ICMB
MADEIRA 2025

XII INTERNATIONAL CONFERENCE ON MARINE BIOINVASIONS

Abstract Book

October 6th - 9th, 2025
Funchal, Madeira Island, Portugal

Hosted by:

SSMB Society for the Study of Marine Bioinvasions · MARE · Parditi agência regional para o desenvolvimento da investigação tecnologia e inovação · UNIVERSIDADE da MADEIRA · ARNET

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Foreword

The XIIth International Conference on Marine Bioinvasions (ICMB-XII) was held in October 2025 in Funchal, Madeira, Portugal. It was a privilege to host this global community of researchers, practitioners, and policymakers in a region that embodies many of the themes central to marine bioinvasions research.

Over the years, the International Conference on Marine Bioinvasions has become a cornerstone event for advancing knowledge, fostering collaboration, and bridging science with policy and management. The twelfth edition continued this tradition by bringing together 274 attendees from 40 countries to share new findings, innovative methodologies, and practical solutions.

The diversity and quality of the contributions compiled in this abstracts book reflect the dynamism of our field, which encompasses eight conference themes:

1. Climate Resilience and Bioinvasions: Species Responses Under Extreme Events
2. Emerging Anthropogenic Pathways: Understanding and Mitigating New Vectors
3. Innovative Detection and Early Warning Systems: Tools and Citizen Science in Action
4. Policy and Collaboration: Bridging Science, Management, Governance, and Community
5. Restoration and Remediation of Invasion-Impacted Ecosystems
6. Bioinvasions and the Blue Economy: Navigating Economic and Ecological Balance
7. Ecological and Evolutionary Impacts
8. Marine Protected Areas and Bioinvasions: Opportunities and Challenges

We extend our sincere gratitude to all authors for their valuable contributions, to the keynote speakers for enriching the scientific programme, and to the reviewers and session chairs for their dedication and expertise. We also warmly thank our sponsors and institutional partners whose support made this conference possible.

Finally, we are deeply grateful to the Local Organizing Committee and the many volunteers whose hard work behind the scenes ensured the success of this meeting.

We hope that the exchanges initiated during ICMB-XII will continue to stimulate rigorous discussion, spark new collaborations, and inspire innovative approaches to understanding and managing marine bioinvasions.

With our best wishes,

Co-chairs,

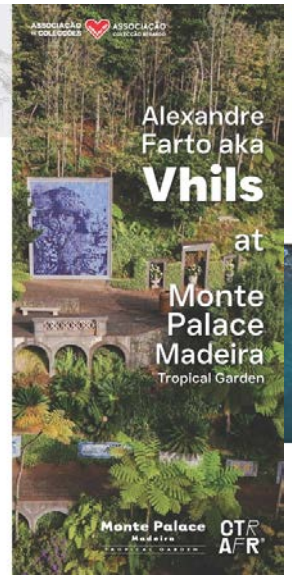
Dr. João Canning-Clode, Dr. Paola Parretti and Dr. Susanne Schäfer

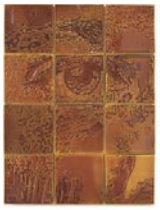
Artist

Portuguese artist Alexandre Farto, aka Vhils (b. 1987) has developed a unique visual language based on the removal of the surface layers of walls and other media with non conventional tools and techniques. He began interacting with the urban environment through the practice of graffiti in the early 2000s. Peeling back the layers of our material culture like a modern-day urban archaeologist, Vhils reflects on the impact of urbanity, development and global homogenisation on landscapes and people's identities. Destroying to create, he delivers powerful and poetic visual statements from materials the city rejects, humanising depressed areas with his poignant large-scale portraits.
Since 2005 he has been presenting his work around the world in exhibitions, events and other contexts – from working with communities in the favelas of Rio de Janeiro, to collaborations with well-reputed institutions such as MAAT – Museum of Art, Architecture and Technology (Lisbon); MIMA Museum (Brussels); Contemporary Arts Center (Cincinnati); Le Centquatre-Paris (Paris); CAFA Art Museum (Beijing); Hong Kong Contemporary Art Foundation (Hong Kong); Palais de Tokyo (Paris); and the Museum of Contemporary Art San Diego (San Diego), among others. An avid experimentalist, besides his groundbreaking bas-relief carving technique, Vhils has been developing his personal aesthetics in a plurality of media: from stencil painting to metal etching, from pyrotechnic explosions and video to sculptural installations. He has also directed several music videos, short films, and two stage productions.

Alexandre Farto aka Vhils

Portuguese artist Alexandre Farto aka Vhils (b. 1987) has developed a unique visual language based on the removal of the surface layers of walls and other media with nonconventional tools and techniques. He began interacting with the urban environment through the practice of graffiti in the early 2000s. Peeling back the layers of our material culture like a modern-day urban archaeologist, Vhils reflects on the impact of urbanity, development and global homogenisation on landscapes and people's identities. Destroying to create, he delivers powerful and poetic visual statements from materials the city rejects, humanising depressed areas with his poignant large-scale portraits. Since 2005 he has been presenting his work around the world in exhibitions, events and other contexts – from working with communities in the favelas of Rio de Janeiro, to collaborations with well-reputed institutions such as MAAT – Museum of Art, Architecture and Technology (Lisbon); MIMA Museum (Brussels); Contemporary Arts Center (Cincinnati); Le Centquatre-Paris (Paris); CAFA Art Museum (Beijing); Hong Kong Contemporary Art Foundation (Hong Kong); Palais de Tokyo (Paris); and the Museum of Contemporary Art San Diego (San Diego), among others. An avid experimentalist, besides his groundbreaking bas-relief carving technique, Vhils has been developing his personal aesthetics in a plurality of media: from stencil painting to metal etching, from pyrotechnic explosions and video to sculptural installations. He has also directed several music videos, short films, and two stage productions.



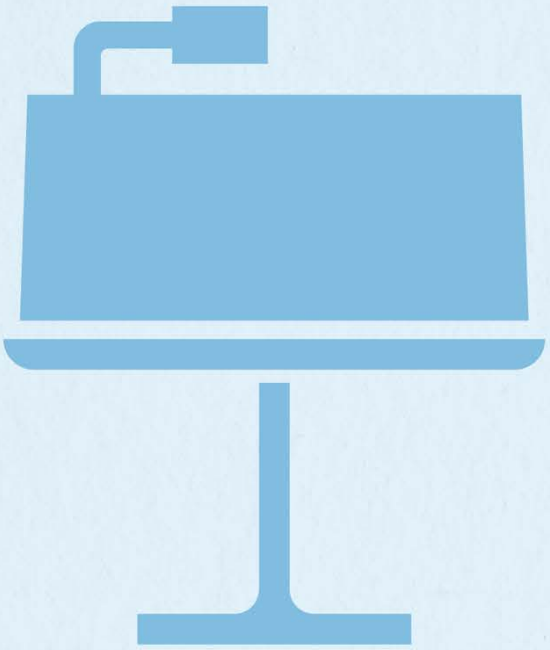


Alexandre Farto aka Vhils
Portugal (1987)
Narrative, 2023
Embossed glazed ceramic tiles
Edition of 50 plus 5 artist's proofs (#27 / 50)
57,3 x 42,9cm
Inv.100-2306
Museum

Alexandre Farto aka Vhils
Portugal (1987)
Multicolour diorama, 2021
Concrete
Inv.100-2254
Garden

Alexandre Farto aka Vhils
Portugal (1987)
Sea portrait, 2025
Homage to Sophia de Mello Breyner
Video, colour, sound, 1'29'', digital file (mp4)
Inv.100-2376
Museum

Alexandre Farto aka Vhils
Portugal (1987)
Manilha, 2025
Embossed glazed ceramic tiles
645 x 503 cm
Inv.100-2377
Garden



Keynotes

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Marine invasion science at scale

Amy L. Freestone

Smithsonian Environmental Research Center, USA. Temple University, USA

Ecologists and evolutionary biologists have long predicted that key local-scale ecological dynamics vary in intensity across biogeographic gradients, such as latitude, shaping global patterns of biodiversity. More recent studies lend support for this prediction and further suggest that these dynamics can have important impacts on patterns of invasion by non-native species. Progress has been hindered, however, by gaps in non-native species occurrence data, which are particularly acute in the tropics. International, coordinated research can help fill these gaps, and standardized distributed experiments can be a powerful approach to both document species occurrences as well as uncover mechanisms that structure these patterns. Our recent distributed experiments that span subpolar to tropical latitudes have demonstrated the impacts of species interactions, particularly predation, on patterns of invasion in the tropics. While central to our understanding of how marine invasions unfold across the globe, a biogeographic perspective has been largely absent from conceptual frameworks that define the field. We are well poised, however, to integrate this perspective into our frameworks and leverage our collaborations to expand knowledge on marine invasion science at scale. From this, we can further improve biosecurity efforts more broadly, as we mobilize our science into action.

Advancing assessments of marine bioinvasion costs

Dr Ross N Cuthbert

School of Biological Sciences, Queen's University Belfast, United Kingdom

Global biological invasions continue to rise — as does the intensity and diversity of their socio-economic and environmental impacts. Recent assessments have quantified the global monetary burden of invasive species at the US$-trillion scale, with costs in marine systems exceeding US$4 billion. This economic toll is compounded by the enormous ecological and health impacts caused by biological invasions that erode all dimensions of sustainability. I will provide an overview of recent impact assessments towards biological invasions, with an emphasis on monetary costs as a metric to raise public and political awareness. Moreover, I will propose a series of priority areas to enhance impact quantifications and management strategies: (1) filling of environmental, geographical, and taxonomic knowledge gaps — particularly to address a paucity of marine cost reporting; (2) developing and linking economic, environmental, and health impact metrics from invasion; (3) improving impact prediction by identifying connections between invasion characteristics and impacted sectors; (4) understanding the implications of rapid environmental changes for future cost escalation; and (5) expanding proactive strategies for prevention, towards timelier investments across existing and emerging invasion pathways. These elements will advance transboundary knowledge and actions to address marine bioinvasion impacts on ecosystems, health, and economies under global change.

Marine bioinvasions in europe: threats, impacts, and response

Dr. Ana Cristina Cardoso, Dr. Chiara Magliozzi, Mr. Eugenio Gervasini

European Commission Joint Research Centre, Italy

European marine waters face a significant threat from non-indigenous species (NIS), with over 1,400 recorded species and 2-10 new introductions annually. The Mediterranean Sea is the most invaded, with over 1,000 NIS, followed by the Atlantic Ocean. Invasive NIS have significant ecological, economic, and social impacts, including altering native species' communities and ecosystem functioning, disrupting nutrient cycles, and introducing diseases and parasites. They cause economic losses to industries like fisheries and tourism, and affect human health. A coordinated response is essential to prevent and mitigate the impacts of marine bioinvasions. The European Alien Species Information Network (EASIN) plays a crucial role in providing EU Member States and policymakers with the necessary information, analysis, and tools to tackle NIS. EASIN hosts comprehensive data on NIS in Europe, including distribution, invasion process, and impacts. By facilitating collaboration and coordinated responses, EASIN supports policy development and implementation to address the impacts of marine bioinvasions. Furthermore, EASIN initiatives promote collaboration among EU Member States to address the significant threat posed by invasive species to European marine ecosystems.

