Best Practices and Future Directions on Ecosystem and Species Restoration for Mediterranean Marine Protected Areas

A Literature Review

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Summary

This literature review provides a detailed exploration of ecological restoration efforts within Mediterranean Marine Protected Areas (MPAs) over the past decade, focusing on the challenges and opportunities these efforts present. Unlike a general overview of global MPA management training programs, this review specifically addresses the ecological restoration practices crucial for the Mediterranean Sea—a significant biodiversity hotspot facing severe threats from human activities and climate change.

Key themes in the review include the distinction between active and passive restoration methods. Active restoration involves direct human interventions, such as transplanting seagrass or coral fragments, which are resource-intensive but yield quicker results. In contrast, passive restoration depends on reducing human impacts to allow natural recovery processes, which are more cost-effective but slower. The review identifies critical habitats, such as seagrass meadows, Cystoseira forests, coralligenous beds, and deep-sea ecosystems, as primary targets for restoration due to their ecological importance and vulnerability.

The document emphasizes the importance of integrating restoration activities into broader MPA management plans, considering factors such as site selection, stakeholder engagement, and regulatory compliance. It also highlights innovative approaches, like using artificial intelligence for monitoring or developing new materials for habitat creation, which could enhance restoration effectiveness.

Through various case studies, the review illustrates the successes and challenges of different restoration projects in the Mediterranean and globally. These examples underscore the necessity of tailored, site-specific solutions and the need for sufficient funding, effective management, and stakeholder involvement to overcome obstacles like climate change impacts and illegal fishing.

Overall, the literature review serves as a critical resource for MPA managers and policymakers, providing insights and recommendations to enhance the resilience and sustainability of Mediterranean marine ecosystems through targeted ecological restoration.

1. Introduction

1.1. Importance of Ecological Restoration in Mediterranean MPAs

Ecological restoration is a critical endeavour aimed at recreating, initiating, or accelerating the recovery of ecosystems that have been disturbed by environmental changes. These disturbances alter the structure and function of ecosystems, necessitating targeted restoration activities that may either replicate pre-disturbance conditions or establish new ecosystems in previously unoccupied areas. As a scientific discipline, restoration ecology focuses on repairing these disturbed ecosystems through human intervention (Vaughn *et al.*, 2010).

The Mediterranean Sea, a recognized biodiversity hotspot, is home to approximately 17,000 marine species, representing about 7% of the world's marine species despite covering only 0.82% of the world's ocean surface (Bianchi *et al.*, 2012; Coll *et al.*, 2010). This region, one of the world's 25 biodiversity hotspots, is characterized by high concentrations of endemic species and significant habitat loss (Myers *et al.*, 2000). However, the rich biodiversity of the Mediterranean faces increasing pressure from human activities and climate change, necessitating robust conservation measures like the establishment of Marine Protected Areas (MPAs).

As of 2019, the Mediterranean Sea hosted 1,087 MPAs, covering about 8.3% of its area, but only 0.06% of this area is designated as fully protected or no-take zones (Claudet *et al.*, 2020; MedPAN and UNEP/MAP-SPA/RAC, 2023.). These MPAs are crucial for marine conservation, but many encompass ecosystems that have already experienced significant degradation. While MPAs can serve as a means of passive restoration, the importance of active and innovative ecological restoration within these areas has become increasingly evident. Restoration efforts in MPAs are essential not only for enhancing biodiversity and improving ecosystem services, but also for boosting the resilience of marine habitats against the impacts of climate change (Bayraktarov *et al.*, 2016).

Moreover, restoration within MPAs plays a crucial role in enhancing connectivity between protected areas, which is vital for the migration and dispersal of species. Improved connectivity fosters biodiversity and resilience not only within the restored MPA but also in adjacent MPAs, creating a network of healthy ecosystems that support one another. This connectivity is particularly important in the Mediterranean context, where key habitats such as seagrass meadows (*Posidonia oceanica*), coralligenous reefs, maerl beds, and deep-sea ecosystems are vital for the survival of endangered species like the Mediterranean monk seal, loggerhead sea turtle, and great white shark.

