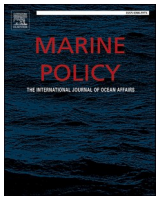
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Full length article

Governing specimen-based biodiversity research in marine protected areas: A Mediterranean framework for policy and practice

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ABSTRACT

Marine protected areas (MPAs) and deep-sea ecosystems are increasingly central to marine conservation policy, yet comparatively little attention has been paid to the governance of scientific research conducted within these environments. Although specimen-based biodiversity research provides essential information for monitoring, conservation planning, and ecosystem assessment, current permitting systems generally evaluate projects individually and rarely consider cumulative sampling pressure, long-term specimen stewardship, preservation strategies, or integration with existing biological collections. Using the Mediterranean Sea as a policy-relevant case study, this review examines governance challenges associated with specimen-based biodiversity research in protected and vulnerable marine ecosystems. Drawing on European marine policy and contemporary research governance approaches, we identify four recurring governance gaps: limited consideration of cumulative specimen extraction, weak integration of natural history collections into permitting processes, insufficient attention to preservation decisions as stewardship issues, and limited traceability across the research lifecycle. To address these challenges, we propose a set of operational standards that can be incorporated into existing research permitting systems, institutional policies, and conservation management frameworks. These standards include structured justification of specimen collection, cumulative-awareness mechanisms, stewardship-oriented preservation practices, and improved traceability of specimens and associated data. Rather than requiring new legislation, the proposed measures operationalize existing principles of precaution, ecosystem-based management, and long-term stewardship. The Mediterranean provides a valuable test case for integrating biodiversity research into marine governance. Strengthening the alignment between scientific practice and conservation policy can improve transparency, reduce avoidable ecological pressures, and enhance the long-term contribution of biodiversity research to adaptive marine management.

1. Introduction: a governance blind spot in marine protected areas

The Mediterranean Sea is one of the most intensively managed and scientifically studied marine regions in the world. Despite covering less than 1% of the global ocean surface, it supports exceptionally high biodiversity and endemism while simultaneously experiencing multiple and interacting anthropogenic pressures, including climate change, biological invasions, fisheries exploitation, maritime transport, coastal development, and pollution [1–3]. This combination of ecological value and cumulative human impact has positioned the Mediterranean as a priority region for marine conservation and as a key testing ground for ecosystem-based governance approaches.

Over the last two decades, European marine policy has increasingly embraced precautionary and ecosystem-based management principles through a suite of complementary governance instruments, including the Habitats Directive (Council Directive 92/43/EEC), the Marine Strategy Framework Directive (MSFD), and the EU Biodiversity Strategy for 2030 [4–6]. Together, these frameworks seek to ensure that human activities are compatible with biodiversity conservation objectives, ecosystem resilience, and the sustainable use of marine resources. More recently, the EU Biodiversity Strategy for 2030 has reinforced these expectations by calling for more effective management of protected areas and stronger integration of biodiversity considerations across

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sectors, including activities that directly support conservation and environmental assessment [6].

Scientific research is widely recognized as an essential component of conservation and environmental management. Biodiversity monitoring, taxonomic assessment, ecological experimentation, and environmental impact evaluation all depend on the collection of biological information, and frequently on the collection of biological specimens. However, specimen-based research is not environmentally neutral. Although individual sampling activities are generally limited in scale and scientifically justified, repeated extraction, cumulative sampling pressure, preservation practices that reduce long-term analytical value, and limited integration with existing biological collections may create tensions with the precautionary and stewardship principles that increasingly underpin marine conservation policy.

These issues are particularly relevant in the Mediterranean because of three converging trends. First, the region contains one of the world's densest networks of MPAs and other protected marine areas [7,8]. Second, scientific activity is highly concentrated in a relatively small number of coastal sites, many of which have been repeatedly sampled for decades. Third, technological advances are rapidly expanding access to deep-sea ecosystems, increasing the need for governance frameworks capable of addressing research impacts in environments characterized by high ecological vulnerability and limited recovery potential [9,10].

Current permitting systems generally evaluate research proposals individually, focusing on legal compliance, methodological feasibility, and scientific merit. In contrast, issues such as cumulative specimen extraction, long-term stewardship of collected material, compatibility of preservation methods with future biodiversity monitoring needs, and coordination among institutions are rarely incorporated into permitting decisions in a systematic manner. As a result, a governance gap emerges between the conservation objectives embedded in marine policy frameworks and the operational management of specimen-based biodiversity research.

As pressures on marine ecosystems increase and conservation governance becomes more integrated, there is a growing need to ensure that specimen-based biodiversity research is managed in ways that remain consistent with precautionary, ecosystem-based, and stewardship principles.

The objective of this policy-oriented narrative review is not to propose new legislation, nor to provide a quantitative assessment of all research practices across Mediterranean MPAs. Rather, it aims to identify operational governance gaps and develop administratively feasible standards that could be integrated into existing research permitting systems, MPA management frameworks, and institutional research practices. Using the Mediterranean Sea as a policy-relevant case study, the article proceeds in four stages. First, it explains the review approach and analytical framework. Second, it examines the regulatory and ethical foundations relevant to specimen-based biodiversity research. Third, it identifies governance gaps associated with cumulative sampling, specimen stewardship, preservation planning, and traceability. Finally, it proposes operational standards that could be incorporated into permitting procedures and conservation management systems to better align scientific research with precautionary and ecosystem-based governance objectives.

By translating broad policy principles into practical governance tools, the Mediterranean can serve as a valuable test case for strengthening accountability, transparency, and long-term stewardship in specimen-based biodiversity research within protected marine ecosystems.

2. Review approach and analytical framework

This study presents a policy-oriented narrative review aimed at synthesising scientific evidence, policy instruments and governance concepts relevant to specimen-based biodiversity research in Marine Protected Areas (MPAs) and deep-sea ecosystems. The objective was not to perform a quantitative synthesis of governance practices but to integrate complementary sources of evidence into a coherent analytical framework capable of identifying recurrent governance challenges and informing practical policy recommendations.

The review integrated three complementary sources of information: (i) peer-reviewed scientific literature on marine biodiversity, specimen-based research, natural history collections, preservation strategies, research integrity and open science; (ii) European and international policy instruments, including the Marine Strategy Framework Directive (MSFD), the Habitats Directive, the EU Biodiversity Strategy for 2030 and the BBNJ Agreement; and (iii) governance literature addressing environmental stewardship, ecosystem-based management, research permitting, cumulative impacts and biodiversity information systems [1–17].

The core review search was conducted between January and March 2026 using targeted searches in Scopus, Web of Science, Google Scholar and institutional policy repositories. The literature was subsequently updated during manuscript revision through July 2026 to incorporate newly published policy-relevant sources. Search strategies were organised around three principal thematic domains. For specimen collection and research governance, the representative Boolean string was: *("marine protected area" OR MPA* OR "deep-sea ecosystem*" OR "vulnerable marine ecosystem*") AND ("specimen-based research" OR "biological specimen*" OR "scientific sampling" OR "specimen collection") AND (permit* OR authorisation OR authorization OR governance OR regulation). For cumulative sampling and research pressure, the search string was: *("marine protected area" OR MPA* OR Mediterranean OR "deep sea") AND ("cumulative impact*" OR "cumulative effect*" OR "sampling pressure" OR "repeated sampling" OR "specimen extraction") AND (research OR monitoring OR biodiversity). For biological collections, preservation and traceability, the search string was: *("natural history collection" OR "biological collection*" OR museum* OR "voucher specimen*" OR repositor*) AND (traceability OR metadata OR FAIR OR "persistent identifier*" OR preservation OR stewardship OR reuse) AND (marine OR biodiversity OR "specimen-based research"). The strings were adapted where necessary to the syntax and search-field requirements of each database. Additional relevant publications and policy documents were identified through backward and forward citation tracking of key references.