Understanding the technical readiness of technologies for marine surveillance

Graeme J Inglis

National Institute of Water & Atmospheric Research Ltd (NIWA), New Zealand

Surveillance plays a critical role in informing management actions at all stages of biological invasions. Yet, publicly funded surveillance for marine invaders is uncommon. The high costs associated with underwater work and scepticism regarding the effectiveness and benefits of surveillance and control in marine environments often discourage government investment. Advances in eDNA, sensors, acoustics, robotics, high-performance computing, and AI have great potential to enhance the sensitivity and efficiency of marine surveillance and reduce its costs. Nevertheless, each technology has its own biases, strengths, weaknesses, and varying levels of technical readiness for operational use. Over 20 years of surveillance in New Zealand offers valuable insights for developing new methods and establishing benchmarks. Inventory surveys of non-indigenous species are inevitably incomplete, but to what extent? Some invasive species can be detected at low population densities, but which ones? How should we optimise trade-offs between surveillance for priority species and vigilance for unexpected arrivals? What strategies are best for delimiting nascent populations? A guiding framework is needed to prioritise technologies for development, design robust survey strategies for their use, and evaluate their performance against anticipated surveillance objectives.

All hands on deck: science, policy, and industry are essential to reduce global shipborne bioinvasions

Lisa Drake

Drake Marine Environmental Services, USA

The ecological and economic effects of invasive species transported by ships—both in ballast water and by biofouling—are evident worldwide. Given the global nature of shipping and the potential transnational transfer of organisms, this issue warrants a global solution consistently implemented across countries. To address such issues, the United Nations' specialized agency, the International Maritime Organization, is devoted to the "safety and security of shipping and the prevention of marine and atmospheric pollution by ships". Thus, an initial step toward effective, global management of this vector is to put in place global conventions dictating best management practices and limits on the discharge of organisms. When such policies are adopted and enforced by the majority of nations, global implementation is ensured. Technological solutions are needed (and have been developed) to meet these requirements. To provide confidence that technologies work as intended, new methods and approaches had to be designed to assess treatment efficacy, and all of this work was underpinned by years of scientific investigations. The resulting testing data can bring confidence to the array of stakeholders—shipowners, regulators, technology vendors, and environmental groups—allowing the global fleet to make the necessary capital and ongoing investments.

The current situation and issues of marine nonnative species in Japan

Taeko Kimura

Mie University, Japan. Committee for the Preservation of the Natural Environment, the Japanese Association of Benthology, Japan

Japan's maritime environment and thriving trade create numerous entry points for foreign marine nonnative species, with a notable prevalence of benthic organisms. The Committee for the Preservation of the Natural Environment, the Japanese Association of Benthology has a long-standing commitment to monitoring these introductions. Two questionnaire surveys conducted by the Committee and their working group revealed the presence of 111 marine nonnative species in Japanese waters. A significant portion, 77 species, were unintentionally introduced via ballast water, hull fouling, or the imported live fish and shellfish for aquaculture. The remaining 34 species were intentionally brought in for aquaculture, fish baits, or as ornamental aquatic plants.

The establishment and spread of saltmarsh cordgrass *Spartina alterniflora*, a legally regulated invasive species, in Aichi and Kumamoto prefectures in Japan since the 2000s is of particular concern. In response, the Committee urged the relevant authorities to implement urgent eradication measures and has provided ongoing guidance for control efforts.

Addressing the ongoing threat requires a deeper understanding of the pathways of introduction, particularly the import and domestic movement of live fish and shellfish. Furthermore, strengthening the legal framework for managing invasive species is deemed essential for the long-term protection of Japan's marine ecosystems.

ORAL PRESENTATIONS

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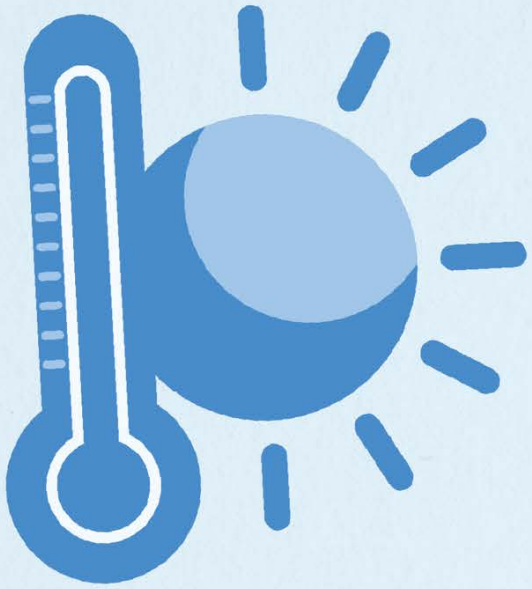

Climate resilience & bioinvasions

Species responses under extreme events

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Climate change facilitates marine invasions: a global meta-analysis

Nicola S Smith[1], William Cheung[2]

[1]Concordia University, Canada. [2]University of British Columbia, Canada

Climate change and invasive species both independently threaten marine biodiversity but can also interact. It is widely thought that climate change will facilitate invasions because invasive species represent a non-random subset of the world's biodiversity in which the same shared traits and life-history characteristics that make an invasive species successful in a novel environment may also allow them to respond favourably to a changing climate. Here, we conduct a systematic literature review and global meta-analysis to quantify the effect of climate change on marine invasions. We show that there are ocean hotspots for invasions globally and that climate change generally facilitates marine invasions with insights into the underlying mechanisms. We also uncover substantial, systematic gaps in the literature and generate testable predictions. Our study suggests that in the future, invasive species are likely to pose a greater threat to ocean biodiversity than previously thought.

Climate change resilience in *Phallusia nigra*: A Comparative Study Between Native and Introduced Populations

Amit Unger[1], Serina Siew Chen Lee[2], Serena Lay Ming Teo[2], Ofir Levy[1], Noa Shenkar[1,3]

[1]Tel Aviv University, Israel. [2]St John's Island National Marine Laboratory, Tropical Marine Science Institute, National University of Singapore, Singapore. [3]The Steinhardt Museum of Natural History and Israel National Center for Biodiversity Studies, Israel

Increasing global maritime trade is intensifying marine connectivity which in turn accelerates bio-invasions. Concurrently, global climate changes are reshaping marine ecosystems, driving species to higher latitudes and deeper waters. Ascidians are notorious invaders, spreading via ship hulls and causing ecological and economic harm. We compared the tolerance of different life stages of native (Red Sea) and non-indigenous (Mediterranean Sea, Singapore) populations of the solitary ascidian *Phallusia nigra* under future climate scenarios, to evaluate their potential for adaptation into different environments. Experiments were conducted on individuals cultured through artificial fertilization and on gametes obtained from adults, using a novel protocol. A month-long multi-factorial experiment tested combinations of salinities (35/40/43PSU) and temperatures (16/25/31°C). Survival was monitored thrice weekly. Blood flow direction was measured weekly as a stress indicator. Salinity affected the Mediterranean population the most, while temperature affected tropical populations significantly. The Singapore individuals tolerated 25°C and 31°C conditions, regardless of salinity. At 16°C, survival and fertilization rates were altered across all populations, indicating a reproductive barrier. The species distribution model based on our results predicts a potential range expansion under future conditions. The study highlights the adaptability and resilience to climate change posed by non-indigenous ascidians.

Warming effects on a non-native predator are not conserved across seasons

Nora Theurich[1,2], Ross Cuthbert[1,3], Elizabeta Briski[1]

[1]GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Germany. [2]Christian Albrecht University of Kiel, Germany. [3]Queen's University Belfast, United Kingdom

Biological invasions and climate change are prominent drivers of global change, yet their complex interactions, particularly in aquatic ecosystems, lack investigation. Most research, both field-based and experimental, often overlooks the impact of seasonality. However, recent studies show more pronounced seasonal than annual shifts in community and species behaviour. We used a model crab-mussel predator-prey system to examine the effects of invasion, temperature, and seasonality on ecological impact. We specifically investigated the impacts of the non-native Japanese brush-clawed shore crab *Hemigrapsus takanoi* on the native blue mussel *Mytilus* sp. in the Baltic Sea, under current and future climate conditions. Utilizing an experimental functional response approach, we uncovered non-linear and sex-dependent effects of warming on *H. takanoi* feeding behaviour, significantly influencing invader impacts depending on the sample season. Population-level impact calculations integrating field abundance data of *H. takanoi* indicated that under ambient conditions, feeding impacts currently peak in the summer months, but as temperature increases, this feeding impact is anticipated to shift later in the year into autumn. These findings underline the critical need for multifaceted research approaches to better understand and predict the context-dependent ecological impacts of non-native species, particularly in the face of ongoing climate change and shifting population characteristics.

Comparative thermal tolerance of embryonic development in *Carcinus maenas* and *Callinectes sapidus*

Ángela Rodríguez-Ruiz[1,2], Gustavo F. de Carvalho-Souza[1], Inma Herrera[3], Enrique González-Ortegón[1]

[1]Institute of Marine Sciences of Andalusia, Spanish National Research Council (ICMAN-CSIC), Spain. [2]Department of Biology, Marine Research Institute (INMAR), University of Cadiz, Spain. [3]Grupo de Investigación en Biodiversidad y Conservación (BIOCON), Instituto Universitario ECOAQUA, Universidad de Las Palmas de Gran Canaria (ULPGC), Spain.

Understanding how embryonic development responds to temperature is crucial for predicting population dynamics and assessing the invasive potential of non-native species under global warming scenarios. This study compares the thermal tolerance of brooding eggs in two decapod species, the European green crab *Carcinus maenas* and the American blue crab *Callinectes sapidus*, using Respiratory Electron Transport System (ETS) activity as a proxy for metabolic response to temperature stress.

For *C. maenas*, a species native to the Gulf of Cadiz but invasive in other regions, three experimental temperatures (10ºC, 17ºC, and 24ºC) were tested, corresponding to its reproductive period. ETS activity increased with temperature, leading to earlier hatching, but optimal embryonic development occurred below 17ºC. C. maenas did not complete development at 24ºC, indicating limited thermal tolerance.

In contrast, C. sapidus, invasive in the Gulf of Cadiz, was tested at 22ºC, 24ºC, 26ºC, and 28ºC, based on its reproductive period. Higher temperatures increased ETS activity, reduced egg size, and accelerated hatching, with optimal development observed at 24ºC. Unlike *C. maenas*, *C. sapidus* tolerated elevated temperatures, suggesting a competitive advantage in warming environments.