In the Mediterranean region, ecological restoration within MPAs is a vital strategy for addressing the degradation of these critical habitats. This section explores three primary approaches to marine restoration: active restoration, passive restoration, and hybrid methods. Active restoration involves direct human intervention, such as transplanting coral fragments or seagrass shoots, to hasten ecosystem recovery. Although resource-intensive and typically applied to smaller areas, active restoration can yield quicker results. Passive restoration, on the other hand, relies on natural recovery processes, facilitated by reducing or eliminating anthropogenic stressors such as fishing regulations and the establishment of protected areas. This method, while more cost-effective and applicable over larger areas, may take longer to show visible outcomes. Innovative approaches, which combine elements of both active and passive strategies or introduce entirely new methods, are increasingly being employed. These might include the use of artificial intelligence for monitoring or the development of new materials for habitat creation.

Well-managed MPAs have shown significant positive impacts, such as a 420% increase in fish biomass compared to unprotected areas, the recovery of vulnerable species, and spillover benefits to local fisheries (Giakoumi *et al*., 2017). However, many MPAs face challenges, including insufficient funding, limited stakeholder engagement, lack of active management, inadequate monitoring, climate change impacts, and transboundary issues.

Addressing these challenges is crucial for enhancing the effectiveness of the Mediterranean MPA network and achieving regional and global conservation targets. The Rest-Coast project aims to support MPA managers in their restoration efforts by developing technical and policy tools, aligning with the EU's Biodiversity Strategy for 2030. Integrating active, passive, and innovative restoration approaches within MPAs is essential for mitigating degradation impacts and ensuring the long-term sustainability of these critical ecosystems. Ultimately, the success of ecological restoration in Mediterranean MPAs will depend on the ability to create resilient, interconnected marine environments that can sustain the region's rich biodiversity for future generations.

1.2. Objective of This Literature Review

The objective of this literature review is to provide a comprehensive foundation for the development of technical tools and training programs that will support managers of Mediterranean Marine Protected Areas (MPAs) in their ecological restoration efforts. This review will synthesize existing knowledge and research on active and passive restoration approaches within MPAs, with a particular focus on the Mediterranean context, where the region's unique biodiversity is under significant threat from human activities and climate change.

The literature review aims to:

1. **Identify and summarize key restoration concepts and methodologies** relevant to the restoration of marine ecosystems in Mediterranean MPAs, including the distinction between active and passive restoration, and the specific challenges and opportunities each approach presents.
2. **Assess the current state of restoration practices** in Mediterranean MPAs by compiling data from existing projects, experiments, and case studies. This assessment will include an evaluation of the alignment between restoration activities and the conservation strategies of MPAs, highlighting both successes and areas in need of improvement.
3. **Highlight critical habitats and species** in the Mediterranean that are the focus of restoration efforts, such as seagrass meadows, coralligenous reefs, and endangered species like the Mediterranean monk seal and loggerhead sea turtle. Understanding the specific needs of these habitats and species will inform the development of targeted restoration strategies.
4. **Analyze the challenges faced by MPA managers** in implementing effective restoration, including issues related to funding, stakeholder engagement, management practices, and the impacts of climate change. The review will also examine the importance of connectivity between MPAs to enhance biodiversity and resilience across the network.

By achieving these objectives, the literature review will serve as a critical resource for enhancing the capacity of Mediterranean MPAs to carry out effective ecological restoration, ultimately contributing to the broader goals of biodiversity conservation and climate change resilience in the region.

1.3. Active Restoration

Active restoration involves direct interventions aimed at accelerating ecosystem recovery, particularly in situations where natural recovery processes are too slow or impaired to meet conservation goals. This section provides an overview of active restoration techniques, with examples from the literature. While it is useful to distinguish between active, passive, and innovative restoration approaches, these methods often overlap in practice.

