A Risk Assessment Study of Fisheries and Contamination in Mediterranean Marine Protected Areas

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Abstract: Mediterranean Maritime Protection Areas (MMPAs), established for long-term preservation, are increasingly overrun by invasive organisms of tropical provenance, presenting fresh difficulties for officials and managers in the twenty-first century. This research evaluated the susceptibility of 140 coastal Marine Managed Protected Areas to nine highly invasive fish species under present and anticipated climatic scenarios. The study forecasted the habitat appropriateness of introduced species by an ensemble forecasting technique and calibrated algorithms based on the comprehensive dispersion of the organism. The research classified three categories of risk for MMPAs, predicated on the idea that enhanced surroundings render protected regions more susceptible to incursion. Future predictions anticipate an expansion of suitable habitats for all evaluated species in the Mediterranean (MT) basins. In the Levantine Ocean, nearly all Marine Protected Areas are in significant danger of intrusion by the organisms under consideration in both present and potential situations. MMPAs in other MT industries are still inadequate for most invasive microorganisms. The study addresses significant data deficiencies on the susceptibility of MMPAs to the impending proliferation of warm-water intruders by delineating spatial objectives within a worldwide change framework.

Keywords: Mediterranean; Marine; Protected Area; Risk Assessment; Fisheries.

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I. Introduction

Marine Protected Areas (MPAs) are fundamental to global marine conservation initiatives (De Matteis et al., 2021). MPAs can enhance regional biodiversity, rehabilitate functional food webs, save endangered species and vulnerable habitats, and bolster neighboring fisheries, amongst other advantages. MPAs were established to safeguard marine biodiversity from exploitation and other anthropogenic influences based on the implicit assumption of stable environmental circumstances defined by a mean state with variance devoid of long-term trends. However, anthropogenic climate change has rendered that premise incorrect, resulting in fast and unexpected environmental alterations throughout the ocean basins. Marine ecosystems have reacted in many ways, such as relocation to higher climes or deeper waters, changes in phenology, and population turnover.

Climate change is reallocating species worldwide, especially marine intruders (Nimma et al., 2025). These species frequently thrive under new climatic circumstances and expand into previously uninhabited regions, resulting in considerable environmental and economic impacts. Ocean invaders can induce population reductions and localized extinctions by altering interactions between species and food web motion, affecting the makeup and operation of communities and their associated services. The primary challenge for environmentalists is the inability to eradicate introduced plants from protected regions. Management initiatives should focus on predicting susceptibility to incursion and equipping vulnerable areas with the capacity to adapt to withstand expected stresses. An essential aspect of invasion management is evaluating the susceptibility of ecological systems before invasion; however, in marine environments, little attempt has been made to enhance forecasts regarding the geographic spread of these organisms under various climate situations. This understanding is currently essential for the Mediterranean (MT) Sea, one of the most extensively occupied marine ecosystems globally, which is experiencing warming at a rate beyond the global norm (Gerovasileiou & Bianchi, 2021).

The study applied Species Distribution Modelling (SDMs) to assess the appropriateness of the surroundings in Mediterranean Marine Protected Areas (MMPAs) currently and under four climate change situations projected for 2050 (Fraschetti et al., 2022). SDMs are relatively new and robust instruments for assuming the geographic distribution of appropriate environments and estimating variations in suitability under shifting circumstances. Lessepsian organisms, originating from tropical regions, are thought to benefit from global warming, enabling their proliferation into new territories, particularly in the cooler Western and Northern sections of the MT. While SDMs are widely utilized to forecast the geographical patterns of plant invasions according to a changing environment, their application has predominantly been confined to terrestrial environments, with limited research on marine organisms and an even scarcer concentration on particular Lessepsian organisms.

II. Background

Planning concepts for biodiversity protection can facilitate the creation and management of MMPAs (Nahrin, 2020). Many structures have been suggested that include climate change adaptability. These encompass systematic preparation for climate-smart preservation, adaptation for conservation objectives, portfolio evaluation, and the mitigation cycle.

The study employed five distinct strategies for planning to enhance the comprehension of integrating environmental adaptations into MMPA planning. Four primary steps exist to incorporate climate change adaptability into conservation strategy, derived from the overarching characteristics of the five aforementioned models. All frameworks establish explicit goals for preservation, including identifying conservation elements and aims for the MMPA. Conservation objectives must be modified to be effective in changing climates and assessed periodically if conservation attributes evolve or network connection is compromised. All guidelines identify a further step, such as conducting a vulnerability study to evaluate the effects of warming temperatures on conservation objectives. One conserving strategy involves safeguarding all instances of coral reef bioregions, specified areas characterized by distinct species groupings and physical attributes, to achieve a specific participation target, such as protecting 25% of each bioregion. A risk evaluation evaluates how climate change affects the geographic representation of every bioregion inside an MMPA, such as a 15% decline in the geographical coverage of a certain bioregion, to ascertain the likelihood of achieving conservation objectives in the future. The third stage entails finding and choosing environmental adaptation solutions to alleviate the effects of climate change, as determined by the vulnerability evaluation. These are then integrated into the MMPA layout by prioritizing the conservation of reef features in climatic refugia that are anticipated to undergo minimal or no alterations shortly.