These findings indicate that rising ocean temperatures could facilitate the expansion of *C. sapidus* into new habitats, potentially outcompeting *C. maenas* and altering local ecosystem dynamics.

Climate-driven expansion of *Petrolisthes armatus*: population trends, reproduction, and parasitism

Mic Schulte, Cameron L. Bolles, Rachel K. Gittman, April M.H. Blakeslee

East Carolina University, USA

Climate change has been implicated in rising ocean temperatures globally, driving poleward range expansions of (sub)tropical marine and estuarine species into increasingly favorable temperate regions. Climate-induced expansions can disrupt native ecosystems by introducing novel interactions, including parasitism. The term “Caribbean creep” describes the northward movement of western Atlantic species from the Caribbean into temperate regions along the southeast U.S. coast. One such species is the green porcelain crab (*Petrolisthes armatus*), an intertidal/subtidal filter-feeder inhabiting oyster reefs, mangroves, and rocky habitats. My research examines *P. armatus* population demographics, reproductive performance, and parasitism by marine bopyrid, *Aporobopyrus curtatus* from the cryptogenic portion of the crab’s range (Indian River Lagoon, FL) through the leading edge of its non-native range (Beaufort, NC). Porcelain crabs were collected via passive samplers and hand collection from sites in Florida, Georgia, South Carolina, and North Carolina in summer and fall 2024. Increasing latitude is expected to correlate with smaller body sizes at maturity, lower reproductive performance, and reduced bopyrid infections, likely due to enhanced physiological stress in temperate waters. Altogether, my research allows us to gauge the status of *P. armatus* populations along the non-native range and provides insight into their biogeography and invasion success.

An invader chronicles: local ecological niche of *Mnemiopsis leidyi* in the Venice Lagoon

Filippo Piccardi[1], Sara Girardello[1], Valentina Tirelli[2], Diego Borme[2], Alberto Barausse[1], Carlotta Mazzoldi[1]

[1]University of Padova, Italy. [2]National Institute of Oceanography and Applied Geophysics, Italy

Mnemiopsis leidyi, an invasive ctenophore, is an ecological threat in various coastal ecosystems, including the Venice Lagoon, due to its high fecundity and adaptability to a wide range of environmental conditions. The study investigates the spatial distribution and environmental tolerance of the invasive ctenophore in the Venice Lagoon over two years. The research involves field sampling relating ctenophore occurrence to water temperature and salinity, considering the lagoon's environmental factors like seasonality, tides, and freshwater inflows. Laboratory experiments tested M. leidyi's survival under various temperature and salinity combinations to identify conditions affecting its survival. Findings show the species blooms in late spring and late summer-early autumn presumably due to optimal environmental conditions. Laboratory experiments reveal *M. leidyi*'s survival across various temperature (10–28°C) and salinity (20–34) ranges, with extreme conditions reducing survival. This study underscores the potential role of climate change in amplifying *M. leidyi* blooms by enhancing favorable conditions, potentially having a cascading effect on local biodiversity and fisheries, as well as the interplay of temperature and salinity in mediating climatic impacts. The findings highlight the importance of monitoring and managing the lagoon's environmental conditions to assess and mitigate the ecological and socio-economic consequences of this invasive species.

An ecological and behavioral comparison between the invasive *Istiblennius meleagris* and native cryptobenthic Blenniidae in the Israeli Mediterranean

Ram Fine Idan[1], Bat-Sheva (Shevy) Rothman[2], Jonathan Belmaker[3]

[1]Department of Zoology, Tel Aviv University, The Steinhardt Museum of Natural History, Israel. [2]The Steinhardt Museum of Natural History, Israel. [3]Department of Zoology, Tel Aviv University, Israel

The Mediterranean Sea is experiencing rapid environmental changes, with rising temperatures and marine heatwaves (MHWs) intensifying due to climate change. These shifts may favor the establishment of thermophilic non-indigenous species (NIS). Although many NIS have colonized various Mediterranean habitats, the shallow rocky reef community along the Israeli coast remains largely composed of native and diverse cryptobenthic fish. In this study, we investigate whether *Istiblennius meleagris*, a blenniid fish recently introduced to the Levant Basin, gains a competitive advantage over native blenniids under warming conditions. We compare behavioral and ecological traits of *I. meleagris* with three native species (*Scartella cristata*, *Aidablennius sphynx*, and *Parablennius sanguinolentus*) through controlled aquarium experiments and a field-based mark-recapture study. To quantify potential ecological impacts under different temperature regimes, we assess species' feeding efficiency via functional response (FR) analysis—measuring how food intake changes with resource availability under current and simulated future temperatures, including gradual warming and MHWs. In parallel, by using in-situ mark-recapture surveys we monitor population dynamics and behavioral responses to seasonal temperature shifts in response to seasonal temperature fluctuations. Together, these approaches evaluate whether the invasive *I. meleagris* may outcompete native species in a warming Mediterranean ecosystem.

Native against allochthonous: multi-disciplinary approach for heatwave response analysis.

Filippo Drigo, Pietro Antolini, Riccardo Trentin, Chiara Stefanelli, Davide Colaianni, Davide De Battisti, Laura Airoldi, Gabriele Sales, Isabella Moro, Cristiano De Pittà

University of Padua, Italy

To investigate heat-stress responses of two habitat-forming plant species in the Venice Lagoon, *Sporobolus maritimus* (native) and *S. anglicus* (allochthonous), we exposed individuals to an artificial heatwave under laboratory-controlled conditions. Morpho-physiological responses (survival, photosynthetic efficiency, antioxidant defenses, quali- and quantitative variations of photosynthetic pigment, photosynthetic membrane organization, metabolites variation) were monitored before, during and after (recovery phase) the heatwave. Additionally, we generated a *de-novo* transcriptome to identify differentially expressed genes across species and conditions.
Shoot mortality was observed in the native species (75%), with individuals failing to recover completely after the heatwave. Functional parameters, such as F_v'/F_m' (maximum quantum yield), **Φ**II (quantum yield of photosystem II), **Φ**NPQ (Non-Photochemical Quenching), **Φ**NO (Non-regulatory energy dissipation), remained significantly lower at the end of the recovery phase compared to both baseline and heatwave levels. Conversely, *S. anglicus* exhibited a high tolerance to heatwave-stress, showing no shoot mortality and complete recovery by the end of the recovery period. Considering preliminary results on metabolites, Vitamin E shows peaks of activity in both species during the heatwave. Conversely, zeaxanthin shows different behavior patterns in each species. While transcriptomic data are still forthcoming, the allochthonous species demonstrates remarkable resilience and adaptability, showcasing its ability to fully recover from heatwave conditions.

Too hot to eat an invasive? Marine heatwaves modulate food preference of sea-urchins between invasive and native macroalgae

Beatriz Jiménez[1], Alejandro Bernal-Ibáñez[2,3,4], Justine Lallau-Vazzoler[2], Esperanza G Sumariva[2], Maria Teresa Jiménez[2], Ismael Hachero-Cruzado[2], Ignacio Gestoso[1,3,5]

[1]Marine Research Institute (INMAR)-Department of Biology, Faculty of Marine and Environmental Sciences, University of Cádiz, Puerto Real, Cádiz, Spain. [2]IFAPA Centro El Toruño, Junta de Andalucía, Camino Tiro Pichón s/n, El Puerto de Santa María, Cádiz 11500 Spain. [3]MARE – Marine and Environmental Sciences Centre / ARNET – Aquatic Research Network, Regional Agency for the Development of Research, Technology and Innovation (ARDITI), Funchal, Madeira Island, Portugal. [4]Faculty of Life Sciences, University of Madeira, Funchal, Portugal. [5]Smithsonian Environmental Research Center, Edgewater, MD, USA.

Identified as invasive a decade ago in the Strait of Gibraltar (S Iberian Peninsula), the brown macroalga *Rugulopteryx okamurae* continuous expanding in European waters, both Atlantic and Mediterranean basis. This species disrupts marine coastal habitats displacing marine flore and disrupting fishing and tourism activities. But it is still necessary to understand how native herbivorous interact with *R. okamurae* in the current and future scenario of climate crisis. We performed a mesocosm experiment to assess the feeding behaviour of the common sea urchin *Paracentrotus lividus* towards *R. okamurae* and the two native macroalgae species, *Dictyota fasciola* and *Ulva* sp. under a gradient of simulated marine heatwaves. Overall, *D. fasciola* was the most consistently consumed alga, followed by *Ulva* sp. and then *R. okamurae*, across all temperatures. However, there was variability in the consumption of the algae depending on temperature and although sea urchins consistently consume either native species over the invasive, at temperature 24ºC consumption of *R. okamurae* rose to rates similar to those for the native species. This pattern suggests that the invasive macroalga may gain a competitive edge through reduced grazing pressure, but also reflects how future warning scenarios may modulate urchin diet by narrowing the consumption gap between *R. okamurae* and native macroalgae

Introducing METRO: a basin-scale, study of Mediterranean tropicalization dynamics, impacts and solutions

Prof. Gil Rilov

[1]National Institute of Oceanography, Israel Oceanographic and Limnological Research (IOLR), Israel. [2]Marine Biology Department, Charney School of Marine Science, University of Haifa, Israel. [3]Mediterranean Science Commission (CIESM), Monaco.

The Mediterranean Sea is a global hotspot of tropicalisation through increasing loss of thermally-sensitive native species and massive invasion of tropical species, both facilitated by climate change. Tropicalization already has major impacts on the ecology of the local ecosystems and the livelihood of people around the basin. Impacts are most apparent in the Levantine region, but are expected to rapidly advance west and north. To fully understand tropicalization dynamics, current and future ecological and socioeconomic impacts, and pathways for adaptation and mitigation, a cross-basin, multiparter, coordinated scientific effort is essential. For this purpose, the Mediterranean Science Commission (CIESM) will be launching “METRO”, a research program that will use coordinated sampling, modeling and experimental work to investigate the loss of native species and the spread and impact of invaders, and their multifaceted implications. Major focus will be on: (1) mechanistic understanding of the shifts in community composition, (2) change in trait diversity and (3) how those are expressed in alteration of ecosystem functions and services, (4) developing options for adaptation and mitigation, including identifying benefits of some invasive species, working together with a range of stakeholders. Examples from current work will be provided and a call for partnership will be announced.

Resilience of the non-indigenous coral *Tubastraea coccinea* under future ocean conditions in the Canary Islands

Martí Vilanova Gallardo, Hortensia Holgado Durán, Alejandro Arechavaleta Faría, Adriana Rodríguez Hernández

BIOECOMAC, Research Group. Dpto. Biología Animal, Edafología y Geología. Facultad de Ciencias (Sección Biología), Universidad de La Laguna, Spain.

