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Meeting of the Ecosystem Approach Correspondence Group on Monitoring (CORMON) Biodiversity and Fisheries

Athens, 7-8 April 2025

Agenda Item 5: **Proposal to revise IMAP on Biodiversity (EO1), Non-Indigenous Species (EO2), and Fisheries (EO3)**

5.1. Way forward to update common indicators factsheets related to Biodiversity (EO1) and Non-indigenous Species (EO2)

Guideline document on the identification and introduction of appropriate measures for the reduction of new introductions and for eradication / control of NIS in priority sites in line with post 2020 SAPBIO.

SPA/RAC
Tunis, 2025

Note by the Secretariat

1. This present guideline document has been developed within the context of the GEF FishEBM MED project "Fisheries and ecosystem-based management for the blue economy of the Mediterranean"[1].

2. The guidelines document and its nine measures were presented and discussed to reduce new Non-Indigenous Species (NIS) introductions and improve their management in priority sites, in line with the Post-2020 Strategic Action Programme for the Conservation of Biodiversity and Sustainable Management of Natural Resources in the Mediterranean Region (Post-2020 SAPBIO) during regional workshop held on January 23, 2025, in Rome, Italy, bringing together experts, non-governmental organisation and representatives from 16 countries.

3. The guidelines examine ecosystem-based NIS management, balancing biodiversity conservation with socio-economic needs. It integrates nine priority measures for prevention, adaptive management, and sustainable use to enhance ecological resilience amid climate change and intense human activities.

4. Key measures include biosecurity, early detection, standardized monitoring, and localized suppression in ecologically sensitive areas. Strengthening native predator communities and restoring habitats enhance resilience against invasions.

5. In cases where non-indigenous species (NIS) are unavoidable, market valorization and adaptive fisheries management strategies can help mitigate control costs. Legislative reforms and socio-economic assessments are crucial for determining whether to prohibit, restrict, or promote exploitation. Additionally, public awareness campaigns play a vital role in fostering behavioral changes to prevent further introductions.

6. The Resist-Accept-Direct framework is a key tool for decision-making, helping managers navigate the complex choices between preventing unwanted changes (Resist), adapting to inevitable transformations (Accept), or leveraging certain NIS for broader socio-economic gains (Direct). Given the Mediterranean's interconnected waters, transboundary collaboration and multi-stakeholder co-management are essential for reconciling conservation goals with the region's dynamic ecological and socio-economic realities.

7. The guideline document is hereby presented to the Meeting of the Ecosystem Approach Correspondence Group on Monitoring (CORMON) Biodiversity and Fisheries for information.

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[1] funded by GEF through a partnership between the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP) with execution facilitated by the General Fisheries Commission for the Mediterranean (GFCM) and the Mediterranean Action Plan (MAP) under the Barcelona Convention, through the Specially Protected Areas Regional Activity Centre (SPA/RAC). The project is implemented in Albania, Algeria, Bosnia and Herzegovina, Lebanon, Libya, Montenegro, Morocco, Tunisia, and Türkiye to foster a sustainable future for Mediterranean fisheries while promoting the broader blue economy agenda

GUIDELINE DOCUMENT ON THE IDENTIFICATION AND INTRODUCTION OF APPROPRIATE MEASURES FOR THE REDUCTION OF NEW INTRODUCTIONS AND FOR ERADICATION / CONTROL OF NIS IN PRIORITY SITES IN LINE WITH POST 2020 SAPBIO

UN environment programme
Mediterranean Action Plan Barcelona Convention
SPA/RAC

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Summary

This report provides a comprehensive, evidence-based examination of Non-Indigenous Species (NIS) management in the Mediterranean Sea. It highlights adaptive, ecosystem-based approaches that reconcile biodiversity conservation with socio-economic imperatives in a region uniquely vulnerable to invasive species. By integrating prevention, adaptive management, and sustainable use of NIS, Mediterranean stakeholders can maintain ecological stability and resilience amid accelerating climate change and intense human activities.

The methodology combines a systematic literature review (following a PRISMA-style protocol) with global case study analyses and consultations with Mediterranean stakeholders. Findings affirm that prevention (e.g., strict biosecurity and early detection) remains the most cost-effective long-term strategy, yet the realities of rapidly warming seas and already-established invasions demand a wider suite of measures. In many instances, complete eradication of an NIS in open marine systems is not feasible, prompting a shift toward multi-faceted tactics—such as localized removals, habitat restoration, and regulatory frameworks that align ecological priorities with livelihood needs. Increasingly, managers are exploring market valorisation of edible invaders, spatial control within Marine Protected Areas (MPAs), and adaptive harvest techniques that sustain local economies while avoiding further spread.

The analysis concludes with nine priority measures for effective NIS management that emerged repeatedly from empirical evidence. These measures start with enhancing biosecurity and early detection protocols that emphasize prevention mechanisms while encouraging rapid-response mechanisms for incipient invasions. They similarly call for standardized, multi-parameter monitoring at key sentinel sites, where consistent data collection will inform impact assessments and guide interventions. In areas with major ecological or socioeconomic stakes, localized suppression of longer-established ones can safeguard valuable habitats. Strengthening native predator communities and restoring essential ecosystems further protects against invasive pressures by enhancing trophic stability and resilience. For those NIS that cannot be eradicated, market valorisation and promotion of derivative products can help offset control costs and generate income, especially if accompanied by adaptive fisheries regulations that align exploitation levels with ecological objectives. Legislative reforms and robust socio-economic cost–benefit analyses offer a means to systematically decide when to ban, limit, or encourage the harvest of specific invaders, while well-crafted public education campaigns reinforce the necessary behavioural changes to control inadvertent introductions. Finally, all these measures depend on transboundary collaboration and multi-stakeholder co-management, given the Mediterranean's connected nature and diverse political, economic, and cultural contexts.

Across all these measures, the Resist-Accept-Direct (RAD) framework helps managers navigate the complex choices between preventing unwanted changes (Resist), adapting to inevitable transformations (Accept), or leveraging certain NIS for broader socio-economic gains (Direct). Ultimately, transboundary collaboration and multi-stakeholder co-management are essential, given the Mediterranean's interconnected waters and the diverse political, economic, and cultural contexts that shape NIS responses. This climate-adaptive and context-aware strategy offers a path to reconcile conservation goals with the region's dynamic ecological and socio-economic realities.

1 INTRODUCTION

1.1 The Mediterranean Sea under transformation

Covering less than 1% of the world's ocean surface, the Mediterranean Sea harbours nearly 10% of global marine biodiversity, making it one of the most biodiverse semi-enclosed seas (Boudouresque, 2004; Coll *et al.*, 2010). This richness is a product of its geological history and its role as a nexus between temperate and tropical biogeographical regions. The unique conditions of the Mediterranean, its salinity gradients, temperature regimes, and biogeographical position (Bas, 2009), have driven the evolution of species and genetic traits uniquely adapted to its environments.

The Mediterranean Sea has historically supported biodiversity and ecosystem services, providing the foundation for fisheries, tourism, and coastal livelihood for over 250 million inhabitants. The ecosystem services relied on a sustained resilience which preserved key functions, such as nutrient cycling, carbon sequestration, and habitat provision. Resilient ecosystems can buffer against cascading effects of disturbances, including those induced by overfishing, pollution, and climate-induced stressors such as marine heatwaves (Côté & Darling, 2010; O'Leary *et al.*, 2022).

In the context of Non-Indigenous Species (NIS), the question of resilience becomes particularly complex. Resilient ecosystems may initially resist the establishment of NIS due to their inherent ecological balance and capacity to absorb pressures. However, once critical thresholds are crossed, these systems may undergo regime shifts, transitioning into alternative stable states that differ significantly from their historical configurations (Figure 1) (Chaffin *et al.*, 2016). These shifts are often triggered by the proliferation of invasive species, which exploit vulnerabilities created by other stressors such as overfishing, climate change, or habitat degradation.

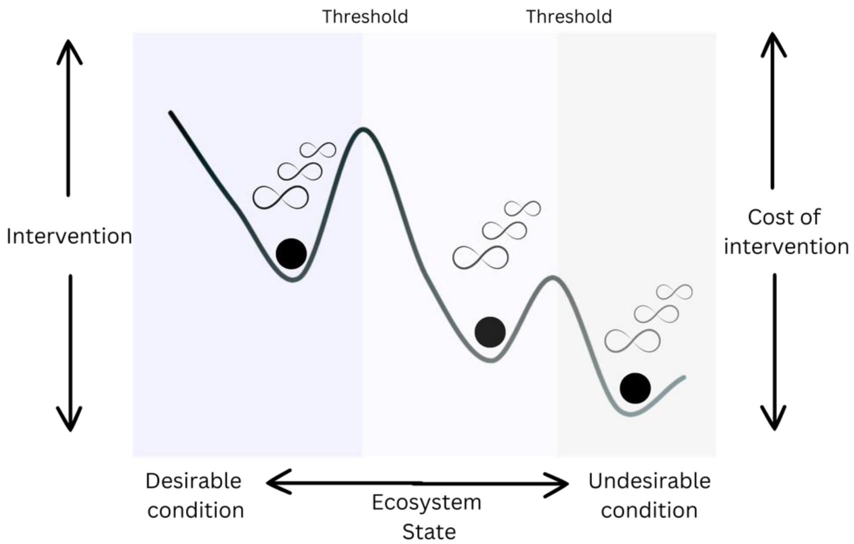


Figure 1. Conceptualization of ecosystem state shifts due to non-indigenous species (NIS) using a ball-and-cup model. Each cup represents a potential stable state, with the ball depicting the ecosystem's current condition. Each state comprises a panarchy of adaptive cycles maintained by feedback loops occurring across various spatial and temporal scales, offering distinct opportunities at different levels for NIS to exploit. Thresholds between cups indicate points where the ecosystem may shift to a less (or more) desirable state. Modified from Chaffin *et al.* (2016) and Ralston and Sarr (2017).

They can result in profound reconfigurations of ecosystem structure and function which are typically difficult to predict, costly to reverse, and have substantial impacts to ecosystem services and human well-being (Andersen *et al.*, 2009; Hastings & Wysham, 2010).

In an era of climate change and escalating ecological transformations, the Mediterranean Sea is a global hotspot for biotic and abiotic changes (Moullec *et al.*, 2019). Major introduction pathways for the NIS in the region are Corridors (interconnected manmade waterways), Transport (stowaway; transfer via biofouling and ballast waters), and Escape From Confinement (aquaculture and aquarium releases) (Katsanevakis *et al.*, 2013). The number of NIS in the region has been accelerating, with around 1000 multicellular NIS, showing a 40% increase in 11 years (Zenetos *et al.*, 2022). Over 750 of the species are established and extend their geographical range northwards and westwards, while native species are in decline (Givan *et al.*, 2018; Azzurro *et al.*, 2019c). The spread rate of NIS within the Mediterranean Sea appears to have exponentially increased after the beginning of this century compared to earlier (Azzurro *et al.*, 2022; Wesselmann *et al.*, 2024). Climate change is expected to exacerbate the spread of thermophilic NIS, giving them a competitive advantage over native species (Moullec *et al.*, 2019; Ofir *et al.*, 2023). Such rapid changes, occurring faster than in other regions, have been classifying the Mediterranean Sea as the most invaded sea worldwide (Bailey *et al.*, 2020).

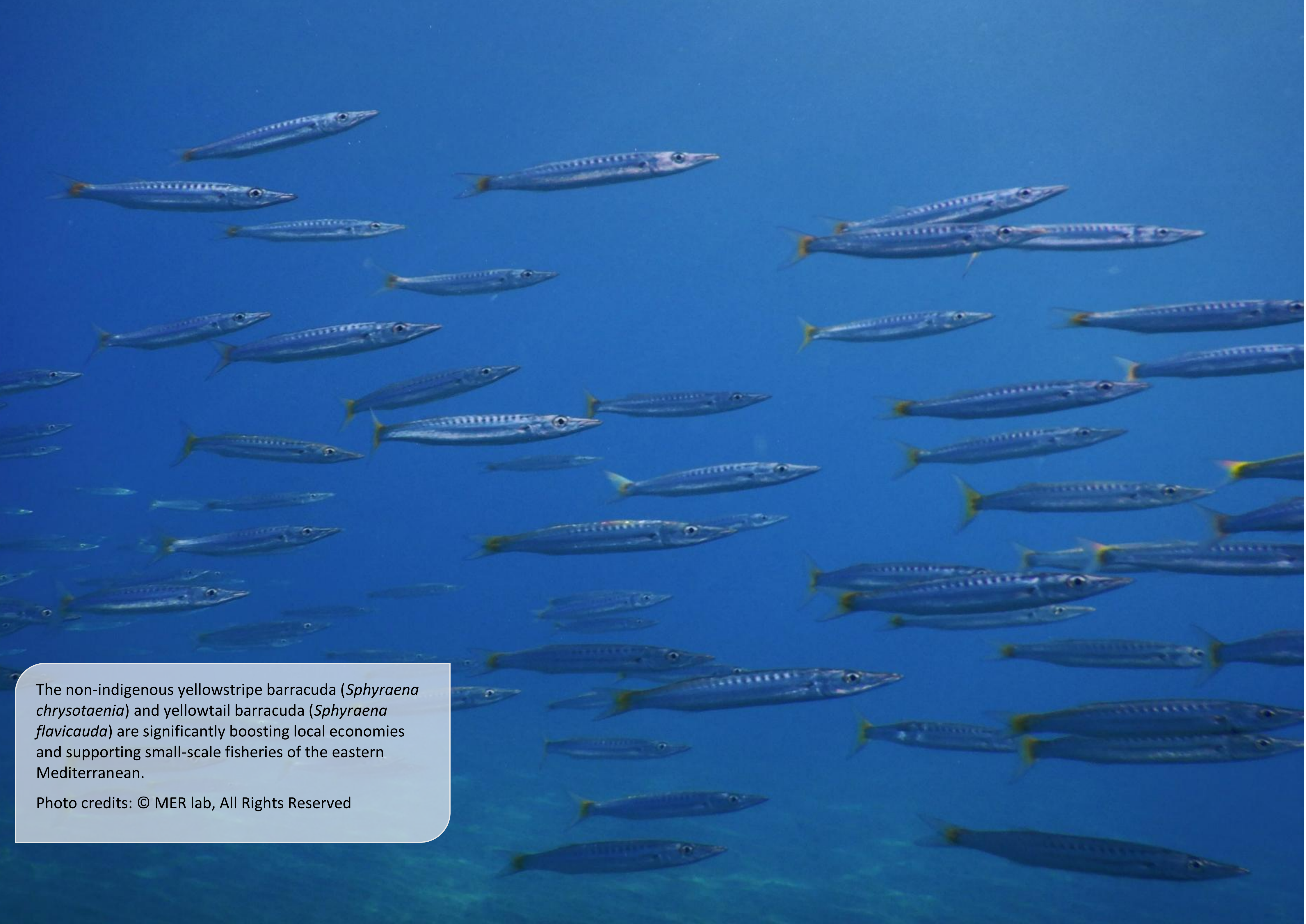
The yellow-spotted toadfish (*Torquigener flavimaculosus*), a poisonous invasive species is thriving in the eastern Mediterranean. Its high density and aggressive behaviour toward benthic life forms and fisheries infrastructure are causing significant ecological disruptions

1.2 Adapting to the transformations

Historically, strategies addressing NIS have been predominantly conservation-centric, emphasizing the eradication and containment of these species to safeguard native biodiversity. However, as described by IUCN (2000), NIS impacts are often 'immense, insidious, and usually irreversible'. They can affect nature at all ecological levels, contribute to the extinction of native species, and disrupt the contributions of nature to people (Bacher *et al.*, 2023). While preventive measures remain critical, efforts to restore ecosystems to their pre-invaded or historical conditions are often impractical and prohibitively costly, particularly when species are established. Successful eradications in marine systems are rare and typically limited to species detected at an early stage, prior to significant spread (Simberloff, 2021). As highlighted by the recent assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) on invasive alien species and their control, restoration in marine and connected systems has been largely ineffective and adaptive management that integrates ecosystem-based approaches can improve management outcomes and enhance ecosystem functioning (Roy *et al.*, 2023). While addressing the urgent need to mitigate climate change remains paramount, there is also a critical need for proactive stewardship of the adaptive capacity of the biosphere as it undergoes rapid transformations (Moore & Schindler, 2022).

During such unprecedented ecological transformations, efforts to maintain or restore previous ecological balances may prove counterproductive, as these systems now persist in novel configurations. These new states are characterized by altered species compositions, redefined ecosystem functions, and transformed socio-economic dynamics. Emerging evidence suggests that many NIS can contribute positively to biodiversity reinforcing and strengthening structural and functional ecosystem processes, for instance, by creating novel habitats, regulating other invasive species, serving as food sources, or through ecosystem engineering (Rilov *et al.*, 2022; Tsirintanis *et al.*, 2022; Katsanevakis *et al.*, 2024) . There is a growing recognition of the need to incorporate the dual nature of NIS impacts into impact assessment frameworks, evaluating both their beneficial and detrimental effects (Vimercati *et al.*, 2020; Gozlan *et al.*, 2024). In practice, management strategies largely overlooked the complex interdependencies within ecosystems and the socioeconomic realities into planning conservation frameworks, such as Marine Protected Areas (MPAs) and fisheries management (Giakoumi *et al.*, 2016; Kleitou *et al.*, 2022b). It is essential for conservation efforts to consider the environmental conditions and biological communities, including NIS, that are critical for sustaining the ecosystem functioning of the region (Giangrande *et al.*, 2020). Embracing a pragmatic and holistic approach that accounts for these complexities and permanence of alternative stable states is essential for achieving Targets 1, 3, 10, and 11 of the Kunming-Montreal Global Biodiversity Framework (GBF) (Katsanevakis *et al.*, 2024).

Managing a complex ecosystem to balance the delivery of its services lies at the core of ecosystem-based management (Palumbi *et al.*, 2009). Adaptive governance builds on these principles, offering a flexible, dynamic, and context-specific framework for addressing the uncertainties and complexities associated with NIS (Chaffin *et al.*, 2016). By integrating socio-ecological feedbacks, adaptive governance enables management strategies to evolve, enhancing system resilience to undesirable changes or facilitating transitions to more desirable states (Chaffin *et al.*, 2014). This approach relies on the adaptation ability to reorganize resources, foster learning, and respond proactively to shifting ecological and socio-economic conditions, ensuring that management remains effective in the face of rapid change (Metcalf *et al.*, 2015).



The non-indigenous yellowstripe barracuda (*Sphyraena chrysotaenia*) and yellowtail barracuda (*Sphyraena flavicauda*) are significantly boosting local economies and supporting small-scale fisheries of the eastern Mediterranean.

1.3 Control of non-indigenous species using the RAD framework

A practical tool of adaptive governance is the **Resist-Accept-Direct (RAD) framework**, which expands response options beyond traditional management approaches focused on maintaining stationary conditions. Instead, RAD recognizes the realities of managing nonstationary and novel conditions, where historical baselines are no longer reliable as management benchmarks (Schuurman *et al.*, 2022) Developed in the United States over the past decade, the RAD framework has gained consensus and significant interest for its applicability in transformation changes based on the recognition that change is inherent in natural systems (Schuurman *et al.*, 2020; Williams & Brown, 2024). It provides managers with three fundamental strategies for adapting to the existing conditions and system state transformations: (1) resisting, (2) accepting, or (3) directing changes in ecosystem processes, functions, structures, or composition (Aplet & Cole, 2010; Lynch *et al.*, 2021; Thompson *et al.*, 2021)

In the **Resist approach**, management interventions aim to maintain or restore ecosystem processes, function, structure, or composition to historical or acceptable current conditions. In contrast, the **Accept approach** involves accepting the trajectory of change by recognizing and allowing ecosystems to transition into new and unprecedented states without direct intervention, often in situations where restoration is impractical or cost prohibitive. Finally, the **Direct approach** actively shapes ecosystem trajectories toward desired new conditions, optimizing ecosystem services and socio-economic outcomes by transforming ecosystems into states better aligned with current and future climates or resource needs.

Implementing a holistic framework for managing Non-Indigenous Species (NIS) in the Mediterranean necessitates a unified approach that aligns ecological integrity with socio-economic objectives. This is crucial for mitigating adverse effects and maximizing benefits across diverse Mediterranean contexts. Our methodological approach integrates various analytical dimensions:

1. **Systematic review**: We conducted a comprehensive bibliographic review to gather existing research on NIS control in the Mediterranean.
2. **Integration of practical knowledge**: We supplemented our review with global case studies that apply RAD strategies, alongside consultations with Mediterranean experts actively engaged in NIS management.
3. **Synthesis and strategy development:** We have formulated a blueprint for NIS control in the Mediterranean, detailing potential strategies through two complementary lenses: (1) RAD strategies targeting ecological objectives and (2) RAD strategies addressing socio-economic goals.

While the non-indigenous rabbitfish (*Siganus rivulatus*) depletes Cyprus' coastal reefs through overgrazing, yet it remains highly valued in local fisheries and one of the most common catches.

2 METHODOLOGY

2.1 General landscape of NIS control research efforts in the Mediterranean Sea

2.1.1 Literature identification

To generate an overview of the current research on **marine NIS control** in the Mediterranean, we conducted a **systematic review** following PRISMA-style guidelines adapted to the environmental science context. On January 3, 2025, we ran a bibliometric search in the Scopus database. While Scopus has recognized gaps such as fewer non-English or pre-2000 records, these were deemed acceptable given our focus on a recently emerged topic and the existing challenges today.

To construct our database, we performed a keyword search on titles, abstracts, and keywords using the following query: ("non-native" OR "non-indigenous" OR "invasive" OR "alien") AND ("marine" OR "lagoon") AND ("Mediterranean") AND ("market" OR "control" OR "removal" OR "biocontrol" OR "biological control" OR "culling" OR "harvesting" OR "management" OR "exploitation" OR "fishery"). We applied filters to exclude conference papers, notes, and other unclassified publications, resulting in an initial retrieval of 406 records.

2.1.2 Screening

We excluded items classified as reviews (n=45), conference papers (n=10), notes (n=2), and short surveys (n=1). This preliminary screening narrowed the dataset to 381 records, ranging from the oldest in 1999 to the most recent in 2025.

Individual review of the abstract and the full text of these 381 articles were then conducted and assessed thoroughly for eligibility according to these criteria:

1. The study must concern marine or brackish habitats within the Mediterranean,
2. It must propose, implement, or discuss **applied control/management/mitigation** of NIS,
3. If a review/perspective, it had to propose a tangible framework or model relevant to NIS control.

A full-text review of these documents excluded a further 135 publications that did not meet our inclusion criteria (e.g., purely terrestrial/freshwater contexts, no applied measures, or insufficient detail on control). To maintain a sharp focus on applied control methods for NIS in the Mediterranean marine and brackish water environments, 'monitoring' was initially excluded from the search terms but retrieved studies focusing on monitoring were still considered eligible for analysis.

Following eligibility screening, 246 articles remained in the corpus (Supplementary Material 1). From each of the articles, we extracted bibliographic metadata (publication year, journal, country of study, etc.), and we classified each study following a RAD framework (Resist, Accept, Direct, or N/A if none clearly applied, based on the control methods discussed and the general sentiment or implications conveyed by the authors regarding NIS management, along with a Measure (adapted list from Azzurro *et al.* (2024b): #1 Develop & Manage A Commercial Fishery, #2 Encourage Recreational Harvesting, #3 Market Promotion & Valorisation, #4 Education & Public Awareness, #5 Foster Stakeholder Engagement, #6 Implement Spatial Control – Targeted Removals, #7 Implement Biological Control, #8 Restore & Protect Ecosystems, #9 Do Nothing (Passive Acceptance), #10 Monitoring, Models, Risk Assessment, #11 Biosecurity) and Monitoring Focus (e.g., "Species detection," "Risk Assessment," "Distribution modelling," etc.). Although monitoring is not typically classified as an active measure (Robertson *et al.*, 2020), it has been incorporated into the analysis because it underpins direct management interventions and is essential to any management strategy (Garcia-Lozano *et al.*, 2025). Finally, we noted any monitoring or evaluation method the article employed (e.g., "Species abundance"

vs. "Awareness and acceptance") to understand the methods used by the researchers to monitor the effectiveness/relevance of the measure applied (Supplementary Material 1).
Summarizing the literature review steps:

- Records identified (n=406)
- Duplicates removed (n=1)
- Screening → Full-text eligibility assessment → Excluded (n=135)
- Included in the final analysis / review → final corpus of 246 studies.

2.1.3 Analysis of the general research landscape

The analysis of bibliometric data was performed in R Studio using packages "tidyr", "dplyr", "ggplot2", "ggalluvial". In addition, the dynamics of scientific contributions on NIS were further analysed using the free and open-source Bibliometrix R package and its accompanying graphical interface, Biblioshiny (Aria & Cuccurullo, 2017). We generated visual representations to illustrate both the social and conceptual frameworks of the NIS research landscape. We employed Multiple Correspondence Analysis (MCA) to assess interrelationships among the most prevalent keywords within our dataset. Keywords were managed through synonym lists to unify different expressions of similar concepts (e.g., 'fish', 'fishes', and 'fishery' were consolidated under a single term). Simultaneously, a thematic map was generated on the top 50 keywords to categorize identified themes into Motor, Emerging or Declining, Niche, and Basic themes using the Walktrap clustering algorithm.

2.2 Targeted review and expert consultations

In this second phase, we complemented our bibliometric landscape analysis by conducting (1) a targeted literature review of global case studies and (2) engaged with experts throughout the Mediterranean running projects focusing on NIS control. This two-pronged approach broadened our scope beyond formally indexed scientific publications, allowing us to integrate practical knowledge, project results, and grey literature that might otherwise remain underrepresented.

For each identified case study, we recorded the following attributes:

- Case study title
- Geographic location
- Habitat/ecosystem type
- Target NIS (species)
- Project timeline
- Lead organizations/implementers
- Control measure categories (aligned with our #1–#11 classification)
- Description of control measure(s) (e.g., mechanical removal, biosecurity inspections, commercial valorisation)
- Effectiveness & outcomes (e.g., reduction in nis biomass, improved native species recovery)
- Challenges & barriers (e.g., insufficient funding, stakeholder resistance, technical difficulties)
- Opportunities & innovations (e.g., novel removal technologies, new partnerships)
- Lessons learned (e.g., best practices, transferability to other regions)

2.3 Synthesis of insights and lessons learned

Insights from both the systematic review (Phase 1) (and additional / relevant literature) and the targeted case study approach (Phase 2) were integrated into a measure-by-measure discussion following the taxonomy introduced in Chapter 2.1.2. Each measure is presented with a cohesive structure, covering rationale, evidence from published sources, illustrative case study examples, critical observations, and a concluding SWOT analysis.

3 RESULTS

3.1 Landscape of NIS control research in the Mediterranean Sea

From 1999 to 2025 in total 1145 authors were involved in the production of the 246 papers that were reviewed. The analysis revealed a substantial growth in literature related to NIS control research efforts, with an annual increase rate of 5.48%. A significant portion of this research involves international collaborations, constituting 48.37% of the total output (Figure 2A). Corresponding authors were mainly from Italy (n=80) followed by Spain (n=33), Greece (n=28) and Israel (n=17). Among the articles, each counted once per affiliated country per author, 40% of the affiliations were associated with Italian organizations, followed by Spain at 18% and Greece at 14.5% (Figure 2B).

(A)

(B)

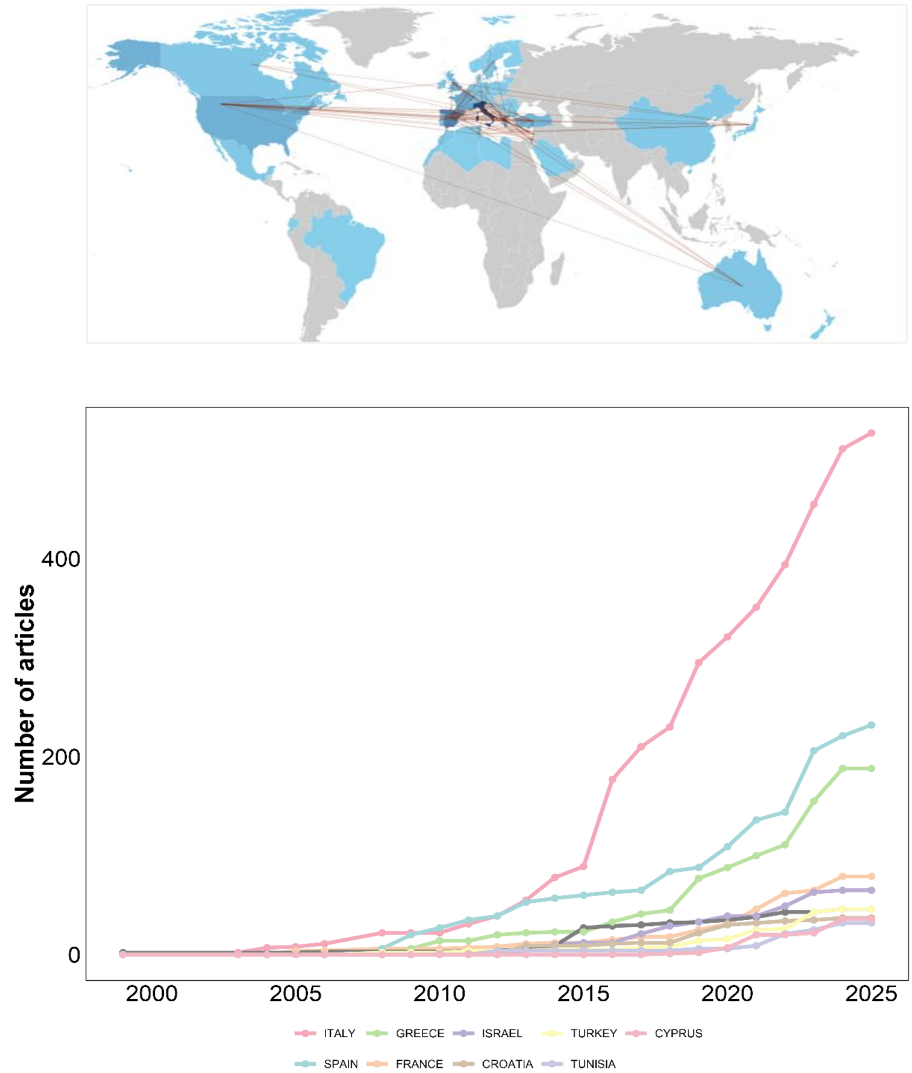


Figure 2. (A) Collaboration map of authors involved in papers related to non-indigenous species control in the Mediterranean. (B) Number of articles attributed to each country ba sed on author affiliations.

The co-occurrence analysis of authors' keywords revealed 'invasive species', 'Mediterranean Sea', and 'biological invasion' as central nodes, closely linked with 'climate change' and 'biofouling', underscoring the focal points and interconnections within the NIS discourse (Figure 3).

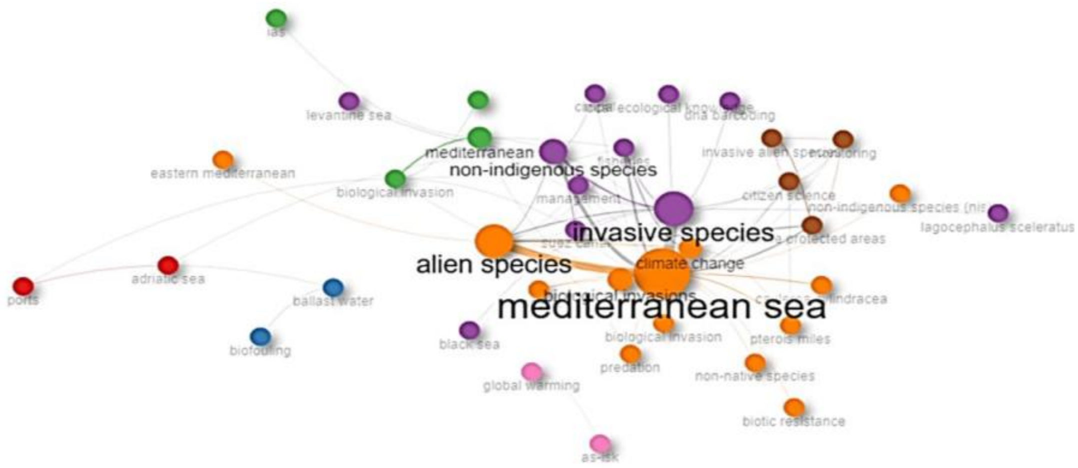


Figure 3. Co-occurrence network of keywords from the literature review on non-indigenous species control, organized using the Walktrap clustering algorithm.

Spatial and thematic clustering of the Multiple Correspondence Analysis (MCA) identified distinct associations between research themes and geographic areas. For instance, 'biological invasions' and 'fisheries management' are frequently associated with the 'Adriatic Sea' and 'Cyprus', respectively, highlighting regional research emphases (Figure 4).

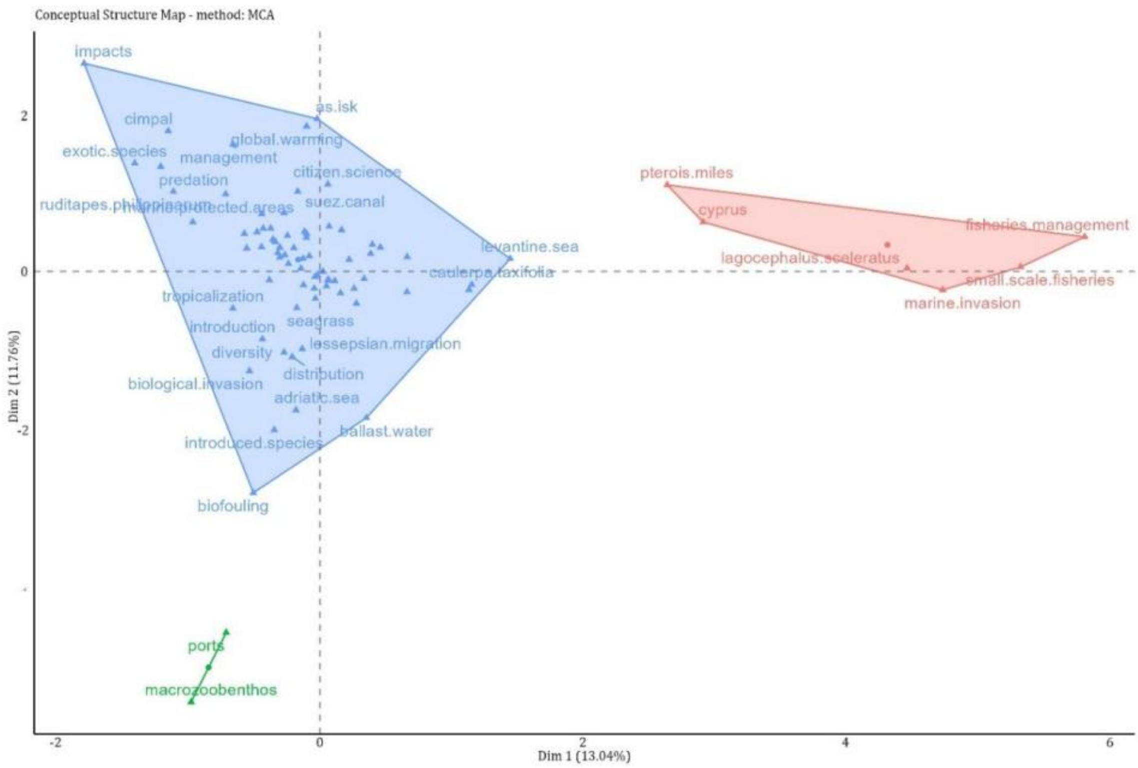


Figure 4. Multiple Correspondence Analysis (MCA) showing the relationship between key research themes in non-indigenous species control studies of the literature review.

This thematic map categorized research themes into Motor, Emerging, or Declining themes based on their centrality and density. Central themes like 'biological invasion' and 'climate change' dominate the discourse, while 'eastern Mediterranean' and 'Atlantic blue crab' emerge as newer areas of focus (Figure 5).

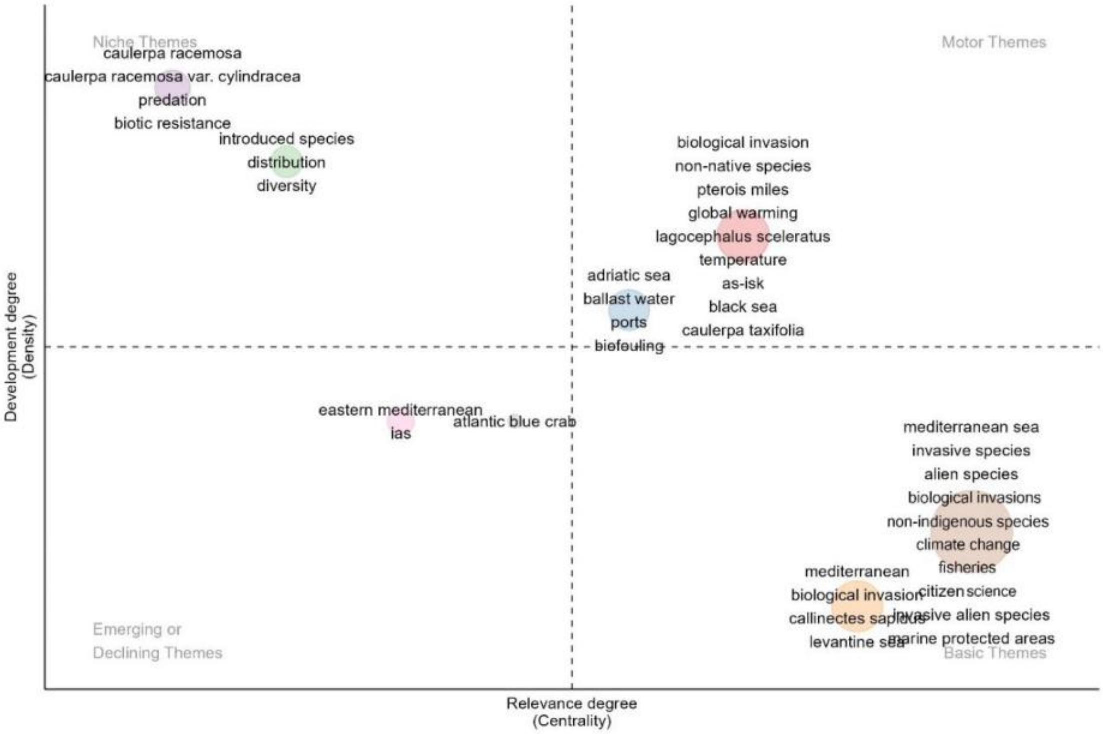


Figure 5. Thematic map categorizing research themes into Motor, Emerging, or Declining, Niche themes, or Basic Themes. Motor Themes like 'biological invasions' and 'climate change' are shown as central and mature, indicating a well-established research foundation. Emerging themes such as 'blue crabs' and 'eastern Mediterranean' signal growing areas of academic interest, while Niche themes identify areas with specialized research.

