commitment to conservation in the long term.
Established	The protected area is recognized or dedicated through other effective means. Implies commitment to conservation outcomes in the long term, but not necessarily with legal or formal recognition.
Inscribed	Only applicable to protected areas designated under the World Heritage Convention.
Proposed	The protected area is in the process of being legally/formally designated. It should be noted that sites may sometimes be functioning as protected areas while proposed, as the legal processes of designation may take a long time.

Supplementary Table 2: Marine protected area (MPA) coverage and Important Shark and Ray Area (ISRA) extent within the Australian Exclusive Economic Zone *(EEZ; total area = 8,992,894 km^2). MPA categories follow the WDPA no-take classification. ISRA areas are calculated from polygon overlap, with the combined ISRA total accounting for spatial overlap between no-movement and movement ISRAs.*

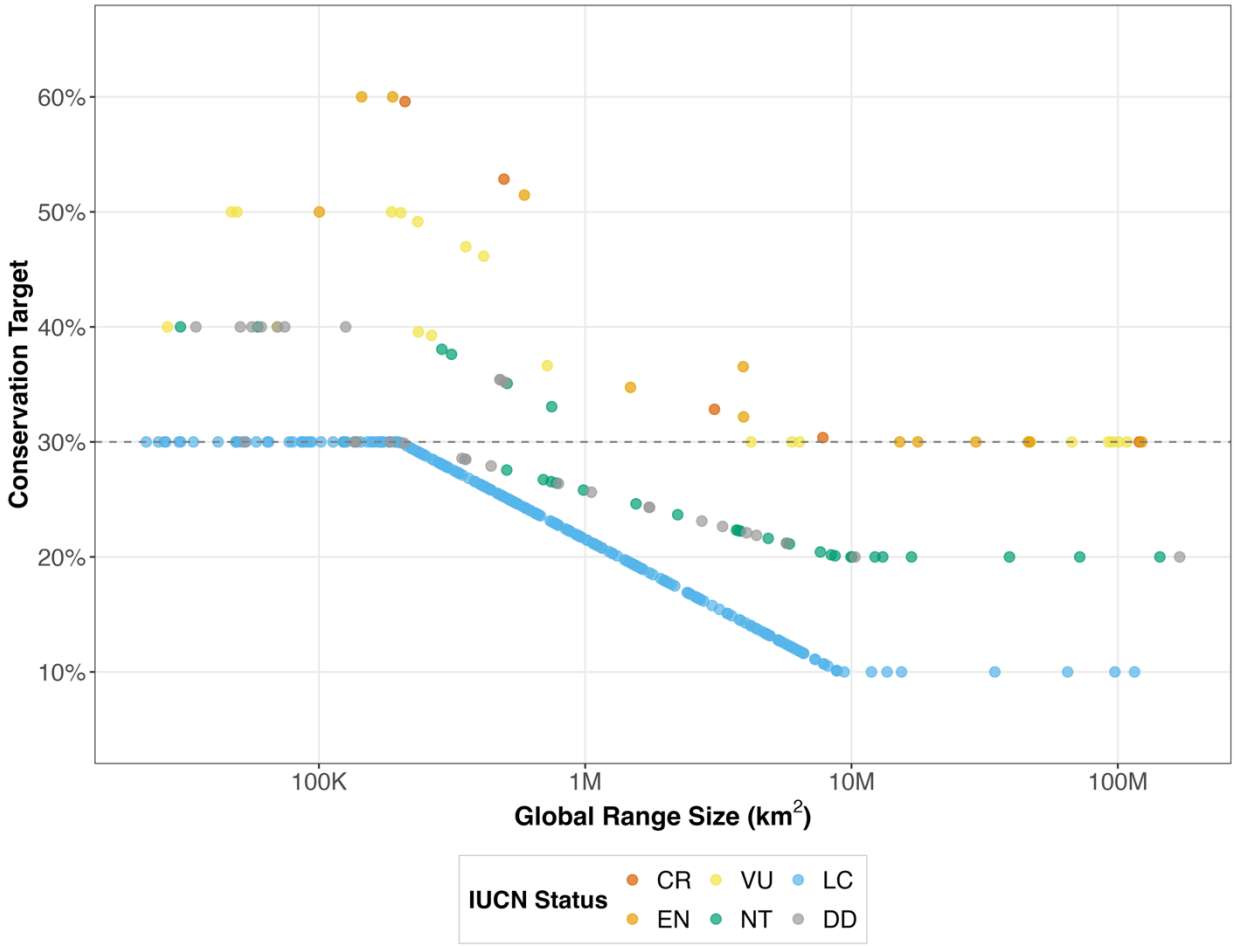
Layer	n	Area (km^2)	% of EEZ
No-take MPA	153	2,164,898	24.1
Part no-take MPA	93	1,423,615	15.8
Take-permitted MPA	198	853,855	9.6
Not reported MPA	368	23,220	0.3
Total MPAs	**812**	**4,465,588**	**49.6**
No-movement ISRAs	148	202,103	2.2
Movement ISRAs	13	1,174,713	13.1
Total ISRAs	**161**	**1,306,370**	**14.5**

Supplementary Table 3: Definitions of the criteria and subcriteria used by the IUCN Species Survival Commission Shark Specialist Group to identify Important Shark and Ray Areas (IUCN SSC Shark Specialist Group, 2024). *The criteria are non-hierarchical.*

(Sub)Criteria	Definition
A – Vulnerability	Areas important to persistence and recovery of threatened sharks *This criterion must be associated with an additional criterion*.
B – Range Restricted	Areas holding the regular and/or predictable presence of range-restricted sharks, that are occupied year-round or seasonally.
C – Life History	Areas that are important to sharks for carrying out vital functions across their life cycle.
C1 – Reproductive Area	Areas that are important for sharks to mate, give birth, lay eggs, or provide refuge and other advantages to the young.
C2 – Feeding Area	Areas that are important for shark nutrition at one or more life-cycle stages.
C3 – Resting Area	Areas that are important for sharks to conserve energy, often related to environmental conditions or temporal factors.
C4 – Movement	Areas used by sharks regularly or predictably during their movements, such as migrations, which contribute to connectivity of other functionally important areas.
C5 – Undefined Aggregations	Areas where an aggregation or assemblage of sharks regularly and/or predictably occur, year-round or seasonally, but the function of the aggregation or assemblage is currently unknown.
D – Special Attributes	Areas important for sharks considered for distinct biological, behavioural, or ecological attributes (unique or associated with a unique habitat type), or which support an important diversity of species.
D1 – Distinctiveness	Areas with sharks that display distinct biological, behavioural, or ecological characteristics.
D2 – Diversity	Areas that sustain an important diversity of sharks.

Supplementary Table 4: Chondrichthyan species assessed in the Australian Shark Action Plan (Kyne et al., 2021) for which no AquaX species distribution map was available for Australian waters. *Australian IUCN Red List categories are given. Australian endemic species are indicated with an* •.