Rising sea surface temperatures and declining pH levels, driven by climate change and intensified maritime traffic, are altering the distribution of non-native marine species. Among them is *Tubastraea coccinea*, an invasive coral recently recorded in the Canary Islands, noted for its ecological adaptability and high colonization potential. This study evaluated the species' response to projected end-of-century ocean conditions (26 °C and pH 7.50) using controlled laboratory experiments over 30 and 80 days. Several physiological parameters were assessed, including dry and buoyant weight, number of polyps, colony area, respiration, calcification, and reproductive output.

Results revealed that ocean acidification negatively affected growth and respiration rates, with significant differences observed across treatments in weight, polyp number, area, and carbon respiration. However, elevated temperature mitigated some of the negative effects of acidification, suggesting that *T. coccinea* may retain resilience under future conditions. The comparison of short- and long-term exposures highlighted the importance of experimental duration, as the coral's response varied over time. These findings suggest that *T. coccinea* could continue to thrive and expand its range under future climate scenarios, emphasizing the need for monitoring and management strategies to address its potential ecological impact in newly colonized regions.

Investigating the impact of low temperatures on the survival of invasive sun-corals in Southwestern Atlantic

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Sun-corals genus *Tubastraea* have successfully invaded the Southwestern Atlantic over the past four decades. These species have ecological traits that facilitate their invasion, including high ecological plasticity and tolerance to abiotic factors. Arraial do Cabo, Southeastern Brazil, is highly influenced by upwelling, with water temperatures reaching as low as 12°C. This study investigates the effects of low temperatures on the survival of two sun-coral species (*T. coccinea* and *T. columnata*) through a series of *ex-situ* bioassays. Colonies were exposed to temperatures of 12°C, 13.5°C, 15°C and 21°C (control) for periods between 24 and 168 hours and kept in quarantine to assess mortality and tissue damages. Additionally, *T. coccinea* colonies were exposed to 15°C for a long-term period (>30 days). Temperature 12°C was lethal for both species after 48 hours, while 13.5°C was lethal only after longer exposures (96 hours and 168 hours). Long-term exposure to 15°C reduced feeding activity but did not cause mortality or tissue damage. Our findings suggest that cold waters are a key limiting factor for these corals, with temperatures below 13.5°C representing a critical survival threshold, especially under long-term exposure. Unravelling these limits contributes to assessing the invasive potential of these species in upwelling-affected systems.

The tropicalization of Baja California coastal ecosystems

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Climate change and especially recent marine heat waves have resulted in dramatic range shifts and abundance changes of many invasive and native coastal and estuarine species, which may allow us to envision potential future distributions of species and perhaps the movement of bio-geographical transition zones due to climate change. Following the 2014-2016 North Pacific warm anomaly (the Blob) and the 2015-2016 El Niño, we observed at least 165 species reacting to these anomalous warm water events. Many of which are northward shift of species' ranges as well as an increase in the abundance of native and invasive species with tropical distributions. We conclude that sub-tropical zones, such as the Southern California Bight, are likely to continue to gain tropical species. Thus, monitoring programs and species interactions studies will allow us to record the tropicalization of the Californias and predict future changes.

Leveraging climate-driven invasions for pollution monitoring and risk assessment

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Climate change is accelerating the spread of tropical marine species into temperate regions, reshaping community structures. This shift creates new opportunities for standardized assessments of emerging contaminants across diverse marine environments. Traditional use of model species often fails to capture emerging threats and offers limited ecological relevance in environmental risk assessments. Advancements in bioinformatics enable the integration of non-model organisms into pollution research, supporting analyses from molecular to population levels. We use the solitary ascidian *Herdmania momus*, non-indigenous to the Mediterranean, as a case study to demonstrate the value of tropical invaders in monitoring and risk assessments. This tropical species originates in the Indian Ocean and has successfully established populations in the eastern Mediterranean. In one study, exposure to environmentally relevant concentrations of the antidepressant carbamazepine led to significant changes in the proteome of *H. momus*. In another, individuals collected from the temperate Mediterranean and tropical Red Sea exhibited significantly different levels of microplastics and plasticizers, including dibutyl phthalate and bis(2-ethylhexyl) phthalate. The ecological success and physiological adaptability of tropical invaders like *H. momus* make them valuable in environmental monitoring programs. Their inclusion offers a unified, cost-effective way to assess and manage human-induced pollution in marine ecosystems under changing climates.

Thermal tolerance and ecological impacts of old and new invasive grazers on Levantine rocky reefs

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In some ocean regions, bioinvasions and climate change can strongly interact in affecting marine ecosystems. Such is the southeastern Mediterranean Sea, a hotspot of both ocean warming and bioinvasions. On shallow Levantine reefs, veteran invasive tropical rabbitfish (*Siganus rivulatus*) were shown to turn lush macroalgal forests into turf barrens, and the newcomer Red Sea urchin, *Diadema setosum*, threaten to further turn the remining turf into bare rock. However, the impact and spread of both invaders can be influenced by their thermal tolerance as well as seascape characteristics. Using mesocosm and field experiments we tested the thermal tolerance and ecological impacts of these two species. The mesocosm experiments showed that both invaders can function well under current summer temperatures, but future warming will probably reduce their metabolic, consumptive, and reproductive functioning. The rabbitfish overgrazing influence appears to be strongly affected by the local seascape. They tend to avoid grazing in flat reef areas distant from potential shelter, thus leaving intact marine forests in such seascapes. The invasive urchin was shown in both mesocosm and field caging experiments to graze algae and turf areas down to bare rock within a few weeks, therefore augmenting the threat to these reefs if not controlled.

Ecological & evolutionary impacts

Invasion traits

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Super Invaders of the Sea: Unraveling the success of non-indigenous ascidians

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Ascidians have become notorious marine invaders, threatening biodiversity and infrastructure. Our research examines key factors driving their invasion success, focusing on dominant non-indigenous species along the Israeli coast (*Styela plicata, Herdmania momus, Microcosmus exasperatus,* and *Phallusia nigra*). Controlled experiments reveal that while adults tolerate broad temperature fluctuations and short-term low salinity exposure, larval development is significantly impaired under reduced salinity, and cold temperatures (<16 °C) alter reproduction in tropical-origin species.
Despite their short larval duration, dispersal models suggest that larvae from newly established populations can travel up to 100 km in a single generation, facilitating range expansion where suitable substrates exist. As solitary hermaphrodites, we found these species exhibit high self-fertilization potential, increasing colonization success. Finally, microbial analyses of *S. plicata* and *H. momus* reveal host-specific microbiomes that may further enhance adaptability.
Our research highlight the interplay between physiological plasticity, reproductive strategies, and microbial symbioses in marine bioinvasions. Combined with human-driven environmental changes, including coastal development and pollution, these factors create favorable conditions for non-indigenous ascidian establishment. A comprehensive understanding of these mechanisms enhances invasion risk predictions and informs the development of biosecurity tools for effective marine conservation and management.

Crabs in a changing Lagoon: seasonal stress tolerance of native and invasive species to heat and hypoxia

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The Venice Lagoon is a hotspot for non-indigenous species. The blue crab Callinectes sapidus settled in the Lagoon in the last century but only recently became invasive, threatening aquaculture and small-scale fisheries, particularly those targeting the native green crab Carcinus aestuarii. This study aims to compare the tolerance of these two species to locally relevant stressors, such as hypoxia and high temperatures, by analyzing aerobic scope through respirometry experiments. Two physiological responses were assessed: one after natural seasonal acclimation, characterized by fluctuations in dissolved oxygen and temperature, and one under constant acclimation, with stable environmental conditions. Results show that seasonal and/or daily acclimation significantly influences hypoxia tolerance and aerobic oxygen consumption of both species. C. aestuarii appears better adapted to summer hypoxic conditions than the invasive C. sapidus, which, however, demonstrates greater tolerance to hypoxia and high temperatures during the cold season. We conclude that 1) the absence of environmental fluctuations amplifies intraspecific physiological differences, and 2) fluctuating environments may trigger a hierarchical physiological response aimed at the optimization of the exploitation of environmental oxygen. These findings provide valuable insights into the impacts of invasive species, as interpreted through invasion models, dispersal dynamics, and trait-based approaches.

Three Faces of the Same Coin: Variability in Native and Invasive Populations of the Sea Spider *Ammothea hilgendorfi*

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Pycnogonids, or sea spiders, are a peculiar group of marine arthropods that have historically been considered negligible in marine ecosystems because of their generally low abundance. However, this perception has been challenged by the recent emergence of *Ammothea hilgendorfi* (Böhm, 1879) in Europe. Native to the North Pacific Ocean, it has settled in many countries since the late 70s, including Belgium, where it was recently classified as invasive. While invasion biology often aims at comparing an alien species with a native counterpart, this comprehensive study takes the problem backwards by comparing the invasive population in Belgium with to two native ones, in the USA and Japan, to help understanding the history of this unprecedented bioinvasion. The same protocol was followed in the three locations: first, a population monitoring to assess their abundance, life cycle, biometry, and preferred environments, followed by different experiments focusing on their behaviour (reaction to stimuli), physiology (stress resistance, respirometry) or population structure (genetics). Results suggest that even if they may still be considered the same species, they differ from each other in many aspects, revealing the great plasticity of *A. hilgendorfi*, and raising concerns on their potential for further invasions.

Environmental niche separation between native and non-native benthic invertebrate species in the northern Baltic Sea

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Understanding species distributions is essential for ecology, conservation, and management. Abiotic factors strongly influence the presence and spread of native and non-native species. Using a long-term macrobenthos dataset from the northern Baltic Sea, we analyzed species presence-absence and biomass across environmental gradients. Abiotic variables such as salinity and depth were derived from bathymetric and hydrodynamic models. Multivariate ordination revealed distinct niche separation: non-native invertebrates were associated with lower salinity, higher temperatures, softer sediments, shallower depths, and reduced wave exposure compared to native species. These patterns likely result from differing evolutionary histories, human-mediated introductions, and the Baltic Sea's geological youth. As climate change is projected to reduce salinity and raise temperatures in coastal areas, conditions may increasingly favor non-native species. Our results offer a basis for early warning and management strategies by identifying coastal regions most susceptible to future invasions.

Intraspecific variation in thermal performance of the common periwinkle suggests the presence of range-edge divergence and phenotypic compensation

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Geographically spread non-native species can be used to study organisms' capacity to acclimate and adapt to environmental changes. We compared the thermal performance of the intertidal snail *Littorina littorea* from different origins throughout its non-native range in North America to investigate how environmental conditions affect intraspecific phenotypic variation. Snails from 10 locations were exposed to a gradient of 12 temperatures in the laboratory and their survival, growth, feeding, metabolic rate, and heat tolerance measured. Snails from the northern and southern range edges show distinctive growth performance patterns, likely evolved due to strong selective pressures at the species range limits. Snails from colder northern locations show greater thermal acclimation capacity for survival, feeding, and heat tolerance, likely reflecting compensation. Our findings highlight the importance of studying non-native species intraspecific variation to evaluate their ability to adapt and acclimate to environmental changes, especially under climate change.

