Title Page

Meeting the Demand: Aligning Marine Biodiversity Data Supply with Policy Needs

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Abstract

The effective implementation of international, regional, and national commitments on marine biodiversity depends on reliable data. However, there is often a disconnect between the information generated by scientists and the data explicitly required by policy processes. This review systematically examined more than thirty policy instruments and mapped over 1,000 explicit data requirements to identify where science can most effectively contribute. Using the pressure–state–response framework, the analysis found that pressures such as pollution, fishing, and habitat degradation dominate policy demand, though important attributes such as intensity, frequency, and cumulative impacts are rarely specified. State-related data on species, habitats, and ecosystems are frequently required but remain difficult to monitor consistently due to technical, logistical, and conceptual challenges. Response-related data are less often highlighted in policy instruments but are increasingly needed to guide and evaluate management interventions, including spatial planning and restoration. Emerging priorities include climate-related stressors, connectivity, invasive species, blue carbon systems, and genetic diversity, which are not yet widely reflected in instruments but are growing in importance. The review concludes that improved monitoring resolution, better integration of pressures, states, and responses, investment in new technologies, and stronger interoperability and inclusivity are all critical. By clarifying points of convergence in policy demand and highlighting key gaps, the study provides practical guidance to help marine scientists and monitoring practitioners generate data that are more directly relevant to policy and governance.

Keywords

Biodiversity, Monitoring, Indicators, Governance, Policy, Ecosystems, Conservation

Highlights

1. Over 1,000 marine biodiversity data needs mapped across more than 30 policy tools
2. Five key themes cover 60% of data needs
3. Pressure, state, and response data gaps hinder effective marine policy support
4. This review offers practical guidance to align marine science with policy priorities

1. Introduction

A wide range of international agreements, conventions, legal frameworks, and strategies (hereafter collectively referred to as instruments) have been developed to address the interconnected planetary crises of biodiversity loss, climate change, and pollution. A corresponding diversity of data is required to support the implementation of these instruments, including information on the state of species, habitats and ecosystems; the pressures and threats they face; and the effectiveness of the responses undertaken to sustainably manage, restore, and conserve them (Stephenson and Stengel, 2020). The supply of relevant data and knowledge is therefore needed from actors including scientists, who are increasingly expected to make their research policy-relevant (McNie, 2007) and who often desire to help address the societal challenges we face (Cvitanovic *et al.*, 2015; Muller-Karger *et al.*, 2018; Rose *et al.*, 2018).

Despite both science and policy professionals having the will and the need to work together, a disconnect often remains between supply and demand across the science-policy interface. This contributes to widespread data gaps (IPBES, 2019; Burgess *et al.*, 2024; McGowan *et al.*, 2024), particularly in marine environments (Addison *et al.*, 2018; Dailianis *et al.*, 2018; Gerovasileiou *et al.*, 2019a; McQuatters-Gollop *et al.*, 2019; Carr, Abas, Boutahar, Caretti, Chan, Abbie S. A. Chapman, *et al.*, 2020), which limit our ability to track progress against instruments, assess the effectiveness of their implementation, and undertake adaptive management as needed (Edmondson and Fanning, 2022; Affinito *et al.*, 2024; Huang and Chang, 2025). For example, a review by Bal *et al.*, 2018 found that species trait–based indicators developed in academic settings rarely align with the requirements of biodiversity policy and management; just 21% of studies explicitly described how the indicators addressed defined policy objectives.

There is an extensive literature on the drivers that shape the effectiveness of the science-policy interface, including both barriers and enabling conditions (McNie, 2007; Rose *et al.*, 2018, 2019). While contexts vary by actors and instruments, scientists gain considerable value by engaging with target audiences, directly or through intermediaries, to understand policy needs and tailor their contributions (Fisher et al., 2020). In practice, this kind of engagement is not always feasible. A scientist’s ability to interact with policymakers or participate in decision-making processes is influenced by factors such as geographic location, institutional context, career stage, disciplinary background, and access to professional networks (Filyushkina *et al.*, 2022; John *et al.*, 2023; Wiegleb and Bruns, 2025)

Where direct engagement with decision makers is not feasible, researchers can identify policy-relevant data needs by analysing published outputs such as decisions, resolutions, technical briefings, and strategies (e.g. Rogers, 2025 for the Biodiversity Beyond National Jurisdiction Agreement). This approach supports the deliberate alignment of research with specific policies, decisions, or processes, which has been shown to be an essential step in ensuring that scientific data are actionable.

The goals, targets, and associated monitoring frameworks of policy instruments allow data needs to be interpreted based on the changes being pursued and what must be monitored, evaluated, and reported on. This in turn could help data providers design outputs or package their data in ways that more directly align with policy demand. However, the goals and targets of policies are often broad or ambiguous, reflecting negotiated political language rather than technical specificity (Mcowen et al., 2016). This creates distance between policy texts and the language or formats familiar to scientists, making it difficult to identify monitoring priorities (Moersberger et al., 2024). Furthermore, determining which instruments are relevant can be difficult and time consuming for data producers, who often lack the legal or policy expertise, time, or institutional support to navigate this complexity. For example, understanding the full set of marine biodiversity-related provisions under the European Union's Habitats Directive requires consulting detailed text including one article, four annexes, two explanatory notes, and one official list (Walton *et al.*, 2024).

Finally, without clarity on when data are needed and in what formats or standards data producers may struggle to align their work with policy requirements (Rogers et al., 2022). A clearer comprehension of reporting mechanisms can support more effective collaboration between data providers and those responsible for monitoring, evaluation, and reporting, helping to strengthen knowledge exchange across the science–policy interface (Hoppe, 2010; Soomai, 2017; Karcher et al., 2022).

This review responds to the persistent disconnect between scientific data and policy demand by systematically examining how marine biodiversity data needs are expressed across global, regional, and national policy instruments. It collates and synthesises the types of data required to track pressures, state, and responses; clarifies where and how these requirements are articulated through targets, reporting provisions, and monitoring frameworks; and identifies points of convergence and divergence across instruments. In doing so, the review provides a resource to help marine data producers navigate the policy landscape, understand what data are needed, when, and in what form, and contribute more effectively to monitoring, evaluation, and reporting processes. By making these requirements more visible and accessible, the review aims to support more structured collaboration across the science–policy interface and enhance the role of marine science in environmental decision-making.

2. Methods

2.1 Source documents and scope

This review examines the data required to support monitoring, evaluation, and reporting across a set of global, regional, and national instruments relevant to marine biodiversity. These were selected to reflect a representative cross-section of biodiversity-relevant obligations (Weatherdon et al., 2017), including legally binding agreements and implementation strategies with direct implications for marine monitoring.

- Global Multilateral Environmental Agreements, including the Convention on Biological Diversity (CBD, Kunming-Montreal Global Biodiversity Framework (KMGBF)); the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; Strategic Vision 2021–2030); the Convention on the Conservation of Migratory Species of Wild Animals (CMS; Strategic Plan for Migratory Species 2024–2032); and the Convention on Wetlands of International Importance (Ramsar; Ramsar Strategic Plan 2016–2024).
- Regional Directives, Conventions and Action Plans, including seven Regional Seas Conventions and Action Plans and six European Union Directives and Regulations (the Marine Strategy Framework Directive, Habitats Directive, Marine Spatial Planning Directive, EU Nature Restoration Law and Deep Sea Access).
- National instruments, including seven National Biodiversity Strategies and Action Plans developed under the Convention on Biological Diversity for the Barcelona Convention (Mediterranean), OSPAR Convention (North-East Atlantic), Bucharest Convention (Black Sea), Cartagena Convention (Wider Caribbean), Helsinki Convention (Baltic Sea), COBSEA (East Asian Seas), and the CAMLR Convention for Conservation of Antarctic Marine Living Resources (CCAMLR; Southern Ocean).

Information was gathered from a combination of primary and secondary sources, including the full texts and annexes of instruments, as well as associated explanatory materials such as official guidance documents, websites, and databases. A summary of the reviewed instruments is provided in Table 1.