Active restoration typically requires intensive human intervention, such as transplanting coral fragments or seagrass shoots. These efforts are typically resource-intensive and applied to smaller areas. In contrast, passive restoration relies on the natural recovery of ecosystems by reducing or eliminating anthropogenic stressors, such as establishing marine protected areas or regulating fishing practices. Passive approaches can be applied over larger areas and tend to be more cost-effective, though they may take longer to show results. Innovative approaches incorporate novel or cutting-edge techniques, sometimes combining elements of both active and passive restoration, or introducing entirely new methods, such as artificial intelligence for monitoring or the development of new materials for habitat creation. Many marine restoration projects, especially within

MPAs, employ a combination of these approaches, tailored to the specific ecosystem, extent of degradation, available resources, and management objectives.

Seagrass Restoration

Seagrass meadows, particularly *Posidonia oceanica*, are critical habitats in the Mediterranean that have suffered significant declines. Active restoration techniques for seagrass include:

- **Transplantation of seedlings or adult plants**
- **Seed collection and dispersal**
- **Use of biodegradable materials for anchoring and protection**

For example, studies by Alagna *et al*. (2019) and Pergent-Martini *et al.* (2024) demonstrated successful transplantation of *P. oceanica* shoots using biodegradable materials in the Mediterranean, including Palermo Bay, achieving a 94% survival rate after one year.

Coral Restoration

Although not as prevalent as in tropical regions, coral restoration in the Mediterranean focuses on species such as *Cladocora caespitosa* and gorgonians. Techniques employed in coral restoration include:

- **Fragmentation and transplantation**
- **Artificial reef structures**
- **Larval propagation and settlement**

Montero-Serra *et al*. (2018) and Shaver *et al.* (2020) reported successful restoration of Mediterranean coral reefs and the gorgonian *Paramuricea clavata* using transplantation techniques, with survival rates exceeding 80% after four years.

Shellfish Reef Restoration

Restoration of oyster and mussel beds is another crucial aspect of active restoration, as these habitats can significantly enhance water quality and provide shelter for other marine species. Techniques for shellfish reef restoration include:

- **Deployment of settlement substrates**
- **Seeding with juvenile shellfish**
- **Translocation of adult individuals**

Basso *et al*. (2015) documented the successful restoration of *Ostrea edulis* beds in the Adriatic Sea, demonstrating increased biodiversity in the restored areas (Baggett *et al*., 2020).

1.4. Passive Restoration

Passive restoration relies on the natural recovery of ecosystems by removing or reducing anthropogenic stressors. This approach is often more cost-effective than active restoration and can be applied over larger areas. In marine environments, passive restoration is frequently combined with active restoration, especially within Marine Protected Areas (MPAs) or historically polluted and abandoned sites. The integration of passive and active restoration approaches can be particularly effective in rehabilitating marine sites degraded by historical industrial activities (Bianchelli *et al*., 2023).

Marine Protected Areas (MPAs)

MPAs are a fundamental strategy for passive restoration in the Mediterranean, allowing ecosystems to recover naturally by minimizing human impacts. The benefits of MPAs include increased biomass and diversity of fish and invertebrates, recovery of trophic structures, and enhanced ecosystem resilience. A meta-analysis by Giakoumi *et al.* (2017) revealed that fish biomass in Mediterranean MPAs was, on average, 420% higher than in unprotected areas. However, the success of MPAs depends heavily on effective management and enforcement. While MPAs are a powerful tool for conservation, they should be integrated into a broader, comprehensive approach to marine conservation and restoration in the Mediterranean.

Cessation of Coastal Industrial Activity

The cessation of coastal industrial activities can create opportunities for passive restoration. Bianchelli *et al*. (2023) investigated the success of transplanting the macroalgal species *Gongolaria barbata*, a protected species, at a historically polluted industrial site in the Adriatic Sea. The study focused on Falconara Marittima, a seaside resort on the Adriatic coast in Italy, where both passive and active restoration techniques were applied to rehabilitate the marine ecosystem. The results demonstrated that combining passive recovery with active interventions, such as transplant experiments, can be successful in restoring degraded marine ecosystems. Even historically polluted sites, depending on contamination levels and environmental characteristics, can serve as optimal locations for restoration efforts and habitat rehabilitation.