Lastly, the MMPA will be consistently evaluated for efficacy to guarantee the conservation objectives are achieved. The monitoring outcomes can subsequently inform the adaptive administration of the MMPA in response to ongoing environmental effects. During the planning phase, it is essential to (a) incorporate stakeholder engagement, (b) evaluate the financial and social implications of preservation, and (c) consider uncertainties in climate change forecasts, environmental reactions, and management efficacy. The whole planning process must be reiterated and adjusted throughout time, contingent upon the outcomes of evaluations of vulnerability and tracking data. While the proposed planning frameworks are predominantly seen as top-down methodologies, grassroots community initiatives can include climate change adaptations.

III. Proposed Risk Assessment Model

The environmental risk index was computed for each species, utilizing a mix of exposure and risk ratings using a rational matrix (Figure 1). Every species was categorized as having a high, reasonable, or low danger level. The research produced an area map of climate-related risk clusters by utilizing species risk levels and their present physical distribution as indicated by Aquamaps payments, highlighting locations with a significant concentration of high climate-risk species. The study investigated how MMPAs in the MT Sea encompass risk regions. The geographic limits of MMPAs were established using the World Directory on Protected Areas, focusing on locations designated as coastal or solely marine. The study conducted a Joint Correspondence Assessment (JCA) utilizing the program to uncover features potentially associated with species' climatic high-risk categories (Peral-Suárez et al., 2024). JCA is an enhanced method of multiple correspondent analyses that facilitates the examination of correlations among many identifiable variables. It reduces an information matrix's dimensions and visualization in a lower-dimensional subsystem while correcting the incorrect estimation of the total given momentum.

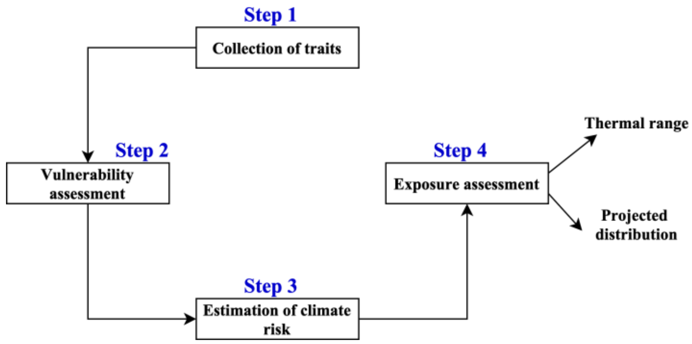

Figure 1: Risk Assessment Model

Selection of Organisms, Occurrence, and Ecological Data

The study examined nine MT Sea's most intrusive Lessepsian fish species. Observation reports in the MT were obtained by upgrading the geo-referenced database Observation Reports of MT Exotic Fisheries (ORMEF), previously utilized for introduced species modelling (Azzurro et al., 2022). Research reviews were conducted by examining the available data on geographically specific instances of the nine chosen species, focusing exclusively on studies from MT nations.

The study obtained information on the native range from the open-access databases OBIS and GBIF (Moudrý & Devillers, 2020). Entries were narrowed to include only those from credible sources and with accurate coordinate data. The ranges were evaluated against the Aqua Maps database for general geographic accuracy, excluding questionable records. This study ultimately consolidated the data from both the invaded and native regions for every kind. The databases were reduced to a depth of 5 arcminutes to align with the ecological layer grids. The ultimate datasets for calibration of models comprised 2800 geo-referenced findings, with species counts varying from 50 to 640.

The ecological layers encompassed both present and projected circumstances for 2050. Four situations were provided for this time frame, formulated under the fresh Representative Consumption Paths (RCP): (i) the RCP-26, indicative of a peak-and-decline situation characterized by minimal greenhouse gas levels by the century's conclusion. This would be achieved through significant reductions in greenhouse gas releases (and, informally, air contaminants) over time; (ii) the RCP-45, a stabilizing situation in which total radiative impact stagnates before 2150 due to developments in technology and decreased greenhouse gas exhausts; (iii) the RCP-60, stabilizing circumstances where greenhouse gas level amounts support; (iv) the RCP-85, a negative situation in which rising pollution over time result in elevated greenhouse gas dosage stages. The variations among possibilities can be ascribed to discrepancies in the employed methods and the underlying financial, economic, and technical parameters.