Table 1: Instruments reviewed. Detailed information is provided in Appendix A and Appendix B

Instrument	Type	Description
Convention on Biological Diversity (Kunming-Montreal Global Biodiversity Framework)	Global	The principal international treaty for biodiversity conservation, sustainable use, and benefit-sharing. The KMGBF, adopted under the CBD in 2022, sets out four long-term goals for 2050 and 23 targets for 2030 to halt and reverse biodiversity loss.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (Strategic Vision 2021–2030)	Global	International agreement to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Provides a legal framework for regulating trade through a permit system, listing species in three Appendices according to their threat status and trade controls. The CITES covers over 40,000 species and requires Parties to adopt domestic legislation and enforcement measures
Convention on the Conservation of Migratory Species of Wild Animals (Strategic Plan for Migratory Species 2024–2032)	Global	International agreement focused on the conservation and sustainable use of terrestrial, aquatic, and avian migratory species, their habitats, and migratory routes, including marine species
Convention on Wetlands of International Importance (Ramsar Strategic Plan 2016–2024	Global	Intergovernmental treaty for the conservation and wise use of wetlands of international importance, including coastal and marine wetlands
Regional Seas Conventions and Action Plans	Regional	Regional legal and policy instruments for the protection and sustainable management of shared marine and coastal environments. Frameworks typically include provisions for marine monitoring, assessment, and reporting. Seven frameworks were reviewed: the Barcelona Convention (Mediterranean), OSPAR Convention (North-East Atlantic), Bucharest Convention (Black Sea), Cartagena Convention (Wider Caribbean), Helsinki Convention (Baltic Sea), COBSEA (East Asian Seas), and the CAMLR Convention for Conservation of Antarctic Marine Living Resources (CCAMLR; Southern Ocean). These instruments vary in legal status and scope but typically include provisions for marine monitoring, assessment, and reporting
European Union Directives and Regulations	Regional/EU	EU legal instruments with defined data and reporting requirements, including the Marine Strategy Framework Directive, Habitats Directive, Deep Sea Access Regulation, Maritime Spatial Planning Directive, and Nature Restoration Law. These directives require Member States to monitor, report, and implement measures for marine and coastal biodiversity
National Biodiversity Strategies and Action Plans	National	Main national instruments for implementing the CBD and KMGBF. Countries set national targets and measures, reporting progress in line with global and regional frameworks. Examples reviewed include Belize, Namibia, New Zealand, South Africa, Canada, South Korea, and Suriname

2.2 Identification of discrete monitoring and evaluation elements

To address the ambiguity and complexity often found in policy language (Mcowen et al., 2016), each policy goal or target was systematically parsed into its constituent elements, defined as discrete actions, conditions, stressors, or outcomes to support the identification of data needs for monitoring, evaluation and reporting. Because of the focus of this review, constituent elements were restricted to environmental, ecological and anthropogenic related data, while language referencing aspects such as gender or Indigenous Peoples was not retained. For example, Target 1 of the Kunming–Montreal Global Biodiversity Framework was parsed into three elements based on distinct monitoring-relevant components: (1) ensuring that all areas are under participatory, integrated, and biodiversity-inclusive spatial planning and/or effective management addressing land- and sea-use change; (2) bringing the loss of areas of high biodiversity importance close to zero; and (3) bringing the loss of ecosystems of high ecological integrity close to zero by 2030. Each element represents a separate action or outcome that could be independently tracked through monitoring.

This method aligns with calls for systematic approaches that link monitoring to clearly defined management objectives (Bal et al., 2018) and clarify the types of scientific information required to support decision-making (Carter et al., 2023). It follows practices applied in previous work, including clause-based parsing (McGowan et al., 2024), the examination of key terms to understand indicator needs (Van Winkle, 2015) and the approach undertaken by the open-ended working group on the post-2020 global biodiversity framework (CBD, 2022).

2.3 Pressure, State and Response categorisation of elements

Each identified element was assigned to a single Pressure, State, or Response (PSR) category based on its primary function within the context of the policy text. To ensure consistency, classification followed a standard logic: pressure elements refer to human-driven inputs or disturbances; state elements describe the ecological condition of species, habitats, or ecosystems; and Response elements capture policy actions or management interventions. While many policy targets are framed in terms of desired outcomes and can implicitly reflect management responses, this review only assigned the response category to elements that explicitly referenced an action, policy commitment, or implementation measure. Elements describing resulting conditions or ecological change, such as reduced habitat loss or improved ecosystem integrity, were treated as State, even if embedded within a response orientated target.

It is acknowledged that some elements could plausibly fall under more than one category. For example, pollution may be considered a Pressure when framed in terms of the activity or source (e.g. discharge, runoff, or emissions), but also a State when described in terms of the resulting condition of the environment (e.g. concentration of pollutants in the water column). In such cases, the element was assigned based on what was being monitored or tracked within the policy context, whether the source of impact (pressure), the condition being measured (state), or the intervention applied to reduce it (response). This aimed to ensure consistent classification while acknowledging the complex and interconnected nature of real-world environmental systems.

2.4 Assigning Standard Data Categories

To ensure consistency in describing the required data and to allow synthesis and comparison across instruments that use varied language and framing, each identified element was assigned to a Standard Data Category that defines the specific type of data it represents (Table 2).

The Standard Data Categories were developed *a priori* based on the authors expert knowledge of biodiversity policy and monitoring practice. They reflect core monitoring priorities relevant to marine biodiversity, while avoiding excessive granularity or conceptual overlap. The list of categories was refined iteratively as new data types were encountered or boundaries between categories required clarification. Any modifications were made systematically and applied retroactively to maintain consistency across the dataset. Each element was assigned to the category that best reflected the primary type of data required for its monitoring or evaluation. Where an element implied multiple data types (e.g., both habitat extent and habitat condition), it was disaggregated into separate entries in the dataset, with each entry mapped to a single Standard Data Category.

2.5 Assigning Data Themes

To provide additional specificity and to capture cross-cutting issues not fully reflected by broader Standard Data Categories, each element was also assigned up to four fine-scale Data Themes (Table 3). These themes allow for a more granular characterisation of the specific biodiversity data need required by the element, for example, distinguishing between “nutrient pollution,” “plastic pollution,” “noise pollution,” or “chemical pollution”. This finer classification was introduced to support more detailed thematic analysis across instruments and to identify recurring issues that may cut across multiple policy frameworks or PSR categories.

Multiple themes were applied where an element clearly intersected more than one topic. For instance, an element related to bycatch could be tagged with both “Bycatch” and “Impacts on Species,” reflecting the multidimensional nature of the issue. This approach preserved analytical clarity while accommodating the complexity of real-world biodiversity challenges. The list of Data Themes was developed using the same expert-led, iterative process as the Standard Data Categories, ensuring internal consistency and thematic coherence across the dataset.

Table 2. Standard Data Categories and included data types used to categorise data

PSR Category	Standard Data Category	Description	Example Data
Pressure	Pollution, nutrient loading & litter	Degradation caused by inputs of contaminants into marine environments	Includes nutrient pollution (nitrogen, phosphorus), chemical pollution (e.g. mercury, hydrocarbons), physical debris including plastic, light and noise pollution; measured in water, sediment, or species; includes data on sources, levels, and ecological impacts
Pressure	Direct mortality and disturbance of species	Anthropogenic activities leading to mortality, injury, or behavioural disturbance of marine species	Includes bycatch, ship strikes, entanglement, physical disturbance during breeding or migration, and infrastructure-related mortality
Pressure	Oceanographic and climate-related stressors	Physical or chemical shifts in ocean conditions due to climate or natural variability	Includes temperature rise, ocean acidification, sea-level rise, salinity changes, and altered current patterns
Pressure	Invasive & non-indigenous species	Introduction and establishment of species outside their native range and associated ecosystem impacts	Includes data on non-native species presence, introduction pathways, establishment patterns, spread, and ecological or economic impacts
Pressure	Habitat disturbance & physical alteration	Physical degradation or modification of marine and coastal habitats	Includes data on dredging, coastal infrastructure, erosion, sedimentation, trawling, or trampling affecting habitat structure
State	Ecosystem extent & condition	The spatial coverage and biological integrity of ecosystems or habitats	Includes area extent, condition assessments, degradation status of seagrass, coral, mangroves; and metrics such as macrophyte depth