The role of species-specific and non-specific settlement cues/signals across spatial scales in barnacle population establishment

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Many coastal barnacle species are expanding their distributional ranges as marine invasive species. In this taxonomic group, larval settlement is thought to be mediated by a combination of conspecific adult-derived proteinaceous pheromones and visual signals. These cues are hypothesized to operate at different spatial scales, allowing adult individuals to promote the settlement of conspecific larvae in close proximity, thereby securing future mating opportunities and enhancing their fitness.
Among these cues, the Settlement-Inducing Protein Complex (SIPC) is a contact pheromone that adheres to substrate surfaces and induces larval settlement. SIPC has been reported to exhibit species specificity and serves as a pivotal factor in species recognition during larval settlement. In contrast, our findings support the hypothesis that broadly acting factors such as waterborne settlement pheromones and shell-associated fluorescence that are suggested to act as visual signals can attract larvae of other species. The species-specificity of SIPC suggests that barnacle larvae ultimately distinguish species in the environment when selecting settlement sites. This capacity to integrate both general and specific cues across spatial gradients may enable barnacles to efficiently form conspecific aggregations even in novel environments, potentially contributing to their success as invasive species.

Survival of invasive corals from genus *Tubastraea* in a highly impacted estuary in Brazil

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Corals of the genus *Tubastraea* are considered invasive along the Brazilian coast. Understanding how different environmental scenarios affect their survival is essential for effective management. We investigated the survival of *Tubastraea coccinea* under continuous water flow from Guanabara Bay, a heavily impacted estuary where this genus has not yet been recorded. Colonies were maintained for five months in open-circuit systems under three treatments: water from Arraial do Cabo (AC, control), unfiltered water from Guanabara Bay (GB), and filtered water from the bay (GBF). Colonies in AC exhibited 97.6% ± 4.43 healthy tissue, 2.4% ± 4.43 altered tissue, and no epibionts. GBF colonies showed 67.43% ± 19.53 healthy tissue, 28.09% ± 14.61 altered tissue, and 4.48% ± 13.96 epibionts. GB colonies presented 55.6% ± 31.66 healthy tissue, 36.58% ± 25.9 altered tissue, and 7.82% ± 11.25 epibionts. Arraial do Cabo colonies showed almost no damage, while in Guanabara Bay filtering reduced but did not prevent tissue damage. These results suggest that a high concentration of suspended sediment, combined with microbial activity and environmental stressors, may compromise coral health in Guanabara Bay. This may explain the absence of these corals in Guanabara Bay despite its occurrence in nearby areas.

Biological insights for management: energetic dynamics of *Tubastraea coccinea* at its southernmost atlantic limit

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The development of effective strategies to control invasive species relies on a comprehensive understanding of the target organism's biology. Sun corals (*Tubastraea coccinea*) are among the most impactful marine invaders along the Brazilian coast. Key biological traits—such as reproductive cycles, growth rates, and ecological preferences—are critical for efficient management efforts. We evaluated growth rate, reproductive development, and lipid content of *T. coccinea* over a 24-month period in the Arvoredo Marine Biological Reserve, its southernmost distribution limit. This region is characterized by seasonal oceanographic shifts: during summer, the shelf is dominated by warm, oligotrophic tropical waters, while winter brings colder, nutrient-rich waters that increase primary productivity. These dynamics may either facilitate or inhibit the spread of this invader. Interannual differences in seawater temperature were observed, with measurable effects on sun coral biology. Our findings suggest that cold water events (persisting below 16 °C) may reduce growth and potentially limit the species' expansion. Colony size influenced individual growth rates, and reproductive activity occurred year-round, with a peak in larval release during summer. Lipid content was closely associated with reproductive development, though nutrient-rich cold waters may enhance nutritional condition. These results will help refine control schedule and improve management strategies by local environmental agencies.

Testing competition mechanisms and habitat fragmentation effects on *Rugulopteryx okamurae* invasion process

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Macroalgae are the most frequent group of invasive alien species (IAS), and a dramatic case is the recent invasion of *Rugulopteryx okamurae* in South European waters across multiple countries. Competition plays a significant role in structuring benthic communities and the introduction of *R. okamurae* is leading to the progressive displacement of native macroalgal communities, process further exacerbated by habitat fragmentation, major anthropogenic stressor in marine ecosystems globally. We evaluated the effects of habitat fragmentation and how the alteration of community structure might promote IAS spread, along with their ecological consequences. Using intertidal rockpools as proxy system, both stressors were simultaneously manipulated to examine their effects on short- and long-term recruitment patterns, and macroalgae assemblages' invasibility. The invasion factor had a significant effect on net primary production (NPP) in both short- and long-term responses, whereas fragmentation significantly influenced dark respiration (DR) across the same time frames. Maximal PSII photochemical efficiency were generally lower for short-term, with significant differences for the native *Corallina officinalis* long-term response in high-invaded rockpools. Higher macrofaunal biomass was observed in the long-term data. This research sheds light on biotic mechanisms shaping the resilience of resident communities against invasive expansions.

Personality, predation, and group size: Unravelling behavioural drivers of lionfish (*Pterois volitans*) invasion success

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Global biodiversity is in rapid decline, with invasive alien species playing a major role. Predicting which are most damaging and under what conditions is key to proactive management. We investigated whether behavioural traits, specifically boldness and exploration, predict ecological impact in the invasive red lionfish (*Pterois volitans*). Despite the modest sample size of adults (n = 8) and juvenile (n = 8) lionfish, using repeated behavioural assays, we found strong personality consistency: 93% of juveniles and 56% of adults used shelter, with traits like latency to interact with novel objects showing high repeatability. Bold individuals spent less time in shelter and interacted more with novel stimuli. However, in groups of eight, personality expression shifted, only 7% of juveniles and 44% of adults used shelter, indicating that social context alters behaviour. Functional response experiments revealed Type II feeding curves across three prey species, reflecting a saturating, hyperbolic relationship in which predators rapidly consume prey at low densities but are increasingly constrained by handling time as prey density rises. Neither adult nor juvenile lionfish reduced feeding effort when prey became scarce, allowing them to exert strong predation pressure even at low prey densities. Adults displayed significantly higher attack rates and shorter handling times on *Artemia salina*, whereas juveniles showed these patterns towards *Gammarus oceanicus*, underscoring the greater per capita feeding impact of adults. Contrary to expectations, boldness did not correlate with feeding impact but was linked to slower reaction times in shy individuals. These findings highlight the complex, context-dependent relationship between personality and ecological impact during invasions.

Ecological & evolutionary impacts

Community shifts and emerging invaders I

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Assessing The Impacts of *Caulerpa recemosa* on Sand Dwelling Benthic Invertebrates In The Galápagos

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Internationally, invasive marine algae has resulted in significant losses to native benthic fauna and incurred substantial costs for monitoring and management efforts. Isolated archipelagos are exceptionally vulnerable to the introduction of nonnative species due to high levels of tourism, marine traffic, and ENSO events. Currently, *Caulerpa racemosa* is under close observation in the Galápagos due to its invasive behavior, posing a severe threat to the nutrient dynamics of native ecosystems. This study examined the impact of the *C. racemosa* on benthic invertebrate populations in the Galápagos Islands' shallow sandy habitats. Invertebrate diversity, richness, and abundance were compared between sites with and without *C. racemosa*. Sediment samples and percent cover were collected along transects. Sediment samples were sieved, preserved, and analyzed for invertebrate abundance (identified to class) and dry weight. Diversity per gram was calculated. No significant correlation was found between *C. racemosa* presence and invertebrate diversity, richness, or abundance. However, significant inter-site differences in species richness and abundance were observed. These variable results underscore the need for continued monitoring to understand the ecological impacts of invasive algae and guide effective management strategies.

Artificial light affects the occurrence of exotic species and the structure of sessile communities

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Coastal urbanization leads to the extensive use of artificial light at night (ALAN), which can significantly impact the diversity of benthic communities. In this study, we examined the effects of ALAN on recruitment, previously established communities on marina walls, and the dynamics of community assembly and predation on sessile organisms. Artificial lights decreased the recruitment of Didemnids, particularly the exotic species *Didemnum perlucidum*. Communities that developed on marina walls beneath light poles exhibited a larger coverage of native sponges than those located farther from light sources, where the exotic coral *Tubastraea* spp. occupied a larger area of the substrate. As the communities developed, ALAN promoted an increase in coverage by the exotic bryozoan *Savignella lafontii* and the cryptogenic ascidian *Botrylloides niger* while reducing the area covered by the exotic bryozoan *Schizoporella errata* and the cryptogenic ascidian *Diplosma listerianum*, altering the community structure without changing species identity or richness. ALAN also did not affect predation intensity, likely due to high generalist predation. Thus, ALAN affected critical processes such as recruitment and the abundance of exotic species, mediating the identity of the dominant exotic species and affecting, along with predation, the structure of fouling communities in the subtropical Southern Hemisphere.

Funding: Fundação de Amparo à Pesquisa do Estado de São Paulo 2019/15628-1

Temporal changes in rock reefs benthic communities following the invasion by the exotic blue-clove octocoral *Sarcothelia sp.* at Western Atlantic, Brazil

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Non-native octocorals are spreading across the Atlantic Ocean, with evidence of impacts such as shifts in community structure observed in several invaded reefs. However, most studies rely on spatial comparisons (control-impact), limiting the understanding of exotic species' effects. Integrating spatial and temporal approaches provides a more comprehensive perspective. We investigated the effects of the invasive octocoral *Sarcothelia* sp. (Alcyonacea, Xeniidae) on the structure and richness of native benthic communities in Brazil. Using a spatiotemporal approach, we sampled one invaded site (IS) and two control sites (C1, C2) across different years. Notably, C1 was later colonized by the invader. Multivariate analyses revealed high dissimilarity between IS and control sites, with octocorals and zoantharians dominating IS and controls, respectively. Over time, C1 experienced drastic changes, with increased *Sarcothelia* sp. cover and declining zoanthids, making it more similar to IS and less to C2. *Sarcothelia* sp. became the most abundant species in IS, associated with reduced macroalgal and turf algal cover. C2 remained uninvaded, showing no significant structural changes. Our findings link shifts in community richness and structure to *Sarcothelia* sp. colonization, reinforcing its invasiveness and highlighting benthic groups susceptible to exotic Xeniid octocoral impacts.

