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Editorial

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Current challenges and progress in global management, research, science and policy: Eleventh International Conference on Marine Bioinvasions (ICMB-XI)

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Co-Editors' Note: This study was first *presented at the 11th International* Conference on Marine Bioinvasions held in Baltimore, Maryland, USA, May 15–19, 2023 (http://www.marinebioinvasions.info). Since their inception in 1999, the ICMB meetings have provided a venue for the exchange of information on various aspects of biological invasions in marine ecosystems, including ecological research, education, management and policies tackling marine bioinvasions.

Abstract

The Eleventh International Conference on Marine Bioinvasions (ICMB-XI), held May 15–19, 2023, in Baltimore, Maryland, USA, convened 213 attendees from 24 countries to discuss the challenges and advancements in managing marine non-indigenous species (NIS). The conference emphasized the urgent need for international collaboration to address the increasing threats posed by marine bioinvasions, which transcend geopolitical boundaries. Participants explored six key themes through 119 oral presentations, 37 posters, and six keynote speakers, providing a platform for researchers, policymakers, and industry professionals to exchange knowledge and strategies. Notably, ICMB-XI implemented the first Code of Conduct for the Society for the Study of Marine Bioinvasions, promoting inclusivity and ethical scientific discourse. Here, we review articles published in Aquatic Invasions and Management of Biological Invasions based on research presented at ICMB-XI. Studies highlighted novel findings on species settlement dynamics, NIS ecological impacts, and advancements in detection methods such as environmental DNA monitoring. Research also examined the role of climate change in facilitating NIS, the influence of biofouling on NIS establishment, and the expansion of NIS into new ecological niches. Beyond scientific discussions, ICMB-XI celebrated the intersection of art and science through a collaboration with artist April Flanders, whose work communicated the impacts of marine invasions to broader audiences. The conference also provided travel awards and student achievement prizes to support early-career scientists. As ICMB-XI concluded, participants reinforced the need for sustained, large-scale efforts to mitigate marine bioinvasions through enhanced research, policy integration, and cross-sector collaboration. The next ICMB, scheduled for 2025 in Madeira, Portugal, aims to continue advancing the field and fostering international partnerships in marine bioinvasion management.

Key words: Collaboration, ecological impacts, management, non-indigenous species

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ICMB-XI Conference and content of the Special Issue

For nearly 25 years, the International Conference on Marine Bioinvasions (ICMB) has been a leading forum for scientists studying the introduction and spread of marine non-indigenous species (NIS), their ecological and economic impacts, and management strategies for their prevention and control. As an established marine invasions conference, ICMB offers a unique opportunity to interact with others interested in these topics, to assess what progress has been made towards improved evidence-based management and policy, and to consider what the most pressing challenges are to developing and implementing effective interventions. In this context, the Eleventh ICMB (ICMB-XI) was held May 15–19, 2023 in Baltimore, Maryland, USA and was hosted by the Smithsonian Environmental Research Center and the Institute of Marine and Environmental Technology. Even though it was postponed by three years due to the COVID-19 pandemic, 213 students, academics, environmental managers, federal/state/local government representatives, and industry leaders from 24 countries on six continents came together to exchange ideas and discuss our understanding of marine invasions and their associated challenges (Fig. 1).

Regardless of the species, vectors/pathways, or ecosystem being invaded, one message was clearly woven among the talks and posters at ICMB-XI – NIS do not recognize geopolitical boundaries. Only through meaningful collaboration can the threats from marine NIS be identified and mitigated. As they continue to spread at national, regional, and global scales, it is increasingly important that science, management, and policy also work at these scales by bridging barriers that are currently limiting our ability to effectively respond to high-risk species or regulate human-mediated vectors beyond ballast water. Not only do we need to increase transparency in how information is gathered and shared, but we need to develop a framework that can harmonize activities at different scales to reduce the impacts of marine NIS and maintain native biodiversity and ecosystem structure and function. Despite calls to work on marine NIS at regional to global scales, existing regulations, policies, and laws are limited with insufficient funding and collaboration to make them a reality. We encourage participants of ICMB and others to continue to engage government officials and those in management positions with the intention of integrating current research into regulations, policies, and laws to prevent and control marine NIS.