State	Species population & extinction risk	Demographic characteristics and threat status of marine species	Includes population trends, age/size/sex structure, Red List status, extinction risk, and conservation priority classifications
State	Ecosystem services	Contributions of ecosystems to human wellbeing, economy, and culture	Includes provisioning services (e.g. fish harvest), regulating services (e.g. carbon storage), cultural values, and associated valuation studies
State	Sustainable use & resource extraction	Resource management strategies aiming to align human use with ecosystem sustainability	Includes sustainable harvest practices, catch quotas, legal frameworks, stock assessments, and restoration-linked extraction rules
Response	Spatial planning and Protected and Conserved Areas	Area-based conservation or management interventions	Includes data on marine protected areas, other effective area-based conservation and management measures, legal zoning, and spatial plans
Response	Restoration & rehabilitation	Actions taken to improve or recover degraded habitats or ecosystems	Includes extent and outcomes of coral or mangrove restoration, seagrass replanting, natural regeneration, or engineered habitat interventions
Response	Sustainable use & resource extraction	Resource management strategies aiming to align human use with ecosystem sustainability	Includes sustainable harvest practices, catch quotas, legal frameworks, stock assessments, and restoration-linked extraction rules

Table 3. Data themes and included data types used to categorise data

Thematic Group	Data Theme	Description	Example Data
Pressures and Threats	Bycatch	Incidental capture of non-target species during fishing operations, including mortality and injury	Data on rates of bycatch, affected species, mitigation measures, and spatial/temporal patterns
	Chemical Pollution	Contamination of marine environments by hazardous chemicals (e.g. mercury, hydrocarbons)	Monitoring of chemical contaminants in water, sediment, and biota; discharge data; compliance with chemical safety standards
	Nutrient Pollution	Excessive nutrient inputs into marine systems	Nitrogen and phosphorus loads, eutrophication, harmful algal blooms
	Plastic Pollution	Presence and impacts of plastic debris	Macro- and microplastic abundance, ingestion rates, entanglement, source attribution
	Noise Pollution	Anthropogenic underwater sound affecting marine life	Ship traffic, seismic, sonar deployments, subsea construction; observed impacts on species behaviour or health
	Light Pollution	Artificial light impacts on marine organisms or habitats	Sources and intensity of light; behavioural or physiological effects on species
	Pollution	General presence of contaminants in the marine environment	Combined or unspecified pollutant data not captured under specific pollution categories

	Invasive Species Introduction and Establishment	Presence and proliferation of non-native species	Occurrence data, pathways, and impact assessments of invasive species
	Disease	Prevalence and spread of diseases affecting marine species	Outbreak data, affected taxa, and impacts on population health
	Sectoral Pressures	Human pressures linked to economic sectors	Impacts from fishing, tourism, aquaculture, energy, or transport sectors
	Climate Change	Indicators reflecting climate change impacts on marine systems	Temperature, salinity, ocean acidification, sea level rise, and other climate-related oceanographic changes
	Cumulative Impacts	Combined pressure from multiple human activities	Integrated assessments of overlapping pressures on habitats, ecosystems, or species
Ecosystems and Habitats	Habitat Identification	Recognition and delineation of habitats	Classification, mapping, or delineation of key marine habitat types
	Habitat Extent	Spatial area of different marine and coastal habitats	Area coverage of coral reefs, mangroves, seagrass, etc.
	Habitat Condition	State of specific marine habitats	Physical integrity, species composition, or signs of degradation (e.g. coral bleaching, seagrass loss)
	Habitat Status	Overall evaluation of habitat health or integrity	Summary assessments of habitat condition, resilience, and threat level
	Ecosystem Condition	Biological and physical state of ecosystems	Biodiversity indicators, trophic structure, presence of key species, and indicators of degradation or resilience

	Ecosystem Function	Processes and interactions within ecosystems	Nutrient cycling, productivity, predator–prey dynamics, and other functional indicators
	Ecosystem Status	Overall condition or classification of an ecosystem	Index scores or thresholds indicating ecosystem health (e.g. ‘good’, ‘degraded’, ‘critical’)
	Connectivity	Ecological or functional linkages between habitats or populations	Data on migration routes, larval dispersal, gene flow, or ecosystem corridors
	Key Areas	Ecologically or biologically significant areas	Identified hotspots for biodiversity, reproduction, feeding, or migration
Species and Populations	Species Biology and Life History	Biological traits and life cycles of marine species	Reproduction, lifespan, migratory behaviour, and growth rates
	Species Status	Threat classification of species	Red List status, legal protection, and threat assessments
	Population Structure	Age, size, or sex distribution within species populations	Demographic data informing population dynamics and viability
	Population Trends	Temporal change in population abundance	Monitoring data indicating increases, declines, or stability of species populations
	Impacts on Species	Stressors affecting individual species or populations	Mortality, displacement, reproductive failure, or behavioural disturbance
	Genetic Diversity	Variation in genetic composition within and among marine species	Data on population structure, gene flow, genetic bottlenecks and phylogenetics
	Sustainable Harvest	Use of marine species at sustainable levels	Catch within biological limits, stock assessments, and harvest controls
Conservation, Restoration, and	Conservation Coverage	Extent of area-based conservation measures	Area coverage of marine protected areas or other effective area-based conservation measures, including spatial plans

Nature-Based Solutions	Conservation Outcomes	Measured results of conservation actions	Trends in species recovery, ecosystem condition, or reduction in threats due to conservation interventions
	Restoration Coverage	Extent of area under ecological restoration	Area of habitats or ecosystems undergoing or completed restoration interventions
	Restoration Outcomes	Results of ecological restoration efforts	Improved habitat condition, species return, or functionality after restoration
	Nature-Based Solutions	Ecosystem-based approaches to climate and development challenges	Projects or indicators related to blue carbon, coastal protection, or ecosystem-based adaptation
Human Use and Socioeconomic Dimensions	Fishing	Direct human extraction of marine species	Catch data, gear types, fishing effort, and spatial/temporal fishing activity
	Trade	Commercial exchange of marine species or products	Data on exports/imports, trade routes, or market demand for marine biodiversity
	Ecosystem Services	Benefits people derive from marine and coastal ecosystems	Valuation studies, provisioning/regulating/cultural services, and related social or economic indicators
Cross-Cutting Impact and Response Categories	Impacts on Habitats	Stressors affecting physical marine habitats	Indicators of erosion, pollution, sedimentation, or physical destruction of habitats
	Impacts on Ecosystems	Stressors affecting ecosystem structure or function	Evidence of decline in ecosystem productivity, species interactions, or spatial extent due to pressures

2.6 Data analyses

Data needs were identified at three levels:

1. Across all instruments to identify overall trends.
2. By instrument type (Multilateral Environmental Agreements, Regional Seas Conventions and Action Plans, European Union Directives and Regulations, and National Biodiversity Strategies and Action Plans); and
3. Within each individual instrument to examine specific patterns of emphasis.

For each level, the frequency of every PSR category, Standard Data Category, and Data Theme was calculated. This allowed the identification of dominant monitoring priorities, assessment of variation across instruments, and detection of areas of thematic convergence. Instruments differ in the level of specificity with which they frame goals and targets. Some refer to broad issues, such as “pollution”, in general terms, while others break these down into more specific components (e.g. “nutrient pollution,” “plastic pollution,” “chemical pollution”), each of which was recorded as a separate entry. While this affects the number of entries per instrument or theme, it does not bias the analysis, which reflects what is explicitly expressed in each policy text. The variation in specificity is itself informative, highlighting differences in how policy frameworks frame and prioritise data needs.

To assess the relative importance of data needs, we developed a composite score based on three components:

1. Frequency Score (50%) = (number of entries assigned to a category) ÷ (maximum number of entries assigned to any category). This reflects the overall demand for that category.
2. Breadth Score (30%) = (number of instruments in which a category was mentioned at least once) ÷ (total number of instruments). This captures cross-cutting relevance.
3. Share Score (20%) = (number of entries assigned to a category) ÷ (total number of entries across all categories). This reflects the dominance of that category relative to others.