Order	Family	Scientific Name	Common Name	IUCN Red List Category
Carcharhiniformes	Carcharhinidae	*Rhizoprionodon oligolinx*	Grey Sharpnose Shark	DD
	Dichichthyidae	•*Dichichthys bigus*	Beige Bristle Shark	DD
Echinorhiniformes	Echinorhinidae	*Echinorhinus cookei*	Prickly Shark	DD
Heterodontiformes	Heterodontidae	•*Heterodontus marshallae*	Zebra Hornshark	DD
Myliobatiformes	Dasyatidae	*Pateobatis jenkinsii*	Jenkins' Whipray	LC
Rajiformes	Rajidae	•*Dentiraja endeavouri*	Endeavour Skate	NT
		•*Dipturus maugeanus*	Maugean Skate	EN
Squaliformes	Centrophoridae	*Deania calceus*	Brier Shark	NT
	Squalidae	*Squalus altipinnis*	Western Highfin Spurdog	LC



Supplementary Figure 1: Range-scaled conservation targets assigned to chondrichthyan species. *Maximum and minimum representation targets were determined by IUCN Red List category and endemism class (Table 1). Species with global ranges ≤200,000 km² and ≥ 8,992,894 km² (study area) were assigned the maximum and minimum target, respectively, with intermediate values interpolated on a log10 scale following Rodrigues et al. (2004).*

Supplementary Table 5: Spatial representation of all chondrichthyan species (n=335) within Australia's marine protected area (MPA) network. *Species are grouped by their Australian IUCN Red List Category, and values indicate the percentage of each species' AquaX distribution within the Australian Exclusive Economic Zone occurring in no-take MPAs, take-permitted MPAs (part no-take, take-permitted, and not reported), and areas outside MPAs. Endemic species and near-endemic species are assigned with a • and *, respectively.*

Scientific Name	Common Name	No-take MPA (%)	Take-permitted MPA (%)	Outside MPA (%)
Critically Endangered (CR)				
Carcharhinus longimanus	Oceanic Whitetip Shark	22.6	29.6	47.8
•*Cephaloscyllium albipinnum*	Whitefin Swellshark	4.9	9.9	85.2
•*Dentiraja confusa*	Australian Longnose Skate	1.1	5.6	93.4
Pristis pristis	Largetooth Sawfish	2.6	23.7	73.7
Pristis zijsron	Green Sawfish	6.6	23.2	70.2
Endangered (EN)				
Alopias pelagicus	Pelagic Thresher	15.5	13.4	71.1
**Centrophorus harrissoni*	Harrisson's Dogfish	6.4	16.7	77.0
•*Centrophorus uyato*	Southern Dogfish	1.8	15.0	83.2
Cetorhinus maximus	Basking Shark	17.6	5.0	77.4
•*Dipturus canutus*	Grey Skate	1.5	8.4	90.1
Galeorhinus galeus	School Shark	4.1	16.0	79.9
Mobula birostris	Giant Manta Ray	7.8	20.8	71.4
Pristis clavata	Dwarf Sawfish	7.5	26.2	66.4
Rhincodon typus	Whale Shark	24.9	27.9	47.2
Sphyrna lewini	Scalloped Hammerhead	5.9	23.9	70.2
Sphyrna mokarran	Great Hammerhead	7.9	21.9	70.2
•*Squalus chloroculus*	Greeneye Spurdog	6.8	13.5	79.7
•*Urolophus orarius*	Coastal Stingaree	4.8	30.2	65.0
Vulnerable (VU)				
Alopias superciliosus	Bigeye Thresher	22.9	30.6	46.5
Anoxypristis cuspidata	Narrow Sawfish	5.9	21.0	73.1
**Aptychotrema timorensis*	Spotted Shovelnose Ray	1.7	45.0	53.3
•*Brachaelurus colcloughi*	Colclough's Shark	23.8	9.4	66.8
Carcharhinus falciformis	Silky Shark	10.6	22.3	67.1
Carcharias taurus	Grey Nurse Shark	9.1	19.8	71.1
Carcharodon carcharias	White Shark	10.3	25.5	64.2
•*Dentiraja australis*	Sydney Skate	1.1	8.1	90.9
Eusphyra blochii	Winghead Shark	6.6	20.7	72.7
**Glyphis garricki*	Northern River Shark	1.3	39.0	59.7
**Glyphis glyphis*	Speartooth Shark	2.2	30.7	67.1
•*Hemitrygon fluviorum*	Estuary Stingray	23.0	10.5	66.5
Isurus oxyrinchus	Shortfin Mako	18.1	27.9	54.0
Isurus paucus	Longfin Mako	26.2	29.5	44.4

**Myliobatis hamlyni*	Purple Eagle Ray	13.8	22.7	63.6
•*Spiniraja whitleyi*	Melbourne Skate	4.3	13.8	81.9
•*Squatina albipunctata*	Eastern Angelshark	13.7	31.8	54.5
**Urolophus bucculentus*	Sandyback Stingaree	2.7	7.8	89.5
•*Urolophus sufflavus*	Yellowback Stingaree	0.6	7.5	91.9
•*Urolophus viridis*	Greenback Stingaree	1.0	6.2	92.9
Near Threatened (NT)				
Aetomylaeus vespertilio	Ornate Eagle Ray	6.7	21.3	72.0
Alopias vulpinus	Common Thresher	8.8	14.2	77.1
Carcharhinus amblyrhynchos	Grey Reef Shark	8.7	26.1	65.2
Carcharhinus obscurus	Dusky Shark	8.9	26.3	64.9
Carcharhinus plumbeus	Sandbar Shark	9.0	25.1	65.9
Centroscymnus owstonii	Owston's Dogfish	4.9	17.5	77.6
•*Cephaloscyllium variegatum*	Saddled Swellshark	11.5	24.7	63.9
**Chimaera ogilbyi*	Ogilby's Chimaera	2.1	9.3	88.7
Dalatias licha	Black Shark	10.6	21.6	67.9
Deania quadrispinosa	Longsnout Dogfish	1.8	13.1	85.1
•*Dentiraja cerva*	Whitespotted Skate	1.6	10.0	88.5
•*Dipturus gudgeri*	Bight Skate	1.3	12.3	86.4
Galeocerdo cuvier	Tiger Shark	6.1	23.5	70.5
Hemitrygon longicauda	Merauke Stingray	6.0	14.9	79.1
Mobula mobular	Giant Devilray	11.2	16.2	72.6
Mobula tarapacana	Chilean Devilray	5.3	15.2	79.5
Mobula thurstoni	Bentfin Devilray	4.7	18.1	77.2
**Neotrygon annotata*	Plain Maskray	0.7	22.5	76.8
Odontaspis ferox	Smalltooth Sandtiger Shark	2.3	24.8	72.9
Oxynotus bruniensis	Prickly Dogfish	0.9	8.6	90.5
Prionace glauca	Blue Shark	18.7	25.7	55.5
Rhina ancylostomus	Shark Ray	6.9	21.8	71.3
Rhynchobatus australiae	Bottlenose Wedgefish	6.7	21.3	72.0
**Rhynchobatus palpebratus*	Eyebrow Wedgefish	4.2	22.5	73.4
Scymnodon macracanthus	Largespine Velvet Dogfish	3.7	12.5	83.8
Sphyrna zygaena	Smooth Hammerhead	6.6	14.2	79.2
•*Squalus grahami*	Eastern Longnose Spurdog	15.8	41.0	43.3
**Squalus montalbani*	Philippine Spurdog	7.1	42.5	50.4
Triaenodon obesus	Whitetip Reef Shark	9.9	27.5	62.6
•*Trygonoptera testacea*	Common Stingaree	2.4	8.8	88.9
•*Urolophus kapalensis*	Kapala Stingaree	0.7	8.8	90.6
Least Concern (LC)				
Aetobatus ocellatus	Spotted Eagle Ray	8.7	22.5	68.8
Aetomylaeus caeruleofasciatus	Bluebanded Eagle Ray	7.6	21.3	71.1