The search strategy yielded approximately 150 potentially relevant records. Following duplicate removal and screening for thematic relevance, approximately 60 publications were examined in full. After qualitative assessment against the inclusion criteria, 22 peer-reviewed articles, policy documents and international agreements formed the core evidence base supporting the governance synthesis presented in this review.

Sources were included when they addressed one or more of the following topics: governance of biodiversity research, marine conservation policy, research permitting, cumulative impacts, specimen stewardship, natural history collections, preservation strategies, traceability or ecosystem-based management. Publications dealing exclusively with unrelated terrestrial systems, purely technical laboratory protocols without governance implications, or taxon-specific biological studies lacking relevance to research governance were excluded.

The selected literature was analysed through qualitative thematic synthesis. Publications were examined to identify recurring governance themes, policy instruments, operational challenges and implementation mechanisms. These themes were subsequently grouped into four recurrent governance gaps that constitute the analytical framework developed in this review and underpin the operational standards proposed in the following sections.

3. Policy and governance context for specimen-based biodiversity research

3.1. From research ethics to research governance

Specimen-based biodiversity research has traditionally been discussed within the framework of scientific ethics, focusing on responsible conduct, methodological rigor, and, where applicable, animal welfare. However, the rapid expansion of marine protected areas (MPAs), ecosystem-based management, and biodiversity monitoring programmes has broadened the governance context in which scientific research is conducted [4–8]. Research activities are increasingly expected not only to generate robust scientific knowledge, but also to operate in a manner consistent with conservation objectives and the sustainable management of marine ecosystems.

This shift reflects a broader transition from viewing research ethics primarily as an internal responsibility of the scientific community towards recognising specimen-based biodiversity research as an activity embedded within environmental governance. Under this perspective, issues such as proportionality in specimen collection, cumulative ecological pressures, stewardship of biological material, transparency, and accountability become matters of public governance rather than solely scientific practice [11,12,14–17]. The challenge is therefore not to restrict scientific research, but to ensure that research activities contribute to conservation objectives while maintaining the highest standards of scientific quality and integrity.

3.2. European and international policy frameworks

The governance of specimen-based biodiversity research in Europe is influenced by a range of policy instruments that, although not specifically designed to regulate scientific sampling, establish the principles under which research activities are expected to operate. At the European level, the Marine Strategy Framework Directive (MSFD) requires Member States to achieve or maintain Good Environmental Status through ecosystem-based management and adaptive monitoring programmes [4]. Similarly, the Habitats Directive establishes obligations for the protection of species and habitats within the Natura 2000 network and provides the legal basis for assessing activities that may affect protected ecosystems [5]. More recently, the EU Biodiversity Strategy for 2030 has reinforced commitments to restore marine ecosystems, expand protected areas, and improve the integration of scientific knowledge into conservation policy [6].

At the international level, the BBNJ Agreement, which entered into force on 17 January 2026, extends this policy trajectory by explicitly recognising the importance of marine scientific research while promoting environmental stewardship, transparency, capacity building, and benefit sharing [13]. Although primarily focused on areas beyond national jurisdiction, many of its governance principles are directly relevant to research conducted within regional seas such as the Mediterranean.

Recent discussions surrounding implementation of the BBNJ Agreement further emphasize that effective governance of marine biodiversity research will require improved traceability of marine genetic resources, greater interoperability among biodiversity data systems, and stronger consideration of cumulative research impacts across jurisdictions. These emerging priorities reinforce the need to integrate research governance more explicitly into marine conservation policy beyond legal compliance alone [22].

Collectively, these instruments promote precautionary decision-making, ecosystem-based management, adaptive governance, and evidence-based conservation [4–6,13,14]. However, they provide only limited operational guidance regarding how specimen-based biodiversity research should be planned, evaluated, and managed in practice.

3.3. Governance principles relevant to specimen-based biodiversity research

Several governance principles emerging from environmental policy provide a useful framework for evaluating specimen-based biodiversity research. The precautionary principle supports preventive action where ecological uncertainty exists, particularly in vulnerable ecosystems where cumulative impacts may be difficult to detect or reverse [14]. Closely related is the principle of proportionality, whereby the ecological costs associated with specimen collection should remain commensurate with the expected scientific benefits.

Stewardship represents a complementary principle, emphasising that specimens collected from natural ecosystems should be regarded as long-term scientific resources rather than disposable research material. This perspective encourages preservation strategies that maximise future analytical value, integration with natural history collections, and long-term accessibility of specimens and associated metadata [11,12]. Contemporary concepts of research integrity reinforce these objectives by promoting transparency, reproducibility, traceability, and responsible data management throughout the research lifecycle [15–17].

Together, these principles suggest that governance of specimen-based biodiversity research should extend beyond the authorization of individual projects to encompass cumulative awareness, long-term stewardship, and institutional accountability.

3.4. From policy principles to governance gaps

Although European and international policy frameworks establish ambitious conservation objectives, they rarely specify how specimen-based biodiversity research should be governed operationally. Existing permitting systems generally assess research projects individually, focusing primarily on legal compliance, species protection, and immediate environmental impacts. By contrast, broader governance issues, including cumulative sampling pressure, integration with existing biological collections, preservation planning, long-term specimen stewardship, and research traceability, are often considered only indirectly or remain outside formal evaluation procedures [7,8,11,12,15,16].

Importantly, these limitations should not be interpreted as failures of current legislation. Rather, they reflect the absence of operational governance mechanisms capable of translating high-level policy principles into routine research practice. Consequently, biodiversity research is frequently managed through project-specific administrative decisions without systematic consideration of its cumulative contribution to conservation objectives.

The following section identifies four recurring governance gaps that emerge from the synthesis of the scientific and policy literature. These gaps provide the analytical basis for the operational standards proposed later in this review and illustrate where existing governance systems could be strengthened to better align specimen-based biodiversity research with ecosystem-based management and long-term biodiversity stewardship [4–17].

4. Governance gaps in current practice

The policy frameworks examined in the previous section establish broad principles for ecosystem-based management, precaution, stewardship, and biodiversity conservation. However, the literature reviewed suggests that these principles are only partially reflected in the governance of specimen-based biodiversity research. Rather than indicating shortcomings in existing legislation, the evidence points to a mismatch between high-level conservation objectives and the practical mechanisms through which research activities are authorized, documented, preserved, and monitored [4–6,13,14].

Across the scientific and policy literature, four recurrent governance challenges emerge. These challenges do not represent isolated administrative failures or inappropriate scientific practice. Instead, they reflect

structural characteristics of current research governance systems, which generally evaluate projects individually and emphasize legal compliance while giving comparatively limited attention to cumulative sampling, long-term stewardship of collected material, preservation planning, and research traceability [11,12,15,16]. Although these issues have been discussed separately in different scientific and policy contexts, they have rarely been considered together as components of an integrated governance framework for specimen-based biodiversity research.