2. Restoration of Species and Habitats

The Mediterranean Sea is home to a diverse array of habitats, each supporting unique assemblages of species. Many of these habitats and species are recognized as endangered and are listed in Appendix II of the SPA/BD Protocol of the

Barcelona Convention, as well as in the IUCN Red List. In this section, we highlight Mediterranean habitats and species that have been the focus of restoration activities, whether passive or active. Additionally, we identify gaps in current restoration efforts based on the literature review.

Seagrass Meadows

Posidonia oceanica meadows are a keystone habitat in the Mediterranean, covering an estimated 1.35-5.00% of the basin (Telesca *et al*., 2015). These meadows are crucial for maintaining biodiversity, supporting numerous marine species, and providing essential ecosystem services. Restoration efforts, particularly active restoration through transplantation and seed dispersal, have been documented in the literature, focusing on mitigating the decline of these critical habitats.

Cystoseira Forests

Cystoseira forests are another vital habitat in the Mediterranean, offering shelter and food for various marine organisms. Although these forests are essential for maintaining coastal biodiversity, restoration activities for *Cystoseira* species are less documented in the literature compared to *Posidonia* meadows.

Coralligenous Beds

Coralligenous habitats, second only to *Posidonia* meadows in terms of species diversity, are biogenic structures primarily built by encrusting coralline algae and support over 1,600 species (Ballesteros, 2006). These habitats are highly vulnerable to climate change and ocean acidification. The literature provides evidence of active restoration for certain species within these habitats, such as red coral (*Corallium rubrum*), pillow coral (*Cladocora caespitosa*), and the small polyped gorgonian (*Paramuricea clavata*). However, there is a noticeable lack of active restoration efforts for other endangered coralligenous species, such as maerl beds (*Phymatolithon calcareum*) and other species listed in Appendix II of the SPA/BD Protocol, including *Lithophyllum byssoides*, *Antipathes dichotoma*, and *Astroides calycularis*.

Deep-Sea Ecosystems

The Mediterranean deep-sea, historically considered species-poor, hosts unique ecosystems such as cold-water coral reefs, seamounts, and deep-sea brine pools. Recent research has revealed high levels of endemism and biodiversity in these habitats (Danovaro *et al*., 2010). The literature suggests guidelines for the passive restoration of deep-sea ecosystems, which are also critical habitats for marine mammals. However, active restoration in these deep-sea environments remains underexplored.

Species

Active restoration efforts have been documented for specific species, including *Posidonia oceanica* meadows, red coral (*Corallium rubrum*), the limpet (*Patella ferruginea*). Passive restoration has been applied to benthic species, seabird colonies (*e.g.*, *Puffinus yelkouan*, *Calonectris diomedea*), and the habitats of the monk seal (*Monachus monachus*). However, there is a notable absence of active restoration efforts for other endangered species, such as sharks and rays, the European eel, and mollusks including *Pinna rudis*.

Case Study: Site Selection for *Posidonia oceanica* Restoration in Spain

The LIFE Blue Natura project in Andalusia, Spain (Life Blue Natura, life-bluenatura.eu) exemplifies the effective application of a multi-criteria approach for selecting *Posidonia oceanica* restoration sites. The project team employed a comprehensive set of factors to identify optimal locations for conservation and restoration efforts. These factors included historical presence of seagrass meadows, current water quality conditions, light availability, hydrodynamic conditions, and substrate type. To gather this information, the project conducted extensive mapping and characterization of seagrass habitats along the Andalusian coast, surveying over 7,115 hectares — significantly exceeding their initial target of 4,451 hectares. This thorough mapping effort provided crucial data on the current distribution of *P. oceanica* and other seagrass species, as well as identifying degraded areas and potential restoration sites.

The project also integrated stakeholder input and logistical considerations into the site selection process. This included consultations with local environmental managers, marine protected area authorities, and other relevant stakeholders to ensure that selected sites aligned with existing conservation priorities and management plans. Accessibility for implementation and monitoring was carefully considered, as it plays a crucial role in the long-term success and cost-effectiveness of restoration efforts. Furthermore, the LIFE Blue Natura project took into account the potential for natural recruitment and connectivity with healthy ecosystems. This involved analysing the spatial distribution of existing healthy *P. oceanica* meadows and assessing the likelihood of natural seed dispersal and vegetative expansion to support restoration efforts.

