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# Editorial: Understanding the response of ecosystems to increasing human pressures and climate change – management options

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## Editorial on the Research Topic

Understanding the response of ecosystems to increasing human pressures and climate change – management options

## 1 Introduction

The escalating human footprint and climate change (Halpern et al., 2015; Halpern et al., 2025; Korpinen et al., 2021) are driving significant and often poorly understood shifts in marine ecosystems, challenging our ability to predict and manage ecological tipping points (Scheffer et al., 2001). Effective conservation requires a clearer understanding of the causal mechanisms behind these changes, supported by interdisciplinary research, innovative monitoring technologies, and comprehensive assessments of management strategies (Sutherland et al., 2004; Borja et al., 2024). Critical issues such as Harmful Algal Blooms (HABs), jellyfish blooms, biological invasions, climate-induced range shifts, marine heatwaves, deoxygenation, pollution, coastal habitat modification, biodiversity loss, and the decline of top predators demand targeted, science-based solutions. Addressing these knowledge gaps, framed as Grand Challenges in Marine Ecosystem Ecology (Borja et al., 2020), is essential for sustaining ocean health and informing ecosystem-based management (EBM).

This Research Topic was conceived to “take the pulse” of current advances addressing these grand challenges. The contributing articles encompass new methods for assessing cumulative impacts, case studies of ecosystem responses to specific pressures, and state-of-the-art reviews on managing phenomena such as invasive species, jellyfish blooms, HABs, and the decline of top predators. Collectively, they illuminate pathways toward more effective EBM in an era of intensifying human pressures.

## 2 New tools and frameworks for cumulative impact assessment and ecosystem management

Multiple contributions introduce innovative conceptual frameworks and tools to assess and manage the cumulative effects of human pressures on marine ecosystems. [Borja et al.](#) present a comprehensive conceptual framework model and toolbox for evaluating cumulative impacts under the EU Marine Strategy Framework Directive (MSFD). Their policy-focused approach outlines an integrated framework – including risk assessment and vulnerability matrices and decision-support tools – to link human activities with pressures and ecosystem components, supporting sustainable use of the seas. In a similar vein, [Papadopoulou et al.](#) offer a critical interrogation of available marine EBM tools, emphasizing that different management objectives (“horses for courses”) require tailored approaches. By systematically comparing tools ranging from ecosystem models to indicator frameworks, they guide practitioners in selecting appropriate methodologies for specific EBM challenges.

Focusing on the Black Sea, [Lazar et al.](#) introduce a robust semi-quantitative framework that combines a habitat sensitivity matrix (scoring the vulnerability of ecosystem components to various pressures) with fuzzy cognitive mapping via the Mental Modeler software to quantitatively prioritize drivers–pressures–impacts linkages. They then apply these tools under future “Shared Socioeconomic Pathways” (SSP1, SSP2, SSP5) scenarios to simulate and compare cumulative impacts across trajectories of management and development. Together, these novel integrations enable adaptive scenario-based assessments and provide decision-makers with a science-based roadmap to target the most damaging pressures under resource or capacity constraints.

Several original research articles tackle the problem of limited data and high uncertainty in impact assessments. [Matos et al.](#) develop “impact chains” (i.e. structured cause-effect pathways) for deep-sea ecosystems with limited data, a novel method to map in a transparent, modular framework how multiple stressors propagate through the ecosystem. Using this framework, they assess human pressure footprints on the deep-sea benthic habitats and identify critical knowledge gaps under conditions of uncertainty. [Pham et al.](#) apply an expert-based risk assessment in the Barents Sea, demonstrating how expert elicitation can evaluate risks to key ecosystem services when empirical data are limited. Their approach integrates certainty assessment into a mixed-method expert-based risk evaluation building on the DAPSI(W)R(M) framework ([Elliott et al., 2017](#)), prioritizing pressures that most endanger the delivery of ecosystem services in a rapidly changing Arctic environment.