Dataset of MPA and Risk Evaluation

Data regarding the locations of current marine protected zones on the coastline of the MT Sea was obtained from the MT records, which compile data on MMPAs and places pertinent to preserving the marine ecosystem in the MT. The study employed final consensus estimations to detect existing and prospective geographical conflicts between MPA and invading non-indigenous fish species. Researchers obtained the average, least, and highest values for each species anticipated under present and future circumstances within each MMPA that intersects the marine coastline area examined in the present research. The study assessed the probable risk posed by nine invasive plants under global warming by evaluating whether the levels in the MMPA system would rise significantly between present circumstances and each prediction for 2050, employing paired t-test statistics. The study divided the maps into three arbitrary groups (<450 = low appropriateness, 450-850 = moderate appropriateness, and >850 = high adaptability) to delineate three risk groups for MMPAs pertinent to management and administration.

IV. Results

Four primary methodologies have been employed to evaluate a species' susceptibility to warming temperatures: correlated, mechanical, trait-based, and integrated approaches (Figure 2(b)) for modeling range periods, extinction probabilities, population dynamics, and developing vulnerability indexes (Figure 2(a)). Correlated and mechanistic approaches often assess climate change contact, whereas trait-based techniques evaluate sensitivity and adaptation potential. Trait-based evaluations are extensively utilized as they allow for the simultaneous assessment of multiple species. The study revealed that trait-based methodologies were the predominant technique employed to evaluate vulnerability in MMPAs, especially those utilizing thermal stress protocols to ascertain the danger of bleaching in corals (Figure 2(c)). Thermal stress systems utilize both observed and displayed data to compute statistics of severe (e.g., degree exposing months) and ongoing (e.g., rate of temperatures) stress, aiming to identify potential climate refuges (areas with inadequate heat being exposed) and regions in which corals exhibit high adaptability due to past or anticipated thermal radiation exposure (Figure 2(d)). Alternative trait-based approaches encompassed employing susceptibility modeling to create a vulnerability metric or utilizing thermal boundaries to analyze distributional alterations. Bibliographies and expert insights have been used to qualitatively assess vulnerabilities inside the MMPA, or the findings from the research hunt have been utilized to create a quantified meter for a resilience measure. The research employed a literature analysis to ascertain the characteristics that enhance coral toughness, formulating six ranking resilience measures incorporated into MMPA building.

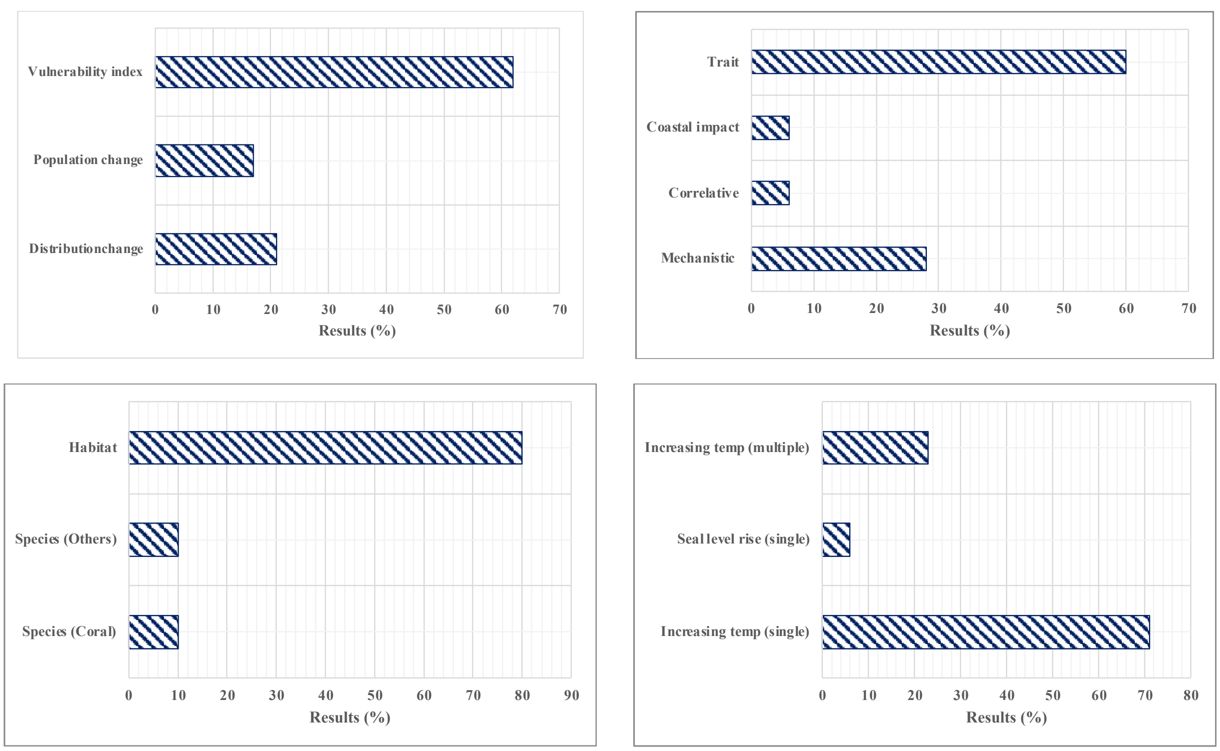

Figure 2: Risk Assessment Analysis

In this scenario, resilience is defined as the capacity of an ecosystem to withstand, recuperate from, or adjust to climate change while preserving essential ecological processes and functions. The study revealed that 45% of research utilized general resiliency characteristics as a global warming adaptation method in