3. Restoration Case Studies in the Mediterranean and at the Global Scale

This section presents a diverse array of restoration efforts targeting key habitats and species, both within the Mediterranean region and globally. The section highlights the use of both active and passive restoration techniques across different countries, including France, Italy, Greece, Tunisia, and others. Passive restoration has been primarily employed for protecting endangered species like the monk seal (*Monachus monachus*) and fish species such as the dusky grouper (*Epinephelus marginatus*), focusing on habitat protection, restricted access, and fishing bans within MPAs. Conversely, active restoration efforts, such as the transplantation of *Posidonia oceanica* meadows and the use of artificial reef structures for coral restoration, have been more resource-intensive but crucial for reversing habitat degradation in specific areas. Each case study outlines the specific challenges encountered, such as warming waters, ocean acidification, illegal fishing, and habitat degradation, along with recommendations for overcoming these obstacles, including strengthening enforcement, public awareness campaigns, and adaptive management strategies. These examples provide valuable insights into the effectiveness of different restoration approaches and emphasize the need for tailored solutions to address the unique ecological challenges within Mediterranean MPAs and beyond.

Table 1. Global and Mediterranean Restoration Case Studies

Country	MPA	Ecosystem /Species Restoration	Active / Passive	Specific Ecosystem / Species	Approach	Challenges	General Recommendations	References
Regional Mediterranean (France, Italy)	**Port Cros, Golfe Juan, Capo Carbonara**	*Posidonia oceanica*	Active	*Posidonia oceanica meadows*	Transplanting from cuttings	Materials, site choice, planting conditions and monitoring	To choose between transplanting local individuals, or climate-adjusted or admixture genotypes which might provide more sustainable options to secure the survival of restored meadows	Pergent-Martini *et al.*, 2024; Alagna et al.2019
France	**Calanques National Park**	Coral reefs	Active	*Corallium rubrum* (red coral)	Artificial reef structures, transplantation	Warming waters, ocean acidification	Reduce local stressors, implement no-take zones	Garrabou *et al.*, 2017

Greece	**National Marine Park of Alonissos**	Monk seal habitat	Passive	*Monachus monachus*	Habitat protection, restricted access	Human disturbance, habitat degradation	Public awareness campaigns, stricter enforcement	Karamanlidis *et al.*, 2004
Montenegro	**Platamuni MPA**	Benthic habitats	Passive	Various benthic species	Trawling restrictions, mooring regulations	Illegal fishing, anchor damage	Improved surveillance, installation of eco-moorings	Mikac *et al.*, 2018
Tunisia	**Galite Archipelago**	Seabird colonies	Passive	*Puffinus yelkouan*, *Calonectris diomedea*	Predator control, restricted access	Invasive species, climate change	Biosecurity measures, long-term monitoring	UNEP-MAP-RAC/SPA, 2015
Tunisia	**Galite Archipelago**	endangered limpet populations	Active	The limpet *Patella ferruginea* populations	Translocation from one national park to another	Poaching, translocation stress for limpets, predation	Consider sex ratio in the translocated sample, use the translocation only for conservation	Zarrouk *et al.*, 2018
Albania	**Karaburun-Sazan National Marine Park**	Dusky grouper	Active/ Passive	*Epinephelus marginatus*	Artificial reefs, fishing bans	Overfishing, lack of enforcement	Strengthen enforcement, involve local communities	Bakiu *et al.*, 2018
Greece	**Rohdes islands**	Oyster reefs	Active	Various oyster species	Substrate addition, spat seeding	Water quality, disease	Improve water quality, develop disease-resistant strains	Barrett et al., 2024
Global	**Various**	Mangrove forests	Active	Various mangrove species	Replanting, hydrological restoration	Coastal development, sea-level rise	Community-based restoration, integrated coastal management	Alongi, 2008

