Biological Conservation 321 (2026) 112010

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Balancing efficiency and equity in regional and national pathways towards 30 × 30 in the Insular Caribbean

M. Rae-Seaman [a,*], S.R. Schill [b], V.P. McNulty [b], D. Muenzel [a,c], M. Heiner [d], A. Olivero [e], S.M. Sait [a], J.G. Singh [b], M. Beger [a,f]

[a] School of Biology, Faculty of Biological Sciences, University of Leeds, LS2 9JT, UK
[b] Caribbean Division, The Nature Conservancy, Florida, USA
[c] Durrell Institute of Conservation and Ecology, University of Kent, CT2 7NZ, UK
[d] Protect Oceans, Lands and Waters, The Nature Conservancy, CO, USA
[e] Center for Resilient Conservation Science, The Nature Conservancy, MA, USA
[f] Centre for Biodiversity and Conservation Science, School of the Environment, University of Queensland, Brisbane, QLD, 4072, Australia

ARTICLE INFO

Keywords:
30 × 30
Caribbean
Equity trade-offs
Marxan
Multi-realm conservation
Systematic conservation planning

ABSTRACT

Global and local biodiversity decline is prompting increased targets for protected area designation, including the Global Biodiversity Framework's target of 30% protection by 2030. As nations look to expand protected area portfolios, regional approaches are often regarded as the most efficient pathway. However, prioritising regional coordination over national-level planning can undermine equity between countries. Here, we assess the efficiency and equity considerations of national and regional-scale approaches in the Insular Caribbean, utilising the systematic conservation planning tool, Marxan.

We represented biodiversity with 343 habitat classes spanning terrestrial, freshwater, and marine realms across over 3 million square kilometres and 29 political jurisdictions. At the time of analysis, baseline regional protection, covering 19% of land and 10% of marine areas, was sufficient to meet representation targets for only 37 of 90 terrestrial classes, 18 of 72 freshwater classes, and 23 of 81 marine classes. To close these gaps, we developed expanded reserve network solutions that achieved 30% coverage for all habitats, and compared results from a fully collaborative, regional solution against those from a nationally-stratified solution.

We found that a regional approach offers the most cost-effective pathway, significantly reducing financial burden on individual nations. However, this approach creates inequities as conservation burdens and benefits are unevenly distributed, resulting in higher cost for some countries and complete exclusion for others. We conclude that both regional and national pathways to conservation can be complementary, allowing a flexible approach to protected area designation, and this multi-scale approach provides a transferable model for other regions.

1. Introduction

Anthropogenic impacts on the environment are driving widespread biodiversity declines and disrupting essential ecosystem functions (Jaureguiberry et al., 2022; Isbell et al., 2023). These ecological shifts, in turn, have profound impact on the ecological goods and services benefiting humans, from nutrient cycling to improving the wellbeing of people (IPCC, 2023). The urgent call to halt biodiversity loss highlights the need for holistic conservation strategies that are underpinned by sound science, translated through enabling policy, and supported by sufficient and sustained financial resources. At the 15th Conference of Parties to the CBD (COP15) in December 2022, delegates formulated the Kunming-Montreal Global Biodiversity Framework which identifies ambitious targets for protected area designation worldwide, with the intention of halting and reversing biodiversity loss by 2030 (CBD, 2022). Target 3 of the framework, to "Conserve 30% of Land, Waters and Seas", provides an opportunity to build on existing protected area systems and enhance current biodiversity protection, providing a clear target for nations and regions to work towards.

A key strategy to preserving biodiversity and minimising future

* Corresponding author.
E-mail addresses: bsmjrs@leeds.ac.uk (M. Rae-Seaman), sschill@tnc.org (S.R. Schill), valerie.mcnulty@tnc.org (V.P. McNulty), fbsdkm@leeds.ac.uk (D. Muenzel), mheiner@tnc.org (M. Heiner), arlene_olivero@tnc.org (A. Olivero), s.m.sait@leeds.ac.uk (S.M. Sait), joth.singh@tnc.org (J.G. Singh), m.beger@leeds.ac.uk (M. Beger).

https://doi.org/10.1016/j.biocon.2026.112010
Received 17 February 2026; Received in revised form 7 July 2026; Accepted 9 July 2026
Available online 16 July 2026

losses is to implement protected areas across terrestrial (Ranius et al., 2023), freshwater (Hermoso et al., 2016) and marine systems (Wilson et al., 2020), allowing for nature recovery and maintenance (Maxwell et al., 2020; Wauchope et al., 2022). A review of 216 marine protected areas found that fish biomass increased by 58% in strict no-take areas and by 13% in mixed-use areas, compared to an unprotected baseline scenario (Gill et al., 2024). In a similar analysis of population trends of terrestrial mammals, species with an IUCN Red List status of Threatened showed consistent population increases inside protected areas, and decreases outside of those designated areas (Magoulick et al., 2024).

Conservation practitioners and policy makers face challenges in identifying the most appropriate areas to propose for protection. For example, competing stakeholder priorities over land use can generate significant conflict, since protected area declarations have the potential to negatively impact livelihoods and disrupt the emotional, cultural, and social values held by local people (Soliku and Schraml, 2018). Limited conservation resources, including time, capacity, and financial support, further constrain the ability to make effective and defensible decisions, creating long-standing tensions around how to allocate limited resources efficiently (Wilson et al., 2006). Systematic conservation planning directly addresses these challenges by applying transparent, data-driven methods to identify spatial solutions that maximise habitat representation whilst minimising costs and negative impacts on people (Giakoumi et al., 2025). The systematic conservation planning approach builds on existing protected area networks to ensure that new areas capture unique or underrepresented habitats, respond to emerging threats, and support ongoing ecological processes essential to biodiversity persistence (Pressey et al., 2007). Outputs from systematic conservation planning allow stakeholders to make science-based decisions that can be evaluated alongside local knowledge and socio-cultural considerations, ultimately enabling more equitable and biodiversity-optimising conservation outcomes (Baker et al., 2025).

Systematic conservation planning can be used across multiple spatial and administrative scales, ranging from broad multi-regional to fine-scale local assessments. Planning at a regional scale can maximise the efficiency of solutions by enabling coordination among countries and supporting balanced, transboundary prioritisation (Mazor et al., 2013; Zhu et al., 2021; Hoffmann, 2022). Such coordination reduces redundancy in the types of habitats protected and reduces total implementation costs through shared collaborative efforts (Delevaux et al., 2024). Regional planning approaches have been successfully applied in a variety of geographies, including the river Nile basin (Allan et al., 2019) and the Mediterranean Sea (Kark et al., 2009), where they have enhanced the maintenance of ecosystem processes, improved the robustness of conservation networks, and delivered more cost effective outcomes at broader scales (Leonard et al., 2017). However, regional planning is not always desirable or beneficial to nations that need to prioritise their own strengths and highlight locally unique biodiversity, which can be overshadowed in regional approaches (Beger et al., 2015). A regional lens may lead to a lack of balance between localities, reducing the equitability of conservation solutions by concentrating conservation burdens in some areas and reducing the benefits for others (Kabbadj et al., 2018). Ideally, countries integrate both national and regional goals to create a complementary, well-balanced protected area portfolio (Beger et al., 2015; Allan et al., 2019). This integrated approach is particularly beneficial for island regions, including the Insular Caribbean, where longstanding mechanisms for regional coordination already exist (Mahadeo and Del Savio, 2023).

Through historical protected area designation and more recent initiatives such as the Caribbean Challenge Initiative (CCI) (Knowles et al., 2015), the Insular Caribbean has achieved 10% ocean protection and 19% land protection (TNC, 2025). These levels were sufficient to meet Aichi Target 11, of the Convention on Biological Diversity (CBD), which called for protecting at least 17% of terrestrial and inland waters and 10% of coastal and marine areas by 2020 (CBD, 2010). However, the shift to the more ambitious 30 × 30 global target to protect 30% of biodiversity by 2030 (CBD, 2022) requires a substantive update to policy priorities and planning frameworks. This transition presents a critical opportunity to adopt a regional multi-realm approach to achieving 30% protection of marine, terrestrial, and freshwater systems across the Caribbean. Since the spatial planning analysis that informed the original CCI effort (Huggins et al., 2007), the region has seen major advances in biodiversity collection and development of ecological models, alongside the establishment of new protected areas and an upward shift in political ambition from 20% to 30% protection.

In this context, we aim to identify updated portfolios of conservation priority areas for terrestrial, freshwater, and marine realms across the Insular Caribbean to support efficient and science-based pathways towards achieving the 30 × 30 targets by 2030. These updated portfolios will aid decision makers to distribute conservation responsibilities more efficiently and equitably between nations, strengthen transboundary collaboration, and promote shared objectives. They will also provide standardised datasets that enhance regional data interoperability and improve the consistency and transparency of future conservation planning across the Insular Caribbean. Specifically, in the work presented herein, we:

1. Compared portfolios of conservation priority sites generated at regional and national scales and identified the key priority areas for protection at each scale.
2. Assessed how planning at alternative scales can alter the conservation burden on different countries.
3. Compared the proportion of features held in conservation planning portfolios across terrestrial, freshwater, and marine realms.

We also developed a suite of resources to support key stakeholders in making strategic decisions that advance progress towards achieving 30% targets in the Insular Caribbean. Our analysis provides a regionally consistent framework that acknowledges existing conservation achievements whilst offering guidance to inform science-based protection targets within each country's National Biodiversity Strategies and Action Plans (NBSAPs). This science-driven approach to shaping policy is aligned with the Roadmap for a Nature-Positive Caribbean by 2030 (CaribbeanRoadmap.tnc.org).

2. Methods

The Insular Caribbean is comprised of over 7000 islands and islets, of which 27 countries and territories are included in this analysis. It is an area of high natural biodiversity both on land and in the sea (Miloslavich et al., 2010; Harvey et al., 2021), with endemism levels ranging from 26% of bird species to 100% of amphibians (Anadón-Irizarry et al., 2012). However, despite its ecological richness, it is recognized as one of the most threatened biodiversity hotspots in the world (Hurtado-Valdivieso et al., 2025). The study area herein spans terrestrial, freshwater, and marine habitats across a vast pelagic ocean space, covering more than 3 million square kilometres.