**Amblyraja hyperborea*	Boreal Skate	23.0	5.7	71.3
Apristurus albisoma	White-bodied Catshark	45.3	24.4	30.3
Apristurus ampliceps	Roughskin Catshark	11.2	15.2	73.6
•*Apristurus australis*	Pinocchio Catshark	9.7	28.8	61.6
•*Apristurus bucephalus*	Bighead Catshark	4.4	17.4	78.2
Apristurus garricki	Garrick's Catshark	19.2	37.1	43.7
Apristurus longicephalus	Smoothbelly Catshark	7.7	19.2	73.1
Apristurus melanoasper	Fleshynose Catshark	7.2	12.2	80.5
Apristurus nakayai	Milk-eye Catshark	0.0	93.9	6.1
Apristurus pinguis	Bulldog Catshark	7.4	8.7	83.9
Apristurus platyrhynchus	Bigfin Catshark	9.0	37.2	53.8
Apristurus sinensis	Freckled Catshark	5.1	17.7	77.2
•*Aptychotrema rostrata*	Eastern Shovelnose Ray	15.6	16.7	67.7
•*Aptychotrema vincentiana*	Western Shovelnose Ray	5.9	20.9	73.2
•*Asymbolus analis*	Grey Spotted Catshark	0.7	5.7	93.6
**Asymbolus galacticus*	Starry Catshark	46.7	9.8	43.6
•*Asymbolus occiduus*	Western Spotted Catshark	6.9	20.4	72.7
•*Asymbolus pallidus*	Pale Spotted Catshark	16.5	76.1	7.4
•*Asymbolus parvus*	Dwarf Catshark	1.9	30.5	67.6
•*Asymbolus rubiginosus*	Orange Spotted Catshark	4.3	9.1	86.6
•*Asymbolus submaculatus*	Variegated Catshark	6.7	16.6	76.7
•*Asymbolus vincenti*	Gulf Catshark	5.7	15.9	78.4
•*Atelomycterus fasciatus*	Banded Catshark	2.5	15.7	81.8
•*Atelomycterus macleayi*	Marbled Catshark	1.6	34.4	64.0
**Atelomycterus marnkalha*	Eastern Banded Catshark	10.7	13.5	75.7
•*Aulohalaelurus labiosus*	Blackspotted Catshark	7.0	20.7	72.3
Bathyraja eatonii	Eaton's Skate	47.1	16.2	36.7
Bathyraja irrasa	Kerguelen Skate	44.1	14.8	41.1
•*Bathyraja ishiharai*	Abyssal Skate	21.3	38.0	40.7
Bathyraja leucomelanos	Domino Skate	0.0	96.7	3.3
Bathyraja murrayi	Murray's Skate	49.3	5.9	44.8
Bathyraja richardsoni	Richardson's Skate	60.7	0.0	39.3
Bathytoshia brevicaudata	Smooth Stingray	4.6	17.3	78.1
Bathytoshia lata	Brown Stingray	5.1	17.1	77.8
•*Brachaelurus waddi*	Blind Shark	2.7	13.5	83.8
**Callorhinchus milii*	Elephantfish	4.3	15.1	80.7
Carcharhinus albimarginatus	Silvertip Shark	12.1	30.3	57.6
Carcharhinus altimus	Bignose Shark	8.5	24.2	67.3
Carcharhinus amblyrhynchoides	Graceful Shark	6.4	17.5	76.1
Carcharhinus amboinensis	Pigeye Shark	7.5	20.9	71.6
Carcharhinus brachyurus	Bronze Whaler	4.2	15.8	80.0

Carcharhinus brevipinna	Spinner Shark	7.2	21.3	71.5
**Carcharhinus cautus*	Nervous Shark	9.8	22.4	67.8
**Carcharhinus coatesi*	Australian Blackspot Shark	6.8	23.2	70.0
**Carcharhinus fitzroyensis*	Creek Whaler	8.8	24.0	67.2
Carcharhinus galapagensis	Galapagos Shark	16.1	38.4	45.5
Carcharhinus leucas	Bull Shark	10.6	25.2	64.1
Carcharhinus limbatus	Common Blacktip Shark	7.2	23.6	69.1
Carcharhinus macloti	Hardnose Shark	7.3	21.7	71.0
Carcharhinus melanopterus	Blacktip Reef Shark	8.8	26.4	64.8
Carcharhinus sorrah	Spot-tail Shark	4.3	22.3	73.4
**Carcharhinus tilstoni*	Australian Blacktip Shark	5.1	17.8	77.1
Centrophorus granulosus	Gulper Shark	18.2	32.6	49.2
**Centrophorus moluccensis*	Endeavour Dogfish	12.1	27.6	60.4
Centrophorus squamosus	Leafscale Gulper Shark	1.5	6.6	92.0
•*Centrophorus westraliensis*	Western Gulper Shark	1.9	15.4	82.7
**Centroscyllium kamoharai*	Bareskin Dogfish	1.6	9.0	89.4
Centroscymnus coelolepis	Portuguese Dogfish	2.6	14.1	83.4
Centroselachus crepidater	Golden Dogfish	1.7	13.2	85.2
•*Cephaloscyllium hiscosellum*	Reticulate Swellshark	1.4	22.7	76.0
•*Cephaloscyllium laticeps*	Draughtboard Shark	4.2	15.3	80.5
Cephaloscyllium signourum	Flagtail Swellshark	45.1	25.9	29.1
•*Cephaloscyllium speccum*	Speckled Swellshark	1.4	27.2	71.4
Chiloscyllium punctatum	Brownbanded Bambooshark	7.7	20.8	71.5
•*Chimaera argiloba*	Whitefin Chimaera	0.5	13.2	86.3
•*Chimaera fulva*	Southern Chimaera	1.9	14.2	83.9
Chimaera lignaria	Giant Chimaera	36.2	8.6	55.3
•*Chimaera macrospina*	Longspine Chimaera	17.1	52.2	30.7
•*Chimaera obscura*	Shortspine Chimaera	6.8	72.5	20.7
Chlamydoselachus anguineus	Frill Shark	2.1	6.6	91.3
•*Dentiraja falloargus*	False Argus Skate	0.4	20.8	78.7
•*Dentiraja healdi*	Heald's Skate	6.6	32.7	60.7
•*Dentiraja lemprieri*	Australian Thornback Skate	1.0	5.9	93.1
•*Dentiraja oculus*	Australian Ocellate Skate	2.6	20.7	76.7
•*Dentiraja polyommata*	Argus Skate	23.0	47.4	29.6
•*Dipturus acrobelus*	Australian Deepwater Skate	1.0	10.7	88.3
•*Dipturus apricus*	Pale Tropical Skate	22.7	37.5	39.8
•*Dipturus grahamorum*	Graham's Skate	0.0	8.5	91.5
•*Dipturus melanospilus*	Blacktip Skate	9.5	46.1	44.4
•*Dipturus queenslandicus*	Queensland Deepwater Skate	15.8	55.8	28.4