Our analysis of documents around the Resist-Accept-Direct (RAD) framework, reveals a predominant focus on 'Resist' strategies across the reviewed literature, which constitute most articles. Despite an exponential growth in publications on 'Resist' strategies, the discourse on 'Accept' or 'Direct' control measures for managing NIS remain sparse. A persistent trend towards preventative and monitoring control strategies over actionable interventions was identified (Figure 6). However, a trajectory towards a broader acknowledgment within fisheries and acceptance strategies was documented after 2015 (Figure 7).

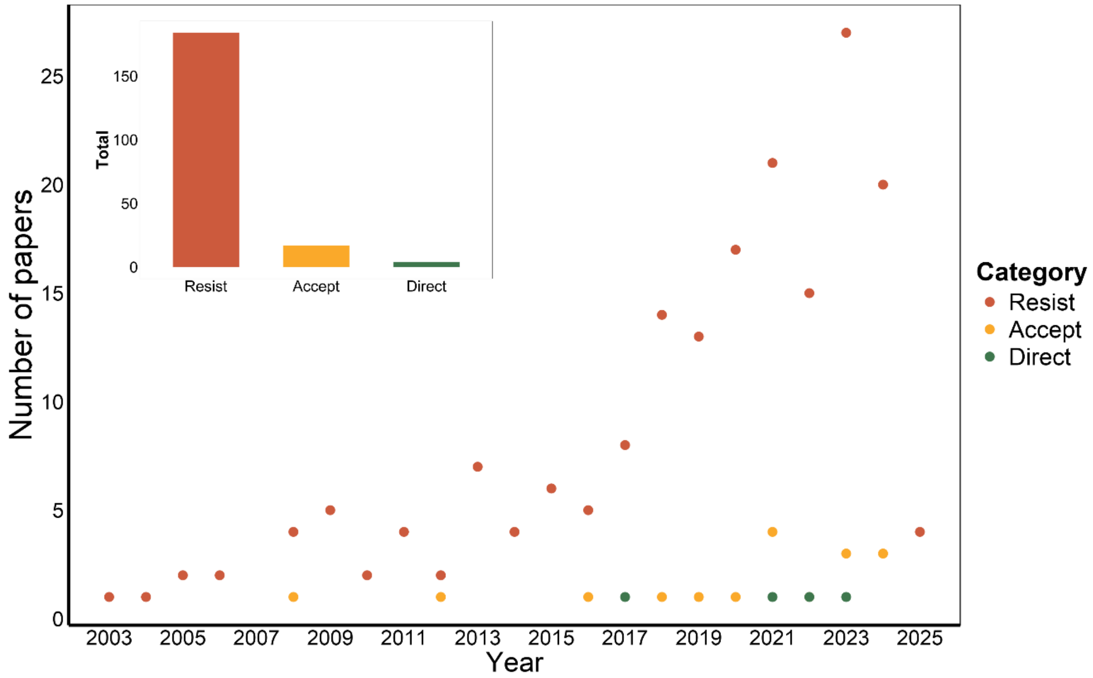


Figure 6. Trajectory of documents extracted from the Scopus database on January 3, 2025, using the keyword terms outlined in the Methodology section and the RAD (Resist, Accept, Direct) classification. When none of the RAD strategies was clearly applied, the document was excluded from this illustration.

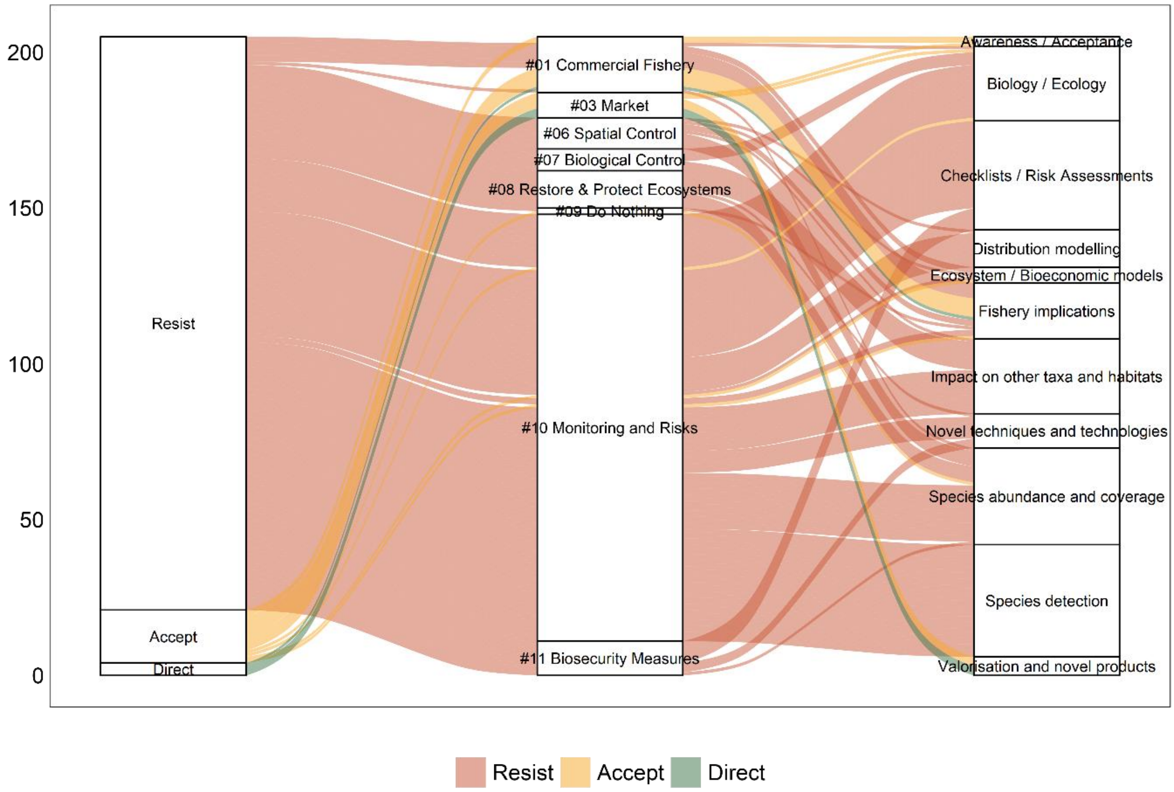


Figure 7. Alluvial chart illustrating the interconnections between the documents categorized by RAD strategy (Resist, Accept, Direct), the specific Measures employed, and the monitoring or evaluation methods used.

3.2 Targeted case studies and expert consultations

An array of case studies was assembled to illustrate how different regions, organizations, and stakeholders approach the control of NIS (Supplementary Material 2). These examples are not exhaustive; rather, they serve as representative snapshots showcasing diverse strategies, target species, habitats, and outcomes. They were identified through both our targeted literature review and expert consultations (Chapter 2), ensuring a blend of well-documented initiatives and more local or emerging Mediterranean efforts

From both published literature (e.g. Critchley *et al.*, 1986; Anderson, 2005; Mancinelli *et al.*, 2017) and expert consultations (e.g., Pick the Alien, RELIONMED, LagoMEAL), a total of 54 case studies were identified (14 from expert consultations and 40 from published articles). The published studies were screened from Katsanevakis (2022) and Azzurro *et al.* (2024a). Each case study was tagged with one or more of the 11 control measure categories (Figure 8). Spatial control measures were the most common across the studies, with 29 instances predominantly sourced from published literature (n=26). Conversely, expert consultations primarily contributed to case studies focusing on market promotion and valorisation (n=12) (Figure 8).

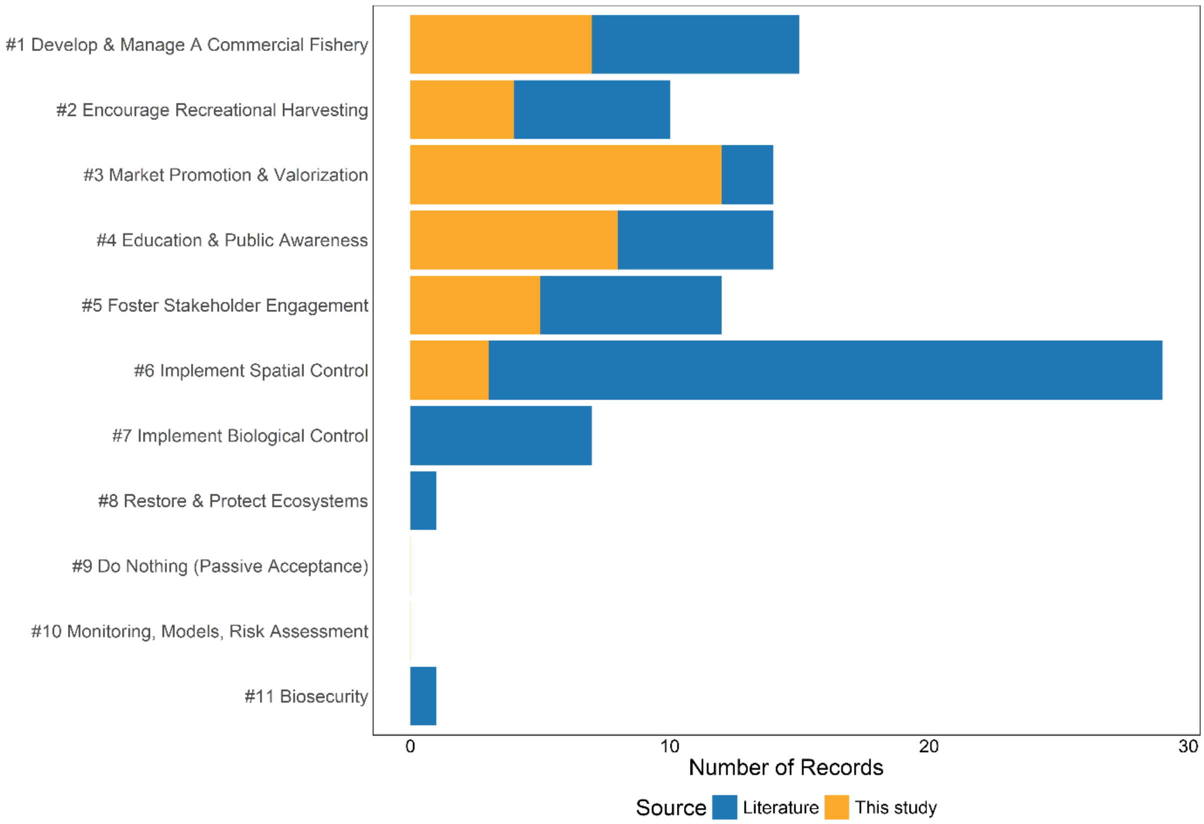


Figure 8. Frequency of control measure categories across the 53 case studies. Each bar represents the counts of case studies that used measures within the specified measure category.

3.3 Measure-based synthesis and lessons learned

In response to the proliferation of NIS, a variety of control measures, albeit limited, were actively being researched and applied. These range from advancing sustainable fisheries to implementing rigorous biosecurity protocols. This section synthesizes insights from both the systematic literature review (Phase 1; Chapter 3.1) and the targeted case study approach (Phase 2; Chapter 3.2) into a measure-by-measure discussion. Each measure is presented with a cohesive structure.

3.3.1 Develop & manage a commercial fishery

Rationale & key insights

Establishing or augmenting commercial fisheries for selected NIS can reconcile ecological imperatives (mitigating invasive biomass) with socio-economic drivers (Marchessaux *et al.*, 2023b; de Carvalho-Souza *et al.*, 2024). This approach can be a **cost-effective, systematic, and sustainable** control measure against biological invasions, aligning with Ecosystem-Based Management principles (Badjeck *et al.*, 2010; Kleitou *et al.*, 2021a; Hidalgo *et al.*, 2022). However, some NIS may exert such disproportionate ecological harm that promoting a fishery would be counterproductive, requiring more aggressive measures (Kleitou *et al.*, 2021a). Distinguishing these species through **robust monitoring** and **cost–benefit analyses** is recommended (Kleitou *et al.*, 2021a; Azzurro *et al.*, 2024c).

Evidence from published documents

- **NIS are part of fisheries sustainability**: In the eastern Mediterranean, NIS now **comprise a large share** of fishery landings without significantly undermining fishers' revenues (Van Rijn *et al.*, 2020). In Cyprus and Greece, for instance, NIS comprise roughly half of small-scale fishery landings; frequent targets include the rabbitfish (*Siganus* spp.), silver-cheeked toadfish (*Lagocephalus sceleratus*), bluespotted cornetfish (*Fistularia commersonii*), Red Sea goatfish (*Parupeneus forsskali*), and lionfish (*Pterois miles*) (Moutopoulos *et al.*, 2021; Kleitou *et al.*, 2022b; Kondylatos *et al.*, 2023).
- **Exploitations can reduce populations of NIS:** Simulation models confirm that **targeted exploitation** can reduce invasive lionfish or pufferfish populations (Michailidis *et al.*, 2023). Surveys further reveal that fishers would willingly target lionfish if stable markets existed, and consumers would accept NIS on menus given safety and quality assurances (Minasidis *et al.*, 2023; Sidiropoulou *et al.*, 2024).
- **The case of blue crabs:** Blue crab (*Callinectes sapidus*, also *Portunus segnis*) has proven **commercially promising** in multiple Mediterranean countries, albeit with challenges such as gear damage and ecological conflicts (Marchessaux *et al.*, 2023b; Rifi *et al.*, 2023; Mancinelli *et al.*, 2024). Tunisia's *Portunus segnis* fishery soared from <1 million USD in 2016 to ~30 million USD in 2022 (Souissi *et al.*, 2024).
- **The case of manila clam:** A parallel example comes from the manila clam (*Ruditapes philippinarum*), whose introduction in Europe decades ago **resulted in new fisheries** in Spain, generating between €10 million and €23 million in annual sales (Ramajal *et al.*, 2016). Though size limits and permissible gear use have promoted a degree of sustainable exploitation (Coelho *et al.*, 2021), overharvesting and widespread non-compliance still threaten long-term profitability (Ponti *et al.*, 2017; Coelho *et al.*, 2021).
- **Lack of markets and incentives:** Some NIS lack meaningful market value, remain undersized, or face low consumer acceptance (Diciotti *et al.*, 2016; Papageorgiou & Moutopoulos, 2023). Overreliance on a single profitable invasive (e.g., the blue crab) can generate perverse incentives to maintain or spread that NIS (Ligorini *et al.*, 2022).
- **Evaluating the trade-offs between ecosystem and fisheries:** Balancing eradication goals with "sustainable exploitation" also raises regulatory dilemmas—an example is the Territorial Plan for Combating the Blue Crab in Corsica (2024–2027) (Marchessaux *et al.*, 2023b), which

conflicts with GFCM Recommendation GFCM/42/2018/7 about maintaining blue crab stocks at MSY while ensuring socio-economic viability. Management is further constrained by complex life cycles and interactions with the ecosystem (Klein & Verlaque, 2011; Akgun & Akoglu, 2023), uncertain stock dynamics (Clavero *et al.*, 2022; Kevrekidis *et al.*, 2023) and regulatory gaps (Coelho *et al.*, 2021; Kleitou *et al.*, 2021a). Continuous cost–benefit analyses to analyze the net trade-offs and adaptive harvest strategies are therefore **essential** (Coelho *et al.*, 2021; Kleitou *et al.*, 2021a; Azzurro *et al.*, 2024c).

Illustrative examples from Case Studies

When an NIS becomes marketable, commercial fisheries can channel economic incentives directly into **systematic removal**.

- Tunisia – Blue swimming crab (*Portunus segnis*) fishery

Authorities supplied traps and supported marketing efforts, thereby increasing fishing pressure on a harmful invader (Souissi *et al.*, 2024; Supplementary Material 2, Literature Case Study 34).

- Northern Adriatic USEIt project (Expert Case Study #4)

Promotes the Atlantic blue crab (*Callinectes sapidus*) for Italian gastronomy. Fishers are encouraged to keep (rather than discard) catches, creating partial economic returns.

- Delta del Po “Blueat” project (Expert Case Study #13)

Began in December 2021, engaging fishers and establishing industrial-scale processing for *C. sapidus*. By 2023, these blue crab products were sold in local supermarkets and exported to the US and South Korea, reframing a “nuisance” species into a revenue generator.

- LagoMEAL project (Expert Case Study #8)

Investigates aquafeed production from the toxic pufferfish *Lagocephalus sceleratus*. If demand and viable pricing emerge, fishers gain incentive to target (and thus reduce) this harmful species.

Critical insights from Case Studies & literature

- **Stable or emerging demand:** Many success stories hinge on immediate local or export markets. Volatile consumer preferences, however, can undermine fishers’ interest (Azzurro *et al.*, 2024c).
- **Perverse incentives:** A highly profitable NIS may tempt some stakeholders to resist eradication or even spread it. Regulatory oversight and monitoring are critical for preventing such outcomes (Kleitou *et al.*, 2021a; de Carvalho-Souza *et al.*, 2024).
- **Bridging acceptance gaps:** Toxic or venomous species (e.g., pufferfish) demand robust safety checks, education, and dependable supply chains to maintain consumer trust (Minasidis *et al.*, 2023).
- **Regulatory complexity:** Strategic removals can conflict with other mechanisms. For instance, intensive removal of female blue crabs (Marchessaux *et al.*, 2024b)can clash with GFCM recommendations for maintaining a stock at MSY levels. Overharvesting or ignoring ecosystem interactions can create new imbalances (Ponti *et al.*, 2017; Kleitou *et al.*, 2021a).

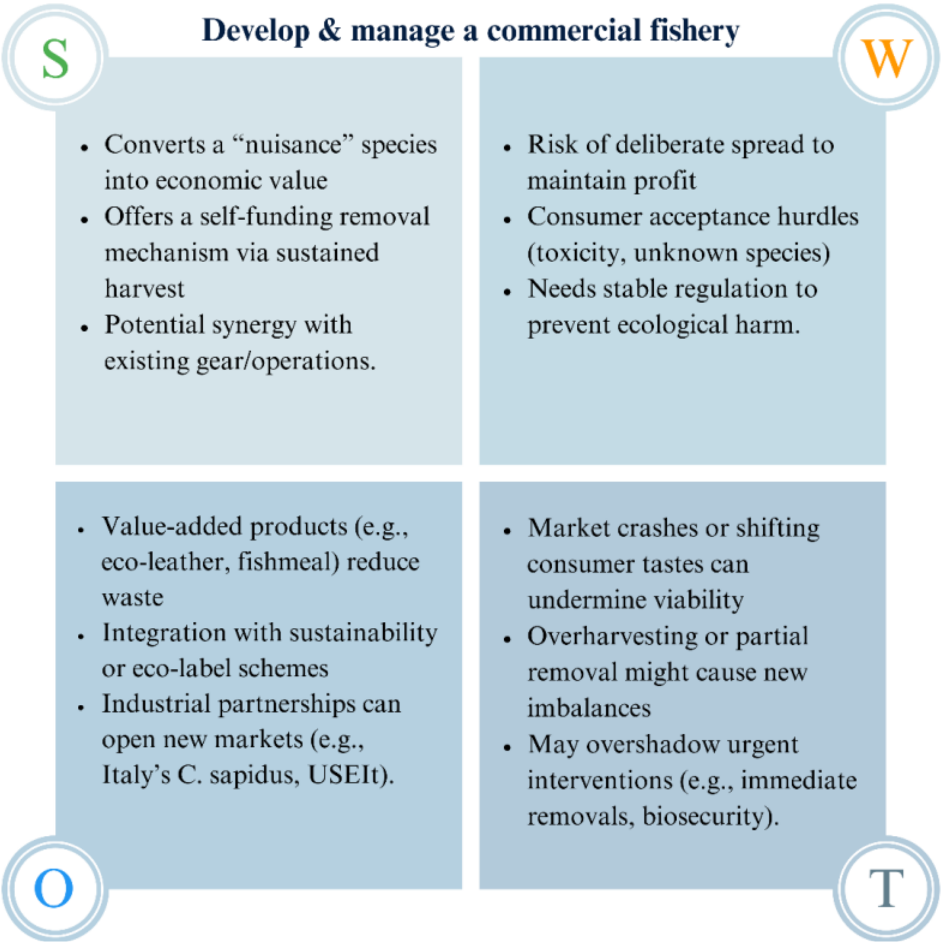


Figure 9. Strengths, Weaknesses, Opportunities, and Threats for "developing and managing commercial fisheries" measures for non-indigenous species control.

Interlink with other measures

Commercial NIS fisheries often require market Promotion & Valorisation (Measure #3) to build or sustain demand, Monitoring & Risk Assessment (Measure #10) to set harvest limits and track population changes, Spatially Targeted Removals (Measure #6) to focus fishing effort on known hotspots or key reproductive periods.

Conceptual relationship between fishing and non-indigenous species

The hypothesis that fishing can mitigate the impacts of NIS with positive net trade-offs is depicted across a series of conceptual diagrams in Figure 10. The initial plot (Figure 10A), informed by the Schaefer model (Schaefer, 1954), illustrates the relationship between fishing effort and yield through a parabolic curve. This curve peaks at the Maximum Sustainable Yield (MSY), and as effort increases beyond this point, the yield declines, highlighting the constraints of sustainable exploitation.

The second plot (Figure 10B) exhibits inverse logistic curves, grounded on the logistic (sigmoid) growth theory of the Schaefer model and the concept that ecological impacts due to NIS populations intensify beyond a certain threshold (Green & Grosholz, 2021). This demonstrates that ecological benefits increase with targeted fishing efforts against harmful NIS. Conversely, benefits decrease beyond a threshold of fishing effort where beneficial non-indigenous species are adversely affected, emphasizing the need for balanced management to optimize ecological outcomes.

The third plot (Figure 10C) integrates the yield data from the first diagram with the ecological impacts from the second to assess the overall marginal benefits of fishing. The final diagram (Figure 10D) expands further by incorporating fishing costs. The categorization of species based on their ecological impact (positive or negative) and commercial value (presence or absence) demonstrates how strategic fishing can mitigate ecological damages while considering economic efficiency. The conceptual diagram indicates that the maximum benefits can be achieved at different levels of fishing effort depending on the commercial value and impacts of NIS, demonstrating how strategic fishing practices can potentially reduce ecological damages while considering economic efficiency.

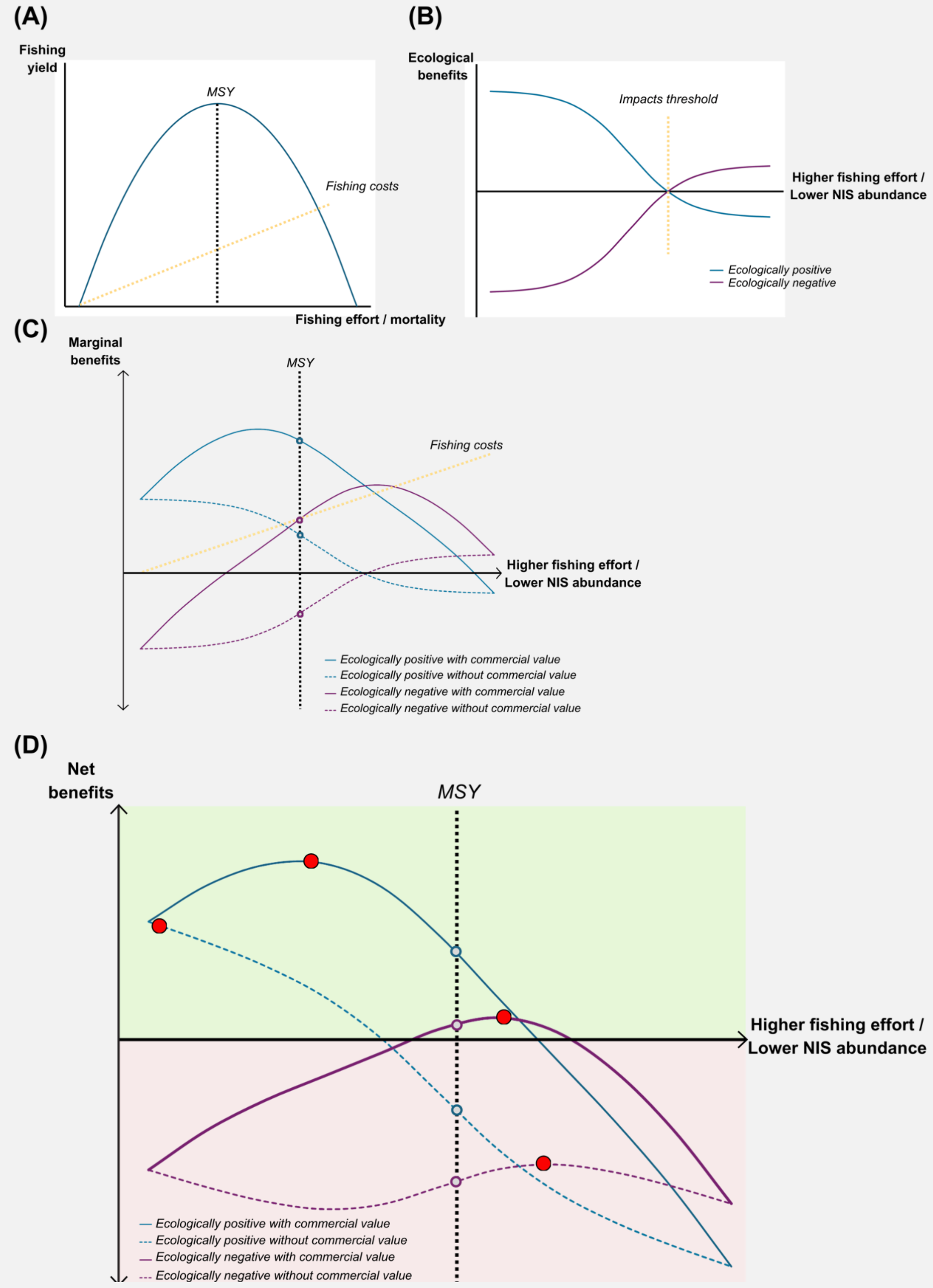


Figure 10. 5A: Relationship between fishing effort and yield, showing the parabolic curve that peaks at the Maximum Sustainable Yield (MSY) and declines with increased effort; 5B: Inverse logistic curves based on the logistic growth theory, demonstrating how ecological benefits vary with fishing efforts, increasing against harmful NIS and decreasing when beneficial NIS are impacted; 5C: Integration of yield data and ecological impacts to assess overall marginal benefits from varied fishing efforts; 5D: Expansion to include fishing costs and the categorization of species by ecological impact and commercial value, highlighting the optimization of net benefits through strategic fishing practices.

Captured at a gastronomic event in Cyprus in 2022, this image illustrates the diverse range of non-indigenous species now commonly found in Mediterranean restaurants. Featured are the yellowtail barracuda (*Sphyraena flavicauda*), the Red Sea goatfish (*Parupeneus forsskali*), the bluespotted cornetfish (*Fistularia commersonii*), and the African blue swimming crab (*Portunus segnis*). These species, once alien to the Mediterranean ecosystem, are increasingly embraced by fisheries, local markets and culinary traditions.

3.3.2 Encourage recreational harvesting

Rationale & key insights

Marine recreational fisheries (MRF) can exert **substantial fishing pressure** and thus play a role in controlling invasive populations (Lewin *et al.*, 2019). Moreover, motivated recreational fishers often contribute to conservation by initiating or joining **removal initiatives** (Granek *et al.*, 2008). Although profit is not their primary motive, the pursuit of personal enjoyment, cultural traditions, or consumptive use can make **recreational fishers** a consistent removal force, even when invasive populations appear overfished (Kleiven *et al.*, 2020).

By mobilizing recreational fishers to perform intensive removals, managers could suppress high-impact invaders and restore aspects of ecosystem balance. This community-driven approach becomes especially relevant where commercial incentives are limited or slow to emerge. In Europe alone, an estimated **8.7 million people** partake in recreational fishing for **78 million days** annually (Hyder *et al.*, 2018), generating **10.5 billion €** and supporting ~99,500 full-time jobs (Hyder *et al.*, 2017). Educating and incentivizing these fishers (and more divers) to target NIS can substantially enhance control efforts.

Evidence from published documents

Despite relatively few formal studies on the role of recreational fisheries in NIS control, emerging evidence points to significant potential:

- **Recreational catches can surpass the commercial ones**: In Cyprus, the combined weight and economic value of recreational catches now **surpasses** that of coastal commercial fisheries, with rabbitfish (*Siganus* spp.) particularly abundant (Michailidis *et al.*, 2020; Kleitou *et al.*, 2022b).
- **Selective harvesting can be effective:** Controlled lionfish (*Pterois miles*) removals by divers in Marine Protected Areas (MPAs) have significantly reduced lionfish densities suggesting that **selective gears**, including free diving and SCUBA with spearfishing, can be highly effective in controlling lionfish populations at selected sites (Dikou, 2024; Kleitou *et al.*, 2024; Savva *et al.*, 2024).
- **Radical new licence for NIS-selective fishing:** A noteworthy concept is the introduction of a **dedicated recreational fishing license** targeting ecologically damaging NIS (Kleitou *et al.*, 2021a). Such a license could train fishers on marine ecosystems, NIS impacts, and safe harvesting practices, with benefits like exclusive access to certain areas or times. This would empower recreational fishers to actively aid invasive species control; especially for species not easily targeted by commercial vessels (Kleitou *et al.*, 2021a).
- **Cultural challenges:** A challenge identified is that **recreational fishers** do not always prioritize NIS over native "trophy" species (Michailidis *et al.*, 2020; Kleitou *et al.*, 2022b). Additionally, targeting toxic or stinging organisms (e.g., pufferfish) raises safety concerns, and the **spatial dispersion** of recreational fishing complicates enforcement. Volunteer engagement can fluctuate, and deeper habitats or remote areas often remain under-impacted, especially by free divers (Kleitou *et al.*, 2022b).

Illustrative examples from Case Studies

- Caribbean lionfish "Derbies"

Multiple NGOs organize weekend events awarding prizes for the largest or most lionfish caught (Literature Case Studies #27 & #30). These derbies build community pride, raise awareness, and effectively reduce lionfish abundance in shallow areas.

- Targeted removals in Cyprus MPAs

In a parallel Mediterranean effort (Literature Case Study #29; Expert Case Study #3), volunteer divers systematically remove *Pterois miles* from priority reefs, generating **temporary declines** in local populations. Public outreach and community buy-in have proven essential for sustained removal events.

Critical Insights from Case Studies & literature

- **Motivation & community pride:** Lionfish "derbies" and other recreational culls add a social or competitive spark, effectively targeting accessible reefs and priority sites like MPAs. However, deeper zones remain largely untouched, allowing re-invasion.
- **Continuity of effort:** Enthusiasm can drop if events or incentives (e.g., prizes, recognition) are not regularly updated. Volunteer fatigue undermines consistent impact.
- **Legal & safety barriers:** In MPAs, spearfishing is frequently restricted, even for invasives, **unless adaptive legislation** provides special permissions (Kleitou *et al.*, 2021c). Handling venomous or toxic species (e.g., lionfish, pufferfish) also demands strict safety protocols.
- **Data gaps:** Recreational fishers may only report partial information. Some prefer to catch "prestigious" species rather than NIS, limiting the focus on real invasive threats (Michailidis *et al.*, 2020; Kleitou *et al.*, 2022b).

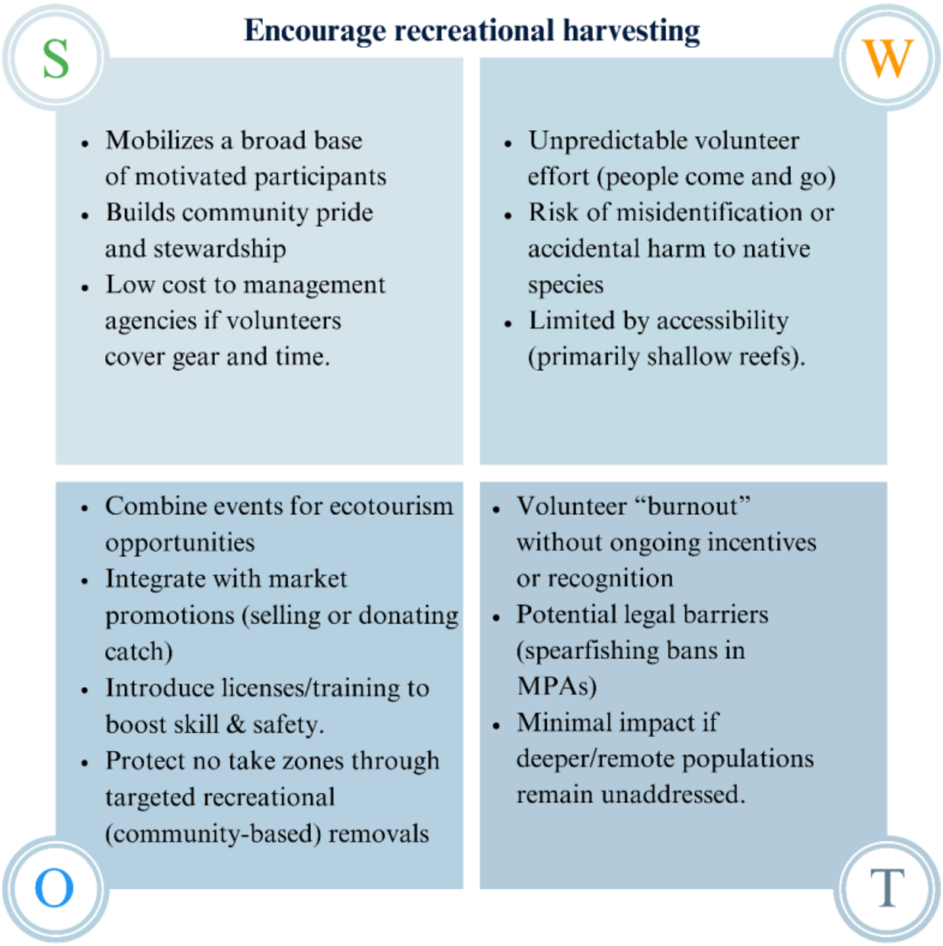


Figure 11. Strengths, Weaknesses, Opportunities, and Threats for "encouraging recreational harvest" measures for non-indigenous species control.

Interlink with other measures

Recreational harvesting efforts align with the "Implement Spatial Control" measures (Measure #6) and rely on strong education and public awareness (Measure #4). They can also be linked with broader monitoring initiatives (Measure #10), where citizen science reporting aids in tracking emergent invasions.

3.3.3 Market promotion & valorisation

Rationale & key insights

Market-based approaches for the valorisation of NIS are emerging as a powerful tool in invasive species management (de Carvalho-Souza *et al.*, 2024). By fostering consumer demand for NIS, the commercial use of these species can incentivize fisheries while mitigating their ecological impact. The valorisation of NIS can take several forms, from food markets to biotechnological applications, each offering distinct avenues for controlling invasive populations and promoting sustainable harvesting. A successful valorisation strategy requires a well-structured supply chain, market acceptance, and consumer education to ensure that these species are consumed or used in ways that contribute to environmental sustainability and the local economy.

Market promotion and valorisation involve creating or expanding markets for non-indigenous species (NIS), providing **financial incentives** for their removal and, ultimately, helping mitigate their ecological impacts (Kleitou *et al.*, 2019b; de Carvalho-Souza *et al.*, 2024). In practical terms, **"valorisation"** can encompass:

- **Food markets** (e.g., restaurants offering invasive fish or crabs),
- **Nutraceutical/biotechnological applications** (e.g., harvesting invasive algae for antibacterial compounds),
- **Industrial products** (e.g., eco-leather from fish skins).

The overarching goal is to **align** conservation objectives (reducing NIS populations) with socio-economic drivers (new revenue streams or employment). Yet, caution is required to avoid **perverse incentives**, where a profitable NIS is seen as too valuable to eradicate (Kourantidou & Kaiser, 2024).