We conducted systematic conservation prioritisations across the Insular Caribbean using Marxan v4.0.6 (Ball et al., 2009). The Marxan algorithm solves a minimum set problem to select a portfolio of planning units that meet conservation feature targets whilst minimising the cost incurred (Ball et al., 2009). All scenarios were executed in R v4.4.1 (R Core Team, 2024) within the RStudio environment. Spatial datasets were compiled between February and July 2024 from publicly available sources and modelled data products (Appendix A). Subsequent cleaning, processing, and manipulation of spatial data were performed in ArcGIS Pro v3.1.0 (ESRI, 2023).

We explored the conservation objectives of national versus regional conservation area solutions by comparing a regional and national scenario for each of the terrestrial, freshwater, and marine realms. To ensure that our planning assumptions were realistic and aligned with stakeholder needs, we presented and discussed all conservation objectives (scenarios), habitats for conservation (features), and their associated representation targets (proportion of features to conserve) during an initial planning workshop with regional and local partners in April 2024. Biodiversity in each realm was represented using regionally consistent, spatially explicit habitat types with additional spatial stratification by bioregion to represent biodiversity turnover among nations and between biogeographic areas (Table 1, also see Appendix B for detailed data generation methods). Although integrated land-sea planning is desirable, it was not feasible in this study due to the absence of a fully-coupled terrestrial-marine dataset.

In all Marxan scenarios, conservation feature targets were uniformly set to 30% representation, with all features assigned equal penalty score if targets were unmet. The cost parameter required for Marxan analysis was represented as conservation implementation cost for terrestrial and freshwater scenarios, and opportunity costs in the marine environment, with all cost values weighted by the area of planning units (see Unit cost development section for more details). To control the spatial compactness of protected area configurations, we calibrated and applied the Boundary Length Modifier (BLM) parameter, optimising its value to produce solutions with both low overall area and minimal boundary length (as described in Serra et al. (2020), see Appendix B for further details). This approach is standard practice to avoid the generation of scattered, fragmented conservation portfolios, instead producing cohesive protected areas that are practical, efficient, and ecologically meaningful. Following calibration, BLM values were set at 1 for marine runs, and 0.01 for terrestrial and freshwater runs, accounting for the difference in planning unit size and structure. Freshwater BLM values were further adjusted to account for longitudinal connectivity (Appendix B). Marxan was set to 1000 runs for each scenario, ensuring robust solution convergence and comparability across runs.

Table 1

Summary of the conservation features included in Marxan scenarios, categorised into administrative, terrestrial, freshwater, and marine types. Data layers within each category contain between 1 and 56 individual habitat classes (features), used as Marxan inputs. All features were set to a species penalty factor (SPF) of 10, with a representation target of 30%. Data sources are detailed in Appendix A.

Data category	Data	No. features	Spatial data type
Administrative (85 features)	Terrestrial ecoregions	25	Polygons
	Freshwater ecological drainage units	28	Polygons
	Marine ecoregions	3	Polygons
	Exclusive economic zones	29	Polygons
Terrestrial (190 features)	Grassland habitats	43	Polygons
	Herbaceous wetland habitats	33	Polygons
	Pine habitats	32	Polygons
	Shrubland habitats	38	Polygons
	Tree cover habitats	43	Polygons
	Mangroves	1	Polygons
Freshwater (72 features)	Rivers and streams	56	Lines
	Wetlands, marshes, flooded flats and swamps	6	Polygons
	Lakes and ponds	2	Polygons
	Floodplains	7	Polygons
	Blue holes	1	Points
Marine (81 features)	Shallow benthic habitats: coral reefs, seagrasses, hardbottom habitats & rocky zones	10	Polygons
	Coastal tidal flats	3	Polygons
	Estuaries	3	Polygons
	Deep ocean habitats combining depth zones, broad seafloor structures (crests, depressions etc.) and finer structures	48	Polygons
	Linear deep ocean features (ridges, canyons etc.)	11	Lines
	Knolls	1	Points
	Seamounts	1	Points
	Sea turtle nesting sites	1	Points
	Seabird nesting sites	1	Points
	Fish spawning aggregations	1	Points
	Coral refugia sites	1	Points

2.1. Spatial data collation and processing

Planning units form the basis of systematic conservation prioritisation, as areas which hold features and can be selected in a final solution for protected area designation. Here, we created watershed-based units (for both terrestrial and freshwater Marxan analyses) and hexagonal marine planning units. Watersheds have been previously identified as natural ecological units that are effective for conservation planning (Li et al., 2025) and hexagons minimise edge effects and allow for increased flexibility in solution creation (Nhancale and Smith, 2011). The watershed-based units were created using HydroSHEDS hydrologically conditioned digital elevation models at 3 arc-second (90 m) resolution (Lehner et al., 2008). The delineation of the sub-watersheds used herein resulted in a total of 12,822 terrestrial and freshwater planning units, with a mean area of 19 km^2. The same planning units were used for terrestrial and freshwater scenarios, as the geography of these scenarios overlaps. For the marine realm, we created size-variant hexagonal planning units across three depth zones, shallow (<30 m depth), shelf (30–200 m), and deep ocean (>200 m) regions, with planning unit areas of 1 km^2, 5 km^2 and 10 km^2, respectively. Coastal marine hexagons with an area smaller than 0.5 km^2 (a result of intersection with the coastline) were merged with their nearest neighbour, resulting in a total of 491,287 marine planning units.

We partitioned conservation analyses biogeographically and/or by administrative boundaries, using a process called stratification to maximise biodiversity representation (Anderson et al., 2023). Stratification subdivides the region into distinct subregions, or strata features, that serve as a proxy of biodiversity turnover in the absence of taxon-level representations of biodiversity, since community compositions and species identities have been shown to vary biogeographically (Olson et al., 2001; Higgins et al., 2005; Spalding et al., 2007). Stratification can also provide a level of redundancy in reserve design, by ensuring the same ecological features are represented across multiple geographical contexts, increasing the robustness of reserve networks to localised disturbances and changes (Visconti and Joppa, 2015). Note that our approach does not subdivide other conservation features (habitat classes) by strata, but ensures 30% representation of each strata feature. We stratified all scenarios by the three major marine ecoregions in the Insular Caribbean (Bahamian, Eastern Caribbean and Greater Antilles; Spalding et al., 2007). In addition, terrestrial scenarios were stratified by 25 discrete ecoregions (Olson et al., 2001), and freshwater scenarios were stratified by 28 discrete ecological drainage units (Higgins et al., 2005). For the national scenarios, solutions were further stratified by Exclusive Economic Zone boundaries (EEZs; Flanders Marine Institute, 2024). EEZ strata conservation features represent biodiversity in each nation and allow generation of Marxan portfolios where each individual country or territory has a goal of 30% land and sea coverage within the bounds of that EEZ. This analysis covers 29 distinct EEZs (see Appendix D for full list). In practice, this means that for each planning unit, alongside holding conservation features (habitats), the unit is also assigned to a marine ecoregion and a jurisdictional EEZ, and land-based units have terrestrial ecoregion and freshwater drainage unit designations. By setting targets for these stratification features, we ensure even biogeographic representation across the study area.

We incorporated existing protected areas into all analyses by retaining them throughout the optimisation process (i.e. locking them in) and selecting additional areas to meet conservation targets (Margules and Pressey, 2000). For this purpose, we used an updated database of protected areas in the Insular Caribbean provided by The Nature Conservancy in September 2024 (TNC, 2024). Planning units with more than 50% coverage by existing protected areas were classified as "protected" in all scenarios. We set all protected areas as providing equal benefits and levels of protection, because data on protection level and enforcement status is inconsistent.

2.2. Unit cost development

All systematic conservation planning uses cost metrics to represent potential conflicts with users, management costs, and the opportunity costs of conservation (Margules and Pressey, 2000). We quantified these costs to represent the extent, patterns, and trends of human land and sea use across the Caribbean. For terrestrial Marxan scenarios, we used a 90 m raster model of mapped human activities that directly or indirectly alter natural systems, cause ecological stress, and contribute to habitat degradation (Theobald et al., 2025). The resulting quantitative estimates of human modification were rescaled to values between 0 and 1, with values closer to 1 indicating a more heavily human-modified environment (Theobald et al., 2025). For freshwater Marxan scenarios, we calculated the flow accumulated values of Theobald's model for each planning unit that flows into a downstream unit based on flow direction. In this way, the total accumulated value is calculated at the coastal outlet, and the total upstream human impacts can be assessed for each watershed (as in McPherson et al., 2008). To estimate opportunity cost from potential marine activities, we used a 1 km-resolution global model developed by Halpern et al. (2019) that includes fishing, climate change, shipping, and land-based pollution, scaled to values between 0 and 1 (as before, 1 indicates highest impact). For each cost surface, we chose the maximum value $max(V)$ in order to heavily select against areas of high human influence, and within each planning unit scaled it by the unit area (km^2) (Eq. (1)),

$$planning\ unit\ cost = (1 + \max(V)) \times unit\ area. \quad (1)$$

This approach resulted in the smallest planning units with minimal anthropogenic impact having the lowest cost value in the Marxan algorithm. Some coastal marine units did not have a cost value due to the spatial resolution of the cost surface, so these units were given a mean-imputed value. Using the maximum value ($max(V)$) within each planning unit may inflate the apparent cost of larger, heterogeneous units that contain both degraded and intact areas. This can bias prioritisation away from locations that still have some conservation potential (Adams, 2024). However, this approach is useful where the finer-scale impact is unknown, such as when planning at coarser regional scales, since it reduces the risk of selecting areas with high human impact that would require high restoration or acquisition costs for conservation (Carwardine et al., 2008).