•*Dipturus wengi*	Weng's Skate	21.7	40.1	38.2
Etmopterus bigelowi	Blurred Smooth Lanternshark	0.3	11.1	88.6
Etmopterus brachyurus	Short-tail Lanternshark	11.1	42.1	46.8
Etmopterus caudistigmus	Tailspot Lanternshark	72.4	0.0	27.7
**Etmopterus dianthus*	Pink Lanternshark	55.3	43.7	1.0
•*Etmopterus dislineatus*	Lined Lanternshark	20.6	75.0	4.4
**Etmopterus evansi*	Blackmouth Lanternshark	8.0	33.1	58.9
**Etmopterus fusus*	Pygmy Lanternshark	0.4	5.6	94.1
Etmopterus granulosus	Southern Lanternshark	16.3	14.6	69.1
Etmopterus lucifer	Blackbelly Lanternshark	9.0	13.6	77.4
Etmopterus molleri	Moller's Lanternshark	0.2	8.7	91.1
Etmopterus pseudosqualiolus	False Lanternshark	74.6	1.3	24.1
Etmopterus pusillus	Smooth Lanternshark	5.1	13.2	81.7
Etmopterus unicolor	Bristled Lanternshark	6.7	14.3	79.0
Etmopterus viator	Traveller Lanternshark	34.7	48.7	16.6
**Eucrossorhinus dasypogon*	Tasselled Wobbegong	8.9	22.7	68.4
Euprotomicrus bispinatus	Pygmy Shark	19.6	26.5	53.9
•*Figaro boardmani*	Sawtail Shark	2.5	14.6	82.9
•*Figaro striatus*	Northern Sawtail Shark	18.5	61.9	19.6
•*Furgaleus macki*	Whiskery Shark	4.9	18.9	76.2
Galeus priapus	Phallic Catshark	46.6	10.5	42.9
Glaucostegus typus	Giant Guitarfish	10.6	21.9	67.4
**Gymnura australis*	Australian Butterfly Ray	7.7	20.6	71.7
•*Halaelurus sellus*	Speckled Catshark	3.4	17.0	79.6
Harriotta raleighana	Bigspine Spookfish	3.5	14.3	82.2
**Hemigaleus australiensis*	Australian Weasel Shark	6.2	20.8	73.0
Hemipristis elongata	Fossil Shark	6.9	21.3	71.8
Hemiscyllium hallstromi	Papuan Epaulette Shark	0.0	20.0	80.0
**Hemiscyllium ocellatum*	Epaulette Shark	13.3	16.0	70.8
**Hemiscyllium trispeculare*	Speckled Carpetshark	5.8	21.7	72.5
•*Hemitriakis falcata*	Sicklefin Houndshark	1.5	18.3	80.2
Heptranchias perlo	Sharpnose Sevengill Shark	9.3	20.8	69.9
•*Heterodontus galeatus*	Crested Hornshark	2.1	10.0	87.9
•*Heterodontus portusjacksoni*	Port Jackson Shark	4.4	16.6	79.1
Hexanchus griseus	Bluntnose Sixgill Shark	12.4	14.6	73.0
Hexanchus nakamurai	Bigeye Sixgill Shark	10.9	20.8	68.4
Hexatrygon bickelli	Sixgill Stingray	6.3	24.7	69.0
**Himantura australis*	Australian Whipray	8.2	16.7	75.1
Himantura leoparda	Leopard Whipray	4.5	22.3	73.2
Hydrolagus homonycteris	Black Ghostshark	6.4	8.7	84.9
•*Hydrolagus marmoratus*	Marbled Ghostshark	11.3	54.0	34.7

Hydrolagus trolli	Abyssal Ghostshark	5.2	23.4	71.4
•*Hypnos monopterygius*	Coffin Ray	7.4	18.6	74.0
**Hypogaleus hyugaensis*	Pencil Shark	9.0	17.6	73.5
Iago garricki	Longnose Houndshark	3.6	27.6	68.8
•*Insentiraja laxipella*	Eastern Looseskin Skate	27.7	71.2	1.1
**Insentiraja subtilispinosa*	Western Looseskin Skate	3.8	25.6	70.6
•*Irolita waitii*	Southern Round Skate	7.2	23.1	69.7
•*Irolita westraliensis*	Western Round Skate	3.2	17.7	79.1
Isistius brasiliensis	Smalltooth Cookiecutter Shark	5.1	41.7	53.2
Isistius plutodus	Largetooth Cookiecutter Shark	3.9	31.5	64.5
Lamna nasus	Porbeagle	13.6	16.7	69.7
•*Leucoraja pristispina*	Sawback Skate	0.9	19.3	79.8
Loxodon macrorhinus	Sliteye Shark	7.3	20.5	72.3
**Maculabatis astra*	Blackspotted Whipray	6.8	20.1	73.1
**Maculabatis toshi*	Brown Whipray	11.5	13.4	75.2
Mitsukurina owstoni	Goblin Shark	3.5	18.1	78.5
Mobula alfredi	Reef Manta Ray	12.0	27.8	60.1
Mobula eregoodootenkee	Long-horned Pygmy Devilray	15.0	30.6	54.4
Mobula kuhlii	Kuhl's Devilray	2.5	13.4	84.2
•*Mustelus antarcticus*	Gummy Shark	7.5	18.1	74.5
•*Mustelus ravidus*	Grey Gummy Shark	1.1	20.7	78.2
•*Mustelus stevensi*	Western Spotted Gummy Shark	0.6	19.8	79.7
**Myliobatis tenuicaudatus*	Southern Eagle Ray	4.4	17.0	78.7
•*Narcinops lasti*	Western Numbfish	1.3	24.9	73.8
•*Narcinops nelsoni*	Eastern Numbfish	20.9	59.2	19.9
•*Narcinops ornatus*	Ornate Numbfish	0.9	24.1	75.0
•*Narcinops tasmaniensis*	Tasmanian Numbfish	0.9	7.7	91.4
•*Narcinops westraliensis*	Banded Numbfish	3.8	18.0	78.2
Nebrius ferrugineus	Tawny Shark	6.7	23.1	70.1
Negaprion acutidens	Sharptooth Lemon Shark	9.1	24.3	66.6
**Neotrygon australiae*	Aust. Bluespotted Maskray	2.6	24.3	73.2
•*Neotrygon leylandi*	Painted Maskray	4.7	17.6	77.6
•*Neotrygon ningalooensis*	Ningaloo Maskray	8.4	35.7	55.9
**Neotrygon picta*	Speckled Maskray	10.3	9.9	79.9
**Neotrygon trigonoides*	Coral Sea Maskray	23.7	13.3	63.0
•*Notoraja azurea*	Blue Skate	1.7	12.4	85.9
•*Notoraja hirticauda*	Ghost Skate	4.0	20.5	75.4
•*Notoraja ochroderma*	Pale Skate	15.4	48.1	36.5
•*Notoraja sticta*	Blotched Skate	0.0	17.1	82.9