Evidence from published documents

Studies from across the Mediterranean suggest that market-driven approaches, when designed carefully, can both **offset removal costs** and **foster stakeholder engagement**:

- **Consumer acceptance & demand:** In Greece, **62%** of surveyed consumers indicated willingness to purchase edible NIS (e.g., *Siganus* spp., lionfish), and **79%** supported certification schemes to guarantee safety and sustainability (Sidiropoulou *et al.*, 2024). In Italy, an online survey found **growing interest** in blue crab (*Callinectes sapidus*), though gaps remain in distribution chains, hindering consistent availability (Azzurro *et al.*, 2024d).
- **Biotechnological & industrial uses:** Many species could potentially be utilized in biotechnological or other industries. For instance, the invasive red alga *Asparagopsis taxiformis* exhibits antibacterial, algicidal, and antioxidant properties, making it attractive for pharmaceutical or cosmetic applications (Ktari *et al.*, 2022). *Caulerpa racemosa var. cylindracea* is under study for water treatment (Cengiz & Cavas, 2008) and broader work on invasive seaweeds suggests diverse **commercial potential** on biotechnological industry (Mollo *et al.*, 2015).
- **Food-related innovations for valorisation:** A flow-through pond system in Italy successfully produced **soft-shell blue crabs**, raising their market value (Cilenti *et al.*, 2024). Nutritional studies highlight the potential of NIS products as healthy food options (Khamassi *et al.*, 2022). Ecolabeling, media campaigns, and culinary promotion can mitigate public concerns about toxicity while also emphasizing conservation goals (Kleitou *et al.*, 2019b).
- **Limited market for some NIS:** Despite these promising avenues, some invasive species **lack** immediate commercial appeal due to size, taste, or strong consumer biases (Diciotti *et al.*, 2016; Papageorgiou & Moutopoulos, 2023). Additionally, **bounty-like** schemes for certain species can distort incentives or management agendas (Ulman *et al.*, 2022; de Carvalho-Souza *et al.*, 2024; Kourantidou & Kaiser, 2024).

Illustrative examples from Case Studies

Below are a few **selected examples** showing how market promotion has been tested:

- Pick the Alien & FishtheAlien (Expert Case Studies #1, #5)

These initiatives organized culinary events (e.g., cooking demos, tastings) featuring lionfish, rabbitfish, or blue crabs. Participants learned how to safely prepare and consume these species, helping to shift negative perceptions (Kleitou *et al.*, 2019b).

- Le Puffer (Expert Case Study #11)

In Türkiye, *Lagocephalus sceleratus* skins were turned into **eco-leather** for fashion items. While media coverage sparked interest, maintaining steady removal of this toxic pufferfish depends on stable production and demand.

- RELIONMED (Expert Case Study #3)

This project explored making **lionfish jewellery** in the eastern Mediterranean. Initial enthusiasm underlined consumer curiosity, but inconsistent catch volumes and retail distribution limited broader commercial adoption.

- CHITELIX (Expert Case Study #14)

This Tunisian company is creating a sustainable industry around **blue crab** (*Portunus segnis*) **bioproducts**, including **chitin and chitosan extraction**

These and similar endeavours demonstrate the **potential** of market-based valorisation to engage local communities, fishers, and entrepreneurs. However, they also highlight **challenges** like fluctuating supply, product novelty, and the need for continuous promotion.

Critical Insights from Case Studies & literature

- **Balancing profit & conservation:** High market value can risk **sustaining** an invader if eradication jeopardizes incomes (Kourantidou & Kaiser, 2024). Clear management objectives, e.g., capping or functionally eradicating populations, should remain primary.
- **Supply chain & safety:** For venomous or toxic species (lionfish, pufferfish), strict handling protocols, labelling, and public awareness are crucial for consistent market acceptance (Minasidis *et al.*, 2023). Supply chains need to be established for newcomers.
- **Consumer engagement**: Surveys confirm that consumers are open to trying NIS when assured of quality and ecological benefits (Sidiropoulou *et al.*, 2024). Marketing campaigns and media exposure (e.g., cooking shows) can reduce stigma and attract new demand (Kleitou *et al.*, 2019b).

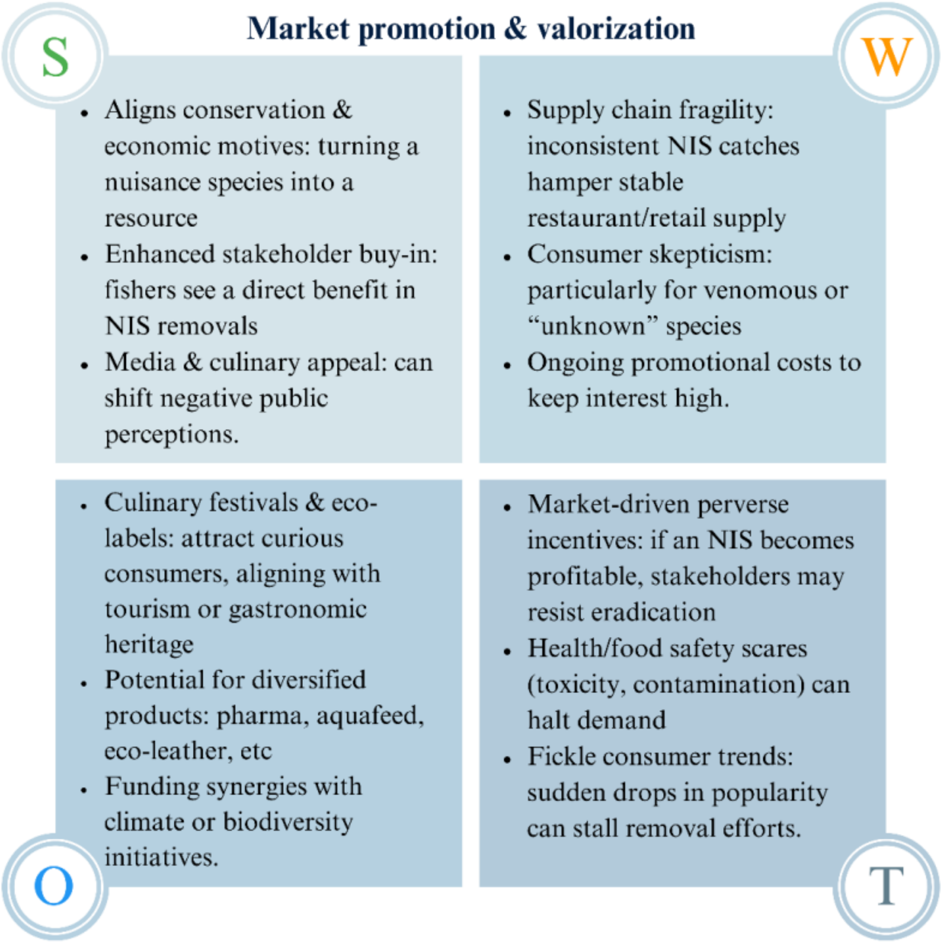


Figure 12. Strengths, Weaknesses, Opportunities, and Threats for "market promotion & valorisation" measures for non-indigenous species control.

Interlink with other measures

Market and valorisation efforts reinforce spatial removal campaigns (Chapter 3.3.6), encouraging targeted and/or sustainable fishing, and they benefit from ongoing monitoring (Chapter 3.3.10) to prevent population rebounds. They also require stakeholder engagement (Chapter 3.3.5) to maintain high compliance and to integrate market solutions with broader ecosystem-based strategies.

HIGHLIGHT CASE STUDY
Transforming an Invasive Pufferfish into Eco-Friendly Leather in Southern Turkey

The poisonous pufferfishes (family Tetraodontidae), especially the silver-cheeked toadfish (*Lagocephalus sceleratus*), has become an increasing concern for Mediterranean fisheries, posing what can be described as an unfair battle due to its rapid spread, high toxicity, lack of commercial value, and strong negative impacts on fishery gears, catches, and native biodiversity. In February 2022, with support from the UNDP Ocean Innovation Challenge, Mersea Consulting launched a pioneering initiative to harness the skins of pufferfish for leather production—turning a harmful invasive species into a valuable commodity while empowering local communities.

By working exclusively with small-scale fishers in southern Turkey, the initiative created the area's only pufferfish fishery dedicated to collecting skins for eco-friendly textiles. Fishers received training on safe handling methods and were provided with deep freezers to ensure high-quality preservation of the catch. Through dedicated research and development, Mersea Consulting perfected a tanning process that highlights the fish's distinct, natural patterns, and ensured that the resulting leather meets stringent EU standards.

A design studio was then established at Mersea Consulting's office, where two women from marginalized backgrounds were trained by leather experts over a 12-week period. Their handcrafted pufferfish leather products quickly garnered interest, leading to the launch of an international sales website in June 2023. The focus for 2024 is to expand brand recognition and build high-end collaborations within the European fashion industry. To reinforce the product's connection to European markets, the brand underwent a rebranding in January 2025, changing its name from "Olta Azul" to "Le Puffer." By providing alternative livelihoods for coastal fishers, engaging local women in craft production, and removing a destructive fish from the ecosystem, the project illustrates a holistic and innovative approach to promoting biodiversity protection, community empowerment, and a new eco-friendly textile line within the global fashion market

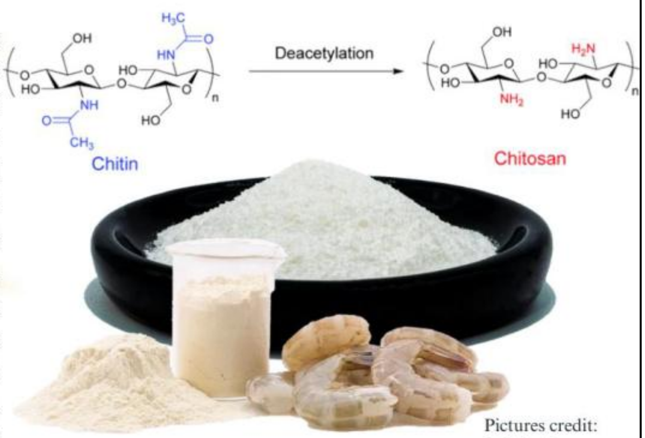
Pictures credit:

References and sources:

- https://pufferfishleather.com/ (accessed 19/01/2025)

HIGHLIGHT CASE STUDY
CHITELIX: Transforming Marine By-products Into High-Value Biotech Solutions

CHITELIX is an innovative biotechnology startup specializing in the valorization of marine byproducts, with a particular focus on chitin and chitosan extraction for advanced applications in health, agriculture, and environmental sustainability. Founded by Anis Ben Ghalia and Kais Aouaieb, CHITELIX was established with the mission of converting seafood waste into high-value, sustainable bioproducts, thereby promoting a circular economy in the marine sector. The startup operates in Tunisia at the Technopôle Alimentaire de Bizerte, with a presence at Startup Village, Tunis, and is currently exploring expansion opportunities in new markets.



Pictures credit:
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The journey of CHITELIX began with rigorous R&D, market research, and raw material validation. By securing early-stage research contracts, they established a proof of concept that paved the way for their initial funding round. In 2023, they achieved a significant milestone by raising $1.3 million USD in pre-seed funding to kickstart the industrial-scale production of their bioproducts.

CHITELIX operates at the intersection of biotechnology and environmental sustainability, developing eco-friendly biomaterials derived from marine resources. Their primary expertise lies in chitin and chitosan extraction, which have broad applications in:

- Biomedical research: Drug delivery systems, wound healing, and tissue engineering.
- Agriculture: Biofertilizers and biopesticides to support sustainable farming.
- Foodand packaging: Natural preservatives and biodegradable packaging alternatives.
- Water treatment: Biopolymers for heavy metal and pollutant removal.

In 2024, they are set to complete the setup of their main factory and begin the acquisition of crucial production equipment. This strategic expansion will enable them to start production and focus on product development and optimization by 2025, with aims to broaden their market reach internationally.

One of their key projects involved the commercialization of the invasive Blue Swimming Crab (Portunus segnis). Instead of treating this species solely as an ecological threat, they developed a processing value chain, creating a sustainable industry around crab-derived bioproducts, including chitin and chitosan extraction. This initiative aligns with CHITELIX's commitment to transforming marine waste into valuable resources, reducing environmental impact, and fostering economic development.

3.3.4 Education & public awareness

Rationale & key insights

Education and public awareness are repeatedly cited as among the most critical measures for reducing new introductions of NIS and mitigating their spread and impacts (Giakoumi *et al.*, 2019a; Azzurro *et al.*, 2024a):

1. **Support** necessary management interventions (e.g., targeted removals, biosecurity measures),
2. **Adopt** safe handling practices for venomous/toxic species,
3. **Avoid** actions that enable NIS spread (e.g., casual aquarium releases, improper hull maintenance, disposal of live bait).

Empirical evidence shows that **effective educational campaigns** also enhance early detection (via citizen science), increase acceptance of control measures, and facilitate broader stakeholder engagement (Seekamp *et al.*, 2016; Kleitou *et al.*, 2019b). Informed citizens and stakeholders are more likely to support necessary management interventions, practice safe handling of venomous or toxic species, and adopt preventative behaviours that reduce new introductions (e.g., boat/hull maintenance, aquarium releases or careless disposal of live bait) (Seekamp *et al.*, 2016; Kleitou *et al.*, 2019b). Effective educational campaigns can also encourage early detection, promote community-driven monitoring, and improve overall acceptance of control measures such as targeted removals or market-based valorisation.

Evidence from published documents

While many studies focus on market or biotechnological approaches to NIS management, education remains a **cornerstone** of success:

- **Consumer attitudes:** In Greece, people's willingness to purchase and consume edible NIS (e.g., rabbitfish, lionfish) correlates strongly with perceived ecological benefits and food safety assurances (Minasidis *et al.*, 2023; Sidiropoulou *et al.*, 2024). Campaigns emphasizing both the **sustainability** and **gastronomic** potential of these species can promote acceptance, thereby aiding targeted removals (Kleitou *et al.*, 2022a; Marchessaux *et al.*, 2024a).
- **Community-focused efforts:** In Tunisia, localized campaigns on the blue crab (*Callinectes sapidus*) clarified its commercial value and proper handling, reducing discard rates and reshaping public perceptions (Rifi *et al.*, 2023). Meanwhile, volunteer-based programs in Cyprus showed that divers who participated in coordinated lionfish removals gained a stronger sense of environmental responsibility and remained active in monitoring (Kleitou *et al.*, 2021c).
- **Preventing inadvertent introductions:** A lack of awareness is frequently identified as a key driver of accidental NIS releases (Carreño & Lloret, 2021). Leisure boats, for instance, spread hitchhiking species via hull fouling or propellers, while aquarium hobbyists may unknowingly release "reef janitors" (Calado, 2012). Clear, consistent messaging about the distinctions between venomous vs. poisonous species can also prevent misunderstandings that undermine public safety or hamper control actions (Kleitou *et al.*, 2022b; Frem *et al.*, 2024).

Ultimately, **education** is essential for dispelling misconceptions, fostering a sense of local stewardship, and creating social norms that discourage behaviours enabling NIS spread.

Illustrative examples from Case Studies

Below are a few **selected examples** showing how market promotion has been tested:

- Pick the Alien & FishtheAlien (Expert Case Studies #1, #5)

These initiatives organized culinary events (e.g., cooking demos, tastings) featuring lionfish, rabbitfish, or blue crabs. Participants learned how to safely prepare and consume these species, helping to shift negative perceptions (Kleitou *et al.*, 2019b).

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These and similar endeavours demonstrate the **potential** of market-based valorisation to engage local communities, fishers, and entrepreneurs. However, they also highlight **challenges** like fluctuating supply, product novelty, and the need for continuous promotion.

Critical Insights from Case Studies & literature

- **Balancing profit & conservation:** High market value can risk **sustaining** an invader if eradication jeopardizes incomes (Kourantidou & Kaiser, 2024). Clear management objectives, e.g., capping or functionally eradicating populations, should remain primary.
- **Supply chain & safety:** For venomous or toxic species (lionfish, pufferfish), strict **handling protocols, labeling, and public awareness** are crucial for consistent market acceptance (Minasidis *et al.*, 2023).
- **Consumer engagement**: Surveys confirm that consumers are open to trying NIS when **assured of quality and ecological benefits** (Sidiropoulou *et al.*, 2024). Marketing campaigns and media exposure (e.g., cooking shows) can reduce stigma and attract new demand (Kleitou *et al.*, 2019b).

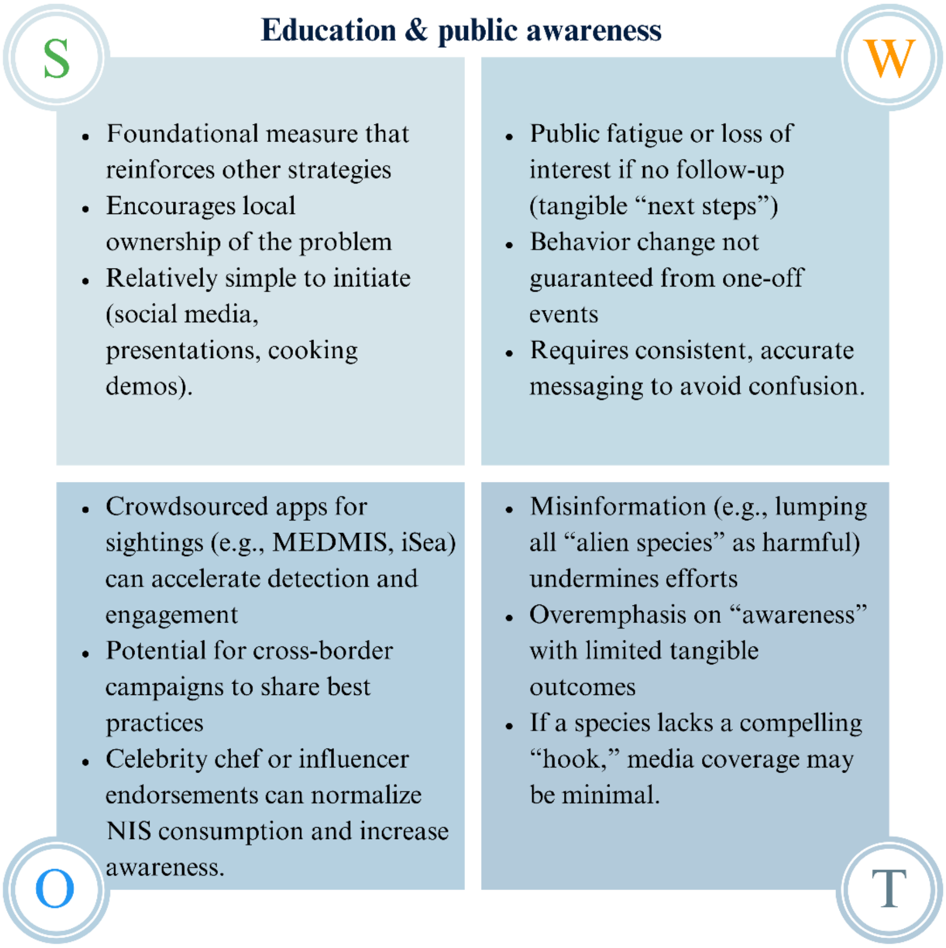


Figure 13. Strengths, Weaknesses, Opportunities, and Threats for "education & public awareness" measures for non-indigenous species control.

Interlink with other measures

Education and public awareness underpin nearly all other NIS management strategies. By informing stakeholders about the ecological value of rapid-response measures (Chapter 3.3.6), education facilitates timely removal campaigns and fosters willingness to collaborate with authorities on biosecurity measures (Chapter 3.3.11). It also complements market promotion (Chapter 3.3.3) by helping to dispel misconceptions around the safety and quality of edible NIS, thereby driving consumer demand for invasive species and supporting local livelihoods. Ultimately, an educated public forms the backbone of any robust, adaptive strategy for controlling NIS in the Mediterranean and beyond.

HIGHLIGHT CASE STUDY
Pick the Alien: Promoting Edible Invasive Species for Sustainable Seafood in Greece

Pick the Alien began in 2019 as a major community-based project to encourage Greek fishers, fishmongers, restaurants, and consumers to embrace edible invasive species in their diets. Over time, the project has grown into a broader initiative that addresses the urgent need to protect native marine ecosystems and replace overexploited commercial fish stocks. By highlighting edible NIS, the project helps safeguard traditional fisheries while providing new income opportunities for local communities.

From its early days, Pick the Alien has run a series of events and outreach campaigns to raise public awareness. Gastronomic festivals, food carts promoting the consumption of NIS, culinary workshops, cooking demonstrations on television shows like MasterChef, and social media campaigns have collectively reached more than 1.6 million consumers.

Innovative fishing trials, including the use of modified (Gittings) traps to target invasive lionfish, were tested with over 120 small-scale fishers across Greece.

Meanwhile, more than 50 chefs and 120 restaurants took part in culinary showcases to demonstrate the flavours and versatility of invasive species in local cuisine. More than 8,000 people attended gastronomic and culinary events.

Through these combined actions, spanning gastronomic events, educational platforms, and collaborations with fishers in Greece, Italy, and Cyprus, Pick the Alien has successfully promoted responsible seafood consumption. Lessons learned are now guiding the next steps and plans with a mission to create a dynamic network of stakeholders that further strengthens the market for edible alien species, supporting healthier marine ecosystems and empowering local communities.

Pictures credit:

References and sources:

- https://isea.com.gr/pick-the-alien-eng/?lang=en (accessed 19/01/2025)
- Sidiropoulou, N., Doumpas, N., Perrakis, E., Tsianis, D., Giovos, I., & Moutopoulos, D. K. (2024). Investigating Consumer Attitudes and Market Trading of Edible Marine Invasive Alien Species in the Greek Seafood Market. Sustainability, 16(19), 8479.

3.3.5 Stakeholder engagement

Rationale & key insights

Stakeholder engagement is recognized as a cornerstone of **effective and adaptive management** of NIS, especially in complex coastal and marine systems that involve multiple user groups (e.g., fishers, aquaculture operators, shippers, tourism entrepreneurs, conservationists, local communities) (Cerri *et al.*, 2020; Di Cintio *et al.*, 2023; de Carvalho-Souza *et al.*, 2024). By **involving stakeholders** early in decision-making, managers can:

- Align ecological goals (e.g., limiting NIS spread) with **socio-economic priorities,**
- Enhance community **acceptance** of regulations and controls,
- Draw on **local knowledge** (e.g., fishers' expertise) to improve prevention, early detection, monitoring, and targeted removals (Otero *et al.*, 2013; Moon *et al.*, 2015).

Collaborative governance approaches, like **co-management committees, participatory forums**, and **consensus-building** processes, have proven invaluable in **anticipating disagreements** or conflicts (Crowley *et al.*, 2017). Such structures allow stakeholders to shape context-specific strategies that distribute responsibilities and benefits fairly, especially when NIS present both threats (gear damage, habitat degradation) and opportunities (new fisheries) (Vimercati *et al.*, 2020; Katsanevakis *et al.*, 2024). Collaborations ultimately yield to more pragmatic and socially accepted management action (Ojaveer *et al.*, 2014).

Evidence from published documents

- Engagement in Mediterranean contexts
  - In the Pelagic Islands MPA, Italy, local fishers and divers shared local ecological knowledge about NIS occurrences, later validated by targeted sampling (Maggio *et al.*, 2022). Such community-driven data collection enhanced overall monitoring.
  - Trained divers in Italy have documented over 24,000 observations (2006–2014), many focusing on the spread of *Caulerpa cylindracea* (Cerrano *et al.*, 2017). Their involvement spurred more pragmatic and socially accepted management action (Ojaveer *et al.*, 2014).
  - In Cyprus, citizen scientists participated in monitoring the effectiveness of lionfish (*Pterois miles*) removals within MPAs (Kleitou *et al.*, 2021c; Savva *et al.*, 2024). Sharing these results among fishers, divers, and conservationists helped build trust and refine removal methods over time.
- Conflicts and resolutions
  - Conflicts sometimes emerge when NIS have both detrimental and beneficial impacts, e.g., fishers see potential income from harvesting lionfish or pufferfish, while conservation groups remain apprehensive about ecological harm (Kleitou *et al.*, 2022b). Nevertheless, adaptive management processes, facilitated dialogues, and transparent information-sharing can reconcile or mitigate these controversies (Novoa *et al.*, 2018).

Illustrative examples from Case Studies

The following selected examples highlight how broad stakeholder collaboration and coordinated response mechanisms, including clear mandates, rapid mobilization of resources, and stakeholders forums, can drive more decisive and rapid outcomes:

- Darwin Harbor, Australia (Literature Case Study #13).

Mytilopsis sallei (an invasive bivalve) was eradicated in ~42 days through a fast quarantine, chemical treatments, and open communication with marina operators

- California's *Caulerpa taxifolia* (Literature Case Study #1).

Eradication was achieved within ~17 days of detection, attributed to multi-agency synergy and the legal empowerment to quickly isolate affected sites (Literature Case Study #1).

- PROMETHEUS Project (Mediterranean) (Expert Case Study #2)

Brings together fishers, chefs, and conservationists to adapt fishing gear that reduces bycatch of sensitive elasmobranchs while also harvesting invasive crabs or lionfish. Mutual benefits (protecting native species, exploring new markets) solidify stakeholder buy-in.

<u>Critical Insights from Case Studies & literature</u>

- **Fast, coordinated response:** Legal or policy frameworks that empower agencies to close harbours, mobilize funds, or standardize gear can accelerate containment or eradication. Delays often occur if authorities must first navigate protracted stakeholder negotiations in the face of an active NIS threat (Giakoumi *et al.*, 2016).
- **Shared costs & buy-in:** Stakeholders, particularly fishers, are more willing to collaborate if they see direct benefits, like receiving gear subsidies to catch NIS or tapping new markets (de Carvalho-Souza *et al.*, 2024). Distributing responsibilities and rewards fairly reduces resentment and fosters long-term commitment.
- **Conflicting agendas:** Some stakeholders may favour commercializing a profitable NIS (e.g., lionfish), while others advocate strict eradication for ecological reasons. Transparent, science-based information and ongoing dialogue help bridge these divides and can yield compromise solutions (Novoa *et al.*, 2018).
- **Maintaining momentum:** Sustaining engagement requires regular communication and result-sharing. Political changes or funding cuts can stall multi-year programs, risking stakeholder fatigue or distrust (Cerri *et al.*, 2020).

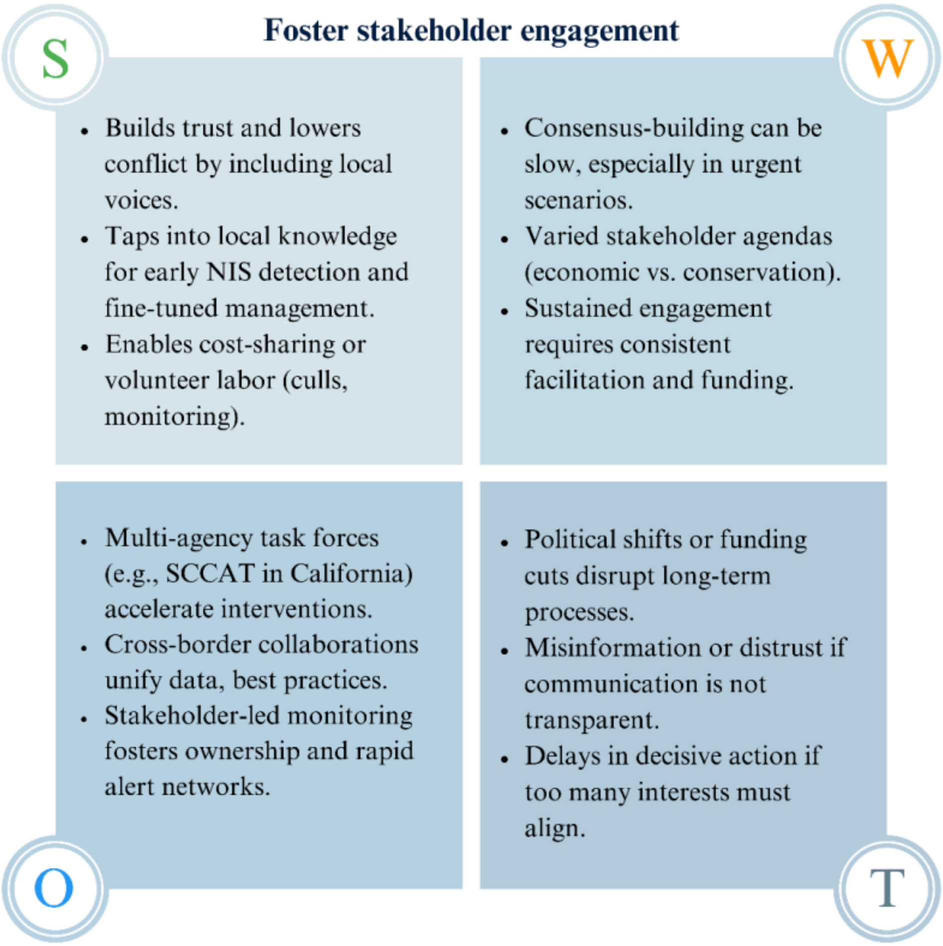


Figure 14. Strengths, Weaknesses, Opportunities, and Threats for "stakeholder engagement" measures for non-indigenous species control.

Interlink with other measures

Robust stakeholder engagement undergirds other NIS strategies by improving data reporting for Monitoring & Risk Assessment (Chapter 3.3.10), sustaining volunteer-based Targeted Removals (Chapter 3.3.6), encouraging buy-in for Market Valorisation (Chapter 3.3.3), and enhancing support for Biosecurity Measures (Chapter 3.3.11). Meaningful participation ensures that local insights, resource constraints, and potential socioeconomic trade-offs are recognized early, allowing for dynamic adjustments of management actions.

HIGHLIGHT CASE STUDY

Blueat: Addressing the Invasive Blue Crab Through the Development of Supply Chains and Novel Products

Blueat grew out of a practical need to address the impacts of alien species on the Mediterranean, especially the highly invasive blue crab (*Callinectes sapidus*). Conversations with fishers along the Italian coast revealed how climate change and the spread of alien species disrupt native biodiversity and harm local economies. Recognizing both a challenge and an opportunity, the team behind Blueat — Mariscadoras Srl Benefit — consists of five young women committed to turning these species, especially the blue crab, from a problem into an opportunity. Their goal is to reduce environmental impacts on marine ecosystems while promoting the culinary potential of these crabs.

Blueat has developed a supply chain for the blue crab, involving partnerships with fishers' cooperatives, fish market managers, local processing companies, and distributors in the HORECA, GDO, and international B2B sectors. This initiative has allowed the introduction of products such as crab meatballs, sauces, and creams into supermarkets and restaurants, with exports primarily to the United States and South Korea. The project aligns with Agenda 2030's Goal 5 by promoting gender equality in the traditionally male-dominated fishing industry. The name "Mariscadoras" honors the Galician women who have long fought for equal rights in the maritime sector. Despite challenges, including gender bias and the difficulty of altering Italian culinary traditions, Blueat has successfully shifted market demand from traditional seafood to alien species, benefiting the environment, local fisheries, and coastal tourism.

Blueat's circular economy initiative aims to minimize waste by using blue crab by-products to create biodegradable packaging and extract chitosan for pharmaceutical applications. The project has garnered several international awards and recognition in prominent publications like National Geographic and The New York Times. As of 2023, Blueat achieved €500,000 in revenue by processing 162,000 kg of blue crab. By 2024, this figure rose to €1.5 million, with a target of doubling or tripling production volumes. Having reached its initial goals, the project now focuses on developing a robust by-product supply chain to ensure full resource utilization and further environmental sustainability.

References and sources:

- https://www.blueat.eu/ (accessed 19/01/2025)

Pictures credit:

Targeted spearfishing by free divers has been proved effective in suppressing lionfish populations. As a diver surfaces with a speared lionfish off Akrotiri, Limassol, Cyprus, it's crucial to exercise caution to avoid the venomous spines.

Photo credits: © Christoph Gerigk / GEO, All Rights Reserved

3.3.6 Implement spatial control – targeted removals

Rationale & key insights

Spatially targeted removals of NIS, such as in MPAs, nursery habitats, or other high-value locations, are widely recognized as a key strategy for **limiting local densities** of invasive organisms and slowing regional spread. These programs often involve **seasonal or recurrent** removal campaigns, timed to precede reproductive peaks and thus reduce recruitment (Rousou *et al.*, 2014; Marchessaux *et al.*, 2023a; Marchessaux *et al.*, 2024b).

Although complete eradication of well-established NIS in open marine systems is typically unfeasible, local-scale suppression can lessen ecological damage in **sensitive or priority zones** and "buy time" for complementary interventions (Savva *et al.*, 2024). In some cases, **bounties or market incentives** encourage fishers to harvest problematic invaders, though managers must guard against **perverse incentives** if an NIS becomes profitable (Kourantidou & Kaiser, 2024).

Evidence from published documents

- **Targeted removals of invasive species (lionfish, and long-spined sea urchin) in Cyprus:** Organized removal efforts with divers were found able to significantly restrict local populations of lionfish (*Pterois miles*) at priority sites while engaging and educating the public (Kleitou *et al.*, 2021c; Kleitou *et al.*, 2024; Savva *et al.*, 2024). The long-spined sea urchin (*Diadema setosum*) removals have been very effective, with low recolonization (population recovery) observed (Huseyinoglu *et al.*, 2024).
- **Bounty program for pufferfish:** In addition, the Cyprus government compensates fishers (€3–5/individual or kg) for pufferfish, leading to catches surpassing 500/day in peak season (Rousou *et al.*, 2014) (Rousou *et al.*, 2014). Türkiye offers a lower compensation which has not been considered attractive (~0.26 USD in 2020, raised to 0.65 USD in 2022); yet adaptations to fishing techniques and gears (steel branch lines, swivel hooks) were recommended to double the catches of *L. sceleratus* (Ersönmez *et al.*, 2023).
- **Mechanical & diver-led removals of seaweeds:** Invasive macroalgae (e.g., *Caulerpa racemosa var. cylindracea, Caulerpa taxifolia*) have been targeted through mechanical and diver-led removals before seasonal expansions, yielding partial or temporary recovery of native communities (Klein & Verlaque, 2011; Bulleri *et al.*, 2016).
- **Feasibility & functional eradication:** Eradication is generally unfeasible unless invasions are detected very early. For instance eradication of established *Caulerpa taxifolia* was considered unfeasible, requiring, for instance, a combined strategy, incorporating 99% removal of all fragments and annual removal of 99% of established patches (Ruesink & Collado-Vides, 2006). Consequently, functional eradication could be suggested to achieve levels where ecological damages are at least mitigated (Green & Grosholz, 2021).
- **Pristine vs. disturbed Areas:** Removals might be more effective in less disturbed habitats (Bulleri *et al.*, 2016). In heavily human-impacted regions, repeated colonization, pollution, and overfishing may undermine the benefits of removal campaigns (Klein & Verlaque, 2011; Diga *et al.*, 2023)
- **Detecting intricate dynamics and positive ecosystem outcomes:** Studies have sometimes struggled to document clear benefits of removal on surrounding communities due to the intricate dynamics of marine ecosystems and multiple anthropogenic stressors (Klein & Verlaque, 2011; Bulleri *et al.*, 2016; Diga *et al.*, 2023). For instance, removals might be more effective in less disturbed habitats (Bulleri *et al.*, 2016). Context-specific investigations are vital to assess potential effects on other native and NIS, as well as possible evolutionary responses of the targeted invaders (behaviour shifts, hyper-fecundity, life-history changes). Long-term monitoring, ideally initiated before invasions occur, can yield deeper insights into the ecological consequences of removals (García-Barón *et al.*, 2021; Kleitou *et al.*, 2021b)

Since 2012, Cyprus has enacted a comprehensive management plan, financed by national and European resources, aimed at controlling the invasive silver-cheeked toadfish (*Lagocephalus sceleratus*). The plan empowers the local professional fishing fleet to intensively fish and eliminate this species, with a subsidy mechanism in place to cover the operational costs and damages incurred. Approximately 500 tons of toadfish have been successfully eradicated under this initiative (DFMR, personal communication). Although conclusive data on the overall effectiveness of the plan is still pending, its preliminary success in mitigating economic losses to fisheries has encouraged the continuation of these measures (DFMR, personal communication).

Illustrative examples from Case Studies

Below are selected—not exhaustive—examples where local removal campaigns yielded significant outcomes:

- Cyprus MPAs (Expert Case Study #3)

Diver-led lionfish *(Pterois miles)* removals reduced densities in priority sites within an MPA, while educating participants about NIS.

- California's *Caulerpa taxifolia* (Literature Case Study #1)

Early detection and chlorine injections under tarps eradicated the species (~17 days).

- Darwin Harbor's *Mytilopsis sallei* (Literature Case Study #13)

Rapid quarantine and chemical treatments cleared the invasive bivalve in ~42 days, preventing regional spread.

Critical Insights from Case Studies & literature

- **Reinvasion & rebound:** Local culls face repeated inflows from nearby uncontrolled populations, requiring ongoing removal campaigns (Ruesink & Collado-Vides, 2006; Michailidis *et al.*, 2023).
- **High cost & labor:** Repeated mechanical, diver-based, or chemical interventions are often resource-intensive, relying on volunteer engagement, fisheries involvement, or external funding (Bulleri *et al.*, 2016).
- **Potential non-target effects:** Broad chemical or mechanical treatments can harm native fauna/flora if not carefully contained (Klein & Verlaque, 2011).
- **Importance of monitoring & timing:** Identifying invasion hotspots and scheduling removals to precede reproductive peaks can maximize cost-effectiveness (Marchessaux *et al.*, 2024b). Early detection also greatly increases the likelihood of eradication success (California's Caulerpa case; Darwin Harbor's Mytilopsis).