2.3. Analyses to compare conservation priorities between national and regional scenarios

To compare regional and national approach realms, we selected the 10 lowest scoring Marxan runs from each scenario, representing the top 1% of solutions generated in the conservation planning analysis. For each EEZ zone (country or territory), we calculated the total cost across all selected planning units for every run within each scenario. From this, we subtracted the cost of any planning units assigned protected status, as we assume the cost for these units has already been incurred, to give a final cost for each nation in each run. We then calculated the percentage cost change by calculating the difference between the regional cost and the local cost, divided by the local cost, across the resulting 100 possible pairwise national and regional cost comparisons (Eq. 2).

$$\%change = \sum_{i=1}^{100} \frac{(cost_{regional} - cost_{national})}{cost_{national}} \times 100 \quad (2)$$

The mean of this metric indicates the change in cost when moving from planning nationally to planning regionally. If the cost is lower in a regional scenario, then the percentage change will be negative, and if the cost is lower in the national scenario, the change will be positive. When comparing percentage change in the cost parameter, we only include results from *newly declared* protected areas (i.e., existing protected areas are removed from the total cost), ensuring that the previously incurred cost is excluded.

We illustrated the differences in spatial configurations between the regional and national planning scenarios with difference maps (see Álvarez-Romero et al., 2015b; Vercammen et al., 2019 for examples). Combining the 1000 runs generated by Marxan for each scenario, we created a selection frequency for each planning unit, indicating how often each unit is selected as part of the final Marxan solution. Then, to compare, we calculated the change in selection frequency for each planning unit, starting with the regional scenario and subtracting the selection frequency from the national scenario. Therefore, units selected more frequently on a regional scale will have a positive value, and vice versa for units selected more frequently on the national scale.

When visualising the changes in selection frequency, we not only depicted the numerical change, but we also classified planning units that have selection frequencies below 100 in both the national and regional scenario as *rarely selected*, and those that always have a high selection frequency as *often selected*. The cutoff for "high" varied with each realm, and was selected based on visual inspection of histograms of selection frequency (Appendix C). For the terrestrial and marine realms, units were classed as *often selected* if both regional and national selection frequencies were above 700. For the freshwater realm, this cutoff was increased slightly to 800, as the distribution curve was slightly shifted.

2.4. Previous and ongoing stakeholder engagement

We presented preliminary scenarios results to project partners and stakeholders (see Acknowledgements for full list) during workshops held in October and December of 2024. These sessions provided an opportunity for participants to identify important areas that may have been overlooked in the initial Marxan analysis and to flag areas that are infeasible for biodiversity protection due to ecological, social, or political constraints. Although no adjustments were needed at the regional scale, the discussions helped clarify potential applications of the results and highlighted opportunities for future collaboration. To broaden accessibility and support decision-making, project results are currently being disseminated through a user-friendly online dashboard (caribbean30x30dashboard.tnc.org) that enables stakeholders to explore national and regional scenario portfolios without requiring extensive technical expertise. This tool permits users to visualise and query various scenario portfolios and conservation feature targets at the regional and national level in order to support decision-makers in establishing protected areas based on their specific goals.

3. Results

3.1. Existing protected areas

Of the 12,822 terrestrial planning units used in the Marxan analysis, 2846 units were classed as existing protected areas, covering 17.4% of the available area. Of the 491,287 marine planning units, 74,931 units were currently protected, representing 10.2% of available marine habitat. Protected areas were present in 27 of the 29 exclusive economic zones. The two areas with no existing formal protected areas are marine spaces; one is a Joint Regime Area shared by Jamaica and Colombia (Bajo Nuevo & Serranilla Cays), and the other is an area of overlapping claim between Puerto Rico and Dominican Republic (Mouchoir Bank). The current existing protected area network is not sufficient to meet 30% targets for all conservation features. In the terrestrial realm, targets for only 37 of a possible 190 conservation features are already met with protected areas. In the freshwater realm, targets for 18 from a possible 72 features are met, and in the marine realm 23 of 81 possible features meet the 30% target (Table 2). Note that we do not compare results for administrative features (Table 1) as these are included for stratification

Table 2
Summarised results contrasting scenarios in the three realms, showing the percentage area selected, the number of features meeting their 30% target, and mean coverage across all conservation features, for regional and national planning objectives. Results from the top ten runs are summarised, with the exception of the protected area (PA) baseline where there is only one run. Note that we considered all protected areas to offer equal protection, and due to variation in enforcement across the region, realistic area and feature coverage may be lower than what is detailed here.

Realm	Targets set (30% for all)	Scenario	Percentage of available area selected	Number of features meeting targets (30% representation)	Mean feature coverage (± SD)
Terrestrial	190	PA baseline	17.4%	37	19.8% (±22.2%)
		National	41.0% (±0.5%)	190	53.3% (±18.7%)
		Regional	40.6% (±0.4%)	190	52.5% (±19.0%)
Freshwater	72	PA baseline	17.4%	18	24.1% (±22.6%)
		National	40.3% (±0.6%)	72	59.2% (±24.3%)
		Regional	39.6% (±0.7%)	72	58.7% (±24.0%)
Marine	81	PA baseline	10.2%	23	20.7% (±16.4%)
		National	37.8 (±0.2%)	81	50.8% (±16.1%)
		Regional	36.5% (±0.5%)	81	49.6% (±16.5%)

purposes only.

3.2. Cost differences when planning at the national and regional scale

We assessed how nations are represented in nationally-stratified and regional scenarios by comparing cost in each exclusive economic zone (EEZ) in the scenarios. We use cost as an indication of the presence that each EEZ holds in a given Marxan solution, with a higher cost resulting from more planning units being selected in that EEZ. In the regional solutions, some EEZs were not included, but all EEZs were represented in all national solutions across terrestrial, freshwater and marine realms, and we now show changes that occur when moving from a fully representative, nationally-stratified solution to a regional approach. Note that overall, a regional approach results in a reduction in total area selected, across the entirety of the geographic space, for all three realms (Table 2). All conservation feature targets were met in all runs presented herein, at both the regional and national scale (Table 2), which ensures fair comparison between the scenarios.

In the terrestrial regional scenario, 21 of the 27 terrestrial economic zones were represented in all the top ten regional runs. Six countries/territories were absent in at least one of the ten best runs: Montserrat (absent twice); Saba (absent eight times); Sint Eustatius (absent five times); Sint Maarten (absent once); St Barthélemy (absent six times) and Barbados (absent four times). Navassa Island contained only one terrestrial planning unit which already holds protected status, so there was no change in cost or representation for this area. When switching from a national-focused to a regional objective, average cost decreased for 15 EEZs (Fig. 1a; Appendix D), with a maximum decrease of −90% (±3%) in Anguilla. The cost was similar in both scenarios for Puerto Rico (mean change +0.2 ± 1%), Martinique (mean change +0.6% ± 3%) and Cuba (mean change −0.7% ± 0.4%). Eight countries/territories experienced an increase in cost in the regional scenario, with the maximum increase occurring in Guadeloupe (increase of 132% ± 23%). This increase is likely due to Guadeloupe holding a high proportion of some terrestrial habitat classes across the region, which are held in planning units with high cost. Guadeloupe also showed high variation in the configuration of solutions at both national and regional scales.

In the freshwater regional scenario, 19 of the 27 available economic zones were represented in all the top ten runs. Eight countries/territories were missing from at least one of the top ten runs analysed: Montserrat (absent five times); Saba (always absent); Sint Eustatius (absent eight times); Sint Maarten (absent five times); Saint Martin (absent five times); St. Barthélemy (always absent); Saint Lucia (absent four times) and Barbados (absent four times). Cost decreased for 15 EEZs in the regional scenario (Fig. 1b), with a maximum decrease of −100% for both Saba and St. Barthélemy, due to these areas not being present at all in the top ten regional runs. Saint Lucia had an average decrease in the regional scenario of 90% (±2%). Cost was relatively similar for Cuba (mean change −0.9% ± 0.6%), Puerto Rico (mean change −2.2% ± 0.9%) and Martinique (mean change +2.9% ± 1.5%). Eight EEZs showed increases in cost in the regional scenarios, with a maximum increase of 35.4% (±13.3%) in Guadeloupe.

In the marine regional scenario, all 29 available economic zones were represented in all top ten solutions. The change in overall cost between regional and national scenarios was smaller for the marine realm compared to land-based realms, with 24 EEZs showing lower cost in the regional solution (Fig. 1c), up to a maximum decrease of −18.6% (±1%) in Mouchoir Bank. Saint Martin (mean change −0.5% ± 2.3%) and Grenada (mean change −0.7% ± 0.9%) showed similar costs in both scenarios, and three zones show increased cost in a regional solution, up to a maximum of 24.1% (±6.3%) in Sint Maarten.

3.3. Conservation feature areas captured at the national and regional scale

A regional approach can be more cost-effective (Fig. 1), but this should not impact on overall feature representation. Here, we examine how individual conservation feature targets are met across the national and regional-scale scenarios, illustrating how some feature targets overshoot due to spatial configurations. As is expected with all Marxan results, all targets were achieved in both the national and regional level scenarios, across all three realms (Table 2). On average between 30% and 100% of features were selected across the top ten runs in all three realms (Fig. 2). Most conservation features showed a similar level of protection in both the national and regional scenarios, suggesting there is little change in feature overrepresentation under a regionally collaborative solution (Appendix E). Not all features start from a 0% protection baseline, which explains why some features are up to 100% protected (Appendix E).

3.4. Contrasting spatial configuration of regional and national priority areas

Difference maps illustrate how conservation priorities compare between regional and national scenarios for all 29 EEZs (Appendix F). Here, we present maps for three representative countries: Jamaica, Dominica and Martinique (Fig. 3).