Notorynchus cepedianus	Broadnose Sevengill Shark	4.4	15.3	80.3
Okamejei arafurensis	Arafura Skate	0.7	26.7	72.6
•*Okamejei leptoura*	Australian Thintail Skate	1.1	15.1	83.8
•*Orectolobus floridus*	Floral Banded Wobbegong	2.3	20.8	76.9
•*Orectolobus halei*	Gulf Wobbegong	5.3	16.1	78.6
•*Orectolobus hutchinsi*	Western Wobbegong	6.2	18.9	74.9
•*Orectolobus maculatus*	Spotted Wobbegong	8.2	18.3	73.5
**Orectolobus ornatus*	Ornate Wobbegong	22.6	6.7	70.6
•*Orectolobus parvimaculatus*	Dwarf Spotted Wobbegong	5.7	22.4	71.9
**Orectolobus wardi*	Northern Wobbegong	3.2	27.8	69.0
•*Parascyllium collare*	Collared Carpetshark	1.8	7.3	90.9
•*Parascyllium ferrugineum*	Rusty Carpetshark	4.4	15.8	79.8
•*Parascyllium variolatum*	Varied Carpetshark	4.5	17.0	78.5
Pastinachus ater	Broad Cowtail Ray	7.4	21.6	71.1
Pateobatis fai	Pink Whipray	7.8	22.0	70.2
•*Pavoraja alleni*	Allen's Skate	3.0	18.3	78.8
•*Pavoraja mosaica*	Mosaic Skate	27.4	55.3	17.3
• *Pavoraja nitida*	Peacock Skate	2.0	9.9	88.1
•*Pavoraja pseudonitida*	False Peacock Skate	27.3	55.6	17.1
•*Pavoraja umbrosa*	Dusky Skate	0.1	16.9	83.0
**Plesiobatis daviesi*	Giant Stingaree	11.5	21.8	66.7
•*Pristiophorus cirratus*	Common Sawshark	3.9	15.7	80.4
•*Pristiophorus delicatus*	Tropical Sawshark	21.6	73.0	5.4
•*Pristiophorus nudipinnis*	Southern Sawshark	3.9	15.5	80.6
Pseudocarcharias kamoharai	Crocodile Shark	24.1	33.4	42.5
Pteroplatytrygon violacea	Pelagic Stingray	7.4	8.0	84.7
•*Rajella challengeri*	Challenger Skate	7.2	14.1	78.7
**Rhinobatos sainsburyi*	Goldeneye Shovelnose Ray	1.5	10.1	88.4
Rhinochimaera africana	Paddlenose Spookfish	0.0	14.1	85.9
Rhinochimaera pacifica	Pacific Spookfish	2.6	20.0	77.5
**Rhinoptera neglecta*	Australian Cownose Ray	13.5	18.0	68.5
Rhizoprionodon acutus	Milk Shark	6.8	21.2	72.0
**Rhizoprionodon taylori*	Australian Sharpnose Shark	6.8	16.6	76.6
**Sinobatis bulbicauda*	West Australian Legskate	0.4	17.8	81.8
•*Sinobatis caerulea*	Indigo Legskate	0.4	23.7	75.9
•*Sinobatis filicauda*	East Australian Legskate	39.4	36.2	24.4
Somniosus antarcticus	Southern Sleeper Shark	42.1	18.2	39.7
Squaliolus aliae	Smalleye Pygmy Shark	9.1	28.3	62.6
Squalus acanthias	Whitespotted Spurdog	3.5	14.3	82.3
•*Squalus albifrons*	Eastern Highfin Spurdog	12.2	33.2	54.6
Squalus crassispinus	Fatspine Spurdog	2.0	28.8	69.2

**Squalus edmundsi*	Edmunds' Spurdog	1.7	21.2	77.1
•*Squalus megalops*	Piked Spurdog	5.2	20.6	74.2
Squalus nasutus	Western Longnose Spurdog	1.8	21.5	76.8
•*Squalus notocaudatus*	Bartail Spurdog	22.6	67.2	10.2
•*Squatina australis*	Australian Angelshark	4.5	15.9	79.6
•*Squatina pseudocellata*	Western Angelshark	1.7	25.0	73.4
•*Squatina tergocellata*	Ornate Angelshark	5.4	21.4	73.2
Stegostoma tigrinum	Zebra Shark	6.8	21.3	71.9
•*Sutorectus tentaculatus*	Cobbler Wobbegong	6.9	20.7	72.4
Taeniura lymma	Bluespotted Fantail Ray	8.8	22.2	69.0
Taeniurops meyeni	Blotched Fantail Ray	4.0	24.4	71.6
Tetronarce nobiliana	Great Torpedo	7.4	15.0	77.6
•*Trygonoptera galba*	Yellow Shovelnose Stingaree	5.7	20.2	74.2
•*Trygonoptera imitata*	Eastern Shovelnose Stingaree	0.8	4.9	94.3
•*Trygonoptera mucosa*	Western Shovelnose Stingaree	7.8	24.5	67.7
•*Trygonoptera ovalis*	Striped Stingaree	4.9	19.2	75.9
•*Trygonoptera personata*	Masked Stingaree	8.1	26.3	65.6
•*Trygonorrhina dumerilii*	Southern Fiddler Ray	6.5	14.8	78.7
•*Trygonorrhina fasciata*	Eastern Fiddler Ray	1.8	8.3	89.9
Urogymnus asperrimus	Porcupine Ray	6.9	23.8	69.3
Urogymnus dalyensis	Freshwater Whipray	0.0	2.7	97.3
Urogymnus granulatus	Mangrove Whipray	4.7	22.6	72.7
•*Urolophus circularis*	Circular Stingaree	3.4	18.7	77.8
•*Urolophus cruciatus*	Banded Stingaree	1.0	5.7	93.3
•*Urolophus expansus*	Wide Stingaree	7.5	19.9	72.6
•*Urolophus flavomosaicus*	Patchwork Stingaree	14.4	13.5	72.1
•*Urolophus gigas*	Spotted Stingaree	5.5	17.0	77.5
•*Urolophus lobatus*	Lobed Stingaree	3.3	20.9	75.8
•*Urolophus mitosis*	Mitotic Stingaree	0.2	2.9	96.9
•*Urolophus paucimaculatus*	Sparsely-spotted Stingaree	4.2	15.0	80.8
•*Urolophus piperatus*	Coral Sea Stingaree	21.0	3.5	75.5
•*Urolophus westraliensis*	Brown Stingaree	0.7	14.5	84.8
Zameus squamulosus	Velvet Dogfish	4.2	16.5	79.4
Data Deficient (DD)				
•*Asymbolus funebris*	Blotched Catshark	2.1	30.2	67.7
Bathyraja maccaini	McCain's Skate	80.3	0.0	19.7
Brochiraja aenigma	Enigma Skate	0.0	96.6	3.4
Brochiraja heuresa	/	0.0	97.2	2.8
•*Bythaelurus incanus*	Dusky Catshark	0.7	0.2	99.1

**Cephaloscyllium cooki*	Cook's Swellshark	0.2	27.4	72.5
•*Cephaloscyllium zebrum*	Narrowbar Swellshark	32.8	67.2	0.0
Cirrhigaleus australis	Southern Mandarin Dogfish	9.0	25.3	65.7
Deania hystricosa	Rough Longnose Dogfish	19.7	37.6	42.6
•*Dentiraja flindersi*	Pygmy Thornback Skate	5.1	23.3	71.6
Echinorhinus brucus	Bramble Shark	6.7	22.4	70.9
Eusphyra laticeps	/	8.6	22.2	69.3
•*Galeus gracilis*	Slender Sawtail Shark	2.2	18.4	79.4
Harriotta chaetirhamphus	Rabbitfish	14.6	29.8	55.7
•*Hemitriakis abdita*	Darksnout Houndshark	29.8	69.5	0.7
**Hemitrygon parvonigra*	Dwarf Black Stingray	0.7	19.3	80.0
Megachasma pelagios	Megamouth Shark	21.3	29.0	49.7
Megatrygon microps	Smalleye Stingray	6.2	15.7	78.2
Narcine brunnea	Brown Numbfish	3.3	34.3	62.3
Notoraja sapphira	Sapphire Skate	51.9	39.8	8.3
•*Orectolobus reticulatus*	Network Wobbegong	0.0	32.4	67.6
•*Parascyllium elongatum*	Elongate Carpetshark	7.8	11.7	80.5
•*Parascyllium sparsimaculatum*	Ginger Carpetshark	3.0	23.5	73.6
Pateobatis hortlei	Hortle's Whipray	8.8	13.7	77.5
•*Pavoraja arenaria*	Sandy Skate	6.7	14.7	78.7
Pseudotriakis microdon	False Catshark	24.0	39.4	36.6
Scymnodalatias albicauda	Whitetail Dogfish	18.9	10.4	70.8
Scymnodalatias sherwoodi	Sherwood's Dogfish	20.0	4.1	76.0
Squalus bucephalus	Bighead Spurdog	37.3	24.0	38.7
**Urogymnus acanthobothrium*	Mumburarr Whipray	0.0	14.5	85.5