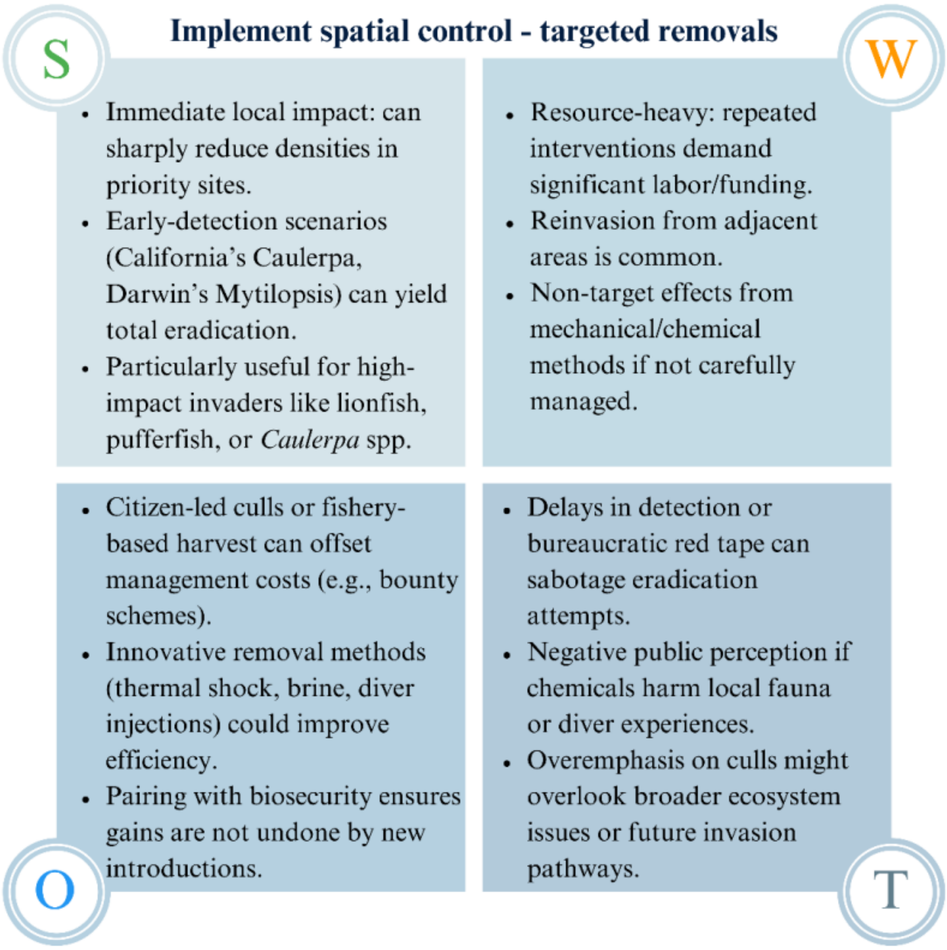


Figure 15. Strengths, Weaknesses, Opportunities, and Threats for "spatial control – targeted removal" measures for non-indigenous species control.

Interlink with other measures

Local removal initiatives require robust Monitoring & Risk Assessment (Chapter 3.3.10) to identify invasion hotspots and effective removal timings. They also benefit from Stakeholder Engagement (Chapter 3.3.5), as consistent volunteer participation or fisher collaboration can make sustained removals feasible. Where edible invasives are subject to Market Valorisation (Chapter 3.3.3), targeted removals can dovetail with economic incentives, and synergy with Biosecurity Measures (Chapter 3.3.11) helps avert reintroductions from adjacent vectors and pathways.

HIGHLIGHT CASE STUDY
RELIONMED: Targeted Removals and Community Engagement to Control Lionfish in the Mediterranean

The EU-funded RELIONMED-LIFE project in Cyprus provided a valuable demonstration of how targeted removals and community engagement can help control lionfish (Pterois miles) in the Mediterranean. Drawing on lessons from the western Atlantic, the project trained volunteer divers, fishers, and established "Removal Action Teams" to systematically remove lionfish from small, high-conservation sites (less than half a hectare), as well as larger areas through single-day "lionfish derbies." Research showed that repeated removals on small patches significantly reduced lionfish abundance over time, while derbies across broader areas lowered lionfish numbers by up to 50%, particularly removing the larger (over 30 cm) individuals.

Citizen participation proved crucial. Volunteers contributed data via surveys and apps, allowing managers to track lionfish presence, plan removal events, and coordinate efforts with fishers and other stakeholders. These citizen science contributions were not only effective at guiding when and where to remove lionfish, but they also helped foster a sense of stewardship and increased public awareness. Many volunteer divers reported feeling more motivated to support marine conservation and were even willing to pay extra costs involved in lionfish removal efforts.

Targeted lionfish removals were most effective when repeated routinely, but the project also recognized that isolated efforts cannot contain the invasion entirely. Continued monitoring of lionfish populations and sustained community involvement are necessary to maintain low densities, especially in warmer months when lionfish reproduce more rapidly. On the economic front, RELIONMED encouraged new market pathways for lionfish, highlighting their value as both a food item and a resource for by-products like jewelry. This synergy of science, citizen engagement, and market incentives offers a promising strategy for other Mediterranean regions facing similar invasive species challenges.

Pictures credit:

References and sources:

- Kleitou, P., Rees, S. E., Kletou, D., Harris, H. E., Cai, L. L., Green, S., ... & Hall-Spencer, J. M. (2024). Marine protected areas can increase the abundance of invasive lionfish (Pterois miles). Conservation Science and Practice, e13147.
- Savva, I., Cai, L. L., Kleitou, P., Hadjioannou, L., Jimenez, C., Karonias, A., ... & Kletou, D. (2024). An underwater clash of spears: Public engagement in Mediterranean lionfish control efforts. Aquatic Conservation: Marine and Freshwater Ecosystems, 34(2), e4104.
- Kleitou, P., Hall-Spencer, J., Rees, S., & Kletou, D. (2022). Guide to lionfish management in the Mediterranean. University of Plymouth.
- Kleitou, P., Rees, S., Cecconi, F., Kletou, D., Savva, I., Cai, L. L., & Hall-Spencer, J. M. (2021). Regular monitoring and targeted removals can control lionfish in Mediterranean Marine Protected Areas. Aquatic Conservation: Marine and Freshwater Ecosystems, 31(10), 2870-2882.

3.3.7 Implement biological control

Rationale & key insights

Biological control in marine environments typically relies on **restoring or protecting native predators** to foster "biotic resistance" against invasive species, rather than introducing novel control agents risks (Giakoumi *et al.*, 2019a). Healthy predator populations can help stabilize food webs and suppress invaders via direct consumption, disrupted life cycles, or competition. This **aligns with ecosystem-based management principles**, which emphasize simultaneous reductions in stressors like overfishing and habitat degradation to bolster native species (Corrales *et al.*, 2018; Dimitriadis *et al.*, 2024). However, outcomes are difficult to predict, given the open, multi-stressor nature of marine ecosystems (Dimitriadis *et al.*, 2021).

Evidence from published documents

- **Native predators in Mediterranean MPAs:** In certain MPAs, scientists have documented groupers and other top predators preying on invasive fish—e.g., lionfish (*Pterois miles*) and pufferfish (*Lagocephalus sceleratus*)—though such effects are often localized or seasonal (Kleitou *et al.*, 2018; Crocetta *et al.*, 2021; Ulman *et al.*, 2021).
- **Partial control of herbivorous NIS:** For rabbitfish (*Siganus luridus* and *S. rivulatus*), predators were found to consume it even in areas where the species are not established yet indicating that partial predation by large carnivores can slow their expansion if no-take regulations allow predator stocks to recover (Giakoumi *et al.*, 2019c). Similarly, native crabs (e.g., *Carcinus aestuarii*) can prey on invasive bivalves like *Musculista senhousia*, providing low-level suppression (Mistri, 2004). Many native herbivorous fish also consume invasive seaweeds populations (Tomás *et al.*, 2011; Santamaría *et al.*, 2021).
- **Limitations of biotic resistance:** Some studies report limited predator-driven control—e.g., lionfish densities remain problematic in certain MPAs (Ulman *et al.*, 2021; Tamburini *et al.*, 2022). Additionally, the dramatic decline of apex predators through overfishing severely weakens their capacity to suppress invaders (Kimbro *et al.*, 2013).
- **Risk of introducing new agents:** Introducing non-native biocontrol agents (e.g., parasites, specialized predators) can lead to new invasions or off-target impacts in open marine systems, so managers generally focus on restoring native predator assemblages instead (Giakoumi *et al.*, 2019a).

Illustrative examples from Case Studies

The following examples highlight biological control efforts in marine systems; not all are Mediterranean, but they illustrate broader approaches.

- Hawaii's *Kappaphycus sp.* control (Literature Case Study #2)

Using native urchins (*Tripneustes gratilla*) in bounded reef plots was more effective at suppressing *Kappaphycus* spp. than manual removals alone. The urchins grazed the invasive algae, demonstrating how restoring a native grazer can outperform mechanical culling.

- Black Sea jellyfish blooms (Literature Case Study #35)

The accidental arrival of the ctenophore *Beroe ovata* naturally curtailed *Mnemiopsis leidyi* blooms. However, this hinged on a second NIS, underscoring the risks of relying on unplanned or non-native introductions for control.

Critical Insights from Case Studies & literature

- **Open marine dynamics:** Marine ecosystems are **open systems**, so predators may alter diet or migrate, reducing consistent NIS control (Dimitriadis *et al.*, 2021).
- **Overfishing & habitat loss:** The **decline of apex predators** (Kimbro *et al.*, 2013) severely undermines "biotic resistance," making it difficult for marine ecosystems to limit invasions naturally.

- **Balancing risks**: Efforts to **introduce** non-native control agents risk new invasions or unintended impacts (Tamburini *et al.*, 2022). Hence, research generally emphasize **restoring** native species or reducing other stressors (Corrales *et al.*, 2018; Kleitou *et al.*, 2021a).

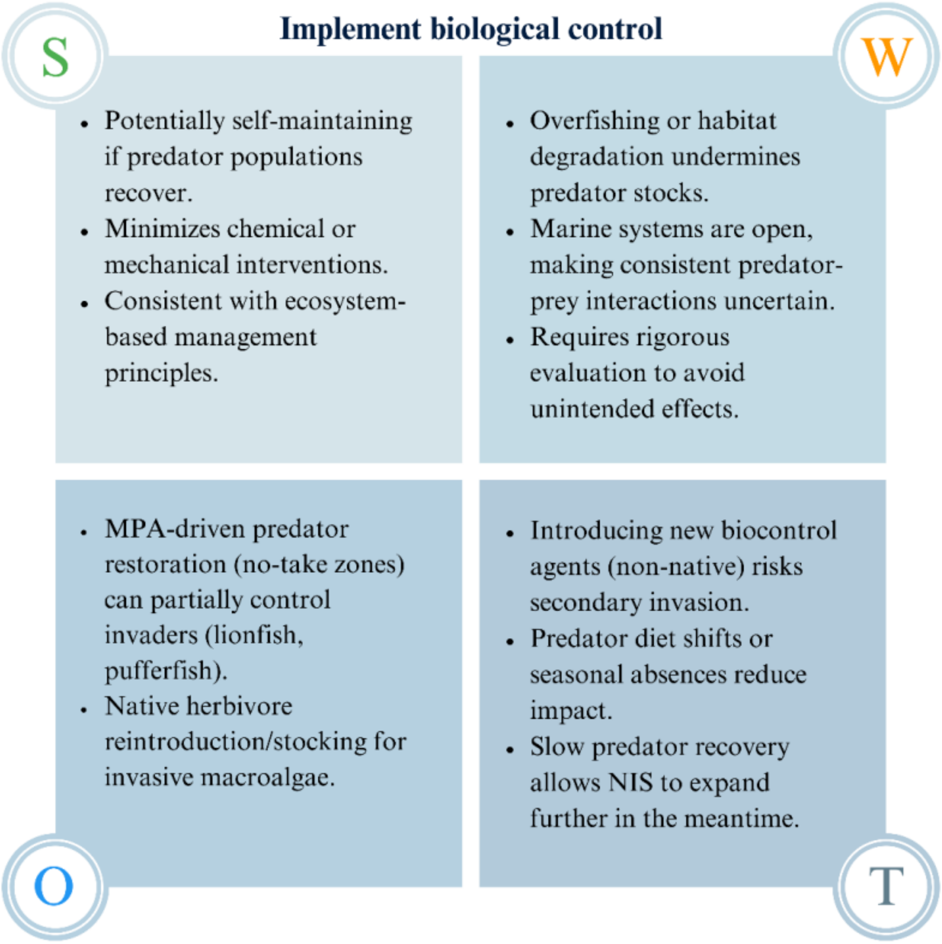
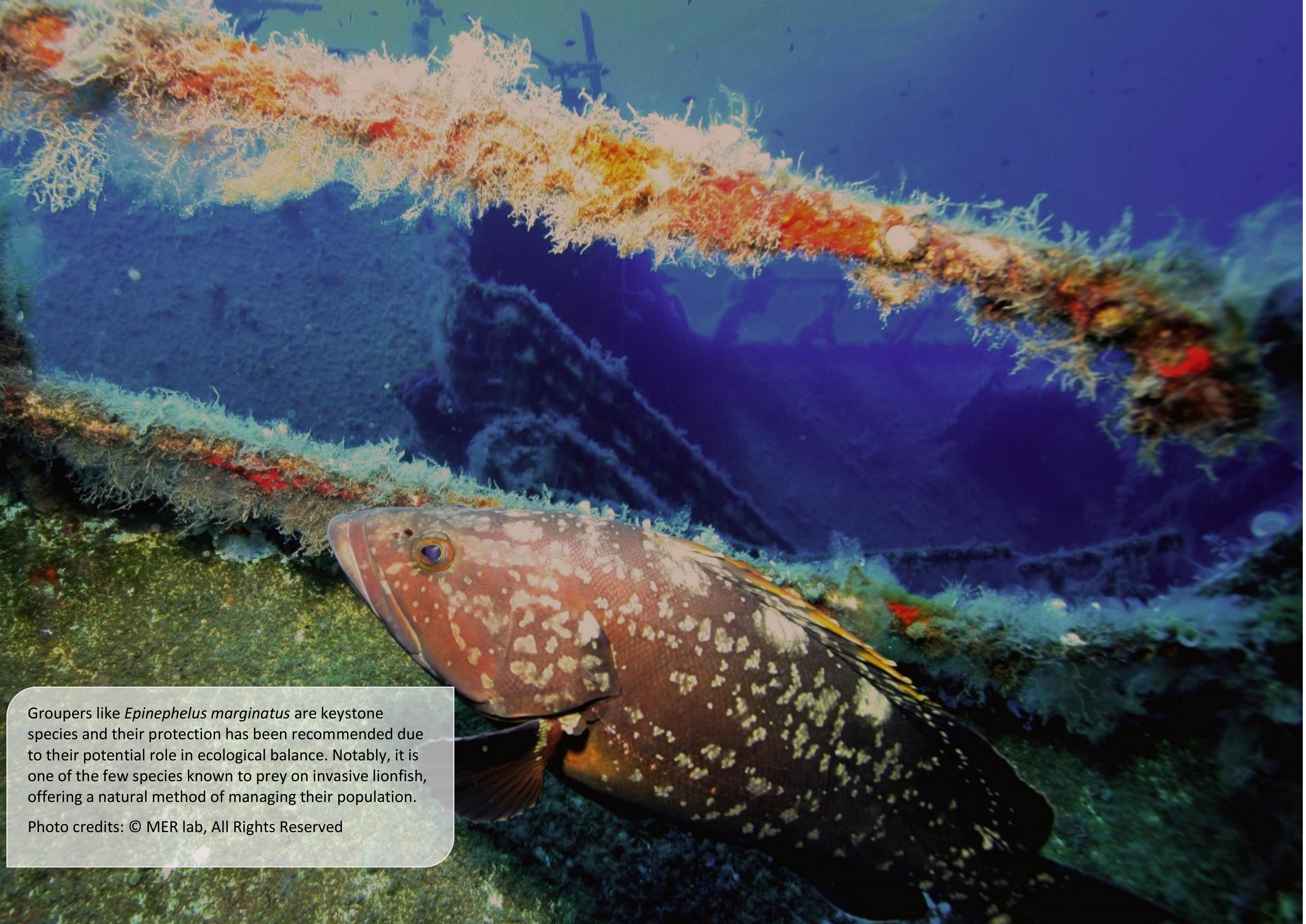


Figure 16. Strengths, Weaknesses, Opportunities, and Threats for "biological control" measures for non-indigenous species control.

Interlink with other measures

Biological control through predator restoration works best when integrated with Ecosystem Restoration (Chapter 3.3.8) that enhances habitat complexity and prey-predator interactions. Monitoring (Chapter 3.3.10) remains crucial to measure predator abundance and detect shifts in NIS populations. Additionally, synergy with Stakeholder Engagement (Chapter 3.3.5) can help ensure that fishing pressure on keystone predators is limited, thus preserving their capacity to suppress invasives.



Groupers like *Epinephelus marginatus* are keystone species and their protection has been recommended due to their potential role in ecological balance. Notably, it is one of the few species known to prey on invasive lionfish, offering a natural method of managing their population.

3.3.8 Restore & protect ecosystems

Rationale & key insights

Ecosystem restoration and protection aim to **strengthen the resilience** of native communities, thereby making habitats less prone to invasive species (NIS) establishment or minimizing their impacts (Stachowicz *et al.*, 2002; Bulleri *et al.*, 2016; Bernardeau-Esteller *et al.*, 2020). Intact seagrass meadows, coralligenous reefs, and other foundational habitats can hamper colonization by **occupying ecological niches**, reducing substrate availability, or supporting robust predator assemblages (Bulleri *et al.*, 2016; Bernardeau-Esteller *et al.*, 2020). However, **local stressors** (pollution, eutrophication, overfishing) and climate change can offset restoration benefits by creating conditions more favourable to certain invasive species (Klein & Verlaque, 2011).

Evidence from published documents

- **Holistic, Ecosystem-Based Management:** Reducing eutrophication, controlling overfishing, and minimizing other anthropogenic pressures often proves essential for effective restoration. Otherwise, **invaders may capitalize** on improved habitat states or vacant niches (Klein & Verlaque, 2011).
- **The role of MPAs:** Ecosystem-based management principles highlight the role of MPAs in fostering adaptive responses to climate change and other stressors, as evidenced by diverse environmental conditions and niches within these protected areas (Katsanevakis *et al.*, 2011; Kleitou *et al.*, 2021a). An example from Gökova Bay, studied between 2013 and 2016, illustrates this point: **apex predator biomass** in several No-Fishing Zones (NFZs) increased dramatically, particularly in No Fishing Zone where it was nearly **25 times higher than in unprotected sites**, leading to a **marked reduction in invasive** herbivorous (*Siganus* spp.) species (Ünal *et al.*, 2019).
- **Risks of MPAs:** Studies indicate that **MPAs alone do not necessarily prevent** the expansion of thermophilic NIS amidst rapid warming and depleted populations of apex predators (Galil, 2017; Giakoumi *et al.*, 2019b; D'Amen & Azzurro, 2020; Dimitriadis *et al.*, 2024; Kleitou *et al.*, 2024). On the other hand, MPAs can also inadvertently promote the **proliferation of NIS** due to the absence of fishing (Giakoumi *et al.*, 2019b; Kleitou *et al.*, 2024). Research is needed to better understand the ecosystem impacts and interactions of NIS proliferation in the MPAs. Moreover, many MPAs, being recently established or still recovering from previous impacts, may not be fully equipped to resist NIS invasions. To enhance their resilience, these areas require **active support through management strategies** that include maintaining robust populations of native predators and targeted removals of invasive species (Kleitou *et al.*, 2021a)
- **Seagrass meadows & macroalgae:** Dense Posidonia *oceanica* meadows often limit the spread of *Caulerpa racemosa var. cylindracea* by restricting light and space for stolons, significantly reducing the alga's biomass (Bernardeau-Esteller *et al.*, 2020). In more degraded or polluted areas, removal of invasive macroalgae has shown limited success due to the lack of native propagules or unsuitable conditions (Bulleri *et al.*, 2016).
- **Coralligenous assemblages under warming:** Coralligenous reefs impacted by rising temperatures show reduced resistance to invasive macroalgae like *Womersleyella setacea* (Cebrian *et al.*, 2012).

Illustrative examples from Case Studies

- Western Japan seaweed replanting (Literature Case Study #39)

Projects that **replant seaweed beds** have been undertaken to counter overgrazing by tropical herbivorous fish expanding into warming waters. While beneficial locally, continued warming and fishing pressure were ongoing challenges.

Critical Insights from Case Studies & literature

- **Holistic measures:** Reducing the **main stressors** (e.g., overfishing, pollution, eutrophication) often underpins successful restoration. Otherwise, a newly restored area can be rapidly invaded or re-invaded (Bulleri *et al.*, 2016; Klein & Verlaque, 2011).
- **Cost & time**: Restoration can be **expensive and slow**, typically requiring multi-year commitments and stable funding (Ponti *et al.*, 2017). Short-term efforts may fail to deliver sustained results.
- **Climate extremes**: Marine heatwaves, storms, or ocean acidification can undermine newly restored habitats, highlighting the importance of **climate-adaptive** restoration strategies (Côté & Darling, 2010).
- **Variable efficacy**: In less-degraded sites, partial or full native recovery is often observed following invasive removal, whereas heavily impacted or polluted areas show limited success (Bulleri *et al.*, 2016).

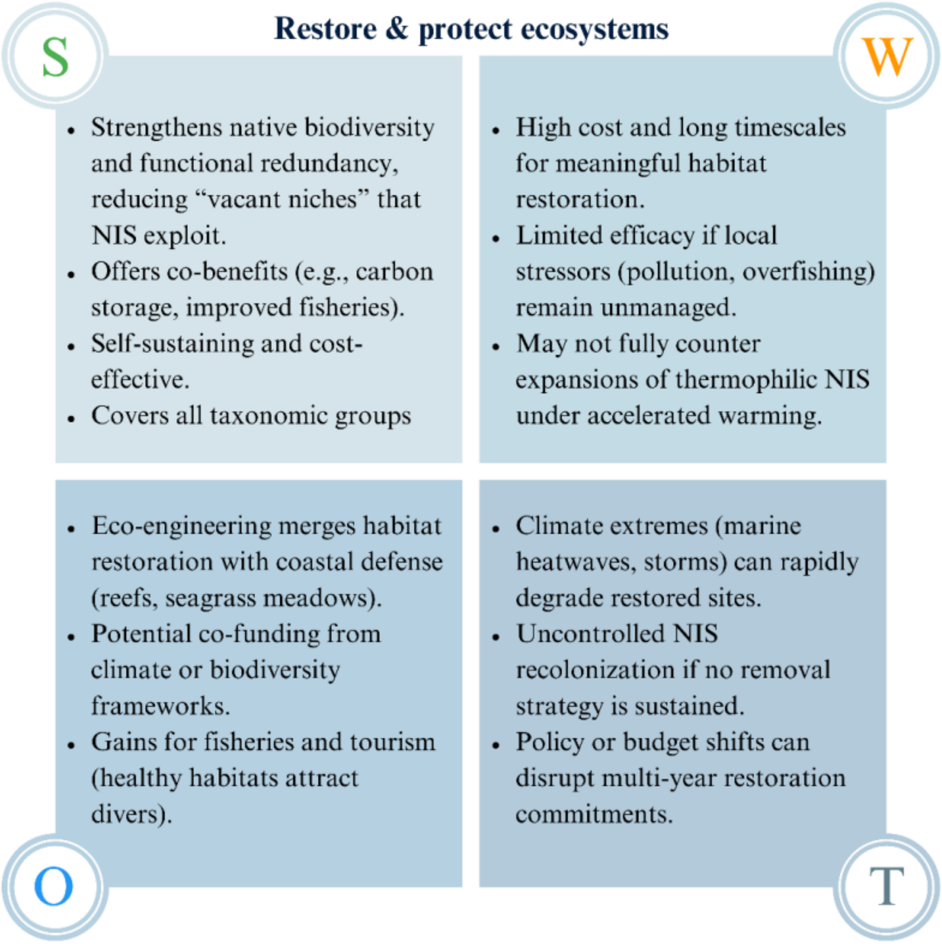


Figure 17. Strengths, Weaknesses, Opportunities, and Threats for "restore & protect ecosystems" measures for non-indigenous species control.

Interlink with other measures

Habitat restoration complements Implement Biological Control (Chapter 3.3.7) by boosting predator recruitment and supporting complex trophic webs. It also synergizes with Targeted Removals (Chapter 3.3.6), since repeated culling of NIS in restored areas can secure long-term positive outcomes. Furthermore, continuous Monitoring (Chapter 3.3.10) helps assess whether restored habitats are resisting new invasions, and Stakeholder Engagement (Chapter 3.3.5) fosters local buy-in for habitat-protection rules.

3.3.9 Do nothing (passive acceptance)

Rationale & key insights

A "**do-nothing" approach, or passive** acceptance, is sometimes adopted when managers conclude that controlling a well-established NIS would be prohibitively expensive, socially unfeasible, or ecologically ineffective (Giakoumi *et al.*, 2019a). Although such inaction may appear rational, it poses several risks. Introductions of novel species can erode ecosystem resilience and heighten the vulnerability of local communities to (irreversible) regime shifts, with undesirable social and ecological impacts (Chaffin *et al.*, 2016). Furthermore, a strict "do-nothing" stance fails to acknowledge cases where NIS have integrated into complex ecological networks and may already underpin certain functions (Kleitou, 2023). In certain contexts, the decision to forego active management is based on the premise that the costs of intervention exceed the perceived risks. However, considering the invaluable nature of aquatic biodiversity and the variable impacts of diverse NIS, ceasing all control or monitoring activities is inadvisable (Tricarico, 2016).

Complete inaction is therefore not recommended: even minimal "do-nothing" cases usually entail ongoing observation, adaptive risk assessment, and (when relevant) exploration of management or market-based opportunities. In cases where a species lacks commercial value, the direct economic incentive for removal is absent, yet targeted research could reveal potential market applications or justify the establishment of a cost-effective monitoring regime for adaptive re-assessment (Azzurro *et al.*, 2024c). When a long-established NIS confers demonstrable ecosystem benefits, such as filling critical ecological niches or augmenting depleted native populations, it is crucial to establish ongoing surveillance and research, integrating this information into a broader, adaptive conservation strategy that may necessitate future interventions (Katsanevakis *et al.*, 2024).

Evidence from published documents

- **Complexity of inaction:** Non-intervention can allow **gradual changes** in community structures, potentially triggering regime shifts with unknown socio-ecological consequences (Chaffin *et al.*, 2016).
- **Actions are always necessary:** Even partial acceptance often involves **basic monitoring** to detect population increases or novel impacts (Tricarico, 2016). Where a species confers certain ecosystem benefits or fills a functional gap, managers may decide not to remove it but remain alert to changes (Kleitou, 2023; Katsanevakis *et al.*, 2024). If an NIS lacks **commercial value**, fishers have no direct incentive to remove it. However, targeted research can reveal potential **market applications** or justify low-cost observation programs.
- **Partial responses:** Coastal communities repeatedly impacted by blooms of the ctenophore *Mnemiopsis leidyi* have sometimes opted to shift fishing calendars and gear specifications to minimize net clogging (Marchessaux *et al.*, 2023c; Piccardi *et al.*, 2024). Similarly, Tunisian fishers have reduced working hours to avoid interacting with dense aggregations of the blue crabs (*P. segnis*) which inflicts gear damage (Souissi *et al.*, 2024). In the eastern Mediterranean, fishers confronting the silver-cheeked toadfish (*Lagocephalus sceleratus*) have relocated fishing operations to deeper waters, abbreviated fishing trips, and modified gear design to sidestep the highly invasive, toxic species (Christidis *et al.*, 2024). Such strategies constitute a "do-nothing" posture with respect to direct NIS removal, yet still reflect a partial response to ongoing invasions. For many taxa, particularly small or cryptic organisms, direct culling is indeed unrealistic. However, monitoring, research, and adaptive scenario-testing are crucial to developing evolving, adaptive, and contextual management strategies.

Illustrative examples from Case Studies

N/A

Critical Insights from Case Studies & literature

- **Minimal immediate cost:** "Doing nothing" avoids short-term expenditures on removal or control but can mask **gradual ecological or economic harm** if the invasion intensifies.
- **Missed early intervention**: Inaction can **forfeit** windows for **rapid response** or local eradication if the species is still at a manageable stage.
- **Potential Pivot:** Monitoring may reveal **new market** opportunities (e.g., emergent demand for edible or industrial uses) or highlight escalating impacts that necessitate a future shift to active control.
- **Functional Acceptance** If a long-established NIS appears to **fill an ecological gap** or has become integral to current ecosystems, managers might decide to integrate it, albeit with ongoing **risk assessments**.

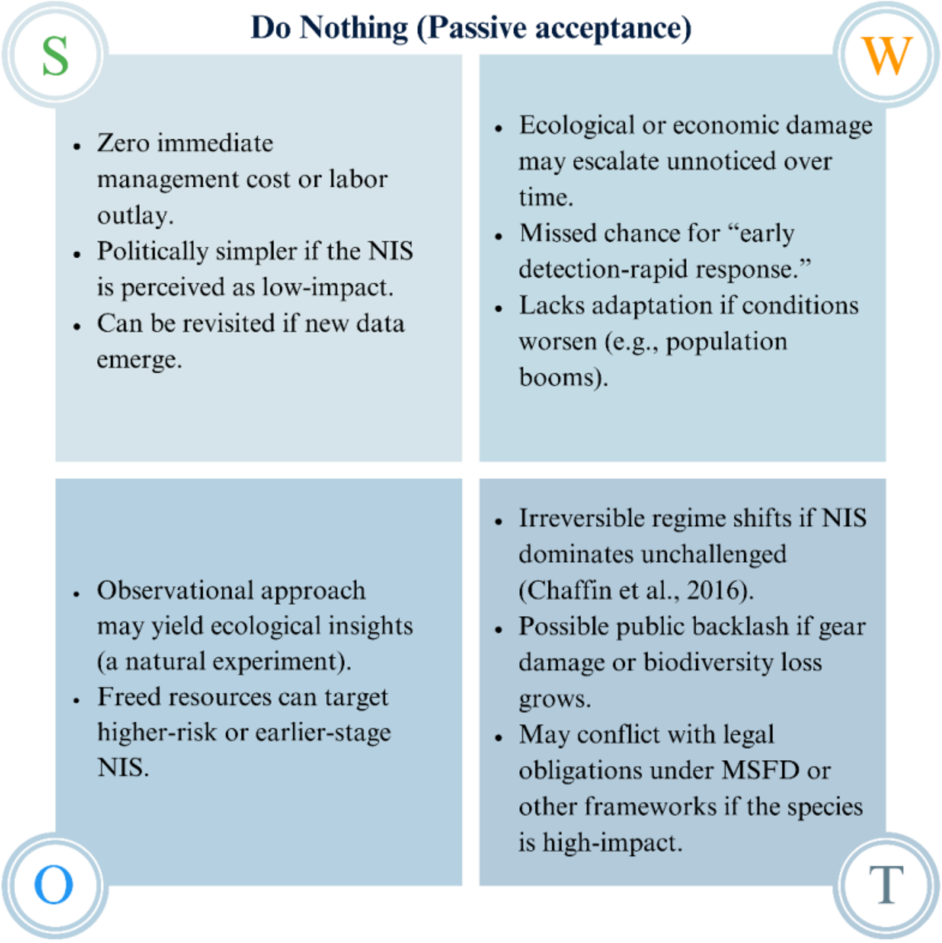


Figure 18. Strengths, Weaknesses, Opportunities, and Threats for "do nothing (passive acceptance)" measures for non-indigenous species control.

Interlink with other measures

Although doing nothing might initially appear to save costs, ongoing Monitoring & Risk Assessment (Chapter 3.3.10) remains vital for detecting escalations or shifts in invader behaviour. Coordination with Biosecurity Measures (Chapter 3.3.11) helps prevent additional introductions that could upend this passive approach. In instances where new markets are discovered for otherwise low-value NIS, collaboration with Market Valorisation (Chapter 3.3.3) may transform a "do-nothing" stance into active harvesting. Likewise, Stakeholder Engagement (Chapter 3.3.5) is beneficial even under minimal interventions, ensuring that local communities' concerns are addressed and that they remain alert to changing conditions or opportunities for sustainable NIS use. Finally, monitoring and surveillance can still accommodate adaptive management principles, pivoting to active control or conservation measures if future data indicates significant costs or benefits tied to the invader's presence.

3.3.10 Monitoring, models, risk assessments

Rationale & key insights

Timely detection, ongoing surveillance, and robust risk assessment frameworks are fundamental for adaptive NIS management that holistically account for the continuous nature of ecosystem change. Accordingly, trends in the abundance, temporal occurrence, and spatial distribution of NIS constitute key indicators under the EU Marine Strategy Framework Directive and the Integrated Monitoring and Assessment Programme (IMAP), adopted by the Contracting Parties of the Barcelona Convention. Monitoring programs track the presence and spread of NIS but they do not consider their ecological, economic, and societal impacts in a holistic approach (Olenin *et al.*, 2024). The insights derived from continuous observations and targeted data collection provide early detection of new introductions, unveil trends in population expansion or decline, and elucidate interactive effects with human and the physicochemical and biological components of the marine environment. Coupled with risk assessment methodologies, prioritized checklists, risk and distribution maps, and ecosystem or bioeconomic models, these **foundational tools enable managers to respond proactively**, fast and/or forecast the outcomes of different interventions (e.g., fishing limits, biosecurity regulations) (Lehtiniemi *et al.*, 2015; Groom *et al.*, 2019).

Through coordinated and multidisciplinary monitoring, ranging from **classical sampling** (e.g., transect surveys, port baseline assessments) to **advanced techniques** (eDNA metabarcoding, remote sensing), researchers and decision-makers can capture evolving patterns in NIS abundance, distribution, and impacts. Such observations may reveal cryptic invasions early on, identifying opportunities for rapid response or allowing managers to explore market-based uses of NIS should they become abundant or stable. Addressing the complex challenges posed by NIS requires an integrated approach that combines ecology, social sciences, and economics to assess management interventions and understand the socio-economic dimensions of these species. Ultimately, monitoring, modelling, and risk assessments are **necessary for adaptive governance of marine ecosystems under NIS pressure**. They allow stakeholders to compare alternative measures, anticipate climate-driven changes, and determine whether a particular species should be suppressed, tolerated, or even promoted if it fills an ecosystem gap. Monitoring and advanced early warning systems can mitigate shocks and enable timely responses to unstable conditions (Hidalgo *et al.*, 2022).

Evidence from published documents

- **Dominance of 'Monitoring' in the literature:** As outlined in Chapter 3.1, monitoring studies dominated the 'control' studies of the literature review, although they were not the explicit focus of our keyword search. These studies range from exploring biotic resistance and the biology and ecology of species to more mature topics such as climate change, ballast water, biofouling, and the presence/first records of NIS (Figure 6; Chapter 3.1).
- **Predictive modelling & risk assessment tools:** Predictive models, including Ecopath with Ecosim (EwE), Ecospace, and species distribution models, assisted the forecasting of the ecological and economic outcomes of different control or environmental scenarios, identifying hotspots where NIS could proliferate under changing temperatures or fishing pressures (Michael-Bitton *et al.*, 2022; Keramidas *et al.*, 2024). For instance, multi-scenario simulations have shown that under projected climate warming, reductions in fishing effort elicit varied responses among functional groups, with certain thermophilic or invasive taxa increasing in biomass (Ofir *et al.*, 2023; Keramidas *et al.*, 2024). Michael-Bitton *et al.* (2022) integrated ecosystem models with the System of Environmental-Economic Accounting to project the economic impact of fishery regulations on fish stocks of Israel including NIS. Data-driven risk assessment methods, such as horizon scanning exercises (Peyton *et al.*, 2019; Peyton *et al.*, 2020; Tsiamis *et al.*, 2020),

CIMPAL (Katsanevakis *et al.*, 2016; Bartolo *et al.*, 2021) risk assessments (Tarkan *et al.*, 2017; Vimercati *et al.*, 2022), and species distribution and dispersal models (D'Amen & Azzurro, 2020; Schilling *et al.*, 2024) further prioritize which species, pathways, and areas demand attention.

- **Monitoring methods:** In all Mediterranean countries, citizen science initiatives have been pivotal in detecting the spread of NIS (Giovos *et al.*, 2019; Katsanevakis *et al.*, 2020; Coppari *et al.*, 2024; Michail *et al.*, 2024). Methods like local ecological knowledge (Azzurro *et al.*, 2019b), regular port baseline surveys (Azzurro *et al.*, 2019a; Tamburini *et al.*, 2021), environmental DNA (eDNA) sampling (Aglieri *et al.*, 2023; Scriver *et al.*, 2024; Zangaro *et al.*, 2024), and fishery data monitoring programmes (Peristeraki *et al.*, 2017; Van Rijn *et al.*, 2020; Evangelopoulos *et al.*, 2024) have been widely used for monitoring, early detection and rapid response.
- **Gaps and fragmentation**: Evidences highlight the fragmentation of current surveillance: many systems are either taxonomically narrow or depend on sporadic sampling, and they often lack standardized protocols and coordinated efforts across sectors (Lehtiniemi *et al.*, 2015; Katsanevakis *et al.*, 2023). The prevailing strategy, focused on responding to species after impacts are observed and lacking long-term surveillance at sentinel locations, demonstrates a reactive rather than proactive approach. Despite invasions having broad spatiotemporal extents, their economic or ecological impacts are generally realized at the local level (Haubrock *et al.*, 2023). This approach also overlooks the dynamic nature of ecosystems and the variable impacts of invasions, which are prone to change and slow to recover (Scheffer *et al.*, 2001).