The weighting scheme (Frequency = 0.5, Breadth = 0.3, Share = 0.2) was selected to balance empirical prominence with cross-instrument relevance. Frequency was given the highest weight as it represents the primary measure of demand, capturing how often each category appears across all entries. Breadth received moderate weight to reflect the extent to which a category is recognised across instruments, indicating cross-cutting importance. Share was assigned a smaller weight because it is partly derivative of frequency but provides useful normalisation across datasets. Together, the weights ensure that the composite score emphasises categories that are both frequently cited and broadly relevant, while limiting redundancy among components. Alternative weight combinations were explored and produced consistent rankings, indicating that the composite scores are robust to reasonable variation in weighting.

A composite importance score was then calculated as: Importance Score= (0.5×Frequency) + (0.3×Breadth) + (0.2×Share)

Each component was scaled to a 0–1 range before weighting to allow comparability. Calculations were performed across all instruments, by instrument type, and within individual instruments The weighting scheme was designed to capture the relative contribution of each component to assessing monitoring priorities in a way that is meaningful for the science–policy interface. Frequency was given the greatest weight (50%) because repeated references within instruments provide the strongest indication of sustained policy demand for a particular type of data. Breadth was weighted at 30% to highlight categories that, while less frequently cited overall, are consistently recognised across global, regional, and national instruments and therefore represent cross-cutting priorities. Share was weighted lower (20%) because of its partial overlap with frequency; it nonetheless provides useful context on the dominance of one category relative to others. Weighting frequency most strongly also reduced the risk that categories mentioned only once in many instruments would receive an artificially high score, ensuring that results reflect both the intensity and breadth of demand. This combination allowed the scores to balance absolute demand with cross-instrument relevance, directly supporting the review's objective of clarifying how marine biodiversity data needs are articulated across instruments and providing guidance for data producers on which types of information are most relevant, when, and in what form. To test robustness, we verified that alternative weightings produced similar rankings of categories, confirming that results were not highly sensitive to the chosen scheme. All quantitative analyses were conducted using R (R Core Team, 2025)

2.7 Reporting provisions

The same sources were used to identify reporting-related provisions for each instrument, focusing on institutional responsibilities, procedures, and monitoring frameworks. Specifically, we examined the following questions:

- Who is responsible for fulfilling reporting obligations?
- Who provides the data used in reports?
- How are reports compiled?
- How are they submitted?
- What is the reporting frequency?
- Does the instrument include a formal monitoring framework?
- If so, are there defined requirements associated with each indicator?

Detailed references to identified data requirements and reporting provisions are included in Appendices A and B, respectively.

3. Results

3.1 All Instruments

3.1.1 Pressure, State and Response

Across all instruments analysed, pressure-related data needs were the most frequent, representing 480 entries, with a composite Importance Score of 0.86. State-related data needs appeared slightly less often (434 entries) but had a similarly high Importance Score of 0.82, reflecting broad relevance across instruments. Response-related data needs were least frequent (189 entries) and had the lowest Importance Score (0.47), reflecting the fact they were less frequently referenced and less consistently distributed. This distribution shows that while pressure data dominate in frequency, both pressure and state categories are widely prioritised, whereas response-related data are more unevenly represented (Table 4).

3.1.2 Standard Data Categories

The most frequently cited Standard Data Category was pollution, nutrient loading and litter, appearing in 289 entries with a composite Importance Score of 0.74. Species population and extinction risk (222 entries; 0.65) and ecosystem extent and condition (177; 0.59) were also prominent, reflecting widespread use across instruments. Spatial planning and protected and conserved areas (91; 0.37) and direct mortality and disturbance of species (65; 0.29) were also frequently cited. Other categories included invasive and non-indigenous species (58; 0.29), sustainable use and resource extraction (57; 0.24), habitat disturbance and physical alteration (56; 0.29), and restoration and rehabilitation (43; 0.21), which were referenced with moderate frequency but had lower Importance Scores, indicating narrower distribution. At the lower end, ecosystem services (26 entries; 0.16) and oceanographic and climate-related stressors (19; 0.13) were less commonly referenced, suggesting more selective or emerging relevance (Table 4).

3.1.3 Data Theme Categories

The most frequently cited Data Theme Category was sectoral pressures, appearing in 227 entries with a composite Importance Score of 0.75. Species status (163; 0.59) and impacts on species (152; 0.56) were also prominent, reflecting broad concern with species-level monitoring and threats. Fishing (115; 0.42), nutrient pollution (109; 0.38), and sustainable harvest (97; 0.41) were also common, though with lower Importance Scores indicating more limited distribution. Other frequently referenced themes included impacts on habitats (96; 0.38), impacts on ecosystems (88; 0.39), key areas (81; 0.33), habitat condition (69; 0.35), chemical pollution (65; 0.28), plastic pollution (62; 0.29), invasive species introduction and establishment (62; 0.32), ecosystem status

(60; 0.31), and conservation outcomes (60; 0.27). At the lower end, several themes were infrequent and narrowly applied. These included disease (3 entries; 0.15), light pollution (2; 0.10), and genetic diversity (5; 0.20), all of which scored low in both frequency and importance (Table 4).

Although the policy instruments analysed span a diversity of scales and mandates, our analysis reveals a high degree of thematic convergence in the types of data required for monitoring and assessment. Notably, five categories, pollution, species status, habitat condition, fishing impacts, and sustainable harvest, accounted for over 60% of identified data needs across instruments.

Table 4. Frequency and importance of PSR, standard data and top 15 data theme categories across all instruments (based on frequency). Frequency is given in numerical values and asterisks indicate importance score: * 0 – 0.19, ** 0.20 – 0.39, *** 0.40 – 0.59, **** 0.60 – 0.79, ***** 0.80 – 1.00.

Category Type	Category	Frequency	Importance
PSR Category	Pressure	480	*****
	State	434	*****
	Response	189	***
Standard Data Category	Pollution, nutrient loading & litter	289	****
	Species population & extinction risk	222	****
	Ecosystem extent & condition	177	****
	Spatial planning and Protected and Conserved Areas	91	**
	Direct mortality and disturbance of species	65	**
	Invasive & non-indigenous species	58	**
	Habitat disturbance & physical alteration	56	**
	Sustainable use & resource extraction	57	**
	Restoration & rehabilitation	43	**
	Ecosystem services	26	*
	Oceanographic and climate-related stressors	19	*
Data Theme Category	Sectoral Pressures	227	*****
	Species Status	163	****
	Impacts on Species	152	****
	Fishing	115	***
	Nutrient Pollution	109	***
	Sustainable Harvest	97	***
	Impacts on Habitats	96	***
	Impacts on Ecosystems	88	***
	Key Areas	81	***

	Habitat Condition	69	***
	Invasive Species Introduction and Establishment	62	***
	Plastic Pollution	62	***
	Conservation Outcomes	60	***
	Ecosystem Status	60	***
	Habitat Extent	59	***

3.2 Multilateral Environmental Agreements

3.2.1 Pressure, State and Response

Among the Multilateral Environment Agreements assessed, state-related data needs were the most frequent, representing 91 entries with a composite Importance Score of 0.91. Pressure-related data needs appeared less often (36 entries) and had the lowest Importance Score (0.47), indicating both limited frequency and narrower distribution. Response-related data needs were similarly infrequent (35 entries) but had a slightly higher Importance Score (0.54), reflecting greater consistency across instruments (Table 5).

3.2.2 Standard Data Categories

The most frequent Standard Data Category was species population and extinction risk, appearing in 46 entries with a composite Importance Score of 0.78. Ecosystem extent and condition was the next most frequent (28 entries; 0.56), followed by spatial planning and protected and conserved areas (21 entries; 0.48). Pollution, nutrient loading and litter appeared less often (15 entries) but retained moderate importance (0.33), reflecting relevance across a limited number of agreements. Ecosystem services (14; 0.32) and restoration and rehabilitation (10; 0.42) were also common, though more unevenly distributed. (Table 5).