Other studies focus on improving monitoring and assessment frameworks to better capture ecosystem change. [Devlin et al.](#) review and redesign the eutrophication assessment regime in UK waters, which is fundamental for water quality management. They highlight successes and gaps in current monitoring, then propose a future assessment structure that integrates new indicators, climate

considerations, and “shifting baselines” to reflect rapid ecological change. This forward-looking framework aims to enhance alignment between directives and incorporate ecosystem impacts of climate-driven stressors (e.g. warming, hypoxia) into coastal water quality evaluations. Likewise, [Olano-Arbulu et al.](#) test the utility of linking ecosystem functioning to human benefits using the Common International Classification of Ecosystem Services (CICES) cascade ([Haines-Young and Potschin, 2012](#)). Focusing on the Bay of Biscay, they find that many indicators in past studies were misassigned to cascade components, emphasizing the need for standardized classifications. Their case study of the anchovy fishery demonstrates that the CICES cascade can effectively trace connections between environmental health and the sustainable supply of ecosystem services. By identifying disconnects and correlations in the service cascade, this work contributes to refining how we quantify the benefits humans derive from well-managed ecosystems.

## 3 Addressing biological invasions, jellyfish and algal blooms, the decline of top predators, and emerging stressors

Human-driven ecosystem changes often manifest as biological disturbances – such as invasive species spread, jellyfish blooms and HABs, or loss of top predators – which pose major challenges for environmental managers. Additionally, emerging stressors such as microplastics, noise, and light also contribute to cumulative impacts. This Research Topic includes several comprehensive reviews that address these phenomena and offer guidance for mitigation and policy.

[Katsanevakis et al.](#) provide a timely review of marine invasive alien species (IAS) in Europe, evaluating progress nine years after the EU adopted its IAS Regulation ([European Union \(EU\), 2014](#)). They synthesize data on the introduction and spread of marine non-indigenous species across European seas, revealing persistent gaps in monitoring and management. The review emphasizes that effective IAS management hinges on coordinated data sharing (through networks like EASIN and AquaNIS) and rapid response strategies. They recommend strengthening biosecurity measures, public awareness, and research on the impacts of invasive species, as invasions can lead to native biodiversity decline, regime shifts, altering food webs, and compromising ecosystem functioning (e.g. [Tsirintanis et al., 2022](#)). This echoes the broader call for science-based interventions to curb biological invasions, which rank among the prominent human-induced stressors on marine ecosystems.

HABs, traditionally managed as public health issues (e.g., causing beach or shellfish bed closures), also have complex ecological and socio-economic linkages. Recognizing this, [Sagarminaga et al.](#) introduce new tools for managing HABs under an ecosystem-based framework. To support Good Environmental Status (GES) goals (according to the EU Marine Strategy Framework Directive), the authors develop two decision-support

tools: GES4HABs, a decision tree for determining management actions based on bloom status and causes, and MAMBO (environMental mAtrix for the Management of BLOoms), a matrix that categorizes regions by natural trophic state and human influence. These tools help managers identify when and where proactive mitigation of HABs is feasible, versus when preventive management (e.g., reducing nutrient inputs) is more appropriate. By streamlining assessment and reporting of HAB conditions, this work enhances our capacity to integrate HAB management into broader marine policy and management.

A complementary review by [Sagarminaga et al.](#) tackles jellyfish outbreaks and how to manage them to achieve GES. This systematic review compiles knowledge on the drivers of jellyfish proliferations (from climate warming and overfishing of competitors to coastal habitat modification) and evaluates control measures ranging from bloom forecasting to jellyfish removal. Managing jellyfish blooms is notoriously difficult, but the review highlights that early warning systems, public engagement through citizen science, and addressing root causes (e.g. rebuilding predator fish stocks, reducing eutrophication that favors jellyfish) can mitigate impact. The authors note that jellyfish management needs to be embedded in EBM, treating blooms as symptoms of broader ecosystem imbalances (often human-induced) rather than isolated nuisances. This perspective aligns with the holistic approach advocated across this Research Topic. [Fernández-Alías et al.](#) provide a comprehensive review of scyphozoan jellyfish bloom dynamics, highlighting the persistent unpredictability of bloom events despite decades of research. They identify overlooked sources of ecological variability – ranging from larval-stage mortality and substrate competition to microbiome interactions – that modulate bloom intensity and challenge forecasting efforts. The authors argue for species- and site-specific models that integrate both biotic and abiotic controls across life stages to improve predictive capacity.

Marine top predators are critical for ecosystem functioning, yet many are in decline due to cumulative human impacts like overfishing, bycatch, and climate change. [Fortuna et al.](#) review the ecological implications of these losses, such as trophic cascades and altered community structure when apex predators are removed. They also review traditional and emerging monitoring tools, highlight successful mitigation measures (from establishing marine protected areas and sustainable fisheries regulations to reducing bycatch through technological innovation), and stress the need for integrated, adaptive EBM. The review calls for embedding predator conservation into governance frameworks that address ecological, social, and economic dimensions.