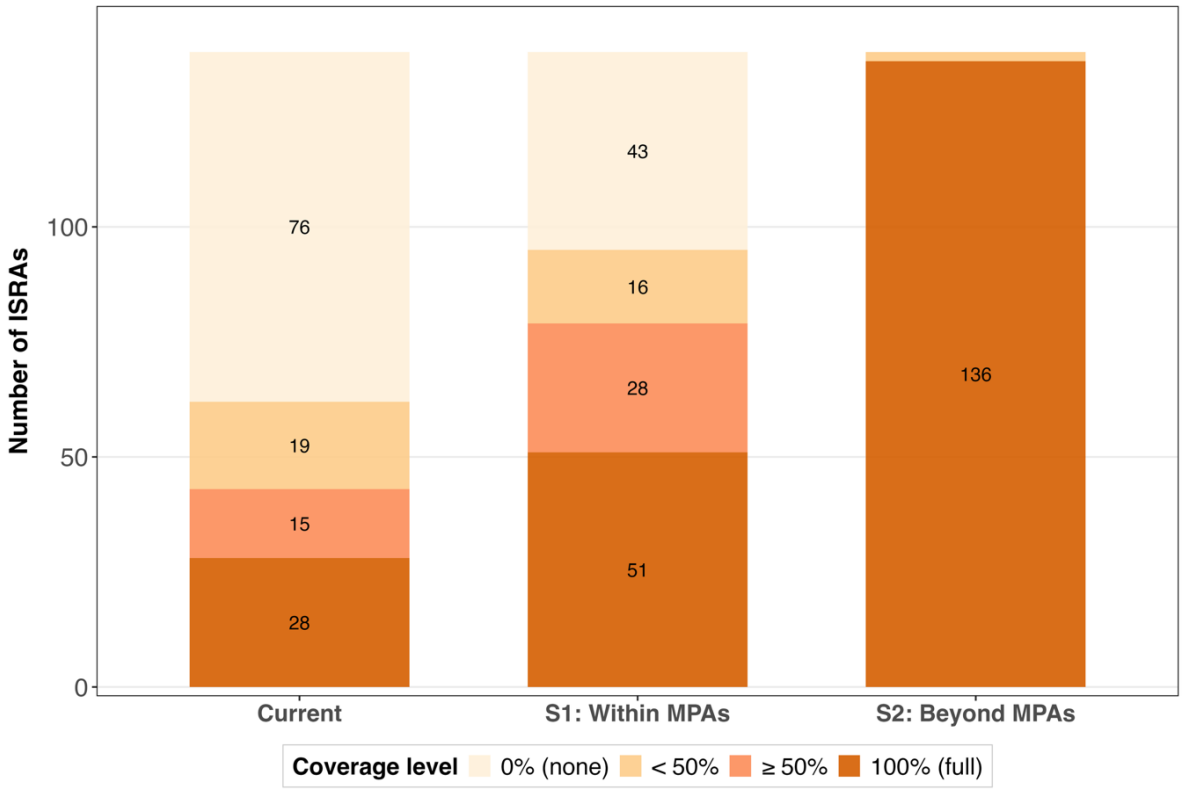
Supplementary Table 6: Summary statistics for the representation of no-movement ISRAs and chondrichthyan species by Australian IUCN Red List category under the current no-take Marine Protected Area (MPA) network and the two prioritization scenarios *(S1: Within-MPA improvement; S2: Outside-no-take MPA). Reported metrics include the number and percentage of conservation targets met, mean coverage, mean conservation shortfall, and the absolute reduction and proportional recovery of the current conservation shortfall relative to the current no-take MPA network. Means are reported along with standard deviation (SD).*

Conservation feature	n	Scenario	n Targets met	% Targets met	Mean ± SD coverage (%)	Mean ± SD shortfall (%)	Mean shortfall ± SD reduction (%)	Mean shortfall ± SD recovery (%)
No-movement ISRA	138	Current	28	20.3	31±40.6	69.0±40.6	-	-
		S1	51	37.0	53.9±43.6	46.1±43.5	22.9±35.1	34.8±41.8
		S2	136	98.6	99.1±7.6	0.9±7.6	68.1±41.2	98.4±11.7
Critically Endangered	5	Current	0	0	9.3±9.2	20.7±9.2	-	-
		S1	1	20.0	18.7±8.1	11.4±8.1	9.3±3.7	54.9±29.8
		S2	2	40.0	23.6±6.8	6.5±6.7	14.2±8.6	72.5±27.0
Endangered	13	Current	0	0	11.0±6.7	19.0±6.7	-	-
		S1	3	23.1	23.5±7.3	7.3±5.8	11.7±6.1	63.9±27.4
		S2	5	38.5	30.4±10.9	3.5±4.3	15.4±7.5	81.6±20.4
Vulnerable	20	Current	2	10.0	13.1±10.6	17.2±9.9	-	-
		S1	8	40.0	26.3±9.3	5.8±6.7	11.4±8.5	70.0±28.0
		S2	13	65.0	32.1±9.1	2.3±4.4	14.9±10.5	85.6±24.2
Near Threatened	31	Current	0	0	8.9±5.3	21.1±5.3	-	-
		S1	1	3.2	20.4±4.4	9.7±4.1	11.4±3.1	55.0±13.3
		S2	10	32.3	27.1±8.7	5.3±5.1	15.8±7.5	72.9±22.7
Least Concern	236	Current	20	8.5	12.5±13.1	19.0±8.6	-	-
		S1	52	22.0	24.4±11.1	7.7±6.7	11.3±6.4	62.5±26.2
		S2	101	42.8	29.0±11.3	4.6±5.6	14.4±8.8	74.6±27.1
Data Deficient	30	Current	6	20.0	16.3±19.3	17.0±11.2	-	-
		S1	12	40.0	28.2±16.1	6.3±7.2	10.7±9.2	62.4±32.8
		S2	16	53.3	31.2±15.0	3.9±5.3	13.1±10.6	73.2±31.0