Changes in the structure, function and ecosystem services of seagrass meadows following the irruption of the green alga *Halimeda incrassata*

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The accelerated expansion of the Caribbean species *Halimeda incrassata* on sandy bottoms of Tenerife, implies a possible direct competition with native species such as *Cymodocea nodosa*, whose meadows were already in regression, and macroalgae such as *Caulerpa prolifera*. To assess the impact of *H. incrassata* on the marine benthic communities of Tenerife we performed four approaches: (1) creation of a database and a model of spatial distribution of the species in the sandy bottoms of the island, (2) determination of the habitat and environmental requirements that the species needs for its development, (3) study of the expansion dynamics of the species' populations, and (4) determination of the impact on native species. An *ex-situ* experimental approach was carried out to assess the thermal and light tolerance of the species to understand its preferences and predict its expansion. Results indicate that temperature is the most limiting factor to its growth, with higher temperatures being the most favorable (26-28ºC), while light intensity has a more negligible effect on the species. To monitor the species expansion and its impact on native communities, a follow-up protocol with sentinel stations and fixed transects was established, which is still on-going and will be finished on September 2025.

Impact of invasive tunicates on rocky shore sessile benthic communities

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This study investigates the effects of the exotic ascidians *Eudistoma carolinense* and *Polyandrocarpa zorritensis* on the structure and dynamics of sessile benthic communities in southern Brazil's intertidal zone of rocky shores. To test the hypothesis of biotic homogenization in invaded sites, we assessed the changes in the richness and abundance of fifteen morphofunctional groups of algae and invertebrates across five rocky shores by comparing current data with records from a decade earlier. Results indicate a significant increase in the richness and the diversity of morphofunctional groups at most sites, except for one location where richness remained stable. Shifts in abundance were also observed, with an increase in arborescent invertebrates and a decrease in reef-building polychaetes at sites colonized by the exotic ascidians. After ten years, betadiversity among the five rocky shores decreased, and both nestedness (gain of functional groups) and turnover (replacement of groups) were observed depending on the site. Thus, although we observed a local increase in biodiversity, there was a tendency for regional homogenization, as predicted. This study provides valuable insights into the ecological impacts of invasive species on intertidal rocky shores, which are marine coastal ecosystems known to be heavily impacted by invasive species.

Unveiling cryptic invasions: a multi-source approach to assess the invasion potential of Tanaididae (Peracarida:Crustacea)

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Tanaidaceans, particularly members of the family Tanaididae, are important components of fouling communities. However, despite increasing evidence of cryptic invasions, these small and taxonomically challenging crustaceans are often overlooked in invasion studies. Furthermore, major databases, including OBIS, GBIF, and GenBank, as well as the literature, lack comprehensive data, hindering effective monitoring of tanaids' expansion.

Recognizing the risks associated with human-mediated dispersal of Tanaidacea and the gaps in existing records, we used a multi-source approach to assess the invasion potential of these crustaceans. We combined occurrence records of Tanaididae in the whole World, their associations with anthropogenic habitats, as well as molecular data from databases and literature. Results indicate that the number of Tanaididae species with invasion potential is up to six times higher than previously estimated, while species linked to human-modified environments—potential contributors to future cryptic invasions—are ten times more numerous. Additionally, we identified a cryptic species complex, consisting of both a widely invasive lineage and multiple geographically restricted lineages. This approach also revealed species with conflicting taxonomic or distributional records, highlighting risks of misidentification.

Our findings emphasize the need for improved monitoring and data integration to better understand and manage cryptic invasions in Tanaididae.

One genome is not enough: population genomics of the introduced ascidian *Styela plicata*

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Monitoring the genomic features of invasive species is crucial to understand their population structure and adaptive processes. Styela plicata is an ascidian introduced to harbours across all temperate seas. We assembled and annotated a reference genome for this species, combining it with whole genome sequencing data from 24 individuals from six populations worldwide. This pangenome revealed key structural features, including large chromosomal inversions on four of the 16 assembled chromosomes. Loci within inversions were enriched in genes associated with response to pollutants, neurotransmission, and cell organization. We then genotyped 87 individuals from 18 global sites using 2b-RADseq. Our results indicated that the inclusion of loci from chromosomes with inversions masked the signal of population structure. When inversions were excluded from the analyses, we found that North and South Carolina populations were distinct from the rest, and a clear separation between Pacific, North Atlantic (including the Mediterranean), and South Atlantic populations. We identified candidate loci for adaptation, related to cellular processes, metabolism, development, and ion transport. Lastly, demographic modelling helped reconstruct the species' introduction history. Our results highlight the importance of generating species-specific pangenomes to detect genomic features that can mask population structure and hinder the analysis of the evolutionary history of invasive species.

Impacts of the incipient invasion of *Rugulopteryx okamurae* in the marine benthic communities of the Canary Islands

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After a decade of invasion of the southern coasts of Europe, *Rugulopteryx okamurae* has proven its ability to produce drastic changes in the shallow marine benthic communities, being nowadays found from Italy to Spain in the Mediterranean, and from the Iberian Peninsula to Morrocco in the Eastern Atlantic, including the archipelagos of Azores, Madeira and Canaries. Since its discovery in 2022, *R. okamurae* has reached five of the seven islands of the archipelago, but in many sites its expansion is still recent, and has not yet monopolized the benthos. The effects of this species in a region whose marine communities have higher tropical affinities as the Canary Islands has not yet been assessed. In this study we aim to assess its spread throughout the archipelago with special focus on areas with high potential of invasion such as those nearby marinas and ports and study the changes that this species produces in the macroalgae and invertebrate communities at different stages of invasion.

From unknown to invasive in a few years – the discovery of the sea spider *Ammothea hilgendorfi* in Belgium

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Pycnogonids, or sea spiders, are unique arthropods that, despite their low abundance, are present in most marine ecosystems. Belgium made no exception as three European species have historically been reported in Knokke, a biodiversity hotspot on the Belgian coast. In 2022, however, a new species named *Ammothea hilgendorfi* (Böhm, 1879) was discovered in densities too high to be considered as normal for that group. It is in fact native to the North Pacific Ocean (i.e., Japan and the USA) and was introduced in Europe in the late 1970s, including Italy, the Netherlands, France, and now Belgium. Therefore, the goal of this study was to investigate this population of *A. hilgendorfi* during a 24-month monitoring using different proxies (phenology, developmental cycle…). For the first time in Europe, results demonstrate that this pycnogonid can be considered as invasive as it can complete its entire life cycle, including all larval instars, and has developed very high densities outnumbering by far the native sea spiders, which have almost disappeared. Our results also suggest that the invasion has likely not reached its capacity yet, emphasizing on the importance to study this peculiar clade.

Community-level effects of a novel invasive species in Finland's Archipelago Sea

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Biotic interactions between native and introduced species can alter community structure, resulting in long-term ecological changes. This is especially true for unique environments, like the Baltic Sea, which host relatively fewer native species due to recent geological history. The North American estuarine mud crab, *Rhithropanopeus harrisii*, invaded the Finnish Archipelago Sea in 2009 and quickly spread. Because this system does not have native crabs, this entirely new type of predator could change the community structure of the marine littoral ecosystem. To explore this, we quantitatively sampled benthic and seaweed-associated invertebrate communities at eight sites with crabs and four control sites without crabs between Aug - Sept 2024. Invertebrates were identified and counted, and differences in community composition were related to crab density and time-since-invasion, taking into account major environmental factors using multivariate statistics. We then compared the 2024 communities with those collected between Aug - Sept 1998 from six sites from the epicenter of the invasion using identical methods. We have not finished data analyses; however, we expect to observe declines in the abundance of gastropod and crustacean herbivore grazers. Future work will examine if the predicted decline in herbivory leads to increased biomass of primary producers through trophic cascades.

A new genome provides insights into the success of the globally invasive European green crab

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Genomic research is an underutilized tool in marine NIS management, in part because we lack high-quality genome assemblies for many species. While other genetic tools can be powerful for understanding the origin and dispersal of invasive populations, full genomes permit additional insights into the basis of fitness-related phenotypic traits that could be targets for management interventions. Here, we present a new genome assembly for the globally invasive European green crab (EGC), developed using a recently-developed proximity ligation approach along with deep long-read sequencing to increase genomic completeness and contiguity. We describe initial insights in to the success of EGC based on this genome, focusing in part on the nature and gene content of a “supergene” (suite of many gene variants inherited together) that is strongly associated with temperature tolerance. Previous transcriptome-based genotyping work in EGC across latitudinal gradients has demonstrated a role for this supergene in adaptation to changing temperatures across short time scales, likely contributing to the species’ global success. Notably, this genomic resource was developed through a partnership between science, management, and state government, with the goal of establishing EGC as a new model system for research and development for 21st-century invasion management.

Ecological & evolutionary impacts

Hidden passengers: parasites and invasion pathways

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Parasite escape: evidence for significant declines in macroparasite diversity in two globally invasive crabs

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Species often leave behind natural enemies, like parasites, when introduced. Numerous marine invertebrates, like crabs, serve as intermediate or final hosts to a variety of metazoan parasites. Two crabs with globally invasive distributions include the green crab *Carcinus maenas* (native to Europe) and the white-fingered mud crab *Rhithropanopeus harrisii* (native to western Atlantic and Gulf of Mexico); they are also intermediate hosts to trophically-transmitting macroparasites (trematodes, acanthocephalans, nematodes, cestodes) and final hosts to parasitic castrators (rhizocephalans, isopods). Here, I examine the crabs' multiple introduced populations (ranging in time-since-introduction) for evidence of parasite escape, while also comparing parasite diversity of trophically-transmitting versus parasitic castrators. Altogether, *C. maenas* has escaped between 67-100% of its native parasite richness throughout its multiple introduced populations, with its oldest introduced range (eastern North America) having the highest parasite prevalence and richness. In contrast, although *R. harrisii* has a rich diversity of parasites in its native range, no metazoan parasites have been detected in any of its introduced populations around the globe (i.e., 100% escape). Altogether, these globally invasive crab hosts help demonstrate that parasite escape is a strong signature of many species introductions worldwide and should therefore be a key consideration in invasion studies.

Spatiotemporal patterns and morphological impacts of parasitic coinfection in an estuarine crab host

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Parasitic co-infections affect the evolutionary “arms race” between host and parasite. One disruptor to this evolutionary “arms race” can be the arrival of an invasive species. In the Chesapeake Bay, two species of estuarine host crabs, *Rhithropanopeus harrisii* and *Eurypanopeus depressus*, are infected with up to two species of macroparasites- the putatively native entoniscid *Cryptocancrion brevibrachium* and the introduced rhizocephalan *Loxothylacus panopaei*. Since April 2024, crabs have been collected and dissected to look for spatiotemporal patterns of parasitic coinfection. Using ImageJ, an image processing software, crab carapace, and abdomen width were then analyzed to observe any host morphological impacts due to single or parasitic coinfection. Dissection data showed that coinfection prevalence is low overall possibly due to negative interactions between the parasites and high energy drain for the host with a peak occurring during the summer months when both hosts and parasites are more reproductively active. ImageJ analysis showed that *L. panopaei*-infected males develop a broader, longer, and segmented abdomen, accompanied by marginal setae. No hyperfeminization was evident in *L. panopaei*-infected females, which remain morphologically unaffected by infection. This induced enlargement of the male abdomen may serve as an adaptation to protect the external reproductive body of the parasite.