Jamaica has six major protected areas: Negril Marine Park & Negril Environmental Protection Area (terrestrial and marine); Cockpit Country Protected Area (terrestrial); Black River Protected Area (terrestrial); Portland Bight Protected Area (terrestrial and marine); Port Royal Protected Area (terrestrial and marine); and the Blue and John Crow Mountains National Park (terrestrial), alongside many smaller protected areas throughout the country, in total covering 23% of available terrestrial space. Conservation priorities for the terrestrial and freshwater realms concentrated on expanding many of these major areas, and avoided central Jamaica (Fig. 3a, d). In the marine realm, we highlight some coastal areas to prioritise protection at intervals around the island (Fig. 3g). Across Jamaica, we see some planning units that are more frequently selected in the regional scenario (blue cells) and some units which are more frequently selected locally (green cells). This represents an example of the variation in solutions from different scenarios, and

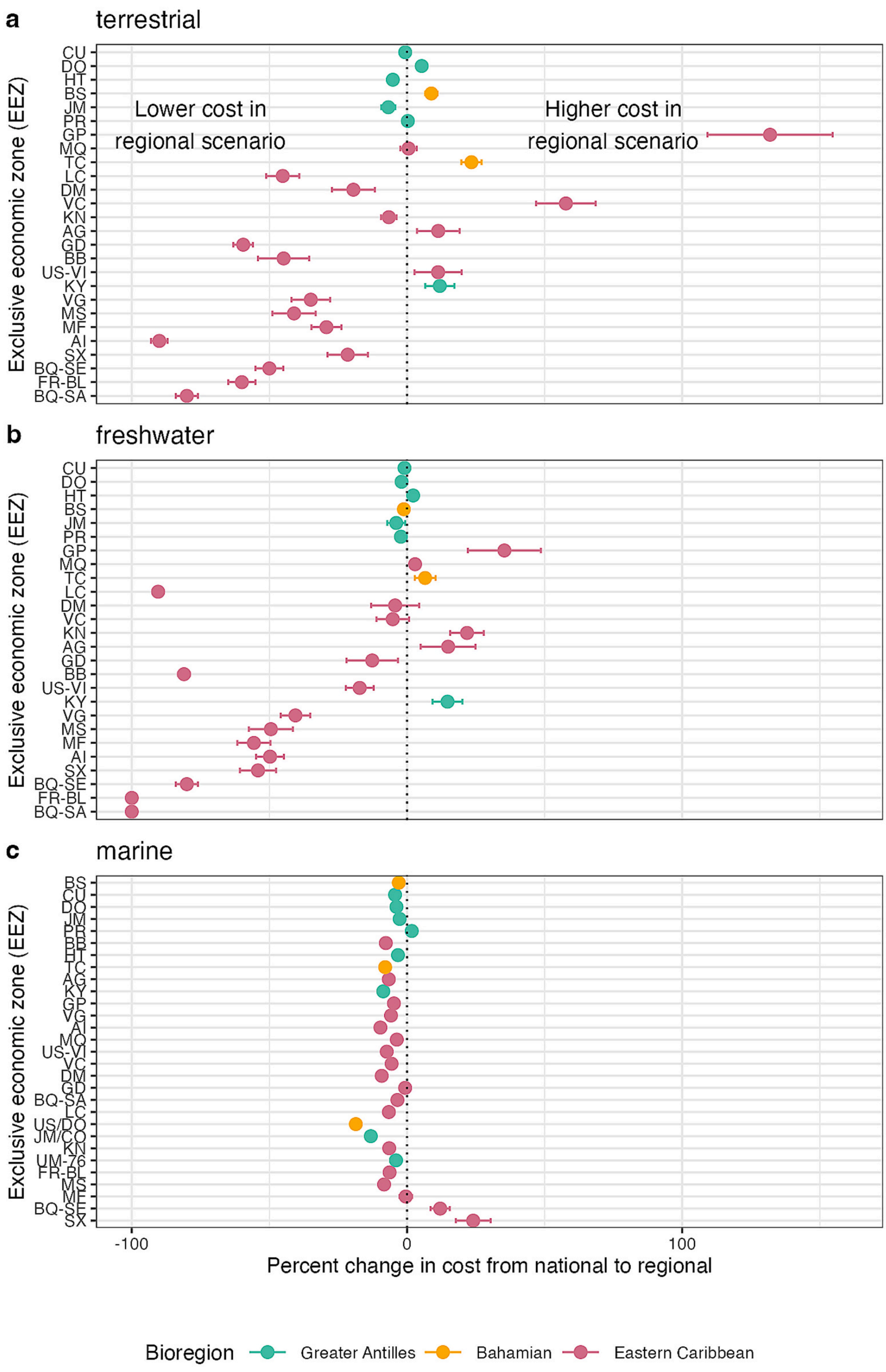

Fig. 1. Mean percentage change (± standard error) in total cost when moving from a national to a regional planning scenario for each exclusive economic zone (EEZ) for the a) terrestrial, b) freshwater, and c) marine realms. A negative change indicates that a regional solution would be more cost-effective for the individual EEZ, and a positive change indicates that more expense is required by that individual EEZ under the regional approach. Countries are ordered by number of available planning units, increasing towards the top of the plots. Countries are represented by their standard ISO country codes, e.g. CU = Cuba, DO = Dominican Republic (see Appendix D for full details).

how conservation priorities may change depending on whether objectives aim at regional or national management.

There are currently two major terrestrial protected areas on the island of Dominica: Morne Diablotin and Morne Trois Pitons (covering 21% of available terrestrial space), and two small marine protected areas: Cabrits National Park in the north, and Soufriere or Scott's Head in the south. Our analyses generally suggest avoiding the central area of the island in favour of expanding either of the protected areas (Fig. 3b,

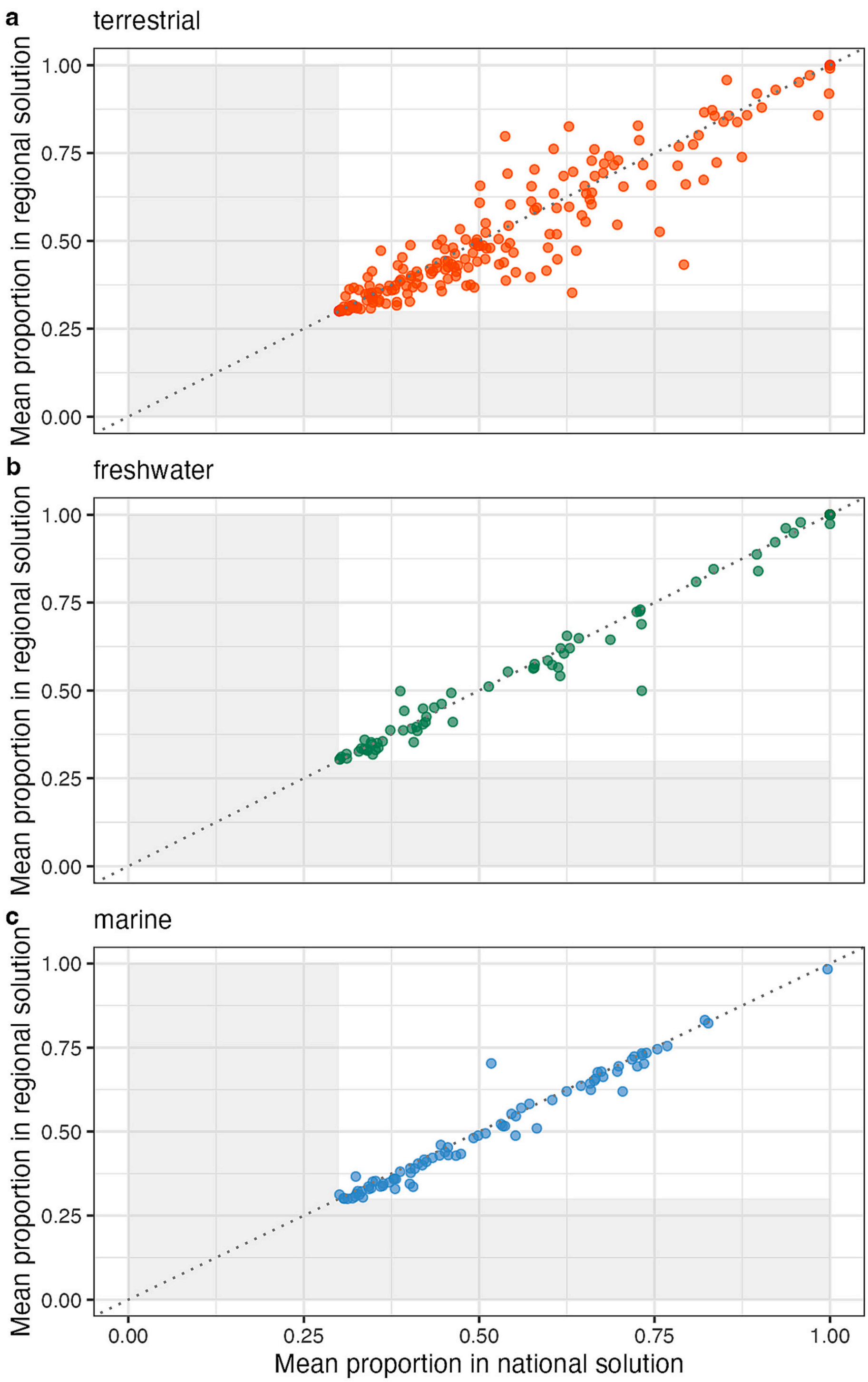

Fig. 2. Mean proportion of each feature held in the national and regional scenarios for a) terrestrial, b) freshwater and c) marine realms. Features on the dotted diagonal line on average have the same proportion held in both scenarios. Features above the line have a higher proportion selected across regional scenarios, and features below the line are more highly represented in the national scenarios. Shaded areas indicate where features would show less than 30% representation.

e). For Dominica, unlike Jamaica, all planning units are selected more frequently in the national scenario, suggesting that at a regional scale, the conservation features held in Dominica can be represented elsewhere at reduced cost. Therefore, Dominica may benefit more from national-level planning, as regional plans can underrepresent their biota. In the marine space, there is a great deal of flexibility across the national and regional scenarios (Fig. 3h) – suggesting that beyond a few patches around the northern coastline, marine protected area designation may be guided by other data sources.