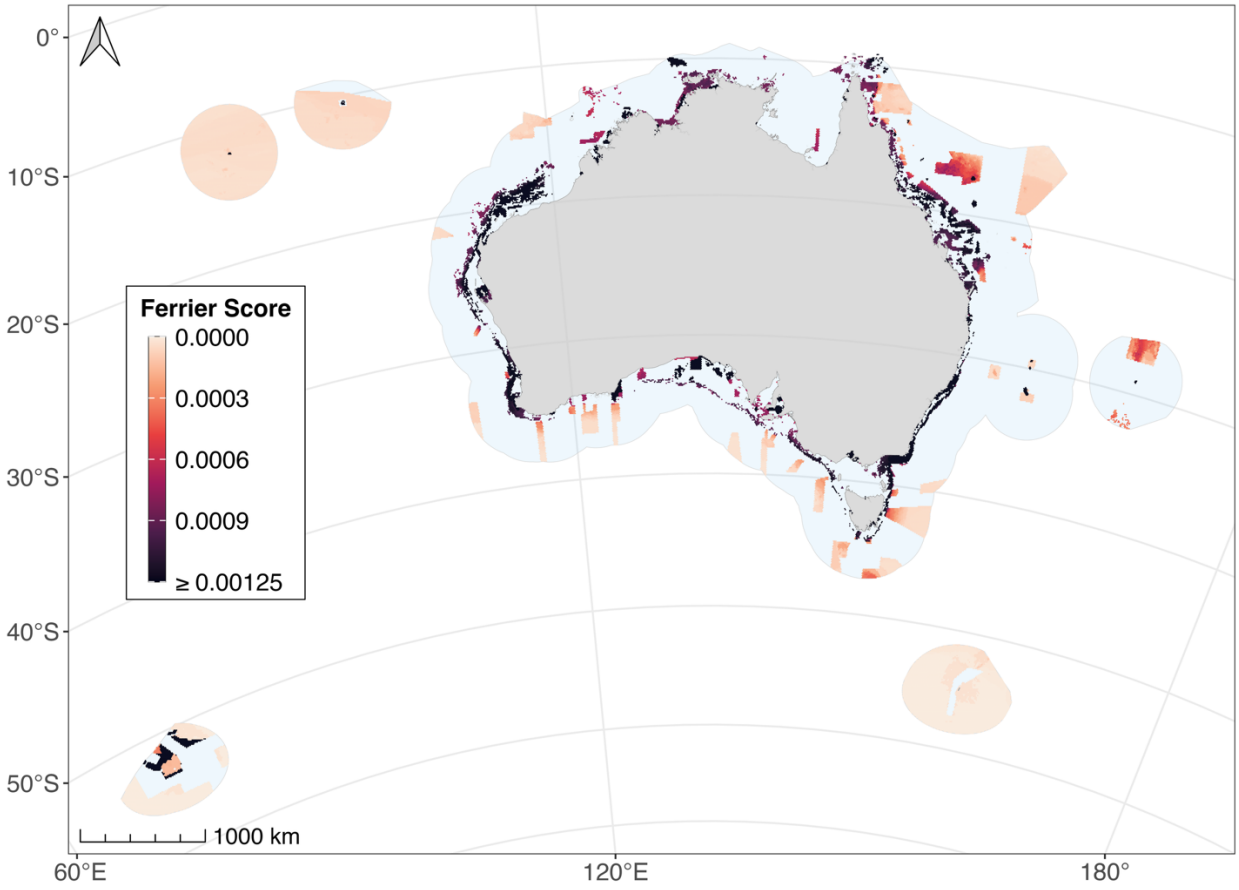
Supplementary Table 7: Australian range representation (%) of threatened chondrichthyan species (n=38) within the current no-take Marine Protected Area (MPA) network and the two prioritization scenarios *(S1: Within-MPA improvement; S2: Outside-no-take MPA). Species are grouped by Australian IUCN Red List category. Values for the current network differ slightly from those in Supplementary Table 5 because that table reports direct spatial overlap with the original species-distribution rasters, whereas values here were calculated after converting species distributions to planning units using a 50% cutoff. Endemic species and near-endemic species are assigned with a • and *, respectively.*

Scientific Name	Common Name	Current (%)	S1 (%)	S2 (%)
Critically Endangered (CR)				
Carcharhinus longimanus	Oceanic Whitetip Shark	25.0	30.2	30.0
•*Cephaloscyllium albipinnum*	Whitefin Swellshark	6.2	13.8	22.8
•*Dentiraja confusa*	Australian Longnose Skate	2.2	10.1	30.8
Pristis pristis	Largetooth Sawfish	3.7	15.6	14.5
Pristis zijsron	Green Sawfish	9.4	23.7	20.1
Endangered (EN)				
Alopias pelagicus	Pelagic Thresher	18.5	27.5	29.2
**Centrophorus harrissoni*	Harrisson's Dogfish	8.0	23.9	58.4
•*Centrophorus uyato*	Southern Dogfish	4.0	21.8	43.6
Cetorhinus maximus	Basking Shark	18.3	20.7	26.5
•*Dipturus canutus*	Grey Skate	2.4	12.9	36.8
Galeorhinus galeus	School Shark	6.6	23.8	30.0
Mobula birostris	Giant Manta Ray	11.1	21.9	24.9
Pristis clavata	Dwarf Sawfish	11.5	30.0	28.2
Rhincodon typus	Whale Shark	27.2	32.8	32.9
Sphyrna lewini	Scalloped Hammerhead	8.4	18.9	20.0
Sphyrna mokarran	Great Hammerhead	10.5	20.8	20.5
•*Squalus chloroculus*	Greeneye Spurdog	8.0	12.7	18.4
•*Urolophus orarius*	Coastal Stingaree	8.8	38.3	26.1
Vulnerable (VU)				
Alopias superciliosus	Bigeye Thresher	25.3	30.7	30.5
Anoxypristis cuspidata	Narrow Sawfish	8.6	19.8	18.6
**Aptychotrema timorensis*	Spotted Shovelnose Ray	2.4	41.8	30.2
•*Brachaelurus colcloughi*	Colclough's Shark	33.2	40.3	37.9
Carcharhinus falciformis	Silky Shark	14.2	25.0	25.4
Carcharias taurus	Grey Nurse Shark	13.6	28.9	29.3
Carcharodon carcharias	White Shark	12.1	16.3	16.9
•*Dentiraja australis*	Sydney Skate	3.9	15.0	47.1
Eusphyra blochii	Winghead Shark	9.4	21.2	18.7
**Glyphis garricki*	Northern River Shark	1.8	31.8	30.0
**Glyphis glyphis*	Speartooth Shark	1.9	33.0	45.8
•*Hemitrygon fluviorum*	Estuary Stingray	33.5	40.6	42.8
Isurus oxyrinchus	Shortfin Mako	21.0	25.5	26.5

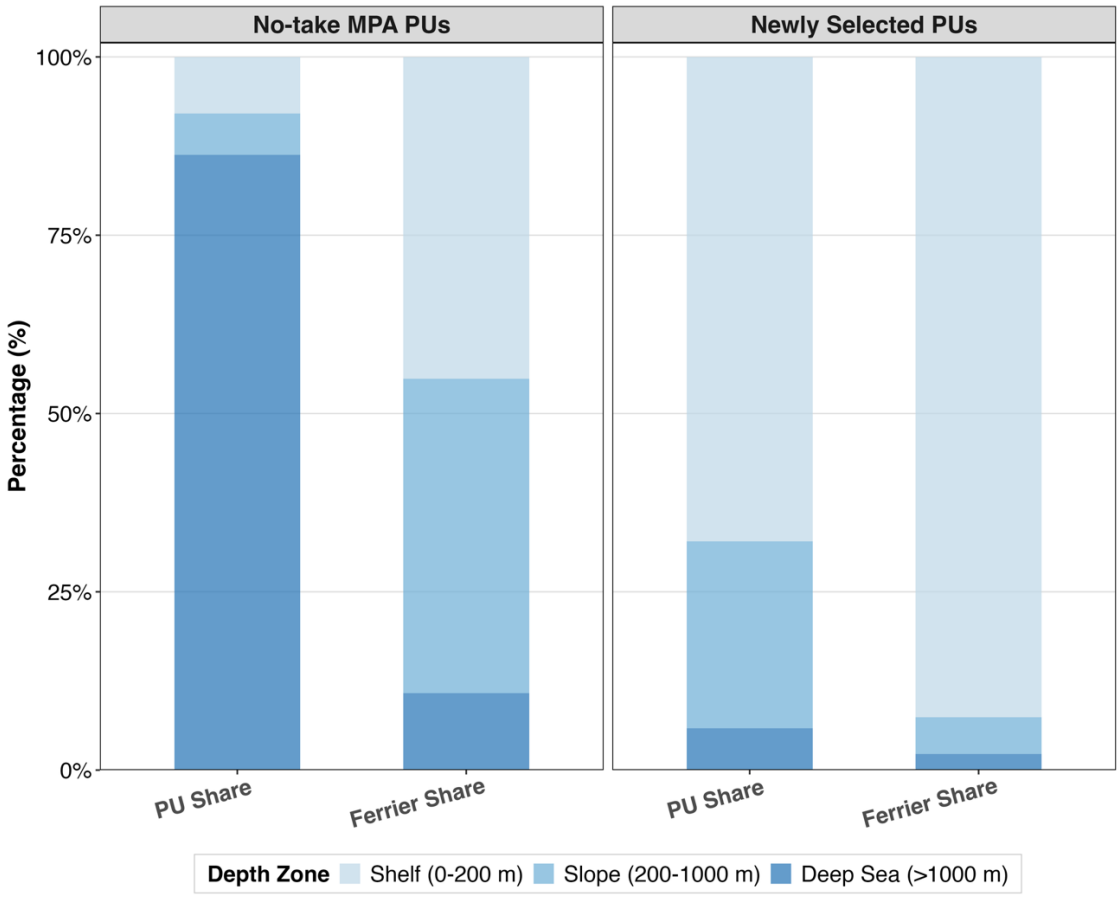
Isurus paucus	Longfin Mako	28.5	33.6	33.4
**Myliobatis hamlyni*	Purple Eagle Ray	18.3	29.1	30.1
•*Spiniraja whitleyi*	Melbourne Skate	7.0	22.3	28.8
•*Squatina albipunctata*	Eastern Angelshark	17.5	29.9	42.3
**Urolophus bucculentus*	Sandyback Stingaree	4.5	15.1	31.4
•*Urolophus sufflavus*	Yellowback Stingaree	3.2	14.0	45.6
•*Urolophus viridis*	Greenback Stingaree	2.4	11.2	30.0