The Mediterranean Sea provides a particularly informative case study because it combines exceptional biodiversity, one of the world's densest networks of marine protected areas, extensive long-term ecological monitoring programmes, and increasing scientific access to vulnerable deep-sea ecosystems [1,7–10]. Within this policy and conservation context, the four governance gaps described below emerge from the literature and illustrate opportunities for strengthening the integration of biodiversity research within existing conservation and management frameworks.

To illustrate this distinction, we present a hypothetical comparison between two Mediterranean MPAs with comparable conservation objectives but different research-permitting procedures. In the first, applications include only the research objectives, target taxa and sampling methods. In the second, applicants must also justify the need for new collection, consult available records of previous sampling and existing biological collections, and specify preservation and repository arrangements. These information requirements are further detailed in Table 2 and illustrated in Box 1. Although both approaches may comply with existing legislation, the second could improve cumulative awareness, reduce avoidable duplication and strengthen long-term specimen stewardship.

4.1. *Limited consideration of cumulative sampling pressure*

Current research authorization systems generally evaluate specimen collection on a project-by-project basis [4,18–20], assessing the expected impact of individual studies rather than the cumulative consequences of repeated sampling across time, institutions, or research programmes. This approach is consistent with many existing permitting procedures, but it provides limited capacity to evaluate the aggregate effects of multiple independently justified collections within the same protected or vulnerable sites.

The literature reviewed indicates that many Mediterranean coastal sites simultaneously function as marine protected areas, long-term monitoring stations, educational field sites, and biodiversity research hotspots. Consequently, the same populations may be sampled repeatedly by different research groups over many years. Although individual collections are typically modest and scientifically justified, their cumulative effects remain largely undocumented because permitting systems rarely include mechanisms to assess previous extraction history or coordinate sampling among projects [7,8,18–20].

Rather than suggesting that research sampling constitutes a major driver of biodiversity loss, this review highlights a governance gap: current administrative systems have limited capacity to incorporate

Box 1
Illustrative application of the proposed governance framework during research permit evaluation.

The following hypothetical scenario illustrates how the governance principles proposed in this review could be applied during the evaluation of a specimen-based biodiversity research permit within a Mediterranean Marine Protected Area (MPA). Although simplified, the example synthesises recurrent governance challenges identified throughout the literature reviewed and demonstrates how existing permitting procedures could incorporate cumulative awareness, specimen stewardship and traceability without requiring new legislation or additional regulatory frameworks.

A university research team submits an application to collect 80 specimens of a common benthic invertebrate from a rocky reef located within a Mediterranean MPA to investigate population genetic structure and connectivity. The application includes a clear scientific rationale, appropriate sampling methods, and evidence of institutional ethical approval. Under conventional permitting procedures, the proposal would typically be evaluated on the basis of its scientific merit, legal compliance, conservation status of the target species, and the anticipated environmental impact of the proposed sampling.

Applying the governance framework proposed in this review would introduce several additional considerations designed to improve transparency and long-term stewardship while remaining fully compatible with existing administrative procedures.

First, the applicants would be asked to provide a structured justification explaining why new specimen collection is necessary and why alternative approaches, such as environmental DNA (eDNA), underwater imagery, previously archived museum material, or existing monitoring datasets, cannot adequately address the research objectives.

Second, permit reviewers would assess cumulative sampling pressure by consulting available information on previous research permits, biodiversity monitoring programmes, museum collections, or specimen registries associated with the proposed study area. Suppose that several independent research projects conducted during the previous five years had already collected specimens from the same population for taxonomic, ecological and molecular studies. Although none of these individual projects would represent a significant environmental impact in isolation, consideration of their cumulative footprint might justify reducing the proposed sample size, selecting an alternative sampling location, or promoting greater coordination among research teams.

Third, reviewers would evaluate the proposed preservation strategy to ensure that specimens are preserved using methods compatible with both the immediate objectives of the project and potential future applications. Preservation protocols supporting subsequent molecular, genomic or other emerging analytical techniques would maximise the long-term scientific value of material collected from protected ecosystems and reduce the likelihood of future re-sampling.

Finally, permit conditions would require traceability and long-term stewardship of collected specimens. This could include assigning unique specimen identifiers, recording standardised metadata, documenting preservation protocols, and depositing representative voucher specimens in an accredited natural history collection or institutional repository. These measures would improve transparency, facilitate future specimen reuse, support biodiversity information systems, and reduce unnecessary duplication of sampling effort.

This illustrative scenario demonstrates that the governance standards proposed in this review do not seek to restrict scientifically justified specimen collection. Rather, they provide practical mechanisms through which existing permitting systems can better incorporate proportionality, cumulative-awareness, stewardship, and traceability into routine research administration. In doing so, they strengthen alignment between specimen-based biodiversity research, conservation objectives, and ecosystem-based management while operating entirely within existing legal and institutional frameworks.

cumulative awareness into permit evaluation. This issue becomes particularly relevant in ecosystems already experiencing multiple anthropogenic pressures, including climate change, biological invasions, habitat degradation, and increasing human use, where precautionary approaches encourage consideration of incremental rather than isolated impacts [1–3,14].

4.2. Weak integration of biological collections into research governance

A second recurring theme identified in the literature concerns the limited integration of natural history collections into research planning and authorization processes. Museums and institutional collections are increasingly recognised as strategic infrastructures supporting biodiversity assessment, environmental monitoring, taxonomy, genomics, and conservation science [12]. At the same time, specimen collection remains essential for many areas of biodiversity research, including taxonomy, species documentation, and ecological assessment [11].

The literature attributes the limited reuse of existing material primarily to practical rather than regulatory barriers, including incomplete digitisation, heterogeneous metadata standards, and limited interoperability among collection databases [12,16]. However, irrespective of the underlying causes, the governance consequence is similar: new specimen collection may occur without systematic consideration of existing material that could satisfy at least part of the scientific objectives.

In protected and vulnerable ecosystems, where specimen collection represents the use of a finite biological resource, stronger integration between permitting systems and collection infrastructures could reduce unnecessary sampling while simultaneously enhancing scientific reproducibility, long-term stewardship, and the policy value of biodiversity data [11,12,15,16].

4.3. Preservation decisions are rarely considered governance issues

The literature also highlights that research governance traditionally focuses on whether specimens may be collected rather than on how they will be preserved following collection. Yet preservation strategies directly influence the long-term scientific value of biological material and its potential contribution to future biodiversity assessments, environmental monitoring, and emerging analytical techniques [11,12,16,17].

Current permitting procedures seldom request information regarding preservation strategies beyond basic specimen handling requirements. Consequently, decisions affecting the future analytical utility of collected material, including compatibility with molecular analyses, long-term curation, occupational safety, and repository management, are generally treated as technical laboratory choices rather than governance considerations [16,17].

From a policy perspective, preservation planning should be understood as an element of biodiversity stewardship. The objective is not to prescribe universal preservation protocols, but to encourage approaches that remain proportionate to research objectives while maximising the long-term value of specimens obtained from ecologically sensitive environments. This is particularly relevant in deep-sea contexts, where sampling opportunities are limited, ecological uncertainty is high, and recovery processes may be slow [9,10].