Martinique is a major biodiversity hotspot, recognised by UNESCO (OFB, 2023), and in reflection of this, the majority of the island has already been designated as protected areas (57% of available space already protected on land, and 99% of marine space). The Martinique Regional Nature Park covers more than half of the island and is complemented by the Caravelle Peninsula and Sainte Anne nature reserves, as well as many smaller protected areas. Here, Martinique contributes significantly to the regional priority selections, with all planning units on the land being more frequently selected in regional scenarios,

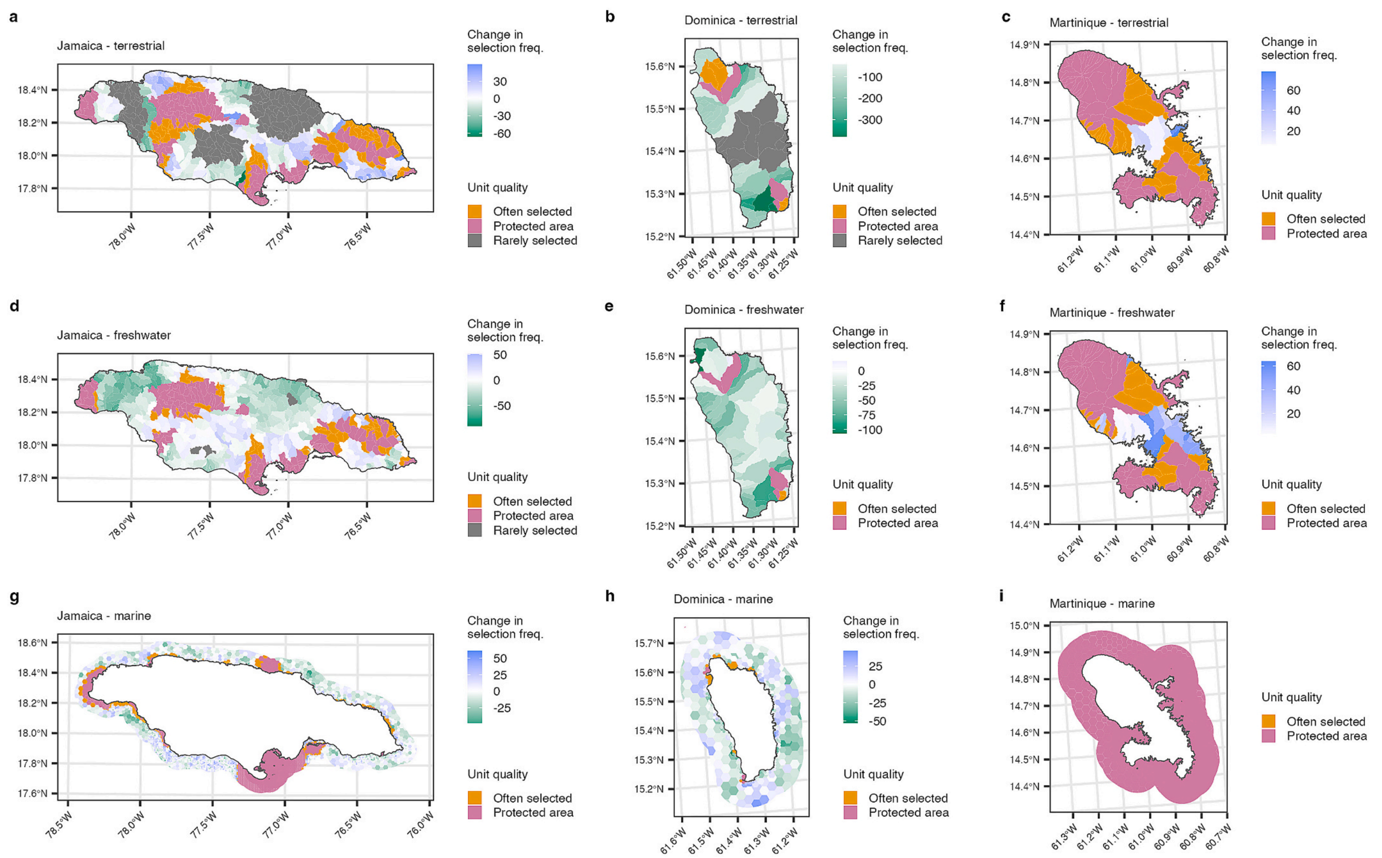

Fig. 3. Difference maps between selection frequencies (freq.) for national and regional planning objectives for terrestrial (a–c), freshwater (d–f) and marine (g–i) realms, across Jamaica, Dominica and Martinique. Colours indicate how planning units are differentially selected when comparing the national scenario against the regional scenario. Positive values (blue) indicate units more frequently selected at a regional scale, and negative values (green) indicate units of higher national importance, but less frequently selected at the regional level. Pre-existing protected areas are highlighted in pink. Rarely selected units (grey) are selected less than 100 times in both scenarios. Often selected units (yellow) are selected most frequently in both scenarios. Cutoffs for "often selected" are specific to the realm of interest (terrestrial = 700 times in both scenarios, freshwater = 800 times in both scenarios, marine = 700 times in both scenarios). Difference maps for all countries and territories included in this analysis are provided in Appendix F. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

compared to national scenarios, as they represent unique or rare habitats that cannot be substituted elsewhere (Fig. 3c, f). Martinique has existing designated protected areas that cover all marine and coastal areas, resulting in no identified changes by the Marxan algorithm (Fig. 3i).

4. Discussion

We identified a portfolio of conservation priority sites across the Insular Caribbean, to provide decision support to governments across the region working towards protecting 30% of terrestrial, freshwater, and marine biodiversity by 2030. Our analysis shows that regional-scale conservation planning offers a more cost-effective pathway for achieving large scale protection targets than approaches focused at the national level. However, prioritising cost-efficiency alone can create inequities, concentrating conservation burdens and benefits in a subset of larger countries, whilst leaving smaller nations with few or no priority areas identified in regional solutions.

Collaborating across countries can be the most cost effective path towards achieving conservation goals, whilst also delivering additional benefits such as ecological connectivity, improved robustness and resilience, and shared resources and expertise (Kark et al., 2009; Gordon et al., 2013; Mazor et al., 2013; Leonard et al., 2017; Allan et al., 2019). The results of this study reinforce these findings. We show that a regional approach to protected area system design in the Caribbean would result in reduced conservation costs for many countries in the region compared to national planning, ranging from small reductions in cost of less than 1%, to the entire removal of any conservation action, depending on the nation and realm of interest (Fig. 1). These disparities may, in some cases, offer benefits, as many Small Island Developing States face acute financial and capacity constraints and are disproportionately vulnerable to climate-related hazards (Thomas et al., 2020). Reducing conservation burdens for these smaller nations could therefore be an important consideration for policy makers. Moreover, several of these countries already participate in sub-regional inter-governmental collaborations such as the Organization of Eastern Caribbean States (Mahadeo and Del Savio, 2023) or benefit from regional initiatives such as the Caribbean Biodiversity Fund (Caribbean Biodiversity Fund, 2024). These existing frameworks further support the practicality and desirability of a regional approach to conservation planning in the Insular Caribbean.

Given these considerations, the most cost-effective regional solution may not always be the most equitable across countries. In a regional approach, some countries have increased responsibility, with an expectation to protect what may be considered more than their "fair share" of the conservation burden, translating into higher financial costs for these countries (Armstrong, 2019; Shen et al., 2023). However, countries that contribute more may also reap greater long-term benefits from expanded protected area systems, such as increased nature-based tourism (Thapa et al., 2022), enhanced fisheries spillover in the marine realm (Lynham and Villaseñor-Derbez, 2024) and improvements in livelihoods, wellbeing, and public health (Jones et al., 2020). Whilst smaller nations may have fewer resources and greater vulnerability to environmental and economic shocks (Thomas et al., 2020), it may be deemed inequitable to completely exclude them from regional solutions. National-scale planning has further advantages, such as more closely aligning with domestic legal and policy frameworks, preserving national autonomy in decision making, and often allowing for more efficient implementation because it involves fewer stakeholders and avoids the complexity of regional negotiations (Eckert et al., 2023; Ferraro and Failler, 2024).

We suggest that presentation, consideration, and comparison of both regional and national solutions is essential for maximising flexibility in decision making, enabling each country or territory to prioritise areas most critical to its own ecological, social, and policy context. Although management decisions are typically made at the national scale (Wyborn and Bixler, 2013), they are informed by multiple factors, such as research priorities, available funding, and public policy (Martín-López et al., 2009), in addition to regional considerations (Beger et al., 2015). A major advantage of juxtaposing national and regional solutions is the ability to identify locations containing regionally rare or spatially limited habitat types that warrant protection under both approaches. For example, Jamaica holds more than 60% of all available area of the terrestrial habitat class of *calcareous tree cover with a very wet climate regime*, and more than 40% of the same habitat class under a wet climate regime. Similarly, Martinique holds almost 80% of the available habitat for *igneous volcanic herbaceous wetlands* under a very wet climate regime. Ultimately, final decisions on conservation designation will be context dependent, and shaped by national priorities, so both regional and national pathways can act as viable and complementary approaches.

We begin the presentation of our results with a brief discussion of the existing protected area network, which is insufficient to meet a 30% coverage goal for 165 of the 243 conservation features included in the analysis. An important point to highlight is that this may be an inaccurate picture of the current protected area network, since many protected areas are capacity limited, resulting in lower levels of realised biodiversity protection (Gill et al., 2017). Therefore, our analysis likely overstates the number of features already sufficiently covered in the existing protected area network, and the realised coverage of protected areas themselves. Whilst a sensitivity analysis to address this quantitatively would be desirable, our regional-level protected area database lacked consistent information on management level, making sensitivity analyses unfeasible in this case.