Several categories had lower frequencies and lower Importance Scores, indicating both limited use and narrower relevance. These included direct mortality and disturbance of species (9; 0.26), invasive and non-indigenous species (7; 0.23), and sustainable use and resource extraction (7; 0.23). Oceanographic and climate-related stressors (3 entries; 0.19) and habitat disturbance and physical alteration (2; 0.17) were least represented and had the lowest Importance Scores, suggesting more specialised and less widely prioritised data (Table 5).

3.2.3 Data Themes

The most frequent Data Theme was sectoral pressures, appearing in 27 entries with a composite Importance Score of 0.82. Species status was next most frequent (24 entries; 0.68), followed by species biology and life history (20; 0.53), conservation outcomes (20; 0.61), and sustainable harvest (19; 0.59). Ecosystem status (18; 0.64), key areas (17; 0.55), and fishing (16; 0.46) were also commonly cited. Other prominent themes included restoration outcomes (15; 0.51), impacts on species (15; 0.44), and ecosystem services (15; 0.44). At a lower frequency, habitat condition, ecosystem function, and impacts on ecosystems each appeared in 10 entries (0.42), while conservation coverage (9; 0.40) was also referenced but less widely distributed (Table 5).

Table 5 Frequency and importance of PSR, standard data and the top 15 data theme categories across the global multilateral environmental agreements (based on frequency). Frequency is given in numerical values and asterisks indicate importance score: * 0 – 0.19, ** 0.20 – 0.39, *** 0.40 – 0.59, **** 0.60 – 0.79, ***** 0.80 – 1.00.

Category Type	Category	Frequency	Importance
PSR Category	State	91	*****
	Pressure	36	***
	Response	35	***
Standard Data Category	Species population & extinction risk	46	****
	Ecosystem extent & condition	28	***
	Spatial planning and Protected and Conserved Areas	21	***
	Pollution, nutrient loading & litter	15	**
	Ecosystem services	14	**
	Restoration & rehabilitation	10	**
	Direct mortality and disturbance of species	9	**
	Invasive & non-indigenous species	7	**
	Sustainable use & resource extraction	7	**
	Oceanographic and climate-related stressors	3	*
	Habitat disturbance & physical alteration	2	*
Data Theme Category	Sectoral Pressures	27	*****
	Species Status	24	****
	Species Biology and Life History	20	***
	Conservation Outcomes	20	****
	Sustainable Harvest	19	***
	Ecosystem Status	18	****
	Key Areas	17	***
	Fishing	16	***
	Restoration Outcomes	15	***
	Impacts on Species	15	***
	Ecosystem Services	15	***
	Impacts on Ecosystems	10	***
	Ecosystem Function	10	***

	Habitat Condition	10	***
	Conservation Coverage	9	***

3.2.4 Reporting and pathways

The reviewed Multilateral Environmental Agreements show a high degree of variation in how reporting processes are structured, but several common features emerge. Reporting is typically the responsibility of national governments, often supported by designated focal points or implementing agencies. However, data provision may also involve scientific authorities, national agencies, or other stakeholders, including contributions from non-governmental sources.

Most instruments use standardised reporting templates or questionnaires, which differ in how structured or flexible they are. For example, reporting under the Kunming–Montreal Global Biodiversity Framework follows a defined set of indicators, while the Ramsar Convention combines specific questions with open sections that allow countries to provide additional information in their own words. Submission is generally conducted online, often through dedicated portals. Reporting cycles differ across instruments. Some require annual updates (e.g., CITES annual trade reports), while others follow three- or five-year cycles aligned with Conference of the Parties processes. Monitoring frameworks range from highly structured systems with computed indicators to more narrative-based approaches.

3.3 Regional Seas Conventions and Action Plans

3.3.1 Pressure, State and Response

Among the Regional Seas Conventions and Action Plans assessed, pressure-related data needs were the most frequent, representing 260 entries, with a composite Importance Score of 0.90. State-related data needs appeared less often (172 entries) and scored moderately in importance (0.70), reflecting substantial but slightly narrower relevance. Response-related data needs were the least common (70 entries) and had the lowest Importance Score (0.33), indicating that this category remains less widely required and unevenly distributed across the Regional Seas Conventions and Action Plans (Table 6).

3.3.2 Standard Data Categories

The most frequently cited Standard Data Category was pollution, nutrient loading and litter, which appeared in 189 entries and had the highest composite Importance Score of 0.83. Species population and extinction risk was cited in 87 entries, with a moderate Importance Score of 0.56. Ecosystem extent and condition was slightly less frequent (78 entries) and had a lower

Importance Score of 0.49, reflecting its more limited application across regional frameworks. Spatial planning and protected and conserved areas (30 entries; 0.22) and direct mortality and disturbance of species (24 entries; 0.29) were also cited, but their lower scores show they are referenced less consistently and with narrower cross-instrument relevance. Other categories such as habitat disturbance and physical alteration (23 entries; 0.28), restoration and rehabilitation (22; 0.20), and sustainable use and resource extraction (18; 0.14) were included less frequently, while invasive and non-indigenous species (15; 0.22), oceanographic and climate-related stressors (9; 0.16), and ecosystem services (7; 0.19) were least cited (Table 6).

3.3.3 Data Themes

The most frequent Data Theme Category was sectoral pressures, which appeared in 108 entries and had the highest Importance Score of 0.78, indicating consistent use across instruments. Nutrient pollution (78 entries; 0.63) and impacts on species (71 entries; 0.60) were also common. Species status (63 entries; 0.56), impacts on ecosystems (46 entries; 0.44), impacts on habitats (43 entries; 0.42), fishing (42 entries; 0.42), and plastic pollution (42 entries; 0.46) were also widely referenced with moderate Importance Scores. Other themes included chemical pollution (33; 0.33), conservation outcomes (33; 0.37), key areas (31; 0.36), population trends (25; 0.38), ecosystem status (24; 0.29), sustainable harvest (24; 0.24), and habitat condition (23; 0.37), reflecting a broad but uneven spread of thematic priorities across regional frameworks (Table 6).

Table 6 Frequency and importance of PSR, standard data and the top 15 data theme categories across the Regional Seas Conventions and Action Plans (based on frequency). Frequency is given in numerical values and asterisks indicate importance score: * 0 – 0.19, ** 0.20 – 0.39, *** 0.40 – 0.59, **** 0.60 – 0.79, ***** 0.80 – 1.00

Category Type	Category	Frequency	Importance
PSR Category	Pressure	260	*****
	State	172	****
	Response	70	**
Standard Data Category	Pollution, nutrient loading & litter	189	*****
	Species population & extinction risk	87	***
	Ecosystem extent & condition	78	***
	Spatial planning and Protected and Conserved Areas	30	**
	Direct mortality and disturbance of species	24	**
	Habitat disturbance & physical alteration	23	**
	Restoration & rehabilitation	22	**
	Sustainable use & resource extraction	18	*
	Invasive & non-indigenous species	15	*

	Oceanographic and climate-related stressors	9	*
	Ecosystem services	7	*
Data Theme Category	Sectoral Pressures	108	*****
	Nutrient Pollution	78	****
	Impacts on Species	71	****
	Species Status	63	****
	Impacts on Ecosystems	46	***
	Impacts on Habitats	43	***
	Fishing	42	***
	Plastic Pollution	42	***
	Chemical Pollution	33	**
	Conservation Outcomes	33	**
	Key Areas	31	**
	Population Trends	25	**
	Ecosystem Status	24	**
	Sustainable Harvest	24	**
	Habitat Condition	23	**

3.3.4 Reporting and pathways

All Regional Seas Conventions and Action Plans examined in this review rely on standardised reporting formats and submit information through online platforms, typically to regional secretariats or to the Conferences of Parties. Reporting frequencies vary, with some agreements requiring annual submissions (e.g., CCAMLR) and others adopting a five-year cycle aligned with broader strategic planning (e.g., COBSEA, Bucharest Convention).