The six themes for ICMB-XI were structured into 13 oral sessions and one poster session, covering the following topics: (1) biofouling dynamics and management of ships and plastics, (2) climate-driven invasion effects and responses, (3) socio-ecology and other diverse, interdisciplinary perspectives on invasions, (4) impacts of invasions: ecology, ecosystem services, and economics, (5) methods for non-native species detection and assessment, and (6) principles, patterns, and contrasts of invasions across ecosystems. ICMB-XI brought together a geographically- and gender-balanced team of six leading keynote speakers, with an additional 119 talks and 37 posters presented. Out of all attendees, 36% were students or early-career scientists. During the preparation of ICMB-XI, the first Code of Conduct of the Society for the Study of Marine Bioinvasions, which oversees ICMB activities, was completed and successfully implemented by the ICMB Scientific Steering Committee, marking an important milestone in the history of this international meeting (https://marinebioinvasions.info/about/policies/code-of-conduct).

ICMB also has a unique history of exploring rich perspectives found at the intersection of the sciences and arts. Previous conferences have worked with artists who, through their chosen media, have enhanced our appreciation and communication of how marine bioinvasions have impacted our world. Artwork inspired by subjects

Figure 1. The Eleventh International Conference on Marine Bioinvasions held May 16–19, 2023 in Baltimore, Maryland, USA Above: Group photo of attendees (Photo: Paula Pappalardo). Middle: Global map of home countries of ICMB-XI participants. Bottom: Front of the abstract booklet, showcasing art by April Flanders.

ranging from marine invertebrates to shipping vessels has connected us to audiences far beyond the scientific and policy making communities. In that spirit, ICMB-XI partnered with USA-based artist April Flanders, a Professor of Studio Art at Appalachian State University, who uses a variety of media including printmaking, painting, drawing and installation to address the problem of NIS on a global scale (Fig. 1).

The ICMB meetings are traditionally an excellent venue for undergraduate and graduate students and post-doctoral researchers to present their research, either as an oral or poster presentation. To that end, the ICMB-XI Local Organizing Committee (LOC) presented five travel awards for students and early-career researchers: one Judith A. Pederson and James T. Carlton Early Career Scientist Award sponsored by Gittenberger Marine Research, Inventory, and Strategy (GiMaRIS), two International Student Travel Awards sponsored by individual donors and souvenir sales, and two North Pacific Marine Science Organization (PICES) Student Travel Awards. In addition, the LOC granted registration fee waivers to 17 additional students and early-career scientists. The LOC awarded Student Achievement Prizes for oral and poster presentations (for 1st, 2nd, and 3rd place), sponsored by Maryland Sea Grant, the Mid-Atlantic Panel on Aquatic Invasive Species, the University of Maryland Institute of Marine and Environmental Technology, and the Biodiversity Heritage Library. Among these prize winners, two student presentations were selected to also receive the PeerJ Awards for Best Overall Student Talk and Best Overall Student Poster, sponsored by the open access journal PeerJ's Life and Environment hub.

Research from all of the sessions was represented by eight papers published in this special issue of Aquatic Invasions (Blumenthal et al. 2025; de Rivera et al. 2025; Golanski et al. 2025; Hoeke et al. 2025; Kupriyanova et al. 2025; Lee et al. 2025; McCann et al. 2025; Zavacki et al. 2025) as well as two additional papers in Management of Biological Invasions (Sheehan et al. 2024; Peters and Meyers 2024). Below, the papers in these special issues are explored in the context of the major themes of ICMB-XI.

Biofouling dynamics of ships and management strategies

Managing marine biological invasions is challenging due to the complexity of species transfer via ballast water and biofouling, particularly in ports and marinas where NIS can establish and spread. The study by Peters and Meyer (2024) investigated the temporal settlement patterns of marine biofouling communities in False Bay Yacht Club marina, South Africa, using PVC settlement plates. They tracked species composition monthly between April and August 2022 and identified and estimated cover for each species. There was significant monthly variation in species richness and abundance, with NIS comprising 55% of the community and establishing dominance early, with eight of 12 NIS settling within the first month. Key species, including the ascidians *Corella eumyota* and *Diplosoma listerianum*, the polychaete *Neodexiospira brasiliensis*, and the barnacle *Balanus trigonus* demonstrated strong competitive traits. The study underscores the importance of ongoing, temporally sensitive monitoring to better manage marine bioinvasions and guide biosecurity efforts.