Examples of MPAs with Integrated Restoration Programs

Several Mediterranean MPAs have integrated diverse restoration programs into their management plans. France's Port-Cros National Park and Spain's Cabrera Archipelago focus on *Posidonia oceanica* seagrass restoration through long-term initiatives and mooring regulations. Italy's Tavolara-Punta Coda Cavallo and

Portofino MPAs emphasize coral and coralligenous assemblage restoration with strict protection and monitoring. Gökova Bay MPA in Türkiye and Zakynthos National Marine Park in Greece target seagrass replanting and loggerhead turtle nesting through no-take zones and tourism regulations. Other efforts include fish and coral protection in Scandola (France) and Medes Islands (Spain), and *Patella ferruginea* transplants in La Galite (Tunisia).

Table 2. Integrated Restoration Initiatives in Mediterranean MPAs

MPA Name	Country	Main Restoration Focus	Integrated Approaches	Reference
Port-Cros National Park	France	*Posidonia oceanica* seagrass	- Long-term restoration program - Anchoring management - Public awareness campaigns	Alami *et al.*, 2021
Tavolara-Punta Coda Cavallo MPA	Italy	Coral restoration	- Strict protection measures - Citizen science initiatives	Pagano *et al.*, 2020
Gökova Bay MPA	Türkiye	Seagrass	- Establishment of no-take zones - Fisheries management	Kıraç and Güçlüsoy, 2018
Portofino MPA	Italy	Coralligenous assemblages	- Monitoring programs - Regulation of recreational activities - Environmental education	Cerrano *et al.*, 2017
Cabrera Archipelago National Park	Spain	*Posidonia oceanica* seagrass	- Mooring regulation - Visitor management - Long-term monitoring	Marbà *et al.*, 2015
Zakynthos National Marine Park	Greece	Loggerhead sea turtle nesting habitats	- Beach restoration - Strict regulations on tourism - Public awareness programs	Schofield *et al.*, 2015

Scandola Nature Reserve	France	Fish populations and benthic communities	- No-take zones - Scientific monitoring - Ecological research programs	Guidetti *et al.*, 2014
Medes Islands Marine Reserve	Spain	Gorgonian coral populations	- Diving regulations - Long-term monitoring - Artificial reef experiments	Linares *et al.*, 2012
La Galite Archipelago	Tunisia	*Patella ferruginea* populations	Transplantations	Zarrouk *et al.*, 2018

4. Restoration Planning and Implementation in Mediterranean MPAs

Effective planning and implementation are crucial for the success of marine ecosystem restoration projects, especially within the complex and vulnerable environments of Mediterranean Marine Protected Areas (MPAs). This section provides an overview of the key considerations and best practices essential for guiding restoration initiatives. By adhering to well-established guidelines and methodologies, MPA managers can significantly enhance the chances of achieving restoration goals, ensuring the recovery and long-term sustainability of marine habitats and species.

4.1 Examples of Marine Ecological Restoration Published Guidelines

This section provides a concise overview of various guidelines tailored to the restoration of different marine ecosystems, such as coral reefs, seagrass meadows, Cystoseira forests, mangrove forests, oyster reefs, and deep-sea habitats, among others. These guidelines emphasize both active and passive restoration methods, depending on the specific needs of the ecosystem. Key approaches include coral gardening, seagrass transplantation, and hydrological restoration, with challenges ranging from climate change and water quality issues to coastal development and enforcement difficulties. The guidelines stress the importance of long-term monitoring, reducing local stressors, and incorporating stakeholder involvement to ensure the success and sustainability of restoration efforts. Each guideline is designed to address the unique challenges of the targeted ecosystem, offering practical recommendations and strategies to enhance the effectiveness of marine restoration initiatives within Mediterranean MPAs.