Data responsibilities are generally divided between national ministries, designated agencies, and specific scientific or technical working groups. For example, the Cartagena Convention mandates regional environmental institutes to compile data, while in COBSEA, separate scientific and policy bodies contribute different types of information. Several conventions are supported by formal monitoring frameworks, such as the Integrated Monitoring and Assessment Program under the Barcelona Convention or the CCAMLR Ecosystem Monitoring Programme. These frameworks define specific indicator requirements and monitoring protocols, although the level of standardisation and harmonisation varies. In some cases, such as the Black Sea and Barcelona Conventions, indicator guidance is detailed and prescriptive. In others, such as COBSEA, no unified indicator framework exists, and countries submit national-level data in alignment with agreed priorities.

3.4 EU Directives and Regulations

3.4.1 Pressure, State and Response

Among the European Union Directives and Regulations assessed, pressure-related data needs were the most frequent, representing 124 entries and yielding a composite Importance Score of 0.85. State-related data needs were also common, cited in 118 entries, and had a slightly lower Importance Score of 0.82. Response-related data needs were the least frequent, appearing in 31 entries and scoring lowest in importance at 0.40. While pressure data dominated in frequency, the broader distribution of state-related data needs across instruments helped maintain their high Importance Score. Response-related data remained less prominent in both frequency and distribution (Table 7).

3.4.2 Standard Data Categories

The most frequent Standard Data Category was pollution, nutrient loading and litter, which appeared in 67 entries and had a composite Importance Score of 0.72. Ecosystem extent and condition was nearly as frequent (57 entries) and scored at a similar level of importance (0.72), reflecting broad use across directives. Species population and extinction risk was cited 54 times, with an Importance Score of 0.57. Other categories such as habitat disturbance and physical alteration (29 entries; 0.49) and direct mortality and disturbance of species (22 entries; 0.31) also featured. Less frequent categories included sustainable use and resource extraction (15; 0.21), invasive and non-indigenous species (11; 0.22), and spatial planning and protected and conserved areas (11; 0.26). Oceanographic and climate-related stressors (3; 0.07), restoration and rehabilitation (3; 0.07), and ecosystem services (1; 0.05) were least represented (Table 7).

3.4.3 Data Themes

The most frequent Data Theme was sectoral pressures, which appeared in 66 entries and had the highest Importance Score at 0.78, indicating widespread and consistent inclusion. Impacts on species (49 entries; 0.64) and impacts on habitats (46; 0.62) were also common, with moderate Importance Scores reflecting their broad but slightly more uneven distribution. Other prominent themes included species status (44 entries; 0.48), habitat extent (41; 0.54), fishing (37; 0.46), and habitat condition (34; 0.48). Nutrient pollution (30 entries; 0.41), impacts on ecosystems (27; 0.43), and sustainable harvest (26; 0.38) were also recorded, while lower frequency themes included key areas (24; 0.32), chemical pollution (18; 0.27), pollution source (16; 0.26), population trends (15; 0.16), and species habitat use (14; 0.24) (Table 7).

Table 7 Frequency and importance of PSR, standard data and the top 15 data theme categories across the EU Directives and Regulations (based on frequency). Frequency is given in numerical values and asterisks indicate importance score: * 0 – 0.19, ** 0.20 – 0.39, *** 0.40 – 0.59, **** 0.60 – 0.79, ***** 0.80 – 1.00.

Category Type	Category	Frequency	Importance
PSR Category	Pressure	124	*****
	State	118	****
	Response	31	**
Standard Data Category	Pollution, nutrient loading & litter	67	****
	Ecosystem extent & condition	57	****
	Species population & extinction risk	54	***
	Habitat disturbance & physical alteration	29	***
	Direct mortality and disturbance of species	22	**
	Sustainable use & resource extraction	15	**
	Invasive & non-indigenous species	11	**
	Spatial planning and Protected and Conserved Areas	11	**
	Oceanographic and climate-related stressors	3	*
	Restoration & rehabilitation	3	*
	Ecosystem services	1	*
Data Theme Category	Sectoral Pressures	66	****
	Impacts on Species	49	****
	Impacts on Habitats	46	****
	Species Status	44	***
	Habitat Extent	41	***
	Fishing	37	***
	Habitat Condition	34	***
	Nutrient Pollution	30	**
	Impacts on Ecosystems	27	**
	Sustainable Harvest	26	**
	Key Areas	24	**
	Chemical Pollution	18	**
	Pollution Source	16	**
	Population Trends	15	*
	Species Habitat Use	14	**

3.4.4 Reporting and pathways

European Union instruments, including the Deep-Sea Access Regulation, Habitats Directive, and Marine Strategy Framework Directive (MSFD), have established structured reporting responsibilities and mechanisms for monitoring. Reporting is primarily the responsibility of national authorities, typically environmental agencies or ministries of environment, though other contributors include research institutions, scientific observers, and academic entities.

Submissions follow standardised reporting formats and occur at regular intervals, most commonly every six years. The Habitats Directive mandates reporting under Article 17, while the

MSFD requires assessment of environmental status, pressures, and measures. Submissions are made online, including through the Eionet Central Data Repository and platforms specified under Regulation (EU) 2017/1004. Monitoring obligations are defined under Article 11 of the MSFD and linked to detailed indicator requirements, including species-specific data, habitat condition, and ecosystem parameters. Data requirements are outlined in multi-annual work programmes and must meet criteria established for each indicator.

3.5 National Biodiversity Strategies and Action Plans

3.5.1 Pressure, State and Response

Among the National Biodiversity Strategies and Action Plans assessed, pressure-related data needs were the most frequent, with 60 entries and the highest composite Importance Score of 0.87. State-related data needs appeared 53 times, with an Importance Score of 0.81. Response-related data needs were cited 53 times and had an Importance Score of 0.76. This shows that all three types of data were relatively well represented, with pressure slightly more dominant but state and response categories both broadly recognised across strategies (Table 8).

3.5.2 Standard Data Categories

The most frequent Standard Data Category was species population and extinction risk, appearing in 35 entries with a composite Importance Score of 0.80. Spatial planning and protected and conserved areas was also common (29 entries; 0.71), as were invasive and non-indigenous species (25; 0.64). Pollution, nutrient loading and litter was referenced in 18 entries (0.45), while sustainable use and resource extraction (17; 0.48) and ecosystem extent and condition (14; 0.47) were moderately represented. Less frequent categories included direct mortality and disturbance of species (10; 0.33), restoration and rehabilitation (8; 0.25), ecosystem services (4; 0.15), oceanographic and climate-related stressors (4; 0.15), and habitat disturbance and physical alteration (2; 0.12) (Table 8).

3.5.3 Data Themes

The most frequent Data Theme was species status, which appeared in 32 entries with a composite Importance Score of 0.78. Invasive species introduction and establishment was also prominent (29; 0.73), along with sustainable harvest (28; 0.71) and sectoral pressures (26; 0.55). Conservation coverage (25; 0.67) and fishing (20; 0.41) were well represented, while impacts on species (17; 0.45) and ecosystem status (13; 0.38) were also cited. Less frequent themes included key areas (9; 0.19), chemical pollution (9; 0.23), population trends (6; 0.18), plastic pollution (6; 0.18), ecosystem services (5; 0.21), and impacts on ecosystems (5; 0.21). Conservation outcomes appeared in 4 entries (0.15), showing more limited distribution across strategies (Table 8).

Table 8 Frequency and importance of PSR, standard data and the top 15 data theme categories across the EU Directives and Regulations (based on frequency). Frequency is given in numerical values and asterisks indicate importance score: * 0 – 0.19, ** 0.20 – 0.39, *** 0.40 – 0.59, **** 0.60 – 0.79, ***** 0.80 – 1.00.