Comparing the native and introduced ranges of the parasitic barnacle, *Loxothylacus panopaei*

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Despite accounting for over 40% of animal species on earth, parasites are consistently overlooked in ecological studies and natural history work. The default spotlight on host organisms obscures the parasitic co-stars behind the scenes that influence behavior, movement patterns, and community dynamics. The impacts of endoparasites are even more ignored in naturalist studies since infection usually cannot be detected without host dissection. However, in North America, a flagship parasite-host system – invasive parasitic barnacle *Loxothylacus panopaei* and native mud crab host *Eurypanopeus depressus* – may help us fill many of the knowledge gaps that exist related to drivers of parasite distribution and evolutionary impact in this current era of human-induced global change. In 2024 and 2025, I sampled several sites in both the parasite's native and introduced ranges to compare the prevalence of infection, parasite population genetic structure, and the effect of infection on the morphology of the host crab. I predict that in the introduced range, infection prevalence will be higher, there will be strong evidence of a genetic bottleneck, and that morphological manipulation will correlate with time since introduction. This research represents the most comprehensive comparison to date between the native and introduced ranges of the invasive parasite and emphasizes the importance of including parasites in invasion ecology.

What comes with the fish? New fish-parasite systems in the Mediterranean Sea

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The Mediterranean Sea has undergone unprecedented modifications, due to human activities, leading native fish populations to decline, and non-native populations to grow, essentially modifying local ichthyofauna. While introduced fishes are well documented, the derived changes in their accompanying parasites, key players in regulating host populations, remain understudied. Here, we review the accumulated knowledge on invasive fish and their associated parasites in the Mediterranean Sea. We focus on co-introductions and parasite potential impact on fish populations.

Of ~100 alien fishes from the Indo-Pacific region now in the Mediterranean Sea, only 27 species underwent parasite examinations, revealing nearly 50 parasite species co-introduced alongside their hosts. For example, the invasive blotchfin dragonet (*Callionymus filamentosus*) hosts a microsporidian infecting ovaries, potentially castrating females, and a gill-infecting copepod that may be involved in the microsporidian's life cycle. Another successful colonizer, the Spanish mackerel (*Scomberomorus commerson*), carries remarkably heavy gill-monogenean infections, which have also spilled over to native and alien sardines and anchovies (Clupeiformes), on which they persist at a premature stage.

These findings highlight overlooked changes in host–parasite dynamics following marine invasions and underscore the ecological importance of integrating parasitological data into assessments of biological invasions.

Utilizing parasites of invasive fish species as bioindicators in the Mediterranean Sea

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Invasive species and rising anthropogenic pressures are transforming marine ecosystems, particularly in the eastern Mediterranean. While free-living invasive species are well studied, their associated parasites remain largely overlooked, despite their potential as sensitive indicators of ecological change. This study examines parasite communities in invasive and native fish species across gradient of temperature, chemical and biological pollution. Four host species are analyzed: *Diplodus sargus* (native to the Mediterranean), *Parupeneus forsskali* and *Siganus rivulatus* (Red Sea natives, invasive in the Mediterranean), and *Sparus aurata* from local fish farms. Sampling spans the Gulf of Eilat, Israel's Mediterranean coast and Cyprus. Thus far several host–parasite interactions have been observed, including new records of co-introductions and parasite acquisition. High infection levels were found on external organs of invasive and native fish by multiple taxonomic groups. These included metacercariae (Digenea) in fin rays, and monogeneans, copepods, and isopods on the gills. A Red Sea-origin copepod infecting gills of *S. rivulatus*, recorded for the first time in the Israeli Mediterranean. Digeneas, cestodes, and nematodes were found in the abdominal cavity of *D. sargus* and *P. forsskali*. By characterizing parasite assemblages and identifying key taxa as bioindicators, this study aims to develop tools for detecting ecological disruption.

Ecological & evolutionary impacts

Altered appetites: trophic shifts, processes & competitive dynamics

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Diet shifts in *Sarpa salpa* following the invasion of the brown algae *Rugulopteryx okamurae*

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This study investigates the dietary shifts of the marine herbivorous fish *Sarpa salpa* in the Azores (NE Atlantic) over a 30-year period, against a backdrop of significant ecological shifts, notably the invasion of *Rugulopteryx okamurae* in 2019. This brown macroalga, with no known natural herbivores in the invaded regions, has reshaped local benthic landscapes by displacing native species and potentially triggering cascading ecological effects. We analyzed 50 specimens of *S. salpa* from various locations in São Miguel island. These were measured and their stomach content analysed and compared to an historical dataset. Although species richness remained statistically unchanged (historic: 69 species total; 12.8 ± 0.2 per individual; present: 70 species total; 13.8 ± 1.2 per individual), the species composition changed notably. Articulated coralline algae such as *Elisollandia* spp. and *Jania* spp., which were absent from the historical dataset, were present and abundant in all current samples. Notably, these algae were also abundant throughout the entire gut of each individual, suggesting that it was as not digested. We propose that *S. salpa* now preferentially feeds on epiphytes associated with coralline algae in shallower, wave-exposed areas, where *R. okamurae* is less prevalent. This dietary shift may involve energetic and nutritional trade-offs, but may be the only viable option in an environment dominated by *R. okamurae*. Our findings highlight how feeding ecology can reveal broader ecosystem responses to environmental change.

Rugulopteryx okamurae vs Paracentrotus lividus: understanding the effects of a highly invasive macroalgae on a common grazer

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The rapid spread and massive proliferation of the invasive macroalga *Rugulopteryx okamurae* in southern European coastal waters is a growing ecological concern with significant socioeconomic consequences. First identified as invasive in the Strait of Gibraltar (southern Iberian Peninsula) in 2014, *R. okamurae* has continued to expand along the Atlantic and Mediterranean coasts. Despite its widespread distribution, the potential for biotic resistance through herbivory and the long-term effects of *R. okamurae* consumption by native grazers remain largely unexplored. In this study, we assess the ability of the common sea urchin *Paracentrotus lividus* to consume *R. okamurae* and whether this is influenced by the consumer-prey interaction history. We analyzed correlations between algal abundance in the field and *P. lividus* stomach content using field surveys conducted along an invasion gradient in the Alboran Sea (southern Iberian Peninsula). Sites represented different invasion histories: 10 years, 6 years, and newly invaded (0 years). Additionally, we conducted a 24-week laboratory experiment to evaluate the physiological effects of *R. okamurae*consumption on *P. lividus* populations. Field data revealed that *P. lividus* consumes *R. okamurae*, although it is not a preferred food source. Consumption remained consistent across sites, with no clear relationship to the duration of invasion. However, sea urchins from long-term invaded sites exhibited lower body weight and a reduced gonadosomatic index. Similarly, in our laboratory experiment, individuals from long-term invaded sites fed a 100% *R. okamurae* diet experienced greater weight loss and increased mortality after 14 weeks. These negative effects were mitigated when individuals were provided a mixed diet. Our findings indicate that while *P. lividus* does consume *R. okamurae*, its ability to exert biotic resistance through herbivory is limited. The long-term physiological costs associated with feeding on *R. okamurae* suggest that native herbivores alone are unlikely to control its spread, underscoring the need for further research into effective management strategies for this highly invasive macroalga.

How do fish interact with *Rugulopteryx okamurae* on Madeira Island?

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The macroalga *Rugulopteryx okamurae* has become a dominant component of invaded shallow benthic communities, altering ecosystem functioning. Its competitive exclusion of resident macroalgae and low palatability may reduce food availability for herbivores, while enhancing foraging opportunities for invertivores. However, it remains unclear to what extent resident secondary consumers, such as fish, interact directly with *R. okamurae*, and how these interactions might influence the composition and dynamics of other associated groups. This study uses remote underwater video experiments to examine fish–benthic interactions in shallow habitats on Madeira Island. We assessed the epifaunal prey availability provided by *R. okamurae* and analyzed fish habitat use and foraging activity in relation to its cover, comparing it with the coexisting *Asparagopsis taxiformis*. Preliminary results show that epifaunal abundance on *R. okamurae* is low, less than half on *A. taxiformis.* Among the 21 fish species observed, 28% were omnivores and mobile invertivores that primarily drove foraging interactions with *R. okamurae*, while territorial herbivores mainly used it as a refuge. Although no significant effects of *R. okamurae* cover are detected on overall fish community structure or activity, its role in specific habitat use suggests potential ecological risks under the monopolization scenarios already documented in other invaded regions.

What goes in must go out? European green crabs alter nutrient cycling dynamics in marine ecosystems

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Although the European green crab (*Carcinus maenas*) is a renowned predator, little consideration has been given to potential benefits it can bring to the ecosystem it invades. One such benefit could be through enhanced animal-mediated nutrient cycling, the process by which metabolic waste such as excretion from animals fertilize primary productivity. Here, we investigate changes to nutrient cycling caused by green crabs at the individual and community scale in British Columbia, Canada. We first measured excretion rates of green crabs and three native crab species and found that green crabs excreted less nitrogen per gram of tissue and per crab. Next, we combined these size- and species-specific excretion rates with 14 years of catch per unit effort and crab size data from 71 sites to model community-level nutrient provisioning. Communities dominated by green crabs had large populations but regenerated significantly less nitrogen than smaller native crab communities. Given their large predation effects and small capacity for nutrient cycling, green crabs appear to be taking more nutrients than they return to the ecosystem. This work highlights the importance of considering multiple pathways through which invaders can disrupt native ecosystems.

Swapping the invader: trophic niche partitioning of *Callinectes sapidus* and *Carcinus* spp. in invaded and native areas

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Biological invasions constitute an increasing threat to marine ecosystems. This study analysed the trophic niche and role of reciprocal brachyurian invaders by comparing invaded and native areas. Samples were collected in Italy (Stagnone di Marsala) and USA (Chesapeake Bay and New Jersey). In the former, the blue crab *Callinectes sapidus* is invader and the Mediterranean green crab *Carcinus aestuarii* is native, while in the other, *C. sapidus* is native and the green crab *C. maenas* is invader. The aim was to evaluate whether the isotopic niche in invaded areas reflects niche conservatism or trophic adaptation.

Samples were collected in 2021-2022 using traps. Stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) were used to estimate isotopic niche and trophic position. In both study areas, invasive species occupied a higher trophic position, and trophic niche partitioning among native and invasive species occurred. Furthermore, *C. sapidus* showed a broader isotopic niche in the invaded than in the native area, suggesting its ability to become more generalist during invasion, while *C. maenas* and *C. aestuarii* showed narrower niches. Overall, these findings highlight divergent strategies in the different areas which may influence invasion dynamics and interactions with native communities.