[Stanton and Cowart](#) shine light on an underappreciated anthropogenic stressor: artificial lighting at night (ALAN). In their perspective, they review the effects of ALAN on the circadian biology of marine animals. From disrupted feeding and reproduction in corals and fish to altered behavioral rhythms, ALAN emerges as an “ecological light pollution” that can compound other stressors in coastal ecosystems. The authors call for incorporating ALAN into marine management considerations, noting that as human coastal development grows, so does the footprint of nocturnal light.

## 4 Case studies: ecosystem responses to climate and anthropogenic pressures

Multiple contributions provide empirical insights from specific regions and species, illustrating how marine ecosystems are responding to intensifying pressures. These case studies, spanning multiple taxa and geographies, reveal both common patterns and context-specific dynamics in ecosystem change.

Several studies document responses to climate change, particularly warming, in marine populations. [Liao et al.](#) focus on a small endemic euryhaline fish in the South China Sea and document significant habitat changes under warming. Using field surveys and species distribution modeling, they show that rising temperatures and shifting salinity regimes are contracting the suitable habitat for this estuarine species. Their findings exemplify how climate change is already driving range shifts and localized population stress for coastal species, particularly in relatively understudied tropical systems.

In European waters, [de Fouw et al.](#) analyze long-term data on the bivalve *Spisula subtruncata* in the North Sea to decipher drivers of its population fluctuations. Their spatio-temporal analysis evaluates the roles of climate and hydrographic change, fishing pressure, predation, and other variables in driving bivalve population swings. Understanding these population dynamics is critical, as such suspension feeders play key roles in coastal food webs and water clarity. Understanding natural variability versus human-induced change can inform thresholds for intervention.

Other case studies focus on ecosystem responses to localized human activities and habitat modifications. [Huang et al.](#) investigate Indo-Pacific humpback dolphins' responses to a megaproject construction, the Hong Kong–Zhuhai–Macao Bridge. Through field observations, they document changes in dolphin behavior and habitat use during bridge construction, indicating disturbance from increased undersea noise, vessel traffic, and habitat alteration. Their findings emphasize that even marine megafauna in urban coastal seas can be significantly affected by infrastructure development, highlighting the need for mitigation (e.g. noise reduction, temporal work closures) to protect top predators during coastal construction.

In a different context of coastal development, [Liu et al.](#) report on the proliferation of green macroalgae in China's Nanhui tidal flat following land reclamation. They found that the newly formed mudflat wetlands experienced blooms of opportunistic green algae, likely due to altered hydrology and nutrient conditions post-reclamation. This case study illustrates how coastal engineering can trigger unforeseen ecological shifts, such as nuisance algal outbreaks, with implications for wetland management and restoration efforts.

The systematic review by [Marguin et al.](#) synthesizes evidence on how fishing alters the trophic structure of fish populations and assemblages in the Mediterranean, highlighting that high fishing pressure—especially from industrial trawling—tends to lower trophic levels and disrupt food web functioning. It identifies major knowledge gaps and emphasizes the need for improved monitoring tools, EBM, and the inclusion of trophic indicators to

assess and mitigate cumulative impacts of fishing and climate change on coastal ecosystems.

Erbay et al. present the first comprehensive assessment of marine recreational fishing in the Turkish Black Sea, revealing high participation rates (about 4.5 million marine recreational fishers) and a significant retained biomass, surpassing commercial landings for some species. The study highlights both the economic value of this sector and its potential ecological impacts, emphasizing the urgency of including recreational fisheries in stock assessments and management frameworks. It also notes encouraging signs of conservation-minded behavior among fishers, such as widespread catch-and-release practices, suggesting potential leverage points for sustainable governance.

Ussi et al. analyze over 20 years of coral reef monitoring data and find a clear long-term change in reef community composition, with increases in dead coral, due to bleaching, particularly during strong El Niño events, crown-of-thorns starfish (COTS) outbreaks, and chronic local human pressures. They observed coral recovery with lower human impact and COTS removal in well-managed sites. The study highlights the need for stronger local management and long-term monitoring to inform ecosystem-based responses and protect reef functions.

Perrois et al. investigate the environmental drivers shaping sessile benthic communities around Jeju Island, a temperate-subtropical transition zone undergoing rapid ecological change. This study highlights the importance of marine climatic transition zones as sentinels of climate-driven faunal turnover, offering critical insights for predicting and managing biogenic habitat shifts under warming scenarios.