Impacts of invasions: ecology, ecosystem services, and economics

Non-indigenous species (NIS) can disrupt marine ecosystems by altering habitats and reducing native species through rapid growth and resource competition. The bryozoan *Amathia verticillata* exemplifies this, acting as an ecosystem engineer that provides complex biogenic habitat for diverse marine invertebrates, including native, cryptogenic, and other NIS. In this context, Zavacki et al. (2025) investigated

the influence of *A. verticillata* on marine invertebrate communities in Mission Bay, San Diego, California, USA between July 2021 and 2022. Invertebrate diversity increased with structural complexity, with elongated morphotypes hosting more polychaetes and compact ones harboring more amphipods. Seasonal patterns showed that *A. verticillata* abundance peaked in warmer months, coinciding with shifts in community composition. The findings suggest that this bryozoan acts as an ecosystem engineer, potentially facilitating the establishment of other NIS and influencing local community dynamics.

Non-indigenous species (NIS) can negatively impact ecosystems by altering food webs and nutrient cycling, as observed with non-indigenous tunicates and mussels affecting aquaculture and primary productivity. Sponges, as filter-feeders, also influence these systems through benthic-pelagic coupling by converting waterborne nutrients into biomass. The population dynamics of NIS sponges is crucial for understanding their ecological impacts. Hoeke et al. (2025) studied the seasonal dynamics of the introduced sponge *Hymeniacidon perlevis* in Elkhorn Slough, California, USA by tracking its distribution, biomass, and correlations with environmental data between 2007 and 2023. The sponge exhibited a distinct seasonal cycle, with biomass peaking in October (fall) and declining to near absence by March (spring). Warmer temperatures and lower dissolved oxygen were positively correlated with sponge cover, with a time lag of 2–4 months. The population has increased in frequency and density since 2007, particularly in the upper estuary. The study highlights the sponge's potential ecological impact through water filtration and its adaptability to environmental changes, emphasizing the need for monitoring strategies.

The Mediterranean Sea hosts over 500 NIS, with a high concentration in the eastern basin due to Indo-Pacific introductions via the Suez Canal. Ascidians, particularly NIS, often colonize artificial substrates in harbors, but soft-bottom habitats in the eastern Mediterranean remain understudied even though these habitats are vulnerable to colonization, especially as anthropogenic and natural disturbances alter benthic community dynamics. Framed by this complex scenario, Golanski et al. (2025) documented a novel colonization of the NIS ascidian *Microcosmus exasperatus* on the sandy bottom of the Israeli Mediterranean coast in September 2022. This species, typically associated with rocky substrates, was observed using polychaete tubes and shells as settlement sites, reaching peak densities of 1.8 individuals per square meter in autumn 2022. The population declined during winter storms and was absent by February 2023 but reappeared in smaller numbers the following summer. The colonization demonstrated the species' potential for niche expansion into soft-bottom habitats, potentially acting as "stepping stones" for further dispersal. The study highlights the need for long-term monitoring to assess the recurrence and ecological impact of such events.

The introduction of NIS can negatively impact local restoration efforts. Blumenthal et al. (2025) investigated the habitat factors influencing the presence and density of the Atlantic oyster drill, *Urosalpinx cinerea*, in Richardson Bay (part of San Francisco Bay), California, USA. In this area, there are extensive efforts to restore native Olympia oyster (*Ostrea lurida*), a prey item of *U. cinerea*. They found that coarse substrate and elevation were significant predictors of drill density but did not explain the species' patchy distribution across sites. Historical introduction patterns and limited dispersal ability likely drive distribution, while habitat conditions influence local abundance. The presence of oyster drills poses a challenge for Olympia oyster restoration, necessitating careful site selection and monitoring. The authors recommend more extensive surveys and preventative measures to minimize drill spread and support restoration efforts.

Methods for non-indigenous species detection and assessment

The Great Lakes basin has experienced over many decades a significant rise in NIS, primarily due to ballast water discharge from commercial vessels. While ballast water exchange regulations have reduced new introductions worldwide, unmanaged and untreated ballast water still poses a risk. Environmental DNA (eDNA) monitoring, despite challenges in distinguishing living from non-living organisms, offers a promising tool for early detection and improved NIS management. Sheehan et al. (2024) investigated the persistence of eDNA from the introduced mysid *Hemimysis anomala* in Great Lakes water to improve NIS monitoring. Using microcosms inoculated with freeze-killed specimens, they measured rapid eDNA decay, with a half-life of 4.5 hours and signal detection ceasing after seven days. The decay followed an exponential pattern, consistent with previous studies on larger organisms, indicating reliable use of qPCR-based eDNA monitoring in ballast water uptake locations. The findings underscore eDNA's potential as a practical early detection tool for preventing NIS spread via untreated ballast water.