4.4. Limited traceability and accountability across the research lifecycle

The final governance gap concerns the traceability of specimens and associated research information. Although scientific publications generally report sampling methods and analytical results, links between collected specimens, preservation protocols, institutional repositories, and subsequent analytical use frequently remain fragmented across multiple databases and organisations.

The reviewed literature indicates that this fragmentation limits cumulative awareness, complicates specimen reuse, and reduces the capacity of permitting authorities and MPA managers to evaluate the long-term outcomes of research activities. By contrast, recent developments in biodiversity informatics, FAIR data principles, and open science demonstrate that substantially greater levels of traceability are technically feasible and increasingly expected within biodiversity research [15,16].

Improved traceability should therefore be viewed not only as a matter of scientific reproducibility but also as a governance mechanism capable of supporting transparency, adaptive management, institutional accountability, and more efficient stewardship of biological resources [12,15,16,20].

The four governance gaps identified above should not be interpreted as deficiencies of current legislation, nor as evidence of inappropriate scientific practice. Rather, they represent recurring governance challenges that emerge from the synthesis of scientific literature, policy instruments, and biodiversity research practices. Building on these findings, the following section proposes a set of operational governance standards designed to improve the alignment of specimen-based biodiversity research with marine conservation objectives while remaining compatible with existing policy instruments and administrative structures.

5. Operational standards for policy integration

The governance gaps identified in the previous section suggest that the principal challenge facing specimen-based biodiversity research is not the absence of regulatory instruments, but the limited translation of existing policy principles into day-to-day research administration. European and international conservation frameworks already promote precaution, ecosystem-based management, transparency, stewardship, and adaptive governance [4–6,13,14]. However, these principles are seldom operationalized within research permitting procedures, institutional policies, or specimen management practices.

Building upon the literature reviewed and the governance challenges identified in Section 4, we propose a set of operational standards that could be incorporated into existing research authorization systems without requiring new legislation. These standards are intended to strengthen the alignment between biodiversity research and conservation policy by improving transparency, accountability, specimen stewardship, and long-term scientific value. Rather than restricting scientific research, they seek to facilitate more consistent and evidence-informed decision-making throughout the research lifecycle. The overall relationship between governance gaps, operational standards, and policy outcomes is summarized in Fig. 2, while the proposed governance standards are presented in Table 1.

5.1. Structured justification of specimen collection

The first operational standard concerns the explicit justification of specimen collection. Existing permit applications generally require researchers to describe project objectives and sampling methodologies but often provide limited information explaining why specimen removal is necessary or whether less invasive alternatives have been considered. Incorporating structured justification into permitting procedures would strengthen transparency and improve consistency between research activities and conservation objectives [4,14].

Applicants should therefore demonstrate that specimen collection is proportionate to clearly defined scientific questions and that alternative approaches, including photographic surveys, underwater video, environmental DNA (eDNA), remote sensing, or the use of existing museum collections, are not sufficient to address the proposed objectives. Such an approach reflects the precautionary principle and encourages efficient use of biological resources while fully recognizing that voucher specimens remain indispensable for taxonomy, biodiversity assessment, and many ecological investigations [4,11,12,14].

Importantly, structured justification should be understood as a

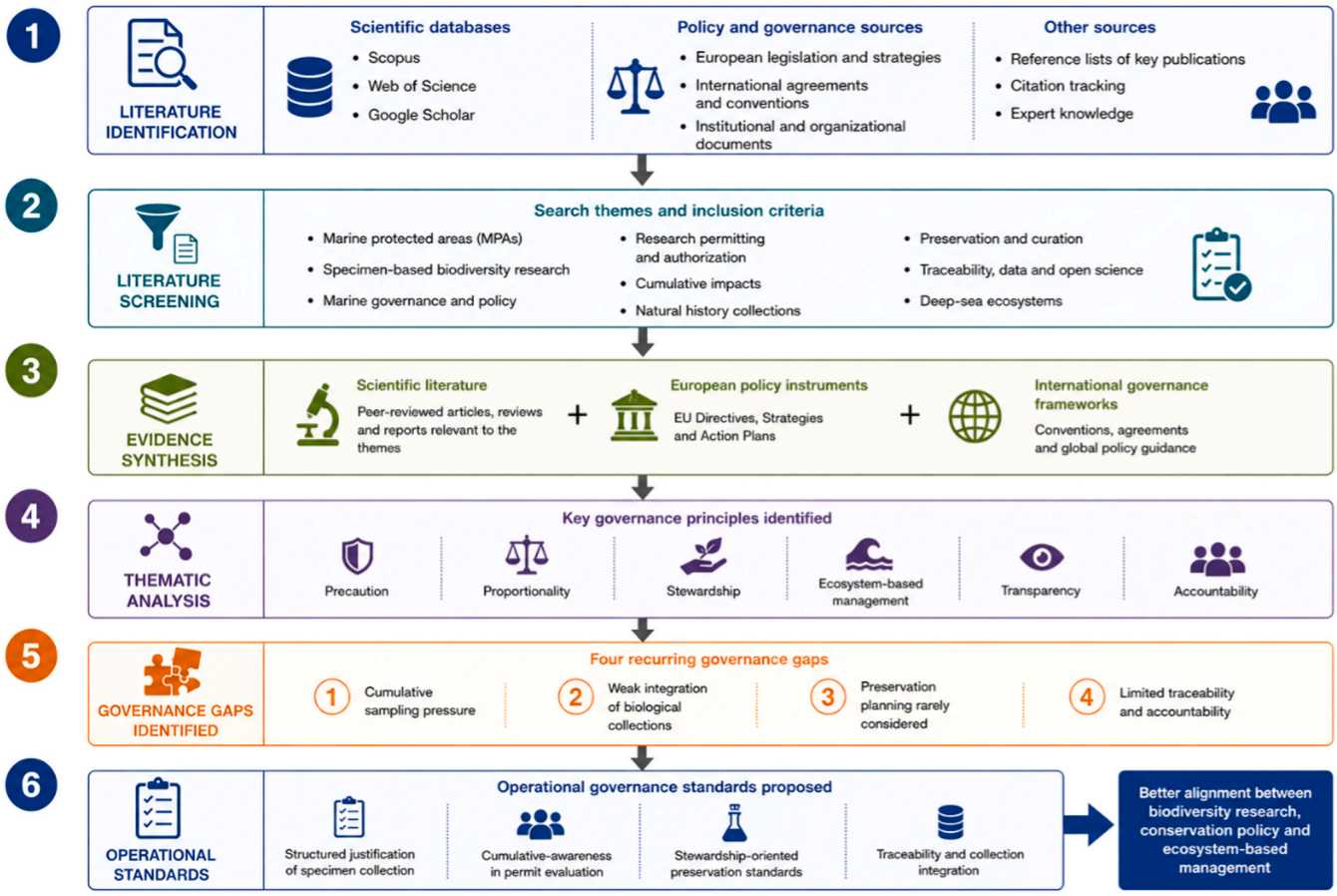


Fig. 1. Methodological workflow used for the policy-oriented narrative review. The review combined peer-reviewed scientific literature, European and international marine policy instruments, and governance concepts relevant to specimen-based biodiversity research. Following literature identification, thematic screening, and qualitative evidence synthesis, recurring governance principles were identified and used to derive four governance gaps. These analytical categories formed the basis for the operational governance standards proposed in this review to strengthen the alignment between biodiversity research, conservation policy, and ecosystem-based management.

governance mechanism rather than an administrative burden. By documenting the scientific necessity of specimen collection, permitting authorities can evaluate proportionality more consistently while maintaining the flexibility required for diverse research objectives.