The **absence of regular surveys** and the **shortage of taxonomic expertise** in some **countries** creates **discrepancies** and can delay detection, missing optimal windows for rapid response (Kleitou *et al.*, 2019a; Mnasri-Afifi *et al.*, 2024). **Variations exist in protocols** related to risk screening and early detection (Katsanevakis *et al.*, 2023). There is currently a **lack of data** on numerous species and an insufficient knowledge sharing between countries (Garcia-Lozano *et al.*, 2025). Joint data repositories, **harmonized sampling standards** and **emphasis on pathways** (e.g. ports, Levantine Sea) and **dispersal hubs** have been repeatedly advocated but remain largely unrealized (Galil *et al.*, 2018; Kleitou *et al.*, 2021b). Furthermore, monitoring efforts predominantly focus on the occurrence of NIS, an approach that fails to provide managers with insights into the interactions of these species within the ecosystem. Despite the acknowledged necessity, long-term standardized monitoring is infrequently implemented including within dispersal hubs and sentinel sites essential for the early detection of invasive species spread and at critical sites such as MPAs (Bianchi *et al.*, 2022). The majority of long-term data studies from the literature review originated from fishery studies, highlighting the **conservation sector's continued struggle** to generate and maintain reliable and actionable long-term data for understanding and predicting NIS dynamics. **Fishery studies are not designed to monitor NIS** and they often lack the required taxonomic resolution and accuracy (Kleitou *et al.*, 2022b).

Illustrative examples from Case Studies

- Darwin harbor's *Mytilopsis sallei* (Literature Case Study #13)

Rapid identification of the bivalve and its potential damage spurred a coordinated response, **eradicating** it in ~42 days. This highlights how **timely monitoring & risk assessment** can prevent wider establishment.

- Lionfish modelling (Literature Case Study #25)

Simulations quantify removal targets (around 35–65% exploitation) to keep lionfish densities below critical ecosystem-impact thresholds, emphasizing the role of **model-driven** management.

- GuardIAS Project (Expert Case Study #10)
- Uses **eDNA** to detect early-stage macroalgae invasions (e.g., *Rugulopteryx okamurae*), allowing pre-emptive interventions before extensive spread.

Critical Insights from Case Studies & literature

- **Early warning & rapid response: Proactive detection** is fundamental for successful eradication or localized control (Darwin Harbor example), whereas delayed recognition often leads to entrenched invasions.
- **Funding & expertise gaps:** Many monitoring programs rely on short-term project funds or volunteer input, lacking stable resources or specialized taxonomic knowledge.
- **Overemphasis on data gathering alone:** Monitoring without subsequent management can generate stakeholder frustration if no action follows evidence of an escalating invasion.
- **Standardization & coordination:** Open access data, and harmonizing methods (e.g., eDNA protocols, distribution modelling) across borders and sectors is **still limited**, despite repeated calls for shared data repositories.
- **Holistic monitoring:** Effective monitoring should comprehensively assess the impacts of species, beyond just tracking their spread. Programs must be designed for long-term NIS monitoring and to evaluate economic, social, and ecological effects. Tools like environmental DNA (eDNA) offer promising solutions for early detection of invasive species.

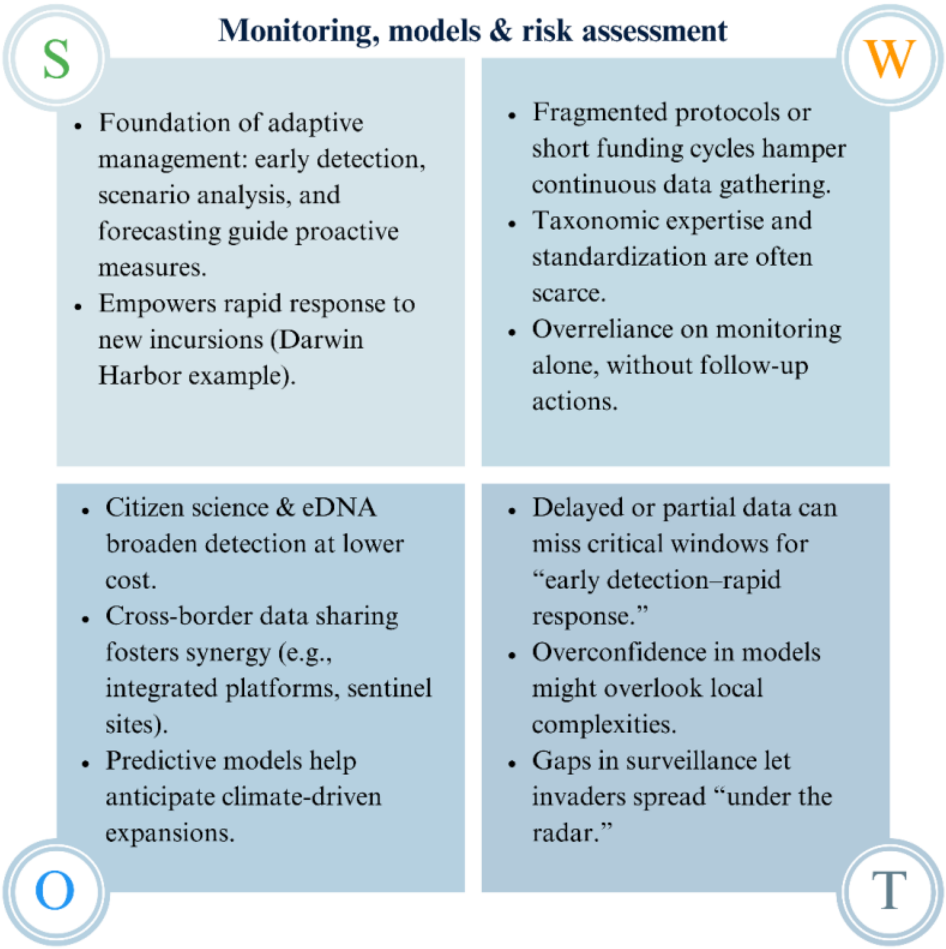


Figure 19. Strengths, Weaknesses, Opportunities, and Threats for "do nothing (passive acceptance)" measures for non-indigenous species control.

Interlink with other measures

Enhanced monitoring, modelling, and risk assessment form the backbone of all other management strategies. High-resolution data on NIS distribution and ecological impacts can inform Targeted Removals (Chapter 3.3.6) by identifying population hotspots or windows of reproductive vulnerability. Likewise, up-to-date risk analyses are fundamental to guiding Biosecurity Measures (Chapter 3.3.11), pinpointing specific pathways or "weak links" in shipping and trade. For Commercial Fishery and Recreational Harvesting (Chapters 3.3.1 and 3.3.2) or Market Valorisation (Chapter 3.3.3), reliable population assessments ensure sustainable exploitation. Finally, shared monitoring protocols underpin cross-border Stakeholder Engagement (Chapter 3.3.5) and collaborative governance, facilitating adaptive responses to newly emerging threats or opportunities in the face of changing environmental and socioeconomic contexts.

Insufficient coverage of non-indigenous species by fisheries

Despite being the most consistent and extensive source of long-time series data for marine resources in the region, fisheries have traditionally not prioritized monitoring NIS, often overlooking their presence. As Kleitou *et al.* (2022b) note, official fishery records may lack specific information on certain NIS, which can be obscured within aggregated categories such as discards, misidentified due to low taxonomic resolution, like in the case of *Sphyraena* spp., making it difficult to distinguish these from native species, mislabelled and/or misreported. Analysis of data from FishStatJ (Accessed on 29 December 2024) on common NIS reveals notable gaps, as some species lack sufficient recorded data (Figure 20). In response, since 2020, the Cyprus government has taken significant steps to close these gaps by enhancing data resolution and incorporating independent scientists and routine monitoring at fishing shelters. This approach serves as a model that other nations could follow to improve their own data collection and management of NIS.

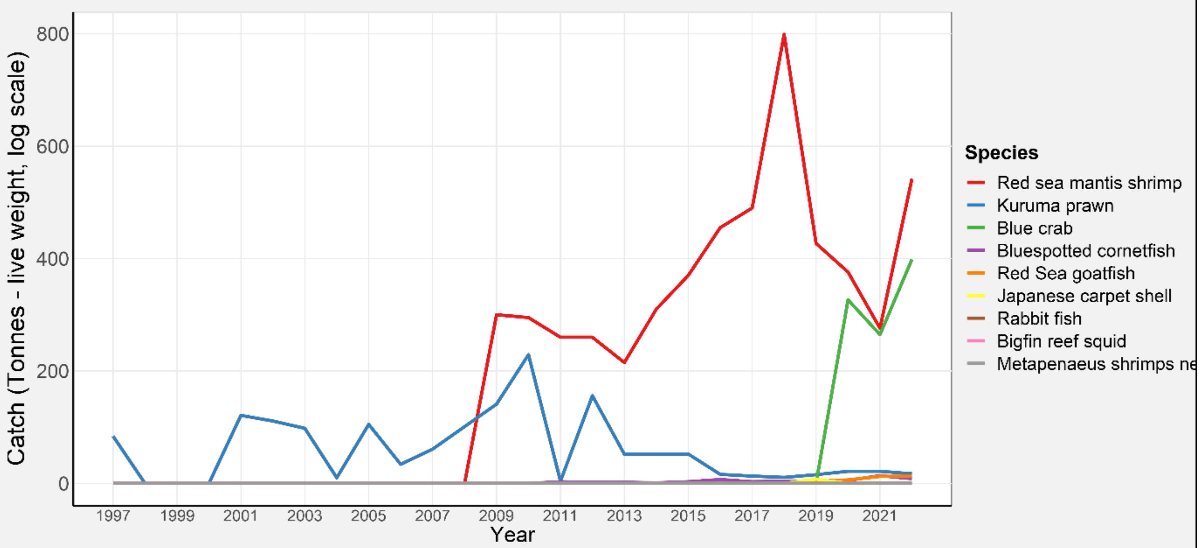


Figure 20. Global capture production of selected non-indigenous species between 1950-2022. Data source: FAO (2024).

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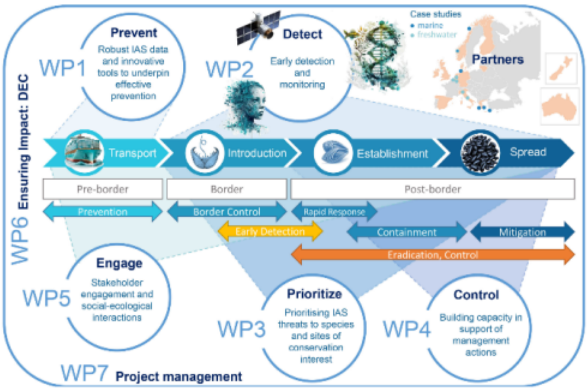
HIGHLIGHT CASE STUDY

GuardIAS: An Innovative Project for Monitoring, Early Detection, and Management of Aquatic Invasions

Launched in January 2025, GuardIAS is a three-year Horizon Europe project that unites experts from fields such as ecology, artificial intelligence, citizen science, and nanotechnology to strengthen Europe's response against aquatic invasive alien species (IAS). Focusing on both marine and freshwater environments, GuardIAS addresses all stages of an invasion—pre-border, border, and post-border—by developing innovative tools for prevention, early detection, and targeted control.



A cornerstone of the project is improving monitoring and early detection. GuardIAS will enhance the European Alien Species Information Network (EASIN) with advanced AI workflows, merging species distribution data, genetic information, and environmental tolerances into a single resource. Citizen scientists will contribute via the iNaturalist platform, which will be enriched with expert-verified images of priority IAS to boost accurate species identifications. Additional technologies include eDNA assays for large-scale surveys and the exploration of acoustic monitoring to detect soniferous invasive species.

On the prevention side, GuardIAS investigates hull biofouling solutions, a major vector for IAS introductions, by testing nanotechnology-based antifouling coatings. In parallel, researchers will map recreational boating routes to pinpoint high-risk marinas and anchorages that can serve as stepping stones for IAS dispersal.

Through a series of case studies on high-impact marine invasive species (including *Pterois miles, Plotosus lineatus, and Rugulopteryx okamurae*), GuardIAS will demonstrate and refine control methods, ranging from removal campaigns to community-based interventions. Engagement is woven throughout the project via citizen science events, "BioArtBlitz" artistic performances, and applied games. These activities not only collect critical IAS data but also foster public awareness, encouraging more inclusive and socially supported management strategies.

By promoting cross-sector collaboration, innovative data integration, and evidence-based policies, GuardIAS aims to strengthen IAS governance in line with the EU Biodiversity Strategy and the IAS Regulation, ultimately contributing to healthier aquatic ecosystems and more resilient coastal communities.

References and sources:

- Katsanevakis, S., Zaiko, A., Olenin, S., Costello, M. J., Gallardo, B., Tricarico, E., ... & Panov, V. E. (2024). GuardIAS-Guarding European Waters from Invasive Alien Species. Management of Biological Invasions, 15(4), 701-730.

Researchers of Marine & Environmental Research (MER) Lab monitoring non-indigenous species densities at artificial reefs of Cyprus.

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3.3.11 Biosecurity (measures to minimize introductions)

Rationale & key insights

Biosecurity is widely recognized as the **first and most cost-effective layer of protection** against new NIS, by **targeting major pathways**—including shipping, aquaculture, the aquarium trade, and engineered corridors (e.g., the Suez Canal), before organisms can become established (Rotter *et al.*, 2020; Roy *et al.*, 2024). **Integrated biosecurity efforts** typically combine:

- **Strict regulations** (ballast water standards, hull-fouling controls),
- **Horizon scanning** and **risk screening** (to detect emerging threats and rank high-risk species), and
- **Robust cross-border cooperation** to synchronize best practices (Groom *et al.*, 2019; Roy *et al.*, 2023)

Because the marine environment is highly connected, **one jurisdiction lagging** in enforcement can undermine broader regional efforts (Faulkner *et al.*, 2020). In addition, **collaborations** among borders, and with resource-limited countries, can leverage shared species reference libraries, open-access NIS databases, **horizon scanning**, and **predictive modelling**, thus enabling even modest local surveys to inform robust risk analyses (Bereza *et al.*, 2023; Carvalho *et al.*, 2023).

Carvalho *et al.* (2023) emphasize that biosecurity should be **practical, feasible, cost-effective**, and focused on **prevention and early detection**. Despite established frameworks (e.g., IMO Ballast Water Management Convention, EU Regulations 708/2007 and 1143/2014), **significant gaps persist** in areas such as ballast-water and hull-fouling regulations, aquaculture protocols, aquarium trade oversight, and the ongoing challenge of the Suez Canal (Katsanevakis *et al.*, 2013). Efforts by the **General Fisheries Commission for the Mediterranean (GFCM)** and other pilot initiatives underscore the importance of synergy and data-sharing among Mediterranean countries, especially when resources are limited.

Evidence from published documents

- **IMO Ballast Water Management (BWM) Convention:** Vessels adhering to the D-2 standard drastically reduce invasive propagules in ballast waters, yet **enforcement gaps** remain, especially among smaller fleets or ports with limited capacity (Wang *et al.*, 2022; Yasakova *et al.*, 2023).
- **Hull-fouling & recreational boats:** Biofouling on commercial and recreational vessels is largely **unregulated** (Carvalho *et al.*, 2023). Smaller or private boats can spread NIS via hulls, propellers, or bilge waters (Martínez-Laiz *et al.*, 2019; Ulman *et al.*, 2019). eDNA metabarcoding for bilge water or standardized sampling plates can detect NIS early, but uptake and techniques are inconsistent (Tamburini *et al.*, 2021; Maggio *et al.*, 2023). Monitoring in 26 marinas located in the Western Mediterranean identified remarkable variability of NIS assemblages and community structures between the marinas; suggesting context-dependent fouling dynamics and therefore context-specific management actions (Tempesti *et al.*, 2025).
- **Aquaculture & aquarium trade:** In aquaculture, legislation and codes of practice aim to limit unintentional releases, but they vary widely across the Mediterranean (e.g., EU Regulations 708/2007 and 1143/2014; (UNEP/MAP, 2017)). The aquarium trade has also introduced an increasing number of NIS into the region, highlighting the need for consistent labelling, import checks, and contingency plans for escaped organisms (Giovos *et al.*, 2018; Dimitriou *et al.*, 2019; Giovos *et al.*, 2020).
- The **Corridor** (Suez Canal) remains a singular challenge: Proposed engineering solutions (salinity barriers, lock-based systems) (Shahhat & Awad, 2022; Galil, 2023) face **political and economic hurdles.** Lessepsian species continue to enter the Mediterranean, prompting to the compromise for innovative **early-warning** methods (e.g., eDNA, horizon scanning) and regionally coordinated contingency measures.

Ultimately, **effective biosecurity** demands a shared legal and technical framework involving government agencies, industries, NGOs, and the public (Carvalho *et al.*, 2023). Without **regional harmonization**, new or secondary introductions can easily undermine local eradication or control successes (Faulkner *et al.*, 2020).

Illustrative examples from Case Studies

- Darwin harbor's *Mytilopsis sallei* (Literature Case Study #13)

Rapid **marina quarantine**, combined with chemical treatments and transparent communication with local operators, halted the bivalve invasion in ~42 days. This highlights **decisive biosecurity** preventing region-wide establishment.

Critical Insights from Case Studies & literature

- **Primary Prevention & Cost-Effectiveness: Blocking** new introductions at their source is more economical than post-invasion control (Rotter *et al.*, 2020; Roy *et al.*, 2024). Even minor enforcement gaps can yield high-impact NIS, especially in smaller ports or among recreational vessels (Carvalho *et al.*, 2023).
- **Practical & Feasible Biosecurity:** Strategies must be **cost-effective** and **focused on early detection** (Carvalho *et al.*, 2023). Resource-limited countries need cross-border support (Bereza *et al.*, 2023), data sharing, and synergy with regional bodies (e.g. GFCM, SPA/RAC) to compensate for limited enforcement capacity.
- **Persistent Gaps**: Hull-fouling is often voluntary or minimally enforced, while aquarium-trade oversight remains patchy. The Suez Canal corridor remains a conduit for Lessepsian species due to economic/political constraints on major engineering solutions.
- **Need for Regional Harmonization: Inconsistent regulations** hamper progress across the Mediterranean. Collaborative frameworks, shared databases (e.g., EASIN), and horizon scanning can improve detection, prioritization, and early response.

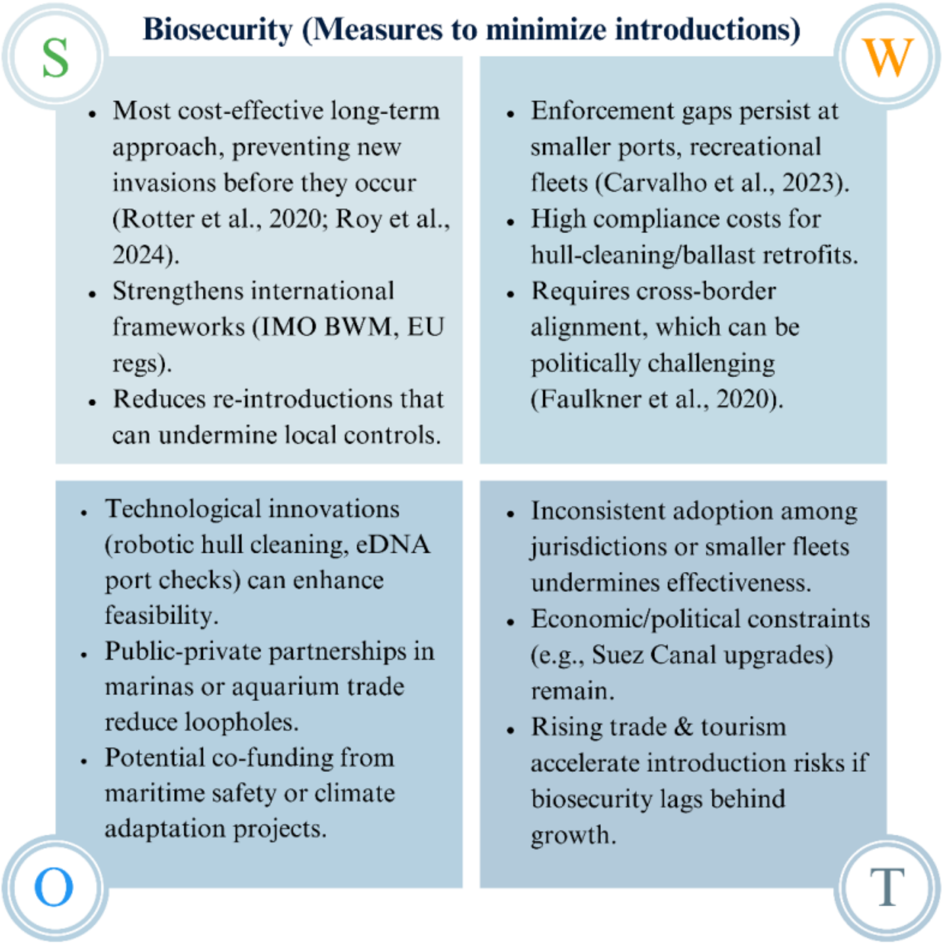

Figure 21. Strengths, Weaknesses, Opportunities, and Threats for "biosecurity" measures for non-indigenous species control.

Interlink with other measures

Comprehensive biosecurity measures work best when integrated with Monitoring & Assessment (Chapter 3.3.10) to detect breaches, verify compliance, and adapt interventions in real time. Stakeholder Engagement (Chapter 3.3.5) enhances compliance in commercial shipping, aquaculture, and the aquarium trade, while also raising public awareness of non-native species. Finally, robust biosecurity underpins all other management and control efforts by limiting additional invasions that might otherwise undermine existing strategies.

4 BLUEPRINT FOR NON-INDIGENOUS SPECIES CONTROL IN THE MEDITERRANEAN SEA

4.1 Stepwise framework for decision making

Using the RAD framework, we propose a stepwise framework to guide decision-making for managing and controlling the NIS in the Mediterranean Sea (Figure 22). The pathways reflect increasing levels of intervention depending on the ecological, economic, and social context, allowing for adaptive and context-specific management responses.

1. Resist: The initial strategy focuses on maintaining the historic ecosystem dynamics or re-implementing preventative measures to avoid the introduction or re-introduction of NIS. This involves monitoring baseline conditions using standardized techniques and tools to ensure early detection and rapid response. Where prevention or rapid eradication is still feasible, this strategy prioritizes resistance to maintain ecological balance and prevent further disruptions.
2. Accept: When prevention or complete eradication is no longer feasible, the next step involves accepting the presence of the invader. This approach scales back restoration efforts and shifts focus on adaptation strategies, such as diversifying fishing targets to include invasive species or implementing functional eradication measures. Functional eradication targets reducing NIS populations to densities that minimize their ecological impact, while still acknowledging their persistence in the ecosystem (Green & Grosholz, 2021). Monitoring remains essential to track the effects of the invader on biodiversity and ecosystem services.
3. Direct: The final strategy involves directing the trajectory of ecosystem change by actively integrating NIS into sustainable use frameworks. This includes developing new industries, such as targeted or selective harvesting, to leverage NIS populations for long-term socio-economic benefits. Institutional reforms may also be required to adapt governance structures and support these initiatives. As in previous steps, monitoring the effects of these actions on biodiversity and ecosystem functions ensures adaptive management remains aligned with ecological and socio-economic goals.

By following this stepwise process, managers can tailor interventions to specific contexts, balancing conservation objectives with the realities of ecosystem transformations (Figure 22). However, the effectiveness of these strategies depends on timely action and the ability to identify and capitalize on windows of opportunity for intervention. While hasty decisions may prove counterproductive, delayed action can result in missed opportunities to implement resist or direct strategies, heighten the risk of irreversible ecological changes, and lead to substantial economic costs and environmental damages (Lynch *et al.*, 2022). When the species is established, a cost-benefit analysis is recommended to decide on the approach (Acceptance vs Direct), as suggested by Kleitou *et al.* (2021a) and Azzurro *et al.* (2024c)

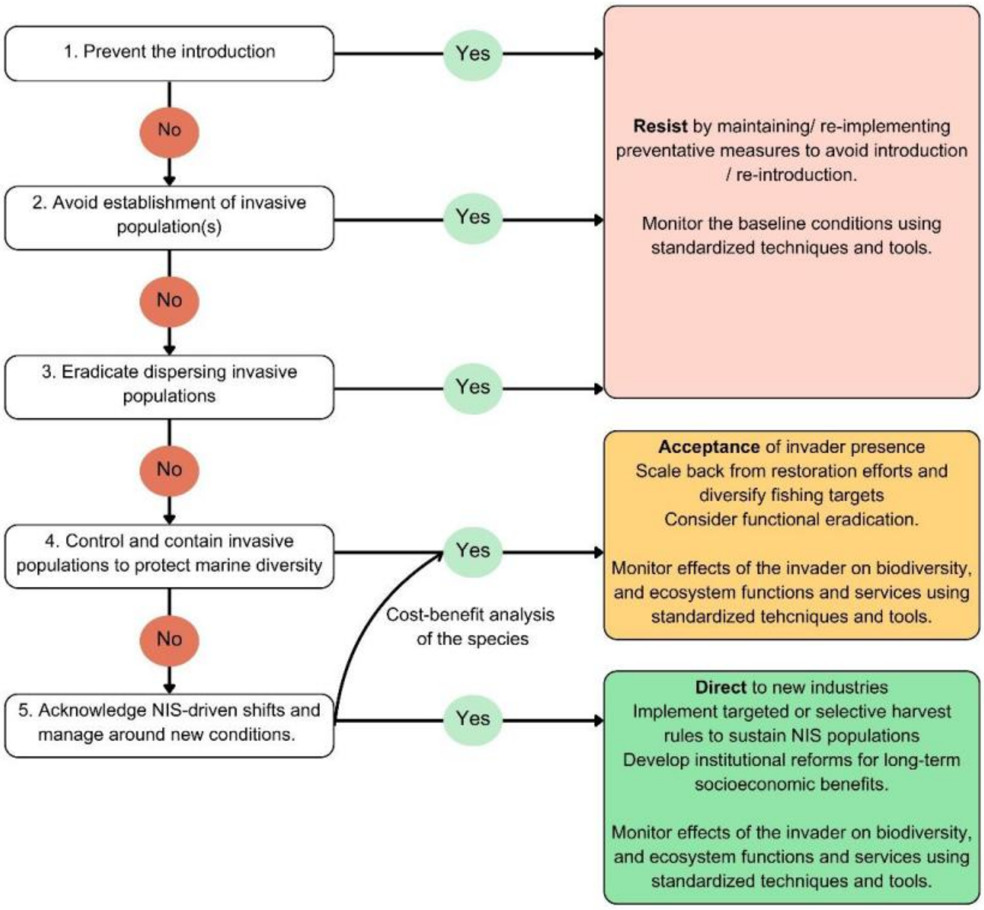

Figure 22. Stepwise process outlining the various pathways for managing the impacts of non-indigenous species (NIS) in marine waters. For information on functional eradication, see Green and Grosholz (2021). Adapted from: Britton *et al.* (2023).

The application of RAD framework can fundamentally alter the traditional invasion curve, offering a dynamic approach to managing NIS that reduces ecological and economic costs while creating opportunities for socio-economic benefits. Traditionally, invasion theory conceptualizes a linear progression, where escalating costs and impacts accompany each stage of an invasion (Figure 23). Early efforts focus on prevention and eradication, while later stages shift toward containment or mitigation, often with diminishing returns. However, this rigid framework overlooks the potential to reshape the trajectory of invasions through adaptive management.

Figure 23 illustrates how RAD strategies can "bend" the invasion curve by tailoring interventions to the stage and context of an invasion. Resistance strategies, applied early, delay or prevent NIS establishment, preserving baseline ecosystem conditions and minimizing costs. As invasions progress, adaptive acceptance reallocates resources from restoration efforts to functional management approaches, such as promoting sustainable exploitation of NIS in fisheries. Finally, directing ecosystem trajectories allows managers to transform invasive pressures into opportunities, aligning ecosystem processes with desired ecological and socio-economic outcomes.

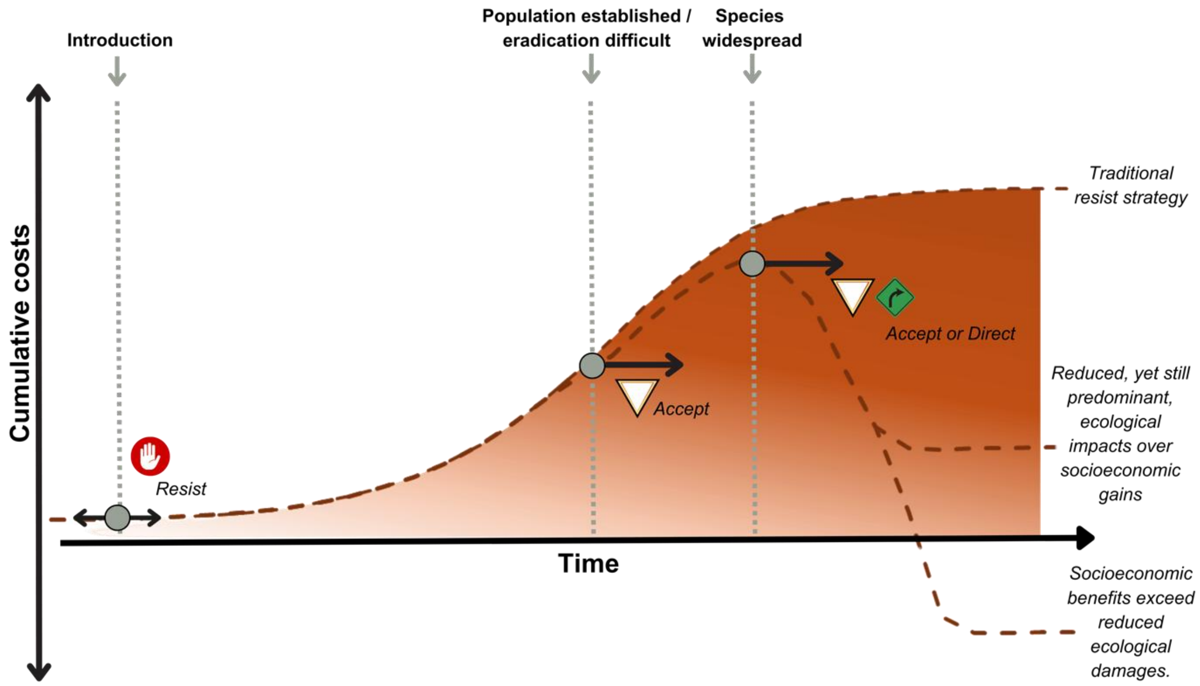

Figure 23. Conceptual model illustrating how the application of the Resist-Accept-Direct (RAD) framework can reshape the traditional invasion curve. By strategically implementing RAD strategies, managers can reduce ecological and economic costs, delay or prevent irreversible changes, and, in some cases, create socio-economic opportunities. The framework emphasizes timely intervention, particularly during critical windows of opportunity, to optimize management outcomes and adapt to dynamic and nonstationary conditions in marine ecosystems.

Non-indigenous species, like fisheries, function as coupled socio-ecological systems, requiring integrated management approaches that address both ecological and socio-economic goals (Lynch *et al.*, 2022). For example, species such as lionfish (*Pterois miles*), rabbitfish (*Siganus* spp.), and blue crabs (*Callinectes sapidus* and *Portunus segnis*) have significantly altered trophic dynamics, yet they also present opportunities for fisheries (Kleitou *et al.*, 2021a; Sidiropoulou *et al.*, 2024). These varying impacts often lead to differing perceptions and priorities among stakeholders, shaped by their economic, cultural, or conservation interests (Kleitou *et al.*, 2022b). Therefore, we distinguish RAD into strategies aimed (1) at ecological goals, and (2) focused on social goals (Figure 24). The distinction is crucial because an intervention that 'resists' an unwanted ecological state may, at times, conflict with or complicate an approach that 'accepts' or 'directs' outcomes desired by stakeholders or local communities. By making these dual dimensions explicit, we can more systematically weigh ecological risks and societal trade-offs.

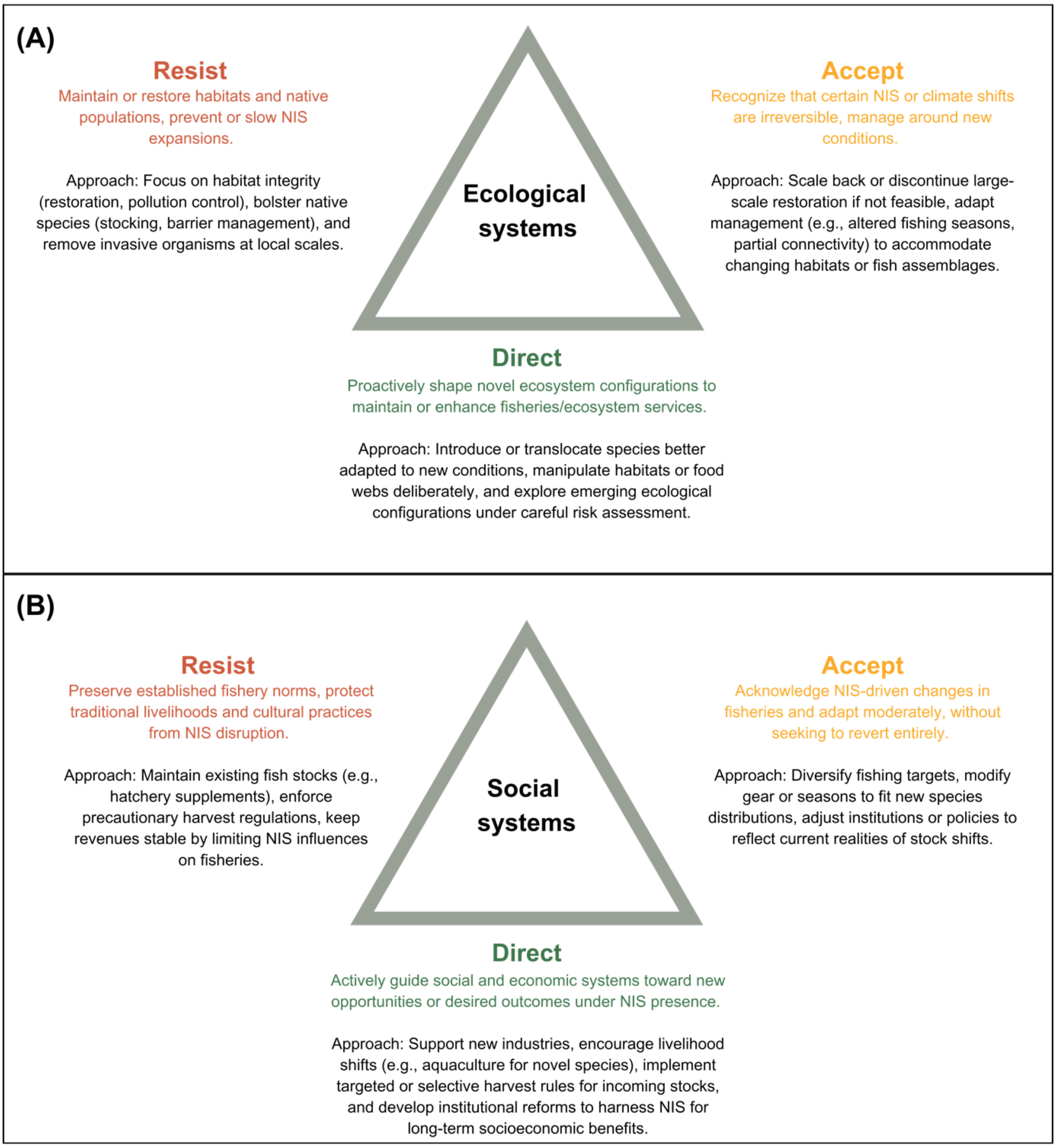

Figure 24. Conceptual framework illustrating the application of Resist-Accept-Direct (RAD) strategies targeting (A) ecological and (B) social objectives for managing Non-Indigenous Species (NIS) in marine ecosystems. Modified from Thompson *et al.* (2021).

4.2 Ecological Dimensions of RAD for NIS

From an ecological perspective, RAD strategies revolve around maintaining or reshaping the composition, structure, and function of marine ecosystems, particularly in the face of proliferating NIS. Here we focus on how ecosystem processes, habitat conditions, and species interactions can be managed at each stage of the RAD continuum.

4.2.1 Resist (Ecological)

Resisting ecological transformation begins with preventative strategies and early rapid-response actions.

- Preventive biosecurity: Enhanced inspection and regulation of ballast water, hull fouling, and aquarium trade are cost-effective ways to keep NIS out (Rotter *et al.*, 2020).
- Local habitat restoration: Managers can reduce invasion susceptibility by preserving or restoring critical habitats, for example, mitigating nutrient pollution in lagoons to limit disturbance (Bulleri *et al.*, 2016).
- Biotic manipulation: Managers may actively restore or protect apex predators that prey on certain NIS. For example, rebuilding grouper populations could help suppress some invasive fish (Kleitou *et al.*, 2021a).
- Eradication at early stages: Where feasible, chemical or mechanical removals can locally extirpate small NIS populations (e.g., examples with *Caulerpa taxifolia* in California, *Mytilopsis sallei* in Darwin Harbor; Chapter 3.3.6). Such rapid actions preserve baseline ecosystem processes before widespread establishment occurs.

A pure ecological Resist strategy can be resource-intensive and may only succeed in discrete areas (e.g., priority sites, Marine Protected Areas). Nonetheless, if enacted swiftly and with robust monitoring, it can help maintain historical ecosystem dynamics or decelerate alterations in strategically important or highly valued locations.

4.2.2 Accept (Ecological)

Accepting the presence of NIS applies once eradication is unachievable or no longer cost-effective.

- Minimizing further stress: Scaling back high-cost removal efforts that yield minimal ecological return may free resources for broader ecosystem management (e.g., controlling other stressors like pollution).
- Functional acceptance: In some cases, NIS can serve beneficial ecological roles (e.g., providing prey for native predators, creating novel reefs) (Katsanevakis *et al.*, 2024). Here, "acceptance" means a deliberate decision to allow these functions; while maintaining vigilance to detect shifts in population size or impacts.
- Ongoing monitoring and adaptive triggers: Even when NIS are accepted, continuous monitoring can detect early signs of ecosystem harm (e.g., population explosions) or need for protection/improved management that might require a renewed Resist or Direct response.