Guideline	Ecosystem / Species Restoration	Active / Passive	Specific Ecosystem / Species	Approach	Challenges	General Recommendations	References
General guidelines for restoration in marine ecology	Ten guiding principles for coastal and marine restoration (Co-design, Fit-for purpose governance, No-gap funding, Access to social, economic and biophysical data, Evidence-based and transparent decision-making, Restoration is coordinated and at scale, Robust monitoring, evaluation and reporting, Clear strategy to adapt to climate change, Nature-based solutions are implemented, Knowledge is shared effectively)				Relevant legislation, or restriction to enhance restoration	More coordinated management, protection, and restoration	Sanders *et al.*, 2024
Coral Reef Restoration	Coral reefs	Active	Various coral species	Coral gardening, fragment transplantation	Climate change, water quality	Implement long-term monitoring, reduce local stressors	Shaver *et al.*, 2020
Seagrass Meadow Recovery	Seagrass beds	Passive /Active	*Posidonia oceanica*, other seagrass species	Trawling bans, transplantation	Slow growth rate, water quality	Establish MPAs, reduce coastal pollution	González-Correa *et al.*, 2005
Cystoseira forests	Cystoseira forests	Passive /Active	Genus *Cystoseira sensu lato*	Restoration decision tree based on forest status and site conditions	Gaps in scientific knowledge about the less known Mediterranean species	Understanding the role of grazers, considering restoration interactions with human activities	Smith et al., 2023
Mangrove Forest Restoration	Mangrove forests	Active	Various mangrove species	Replanting, hydrological restoration	Coastal development, sea-level rise	Community-based restoration, integrated coastal management	Lewis III *et al.*, 2019

Oyster Reef Restoration	Oyster reefs	Active	Various oyster species	Substrate addition, spat seeding	Water quality, disease	Improve water quality, develop disease-resistant strains	Baggett *et al.*, 2020
Marine Mammal Habitat Protection and restoration	Coastal and pelagic zones	Passive	Various marine mammals	Habitat protection, restricted access	Human disturbance, pollution	Public awareness campaigns, stricter enforcement of regulations	Moore *et al.*, 2007
Kelp Forest Restoration	Subtidal rocky reefs	Active	Various kelp species	Urchin culling, kelp transplantation	Climate change, overgrazing by sea urchins	Implement ecosystem-based management, reduce local stressors	Eger *et al.*, 2023
Saltmarsh Restoration	Coastal wetlands	Active	Various saltmarsh plants	Hydrological restoration, replanting	Sea-level rise, coastal development	Integrated coastal zone management, managed retreat	Adam, 2019
Deep-sea Habitat Protection	Deep-sea ecosystems	Passive	Various deep-sea species	Establishing MPAs, regulating deep-sea mining	Limited scientific knowledge, enforcement challenges	Increase research efforts, implement precautionary approach	Danovaro *et al.*, 2020
Coastal Dune Restoration	Coastal dune systems	Active	Various dune plants	Sand nourishment, vegetation planting	Coastal erosion, human disturbance	Restrict access, implement nature-based coastal defense	Walker *et al.*, 2022
Posidonia oceanica	Posidonia meadows ecosystem	Active	Posidonia ecosystem and associate fauna	Transplanting	To choose between transplanting local individuals, or climate-adjusted or admixture genotypes which might provide more sustainable options to secure the survival of restored meadows	Diagram showing the main considerations that must be fulfilled to authorize a transplantation of Posidonia.	Pergent-Martini *et al.*, 2024

4.2. Consideration of the Restoration Goals and Objectives in MPA Management Plan: Lessons from Literature

Setting Restoration Goals and Objectives

Clear, measurable goals are essential for guiding restoration efforts and evaluating their success. Ounanian *et al.*, (2018) emphasise the importance of integrating socio-ecological objectives in marine restoration projects to ensure long-term sustainability and stakeholder support.

Site Selection Criteria

Choosing appropriate sites for restoration is critical for project success. According to Pergent-Martini *et al.*, 2024, Key criteria to consider include:

- Historical presence of target habitats or species
- Current environmental conditions (*e.g.*, water quality, substrate type)
- Level of protection and management in place
- Accessibility for implementation and monitoring
- Potential for natural recruitment or connectivity with healthy ecosystems

Stakeholder Engagement in Restoration Projects

Engaging stakeholders throughout the restoration process is crucial for project success and long-term sustainability (Pagès *et al.*, 2020). Key aspects include:

- **Early identification and involvement of relevant stakeholders**
- **Transparent communication of project goals, methods, and expected outcomes**
- **Integration of local and traditional ecological knowledge**
- **Participatory decision-making processes**
- **Opportunities for stakeholder involvement in implementation and monitoring**

Pagès *et al.*, (2020) demonstrated that stakeholder engagement in Mediterranean seagrass restoration projects enhanced project outcomes and fostered a sense of stewardship among local communities.