5.2. *Incorporating cumulative awareness into permit evaluation*

A second operational standard is the incorporation of cumulative-awareness mechanisms into research permitting. Current authorization systems generally evaluate projects independently, even when multiple studies target the same protected area or biological populations over extended periods. As discussed in Section 4, this project-based approach limits the ability of managers to assess cumulative extraction pressure across institutions and research programmes [18–20].

One practical solution would be to incorporate information on previous sampling activities into permit applications and to encourage consultation of existing extraction records before authorizing new specimen collection. Over time, centralized registries documenting research activities within MPAs could facilitate cumulative awareness, improve coordination among institutions, and support more informed permitting decisions [18–20].

These measures would not require precise estimates of cumulative ecological impacts, which are rarely available. Instead, they would provide decision-makers with contextual information consistent with precautionary and ecosystem-based management [4,14,18]. A conceptual example of how such information could be integrated through a cumulative specimen extraction registry is presented in Fig. 3.

5.3. *Stewardship-oriented preservation planning*

The review also indicates that preservation strategies should be considered an integral component of biodiversity governance rather than solely a technical laboratory decision. Preservation methods directly determine the future analytical value of collected material and therefore influence the long-term return obtained from specimen extraction [11,12].

Different research objectives require different preservation strategies, and no single method is universally appropriate. Formalin remains valuable for specific morphological and histological applications, whereas ethanol and other molecular-compatible media facilitate genetic, genomic, and emerging multi-omic analyses [17]. Consequently, permitting systems should encourage applicants to justify preservation decisions in relation to both immediate research objectives and potential future scientific applications [11,12,17].

Such an approach reinforces the concept of specimen stewardship by recognising that material collected from protected or difficult-to-access ecosystems represents a long-term scientific resource whose value extends well beyond the duration of the original project [11,12,16].

5.4. *Strengthening traceability and integration with biological collections*

Effective governance also requires robust traceability throughout the research lifecycle. Scientific publications commonly document analytical methods and results, yet information linking collected specimens, preservation protocols, institutional repositories, and subsequent

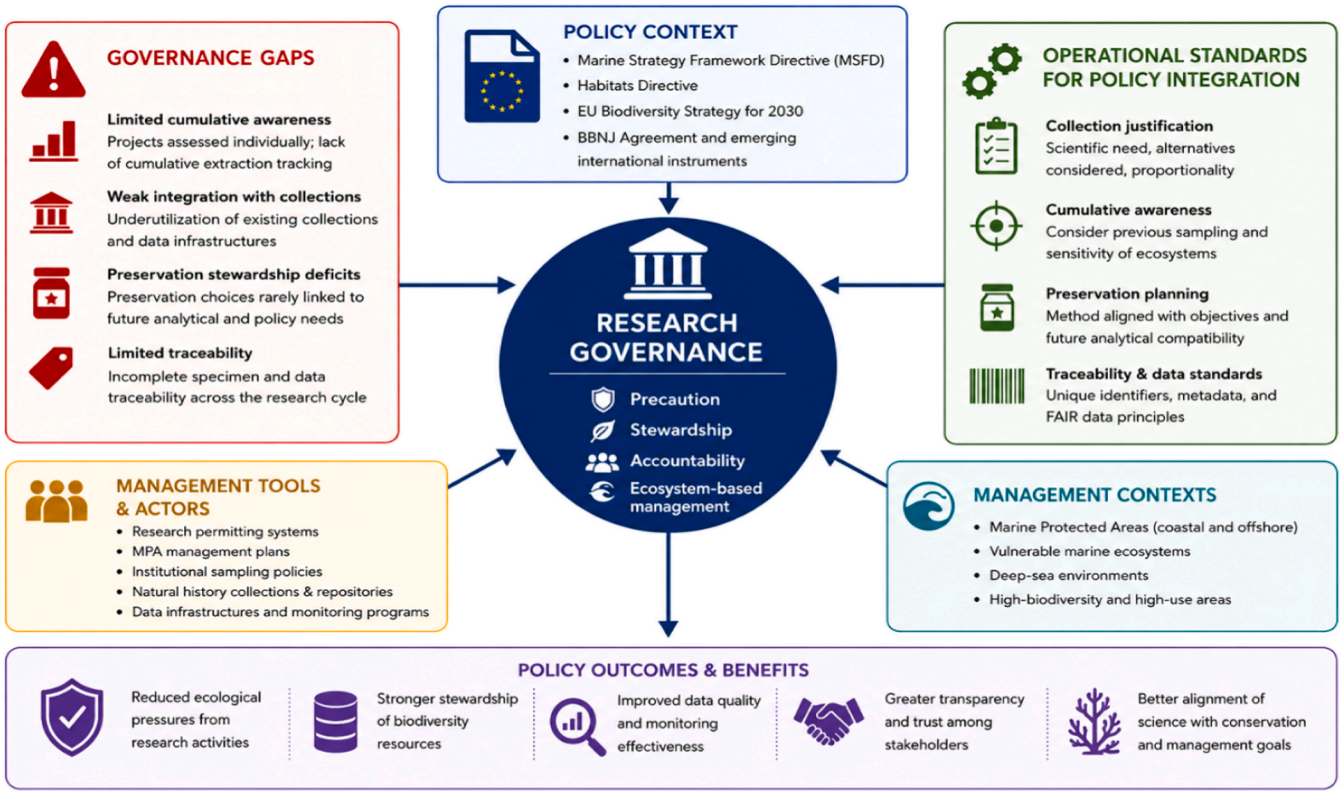


Fig. 2. Conceptual research governance framework for specimen-based biodiversity research in marine protected areas and deep-sea ecosystems. The framework synthesizes the principal findings of this review by illustrating how existing policy instruments, identified governance gaps, operational standards, implementation mechanisms, and management contexts can be integrated within a coherent research governance framework. Rather than proposing new legislation, the framework demonstrates how existing conservation principles, including precaution, stewardship, accountability, and ecosystem-based management, can be operationalized through research permitting, institutional policies, biological collections, and biodiversity information systems. The proposed governance approach aims to strengthen transparency, reduce cumulative research pressures, improve specimen stewardship and traceability, and enhance alignment between biodiversity research and marine conservation policy.

analytical use often remains fragmented across organisations and databases.

Minimum governance standards should therefore include unique specimen identifiers, standardized metadata, documentation of preservation protocols, and deposition of collection information within accessible repositories whenever feasible. These practices are consistent with the FAIR Guiding Principles and with current recommendations promoting transparency, reproducibility, and long-term accessibility of biodiversity information [15,16].

Beyond improving scientific reproducibility, integrated biodiversity information systems are increasingly recognised as essential components of ecosystem-based management because they facilitate the translation of monitoring data into conservation actions and adaptive governance [21].