4.2.3 Direct (Ecological)

Direct strategies shape or steer ecosystems into new but still functional or desirable states. Direct strategies can include deploying artificial reefs or removing competing macroalgae to favour NIS. Due to high risks associated with such actions, **we exclude any possible ecological measure that directly favours the NIS**.

4.3 Social Dimensions of RAD

NIS management also involves direct impacts on livelihoods, cultural values, and governance systems. The same Resist–Accept–Direct logic can guide social responses, ensuring that fisheries, tourism, and coastal communities remain resilient.

4.3.1 Resist (Social)

Resisting social change due to NIS focuses on preserving existing livelihoods and market structures against invasive threats.

- Short-term compensation: Governments or NGOs may subsidize gear replacements for fishers whose nets suffer damage from invasive crabs or pufferfish; helping them maintain status quo operations.
- Restrictive regulations: Communities might ban or discourage the sale and consumption of new invasives (e.g. EU IAS Regulation 1143/2014), preventing these species from gaining a commercial foothold that could undermine ecological eradication goals.
- Public information campaigns: Messaging that highlights risks from certain invaders (e.g., toxic species) can unify stakeholders to remove or avoid them, thereby maintaining traditional fisheries and local practices.

While this can safeguard current social and economic patterns, it may come at high financial cost and **can delay necessary adaptations** if an invader becomes irreversibly abundant.

4.3.2 Accept (Social)

Social acceptance focuses on adjusting livelihoods and cultures to the changed reality of NIS presence.

- Diversifying fisheries: Communities can pivot to harvesting newly abundant invasive fish (e.g., lionfish, *Siganus* spp.) when native stocks decline (Kleitou *et al.*, 2022b).
- Adaptive Regulations and Institutions. Local authorities might update fishing seasons, licensing, or cooperative agreements to accommodate an emerging NIS fishery, ensuring legal frameworks evolve with changing ecological baselines (Holsman *et al.*, 2019).
- Maintaining socio-Economic stability. By harnessing NIS to stabilize or supplement incomes, managers can reduce conflict and keep coastal communities economically viable, even if native species continue to decline.

Accepting social transformation is often a more deliberate and transparent choice than doing nothing. It leverages new opportunities presented by invasive species but requires clear stakeholder engagement to balance risks and rewards.

4.3.3 Direct (Social)

Directing social systems means actively steering societal responses and market developments in ways that harness or minimize the impacts of NIS.

- Market valorisation. Targeted support for product development, like crab-processing facilities or marketing campaigns for edible invasive fish, can transform harmful invaders into resources (Chapter 3).
- Livelihood transition. In areas severely affected by ecosystem shifts, public agencies can facilitate retraining or microloans to help fishers shift into tourism, aquaculture, or other complementary sectors.
- Institutional reform. Adapting governance (e.g., multi-country agreements, cross-border data sharing) can ensure NIS are monitored, regulated, or even incentivized for harvest, thereby 'directing' local economies toward sustainable use while preventing perverse incentives (de Carvalho-Souza *et al.*, 2024).

4.4 No single approach addresses the complexities of NIS

Despite the distinction between Resist, Accept, and Direct strategies, no single approach fully addresses the socio-economic and ecological complexities of NIS management. In practice, parallel or hybrid interventions are often essential, for example, combining targeted removal and enhanced biosecurity in critical conservation areas, while simultaneously incentivizing market-based exploitation in other zones. Such integrated approaches allow managers to adapt as conditions evolve, harness stakeholder engagement, and balance conservation imperatives with socio-economic realities. Moreover, each strategy must be revisited iteratively, recognizing that new evidence, shifting climate patterns, and emerging stakeholder priorities can quickly alter the feasibility and desirability of any chosen measure. After reviewing multiple possible measures (Table 4-1), in the next section (Chapter 5), we propose at least 9 recommendations, framed around the measures analysed in Chapter 3, offering actionable guidance on how managers can integrate the RAD framework to align ecological integrity with socio-economic opportunities under the accelerating pace of NIS expansion in the Mediterranean Sea.

Table 4-1. Preliminary lists of measures identified and assessed considering their strengths and challenges including costs, feasibility, potential ecological impact, social acceptance, and alignment with Post-2020 SAPBIO.

RAD Component	Measure	Strengths	Challenges
RESIST (ECOLOGICAL)	1. Comprehensive biosecurity & pathway control (corridor, strict ballast-water regulation, hull-fouling inspections, aquarium trade restrictions)	- Most cost-effective strategy to prevent new introductions - Can be harmonized at regional scales to limit reinvasion - Reduces long-term control costs and ecological damage	- Requires strong legal frameworks and inter-agency cooperation - Enforcement gaps can undermine success - May need infrastructure upgrades at ports or shipping routes
	2. Horizon scanning & risk assessment (climate-based modelling, expert workshops, priority lists)	- Proactive approach: identifies high-risk NIS before they establish - Guides targeted monitoring and preparedness - Can integrate climate scenarios	- Data-intensive, dependent on taxonomic expertise - Uncertain under a rapidly changing climate - May overlook cryptic or poorly studied species
	3. Standardized monitoring & early detection (EDRR) (sentinel sites, eDNA, citizen science, rapid-response protocols)	- Timely detection can enable local eradication at lower cost - Fosters stakeholder engagement (divers, fishers) - Provides a basis for rapid-response	- Requires sustained funding and coordination - Cryptic species may remain undetected if sampling is sparse - Logistics can be complex for effective rapid-response
	4. Localized eradication / suppression campaigns (diver removals, suction devices, chemical spot treatments)	- Effective if invasions are small-scale or newly discovered - Demonstrated successes (e.g., *Caulerpa taxifolia* in California)	- Labor-intensive and costly for large/established infestations - Potential non-target impacts (chemicals, mechanical removal) - Requires repeated efforts if reinvasion occurs
	5. Habitat restoration to enhancing native resilience (restoring seagrass meadows, oyster reefs, coralligenous habitats)	- Strengthens biotic resistance via healthy native communities - Aligns with broader conservation (improved water quality, structural complexity)	- Expensive, slow and uncertain outcomes - Climate change can undermine gains - Restored areas may remain vulnerable to adaptable NIS
	6. Zero-limits harvest for high-risk nis (e.g., no size/possession limits for toxic pufferfish)	- Disincentivizes NIS retention or release - Sends a clear signal that the species is "unwanted"	- Compliance can be low if the NIS has hidden market value - May yield excessive bycatch discards if not paired with market solutions
	7. Rebuilding native predators / competitors (protecting groupers, large sparids)	- Maintains historical balances via top-down control	- Requires long-term fishing restrictions (e.g., no-take zones)

RAD Component	Measure	Strengths	Challenges
		- Enhances biodiversity if predator populations recover	- May have limited success if NIS is widespread or if predators switch diet
	8. Quarantine barriers at engineered corridors (lock systems, salinity barriers)	- Physically blocks cross-basin introductions (e.g., canal expansions) - Reduces large-scale species exchange	- High capital cost, complex political negotiations - Potential economic trade-offs for shipping - Not always feasible or publicly supported
	9. Transboundary collaboration & data sharing (regional nis databases, joint protocols, cross-border agreements)	- Enhances coordinated early detection & response - Reduces duplication, fosters mutual capacity-building	- Requires consensus on data standards - Unequal capacities among countries can hamper uniform application - Political will may fluctuate
ACCEPT (ECOLOGICAL)	1. Functional acceptance / novel ecosystem management (tolerating certain entrenched nis for partial benefits)	- Stops futile removals, saving resources - Can retain emergent ecosystem services (habitat complexity, prey availability)	- Risk of unforeseen long-term impacts if NIS expands further - Public perception of "giving up" can spark controversy
	2. Habitat triage & resource reallocation (focusing on sites with higher resilience or ecological value)	- Optimizes limited funds by focusing on "winnable" areas - Straightforward triage principle in conservation	- Politically sensitive to abandon heavily invaded sites - Requires robust data to justify choices
	3. Ceasing repeated mechanical / chemical removals (where local eradication is unfeasible)	- Minimizes ongoing disturbance to native communities - Frees resources for more promising interventions	- Possible NIS population spike if no control remains - Public opposition if the species causes economic or ecological harm
	4. Threshold-based triggers for action (monitor nis density/impacts; act if thresholds exceeded)	- Prevents overreaction to low-level presence - Data-driven pivot between Accept & Resist/Direct	- Requires consistent monitoring and clear thresholds - Thresholds can be contentious or difficult to set
	5. Adaptive harvest / exploitation for minimal control (encourage moderate removals if safely edible)	- Recoups some ecological control while generating economic benefit - Aligns fishers' incentives with removing the invasive	- May hamper future eradication if fishers become dependent on NIS - Market fluctuations can undermine viability
	6. Low-intensity long-term monitoring ("keep watch" once high-intensity measures stop)	- Cost-effective for ongoing observation - Detects population surges that may require renewed intervention	- May miss rapid changes if sampling frequency is too low - Limited ecological data on complex interactions

RAD Component	Measure	Strengths	Challenges
	7. Open-access data & periodic review (publishing local nis trends, ensuring transparency)	- Improves regional learning, fosters trust - Encourages collaborative adaptation if impacts intensify	- Resources needed for data curation/updates - Data inconsistencies across programs can reduce utility
DIRECT (ECOLOGICAL)	1. Habitat engineering to steer toward native assemblages (targeted macroalgae removal, adding reef structures)	- Creates a novel but desirable state dominated by resilient natives - Mitigates the NIS by altering habitat in a controlled way	- Potentially high cost - Long lag times for new habitats to establish - Outcomes uncertain if climate extremes shift conditions
	2. Biocontrol using native / well-studied agents (restoring or boosting populations of parasites/grazers that reduce nis)	- Can be self-sustaining if successful - Avoids introducing another non-native species	- Risk of off-target effects - Complex regulatory/ethical hurdles - Requires robust efficacy evidence
RESIST (SOCIAL)	1. Prohibited species lists & zero-tolerance policies (banning possession, sale, transport of specific nis)	- Clear legal stance: species is “unwanted” - Reduces market or black-market demand	- Enforcement burdensome - Black markets can emerge if species is profitable - Fishers/traders may resist if they see economic opportunity
	2. Financial compensation / subsidies to maintain status quo (gear damage reimbursements, direct support to fishers)	- Short-term relief for fishers losing gear/income to NIS - Minimizes immediate socio-economic disruption	- Can foster dependency on subsidies - Expensive for governments/NGOs - May discourage more adaptive or innovative approaches
	3. Public information campaigns emphasizing nis harms (discouraging consumption or release)	- Builds collective awareness to “stop the spread” - Relatively low-cost approach	- Behaviour change not guaranteed - Risks oversimplifying or demonizing NIS with nuanced impacts
	4. Restrictive fisheries regulations (no catch / no sale) (actively preventing an NIS-based fishery)	- Ends economic incentives to keep/spread the NIS - Aligns with eradication efforts	- May undermine removal if fishers discard the NIS at sea - Perceived as lost opportunity by some stakeholders
	5. Preservation of traditional cultural resource use (areas exclusively for native species harvest)	- Reinforces cultural identity - Mobilizes communities to resist NIS expansion	- May be unfeasible if the NIS is pervasive - Possible conflicts with modernization or alternative livelihoods
	6. Strict licensing / permitting for potential vectors (aquarium trade, ornamental species, live bait)	- Tracks who handles invasive species - Paper trail for	- Requires administrative capacity - Illegal/unlicensed

RAD Component	Measure	Strengths	Challenges
		enforcement & education	trade may persist clandestinely
	7. International policy alignment (transboundary regulations ensuring consistent restrictions)	- Closes regulatory loopholes across borders - Powerful synergy with Resist (Ecological) measures	- Negotiations can be slow - National priorities and capacities vary
ACCEPT (SOCIAL)	1. Diversification of catch portfolios (including nis in regular landings if safely edible)	- Stabilizes incomes if native stocks decline - Partially controls NIS via removal	- Could create incentives to maintain high NIS abundance - Market fluctuations can affect fishers' interest
	2. Adapted harvest regulations (redefining seasons, quotas, bycatch rules)	- Legal frameworks reflect current ecological reality - Protects overfished natives while allowing safe NIS exploitation	- Requires timely ecological data - Can be contentious

Native to the Indo-Pacific, lionfish (*Pterois miles)* have become a significant invasive threat in Mediterranean ecosystems, where they prey on native fish and disrupt local marine biodiversity. Efforts to control their population include targeted fishing and public awareness campaigns.

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5 PRIORITIZED MEASURES FOR REDUCTION AND CONTROL OF NON-INDIGENOUS SPECIES IN THE MEDITERRANEAN SEA

5.1 Introduction to the measures

The previous Chapters laid out the conceptual foundations of Resist-Accept-Direct (RAD) as an adaptive governance tool for managing Non-Indigenous Species (NIS). We also explored a range of measures, from biosecurity to ecosystem restoration, illustrating how interventions can either resist environmental change, accept transformations that are difficult to reverse, or direct ecosystems toward more desirable states. In the Mediterranean context—where climate warming, intense human use, and a high rate of introductions converge—NIS management demands integrated, regionally coordinated, and context-specific strategies.

We have identified nine priority measures that span the full RAD spectrum. These recommendations aim to mitigate harmful impacts while, where appropriate, harnessing potential socio-economic opportunities. For the proposed measures, we considered the following:

- The literature review (Chapter 3),
- The RAD-based conceptual framework (Chapter 4),
- The Kunming–Montreal Global Biodiversity Framework,
- The Post-2020 Strategic Action Programme for the Conservation of Biodiversity and Sustainable Management of Natural Resources in the Mediterranean Region (Post-2020 SAPBIO) and the updated Action Plan of 2023 concerning species introductions and invasive species in the Mediterranean Sea,
- The feedback received from attendees of an international workshop organized in Rome (Italy) on January 23, 2025, at the Ministry of Agriculture, Food Sovereignty and Forestry (MASAF) by SPA/RAC. The workshop brought together 43 participants and experts of invasive species from 16 Mediterranean countries to present control measures of NIS across the region. A round-table discussion was organized to propose recommendations for the implementation of a control plan against NIS in the Mediterranean.

5.2 Measure #1: Comprehensive biosecurity & early detection

RAD component:
Primarily Resist (Ecological)

Selection rationale
This measure directly tackles the most cost-effective way to halt new invasions, preventing them at the source, and was repeatedly highlighted in the literature (Chapter 3.3.11) as crucial to avoid costly downstream eradication efforts.

Key actions
(1) Enhanced Regulation and controls on pathways
- Ballast water & biofouling
  - All Mediterranean countries to collaborate in the enforcement of the Mediterranean Ballast Water Management Strategy (2022- 2027) in line with the Post-2020 SAPBIO Action 4.
  - Align with the International Maritime Organization (IMO) convention on ballast-water management (BWM Convention).
  - Enforce hull-fouling guidelines for both commercial and recreational vessels. Promote the 2023 guidelines for the control and management of ships' biofouling of the IMO.
  - Adopt or promote eco-sustainable antifouling solutions (e.g., non-toxic hull coatings, in-water cleaning technologies) to minimize water pollution and biofouling while preventing NIS spread.
- Aquaculture controls
  - Harmonize aquaculture Regulations across the Mediterranean region. Recognize that EU Regulation (EC) No 708/2007 (and its Annex IV) exempts certain widely used alien species (e.g., Pacific oyster *Magallana gigas*) from the full permit process, yet Member States can vary in their interpretations and restrictions.
  - Where feasible, develop shared "white," "black," or "watch" lists for aquaculture species, reflecting both EU frameworks (e.g., Annex IV) and regional risk assessments. Encourage periodic reviews of the species lists considering evolving evidence on ecological impacts, coordinating with national authorities to reduce regulatory gaps and ensure consistent risk management.
- Aquarium and pet trade controls
  - Strengthen aquarium import checks (particularly in non-EU countries) and require traceability systems (species labelling, importer registration).
  - Standardize permit requirements and risk assessments for all translocations of NIS, drawing on best practices from GFCM and SPA/RAC.
- Physical barriers (where feasible)
  - Establish biofouling cleaning stations for vessels, partial salinity or lock-based barriers in strategic high-risk corridors (e.g., shipping canals) if socio-economic and environmental impact assessments indicate feasibility and net benefit.

(2) Early Detection & Rapid Response (EDRR)
- Horizon scanning and risk assessments
  - Conduct horizon scanning and risk assessments for existing NIS and potential future introductions to prioritize surveillance and management efforts.
  - Perform data-based assessments of introduction risks associated with the pathways (aquaculture, ornamental trade and live food trade sector).
  - Identify high risk locations (areas where NIS are most likely to be first recorded in the Mediterranean region) and prioritize regional surveillance efforts.

- Monitoring and response
    - Promote Rapid Assessment Surveys (RAS) and innovative monitoring tools (e.g. eDNA-based screening) in ports, marinas, aquaculture sites, and other high-risk zones to detect cryptic invaders before they establish.
    - Expand cooperation with ecotourism, dive operators, and citizen science networks to report unusual sightings quickly.
    - Establish early warning system and rapid response plans through coordinated legal and funding mechanisms to enable immediate quarantine, culling and control if a new priority invasive species is detected in the region.
    - Harmonize EDRR protocols regionally so that neighbouring countries can coordinate across shared waters.

(3) Public outreach & education

- Aquarium & pet trade campaigns
    - Develop targeted campaigns discouraging aquarium pet releases into local waters, explaining the ecological risks.
    - Provide training and certification for aquarists (e.g., in public aquaria and pet shops) on responsible handling, disposal, and species identification.
    - Require clear labelling of all potentially invasive species sold in pet shops, including basic care and disposal instructions.
- "Clean Hull" & Eco-fouling initiatives
    - Promotion of eco-fouling initiatives and partnerships with marinas, sailing clubs, and shipping associations to promote regular hull cleaning and use of non-toxic antifouling products.

Considerations

Implementing strict biosecurity measures across Mediterranean countries is logistically complex and often constrained by uneven regulations, enforcement gaps, and limited financial resources. Early detection programs can be costly to maintain, particularly in countries lacking advanced monitoring capacities. The high connectivity of maritime trade, tourism, and aquaculture consistently increases the likelihood of new introductions, so prevention requires sustained cooperation among diverse sectors. Yet coordination across multiple jurisdictions can be hindered by economic and political disparities, with inconsistent enforcement at ports and weak oversight in small or recreational marinas further fragmenting biosecurity efforts.

Challenges

Aligning ballast-water regulations, hull-fouling guidelines, and aquaculture protocols is politically sensitive due to possible short-term economic losses for some stakeholders. Cross-border data sharing and the adoption of practical barriers (e.g., salinity locks) face obstacles in regions with weak infrastructure or high maritime traffic. The Suez Canal remains an important pathway; large-scale engineering solutions here encounter major political and economic hurdles. Overall, achieving consistent and durable biosecurity measures across the basin is difficult when national priorities diverge, and enforcement remains voluntary or minimally funded.

5.3 Measure #2: Standardized, multi-parameter monitoring at sentinel sites

RAD component

Underpins all (Resist, Accept, Direct)

Selection rationale

Long-term, systematic monitoring was consistently cited (Chapters 3.3.10) as the backbone for effective decision-making and adaptive management, especially in hotspot areas like major ports, the Levantine area near the Suez Canal, and MPAs. It can inform about the impacts of species as well as about the efficiency of management interventions. By 2030, the Mediterranean Post-2020 SAPBIO requires all participating countries to complete a baseline study and engage in ongoing data collection and monitoring. This initiative, part of the IMAP framework, focuses on the presence of NIS, their introduction pathways, and population trends, including those species used in aquaculture.

Key actions

(1) Multi-parameter observations

- Establish multi-parameter long-term observations to collect data on NIS abundance, native species trends, water quality, fishing intensity, and other environmental variables (e.g. temperature and salinity). Multi-parametric observations are critical to elucidate impacts from NIS, other pressures, or natural variability.
- Incorporate baseline data in areas not yet invaded and collect time-series data, enabling detection of ecological changes if/when NIS arrives.

(2) Surveillance and impact studies

- Compare “before” vs. “after” and “invaded” vs. “non-invaded” sites (BACI-design) to distinguish the impacts of NIS from other stressors.
- Leverage fishery surveys (e.g. DCF) and other monitoring programmes (e.g. MSFD, WFD, EcAp) but refine taxonomic resolution and goals to properly identify and quantify NIS using standardized and long-term practices techniques.
- Encourage co-creation of data with fishers or citizen scientists, validated by experts to maintain data quality.
- Focused impact studies (field and laboratory experiments, modelling studies) for priority species to identify acceptable abundance levels and guide potential management interventions.

(3) Open-access data & regional coordination

- Adopt shared monitoring protocols (e.g., standardized and traditional visual census surveys, eDNA, LEK, citizen science, fishery monitoring methods) and streamline reporting & data-sharing protocols, harmonize, increase interoperability, and ensure rapid data exchange at regional level (e.g., with MAMIAS digital data infrastructure, SPA/RAC, GFCM, national agencies) so that alerts can trigger immediate cross-border responses.

Considerations

Long-term, systematic monitoring helps managers detect new invasions, track established populations, and assess the impacts of interventions. However, creating uniform protocols that cover a wide range of ecosystems and address taxonomic gaps is inherently challenging, especially in a region as diverse as the Mediterranean. Many monitoring initiatives rely on time-limited external funding, which undermines continuity and data consistency. Incorporating fishers, divers, and other local stakeholders can fill information gaps but demands consistent training, expert validation, and shared data standards.

Challenges

Sustained financial and technical support for large-scale monitoring is lacking in many Mediterranean countries, leading to fragmented or sporadic datasets. Taxonomic expertise and advanced tools, such as eDNA-based surveys, may not be equally available across all nations. Databases frequently remain incompatible or scattered among different institutions and agencies, impeding regional interoperability. The result is a monitoring landscape in which efforts cannot always provide timely or comprehensive alerts for adaptive management.

5.4 Measure #3: Localized control in priority sites

RAD component
Resist if eradication / Accept if suppression (Ecological)

Selection rationale
Multiple case studies (Chapter 3.3.6) have shown that highly committed control efforts can achieve suppression of NIS in ecologically valuable areas (e.g., MPAs, nursery grounds), preserving conditions despite broader NIS presence. By 2030, the Mediterranean Post-2020 SAPBIO requires that all member countries implement regulations to control the introduction and proliferation of the most damaging invasive NIS. The goal is to prevent their impacts in all vulnerable or priority areas, reduce the threat to protected species by 50%, and effectively manage 50% of the major pathways of introduction.

Key actions

(1) Identify high-value areas, species, and management required effort
- Map sites (MPAs, seagrass meadows, coralligenous reefs) where local removal offers the greatest biodiversity benefit.
- Identify invasive species of priority and create a list of invasive species with feasible control mechanism.
- Consider functional eradication—reducing NIS density below an ecological-impact threshold if total eradication is unrealistic.

(2) Removal protocols & tools
- Deploy trained diver teams, mechanical devices (nets, traps, suction) or other targeted removal devices that have low bycatch and impact on the benthic habitats.
- Collaborate with volunteers and organize "derbies" or targeted fishing events to remove invasive species such as lionfish or pufferfish, building public engagement.
- Promote the development of eco-touristic diving and fishing-tourism mechanisms focused on removal practices to ensure consistent and sustainable management of invasive species removals.

(3) Community involvement
- Offer recognition or small incentives for fishers, volunteer divers, or NGOs who assist.
- Continue post-removal monitoring to catch re-invasions quickly and understand the efficacy of the measures.

Considerations
Localized control efforts in ecologically or socio-economically significant areas, such as MPAs or nursery grounds, can preserve valuable habitats and species. Basin-wide eradication is largely impossible and targeted removals or suppression campaigns, including diver-led removals or volunteer-driven derbies, can be the only feasible options. Nonetheless, success depends on rigorous site prioritization, robust ecological data, and ongoing community involvement. Even with consistent removals, reinvasion pressures from neighbouring unmanaged zones often pose a persistent threat.

Challenges
In many cases, total eradication is unattainable in open marine systems where multiple NIS overlap and reintroduction vectors remain active. Removal methods, whether mechanical, chemical, or biological, can inadvertently harm native fauna and flora if poorly controlled. Limited data on the effectiveness of different approaches for specific taxa complicates planning. Local resistance may arise if proposed removals affect activities like fishing or tourism, making it hard to sustain long-term efforts without clear evidence of ecological and socio-economic benefits.

5.5 Measure #4: Protect ecosystems & native predators

RAD component:
Resist (Ecological)

Selection rationale
Repeatedly emphasized in the literature (Chapters 3.3.7 and 3.3.8), healthy native communities and apex predators form a natural defense against NIS expansions, reducing the need for costly continuous, species-specific removals and management interventions.

Key actions
(1) Habitat preservation & restoration
- Limit pollution and sedimentation, restore structural features (reef building, Posidonia replanting).
- Target less-degraded areas first, where success rates (resistance and resilience against NIS) are higher.

(2) Rebuild predator stocks
- Expand ecosystem-based marine protected areas and no-take zones, set minimum size limits or seasonal closures for apex predators.

(3) Broader ecosystem management
- Integrate NIS considerations into ecosystem-based fisheries management (EBFM), reducing overfishing and strengthening trophic webs.
- Consider NIS targeted removals (Measure #3) to support resilience of ecosystems.
- Factor climate adaptation into restoration plans, given warming waters that favour certain invasives.

Considerations
Localized control efforts in ecologically or socio-economically significant areas, such as MPAs or nursery grounds, can preserve valuable habitats and species. Basin-wide eradication is largely impossible and targeted removals or suppression campaigns, including diver-led removals or volunteer-driven derbies, can be the only feasible options. Nonetheless, success depends on rigorous site prioritization, robust ecological data, and ongoing community involvement. Even with consistent removals, reinvasion pressures from neighbouring unmanaged zones often pose a persistent threat.

Challenges
In many cases, total eradication is unattainable in open marine systems where multiple NIS overlap and reintroduction vectors remain active. Removal methods, whether mechanical, chemical, or biological, can inadvertently harm native fauna and flora if poorly controlled. Limited data on the effectiveness of different approaches for specific taxa complicates planning. Local resistance may arise if proposed removals affect activities like fishing or tourism, making it hard to sustain long-term efforts without clear evidence of ecological and socio-economic benefits.

5.6 Measure #5: Adaptive harvest / fisheries

RAD components

Accept (Ecological), Direct (Social)

Selection rationale

Chapter 3.3 repeatedly underscored regulatory dilemmas, for instance, whether to prioritize eradication if an NIS also yields socio-economic benefits. A robust legislative framework, grounded in cost–benefit or cost–effectiveness analyses, can clarify whether an NIS fishery should be managed at MSY or targeted for maximum removal. This measure ensures that decisions reflect both ecological impacts (e.g., competition with native species) and fishery/economic values (employment, exports), reducing contradictory or knee-jerk laws. For example, if a Mediterranean region finds that blue crab revenues significantly outweigh ecological damage and can be managed under a formal stock assessment (GFCM guidelines), legislation might treat it like a regulated fishery with quotas, size limits, and season closures. Alternatively, a region finding that lionfish outcompetes keystone grazers in MPAs may uphold more eradication-driven laws (open bag limits, bounty programs) while still enabling limited harvest in non-priority sites. Cost–benefit frameworks ensure these judgments are not made arbitrarily but reflect empirical evidence and stakeholder interests. This approach acknowledges that not all NIS must be removed at any cost; if a species provides net benefits, sustainably managing it at moderate/high biomass might be the best outcome.

Key actions

(1) Regulatory adjustments

- Evaluate whether to commercialize, partially restrict, or ban an NIS based on (i) ecosystem service impacts, (ii) fishery/community value, and (iii) potential perverse incentives.
- Use scientific data and modelling (exploitation thresholds, climate-driven distribution shifts, stock assessments, growth rates) to set catch limits if you opt for sustainable management (akin to MSY and 'functional eradication').
- Tailor rules (e.g., open bag limits, no minimum size) if the NIS is highly destructive and net costs exceed benefits.
- Conversely, do-nothing or introduce sustainability fishery measures (e.g. size or quota controls) if analysis shows partial or full retention is beneficial (e.g., the species brings fishery value or controls another invasive).
- In both scenarios, ensure periodic re-evaluation if conditions (market demand, climate shifts) change. Track fishery-based measures and ecological indicators to assess success.

(2) Empower local fisheries

- Carefully evaluate the option for gear subsidies (e.g., steel leaders for pufferfish) or short-term bounties in hotspots to incentivize removal where net damages are high. Utilize recreational fishers that can remove large amounts of individuals at lower costs (e.g. 3-day competition event for *L. sceleratus* removals with small prices can be a significant conservation and simultaneously a public outreach activity)
- Provide specialized NIS licenses, potentially at reduced cost, granting fishers priority access (or exclusive rights) to exploit the NIS.
- Monitor for perverse incentives, ensuring fishers do not intentionally spread or farm the NIS.
- Invest on knowledge, technological, and infrastructure developments related to NIS exploitation.
- Offer tax breaks or streamlined licensing for businesses developing NIS-based products, contingent on verified removal or sustainable exploitation.

(3) Behavioural incentives

- Allow invasive fishing on days/zones otherwise closed for native species, encouraging fishers to pivot their effort toward the NIS.

- Promote tourism-related fishing (e.g., lionfish dives, blue crab tours) under responsible supervision, tapping new revenue streams.

Considerations

When NIS have established populations but also possess fisheries or market potential, adaptive harvest strategies can mitigate ecological damage while providing economic opportunities. Managers may adjust gear, quotas, or seasons to optimize removal of harmful NIS, in some cases opting for zero limits (no minimum size) or partial retention if the species delivers ancillary benefits. Adaptive fisheries require real-time, continuous, iterative processes and monitoring, stock assessments, and flexible regulations that can adapt to changing population dynamics or market conditions.

Challenges

Enforcement of adaptive rules is difficult in contexts with limited administrative capacity, and fisher compliance may be uncertain if profits are volatile or if regulations shift rapidly. Key information on the biology, growth rates, or ecological roles of certain NIS is often incomplete, making stock assessments and exploitation thresholds tenuous. Where a lucrative fishery for an invasive arises, there is a risk of fostering dependency on that species, reducing incentives to eradicate or further suppress it. Market fluctuations also complicate consistent removal efforts if prices drop or consumer interest decreases.

5.7 Measure #6: Market valorisation & promotion of NIS products

RAD components
Accept (Ecological), Accept/Direct (Social)

Selection rationale
Case studies (Chapter 3.3.3) show that profitable markets for lionfish, rabbitfish, blue crab, etc. can incentivize removal and recognize the importance of marketing those species for increased demand, exploitation, and potential contribution to fishers' livelihoods and markets.

Key actions

(1) Pilot programs & market research

- Support and/or provide grants or microloans to fishers and small businesses exploring new NIS products (e.g., crab canning, lionfish fillets).
- Investigate by-product uses (fish skin leather, chitin, fertilizers, bioplastics) for invasive species like blue crabs, *Caulerpa* spp. or *Lagocephalus* spp.
- Develop valorisation and market strategies for NIS products.

(2) Food safety & handling protocols

- Establish mandatory training for venomous/toxic species, ensuring safe supply chains.
- Consider ecolabeling that promotes "sustainably harvested invasives."

(3) Well-structured supply chains

- Establish and facilitate well-structured supply chains between fishers, retailers, fish markets, restaurants, etc. for NIS.

(4) Media campaigns & culinary promotion

- Partner with chefs, influencers, and tourism boards to showcase NIS recipes and local gastronomic events.
- Conduct gastronomic and educational activities to promote the consumption of NIS and increase the market demand in ways that contribute to environmental sustainability and the local economy.
- Offer tax breaks or streamlined regulations for businesses investing in large-scale NIS processing or distribution.

Considerations
Developing markets for invasive species can offset removal costs and incentivize harvest, channelling economic interests toward ecological objectives. Successful valorisation has taken forms like gastronomic promotion (blue crabs, lionfish), biotechnological uses (algal compounds), and craft products (fish leather). If integrated with appropriate regulations and consumer education, these markets can generate positive feedback loops that reduce invasive biomass. However, consistent supply chains, food safety protocols for toxic species, and stable consumer demand must be in place for initiatives to persist.

Challenges
Many potentially marketable NIS remain unfamiliar or unappealing to local consumers, necessitating prolonged marketing and outreach. The risk of perverse incentives arises if a profitable species becomes entrenched or intentionally propagated. In the case of venomous or toxic NIS, fear or safety concerns may limit consumer acceptance, while poor handling can pose public health risks. Uncertain profitability and the cost of product development can deter small businesses, and large-scale adoption may require substantial start-up investments and regulatory oversight to prevent unintended expansions of the invasive.

5.8 Measure #7: Policy alignment & legislative reforms

RAD components

Shapes all (Resist, Accept, Direct)

Selection rationale

Effective NIS management requires enabling legal frameworks across all relevant sectors (e.g., fisheries, shipping, aquaculture, aquarium trade, tourism, and environment). Harmonized legislation ensures that prevention, control, and management actions are not undermined by outdated or fragmented policies. Clear, flexible rules—grounded in socio-economic cost–benefit or cost–effectiveness analyses—provide consistent guidance on when to resist (e.g., eradicate incipient invasions), accept (e.g., allow established NIS if they bring net benefits), or direct (e.g., promote sustainable use of certain NIS).

Key actions

(1) Review & update sector-wide laws

- Conduct comprehensive reviews of existing laws, codes, and regulations that affect NIS (e.g., fisheries management, aquaculture licensing, maritime shipping, pet-trade oversight, coastal tourism) to identify legal gaps, discrepancies, conflicting strategies / goals and suggest areas for improvements.
- Ensure measures like no-take zones with artificial reefs do not inadvertently shield harmful NIS and disproportionately damage the environment.

(2) Incorporate socio-economic analyses into decision-making

- Establish standardized cost–benefit frameworks and require legislation to account for ecological impacts, market opportunities, and public health/safety when deciding whether to collapse, limit, or promote the population of a particular NIS.
- Empower authorities to adaptively modify permits/licences for commercial use (e.g., aquaculture, fisheries, ornamental trade) if new risk or economic data emerge.

(3) Align with regional & international standards

- Coordinate at a Mediterranean level with Barcelona Convention protocols, SPA/RAC, GFCM, and EU regulations (e.g., 1143/2014 on invasive alien species). Seek mutual agreement of risk assessments, watch lists, and rapid-response protocols.
- Strengthen pathway-specific regulations including synergy with international conventions (e.g., IMO BWM Convention) for shipping and alignment aquaculture licensing with regional best practices to reduce accidental introductions.

(4) Continuous monitoring, evaluation & adaptation

- Require periodic reviews of legislation's effectiveness at preventing new introductions, safeguarding social and economic security while mitigating ecological impacts.
- Allow stakeholder input on proposed amendments, ensuring laws remain relevant to evolving ecological and socio-economic conditions.

Considerations

Effective NIS management spans fisheries, shipping, aquaculture, and coastal tourism, demanding coherent legal frameworks that address introduction pathways and regulate control measures. Socio-economic cost–benefit analyses can ensure legislation accounts for local livelihoods and public health, providing a structured basis for deciding whether to restrict or promote certain invasive species. Aligning with regional or international standards (e.g., IMO, GFCM, EU regulations) increases the likelihood that preventive actions, risk assessments, and watch lists can be mutually recognized, fostering shared best practices.

Challenges

Policy reforms often proceed slowly due to bureaucratic inertia, political lobbying, or conflicting economic interests. Some Mediterranean countries struggle to collect reliable data on the economic impacts or ecological risks of NIS, impeding accurate cost–benefit evaluations. Fragmented legal frameworks across borders and uneven enforcement capacity undermine consistent measures, resulting in patchy outcomes. Even when progressive laws are enacted, insufficient monitoring or low penalties for noncompliance can negate their intended effect.

5.9 Measure #8: Education & public awareness

RAD components
Horizontal measure for Resist, Accept, Direct

Selection rationale
Education and public awareness underpin all management actions including fisheries, market, acceptance to removals and/or exploitation, etc. Furthermore, across case studies (Chapter 3.3.4), lack of awareness about venomous species, aquarium releases, and hull maintenance repeatedly facilitated NIS spread. Effective education fosters a "stop the spread" culture and increases acceptance of removal strategies.

Key actions

(1) Targeted campaigns

- Use multiple media (e.g., social media, local radio, signage) to increase public awareness and clarify how to recognize NIS, why they are harmful, and what actions to take (e.g., reporting sightings, choosing it in the market).
- Create guidelines that explain safe disposal methods for aquarium and pet trade, discourage fishery releases for harmful NIS, and discourage aquarium releases and introductions/spread of NIS.
- Promote "Clean Hull" campaigns among boat owners, yacht clubs, and marinas to reduce biofouling and potential new introductions.
- Run social media, local radio, and signage campaigns to highlight species ID, risks, and best practices.
- Mobilize volunteers to participate in citizen science activities and management interventions (e.g. removals or markets)
- Distinguish venomous vs. poisonous species to avoid confusion (e.g., lionfish vs. pufferfish).

(2) Capacity building & citizen science

- Targeted stakeholder training: Incorporate NIS modules into courses for fishers, dive operators, pet shops, and aquaculture practitioners.
- Encourage volunteers (citizen science mobilization) to report invasive sightings (e.g., with smartphone apps), join local removal events (such as lionfish "derbies"), and gather data crucial for monitoring.

(3) Showcasing successes

- Publicize successful removal events, highlight economic or environmental wins (e.g., successful valorisation of lionfish or blue crabs).
- Leverage "ambassadors"—fishers, divers, chefs, or community leaders who have turned an NIS problem into an economic or conservation opportunity.
- Collaborate with popular chefs, influencers, or festivals to feature NIS-based recipes or products, emphasizing sustainability and community involvement.