Category Type	Category	Frequency	Importance
PSR Category	Pressure	60	*****
	State	53	****
	Response	53	****
Standard Data Category	Species population & extinction risk	35	****
	Spatial planning and Protected and Conserved Areas	29	****
	Invasive & non-indigenous species	25	****
	Pollution, nutrient loading & litter	18	***
	Sustainable use & resource extraction	17	***
	Ecosystem extent & condition	14	***
	Direct mortality and disturbance of species	10	**
	Restoration & rehabilitation	8	*
	Ecosystem services	4	*
	Oceanographic and climate-related stressors	4	*
	Habitat disturbance & physical alteration	2	*
Data Theme Category	Species Status	32	****
	Invasive Species Introduction and Establishment	29	****
	Sustainable Harvest	28	****
	Sectoral Pressures	26	***
	Conservation Coverage	25	****
	Fishing	20	***
	Impacts on Species	17	***
	Ecosystem Status	13	***
	Key Areas	9	**
	Chemical Pollution	9	**
	Population Trends	6	*
	Plastic Pollution	6	*
	Ecosystem Services	5	**
	Impacts on Ecosystems	5	**
	Conservation Outcomes	4	*

3.5.4 Reporting and pathways

Reporting under National Biodiversity Strategies and Action Plans is undertaken at the national level and forms the primary mechanism through which Parties communicate progress to the Convention on Biological Diversity. Each Party is responsible for developing, updating, and implementing its NBSAP in line with global targets, and for submitting periodic National Reports to the CBD Secretariat. These reports provide structured information on policy actions, outcomes, and indicators used to track implementation of the Kunming–Montreal Global Biodiversity Framework.

Although formats vary, reporting follows CBD guidelines that specify thematic areas, indicators, and links to national targets. Data are compiled by national environment ministries, often with input from statistical offices, scientific institutions, and civil society. Submissions are made through the CBD online reporting portal, and national datasets contribute to global assessments, including the Global Biodiversity Outlook and monitoring under SDG 15. National indicator frameworks are expected to align with the CBD monitoring framework, ensuring that data generated through NBSAPs feed directly into global synthesis and policy evaluation processes.

4. Discussion

There is widespread interest among marine scientists in contributing to global biodiversity instruments, and growing recognition of the role of science in informing biodiversity policy. However, marine research and monitoring efforts can be poorly aligned with the specific and evolving data needs of policy instruments (McQuatters-Gollop *et al.*, 2019; Carr, Abas, Boutahar, Caretti, Chan, Abbie S.A. Chapman, *et al.*, 2020; Guy *et al.*, 2021). Part of the challenge faced by data providers is the fragmented governance landscape and a lack of clarity on what constitutes policy-relevant data. This has contributed to a persistent disconnect between the production of scientific knowledge and its application in decision-making (Rose *et al.*, 2018; Hochkirch *et al.*, 2021).

To support more policy-aligned data generation that can be applied across global, regional, and national instruments, we systematically mapped over 1,000 explicit data requirements from more than thirty policy instruments relevant to marine biodiversity. This analysis aimed to identify areas of convergence in data needs and offer practical guidance for researchers and monitoring practitioners seeking to enhance policy relevance of their research (see also Addison *et al.*, 2018). By clarifying where policy demands overlap, and where scientific data and investment are likely to have the greatest impact, this review seeks to strengthen the science-policy interface and promote more efficient, targeted contributions from marine science to biodiversity governance.

Although the policy instruments analysed span a diversity of scales and mandates, our analysis reveals a high degree of thematic convergence in the types of data required for monitoring and assessment. Notably, five categories, pollution, species status, habitat condition, fishing impacts, and sustainable harvest, accounted for over 60% of identified data needs across instruments. These finding echoes other recent syntheses which also highlight the foundational role of such information in marine policy (Borja *et al.*, 2010; Teixeira *et al.*, 2016; McQuatters-Gollop *et al.*, 2019). By translating these points of policy consensus into practical data priorities, this analysis provides actionable guidance for marine scientists seeking to contribute impactfully to national, regional, and global policy. It also highlights areas that are less frequently represented—or absent altogether—indicating where policy ambition may currently be constrained by data availability or integration.

4.1 Pressure

Data on human pressures form the foundation of many international, regional, and national policy instruments. In particular, the Regional Seas Conventions and Action Plans and the European Union Directives consistently emphasise pressures such as pollution, nutrient enrichment, and fishing, reflecting their established monitoring systems and clear links to ecological degradation. This emphasis reflects both the availability of well-established monitoring systems for these pressures and their direct links to ecological degradation. However, most available data on pressures describe only their spatial footprint or presence, rather than providing information on key attributes such as intensity, frequency, duration, or the locations in the ocean where pressures are experienced (Dailianis *et al.*, 2018; Kenny *et al.*, 2018; Matos, Hilário and Teixeira, 2025). This limitation is especially pronounced for diffuse or mobile stressors, such as nutrient enrichment, underwater noise, or light pollution, where data remain sparse and unevenly reported (Marangoni *et al.*, 2022; Moretti and Affatati, 2023).

Many instruments also require data on the ecological consequences of pressures, including impacts on species (such as bycatch and mortality), habitat degradation, and broader measures of ecosystem condition, which is often difficult to obtain (Borja *et al.*, 2020; Bastardie *et al.*, 2021). This means pressure data are frequently collected in isolation, without being connected to measures of ecological change or system dynamics. In addition, Identifying, quantifying, and understanding the consequences of cumulative pressures remains an ongoing technical challenge (Piet *et al.*, 2021; Bozec *et al.*, 2022; Borja *et al.*, 2024). While relatively few instruments contain explicit data needs associated with cumulative impacts, their number is growing, and the issue is increasingly recognised as critical to the health and resilience of marine ecosystems (Willsteed *et al.*, 2023).

Improving our ability to characterise and interpret pressure data is a key requirement for the implementation, monitoring and assessment of marine environmental instruments. This includes generating more detailed data on the nature of the pressures, expanding data coverage for diffuse and intermittent stressors, and developing robust methods to trace ecological consequences and interactions across space and time (Rogers *et al.*, 2023).

4.2 State

Data on the state of species, habitats, and ecosystems are central to assessing the health of the marine environment. Across policy instruments, state-related data needs are frequent and carry high importance, with common priorities including species population status, extinction risk, habitat extent and condition, and indicators of ecosystem functioning and resilience. These data not only capture ecological condition but also provide the basis for evaluating progress toward conservation and sustainable use goals.

However, despite its agreed importance, monitoring the state and richness of species, habitats and ecosystems is technically and conceptually challenging, resulting in widespread data gaps and spatial and taxonomic biases in existing and baseline data (Gerovasileiou *et al.*, 2019b; Smit *et al.*, 2021a; Ramírez *et al.*, 2022). For example, while EU Member States must report on the conservation status of habitats and species every six years, more than 60% of countries struggle with poor data quality and completeness (Ellwanger *et al.*, 2018). Data collection is often constrained by cost, logistical complexity, and limited access (Miloslavich *et al.*, 2019; Cavanaugh *et al.*, 2025), especially in offshore or deep-sea areas (Levin *et al.*, 2019). Lack of taxonomic expertise and the length of time to identify specimens to a relevant level of classification (e.g. species, genus, family) also add to the complexity and costs of such studies (Rogers *et al.*, 2023).

Beyond data availability, there are also conceptual challenges, for example, in defining what constitutes good ecological condition and state (Smit *et al.*, 2021b; De Carvalho *et al.*, 2025). Frameworks such as the IUCN Red List of Ecosystems (Keith *et al.*, 2015), the Essential Biodiversity Variables (Schmeller *et al.*, 2018), and the UN System of Environmental-Economic Accounting (Czúcz *et al.*, 2021) are advancing efforts to standardise metrics and develop global benchmarks. Yet such approaches are not fully operationalised in most marine monitoring systems and remain subject to conceptual debates and sampling biases (Rogers *et al.*, 2022).

To supply the data demanded by policy, it is essential to invest in long-term, methodologically harmonised time series that capture the state (including trends) of marine species, habitats and ecosystems. This includes improving geographic representation and undertaking baseline mapping of species and habitats as these are fundamental to documenting and recognising change, increasing the resolution and frequency of core state indicators, to support further understanding of drivers of change, and integrating novel approaches to assess functional and ecosystem-level properties to more consistently measure ecosystem health.

There is therefore an opportunity for scientists to support to policy by contributing improved baseline mapping of species and habitats, higher resolution and frequency of core state indicators, and functional and ecosystem-level properties.

4.3 Response

Compared to pressure and state, response-related data needs are less frequently cited across instruments and carry lower importance scores. This reflects their focus on management actions such as the extent of marine protected areas, implementation of restoration projects, or adoption of regulatory measures. These indicators are usually reported by implementing agencies, while scientific contributions are more often directed toward monitoring pressures and ecological condition.