Closer integration between research permitting systems and biological collections would provide additional governance benefits by increasing the visibility of existing material, facilitating specimen reuse, reducing redundant sampling, and strengthening the contribution of natural history collections to conservation policy and adaptive management [11,12,15,16].

5.5. *From governance principles to administrative practice*

Taken together, these operational standards illustrate how existing conservation principles can be translated into practical governance mechanisms without requiring major legislative reform. Rather than introducing new regulatory obligations, they provide a framework for incorporating precaution, proportionality, stewardship, transparency, and accountability into routine research administration [4–6,13,14].

Implementation could occur through existing permitting procedures, institutional research policies, MPA management plans, collection-management guidelines, and biodiversity information systems. The governance criteria associated with each stage of the research lifecycle are summarized in Table 1, while Table 2 illustrates key information elements that could be incorporated into research permit evaluation procedures.

By embedding structured justification, cumulative-awareness mechanisms, stewardship-oriented preservation planning, and improved traceability within existing administrative processes, biodiversity research can become more closely aligned with ecosystem-based management while maintaining the scientific flexibility necessary for innovation and discovery [4–6,12–16,20]. These implementation pathways are explored further in the following section on implications for MPA management and deep-sea governance.

6. Implications for MPA management and deep-sea governance

The governance standards proposed in the previous section have direct implications for marine protected area (MPA) management, deep-sea governance, and institutional research administration. Their purpose is not to create a separate regulatory regime for scientific research, but to strengthen existing governance mechanisms by incorporating cumulative-awareness, specimen stewardship, preservation planning, and traceability into routine decision-making. This approach is consistent with ecosystem-based management under European marine policy and with emerging international expectations regarding transparency, environmental assessment, and biodiversity stewardship [4–6,13].

Table 1
Operational governance standards derived from the review synthesis for specimen-based biodiversity research in Mediterranean MPAs and deep-sea ecosystems. The table links the governance gaps identified through the policy-oriented narrative review with operational standards that can be incorporated into existing research permitting, specimen management, and conservation governance procedures. The standards translate precautionary, ecosystem-based, stewardship, transparency, and accountability principles into practical administrative criteria intended to improve coherence between biodiversity research and marine conservation objectives.

Research stage	Governance gap or review finding	Operational governance standard	Policy rationale	Administrative application
Study design	Permit applications often describe research objectives but provide limited justification for why specimen removal is necessary.	Structured scientific justification for specimen collection.	Precaution and proportionality in ecosystem-based management.	Mandatory justification section in permit applications explaining scientific necessity and alternatives considered.
Site selection	Previous sampling history is rarely considered when selecting sites in intensively studied MPAs.	Consideration of cumulative sampling pressure.	Reduction of incremental impacts in protected and heavily studied areas.	Consultation of extraction registries, previous permits, monitoring records, or prior sampling information.
Sampling intensity	Sample sizes may be based on convention, logistical convenience, or taxonomic practice rather than explicit quantitative rationale.	Definition of minimum necessary sample size.	Minimization of avoidable extraction while maintaining scientific robustness.	Quantitative or qualitative rationale required during permit review.
Field methods	Low-impact or non-invasive alternatives are not always explicitly evaluated before authorizing specimen removal.	Preference for low-impact, minimally invasive, or observational approaches when scientifically appropriate.	Habitat protection and reduction of avoidable disturbance within MPAs.	Permit conditions encouraging photographic surveys, video monitoring, eDNA, limited tissue sampling, or other lower-impact methods.
Deep-sea research	Deep-sea sampling occurs under conditions of high uncertainty, low resilience, and limited baseline knowledge.	Elevated justification threshold for extractive sampling in deep-sea and offshore environments.	Precaution under ecological uncertainty and slow recovery potential.	Stricter review criteria for deep-sea permits, prioritizing observation-based methods where feasible.
Preservation	Preservation decisions are often treated as technical choices rather than stewardship decisions affecting long-term scientific value.	Stewardship-oriented preservation planning.	Long-term policy utility for biodiversity monitoring, adaptive management, and future analytical compatibility.	Documentation of preservation method, justification where formalin is used, and consideration of complementary molecular-compatible preservation.
Documentation	Specimen-level information is frequently fragmented across publications, institutions, and repositories.	Unique identifiers and standardized metadata.	Traceability, reproducibility, and cumulative-awareness.	Mandatory deposition of metadata in institutional or public repositories where feasible.
Specimen management	Existing collections are not systematically consulted before new specimen collection is authorized.	Integration with natural history collections and repositories prior to new extraction.	Efficient resource use, reduction of redundant sampling, and strengthened specimen stewardship.	Confirmation of collection consultation and planned repository deposition during permit evaluation.
Teaching and outreach	Routine lethal sampling for educational activities may continue even when non-lethal or archived alternatives are available.	Avoidance of routine lethal sampling in MPAs for teaching or demonstration unless explicitly justified.	Coherence between conservation goals, institutional responsibility, and research training.	Institutional guidelines aligned with MPA management plans, promoting preserved material, digital tools, or in situ observation.

6.1. Strengthening research governance in marine protected areas

MPAs increasingly function as conservation tools, scientific reference sites, monitoring locations, educational spaces, and platforms for stakeholder engagement. This multifunctional role creates a practical governance challenge: the same ecological value that justifies protection also attracts scientific attention, potentially concentrating research effort in a limited number of well-studied sites.

The proposed standards could be implemented by MPA managers, environmental authorities, and research-permitting bodies through existing authorization procedures. For example, permit application forms could include structured fields requiring applicants to justify specimen removal, report whether non-invasive alternatives were considered, indicate whether previous sampling records were consulted, and describe preservation and deposition plans [18,20]. These changes would not replace scientific evaluation but would provide managers with additional information needed to assess proportionality, cumulative-awareness, and long-term stewardship.

Evidence from Mediterranean MPAs indicates that conservation outcomes depend strongly on governance quality, enforcement, stakeholder coordination, and alignment between management objectives and operational practices [7,8,18,19]. Recent work on MPA management effectiveness and equitable governance further emphasizes the importance of practical assessment tools capable of linking management processes to conservation outcomes [20]. Incorporating research governance into these assessment frameworks would allow scientific activities to be evaluated not only by their scientific merit, but also by their contribution to long-term conservation objectives.

Recent international initiatives also advocate closer integration between biodiversity monitoring, research infrastructures, and management decisions, recognising that effective conservation increasingly depends on the ability to connect scientific observations with operational governance and policy implementation [21].

6.2. Integrating research permitting with biological collections and repositories

A second implementation pathway concerns stronger integration between permitting systems, natural history collections, and biodiversity repositories. Specimens collected from protected ecosystems represent finite biological resources whose scientific value may extend far beyond the objectives of the original project. Natural history collections are increasingly recognised as strategic infrastructures for biodiversity research, climate-change biology, environmental monitoring, and conservation policy [12].

In practice, permitting authorities and research institutions could require applicants to indicate whether comparable material already exists in accessible collections and to specify where newly collected specimens will be deposited. This would not prevent new collection when scientifically justified, since specimen collection remains essential for taxonomy, biodiversity discovery, and many ecological studies [11]. Rather, it would reduce unnecessary duplication, promote reuse of existing material, and increase the long-term return on specimens collected from sensitive environments.