For terrestrial and freshwater realms, the priority sites exhibit clear variation in selection frequency across the landscapes (Fig. 3 & Appendix F). These patterns may indicate intuitive priority sites for protection and suggest natural next steps for decision makers. In contrast, selection frequencies in the marine realm, especially at deeper offshore depths, are less distinct, reflecting higher uncertainty. This uncertainty likely arises from a lack of data in the open ocean (Webb et al., 2010) or from the presence of uniform habitat patterns that recur across space. Future spatial planning could help resolve this uncertainty through the inclusion of additional datasets, such as improved seabed and substrate data, marine mammal and migratory corridors (Sahri et al., 2022), ocean currents, and indicators of primary productivity (Santora et al., 2017). Strengthening our understanding of pelagic ecosystems is particularly important because the deep ocean is historically underrepresented in marine protected areas (Game et al., 2009). A targeted, marine-specific prioritisation may therefore be a valuable avenue for future work. A potential interim solution to the missing marine data may be a form of dynamic management, whereby protected areas are not fixed in space and can move as human needs and environmental conditions change (Maxwell et al., 2015; Briscoe et al., 2016). However, such approaches pose legal and governance challenges (Westholm and Argüello, 2023) and uncertainties related to practical implementation (Welch et al., 2024). Additionally, because of the three-dimensional nature of marine systems, marine protected areas often confer uneven levels of protection to different marine species and benthic habitats. For example, a marine mammal sanctuary may protect surface-dwelling species, but offers little to no protection to coral reefs, seagrasses, or deep ocean habitats on the seafloor. Future work could focus on evaluating management objectives of individual parks to evaluate protection status of specific habitats within them, as well as evaluating level of implementation and enforcement.

In this analysis, we generated Marxan solutions separately for terrestrial, freshwater, and marine realms, which limits our ability to produce a fully integrated, multi-realm conservation strategy. This approach was motivated by practical considerations, such as the need for different planning unit designs and realm-specific Marxan parameters (notably for boundary length modifiers). Whilst cross-realm integrated conservation planning can improve biodiversity outcomes (Leal et al., 2020), there are ecological reasons for treating realms independently. Terrestrial, freshwater, and marine systems are governed by fundamentally different processes, connectivity pathways, and scales of ecological interaction, meaning a combined optimisation can obscure important trade-offs and potentially misallocate conservation effort (Adams et al., 2014). Further, integrated outputs may be less readily actionable within existing governance frameworks or management structures, where terrestrial, freshwater, and marine management are typically administered through separate institutions (Beger et al., 2010; Álvarez-Romero et al., 2015a).

Whilst previous spatial plans have used species distribution models (SDMs) as features, we chose to model abiotic habitats rather than species ranges. Regionally consistent and reliable SDMs were not available for this work, but the habitat-modelling approach we have taken aligns with the theory of protecting the "stage" of biodiversity and evolution, rather than specific "players" (Lawler et al., 2015). By protecting a diversity of habitat types and environmental conditions, the natural evolutionary processes and ecological dynamics that shape species assemblages over time can continue throughout the land and seascape (Hanson et al., 2020). This allows for a whole-ecosystem, functional approach to conservation, and avoids placing too much emphasis on static community compositions and specific species, which may be ineffective (Leuzinger and Rewald, 2021). Secondly, specific species ranges are subject to shift over time (Voskamp et al., 2021), and so by protecting a significant baseline of 30% of all habitat classes, we ensure variable and well-represented landscapes across space. This strategy promotes redundancy and a diversity of well-represented habitat types that can buffer the effects of climate change, even if the specific habitat classes within the network evolve (Schneider and Bayne, 2015).

We chose a moderately high boundary length modifier (BLM) to encourage the generation of spatially "clumped" solutions, resulting in priority that expand existing protected areas and promote the creation of larger, contiguous reserves. This approach reflects both practical and ecological considerations as it is generally more straightforward from a management perspective to increase existing reserves than set up new ones. This approach also promotes strengthening existing protection, which can be more effective than the generation of new isolated parks (Zeng et al., 2023). Further, larger reserves encompass broader gradients of environmental conditions, fostering long-term species persistence and buffering ecological processes against environmental change (Ranius et al., 2023). However, the relationship between reserve size and conservation benefit is not linear. In some contexts, networks comprising many smaller reserves may provide increased connectivity and cover more discrete habitat types for the same overall area, than one large reserve (Fahrig et al., 2022). For this reason, designation of reserves and decisions on network configurations should be made on a case-by-case basis. The results presented here can be viewed as an initial decision-support framework - one that can guide, but not predetermine, the final design of protected-area systems as planners integrate ecological, social, and governance considerations. We also note that adjusting the BLM value an order of magnitude either side of the calibrated choice did not result in a change to the pattern of our cost comparison results

(Appendix B).

Within our study area, we utilise a large number of planning units, particularly in the marine space, which can make finding a mathematically optimal solution challenging due to a large decision space (Serra et al., 2020; Appendix G). An alternative method, such as integer linear programming (ILP) algorithms may be able to find truly optimal solutions (Beyer et al., 2016; Teschke et al., 2026), with different absolute cost values, but the overall pattern of our results would likely remain consistent. We chose to continue to use Marxan with a smaller-scale planning grid to allow for flexibility and realism in the national-level approaches. In addition, Marxan has previously been used successfully in other large-scale cases, including in Australia (Klein et al., 2009), and more recently across the entirety of Chile (Martinez-Harms et al., 2021). Further, it is important to emphasise that any Marxan results are not prescriptive and should not be interpreted as the definitive "right answer" to a conservation problem, rather, they serve as a decision-support tool to guide future action (Game et al., 2013). Each country will have finer-scale and updated data which may be highly relevant to that specific country's biodiversity action plan, which was not included in the regional analysis, but is essential for implementation (Adams et al., 2019). We therefore recommend that individual countries and territories apply their best judgement and incorporate these Marxan results as insights to evaluate and include regionally important areas when developing or revising national biodiversity plans. Local enabling conditions, such as political will, social acceptance, land tenure, and feasibility, will ultimately shape which areas can realistically be protected (Zuercher et al., 2022). By working collaboratively with stakeholders from across the region, we ensured that the questions addressed in this study are relevant, actionable, and an effective use of time and resources. This approach helps avoid common pitfalls in conservation planning, including biased allocation of effort, poorly framed or irrelevant questions, flawed analyses, inaccessible outputs, and inadequate reporting (Buxton et al., 2021). This study was designed as a regional biophysical prioritisation to inform progress towards the 30 × 30 targets and does not prescribe protected area designation or governance outcomes. In the Insular Caribbean, proposed conservation priorities may intersect with Indigenous territories, community held lands, and areas supporting customary and subsistence livelihoods. Consequently, any application of these results must occur through rights based, participatory processes, including free, prior and informed consent (FPIC) where applicable. Our outputs are intended to support locally led planning, negotiation, and co-design of conservation actions consistent with national law and community self-determination.

In conclusion, we propose that both regional and national pathways to conservation are necessary and have the potential to be successful in the Insular Caribbean. Whilst regional planning offers clear advantages such as cost-effectiveness, collaborative actions, and enhanced ecological coherence, it risks concentrating conservation responsibilities on a subset of nations, whilst limiting the contributions of others. National-scale planning, by contrast, allows each country to align conservation decisions with its own priorities, governance structures, and feasibility constraints. Providing multiple pathways towards shared conservation objectives, as we have done here, maximizes flexibility and increases the likelihood of effective and equitable implementation. Our multi-scale spatial planning approach is broadly applicable to other regions where regional-level prioritisation must be complemented by national-level options to ensure fairness, feasibility, and political uptake. As countries seek to expand their protection levels over the next four years in the face of escalating anthropogenic impacts on biodiversity, these analyses provide an actionable, science-based framework to support governments and conservation practitioners on the ground. These results are therefore directly contributing to informed decisions that advance meaningful, robust protection in the Insular Caribbean.

CRediT authorship contribution statement

M. Rae-Seaman: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis. **S.R. Schill:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **V.P. McNulty:** Writing – review & editing, Methodology, Data curation. **D. Muenzel:** Writing – review & editing, Software. **M. Heiner:** Data curation. **A. Olivero:** Data curation. **S.M. Sait:** Writing – review & editing, Supervision. **J.G. Singh:** Project administration. **M. Beger:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the Leeds-York-Hull Natural Environment Research Council (NERC) Doctoral Training Partnership (DTP) Panorama under grant NE/S007458/1. We thank the following project partners for their contributions to scenario development and for future implementation of the work: CANARI - Caribbean Natural Resources Institute; CARICOM (Caribbean Community) Secretariat; CAR-SPAW/RAC – Protocol Concerning Specially Protected Areas and Wildlife in the Caribbean/Regional Activity Center; CBC - Corredor Biologico en el Caribe; CBF - Caribbean Biodiversity Fund; CMLE+ Partnership/ProCaribe+; CI - Conservation International; CRFM - Caribbean Regional Fisheries Mechanism; GCFI - Gulf and Caribbean Fisheries Institute; IOCARIBE Secretariat, UNESCO; JNCC - Joint Nature Conservation Committee; Marine Conservation Society in the UK; IUCN – International Union for the Conservation of Nature; OECS (Organization of Eastern Caribbean States) Commission; CPAG – Caribbean Protected Areas Gateway; SI – Smithsonian Institution; TNC – The Nature Conservancy; UNDP - United Nations Development Programme; UNEP/Cartegena Convention Secretariat; UWI/CERMES - University of West Indies/Centre for Resource Management and Environmental Studies; WCS - Wildlife Conservation Society.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2026.112010.

Data availability

Data layers and outputs from the prioritisation analysis are publicly available for viewing and download at caribbean30x30dashboard.tnc.org.

Code to reproduce the analysis is available at https://doi.org/10.5281/zenodo.21233457.