The invasion status of cryptic species is particularly difficult to understand without genetic methods, but species identification is crucial to understand the ecological and management impacts of a species invasion. Kupriyanova et al. (2025) investigated the origins of the polychaete *Spirobranchus* cf. *tetraceros* in the Western Mediterranean, previously considered a Lessepsian migrant from the Red Sea. Through genetic analysis (18s rRNA and cyt-b), they identified the species as *S. arabicus*, originating from the Persian Gulf rather than the Red Sea. The findings challenge the assumption of a natural migration via the Suez Canal, suggesting ship-fouling as the primary introduction vector. The study highlights the complexity of the *S. tetraceros* species complex and the need for further genetic research to distinguish native from introduced populations. These results underscore the importance of integrative taxonomy for understanding marine bioinvasion pathways.

Principles, patterns, and contrasts of invasions across ecosystems

Climate change is expected to increase the introduction of non-native species in coastal ecosystems, but documenting these changes is challenging due to a shortage of funding for monitoring surveys and lack of taxonomists for specialized groups of organisms. In addition, repeated sampling across locations is crucial for understanding long-term patterns of NIS diversity and abundance. McCann et al. (2025) synthesized a 20-year study on NIS marine bryozoans along both the eastern and western coasts of North America (i.e., the continental United States and Canada), using standardized settlement plate surveys across 35 bays. Additional records were added via literature reviews and rapid assessment survey data. They documented 48 NIS bryozoans, with the Pacific coast hosting the highest diversity, particularly in San Francisco Bay, California. Latitude influenced species richness, with fewer species found at higher latitudes. Hull fouling and ballast water were identified as the primary vectors of introduction, while oyster transplants played a lesser role. The study highlights the importance of ongoing monitoring and the role of shipping activities in the spread of these invasive species.

Biological invasions are a growing environmental concern due to their significant impacts on biodiversity and ecosystem structure, especially when species act as ecosystem engineers by altering habitat complexity. Foundation species, like macroalgae, provide food and shelter for various invertebrates, influencing community dynamics when their composition changes. Human activities such as shipping and aquaculture have facilitated the global spread of these habitat-forming species,

leading to significant shifts in marine community structure. Lee et al. (2025) investigated the biogeographic patterns of macroinvertebrate and trematode communities associated with the introduced red alga *Gracilaria vermiculophylla* along the Atlantic Coast of the United States. Across 17 sites, they found 39 macroinvertebrate taxa, with amphipods dominating the assemblages, and identified the biogeographic region of the recipient community as a key predictor of species richness and abundance. Trematode diversity in the snail host *Ilyanassa obsoleta* decreased with increasing *G. vermiculophylla* biomass, though the relationship was not statistically significant. The study revealed distinct community compositions across regions, highlighting the ecological influence of this invasive foundation species. These findings underscore the need for ongoing monitoring to understand long-term ecosystem impacts.

Biotic interactions, particularly predation, vary along environmental stress gradients such as salinity changes in estuaries, where NIS often thrive due to their enhanced stress tolerance. Traditional models like the Consumer Stress Model and Prey Stress Model predict different patterns of predation under stress, but recent research suggests the Invasion Stress Model better explains estuarine dynamics by accounting for invasive species' influence. Understanding these interactions is essential for predicting community structure changes in invaded estuarine systems. De Rivera et al. (2025) investigated how predator consumption varies along estuarine salinity gradients in five Oregon, USA estuaries. Using standardized bait, they found that consumption peaked at mid-estuary salinities, and declined in fresher waters, especially with higher temperatures. The data did not support existing models like the Consumer Stress Model but aligned with the Prey Stress Model and the Invasion Stress Model. While the introduced green crab *Carcinus maenas* was present, its abundance did not correlate with consumption patterns, although laboratory experiments showed higher feeding rates at intermediate salinities. The study highlights the need for further research to refine predictive models of predator-prey interactions along estuarine stress gradients.

Concluding remarks

Since their inception in 1999, the ICMB meetings have provided a venue for the exchange of information on various aspects of biological invasions in marine ecosystems, including ecological research, education, management, and policies tackling marine bioinvasions. While topic categories like Climate-driven invasion effects and responses, or Socio-ecological perspectives on invasions, still require more attention, we are pleased to acknowledge that most other areas and topics have shown considerable progress. With the next ICMB planned for October 6–9, 2025 in Madeira, Portugal (hosted by Dr. João Canning-Clode and the MARE-Madeira Local Organizing Committee; https://www.marinebioinvasions.info), we are excited to continue to advance the field of marine bioinvasions!

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