Permitting and Regulatory Considerations

Navigating the regulatory landscape is a critical aspect of restoration planning. According to Fraschetti *et al.*, (2018) Key considerations include:

- **Compliance with national and international environmental regulations**
- **Obtaining necessary permits for restoration activities**
- **Adherence to MPA-specific regulations and management plans**
- **Coordination with relevant authorities** (*e.g.*, environmental agencies, fisheries departments)

Fraschetti *et al.*, (2018) highlight the complex regulatory framework for marine restoration in the Mediterranean and call for streamlined permitting processes to facilitate restoration efforts.

Restoration Project Timelines and Phases

Following Bayraktarov *et al.*, (2020), effective restoration projects typically follow a phased approach:

1. **Planning and Design:** Goal setting, site selection, stakeholder engagement, and project design
2. **Permitting and Preparation:** Obtaining necessary permits, securing funding, and preparing materials
3. **Implementation:** Active / Passive restoration activities (*e.g.*, transplantation, substrate deployment)
4. **Short-term Monitoring:** Assessing initial survival and growth of restored elements
5. **Long-term Monitoring and Adaptive Management:** Evaluating ecosystem recovery and adjusting strategies as needed

Bayraktarov *et al.*, (2020) analysed restoration project timelines across various marine ecosystems, emphasising the need for long-term commitments to ensure project success and demonstrate ecological recovery.

4.3. Challenges and Opportunities

The literature highlights several challenges and opportunities in marine restoration within Mediterranean MPAs. Basconi *et al*. (2020) stress the necessity of robust monitoring programs to assess the effectiveness of restoration interventions and support evidence-based conservation. These programs are pivotal in providing feedback that can refine restoration techniques and ensure long-term success.

In active restoration efforts, Pergent-Martini *et al*. (2024) outline significant challenges, including the selection of appropriate sites and methods, as well as the ecological condition of target habitats like *Posidonia oceanica* meadows. These challenges are not unique to seagrass, but are relevant to all vulnerable benthic species, underscoring the need for tailored approaches that consider the specific ecological context of each restoration project.

Mazaris *et al*. (2019) advocate for adaptive and collaborative approaches in integrating restoration ecology into MPA management. Their perspective highlights the importance of balancing the inherent difficulties of restoration with its potential benefits, particularly in the Mediterranean context. They emphasize that successful integration requires not only technical expertise, but also the involvement of diverse stakeholders and the flexibility to adjust strategies as conditions change.

5. Conclusion

This literature review highlights the critical role of ecological restoration within Mediterranean Marine Protected Areas (MPAs) in combating the significant degradation of vital marine habitats. The Mediterranean Sea, renowned for its unique biodiversity, faces pressing threats from human activities and climate change, making restoration initiatives indispensable for the preservation of its ecosystems. The success of these initiatives depends on a carefully balanced integration of active and passive restoration methods, tailored to the distinct needs of each habitat and species.

The review identifies key challenges, including funding constraints, regulatory hurdles, and the need for effective stakeholder engagement. Addressing these challenges requires a coordinated and comprehensive approach to restoration, encompassing not only the implementation of effective techniques but also the development of supportive policies, active involvement of local communities, and a commitment to long-term monitoring and adaptive management.

By fostering collaboration among stakeholders, advancing innovative restoration methods, and aligning efforts with broader conservation strategies such as the EU's

Biodiversity Strategy for 2030, we can enhance the resilience of Mediterranean marine ecosystems. Sustained efforts are essential to create interconnected and resilient marine environments that will continue to support the rich biodiversity of the Mediterranean Sea for generations to come.

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