References

Adams, V.M., 2024. Costs in conservation: common costly mistakes and how to avoid them. PLoS Biol. 22, e3002676.

Adams, V.M., Álvarez-Romero, J.G., Carwardine, J., Cattarino, L., Hermoso, V., Kennard, M.J., Linke, S., Pressey, R.L., Stoeckl, N., 2014. Planning across freshwater and terrestrial realms: cobenefits and tradeoffs between conservation actions. Conserv. Lett. 7, 425–440.

Adams, V.M., Mills, M., Weeks, R., Segan, D.B., Pressey, R.L., Gurney, G.G., Groves, C., Davis, F.W., Álvarez-Romero, J.G., 2019. Implementation strategies for systematic conservation planning. Ambio 48, 139–152.

Allan, J.R., Levin, N., Jones, K.R., Abdullah, S., Hongoh, J., Hermoso, V., Kark, S., 2019. Navigating the complexities of coordinated conservation along the river Nile. Sci. Adv. 5, eaau7668. American Association for the Advancement of Science.

Álvarez-Romero, J.G., et al., 2015a. Integrated cross-realm planning: a decision-makers' perspective. Biol. Conserv. 191, 799–808.
Álvarez-Romero, J.G., Pressey, R.L., Ban, N.C., Brodie, J., 2015b. Advancing land-sea conservation planning: integrating modelling of catchments, land-use change, and river plumes to prioritise catchment management and protection. PLoS One 10, e0145574. Public Library of Science.
Anadón-Irizarry, V., et al., 2012. Sites for priority biodiversity conservation in the Caribbean Islands Biodiversity Hotspot. J. Threat. Taxa 4, 2306–2844.
Anderson, M.G., et al., 2023. A resilient and connected network of sites to sustain biodiversity under a changing climate. Proc. Natl. Acad. Sci. U. S. A. 120, e2204434119.
Armstrong, C., 2019. Sharing conservation burdens fairly. Conserv. Biol. 33, 554–560.
Baker, D.J., Gaston, K.J., Metcalfe, K., Maclean, I.M.D., 2025. Systematic conservation planning for nature recovery. BioScience 75, 472–489.
Ball, I.R., Possingham, H.P., Watts, M., 2009. Marxan and relatives: Software for spatial conservation prioritisation. In: Moilanen, A., Wilson, K.A., Possingham, H., Possingham, H. (Eds.), Spatial Conservation Prioritization: Quantitative Methods and Computational Tools. Oxford University Press, Oxford, UK, pp. 185–195.
Beger, M., Grantham, H.S., Pressey, R.L., Wilson, K.A., Peterson, E.L., Dorfman, D., Mumby, P.J., Lourival, R., Brumbaugh, D.R., Possingham, H.P., 2010. Conservation planning for connectivity across marine, freshwater, and terrestrial realms. Biol. Conserv. 143, 565–575.
Beger, M., McGowan, J., Treml, E.A., Green, A.L., White, A.T., Wolff, N.H., Klein, C.J., Mumby, P.J., Possingham, H.P., 2015. Integrating regional conservation priorities for multiple objectives into national policy. Nat. Commun. 6, 8208.
Beyer, H.L., Dujardin, Y., Watts, M.E., Possingham, H.P., 2016. Solving conservation planning problems with integer linear programming. Ecol. Model. 328, 14–22.
Briscoe, D., Maxwell, S., Kudela, R., Crowder, L., Croll, D., 2016. Are we missing important areas in pelagic marine conservation? Redefining conservation hotspots in the ocean. Endanger. Species Res. 29, 229–237.
Buxton, R.T., et al., 2021. Avoiding wasted research resources in conservation science. Conserv. Sci. Pract. 3, e329.
Caribbean Biodiversity Fund, 2024. Caribbean Biodiversity Fund: 2023 annual report. Caribbean Biodiversity Fund (CBF), Kingston, Jamaica. Available from. https://bvearmb.do/handle/123456789/5205 (accessed April 9, 2025).
Carwardine, J., Wilson, K.A., Watts, M., Etter, A., Klein, C.J., Possingham, H.P., 2008. Avoiding costly conservation mistakes: the importance of defining actions and costs in spatial priority setting. PloS One 3, e2586.
CBD, 2010. Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets. Available from. https://www.cbd.int/sp/.
CBD, 2022. Decision adopted by the conference of the parties to the convention on biological diversity 15/4. Available from. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf.
Delevaux, J.M.S., et al., 2024. Social–ecological benefits of land–sea planning at multiple scales in Mesoamerica. Nat. Sustainability. https://doi.org/10.1038/s41893-024-01325-7.
Eckert, I., Brown, A., Caron, D., Riva, F., Pollock, L.J., 2023. 30×30 biodiversity gains rely on national coordination. Nat. Commun. 14, 7113.
ESRI, 2023. ArcGIS Pro.
Fahrig, L., et al., 2022. Resolving the SLOSS dilemma for biodiversity conservation: a research agenda. Biol. Rev. 97, 99–114.
Ferraro, G., Failler, P., 2024. Biodiversity, multi-level governance, and policy implementation in Europe: a comparative analysis at the subnational level. J. Publ. Policy 44, 546–572.
Flanders Marine Institute, 2024. Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM). Available from. https://www.marineregions.org/ (accessed March 24, 2024).
Game, E.T., Grantham, H.S., Hobday, A.J., Pressey, R.L., Lombard, A.T., Beckley, L.E., Gjerde, K., Bustamante, R., Possingham, H.P., Richardson, A.J., 2009. Pelagic protected areas: the missing dimension in ocean conservation. Trends Ecol. Evol. 24, 360–369.
Game, E.T., Kareiva, P., Possingham, H.P., 2013. Six common mistakes in conservation priority setting. Conserv. Biol. 27, 480–485.
Giakoumi, S., et al., 2025. Advances in systematic conservation planning to meet global biodiversity goals. Trends Ecol. Evol. https://doi.org/10.1016/j.tree.2024.12.002.
Gill, D.A., et al., 2017. Capacity shortfalls hinder the performance of marine protected areas globally. Nature 543, 665–669.
Gill, D.A., et al., 2024. A diverse portfolio of marine protected areas can better advance global conservation and equity. Proc. Natl. Acad. Sci. U. S. A. 121, e2313205121.
Gordon, A., Bastin, L., Langford, W.T., Lechner, A.M., Bekessy, S.A., 2013. Simulating the value of collaboration in multi-actor conservation planning. Ecol. Model. 249, 19–25.
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. Sci. Rep. 9, 11609. Nature Publishing Group.
Hanson, J.O., Marques, A., Veríssimo, A., Camacho-Sanchez, M., Velo-Antón, G., Martínez-Solano, Í., Carvalho, S.B., 2020. Conservation planning for adaptive and neutral evolutionary processes. J. Appl. Ecol. 57, 2159–2169.
Harvey, M.S., Ralph, G.M., Polidoro, B.A., Maxwell, S.M., Carpenter, K.E., 2021. Identifying key biodiversity areas as marine conservation priorities in the greater Caribbean. Biodivers. Conserv. 30, 4039–4059.
Hermoso, V., Abell, R., Linke, S., Boon, P., 2016. The role of protected areas for freshwater biodiversity conservation: challenges and opportunities in a rapidly changing world. Aquat. Conserv. Mar. Freshwat. Ecosyst. 26, 3–11.
Higgins, J.V., Bryer, M.T., Khoury, M.L., Fitzhugh, T.W., 2005. A freshwater classification approach for biodiversity conservation planning. Conserv. Biol. 19, 432–445.
Hoffmann, S., 2022. Challenges and opportunities of area-based conservation in reaching biodiversity and sustainability goals. Biodivers. Conserv. 31, 325–352.
Huggins, A.E., et al., 2007. Biodiversity Conservation Assessment of the Insular Caribbean Using the Caribbean Decision Support System Summary Report. The Nature Conservancy. Available from. https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/Caribbean/science/planning/Documents/CDSS_summary_report_final.pdf (accessed April 23, 2025).
Hurtado-Valdivieso, R., Mancera-Pineda, J.E., Martin, A., Quintero, P., Ruíz, D., Baggio, J., 2025. Informing coastal futures: sea level rise and ecosystem service disruption in Caribbean biodiversity hotspots. Curr. Clim. Change Rep. 11, 8.
IPCC, 2023. Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 1st edition. Cambridge University Press. Available from. https://www.cambridge.org/core/product/identifier/9781009325844/type/book. (accessed March 20, 2025).
Isbell, F., et al., 2023. Expert perspectives on global biodiversity loss and its drivers and impacts on people. Front. Ecol. Environ. 21, 94–103.
Jaureguiberry, P., et al., 2022. The direct drivers of recent global anthropogenic biodiversity loss. Sci. Adv. 8, eabm9982. American Association for the Advancement of Science.
Jones, N., Graziano, M., Dimitrakopoulos, P.G., 2020. Social impacts of European Protected Areas and policy recommendations. Environ. Sci. Policy 112, 134–140.
Kabbadj, L., Van Wynsberge, S., Andréfouët, S., 2018. Scaling tropical island conservation planning to the regional level can lead to unbalanced ecological representation and poor social equity among islands. Mar. Policy 93, 31–39.
Kark, S., Levin, N., Grantham, H.S., Possingham, H.P., 2009. Between-country collaboration and consideration of costs increase conservation planning efficiency in the Mediterranean Basin. Proc. Natl. Acad. Sci. 106, 15368–15373.
Klein, C., Wilson, K., Watts, M., Stein, J., Berry, S., Carwardine, J., Smith, M.S., Mackey, B., Possingham, H., 2009. Incorporating ecological and evolutionary processes into continental-scale conservation planning. Ecol. Appl. 19, 206–217.
Knowles, J.E., Doyle, E., Schill, S.R., Roth, L.M., Milam, A., Raber, G.T., 2015. Establishing a marine conservation baseline for the insular Caribbean. Mar. Policy. https://doi.org/10.1016/j.marpol.2015.05.005.
Lawler, J.J., Ackerly, D.D., Albano, C.M., Anderson, M.G., Dobrowski, S.Z., Gill, J.L., Heller, N.E., Pressey, R.L., Sanderson, E.W., Weiss, S.B., 2015. The theory behind, and the challenges of, conserving nature's stage in a time of rapid change: conserving nature's stage in a time of rapid change. Conserv. Biol. 29, 618–629.
Leal, C.G., et al., 2020. Integrated terrestrial-freshwater planning doubles conservation of tropical aquatic species. Science 370, 117–121.
Lehner, B., Verdin, K., Jarvis, A., 2008. New global hydrography derived from spaceborne elevation data. Eos Trans. Am. Geophys. Union 89, 93–94.
Leonard, P.B., Baldwin, R.F., Hanks, R.D., 2017. Landscape-scale conservation design across biotic realms: sequential integration of aquatic and terrestrial landscapes. Sci. Rep. 7, 14556.
Leuzinger, S., Rewald, B., 2021. The who or the how? Species vs. ecosystem function priorities in conservation ecology. Front. Plant Sci. 12, 758413.
Li, J.-J., Fang, Y.-H., Zhan, J.-C., Yang, X.-J., Huang, C.-B., Li, Y.-P., Tan, K., Huang, Z.-P., Cui, L.-W., Xiao, W., 2025. Watershed: a more efficient sampling unit for mountain camera traps. Sci. Rep. 15, 4270. Nature Publishing Group.
Lynham, J., Villaseñor-Derbez, J.C., 2024. Evidence of spillover benefits from large-scale marine protected areas to purse seine fisheries. Science 386, 1276–1281.
Magoulick, K.M., Hull, V., Liu, J., 2024. Mammal recovery inside and outside terrestrial protected areas. Ambio 53, 1296–1306.
Mahadeo, S., Del Savio, L., 2023. Transboundary maritime cooperation: the case of the Eastern Caribbean Region. Front. Mar. Sci. 10. Frontiers.
Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253. Nature Publishing Group.
Martinez-Harms, M.J., Wilson, K.A., Costa, M.D.P., Possingham, H.P., Gelcich, S., Chauvenet, A., Pliscoff, P., Marquet, P.A., Bryan, B.A., 2021. Conservation planning for people and nature in a Chilean biodiversity hotspot. People Nat. 3, 686–699.
Martín-López, B., Montes, C., Ramírez, L., Benayas, J., 2009. What drives policy decision-making related to species conservation? Biol. Conserv. 142, 1370–1380.
Maxwell, S.M., et al., 2015. Dynamic ocean management: defining and conceptualizing real-time management of the ocean. Mar. Policy 58, 42–50.
Maxwell, S.L., et al., 2020. Area-based conservation in the twenty-first century. Nature 586, 217–227.
Mazor, T., Possingham, H.P., Kark, S., 2013. Collaboration among countries in marine conservation can achieve substantial efficiencies. Diversity Distrib. 19, 1380–1393.
McPherson, M., Schill, S., Raber, G., John, K., Zenny, N., Thurlow, K., Sutton, A., 2008. GIS-based modeling of environmental risk surfaces (ERS) for conservation planning in Jamaica. J. Conserv. Plan. 4.
Miloslavich, P., et al., 2010. Marine biodiversity in the Caribbean: regional estimates and distribution patterns. PloS One 5, e11916.
Nhancale, B.A., Smith, R.J., 2011. The influence of planning unit characteristics on the efficiency and spatial pattern of systematic conservation planning assessments. Biodivers. Conserv. 20, 1821–1835.
OFB, 2023. Martinique: an exceptional biodiversity recognized by UNESCO | French Office of Biodiversity. September 25. Available from. https://ofb.gouv.fr/actualites/martinique-une-biodiversite-exceptionnelle-reconnue-par-unesco (accessed December 11, 2025).
Olson, D.M., et al., 2001. Terrestrial ecoregions of the world: a new map of life on earth. BioScience 51, 933–938.