Effective management also hinges on accurate monitoring and recognition of novel stressors, and several papers in this Research Topic tackle this challenge. Hill et al. provide a striking example from the Southern Ocean: they show how apparent trends in Antarctic krill populations can be confounded by shifts in sampling methods over time. As surveys transition from net catches and acoustics to autonomous moorings, gliders, and meta-genetics the authors caution that observed “changes” in krill abundance may partly reflect methodological differences rather than true ecological shifts. Their analysis, focusing on a keystone pelagic species, highlights the broader point that long-term ecological datasets must be interpreted in light of evolving techniques. Maintaining continuity in monitoring or calibrating among methods is essential to reliably detect biological change.

## 5 Nature-based solutions

Ter Hofstede and van Koningsveld explore solutions by integrating nature-based approaches into construction of human infrastructure. They advance this concept, defining operational objectives to achieve system-scale ecological benefits. Using examples from the Dutch North Sea, they argue that engineered structures (like wind farms, artificial reefs, dikes) can be deliberately designed or retrofitted to support biodiversity and ecosystem functions. Establishing clear objectives, such as enhancing fish habitat connectivity or promoting reef community development, is key to assessing the success of these interventions. This work

aligns with the growing recognition that nature-based solutions and habitat restoration can help offset some impacts of development and bolster ecosystem resilience in the face of global change.

Rasowo et al. review Kenya’s pioneering blue carbon initiatives, including mangrove conservation, carbon credit schemes, and seaweed farming, highlighting their dual role in climate mitigation and community development. These projects are notable for their participatory governance—linking national policy frameworks with grassroots co-management—and for empowering local stakeholders, particularly women and youth, through sustainable income generation. By aligning with multiple United Nations Sustainable Development Goals, the initiatives exemplify how blue economy strategies can deliver integrated environmental and socio-economic benefits.

Da Conceição Felisberto Macamo et al. assessed a community-based mangrove management initiative in Nhangau, Mozambique, revealing partial success in restoring 10 ha of mangrove forest and promoting local awareness and alternative livelihoods. They discuss challenges in law enforcement and long-term financial sustainability, limiting its capacity to curb illegal harvesting and fully implement regulatory mechanisms.

Wang et al. present a novel seascape connectivity modeling framework tailored to China’s coastal seas, integrating species dispersal potential with hydrodynamic and habitat data to identify conservation priorities. Their approach reveals key connectivity corridors and larval sources across fragmented coastal systems, offering actionable guidance for designing spatially coherent marine protected area networks. The study demonstrates the value of connectivity-informed planning in achieving effective and ecologically representative conservation outcomes.

## 6 Toward resilient marine ecosystems: synthesis and future directions

The diverse contributions in this Research Topic collectively reinforce key themes for future marine ecosystem management. First, the need for interdisciplinary, integrated ecosystem-based approaches is clear, in which humans are recognized as integral components of marine ecosystems. Single indicators or sectoral perspectives are no longer sufficient when dealing with complex problems like cumulative impacts from multiple anthropogenic pressures and natural stressors in an era of climate change. Many authors advocate for combining tools and breaking silos between disciplines (oceanography, ecology, social science, policy) to improve predictability of ecosystem responses.

Second, the importance of proactive management and early warning comes through strongly. Whether it is anticipating regime shifts, identifying tipping points, or forecasting blooms, timely information can enable managers to act before irreversible damage occurs. The decision-support systems, tools, and frameworks proposed in the Research Topic are valuable steps toward that goal.

Third, many studies highlight ecosystem resilience and nature-based solutions as cornerstones of long-term sustainability. Enhancing resilience might involve restoring top predators and



keystone species (to control invasive species or jellyfish), implementing marine protected areas and habitat restoration, or designing climate-ready conservation strategies. For example, nature-inclusive design of infrastructure and habitat-focused planning can create win-win scenarios for development and conservation.

Finally, a recurring message is the need to close knowledge gaps through continued research and monitoring. From the deep sea to coastal wetlands, understanding cause-effect linkages – especially for emerging issues like microplastic pollution, artificial lighting, or ocean noise – remains a priority. The contributions in this Research Topic not only advance scientific understanding but also translate that knowledge into practical recommendations for managers and policymakers.

## Author contributions

SK: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing. AB: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing. EG: Conceptualization, Writing – original draft, Writing – review & editing. SF: Conceptualization, Writing – original draft, Writing – review & editing. HT: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing.

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