MMPA design (Figure 3). The resilience rules encompassed guidelines regarding minimum MMPA size, configuration, strategies for risk distribution through illustration and reproduction objectives, safeguarding critical habitats (environmentally significant and climate refugia), ensuring connection (for larval spreading, mobility of organisms, and interlinkage of diverse habitat kinds), preserving ecosystem functionality, permitting recovery time, mitigating additional stressors, and employing ecosystem-based leadership. Recent research identified 45 biological and physical traits that enhance resistance to warming temperatures across several ecological organizational levels. Certain studies have recognized unique resilience attributes of MMPAs that have been chosen for conservation. In the suggested modification, illustrations were established for fundamental difficulty, water combining, seaweed protection, coral cover, proximity to civilization, and least levels of water, as these features enhance resilience and protect sufficient illustration of areas that are strongest or likely to emerge from thermal interruptions.

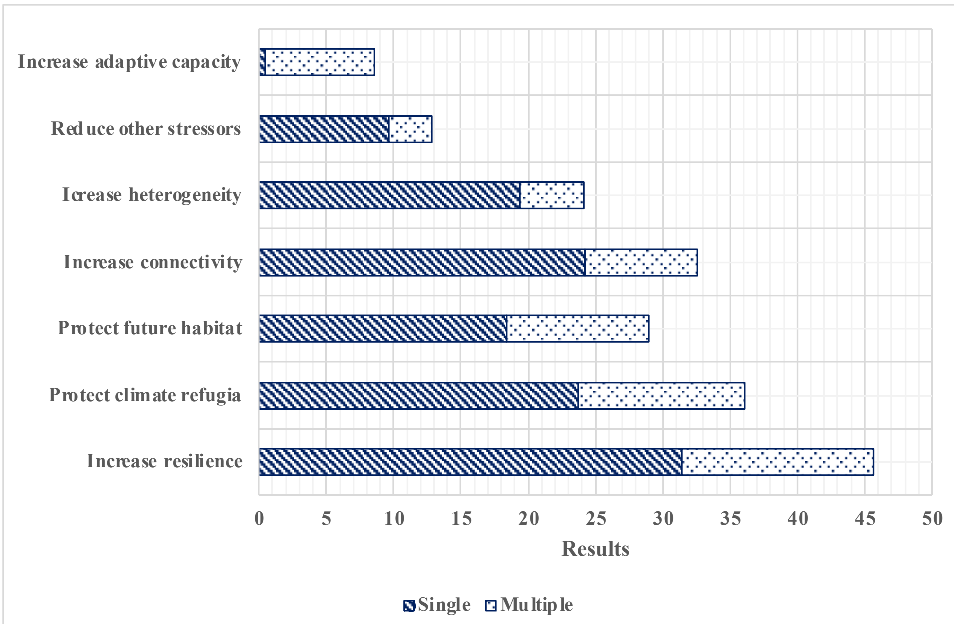

Figure 3: Climatical Change Analysis

V. Conclusion

In the twenty-first century, managers of MMPA will be compelled to meticulously evaluate the significant biodiversity and operational alterations induced by warming temperatures and shifting species within coastline MT environments. Certain MMPAs are experiencing these repercussions, while others are expected to encounter them in the forthcoming decades. Formulating biodiversity conservation strategies and allocating resources to surveillance initiatives in regions increasingly susceptible to climate-driven intruders is imperative. The geographically explicit findings offer essential insights into the area's most vulnerable to invasive species challenges, hence facilitating the optimization of typically limited assets and establishing monitoring programs. While the forecasts from this study are valuable for comprehending regional risks posed by introduced species, it is imperative to apply adaptive actions locally. Management methods should be devised to assist the marine environment and people adapt to these challenges.

Regarding warming hotspots where numerous permanent modifications have transpired, it is essential to assess methods for transitioning from consideration to one focused on environmental processes or socio-financial variables in conservation organizing; additional research is necessary to tackle the intrinsic unpredictability of socio-ecological answers. This data is anticipated to benefit local conservation initiatives and coastal-related entities tasked with monitoring, detecting, predicting, and swiftly responding to the problems presented by a fast-evolving maritime environment.

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