Pressey, R.L., Cabeza, M., Watts, M.E., Cowling, R.M., Wilson, K.A., 2007. Conservation planning in a changing world. Trends Ecol. Evol. 22, 583–592. Elsevier.

R Core Team, 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. . Available from. https://www.R-project.org/.

Ranius, T., Widenfalk, L.A., Seedre, M., Lindman, L., Felton, A., Hämäläinen, A., Filyushkina, A., Öckinger, E., 2023. Protected area designation and management in a world of climate change: a review of recommendations. Ambio 52, 68–80.

Sahri, A., Jak, C., Putra, M.I.H., Murk, A.J., Andrews-Goff, V., Double, M.C., Van Lammeren, R.J., 2022. Telemetry-based home range and habitat modelling reveals that the majority of areas important for pygmy blue whales are currently unprotected. Biol. Conserv. 272, 109594.

Santora, J.A., Sydeman, W.J., Schroeder, I.D., Field, J.C., Miller, R.R., Wells, B.K., 2017. Persistence of trophic hotspots and relation to human impacts within an upwelling marine ecosystem. Ecol. Appl. 27, 560–574.

Schneider, R.R., Bayne, E.M., 2015. Reserve design under climate change: from land facets back to ecosystem representation. PLoS One 10, e0126918. Public Library of Science.

Serra, N., Kockel, A., Game, E.T., Grantham, H., Possingham, H.P., McGowan, J., 2020. Marxan User Manual: For Marxan Version 2.43 and Above. The Nature Conservancy (TNC) and Pacific Marine Analysis and Research Association (PacMARA), Arlington, Virginia, United States and Victoria, British Columbia, Canada.

Shen, X., Liu, M., Hanson, J.O., Wang, J., Locke, H., Watson, J.E.M., Ellis, E.C., Li, S., Ma, K., 2023. Countries' differentiated responsibilities to fulfill area-based conservation targets of the Kunming-Montreal Global Biodiversity Framework. One Earth 6, 548–559.

Soliku, O., Schraml, U., 2018. Making sense of protected area conflicts and management approaches: a review of causes, contexts and conflict management strategies. Biol. Conserv. 222, 136–145.

Spalding, M.D., et al., 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. BioScience 57, 573–583.

Teschke, K., Konijnenberg, R., Bellotto Trigo, F.C., 2026. Conservation planning in the Weddell Sea (Antarctica): a comparative analysis of decision-support tools. Conserv. Sci. Pract. 8, e70311.

Thapa, K., King, D., Banhalmi-Zakar, Z., Diedrich, A., 2022. Nature-based tourism in protected areas: a systematic review of socio-economic benefits and costs to local people. Int. J. Sustain. Dev. World Ecol. 29, 625–640. Taylor & Francis.

Theobald, D.M., Oakleaf, J.R., Moncrieff, G., Voigt, M., Kiesecker, J., Kennedy, C.M., 2025. Global extent and change in human modification of terrestrial ecosystems from 1990 to 2022. Sci. Data 12, 606.

Thomas, A., Baptiste, A., Martyr-Koller, R., Pringle, P., Rhiney, K., 2020. Climate change and small island developing states. Annu. Rev. Environ. Resour. 45, 1–27. Annual Reviews.

TNC, 2024. Protected Areas of the Insular Caribbean. Available from. https://caribbeanscienceatlas.tnc.org/.

TNC, 2025. Caribbean Protection Dashboard. Available from. http://CaribbeanProtection.tnc.org (accessed May 21, 2025).

Vercammen, A., et al., 2019. Evaluating the impact of accounting for coral cover in large-scale marine conservation prioritizations. Divers. Distrib. 25, 1564–1574.

Visconti, P., Joppa, L., 2015. Building robust conservation plans. Conserv. Biol. 29, 503–512.

Voskamp, A., Butchart, S.H.M., Baker, D.J., Wilsey, C.B., Willis, S.G., 2021. Site-based conservation of terrestrial bird species in the Caribbean and central and South America under climate change. Front. Ecol. Evol. 9. Frontiers.

Wauchope, H.S., et al., 2022. Protected areas have a mixed impact on waterbirds, but management helps. Nature 605, 103–107.

Webb, T.J., Berghe, E.V., O'Dor, R., 2010. Biodiversity's big wet secret: the global distribution of marine biological records reveals chronic under-exploration of the deep Pelagic Ocean. PLoS One 5, e10223. Public Library of Science.

Welch, H., Liu, O.R., Riekkola, L., Abrahms, B., Hazen, E.L., Samhouri, J.F., 2024. Selection of planning unit size in dynamic management strategies to reduce human–wildlife conflict. Conserv. Biol. 38, e14201.

Westholm, A., Argüello, G., 2023. Dynamic ocean management in areas beyond national jurisdiction. Ocean Dev. Int. Law 54, 448–468. Taylor & Francis.

Wilson, K.A., McBride, M.F., Bode, M., Possingham, H.P., 2006. Prioritizing global conservation efforts. Nature 440, 337–340.

Wilson, K.L., Tittensor, D.P., Worm, B., Lotze, H.K., 2020. Incorporating climate change adaptation into marine protected area planning. Glob. Chang. Biol. 26, 3251–3267.

Wyborn, C., Bixler, R.P., 2013. Collaboration and nested environmental governance: scale dependency, scale framing, and cross-scale interactions in collaborative conservation. J. Environ. Manage. 123, 58–67.

Zeng, Y., Senior, R.A., Crawford, C.L., Wilcove, D.S., 2023. Gaps and weaknesses in the global protected area network for safeguarding at-risk species. Sci. Adv. 9, eadg0288.

Zhu, L., Hughes, A.C., Zhao, X.-Q., Zhou, L.-J., Ma, K.-P., Shen, X.-L., Li, S., Liu, M.-Z., Xu, W.-B., Watson, J.E.M., 2021. Regional scalable priorities for national biodiversity and carbon conservation planning in Asia. Sci. Adv. 7, eabe4261.

Zuercher, R., et al., 2022. Enabling conditions for effective marine spatial planning. Mar. Policy 143, 105141.