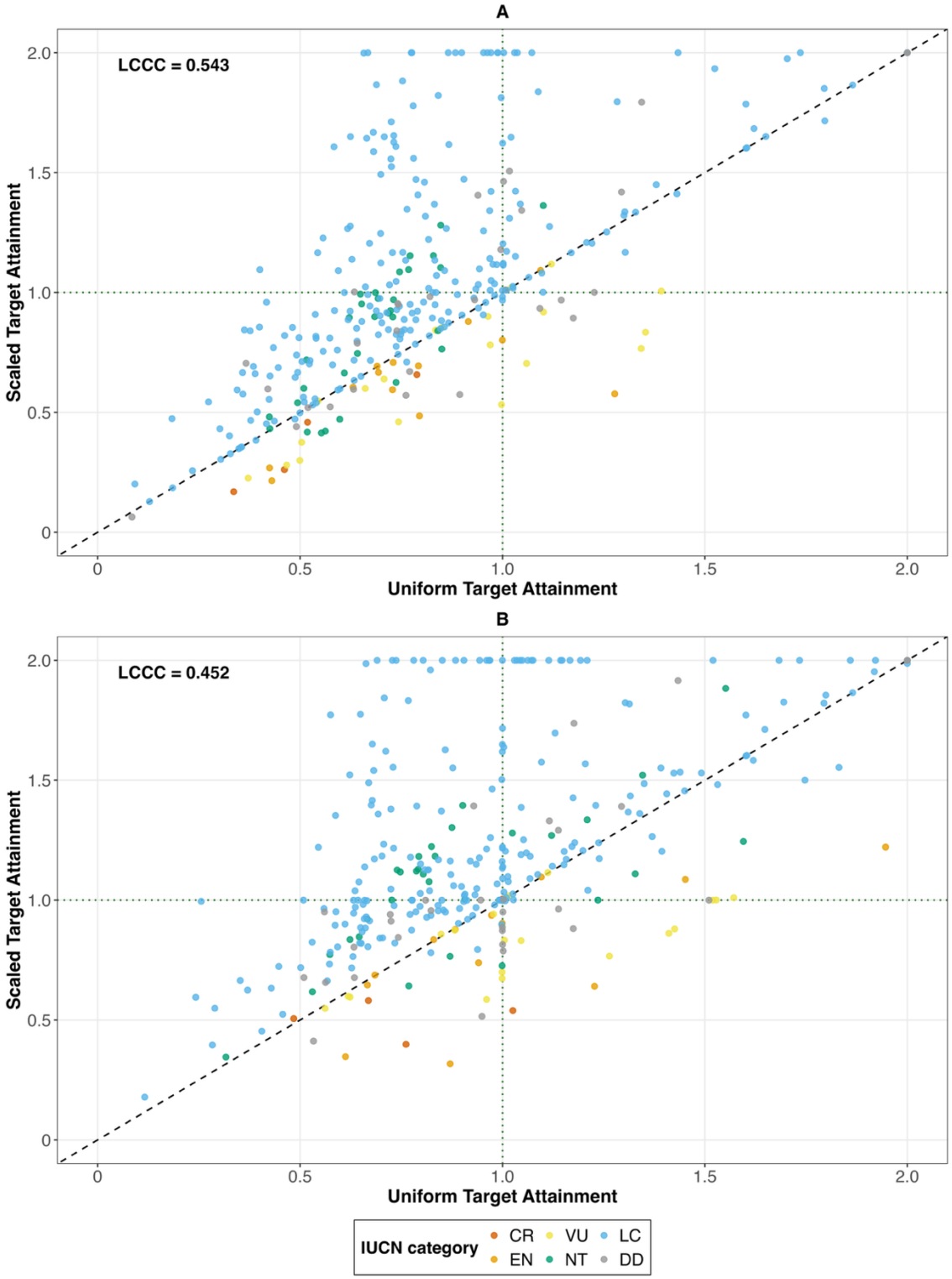
Supplementary Figure 2: Distribution of no-movement ISRAs (n=138) coverage under the current no-take Marine Protected Area (MPA) network and the two prioritization scenarios *(S1: Within-MPA improvement; S2: Outside-no-take MPA). Bars show the number of ISRAs with 0%, <50%, ≥50%, and complete (100%) representation in each scenario. Values within bars indicate the number of ISRAs in each coverage class.*



Supplementary Figure 3: Spatial distribution of Ferrier irreplaceability scores for planning units (PUs) selected under the S2 Outside-no-take scenario. *Darker colors indicate higher Ferrier scores and therefore PUs with greater irreplaceability within the S2 solution. The color scale is capped at the 90th percentile (≥0.00125) to improve visibility.*



Supplementary Figure 4: Comparison of the depth composition of locked-in no-take Marine Protected Area (MPA) planning units (PUs) and newly selected PUs under the outside no-take scenario (S2). *Bars show the proportion of PUs (PU share) and the proportion of the summed Ferrier irreplaceability score (Ferrier share) contributed by each depth zone. Percentages are calculated separately for each panel and sum to 100%.*



Supplementary Figure 5: Comparison of species target attainment under uniform and range-scaled conservation targets. *Target attainment is expressed as coverage divided by the species-specific target, with values ≥1 indicating that the target was met. The dashed line indicates equal target attainment under both target-setting approaches, and the dotted lines indicate the target attainment threshold of 1. Points represent individual chondrichthyan species and are colored by Australian IUCN Red List category. Panels show (A) within Marine Protected Area (MPA) improvement scenario (S1) and (B) outside no-take MPA expansion scenario (S2). Lin's Concordance Correlation Coefficient (LCCC) indicates agreement between uniform and scaled target attainment. Spatial overlap between corresponding uniform- and scaled target solutions was Jaccard = 0.76 for S1 and Jaccard = 0.60 for S2.*