Considerations
In many instances, lack of knowledge underlies the inadvertent spread of invasive species, whether through fishery and aquarium releases, hull fouling, or reluctance to try an "alien" fish. Tailored awareness campaigns and capacity-building initiatives across user groups (fishers, aquarists, diving operators, and the general public) can enhance the effectiveness of all other measures by promoting vigilant detection, safer handling, and acceptance of necessary controls. Showcasing successes, such as

lucrative fisheries or culinary uses derived from NIS, can also foster positive engagement.

Challenges

Long-term shifts in public or stakeholder behaviour may require sustained efforts that extend beyond single projects or short campaigns. People whose livelihoods depend on certain NIS, or who benefit from them in other ways (tourism curiosities, for instance), may resist messages urging removal. Education strategies that lack practical guidance or financial support for alternative practices often achieve limited impact. Reaching across linguistic, cultural, and socio-economic differences in the Mediterranean can also pose significant outreach hurdles.

5.10 Measure #9: Transboundary collaboration & stakeholder co-management

RAD component

Spans Resist, Accept, Direct (Social)

Selection rationale

The Mediterranean Sea comprises numerous jurisdictions, making it easy for gaps in one area to undermine progress in another. Equally, local resource users (e.g., fishers, divers, aquaculture operators) have critical roles and knowledge that can enhance or hinder NIS management. Effective responses therefore require both cross-border collaboration—to coordinate policy, data, and enforcement—and stakeholder co-management at the local level, ensuring buy-in and leveraging community expertise.

Key actions

(1) Regional cooperation frameworks

- Strengthen or create formal committees under GFCM, UNEP/MAP, or SPA/RAC to synchronize horizon scanning, risk assessments, and emergency responses (e.g., if a high-impact species suddenly appears).
- Agree on standardized monitoring protocols and region-wide sampling approaches (eDNA, visual surveys) for ports, marinas, and MPAs; share data in real time to detect and contain new incursions faster.
- Develop or participate in cooperative research projects (e.g., EU-funded) to fill knowledge gaps on high-risk species, ecological impacts, or best control practices.

(2) Multistakeholder co-management

- Integrate NIS-specific objectives into existing fisheries or coastal councils. Ensure meaningful representation from fishers, conservation groups, tourism operators, local municipalities, and scientific experts.
- Train stakeholder representatives in relevant NIS issues (identification, safe handling, reporting channels) and encourage knowledge exchange / peer-to-peer learning (e.g., fishers in one area sharing effective gear adaptations to reduce bycatch of natives while targeting invasives).
- Work with MPA managers and adjacent communities to decide if and how to remove NIS within protected zones, balancing restoration goals with local livelihoods.

(3) Conflict resolution and networking

- Organize structured sessions to resolve disputes between different interests—e.g., fishers benefiting from a newly profitable NIS vs. conservation groups wanting strict eradication in MPAs.
- Use socio-economic and ecological data to clarify potential gains and losses under various NIS strategies, helping stakeholders find fair compromises.
- Where species migrate across national boundaries, promote consistent rules on harvest, sales, or protective measures to prevent “policy leakage” (i.e., an invader controlled in one country but thriving next door).

(4) Infrastructure & policy alignment

- Coordinate investments in shared facilities (e.g., quarantine stations, hull-cleaning docks) and patrols, preventing duplication of effort and lowering costs.
- Explore establishing special removal areas in shared waters, with unified rules on fishing, culling invasive species, and enforcement.
- Maintain open channels for updating management agreements, ensuring stakeholders adapt actions and rules as invasions or market conditions evolve.

Considerations

The Mediterranean's interconnected seas and varied national jurisdictions call for shared policies, data, and interventions. Regional bodies, such as GFCM or SPA/RAC, can help harmonize risk assessments and horizon scanning, while local co-management committees that include fishers, conservationists, scientists, and tourism operators ensure that measures address realities on the ground. By sharing infrastructure, exchanging best practices, and pooling resources, Mediterranean countries can avoid duplicative or conflicting approaches.

Challenges

Long-term shifts in public or stakeholder behaviour may require sustained efforts that extend beyond single projects or short campaigns. People whose livelihoods depend on certain NIS, or who benefit from them in other ways (tourism curiosities, for instance), may resist messages urging removal. Education strategies that lack practical guidance or financial support for alternative practices often achieve limited impact. Reaching across linguistic, cultural, and socio-economic differences in the Mediterranean can also pose significant outreach hurdles.

6 AN EXAMPLE OF THE MEASURES' APPLICATION USING RAD LENSES: THE CASE OF BLUE CRAB MANAGEMENT IN THE MEDITERRANEAN

In Chapter 5, nine measures were proposed to address NIS in the Mediterranean, ranging from enhanced biosecurity and standardized monitoring to targeted removals and market valorisation. While these measures can be applied universally, each country's ecological vulnerability and socio-economic situation influences how they are deployed—whether geared toward Resist (limiting establishment), Accept (managing impacts and uses), or Direct (actively promoting new economic pathways).

Blue crabs (*Callinectes sapidus* and *Portunus segnis*) have rapidly established in many parts of the Mediterranean and invasions serves as an excellent example of varied responses that reflect the distinct socio-economic contexts and ecological priorities of each country. While certain elements of a cohesive, region-wide strategy exist, actual management thus far remains highly localized. Although several countries have enacted management actions, the overall approach remains patchy. Some focus on rapid suppression to protect biodiversity and vulnerable lagoon ecosystems (a strong **Resist** stance from an ecological perspective), while others view blue crab primarily as an economic opportunity and are thus **Accepting or even Directing** socio-economic transformations (e.g., building new markets, creating industrial processing). For a concerted and coordinated response, it is important to recognize and decide on the approach before following any management measures.

Below are highlights from five countries, Spain, France, Italy, Tunisia, and Türkiye, illustrating how **local contexts shape either partial or more comprehensive applications of the RAD framework**. The information was largely extracted from UNEP/MAP-SPA/RAC (2025). Figure 25 presents a tiered visualization of how the nine measures (Chapter 5) can be layered under Resist–Accept–Direct. The top (foundational) tier outlines the baseline (horizontal) measures that can be applied regionally, horizontally in a consistent and coordinated manner such as strengthened biosecurity or stakeholder engagement—underpinning any robust management strategy, regardless of stance. The second tier shows how certain actions (such as localized control or adaptive harvest) can scale differently if a country aims to Resist (heavy culling, habitat protections), Accept (selective removals, moderate exploitation), or Direct (intensive fishery promotion, industrial valorisation). Examining the blue crab case in more detail makes it clear how these measures converge or diverge across Spain, France, Italy, Tunisia, and Türkiye.

Foundational (horizontal) measures for all contexts

Biosecurity and early detection (#1): Adopt eDNA or Rapid Assessment Surveys in key ports/lagoons (areas where the species is not yet established)

Standardized, multi-parameter monitoring (#2): Integrate fishery logbooks, eDNA results, and environmental data; Maintain consistent sentinel sites for early detection and trends

Policy alignment & legislative reforms (#7): Use cost–benefit analyses to guide decisions (e.g., culling vs fishery).

Education & public awareness (#8): Campaigns in ports, markets, and local media; Workshops for fishers and citizen science apps for sightings.

Transboundary collaboration & co-management (#9): Share real-time data with neighbouring countries via GFCM, SPA/RAC; Standardize mechanisms and establish cross-border or regional committees

Local actions that could be applied depending on environmental and socioeconomic contexts

	Resist	**Accept**	**Direct**
Ecological measures	*Priority: limit or eradicate blue crabs*	*Tolerate partial presence; manage impact*	*Rare and highly risky; not recommended*
Localized control in priority sites (#3)	- Aggressive culling in high-value lagoons (e.g., bounties). - Severely limit crab in protected MPAs, with rapid response to new incursions.	- Use targeted removals only in areas with conflicts (e.g., clam farms). - Let crab persist outside critical habitats.	- Minimal culling, only in top-priority MPAs. - Primarily allow or encourage crab presence for fishery exploitation.
Protect ecosystems & native predators (#4)	- Comprehensive predator protection (bans on key predator harvest). - Active habitat restoration (reef building, lagoon improvements) to limit crab expansion.	- Focus on predator support if crab becomes too dense in certain sites. - Restore habitats only where it offsets major crab damage (e.g., to seagrass).	- Possibly engineer habitats that balance native predators with profitable crab stocks. - Building artificial reefs for tourism & crab fishery).
Social measures	*Limit commercial entrechment, strongly restrict fisheries or markets*	*Balance partial fisheries with biodiversity concerns*	*Promote large-scale exploitation, industrial processing, brand-building*
Adaptive harvest / fisheries (#5)	- Maximum removal: no size limits, open seasons, or bounty-based harvesting. - Compensation schemes to ensure continuous crab extraction.	- Regulated fishery (e.g., no harvest of egg-bearing females). - Target culling in sensitive areas; moderate fishery in others.	- Full integration into fishery management plans (quotas, stock assessments). - Provide specialized licenses, gear improvements, marketing support.
Market valorisation & promotion (#6)	- Discourage or ban large-scale sales to avoid entrenching crab. - Provide minimal or no market presence to keep control options open.	- Allow local commerce in areas already invaded. - Encourage partial consumer acceptance while monitoring ecological risks.	- Promote new products, industrial processing, exports, branding. - Offer subsidies or incentives for factories and new product lines.

Country snapshots (Ecological vs. Social)

Spain: Ecological ~ Resist in sensitive lagoons, partial Accept for fishery in Catalonia; Social ~ Accept (some commercial sale) but not fully Direct.

France (Corsica): Ecological ~ Strong Resist (in lagoon plan); Social ~ Resist (no major fishery).

Italy: Ecological ~ Resist in lagoons, might Accept if minimal impact; Social ~ partial Accept if markets expand.

Tunisia: Ecological ~ minimal Resist in favour of expansion; Social ~ Direct (industrial promotion).

Türkiye: Ecological ~ Weak Resist (uncoordinated culls), Social ~ Accept / Direct (opportunistic exporting).

Figure 25. Example of a two-tier application (horizontally/regionally and localized actions) of the nine measures for blue crab management under the RAD framework

6.1 Spain

In Spain, *Callinectes sapidus* is excluded from the national catalogue of invasive alien species under Decree 630/2013 and is formally classified as a commercial species. A professional fishing plan aims to reduce its abundance by permitting regulated landings, especially in Catalonia, where reported catches rose from 15.8 tons in 2017 to around 450 tons in 2019; a level that has remained stable and yields approximately 1.5 million euros annually. Although the initial objective was to limit population growth and curb its ecological impact, the reality is that controlling an invasion by means of a profitable fishery raises concerns. Spanish authorities caution that sustaining commercial interest in the crab may complicate future eradication or more intensive control measures should they become necessary. In Balearic waters, the crab is largely harvested by recreational fishers rather than professionals, though commercial capture is technically allowed. Economic viability remains low in the islands, so most market supply there still originates from mainland Spain. Meanwhile, granting limited recreational fishing permits has proved helpful in certain localities to reduce crab numbers. Overall, Spain blends an ecological drive to minimize impacts (**a partial Resist stance**) with the **social and economic acceptance** of *C. sapidus* as a fishery resource.

6.2 France (Corsica)

France introduced a Territorial Plan for controlling the American blue crab in Corsica in 2024, integrating five national pillars on invasive alien species: prevention, management and restoration, knowledge, communication, and governance. In lagoon areas considered ecologically vital, the plan focuses on site-specific removals and timing periods to suppress crab populations and minimize harm to native fauna. This approach **strongly emphasizes Resist** from an ecological perspective: the national and regional authorities aim to prevent or contain proliferation, rather than promote commercial use. There is not, however, a major local fishery for the blue crab in Corsica, so the **social or economic dimension remains limited.**

6.3 Italy

The Italian Blue Crab Containment Plan for 2025–2026 sets aside 10 million euros to safeguard biodiversity and mitigate economic losses, particularly among clam-farming operations in lagoon areas. The presence of blue crabs (*C. sapidus*) has severely depleted the Philippine clams (*Ruditapes philippinarum*) production in lagoons of Italy (Tiralongo *et al.*, 2025). Additional decrees authorize reimbursements for fishers who remove blue crabs (about 1 EUR/kg) and promote gear innovations that can selectively target crabs without harming native species. Measures also include disposing of crab biomass, introducing morphological changes to lagoon environments, and providing limited support for commercial sales of the crab. **Ecologically, Italy's standpoint is largely Resist**, with extensive funding directed at culling ovigerous females and minimizing lagoon damage. Still, there are references in the containment plan to a **possible commercial development of the crab if markets further evolve**. This dual posture, trying to eliminate crabs in critical habitats while allowing some sales, demonstrates a flexible strategy that can **pivot from Resist to partial Accept** if the fishery becomes beneficial for local livelihoods. Effective monitoring and stakeholder coordination under working groups remain crucial for adapting these efforts over time.

6.4 Tunisia

Tunisia's policy differs significantly, having responded with a national plan that **actively promotes blue crabs fishing, industrial processing, and marketing.** The government guarantees payment to fishers of about 0.8 USD/kg (half publicly subsidized, half privately financed), thereby ensuring the crabs are kept out of nets rather than discarded alive. Over 25,000 tons of *Portunus segnis* were caught in 2022, with around 6,000 tons exported for nearly 30 million USD (Souissi *et al.*, 2024). Tunisia has also encouraged investment in factories dedicated to crab processing: nearly half of the 49 seafood factories in the country handle crabs, generating hundreds of jobs and potentially transforming the crab from a "nuisance" into a source of income. This reflects a **strong Direct stance on socio-economic grounds.** While some minimal precautions prevent live re-release of crabs, the primary focus remains building value chains, underlining how robust market potential, combined with favourable labour costs and supportive policies, can lead to large-scale exploitation.

6.5 Türkiye

In Türkiye, *Callinectes sapidus* has emerged as an economically valuable resource in areas such as the Göksu Delta, Dalyan, and the Akyatan lagoon. Harvesting has increased, and exports reportedly vary between 300 and 500 tons annually, often commanding high prices. Promotional events raise awareness and highlight the crab's gastronomic or cultural appeal. Although these local initiatives have boosted livelihoods, ecological impacts remain only partially addressed, since Türkiye has no unified national management policy for alien species, nor a formal Resist posture. Instead, the focus is on capturing and selling the crab, **an opportunistic approach that points loosely to Accept or Direct** for social and economic reasons. Without consistent legislation or risk assessments, the long-term ecological consequences remain uncertain.

6.6 Lessons from the tiered, climate-adaptive example

These country-specific cases show how the Mediterranean manages blue crabs in widely different ways, combining partial Resist measures with open or active promotion (Accept or Direct) depending on socio-economic demands. Even where Resist is crucial for preserving lagoon habitats, a concurrent commercialization of crabs can create trade-offs. Conversely, a fully Direct stance, as in Tunisia, has yielded strong economic returns but might heighten ecological risks if crab populations keep expanding. Each local setting, such as Italy's reliance on clam farming, **calls for adaptive, place-based solutions**.

At the same time, **streamlined biosecurity, standardized monitoring, and stronger legislative alignment remain essential across the region**. Coordinated **early detection programs** would help each country **adapt local responses**—whether culling crabs in key habitats or facilitating industrial harvest—based on **up-to-date science and mutually shared data**. Ultimately, the Mediterranean's experience demonstrates that balancing ecological imperatives with economic opportunities calls for robust local autonomy, guided by overarching frameworks that prevent short-term gains from undermining long-term ecosystem health. The RAD model's flexibility also supports climate adaptation, helping authorities address range shifts, adjust fishery policies to evolving conditions, and protect vulnerable habitats under compounding stressors.

REFERENCES

Aglieri, G., Quattrocchi, F., Mariani, S., Baillie, C., Spatafora, D., Di Franco, A., Turco, G., Tolone, M., Di Gerlando, R., & Milazzo, M. (2023). Fish eDNA detections in ports mirror fishing fleet activities and highlight the spread of non-indigenous species in the Mediterranean Sea. *Marine pollution bulletin*, *189*, 114792.

Akgun, Y., & Akoglu, E. (2023). Randall's Threadfin Bream (Nemipterus randalli, Russell 1986) Poses a Potential Threat to the Northeastern Mediterranean Sea Food Web. *Fishes*, *8*(8), 402.

Andersen, T., Carstensen, J., Hernández-García, E., & Duarte, C. M. (2009). Ecological thresholds and regime shifts: approaches to identification. *Trends in Ecology & Evolution*, *24*(1), 49-57.

Anderson, L. W. (2005). California's reaction to Caulerpa taxifolia: a model for invasive species rapid response. *Biological Invasions*, *7*, 1003-1016.

Aplet, G. H., & Cole, D. N. (2010). The trouble with naturalness: Rethinking park and wilderness goals. *Beyond naturalness: Rethinking park and wilderness stewardship in an era of rapid change*, *12*, 21-22.

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of informetrics*, *11*(4), 959-975.

Azzurro, E., Bolognini, L., Dragičević, B., Drakulović, D., Dulčić, J., Fanelli, E., Grati, F., Kolitari, J., Lipej, L., & Magaletti, E. (2019a). Detecting the occurrence of indigenous and non-indigenous megafauna through fishermen knowledge: A complementary tool to coastal and port surveys. *Marine pollution bulletin*, *147*, 229-236.

Azzurro, E., Sbragaglia, V., Cerri, J., Bariche, M., Bolognini, L., Ben Souissi, J., Busoni, G., Coco, S., Chryssanthi, A., & Fanelli, E. (2019b). Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: A large-scale survey based on local ecological knowledge. *Global Change Biology*, *25*(8), 2779-2792.

Azzurro, E., Sbragaglia, V., Cerri, J., Bariche, M., Bolognini, L., Souissi, J. B., Busoni, G., Coco, S., Chryssanthi, A., & Garrabou, J. (2019c). The shifting distribution of Mediterranean fishes: a spatio-temporal assessment based on Local Ecological Knowledge.

Azzurro, E., Smeraldo, S., & D'Amen, M. (2022). Spatio-temporal dynamics of exotic fish species in the Mediterranean Sea: Over a century of invasion reconstructed. *Global Change Biology*, *28*(21), 6268-6279.

Azzurro, E., Bahri, T., Valbo-Jørgensen, J., Ma, X., Strafella, P., & Vasconcellos, M. (2024a). *Fisheries responses to invasive species in a changing climate: Lessons learned from case studies*. Food & Agriculture Org.

Azzurro, E., Bahri, T., Valbo-Jørgensen, J., Ma, X., Strafella, P., Vasconcellos, M., Behrens, J. W., Falk-Andersson, J., Giakoumi, S., & Grosholz, E. D. (2024b). Good practices to address aquatic invasions. In *Fisheries responses to invasive species in a changing climate: Lessons learned from case studies* (pp. 9-41). Food and Agriculture Organization of the United Nations.

Azzurro, E., Bahri, T., Valbo-Jørgensen, J., Ma, X., Strafella, P., Vasconcellos, M., Behrens, J. W., FalkAndersson, J., , Giakoumi, S., Grosholz, E. D., Harris, H. E., Hall-Spencer, J., Keane, J. P., Kleitou, P., Kourantidou, M., Marshall, B., Nakamura, Y., Natugonza, V., Shiganova, T., Singh, A., . . . Damme, P. A. V. (2024c). Good practices to address aquatic invasions. In *Fisheries responses to invasive species in a changing climate: Lessons learned from case studies* (pp. 9-41). Food and Agriculture Organization of the United Nations.

Azzurro, E., Bonanomi, S., Chiappi, M., De Marco, R., Luna, G. M., Cella, M., Guicciardi, S., Tiralongo, F., Bonifazi, A., & Strafella, P. (2024d). Uncovering unmet demand and key insights for the invasive blue crab (Callinectes sapidus) market before and after the Italian outbreak: Implications for policymakers and industry stakeholders. *Marine Policy*, *167*, 106295.

Bacher, S., Galil, B., Nuñez, M., Ansong, M., Cassey, P., Dehnen-Schmutz, K., Fayvush, G., Hiremath, A., Ikegami, M., & Martinou, A. (2023). Chapter 4: Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life. *Thematic Assessment Report on*

Invasive Alien Species and Their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn. https://doi. org/10.5281/zenodo, 7430731.

Badjeck, M.-C., Allison, E. H., Halls, A. S., & Dulvy, N. K. (2010). Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy*, *34*(3), 375-383.

Bailey, S. A., Brown, L., Campbell, M. L., Canning-Clode, J., Carlton, J. T., Castro, N., Chainho, P., Chan, F. T., Creed, J. C., & Curd, A. (2020). Trends in the detection of aquatic non-indigenous species across global marine, estuarine and freshwater ecosystems: A 50-year perspective. *Diversity and distributions*, *26*(12), 1780-1797.

Bartolo, A. G., Tsiamis, K., & Küpper, F. C. (2021). Identifying hotspots of non-indigenous species' high impact in the Maltese islands (Central Mediterranean Sea). *Marine pollution bulletin*, *164*, 112016.

Bas, C. (2009). The Mediterranean: a synoptic overview. *Contributions to Science*, *5*(1), 25-39.

Bereza, D., Grey, E., & Shenkar, N. (2023). Prioritizing management of high-risk routes and ports by vessel type to improve marine biosecurity efforts. *Journal of Environmental Management*, *336*, 117597.

Bernardeau-Esteller, J., Marín-Guirao, L., Sandoval-Gil, J. M., García-Muñoz, R., Ramos-Segura, A., & Ruiz, J. M. (2020). Evidence for the long-term resistance of Posidonia oceanica meadows to Caulerpa cylindracea invasion. *Aquatic Botany*, *160*, 103167.

Bianchi, C. N., Azzola, A., Cocito, S., Morri, C., Oprandi, A., Peirano, A., Sgorbini, S., & Montefalcone, M. (2022). Biodiversity monitoring in Mediterranean marine protected areas: Scientific and methodological challenges. *Diversity*, *14*(1), 43.

Boudouresque, C.-F. (2004). Marine biodiversity in the Mediterranean: status of species, populations and communities. *Travaux scientifiques du Parc national de Port-Cros*, *20*, 97-146.

Britton, J. R., Lynch, A. J., Bardal, H., Bradbeer, S. J., Coetzee, J. A., Coughlan, N. E., Dalu, T., Tricarico, E., Gallardo, B., & Lintermans, M. (2023). Preventing and controlling nonnative species invasions to bend the curve of global freshwater biodiversity loss. *Environmental Reviews*, *31*(2), 310-326.

Bulleri, F., Badalamenti, F., Iveša, L., Mikac, B., Musco, L., Jaklin, A., Rattray, A., Fernández, T. V., & Benedetti-Cecchi, L. (2016). The effects of an invasive seaweed on native communities vary along a gradient of land-based human impacts. *PeerJ*, *4*, e1795.

Calado, R. (2012). Invasive alien crabs can be used for marine aquariums—Turning a threat into profit. *Crustaceana*, 257-265.

Carreño, A., & Lloret, J. (2021). Environmental impacts of increasing leisure boating activity in Mediterranean coastal waters. *Ocean & Coastal Management*, *209*, 105693.

Carvalho, S., Shchepanik, H., Aylagas, E., Berumen, M. L., Costa, F. O., Costello, M. J., Duarte, S., Ferrario, J., Floerl, O., & Heinle, M. (2023). Hurdles and opportunities in implementing marine biosecurity systems in data-poor regions. *BioScience*, *73*(7), 494-512.

Cebrian, E., Linares, C., Marschal, C., & Garrabou, J. (2012). Exploring the effects of invasive algae on the persistence of gorgonian populations. *Biological Invasions*, *14*, 2647-2656.

Cengiz, S., & Cavas, L. (2008). Removal of methylene blue by invasive marine seaweed: Caulerpa racemosa var. cylindracea. *Bioresource technology*, *99*(7), 2357-2363.

Cerrano, C., Milanese, M., & Ponti, M. (2017). Diving for science-science for diving: volunteer scuba divers support science and conservation in the Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(2), 303-323.

Cerri, J., Chiesa, S., Bolognini, L., Mancinelli, G., Grati, F., Dragičević, B., Dulčic, J., & Azzurro, E. (2020). Using online questionnaires to assess marine bio-invasions: A demonstration with recreational fishers and the Atlantic blue crab Callinectes sapidus (Rathbun, 1986) along three Mediterranean countries. *Marine pollution bulletin*, *156*, 111209.

Chaffin, B. C., Gosnell, H., & Cosens, B. A. (2014). A decade of adaptive governance scholarship: synthesis and future directions. *Ecology and society*, *19*(3).

Chaffin, B. C., Garmestani, A. S., Angeler, D. G., Herrmann, D. L., Stow, C. A., Nyström, M., Sendzimir, J., Hopton, M. E., Kolasa, J., & Allen, C. R. (2016). Biological invasions, ecological resilience and adaptive governance. *Journal of Environmental Management*, *183*, 399-407.

Christidis, G., Batziakas, S., Peristeraki, P., Tzanatos, E., Somarakis, S., & Tserpes, G. (2024). Another One Bites the Net: Assessing the Economic Impacts of Lagocephalus sceleratus on Small-Scale Fisheries in Greece. *Fishes*, *9*(3), 104.

Cilenti, L., Lago, N., Lillo, A. O., Li Veli, D., Scirocco, T., & Mancinelli, G. (2024). Soft-Shell Production of the Invasive Atlantic Blue Crab Callinectes sapidus in the Lesina Lagoon (SE Italy): A First Assessment. *Journal of marine science and engineering*, *12*(2), 310.

Clavero, M., Franch, N., Bernardo-Madrid, R., López, V., Abelló, P., Queral, J. M., & Mancinelli, G. (2022). Severe, rapid and widespread impacts of an Atlantic blue crab invasion. *Marine pollution bulletin*, *176*, 113479.

Coelho, P., Carvalho, F., Goulding, T., Chainho, P., & Guerreiro, J. (2021). Management models of the Manila clam (Ruditapes philippinarum) fisheries in invaded European coastal systems. *Frontiers in Marine Science*, *8*, 685307.

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais Lasram, F., Aguzzi, J., Ballesteros, E., Bianchi, C. N., Corbera, J., & Dailianis, T. (2010). The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PloS one*, *5*(8), e11842.

Coppari, M., Roveta, C., Di Camillo, C., Garrabou, J., Lucrezi, S., Pulido Mantas, T., & Cerrano, C. (2024). The pillars of the sea: strategies to achieve successful marine citizen science programs in the Mediterranean area. *BMC Ecology and Evolution*, *24*(1), 100.

Corrales, X., Coll, M., Ofir, E., Heymans, J. J., Steenbeek, J., Goren, M., Edelist, D., & Gal, G. (2018). Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming. *Scientific reports*, *8*(1), 1-16.

Côté, I. M., & Darling, E. S. (2010). Rethinking ecosystem resilience in the face of climate change. *PLoS biology*, *8*(7), e1000438.

Critchley, A., Farnham, W., & Morrell, S. (1986). An account of the attempted control of an introduced marine alga, Sargassum muticum, in southern England. *Biological Conservation*, *35*(4), 313-332.

Crocetta, F., Shokouros-Oskarsson, M., Doumpas, N., Giovos, I., Kalogirou, S., Langeneck, J., Tanduo, V., Tiralongo, F., Virgili, R., & Kleitou, P. (2021). Protect the natives to combat the aliens: Could Octopus vulgaris Cuvier, 1797 be a natural agent for the control of the lionfish invasion in the Mediterranean Sea? *Journal of marine science and engineering*, *9*(3), 308.

Crowley, S. L., Hinchliffe, S., & McDonald, R. A. (2017). Conflict in invasive species management. *Frontiers in Ecology and the Environment*, *15*(3), 133-141.

D'Amen, M., & Azzurro, E. (2020). Lessepsian fish invasion in Mediterranean marine protected areas: a risk assessment under climate change scenarios. *ICES Journal of Marine Science*, *77*(1), 388-397.

de Carvalho-Souza, G. F., Kourantidou, M., Laiz, I., Nuñez, M. A., & González-Ortegón, E. (2024). How to deal with invasive species that have high economic value? *Biological Conservation*, *292*, 110548.

Di Cintio, A., Sulanke, E., Di Genio, S., Niccolini, F., Sbragaglia, V., Visintin, F., & Bulleri, F. (2023). A socio-economic characterization of Tuscan Archipelago's artisanal fisheries: Status quo, challenges and new business opportunities. *Regional Studies in Marine Science*, *68*, 103275.

Diciotti, R., Culurgioni, J., Serra, S., Trentadue, M., Chessa, G., Satta, C., Caddeo, T., Luglie, A., Sechi, N., & Fois, N. (2016). First detection of Mnemiopsis leidyi (Ctenophora, Bolinopsidae) in Sardinia (S'Ena Arrubia Lagoon, Western Mediterranean): a threat for local fishery and species recruitment. *Mediterranean Marine Science*, *17*(3), 714-719.

Diga, R., Gilboa, M., Moskovich, R., Darmon, N., Amit, T., Belmaker, J., & Yahel, G. (2023). Invading bivalves replaced native Mediterranean bivalves, with little effect on the local benthic community. *Biological Invasions*, *25*(5), 1441-1459.

Dikou, A. (2024). Depletion fishing of the alien fish species Siganus luridus, S. rivulatus, Pterois miles, and Etrumeus golanii in the Mediterranean Sea-gear, ecosystem impacts, and resolution. *Fisheries Research*, *278*, 107095.

Dimitriadis, C., Fournari-Konstantinidou, I., Sourbès, L., Koutsoubas, D., & Katsanevakis, S. (2021). Long term interactions of native and invasive species in a marine protected area suggest complex cascading effects challenging conservation outcomes. *Diversity*, *13*(2), 71.

Dimitriadis, C., Marampouti, C., Calò, A., Di Franco, A., Giakoumi, S., Di Franco, E., Di Lorenzo, M., Gerovasileiou, V., Guidetti, P., & Pey, A. (2024). Evaluating the long term effectiveness of a Mediterranean marine protected area to tackle the effects of invasive and range expanding herbivorous fish on rocky reefs. *Marine Environmental Research*, *193*, 106293.

Dimitriou, A. C., Chartosia, N., Hall-Spencer, J. M., Kleitou, P., Jimenez, C., Antoniou, C., Hadjioannou, L., Kletou, D., & Sfenthourakis, S. (2019). Genetic data suggest multiple introductions of the lionfish (Pterois miles) into the Mediterranean Sea. *Diversity*, *11*(9), 149.

Ersönmez, H., Özyurt, C. E., Mavruk, S., Yıldız, T., & Ulman, A. (2023). An in-depth study of the biology, trophic ecology and catchability of the invasive pufferfish Lagocephalus sceleratus from southern Turkey, eastern Mediterranean Sea. *Scientia Marina*, *87*(4), e075-e075.

Evangelopoulos, A., Karampetsis, D., Christidis, A., Gubili, C., Sapounidis, A., Adamidou, A., Kamidis, N., & Koutrakis, E. (2024). Alien fish species in the North Aegean Sea: a review of their distributions integrating unpublished fisheries data.

FAO. (2024). *FishStat: Global capture production 1950-2022. In FishStatJ*. Retrieved Accessed on 29 December 2024 from Available at www.fao.org/fishery/en/statistics/software/fishstatj

Faulkner, K. T., Robertson, M. P., & Wilson, J. R. (2020). Stronger regional biosecurity is essential to prevent hundreds of harmful biological invasions. *Global Change Biology*, *26*(4), 2449-2462.

Frem, M., Nardelli, L., Petrontino, A., Navrud, S., Colonna, M. A., Fucilli, V., & Bozzo, F. (2024). Public preferences for edible invasive alien marine species-The Atlantic blue crab in southern Italy. *NeoBiota*, *96*, 19-47.

Galil, B. (2017). Eyes wide shut: managing bio-invasions in Mediterranean marine protected areas. *Management of marine protected areas: A network perspective*, 187-206.

Galil, B. S., Marchini, A., & Occhipinti-Ambrogi, A. (2018). East is east and West is west? Management of marine bioinvasions in the Mediterranean Sea. *Estuarine, Coastal and Shelf Science*, *201*, 7-16.

Galil, B. S. (2023). A sea, a canal, a disaster: the suez canal and the transformation of the mediterranean biota. In *The suez canal: past lessons and future challenges* (pp. 199-215). Springer.

Garcia-Lozano, C., Pueyo-Ros, J., Canelles, Q., Latombe, G., Adriaens, T., Bacher, S., Cardoso, A. C., Cleary, M., Coromina, L., Courchamp, F., Dawson, W., de Groot, M., Essl, F., Gallardo, B., Golivets, M., Huusela, E., Jauni, M., Jelaska, S. D., Jeschke, J. M., . . . Roura-Pascual, N. (2025). Management measures and trends of biological invasions in Europe: A survey-based assessment of local managers. *Global Change Biology*, *31*(1), e70028.

García-Barón, I., Giakoumi, S., Santos, M. B., Granado, I., & Louzao, M. (2021). The value of time-series data for conservation planning. *Journal of Applied Ecology*, *58*(3), 608-619.

Giakoumi, S., Guilhaumon, F., Kark, S., Terlizzi, A., Claudet, J., Felline, S., Cerrano, C., Coll, M., Danovaro, R., & Fraschetti, S. (2016). Space invaders; biological invasions in marine conservation planning. *Diversity and distributions*, *22*(12), 1220-1231.

Giakoumi, S., Katsanevakis, S., Albano, P. G., Azzurro, E., Cardoso, A. C., Cebrian, E., Deidun, A., Edelist, D., Francour, P., & Jimenez, C. (2019a). Management priorities for marine invasive species. *Science of the total environment*, *688*, 976-982.

Giakoumi, S., Pey, A., Di Franco, A., Francour, P., Kizilkaya, Z., Arda, Y., Raybaud, V., & Guidetti, P. (2019b). Exploring the relationships between marine protected areas and invasive fish in the world's most invaded sea. *Ecological Applications*, *29*(1), e01809.

Giakoumi, S., Pey, A., Thiriet, P., Francour, P., & Guidetti, P. (2019c). Patterns of predation on native and invasive alien fish in Mediterranean protected and unprotected areas. *Marine Environmental Research*, *150*, 104792.

Giangrande, A., Pierri, C., Del Pasqua, M., Gravili, C., Gambi, M. C., & Gravina, M. F. (2020). The Mediterranean in check: Biological invasions in a changing sea. *Marine Ecology*, *41*(2), e12583.

Giovos, I., Bernardi, G., Romanidis-Kyriakidis, G., Marmara, D., & Kleitou, P. (2018). First records of the fish Abudefduf sexfasciatus (Lacepède, 1801) and Acanthurus sohal (Forsskål, 1775) in the Mediterranean Sea.

Giovos, I., Kleitou, P., Poursanidis, D., Batjakas, I., Bernardi, G., Crocetta, F., Doumpas, N., Kalogirou, S., Kampouris, T. E., & Keramidas, I. (2019). Citizen-science for monitoring marine invasions and stimulating public engagement: a case project from the eastern Mediterranean. *Biological Invasions*, *21*, 3707-3721.

Giovos, I., Tiralongo, F., Langeneck, J., Kaminas, A., Kleitou, P., Crocetta, F., & Doumpas, N. (2020). First record of the Atlantic spadefish Chaetodipterus faber (Broussonet, 1782) in the Mediterranean Sea: is it a new aquarium release?

Givan, O., Edelist, D., Sonin, O., & Belmaker, J. (2018). Thermal affinity as the dominant factor changing Mediterranean fish abundances. *Global Change Biology*, *24*(1), e80-e89.

Gozlan, R. E., Bommarito, C., Caballero-Huertas, M., Givens, J., Mortillaro, J.-M., Pepey, E., Ralaiarison, R. P., Senff, P., & Combe, M. (2024). A one-health approach to non-native species, aquaculture, and food security. *Water Biology and Security*, 100250.

Granek, E. F., Madin, E. M., Brown, M., Figueira, W., Cameron, D. S., Hogan, Z., Kristianson, G., de Villiers, P., Williams, J. E., & Post, J. (2008). Engaging recreational fishers in management and conservation: global case studies. *Conservation Biology*, *22*(5), 1125-1134.

Green, S. J., & Grosholz, E. D. (2021). Functional eradication as a framework for invasive species control. *Frontiers in Ecology and the Environment*, *19*(2), 98-107.

Groom, Q., Strubbe, D., Adriaens, T., Davis, A. J., Desmet, P., Oldoni, D., Reyserhove, L., Roy, H. E., & Vanderhoeven, S. (2019). Empowering citizens to inform decision-making as a way forward to support invasive alien species policy. *Citizen Science: Theory and Practice*, *4*(1).

Hastings, A., & Wysham, D. B. (2010). Regime shifts in ecological systems can occur with no warning. *Ecology letters*, *13*(4), 464-472.

Haubrock, P. J., Pilotto, F., Soto, I., Kühn, I., Verreycken, H., Seebens, H., Cuthbert, R. N., & Haase, P. (2023). Long-term trends in abundances of non-native species across biomes, realms, and taxonomic groups in Europe. *Science of the total environment*, *884*, 163808.

Hidalgo, M., El-Haweet, A., Tsikliras, A., Tirasin, E., Fortibuoni, T., Ronchi, F., Lauria, V., Ben Abdallah, O., Arneri, E., & Ceriola, L. (2022). Risks and adaptation options for the Mediterranean fisheries in the face of multiple climate change drivers and impacts. *ICES Journal of Marine Science*, *79*(9), 2473-2488.

Huseyinoglu, M., Jimenez, C., Resaikos, V., Arda, Y., Beton, D., Snape, R., Tari, G., & Günay, M. E. (2024). Assisted recovery of mediterranean native fish species by removal of two established invasive alien species, Pterois miles and Diadema setosum. *Estuarine, Coastal and Shelf Science*, *304*, 108826.