There is growing demand for data related to responses. Data on habitat suitability, connectivity, and species movement patterns are needed to guide the design of effective management measures such as spatial planning and restoration (Fraschetti *et al.*, 2021; Stuart *et al.*, 2021; Beger *et al.*, 2022). In addition, data are required to evaluate the effectiveness of these responses, including evidence of changes in species populations, habitat condition, ecosystem functioning and services, and the pressures acting on them (Bal *et al.*, 2018; Visconti *et al.*, 2019; Dudley *et al.*, 2022; Pulido-Chadid, Virtanen and Geldmann, 2023; Moersberger *et al.*, 2024). However, as discussed in the pressure and state sections, scientific capacity to track and attribute changes in species, habitats, and ecosystems to management responses remains limited. Key challenges include the lack of robust baselines, long ecological response times, and the difficulty of attributing observed changes to a single intervention in systems shaped by multiple, interacting pressures and complex ecological dynamics.

Strengthening the availability of response-related data is essential for marine monitoring, evaluation, and reporting. Developing integrated datasets that track responses alongside pressures and ecological state can help establish causal links and provide the evidence needed to assess management outcomes. Meeting this often-unmet policy demand creates an important opportunity for scientists to contribute to the design and implementation of monitoring systems that enable more outcome-oriented governance.

4.4 Emerging priorities

Data needs related to climate stressors, invasive species, blue carbon ecosystems, and genetic diversity were cited infrequently in the instruments analysed, despite being prominent areas of scientific research (Giakoumi *et al.*, 2019; Macreadie *et al.*, 2019; Thomson *et al.*, 2021; Trégarot *et al.*, 2024). Their relatively low importance scores likely reflect a lag between emerging scientific priorities and their formal articulation in policy frameworks. As climate pressures intensify and policy attention expands, these issues are expected to become central to future biodiversity data needs, creating opportunities to establish baselines, develop monitoring approaches, and design indicators that inform decision making.

4.5 Expanding and integrating monitoring systems

Many of the data challenges identified in this review, such as limited detail on the location, intensity, and frequency of pressures, infrequent or incomplete observations of ecological state, and the difficulty of attributing outcomes to specific management actions, highlight needs and opportunities related to data collection and monitoring systems. Advances in technology offer opportunities to fill data gaps related to pressures, states, and the effectiveness of responses (Rogers et al., 2022). For example, satellite-based and autonomous monitoring technologies are enhancing the amount and frequency of data collected, its spatial and temporal coverage (Allard *et al.*, 2023; Moersberger *et al.*, 2024) and environmental DNA can be applied to detect the presence of threatened species (Rogers *et al.*, 2022). However, these tools are not a panacea. Effective data collection requires sustained financial support, capacity development, and methodological validation (Schmeller *et al.*, 2017; Garzon-Lopez *et al.*, 2024). Realising the benefits of new technology also depends on overcoming systemic barriers: many monitoring programmes still operate in isolation, with limited interoperability, inconsistent standards, and fragmented institutional responsibilities (Navarro *et al.*, 2017; Kühl *et al.*, 2020; Hassoun *et al.*, 2024). Efforts to promote open data and apply FAIR (Findable, Accessible, Interoperable, Reusable) principles are essential, yet translating these into fully operational, federated data infrastructures remains a major technical and institutional challenge (Hassoun *et al.*, 2024). Nevertheless, collaborative efforts such as the Global Ocean Observing System (Tanhua *et al.*, 2019), the Global Biodiversity Information Facility (Heberling *et al.*, 2021), the Ocean Biodiversity Information System (Ocean Biodiversity Information System) and Ocean Census (Rogers *et al.*, 2023) have significantly increased and supported data collection, accessibility and standardisation.

In addition, whilst not explicitly assessed in the analysis of instruments, many policies reflect the importance of inclusive and participatory approaches to data and knowledge. Indigenous peoples, local communities, and other non-state actors are increasingly recognised not only as holders of rich, place-based knowledge, but also as contributors of primary data, through local observations, community science initiatives, and long-standing environmental stewardship (Ban and Frid, 2018; Parsons, Taylor and Crease, 2021; Strand, Rivers and Snow, 2022). Responding to this shift requires moving beyond extractive or tokenistic engagement toward genuine collaboration: co-defining indicators, respecting distinct knowledge systems, supporting rights to data sovereignty, and ensuring that benefits, responsibilities, and decision-making power are equitably shared (Kaiser *et al.*, 2019; Caldeira, Sekinairai and Vierros, 2025).

4.6 Reporting structures, formats, and entry points for data contribution

Understanding the structure, timing, and format of reporting mechanisms is essential for aligning marine biodiversity data with policy processes. However, the role of scientists extends far beyond generating and supplying data. This includes agenda setting, indicator development, adaptive management, and evaluation (Pülzl and Rametsteiner, 2009; Buschman, 2022; Caro *et al.*, 2023). In formal international processes such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the World Ocean Assessment, and the scientific and technical bodies of Multilateral Environmental Agreements, scientists can contribute to problem identification, scenario development, and the formulation of targets and indicators.

Beyond formal structures, scientists frequently participate in technical working groups, advisory panels, or expert dialogues that support the development and implementation of policy at national, regional, and international levels. These informal, relational mechanisms are often the main points of interaction between science and policy, where evidence is shaped by evolving policy questions and interpreted through trust-based relationships and ongoing dialogue (Taylor *et al.*, 2021; Suazo-Galdames, Saracostti and Chaple-Gil, 2025)

This reinforces the need to move beyond viewing marine scientists solely as data providers. Their role increasingly involves translating complex evidence for policy audiences, synthesising information across disciplines and scales, and co-developing approaches that support more adaptive, inclusive, credible, and transparent decision-making (Meeson *et al.*, 2006; Weatherdon *et al.*, 2017; Morgera, McGarry and Sink, 2024). Supporting these contributions, through investment in knowledge brokering, boundary-spanning roles, and long-term science–policy partnerships (Posner and Cvitanovic, 2019; Duncan, Robson-Williams and Edwards, 2020; Karcher *et al.*, 2025), is essential for ensuring that marine biodiversity data contributes meaningfully to governance, conservation, and sustainable use.

4.7 Key recommendations

- Align data production with defined policy needs by identifying where scientific inputs can directly inform reporting requirements and decision-making processes.
- Improve the resolution, coverage, and dimensionality of pressure data by expanding monitoring of attributes such as intensity, frequency, and duration, especially for diffuse or mobile stressors.
- Invest in the sustained collection of high-quality data on the state of species, habitats, and ecosystems, including time series that capture trends and variability at relevant spatial and temporal scales.
- Strengthen the ability to link pressures with ecological state by developing integrated monitoring frameworks that support attribution and causal inference.

- Advance the development of response-related indicators that can assess the effectiveness of management actions.
- Promote system-level monitoring approaches that integrate data on pressures, state, and responses to enable more complete data assessments and provisioning.
- Anticipate emerging data needs by expanding monitoring efforts to include topics such as climate-related stressors, ecological connectivity, invasive species, blue carbon systems, and genetic diversity.
- Incorporate innovative technologies such as environmental DNA, in situ sensors, and satellite remote sensing to increase spatial and temporal resolution and improve access to under-observed areas.
- Support interoperability and reuse of biodiversity data by adopting data standards and applying FAIR principles to enable integration across instruments and scales.
- Facilitate inclusive monitoring approaches by recognising the contributions of Indigenous peoples, local communities, and other non-state actors, and by supporting co-developed indicators, data sovereignty, and equitable access and attribution mechanism.

Together, these recommendations highlight practical steps for bridging the gap between scientific capacity and policy demand. They emphasise not only the need for improved data, but also for more inclusive, interoperable, and policy-relevant monitoring systems. In line with the aims of this review, they provide a roadmap to help marine data producers navigate the policy landscape, understand which types of information are most needed, and contribute more effectively to monitoring, evaluation, and reporting processes.

Supplementary material

Appendix A: Data requirements of frameworks.

Appendix B: Reporting requirements of frameworks.

Appendix C: Frequency and Importance Scores

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