Institutional repositories and museums would therefore become active components of research governance rather than passive endpoints for specimen storage. By linking permits, specimen identifiers, preservation metadata, and repository accession numbers, management

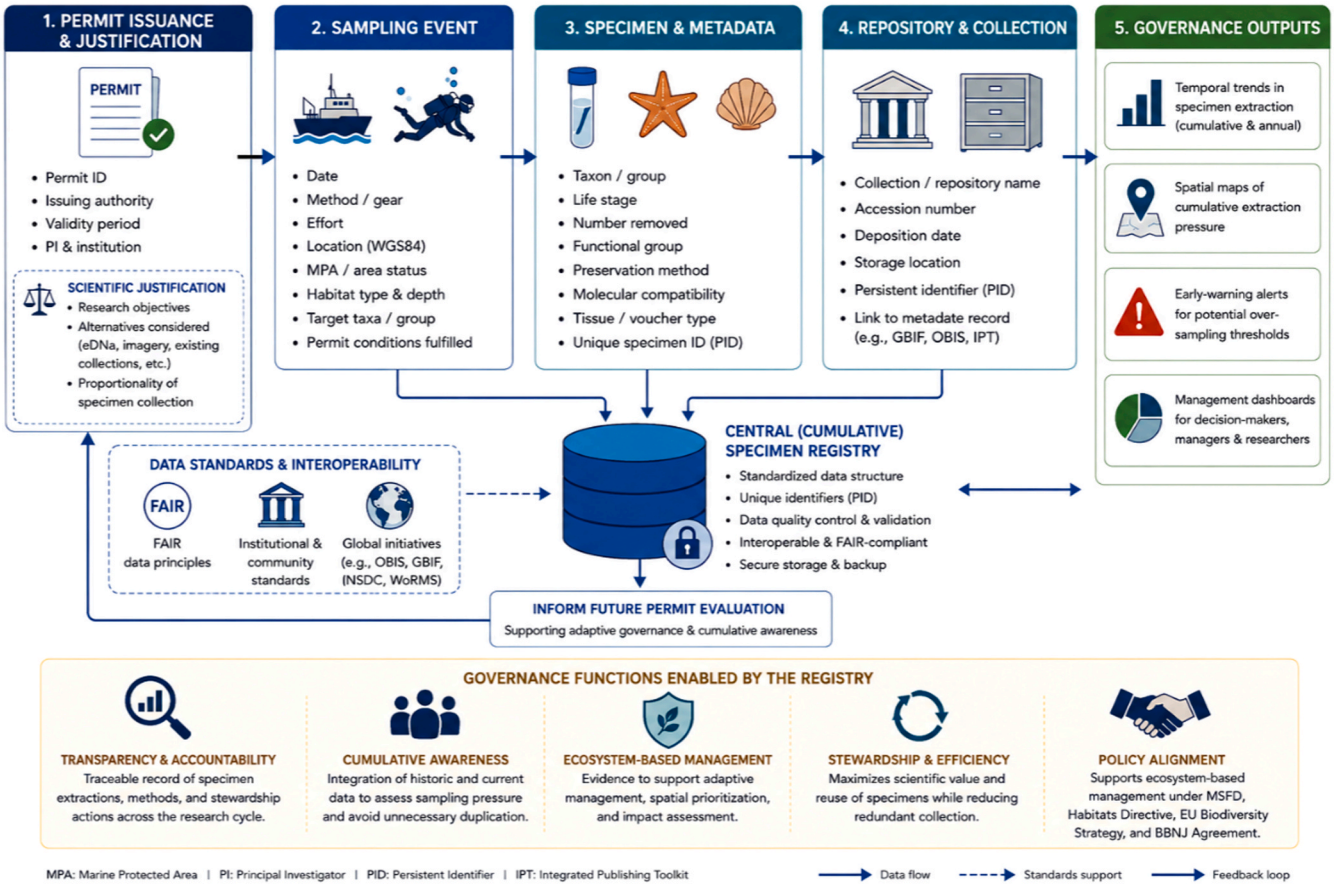


Fig. 3. Conceptual workflow for a cumulative specimen registry supporting research governance. Information generated throughout the specimen-based research lifecycle, from permit evaluation and field sampling to specimen deposition and repository management, is integrated into a cumulative specimen registry that supports adaptive governance, transparency, specimen stewardship, and long-term biodiversity management. The registry combines administrative, spatial, biological, preservation, and repository metadata using standardized and interoperable data structures consistent with FAIR principles. By linking historical and ongoing sampling activities, it enables cumulative extraction assessments, spatial analyses of sampling pressure, early-warning indicators for potential over-sampling, and evidence-informed permit evaluation. Beyond improving traceability and accountability, the registry facilitates specimen reuse, reduces unnecessary duplication of sampling, and strengthens alignment between biodiversity research and ecosystem-based management under existing policy frameworks, including the Marine Strategy Framework Directive (MSFD), the Habitats Directive, the EU Biodiversity Strategy for 2030, and the BBNJ Agreement. The framework is presented as a conceptual governance tool that could be implemented through existing institutional, national, or regional biodiversity information systems.

authorities could improve traceability and support future reuse of biological material in monitoring, assessment, and policy-relevant research.

6.3. *Deep-sea governance and precautionary research standards*

The proposed framework is particularly relevant to deep-sea ecosystems, where scientific uncertainty, low resilience, high logistical cost, and slow recovery processes make precautionary governance especially important [9,10]. Mediterranean bathyal and abyssal environments are becoming increasingly accessible through remotely operated vehicles, autonomous platforms, and offshore research campaigns, while also gaining attention within conservation planning and ecosystem-based management.

In these contexts, research permitting should apply elevated justification thresholds for extractive sampling. Observation-based methods should be prioritized where they can address research objectives, while specimen removal should be limited to cases of clear taxonomic, functional, or conservation relevance. When collection is necessary, each specimen should be treated as a long-term scientific resource, with preservation, deposition, and metadata plans defined before fieldwork.

This approach aligns with the precautionary principle and with emerging international governance expectations under the BBNJ Agreement, which emphasizes environmental assessment, transparency, and the sustainable use of marine biodiversity [13,14]. Although the BBNJ Agreement applies to areas beyond national jurisdiction, its governance logic is relevant to vulnerable marine ecosystems more broadly, including deep Mediterranean settings where scientific access is expanding.

These recommendations are also consistent with recent analyses of BBNJ implementation, which highlight transparent documentation of biodiversity sampling, traceability of biological material, and coordinated data infrastructures as essential components of future governance for areas beyond national jurisdiction [22].

6.4. *Institutional responsibilities and implementation pathways*

Implementation of the proposed standards requires shared responsibility across multiple governance actors. MPA managers and permitting authorities are best placed to incorporate structured justification, cumulative-awareness, and traceability requirements into authorization procedures. National and regional environmental agencies can support harmonized reporting formats and cumulative extraction registries. Universities and research institutions can implement internal review procedures, training modules, and preservation guidelines. Museums and biological repositories can provide accession systems, metadata standards, and collection-access platforms that reduce redundant sampling.