Hyder, K., Radford, Z., Prellezo, R., Weltersbach, M. S., Lewin, W.-C., Zarauz, L., Ferter, K., Ruiz, J., Townhill, B., & Mugerza, E. (2017). *Research for PECH Committee-Marine recreational and semi-subsistence fishing-its value and its impact on fish stocks*.

Hyder, K., Weltersbach, M. S., Armstrong, M., Ferter, K., Townhill, B., Ahvonen, A., Arlinghaus, R., Baikov, A., Bellanger, M., & Birzaks, J. (2018). Recreational sea fishing in Europe in a global context—participation rates, fishing effort, expenditure, and implications for monitoring and assessment. *Fish and Fisheries*, *19*(2), 225-243.

IUCN. (2000). *IUCN guidelines for the prevention of biodiversity loss caused by alien invasive species*. Retrieved 05/01/2025 from https://portals.iucn.org/library/efiles/documents/Rep-2000-052.pdf

Katsanevakis, S., Stelzenmüller, V., South, A., Sørensen, T. K., Jones, P. J., Kerr, S., Badalamenti, F., Anagnostou, C., Breen, P., & Chust, G. (2011). Ecosystem-based marine spatial management: review of concepts, policies, tools, and critical issues. *Ocean & Coastal Management*, *54*(11), 807-820.

Katsanevakis, S., Zenetos, A., Belchior, C., & Cardoso, A. C. (2013). Invading European Seas: assessing pathways of introduction of marine aliens. *Ocean & Coastal Management*, *76*, 64-74.

Katsanevakis, S., Tempera, F., & Teixeira, H. (2016). Mapping the impact of alien species on marine ecosystems: the Mediterranean Sea case study. *Diversity and distributions*, *22*(6), 694-707.

Katsanevakis, S., Poursanidis, D., Hoffman, R., Rizgalla, J., Rothman, S. B.-S., Levitt-Barmats, Y. a., Hadjioannou, L., Trkov, D., Garmendia, J. M., & Rizzo, M. (2020). Unpublished Mediterranean records of marine alien and cryptogenic species. *BioInvasions Records*, *9*(2), 165-182.

Katsanevakis, S. (2022). Management Options for Marine IAS. Technical note prepared by IUCN for the European Commission. In.

Katsanevakis, S., Olenin, S., Puntila-Dodd, R., Rilov, G., Stæhr, P. A., Teixeira, H., Tsirintanis, K., Birchenough, S. N., Jakobsen, H. H., & Knudsen, S. W. (2023). Marine invasive alien species in Europe: 9 years after the IAS Regulation. *Frontiers in Marine Science*, *10*, 1271755.

Katsanevakis, S., Belmaker, J., Rilov, G., Yeruham, E., Konstantinidis, A., Papazekou, M., Giakoumi, S., & Mazaris, A. D. (2024). Navigating the new normal: rethinking conservation strategies in the climate-impacted and highly invaded eastern Mediterranean.

Keramidas, I., Dimarchopoulou, D., Kokkos, N., Sylaios, G., & Tsikliras, A. C. (2024). Temporal ecotrophic impacts of fisheries and climate change in the Aegean Sea. *Marine Ecology Progress Series*, *749*, 19-45.

Kevrekidis, K., Kevrekidis, T., Mogias, A., Boubonari, T., Kantaridou, F., Kaisari, N., Malea, P., Dounas, C., & Thessalou-Legaki, M. (2023). Fisheries biology and basic life-cycle characteristics of the invasive blue crab Callinectes sapidus Rathbun in the estuarine area of the Evros River (Northeast Aegean Sea, Eastern Mediterranean). *Journal of marine science and engineering*, *11*(3), 462.

Khamassi, F., Bahri, W. R., Bhouri, A. M., Chaffai, A., Ghanem, R., & Souissi, J. B. (2022). Biochemical composition, nutritional value and socio-economic impacts of the invasive crab Callinectes sapidus Rathbun, 1896 in central Mediterranean Sea. *Mediterranean Marine Science*, *23*(3), 650-663.

Kimbro, D. L., Cheng, B. S., & Grosholz, E. D. (2013). Biotic resistance in marine environments. *Ecology letters*, *16*(6), 821-833.

Klein, J., & Verlaque, M. (2011). Experimental removal of the invasive Caulerpa racemosa triggers partial assemblage recovery. *Journal of the Marine Biological Association of the United Kingdom*, *91*(1), 117-125.

Kleitou, P., Kalogirou, S., Marmara, D., & Giovos, I. (2018). Coryphaena hippurus: A potential predator of Lagocephalus sceleratus in the Mediterranean Sea. *International Journal of Fisheries and Aquatic Studies*, *6*(3), 93-95.

Kleitou, P., Giovos, I., Wolf, W., & Crocetta, F. (2019a). On the importance of citizen-science: the first record of Goniobranchus obsoletus (Rüppell & Leuckart, 1830) from Cyprus (Mollusca: gastropoda: Nudibranchia).

Kleitou, P., Savva, I., Kletou, D., Hall-Spencer, J. M., Antoniou, C., Christodoulides, Y., Chartosia, N., Hadjioannou, L., Dimitriou, A. C., & Jimenez, C. (2019b). Invasive lionfish in the Mediterranean: Low public awareness yet high stakeholder concerns. *Marine Policy*, *104*, 66-74.

Kleitou, P., Crocetta, F., Giakoumi, S., Giovos, I., Hall-Spencer, J. M., Kalogirou, S., Kletou, D., Moutopoulos, D. K., & Rees, S. (2021a). Fishery reforms for the management of non-indigenous species. *Journal of Environmental Management*, *280*, 111690.

Kleitou, P., Hall-Spencer, J. M., Savva, I., Kletou, D., Hadjistylli, M., Azzurro, E., Katsanevakis, S., Antoniou, C., Hadjioannou, L., & Chartosia, N. (2021b). The case of lionfish (Pterois miles) in the

Mediterranean Sea demonstrates limitations in EU legislation to address marine biological invasions. *Journal of marine science and engineering*, *9*(3), 325.

Kleitou, P., Rees, S., Cecconi, F., Kletou, D., Savva, I., Cai, L. L., & Hall-Spencer, J. M. (2021c). Regular monitoring and targeted removals can control lionfish in Mediterranean Marine Protected Areas. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *31*(10), 2870-2882.

Kleitou, P., Hall-Spencer, J., Rees, S., & Kletou, D. (2022a). *Guide to lionfish management in the Mediterranean*. University of Plymouth.

Kleitou, P., Moutopoulos, D. K., Giovos, I., Kletou, D., Savva, I., Cai, L. L., Hall-Spencer, J. M., Charitou, A., Elia, M., & Katselis, G. (2022b). Conflicting interests and growing importance of non-indigenous species in commercial and recreational fisheries of the Mediterranean Sea. *Fisheries Management and Ecology*, *29*(2), 169-182.

Kleitou, P. (2023). *Management of Non-Indigenous Species in the Mediterranean Sea with an Emphasis on Lionfish (Pterois miles)* University of Plymouth]. Plymouth.

Kleitou, P., Rees, S. E., Kletou, D., Harris, H. E., Cai, L. L., Green, S., Hadjioannou, L., Savva, I., Giovos, I., & Jimenez, C. (2024). Marine protected areas can increase the abundance of invasive lionfish (Pterois miles). *Conservation Science and Practice*, e13147.

Kleiven, A. R., Moland, E., & Sumaila, U. R. (2020). No fear of bankruptcy: the innate self-subsidizing forces in recreational fishing. *ICES Journal of Marine Science*, *77*(6), 2304-2307.

Kondylatos, G., Perdikaris, K., Kaoukis, I., Patatoukos, I., Corsini-Foka, M., Conides, A., & Klaoudatos, D. (2023). Small-scale fishery catch composition in Rhodes (Eastern Mediterranean Sea). *Mediterranean Marine Science*, *24*(3), 586-600.

Kourantidou, M., & Kaiser, B. A. (2024). Rethinking user rights of profitable marine invasions: Lessons from the Norwegian Barents Snow Crab fishery. *Ocean & Coastal Management*, *259*, 107430.

Ktari, L., Ismail, A., Selmi, H., Hmani, I., & Bour, M. E. (2022). Biological potential of the alien red alga Asparagopsis taxiformis and characterization of its culturable associated bacteria. *Journal of Applied Phycology*, *34*(6), 2769-2782.

Lehtiniemi, M., Ojaveer, H., David, M., Galil, B., Gollasch, S., McKenzie, C., Minchin, D., Occhipinti-Ambrogi, A., Olenin, S., & Pederson, J. (2015). Dose of truth—monitoring marine non-indigenous species to serve legislative requirements. *Marine Policy*, *54*, 26-35.

Lewin, W.-C., Weltersbach, M. S., Ferter, K., Hyder, K., Mugerza, E., Prellezo, R., Radford, Z., Zarauz, L., & Strehlow, H. V. (2019). Potential environmental impacts of recreational fishing on marine fish stocks and ecosystems. *Reviews in Fisheries Science & Aquaculture*, *27*(3), 287-330.

Ligorini, V., Malet, N., Garrido, M., Four, B., Etourneau, S., Leoncini, A. S., Dufresne, C., Cecchi, P., & Pasqualini, V. (2022). Long-term ecological trajectories of a disturbed Mediterranean coastal lagoon (Biguglia lagoon): Ecosystem-based approach and considering its resilience for conservation? *Frontiers in Marine Science*, *9*, 937795.

Lynch, A. J., Thompson, L. M., Beever, E. A., Cole, D. N., Engman, A. C., Hawkins Hoffman, C., Jackson, S. T., Krabbenhoft, T. J., Lawrence, D. J., & Limpinsel, D. (2021). Managing for RADical ecosystem change: applying the Resist-Accept-Direct (RAD) framework. *Frontiers in Ecology and the Environment*, *19*(8), 461-469.

Lynch, A. J., Rahel, F. J., Limpinsel, D., Sethi, S. A., Engman, A. C., Lawrence, D. J., Mills, K. E., Morrison, W., Peterson, J. O., & Porath, M. T. (2022). Ecological and social strategies for managing fisheries using the Resist-Accept-Direct (RAD) framework. *Fisheries Management and Ecology*, *29*(4), 329-345.

Maggio, T., Perzia, P., Falautano, M., Visconti, G., & Castriota, L. (2022). From LEK to LAB: The case of the blue crab Portunus segnis in the Pelagie Islands Marine Protected Area, central Mediterranean Sea. *Ocean & Coastal Management*, *219*, 106043.

Maggio, T., Cattapan, F., Falautano, M., Julian, D., Malinverni, R., Poloni, E., Sanseverino, W., Todesco, S., & Castriota, L. (2023). eDNA Metabarcoding Analysis as Tool to Assess the Presence of Non-Indigenous Species (NIS): A Case Study in the Bilge Water. *Diversity*, *15*(11), 1117.

Mancinelli, G., Chainho, P., Cilenti, L., Falco, S., Kapiris, K., Katselis, G., & Ribeiro, F. (2017). The Atlantic blue crab Callinectes sapidus in southern European coastal waters: Distribution, impact and prospective invasion management strategies. *Marine pollution bulletin*, *119*(1), 5-11.

Mancinelli, G., Lago, N., Scirocco, T., Lillo, O. A., De Giorgi, R., Doria, L., Mancini, E., Mancini, F., Potenza, L., & Cilenti, L. (2024). Abundance, Size Structure, and Growth of the Invasive Blue Crab Callinectes sapidus in the Lesina Lagoon, Southern Adriatic Sea. *Biology*, *13*(12), 1051.

Marchessaux, G., Gjoni, V., & Sarà, G. (2023a). Environmental drivers of size-based population structure, sexual maturity and fecundity: A study of the invasive blue crab Callinectes sapidus (Rathbun, 1896) in the Mediterranean Sea. *PloS one*, *18*(8), e0289611.

Marchessaux, G., Mangano, M. C., Bizzarri, S., M'Rabet, C., Principato, E., Lago, N., Veyssiere, D., Garrido, M., Scyphers, S. B., & Sarà, G. (2023b). Invasive blue crabs and small-scale fisheries in the Mediterranean sea: Local ecological knowledge, impacts and future management. *Marine Policy*, *148*, 105461.

Marchessaux, G., Thibault, D., & Claeys, C. (2023c). An interdisciplinary assessment of the impact of invasive gelatinous zooplankton in a French Mediterranean lagoon. *Biological Invasions*, *25*(2), 499-518.

Marchessaux, G., Sibella, B., Garrido, M., Abbruzzo, A., & Sarà, G. (2024a). Can we control marine invasive alien species by eating them? The case of Callinectes sapidus. *Ecology and society*, *29*(2).

Marchessaux, G., Veyssiere, D., Durieux, E. D., Sarà, G., & Garrido, M. (2024b). Using species population structure to assist in management and decision-making in the fight against invasive species: The case of the Atlantic blue crab Callinectes sapidus. *Global Ecology and Conservation*, *54*, e03168.

Martínez-Laiz, G., Ulman, A., Ros, M., & Marchini, A. (2019). Is recreational boating a potential vector for non-indigenous peracarid crustaceans in the Mediterranean Sea? A combined biological and social approach. *Marine pollution bulletin*, *140*, 403-415.

Metcalf, S. J., van Putten, E. I., Frusher, S., Marshall, N. A., Tull, M., Caputi, N., Haward, M., Hobday, A. J., Holbrook, N. J., & Jennings, S. M. (2015). Measuring the vulnerability of marine social-ecological systems: a prerequisite for the identification of climate change adaptations. *Ecology and society*, *20*(2).

Michael-Bitton, G., Gal, G., Corrales, X., Ofir, E., Shechter, M., & Zemah-Shamir, S. (2022). Economic aspects of fish stock accounting as a renewable marine natural capital: The Eastern Mediterranean continental shelf ecosystem as a case study. *Ecological Economics*, *200*, 107539.

Michail, C., Tanduo, V., Crocetta, F., Giovos, I., Litsiou, S., & Kleitou, P. (2024). Engagement of fishers in citizen science enhances the knowledge on alien decapods in Cyprus (eastern Mediterranean Sea). *Aquatic Ecology*, *58*(1), 107-116.

Michailidis, N., Katsanevakis, S., & Chartosia, N. (2020). Recreational fisheries can be of the same magnitude as commercial fisheries: The case of Cyprus. *Fisheries Research*, *231*, 105711.

Michailidis, N., Chartosia, N., & Katsanevakis, S. (2023). Exploring the role of fishing in a heavily bioinvaded shelf ecosystem. *Fisheries Research*, *259*, 106554.

Minasidis, V., Doumpas, N., Giovos, I., Kleitou, P., Kaminas, A., & Moutopoulos, D. K. (2023). Assessing Consumer Attitude Towards Marine Non-Indigenous Fish Species: A Case Study From Greece (Eastern Mediterranean Sea). *Thalassas: An International Journal of Marine Sciences*, *39*(1), 35-53.

Mistri, M. (2004). Prey preference of Carcinus aestuarii: possible implications with the control of an invasive mytilid and Manila clam culture in a northern Adriatic lagoon. *Aquaculture*, *230*(1-4), 261-272.

Mnasri-Afifi, I., Zribi, I., Abdelkader, N., Charfi-Cheikhrouha, F., & Zakhama-Sraieb, R. (2024). Rapid assessment survey of non-indigenous and cryptogenic species in Tunisian marinas. *BioInvasions Record*, *13*(2).

Mollo, E., Cimino, G., & Ghiselin, M. T. (2015). Alien biomolecules: a new challenge for natural product chemists. *Biological Invasions*, *17*, 941-950.

Moon, K., Blackman, D. A., & Brewer, T. D. (2015). Understanding and integrating knowledge to improve invasive species management. *Biological Invasions*, *17*, 2675-2689.

Moore, J. W., & Schindler, D. E. (2022). Getting ahead of climate change for ecological adaptation and resilience. *Science*, *376*(6600), 1421-1426.

Moullec, F., Barrier, N., Drira, S., Guilhaumon, F., Marsaleix, P., Somot, S., Ulses, C., Velez, L., & Shin, Y.-J. (2019). An end-to-end model reveals losers and winners in a warming Mediterranean Sea. *Frontiers in Marine Science*, *6*, 345.

Moutopoulos, D. K., Giovos, I., Kleitou, P., Kletou, D., Savva, I., Cai, L. L., & Katselis, G. (2021). Multi-disciplinary approach of reported and unreported fisheries in a new established MPA: The case of Cavo Greco, Cyprus. *Regional Studies in Marine Science*, *47*, 101922.

Novoa, A., Shackleton, R., Canavan, S., Cybele, C., Davies, S. J., Dehnen-Schmutz, K., Fried, J., Gaertner, M., Geerts, S., & Griffiths, C. L. (2018). A framework for engaging stakeholders on the management of alien species. *Journal of Environmental Management*, *205*, 286-297.

O'Leary, B., Fonseca, C., Cornet, C., de Vries, M., Degia, A., Failler, P., Furlan, E., Garrabou, J., Gil, A., & Hawkins, J. (2022). Embracing Nature-based Solutions to promote resilient marine and coastal ecosystems. Nature-Based Solutions, 3, 100044. In.

Ofir, E., Corrales, X., Coll, M., Heymans, J. J., Goren, M., Steenbeek, J., Amitai, Y., Shachar, N., & Gal, G. (2023). Evaluation of fisheries management policies in the alien species-rich Eastern Mediterranean under climate change. *Frontiers in Marine Science*, *10*, 1155480.

Ojaveer, H., Galil, B. S., Minchin, D., Olenin, S., Amorim, A., Canning-Clode, J., Chainho, P., Copp, G. H., Gollasch, S., & Jelmert, A. (2014). Ten recommendations for advancing the assessment and management of non-indigenous species in marine ecosystems. *Marine Policy*, *44*, 160-165.

Olenin, S., Elliott, M., Minchin, D., & Katsanevakis, S. (2024). Marine ecosystem health and biological pollution: Reconsidering the paradigm. *Marine pollution bulletin*, *200*, 116054.

Otero, M., Cebrian, E., Francour, P., Galil, B., & Savini, D. (2013). Monitoring marine invasive species in Mediterranean marine protected areas (MPAs): a strategy and practical guide for managers. *IUCN, Malaga*, *136*.

Palumbi, S. R., Sandifer, P. A., Allan, J. D., Beck, M. W., Fautin, D. G., Fogarty, M. J., Halpern, B. S., Incze, L. S., Leong, J.-A., & Norse, E. (2009). Managing for ocean biodiversity to sustain marine ecosystem services. *Frontiers in Ecology and the Environment*, *7*(4), 204-211.

Papageorgiou, M., & Moutopoulos, D. K. (2023). Small-scale fisheries discards in the eastern Mediterranean Sea: Discarding species, quantities, practices and drivers. *Fisheries Research*, *267*, 106798.

Peristeraki, P., Tserpes, G., Lampadariou, N., & Stergiou, K. I. (2017). Comparing demersal megafaunal species diversity along the depth gradient within the South Aegean and Cretan Seas (Eastern Mediterranean). *PloS one*, *12*(9), e0184241.

Peyton, J., Martinou, A. F., Pescott, O. L., Demetriou, M., Adriaens, T., Arianoutsou, M., Bazos, I., Bean, C. W., Booy, O., & Botham, M. (2019). Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island. *Biological Invasions*, *21*, 2107-2125.

Peyton, J. M., Martinou, A. F., Adriaens, T., Chartosia, N., Karachle, P. K., Rabitsch, W., Tricarico, E., Arianoutsou, M., Bacher, S., & Bazos, I. (2020). Horizon scanning to predict and prioritize invasive alien species with the potential to threaten human health and economies on Cyprus. *Frontiers in Ecology and Evolution*, *8*, 566281.

Piccardi, F., Poli, F., Sguotti, C., Tirelli, V., Borme, D., Mazzoldi, C., & Barausse, A. (2024). Assessing the impact of the invasive ctenophore Mnemiopsis leidyi on artisanal fisheries in the Venice Lagoon: an interdisciplinary approach. *Hydrobiologia*, 1-19.

Ponti, M., Castellini, A., Ragazzoni, A., Elena, G., Ceccherelli, V. U., & Abbiati, M. (2017). Decline of the Manila clams stock in the northern Adriatic lagoons: a survey on ecological and socio-economic aspects. *Acta Adriatica*, *58*(1), 89-104.

Ralston, B. E., & Sarr, D. A. (2017). *Case studies of riparian and watershed restoration in the southwestern United States—Principles, challenges, and successes* (2331-1258).

Ramajal, J., Picard, D., Costa, J., Carvalho, F., Gaspar, M., & Chainho, P. (2016). Amêijoa-japonesa, uma nova realidade no estuário do Rio Tejo: Pesca e pressão social e impacto socio-económico. *Entre Rios e Mares: um Património de Ambientes, Histórias e Saberes*, *5*, 17-30.

Rifi, M., Basti, L., Rizzo, L., Tanduo, V., Radulovici, A., Jaziri, S., Uysal, İ., Souissi, N., Mekki, Z., & Crocetta, F. (2023). Tackling bioinvasions in commercially exploitable species through interdisciplinary approaches: A case study on blue crabs in Africa's Mediterranean coast (Bizerte Lagoon, Tunisia). *Estuarine, Coastal and Shelf Science*, *291*, 108419.

Rilov, G., Klein, L., Iluz, D., Dubinsky, Z., & Guy-Haim, T. (2022). Last snail standing? superior thermal resilience of an alien tropical intertidal gastropod over natives in an ocean-warming hotspot. *Biological Invasions*, *24*(12), 3703-3719.

Robertson, P. A., Mill, A., Novoa, A., Jeschke, J. M., Essl, F., Gallardo, B., Geist, J., Jarić, I., Lambin, X., & Musseau, C. (2020). A proposed unified framework to describe the management of biological invasions. *Biological Invasions*, *22*, 2633-2645.

Rotter, A., Klun, K., Francé, J., Mozetič, P., & Orlando-Bonaca, M. (2020). Non-indigenous species in the Mediterranean Sea: turning from pest to source by developing the 8Rs model, a new paradigm in pollution mitigation. *Frontiers in Marine Science*, *7*, 178.

Rousou, M., Ganias, K., Kletou, D., Loucaides, A., & Tsinganis, M. (2014). Maturity of the pufferfish Lagocephalus sceleratus in the southeastern Mediterranean Sea. *Sexuality and early development in aquatic organisms*, *1*(1), 35-44.

Roy, H. E., Pauchard, A., Stoett, P., Renard Truong, T., Bacher, S., Galil, B. S., Hulme, P. E., Ikeda, T., Sankaran, K., McGeoch, M. A., Meyerson, L. A., Nuñez, M. A., Ordonez, A., Rahlao, S. J., Schwindt, E. S., Hanno, Sheppard, A. W., & Vandvik, V. (2023). *The thematic assessment report on Invasive Alien Species and their control: Summary for policymakers* (56).

Roy, H. E., Pauchard, A., Stoett, P. J., Renard Truong, T., Meyerson, L. A., Bacher, S., Galil, B. S., Hulme, P. E., Ikeda, T., & Kavileveettil, S. (2024). Curbing the major and growing threats from invasive alien species is urgent and achievable. *Nature ecology & evolution*, 1-8.

Ruesink, J. L., & Collado-Vides, L. (2006). Modeling the increase and control of Caulerpa taxifolia, an invasive marine macroalga. *Biological Invasions*, *8*, 309-325.

Santamaría, J., Tomas, F., Ballesteros, E., & Cebrian, E. (2021). Herbivory on the invasive alga Caulerpa cylindracea: the role of omnivorous fishes. *Frontiers in Marine Science*, *8*, 702492.

Savva, I., Cai, L. L., Kleitou, P., Hadjioannou, L., Jimenez, C., Karonias, A., Nicolaou, E., Chartosia, N., Hall-Spencer, J. M., & Kletou, D. (2024). An underwater clash of spears: Public engagement in Mediterranean lionfish control efforts. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *34*(2), e4104.

Schaefer, M. B. (1954). Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bulletin of the Inter-American Tropical Tuna Commission*, *1*, 25-56.

Schilling, H. T., Kalogirou, S., Michail, C., & Kleitou, P. (2024). Testing passive dispersal as the key mechanism for lionfish invasion in the Mediterranean Sea using Lagrangian particle tracking. *Biological Invasions*, *26*(2), 505-514.

Schuurman, G. W., Hawkins Hoffman, C., Cole, D. N., Lawrence, D. J., Morton, J. M., Magness, D. R., Cravens, A. E., Covington, S., O'Malley, R., & Fisichelli, N. A. (2020). Resist-accept-direct (RAD)-A framework for the 21st-century natural resource manager. *USGS Report*, 20.

Schuurman, G. W., Cole, D. N., Cravens, A. E., Covington, S., Crausbay, S. D., Hoffman, C. H., Lawrence, D. J., Magness, D. R., Morton, J. M., & Nelson, E. A. (2022). Navigating ecological transformation: Resist–accept–direct as a path to a new resource management paradigm. *BioScience*, *72*(1), 16-29.

Scriver, M., von Ammon, U., Youngbull, C., Pochon, X., Stanton, J.-A. L., Gemmell, N. J., & Zaiko, A. (2024). Drop it all: extraction-free detection of targeted marine species through optimized direct droplet digital PCR. *PeerJ*, *12*, e16969.

Seekamp, E., McCreary, A., Mayer, J., Zack, S., Charlebois, P., & Pasternak, L. (2016). Exploring the efficacy of an aquatic invasive species prevention campaign among water recreationists. *Biological Invasions*, *18*, 1745-1758.

Shahhat, A., & Awad, M. (2022). Effect of the Suez Canal on Marine Invasive Species Entry to the Mediterranean and Methods of Mitigation. *AIN Journal*(44).

Sidiropoulou, N., Doumpas, N., Perrakis, E., Tsianis, D., Giovos, I., & Moutopoulos, D. K. (2024). Investigating Consumer Attitudes and Market Trading of Edible Marine Invasive Alien Species in the Greek Seafood Market. *Sustainability*, *16*(19), 8479.

Simberloff, D. (2021). Maintenance management and eradication of established aquatic invaders. *Hydrobiologia*, *848*(9), 2399-2420.

Souissi, J. B., Ghanem, R., Rjiba, W., Ben, K. O., Amor, F. N., Hafsia, I. B., & Alaya, S. (2024). Managing the explosion of the blue swimming crab Portunus segnis (Forskål, 1775) in Tunisia. *Fisheries responses to invasive species in a changing climate*, 54.

Stachowicz, J. J., Fried, H., Osman, R. W., & Whitlatch, R. B. (2002). Biodiversity, invasion resistance, and marine ecosystem function: reconciling pattern and process. *Ecology*, *83*(9), 2575-2590.

Tamburini, M., Keppel, E., Marchini, A., Repetto, M. F., Ruiz, G. M., Ferrario, J., & Occhipinti-Ambrogi, A. (2021). Monitoring non-indigenous species in port habitats: first application of a standardized North American protocol in the Mediterranean Sea. *Frontiers in Marine Science*, *8*, 700730.

Tamburini, M., Occhipinti-Ambrogi, A., Vullo, M. L., & Ferrario, J. (2022). Biotic resistance of native fouling communities to bioinvasions could not be demonstrated by transplant experiments in Northern Italy. *Marine pollution bulletin*, *182*, 113961.

Tarkan, A. S., Vilizzi, L., Top, N., Ekmekçi, F. G., Stebbing, P. D., & Copp, G. H. (2017). Identification of potentially invasive freshwater fishes, including translocated species, in Turkey using the Aquatic Species Invasiveness Screening Kit (AS-ISK). *International Review of Hydrobiology*, *102*(1-2), 47-56.

Tempesti, J., Langeneck, J., Romani, L., Garrido, M., Lardicci, C., Maltagliati, F., & Castelli, A. (2025). Spatial variability and context-dependence of fouling communities in recreational marinas: A study in the Western Mediterranean with a focus on non-indigenous species (NIS). *Marine pollution bulletin*, *212*.

Thompson, L. M., Lynch, A. J., Beever, E. A., Engman, A. C., Falke, J. A., Jackson, S. T., Krabbenhoft, T. J., Lawrence, D. J., Limpinsel, D., & Magill, R. T. (2021). Responding to ecosystem transformation: Resist, accept, or direct? *Fisheries*, *46*(1), 8-21.

Tiralongo, F., Mancini, E., Gattelli, R., di Pasquale, C., Rossetti, E., Martellucci, R., Felici, A., Mancinelli, G., & Mulder, C. (2025). The devasting economic impact of Callinectes sapidus on the clam fishing in the Po Delta (Italy): Striking evidence from novel field data. *arXiv preprint arXiv:2502.07095*.

Tomás, F., Cebrian, E., & Ballesteros, E. (2011). Differential herbivory of invasive algae by native fish in the Mediterranean Sea. *Estuarine, Coastal and Shelf Science*, *92*(1), 27-34.

Tricarico, E. (2016). Do alien invasive species and climate change foster conservation behaviour? *Aquatic conservation - Marine and Freshwater Ecosystems*, *2*(26), 228-232.

Tsiamis, K., Azzurro, E., Bariche, M., Çinar, M. E., Crocetta, F., De Clerck, O., Galil, B., Gómez, F., Hoffman, R., & Jensen, K. R. (2020). Prioritizing marine invasive alien species in the European Union through horizon scanning. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *30*(4), 794-845.

Tsirintanis, K., Azzurro, E., Crocetta, F., Dimiza, M., Froglia, C., Gerovasileiou, V., Langeneck, J., Mancinelli, G., Rosso, A., & Stern, N. (2022). Bioinvasion impacts on biodiversity, ecosystem services, and human health in the Mediterranean Sea. Aquat Invasions 17: 308–352. In.

Ulman, A., Ferrario, J., Forcada, A., Seebens, H., Arvanitidis, C., Occhipinti-Ambrogi, A., & Marchini, A. (2019). Alien species spreading via biofouling on recreational vessels in the Mediterranean Sea. *Journal of Applied Ecology*, *56*(12), 2620-2629.

Ulman, A., Harris, H. E., Doumpas, N., Deniz Akbora, H., Al Mabruk, S. A. A., Azzurro, E., Bariche, M., Çiçek, B. A., Deidun, A., & Demirel, N. (2021). Low pufferfish and lionfish predation in their native and invaded ranges suggests human control mechanisms may be necessary to control their Mediterranean abundances. *Frontiers in Marine Science*, *8*, 670413.

Ulman, A., Ali, F. Z., Harris, H. E., Adel, M., Mabruk, S. A. A., Bariche, M., Candelmo, A. C., Chapman, J. K., Çiçek, B. A., & Clements, K. R. (2022). Lessons from the Western Atlantic lionfish invasion to inform management in the Mediterranean. *Frontiers in Marine Science*, *9*, 865162.

Ünal, V., Kızılkaya, Z., Krueger, C., Taylor, W., & Youn, S. (2019). A long and participatory process towards successful fishery management of Gökova Bay, Turkey. *From Catastrophe to Recovery: Stories of Fishery Management Success*, 509-532.

UNEP/MAP-SPA/RAC. (2025). Best practices and management measures of the blue crabs in the Mediterranean In SPA/RAC (Ed.), (pp. 14). Guillaume Marchessaux.

UNEP/MAP. (2017). Action plan concerning species introductions and invasive species in the Mediterranean Sea. In: UN Environment/MAP Athens, Greece.

Van Rijn, I., Kiflawi, M., & Belmaker, J. (2020). Alien species stabilize local fisheries catch in a highly invaded ecosystem. *Canadian Journal of Fisheries and Aquatic Sciences*, *77*(4), 752-761.

Vimercati, G., Kumschick, S., Probert, A., Volery, L., & Bacher, S. (2020). The importance of assessing positive and beneficial impacts of alien species. NeoBiota 62: 525–545. In.

Vimercati, G., Probert, A. F., Volery, L., Bernardo-Madrid, R., Bertolino, S., Céspedes, V., Essl, F., Evans, T., Gallardo, B., & Gallien, L. (2022). The EICAT+ framework enables classification of positive impacts of alien taxa on native biodiversity. *PLoS biology*, *20*(8), e3001729.

Wang, Z., Saebi, M., Grey, E. K., Corbett, J. J., Chen, D., Yang, D., & Wan, Z. (2022). Ballast water-mediated species spread risk dynamics and policy implications to reduce the invasion risk to the Mediterranean Sea. *Marine pollution bulletin*, *174*, 113285.

Wesselmann, M., Hendriks, I. E., Johnson, M., Jordà, G., Mineur, F., & Marbà, N. (2024). Increasing spread rates of tropical non-native macrophytes in the Mediterranean Sea. *Global Change Biology*, *30*(4), e17249.

Williams, B. K., & Brown, E. D. (2024). Managing ecosystems with resist–accept–direct (RAD). *Methods in Ecology and Evolution*, *15*(5), 796-805.

Yasakova, O. N., Zuykov, O. T., Okolodkov, Y. B., Center, S. S., & y Planctología, L. d. B. M. (2023). Efficacy of ballast water treatment systems installed onboard ships entering the seaport of Novorossiysk, the Black Sea. *Ecological Safety of Coastal and Shelf Zones of Sea*(4), 134-154.

Zangaro, F., Pinna, M., & Specchia, V. (2024). Environmental DNA as Early Warning for Alien Species in Mediterranean Coastal Lagoons: Implications for Conservation and Management. *Diversity*, *16*(9), 525.

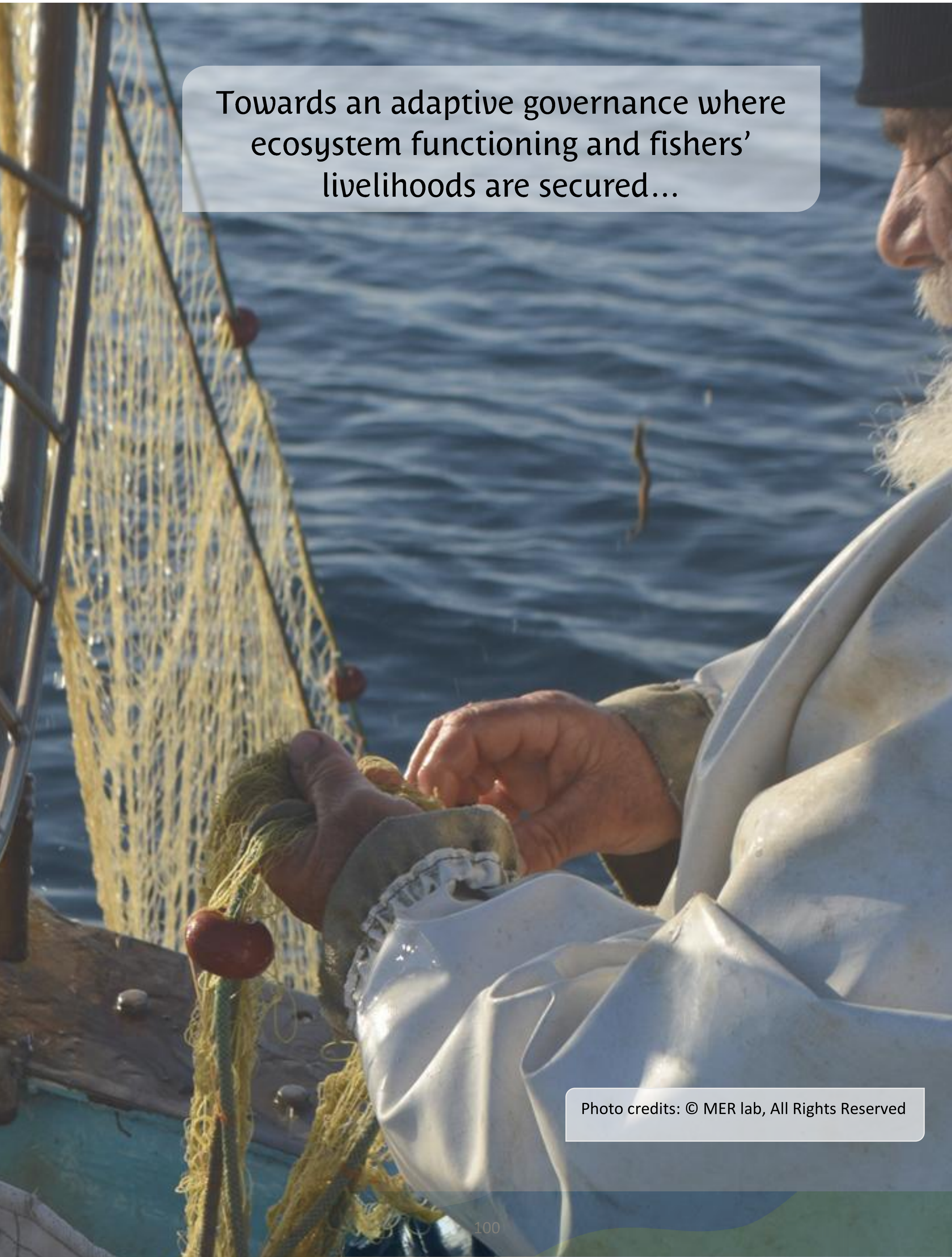
Zenetos, A., Albano, P. G., Garcia, E. L., Stern, N., Tsiamis, K., & Galanidi, M. (2022). Established non-indigenous species increased by 40% in 11 years in the Mediterranean Sea. *Mediterranean Marine Science*, *23*(1).

SUPPLEMENTARY MATERIALS

(1) **Literature review documents:** A comprehensive list of documents extracted and analysed from Scopus is provided. This collection forms the basis of the systematic literature review. The details are contained in the Excel file through this Link

(2) **Case Studies and expert consultations**: Details of the case studies derived from a global review, along with insights from consultations with Mediterranean experts, are documented. This information is crucial for understanding the practical applications and regional specifics of NIS management. The case studies are summarized in the Excel file through this Link

Towards an adaptive governance where ecosystem functioning and fishers' livelihoods are secured...



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