These measures are administratively feasible because they build on

Table 2
Key information elements for research permit evaluation derived from the governance gaps identified in this work. The proposed information elements illustrate how existing research authorisation procedures can incorporate considerations of proportionality, cumulative-awareness, specimen stewardship, preservation planning, and traceability without requiring new regulatory frameworks. The table is intended as a governance-support tool that can be adapted to different institutional, national, or regional management contexts.

Governance gap addressed	Information element	Minimum information to be provided	Permit evaluation purpose	Example administrative application
Limited project justification	Project identification	Principal investigator, institution, funding source, project duration, responsible contact	Ensure transparency and institutional accountability	Standardised permit record and responsible-party identification
Limited project justification	Legal and management context	Protected-area status, management authority, applicable management plan, jurisdiction	Verify consistency with conservation regulations	Cross-check with MPA regulations, national legislation and management plans
Limited project justification	Site characterisation	Geographic coordinates, habitat type, depth, ecological sensitivity	Evaluate site-specific vulnerability	Spatially explicit review of proposed sampling locations
Limited project justification	Target taxa or biological material	Taxonomic group, conservation status, life stage, scientific justification	Support precautionary biodiversity assessment	Cross-reference with protected species lists and conservation priorities
Limited project justification	Scientific necessity	Justification for specimen collection and explanation of why lower-impact alternatives are insufficient	Assess proportionality of specimen removal	Structured justification statement included in permit application
Limited cumulative sampling awareness	Sampling design and intensity	Number of specimens, sampling frequency, spatial distribution, sample-size rationale	Evaluate proportionality and minimise unnecessary extraction	Review of proposed sampling effort before authorisation
Limited cumulative sampling awareness	Previous sampling history	Previous collections at the study site or on the target taxa (where available)	Incorporate cumulative-awareness into permit review	Consultation of permit records, monitoring programmes, museum databases or expedition reports
Weak integration of biological collections	Existing collections consulted	Museums, institutional collections or repositories examined before new collection	Reduce redundant specimen extraction	Documentation of collection consultation during permit evaluation
Limited consideration of low-impact approaches	Collection methods and impact mitigation	Sampling methods, expected habitat disturbance, mitigation measures, non-invasive alternatives considered	Promote ecosystem-based management	Permit conditions favouring least-impact sampling methods where appropriate
Preservation planning rarely addressed	Preservation and analytical plan	Preservation protocol, intended analyses, subsampling strategy, compatibility with future research	Maximise long-term scientific value	Documentation of preservation strategy and analytical compatibility
Weak specimen stewardship	Specimen deposition and long-term curation	Repository, accession strategy, long-term curation arrangements	Ensure long-term stewardship and accessibility	Verification of deposition in recognised museum, biobank or institutional collection
Limited traceability	Metadata and specimen identifiers	Unique specimen identifiers, georeferencing, collection metadata, images, associated datasets	Strengthen traceability and reproducibility	Integration with biodiversity repositories and institutional databases
Limited traceability	Data accessibility and reuse	Availability of metadata, sequence data, images and environmental information, including justified restrictions	Promote open science and future reuse	Facilitate monitoring, synthesis studies and reduction of duplicate sampling
Limited accountability	Post-project reporting and permit compliance	Final number of specimens collected, deviations from permit conditions, repository accession numbers, data availability statement	Verify compliance and improve governance transparency	Final report required before permit closure or renewal

existing governance instruments rather than requiring new legislation. Practical implementation could occur through revised permit application forms, MPA management plans, institutional sampling policies, collection-management protocols, and biodiversity data infrastructures. Table 2 summarizes key information elements that could be incorporated into research permit evaluation, while Fig. 3 illustrates how cumulative extraction information could be organized through a registry-based approach.

By embedding these mechanisms within existing administrative systems, specimen-based biodiversity research can be governed as part of conservation management rather than as a parallel activity. This would strengthen transparency, improve institutional accountability, increase the policy value of collected specimens, and support ecosystem-based management without undermining legitimate scientific inquiry.

6.5. From research administration to conservation governance

A central implication of this review is that specimen-based biodiversity research should be treated not only as a source of scientific knowledge, but also as an activity requiring governance consistent with conservation objectives. Decisions regarding specimen collection, preservation, curation, metadata, and reuse determine how biological resources are managed over time and therefore intersect directly with biodiversity policy.

The proposed standards provide a practical pathway for moving from project-by-project research administration towards a more integrated model of conservation governance. By incorporating stewardship, traceability, proportionality, and cumulative-awareness into existing permitting and management systems, marine authorities and research institutions can improve coherence between scientific practice and ecosystem-based management.

The challenge is therefore not whether specimen-based research should continue, but how it can be governed in ways that maximize its contribution to conservation outcomes while minimizing avoidable ecological costs. In this sense, research governance should be considered a component of effective MPA management and deep-sea conservation policy.

7. Conclusions

Specimen-based biodiversity research remains an essential component of marine science and conservation. However, in regions such as the Mediterranean Sea, where high biodiversity, dense Marine Protected Area (MPA) networks, expanding deep-sea exploration, and sustained scientific activity converge, research itself must be considered within broader governance frameworks.

This review identifies a governance gap between existing conservation policy objectives and the operational management of specimen-based research. While current permitting systems generally regulate scientific access to protected environments, they rarely incorporate mechanisms to address cumulative sampling pressure, long-term specimen stewardship, preservation strategies, or integration with existing

biological collections. As a result, precautionary and ecosystem-based management principles embedded in European marine policy are only partially translated into research administration. This disconnect is particularly notable given that the Marine Strategy Framework Directive explicitly promotes integrated and ecosystem-based management of human activities affecting marine ecosystems [4], yet research permitting systems generally do not incorporate explicit mechanisms capable of evaluating cumulative scientific pressures at the ecosystem scale.

Rather than advocating new legislation, we propose a set of operational governance standards that can be incorporated into existing permitting and management frameworks. Structured justification of specimen collection, cumulative extraction awareness, proportional preservation strategies, traceability systems, and stronger integration with natural history collections represent practical and administratively feasible measures that can improve coherence between scientific practice and conservation objectives.

The Mediterranean provides a particularly suitable test case for this approach. Its ecological vulnerability, extensive MPA network, and long history of marine research create conditions in which governance innovations can be evaluated and refined. At the same time, the proposed framework is transferable to other marine regions facing similar challenges associated with biodiversity monitoring, protected-area management, and increasing scientific access to sensitive ecosystems.

Ultimately, the central question is not whether specimen-based research should continue, but how it should be governed. Strengthening the alignment between research permitting, biodiversity policy, and long-term stewardship of biological material offers an opportunity to enhance both conservation outcomes and the legitimacy of scientific activity. As international initiatives such as the BBNJ Agreement and the EU Biodiversity Strategy increasingly emphasize accountability, ecosystem-based management, and sustainable use of marine biodiversity, integrating governance standards into research practice will become an increasingly important component of effective marine conservation.

CRediT authorship contribution statement

David Verdiell-Cubedo: Writing – review & editing, Validation, Supervision, Methodology, Investigation. **Hayfa Chammem:** Writing – original draft, Validation, Supervision, Investigation, Conceptualization. **José Galián:** Writing – review & editing, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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Data availability

No data was used for the research described in the article.

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