Snail responses to invasion of a novel predator: do shell traits show adaptive plasticity?

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Native prey may show various adaptive responses to novel invasive predators. Here we hypothesise that the invasive predator, the mud crab *Rhithropanopeus harrisii*, poses strong selection for anti-predator traits of the snail *Theodoxus fluviatilis,* thus provoking adaptive responses. We sampled snails from several populations that either had or had not been exposed to the invasion of this novel predator in the northern Baltic Sea. Moreover, we conducted predation experiments to investigate selection by the novel predator on prey traits and long-term rearing experiments of the snail with crab and alarm cues to study potential adaptive responses of the prey. The focal prey traits included body-size, body-shape, shell thickness and shell strength. We found differences in shell traits among *T. fluviatilis* populations, partly attributable to coexistence with the crab. Furthermore, we found a decrease in body-size with increasing shell strength in snails exposed to alarm cues of wounded conspecifics. The predation experiments indicated that crabs choose larger snails. These results demonstrate that selection by a novel invasive predator can lead to adaptive prey responses in an ecological time scale. Therefore, to fully understand the dynamics of invasion impacts it is important to consider the evolutionary consequences of invasions.

Native species can adapt and evolve in response to an introduced marine predator

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Introduced predators can have devastating impacts on native ecosystems and are responsible for significant declines in native biodiversity. This is because introduced predators can exploit novel prey species that lack a shared evolutionary history. If native species fail to evolve and adapt to the invasive predator, local extinction can occur. Here we explore the anti-predatory behaviour of two native prey species (a scallop and marine snail) to the introduced predatory Northern Pacific seastar (*Asterias amurensis*). Predator response trials showed that some native species can rapidly adapt their anti-predatory behaviours to avoid predation by the invasive seastar, and that these responses are genetically determined. These results suggest that rapid adaptation in some native species has occurred in response to an invasive predatory seastar, likely reducing impacts and permitting coexistence.

Predation shapes abundance of non-native marine invertebrates differently at a tropical and temperate site

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Predators can limit the abundance of non-native species, yet their effects vary across regions and habitats. In marine systems, predation is generally stronger in the tropics, but conflicting evidence suggests that predator identity and habitat also influence outcomes. We conducted parallel predator exclusion experiments in Panama (tropical) and Chile (temperate), comparing benthic and suspended habitats to assess predation effects on sessile invertebrate communities, with particular focus on native versus non-native species. In Panama, predators significantly reduced the abundance of certain non-native species in both habitats. In contrast, in Chile, predation effects were limited to benthic habitats, where declines in non-native species were observed. Encrusting species in Chile also persisted despite predator presence, suggesting trait-based resistance. These findings suggest that non-native species success is shaped by interaction between habitat, species traits, and predator guilds. Understanding context-dependence of biotic resistance is essential for improving predictions of invasion success and for developing targeted management strategies in changing coastal environments.

The role of macroalgae abrasion on corals of the genus Tubastraea

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Tubastraea corals are invasive in the Western Atlantic, competing with native species. A survey conducted in a Marine Protected Area in Arraial do Cabo, Brazil— a region characterized by a seasonal upwelling system — revealed interactions between macroalgae and *Tubastraea* colonies, with visible tissue damage observed on the corals. Abrasion from flexible macroalgae is hypothesized as the cause. The potential effect of macroalgal abrasion on corals has been tested multiple times, but never with an invasive species. To evaluate whether macroalgal abrasion can damage *Tubastraea* colonies, we conducted an active survey in Arraial do Cabo to identify macroalgae that could cause abrasion on *Tubastraea* colonies. Additionally, we performed a manipulative experiment using *Dictyota* sp. and plastic mimics in contact with *Tubastraea* colonies to test the effects of abrasion. The survey indicated that at least five macroalgae species can cause tissue damage to the corals. The manipulative experiment demonstrated that abrasion alone is sufficient to cause the damage observed in the field and may facilitate the overgrowth of native organisms in damaged areas. This study highlights the importance of biodiversity and seasonality for the resilience of marine ecosystems and demonstrates how native species can play a role in controlling invasive species.

Food web impacts of marine fish incursions into the Panama Canal

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Species introductions have the potential to change food web dynamics. Understanding these changes is a major challenge given the rapid pace of contemporary introductions and the lack of ecological reference points pre- species introductions. Within the Panama Canal in Central America, a > 100-year-old reservoir, i.e., Lake Gatun, has experienced repeated fish introductions dating back at least to the 1940s, with the ecological impacts of these introductions being relatively well-documented for a tropical system. A dominance of marine fishes in this freshwater reservoir following the Canal expansion in 2016 has transformed once again the ecological dynamics of Lake Gatun, with implications for the native and introduced freshwater biota in this system. Here we document these changes using a pre- and post-Canal expansion fish stable isotope (δ13C and δ15N) dataset that includes 45 fish species and four baselines. Marine fishes now dominate the upper trophic levels of Lake Gatun's food web. Many of these marine species are now feeding on the lake's native and introduced freshwater fish fauna, indicating their potential to control freshwater fish populations. A marine fish community able to benefit from Lake Gatun's food sources makes inter-oceanic fish migrations through the Panama Canal more likely.

Invasional meltdown: how jellyfish facilitate the dominance of non-indigenous fish

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Jellyfish are generally considered voracious zooplanktivores, preying on fish eggs and larvae while competing with fish for zooplankton, significantly impacting pelagic food webs. In the Eastern Mediterranean Sea (EMS), the invasive *Rhopilema nomadica* forms massive swarms. A previous study showed that the guts of *R. nomadica* medusae collected during summertime contain mostly microzooplankton. We assessed its trophic position using stable isotope analysis.

Jellyfish were collected in the EMS during summer and wintertime. Potential prey items, including phytoplankton, microzooplankton, copepods, and native and non-indigenous fish larvae, were collected seasonally. *R. nomadica* had a higher trophic level in winter ($\delta^{15}N$: 14.94±4.69‰) than in summer (7.43±1.89‰), indicating a seasonal shift. Bayesian mixing models showed a contribution of 34% of fish larvae to the diet of *R. nomadica* in the winter and <5% in the summer.

Seasonal trophic shifts were previously considered an inherent scyphozoan ontogenetic trait. Nonetheless, such shifts in *R. nomadica* have far-reaching implications for the EMS biodiversity. In winter, only native fish larvae and eggs are present in EMS waters, while non-indigenous fish reproduce in spring and summer. Thus, *R. nomadica* may exert greater predatory pressure on native fish, facilitating the dominance of non-indigenous fish through an indirect invasional meltdown process.

Does an invasive marine omnivore disrupt ecosystem functions in the Archipelago Sea, Finland?: An exploration of shifting energy and matter transport

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Biotic invasion events are increasing around the globe, especially in marine environments. While the stages of invasions and their potential to negatively effect ecosystems are well documented, research on their actual impacts on organism communities and ecosystem functions is sparse. Understanding these effects is critical for effective conservation and management of future invasions.
In the archipelago of the Finnish south-western Baltic Sea coast, the invasive crab *Rhithropanopeus harrisii* presents a novel predator to native herbivores, causing significant declines or local extinctions of native key herbivores *Theodoxus fluviatilis* and *Idothea balthica*. Due to the area's low biodiversity and functional redundancy, predation effects could cause trophic cascades, altering the composition of primary producers and disrupting energy transfer between trophic levels. In the shallow rocky littoral zones dominated by stands of *Fucus vesiculosus*, this could cause a shift from macroalgal stands to fast-growing filamentous algae and periphyton, along with increased sedimentation and hypoxia, altering ecosystem functions. Preliminary results show no significant difference in *Fucus* and filamentous algae biomass across sites with varying mud-crab invasion histories. We hypothesize that though standing biomasses and macroalgal species composition remain indistinguishable, energy and matter fluxes to consumers and decomposers may differ significantly based on invasion history.

Trophic structure and isotopic niche of invaded benthic communities on tropical rocky shores

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When a species is introduced in a new location, it is common for it to establish itself when it finds favorable conditions in the receptor community with regard to interspecific interactions with native species. The corals *Tubastraea coccinea* and *Tubastraea tagusensis* are invasive species introduced in the Caribbean Sea, the Gulf of Mexico, and the Brazilian Southwest Atlantic. They are successful competitors for space, have multiple reproductive modes, and have high larval dispersion and recruitment, but studies on food and trophic relationships of the genus *Tubastraea* are still scarce. In the present study, we used isotopic values of C and N ($\delta^{13}C$ and $\delta^{15}N$) of consumers and food resources to investigate trophic relationships in rocky shore communities invaded by *T. tagusensis* and *T. coccinea* corals under different oceanographic and anthropogenic contexts. Using metrics derived from the isotopic values, we show that invaded communities have a lower degree of trophic diversity, with species characterized by similar trophic ecologies while abiotic factors seem to contribute to the biotic resistance of communities exposed to invasion events. *Tubastraea* spp. occupy a niche space similar to that occupied by the native community of suspension feeders, sharing resources already consumed by the receptor community, which makes invading corals successful competitors for food.

The invasion process consists of nine (not four) stages

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We present a revised and updated model for the biological invasions framework. A finer-grained approach permits recognition of nine stages, rather than the traditional framework of Transport-Introduction-Establishment-Spread. A more refined conceptualization acknowledges biodiversity changes in source regions, as well as permitting the mirroring of each stage with a probability outcome. The latter then sets up stage-specific quantification and experimental approaches. Throughout this expanded model, lag times and survival windows are identified, as are stage-specific effects of climate change.

Bioinvasions & the blue economy

Navigating economic and ecological balance

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Biosecurity vs food security – the dilemma in aquaculture

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Aquaculture significantly contributes to food security by serving as an essential food source, boosting economic development, and enhancing community livelihood. Most aquaculture production comes from developing countries, where cultivation heavily relies on non-native species as target crops.

The biosecurity risks associated with non-native aquaculture species have been widely recognised, from either the cultivated species themselves as escapees, or their co-transported pathogens and diseases, with multiple socially, economically, and ecologically detrimental incidents witnessed worldwide. As food demand rises, the need to diversify farmed species and increasing reliance on non-native species create a biosecurity dilemma, where socio-economic benefits take priority over ecological concerns.

While the recent shift toward sustainable aquaculture emphasises environmental responsibility and resource conservation, biosecurity efforts in aquaculture mainly focus on diseases and pathogens, rather than the risks posed by the introduced farmed species. Varying social, economic, environmental, and political considerations across aquaculture stakeholders result in an uneven distribution of regulatory attention and risk assessment efforts. This leads to management loopholes in biosecurity in aquaculture where non-native farmed species are involved.

We aim to investigate the critical gaps in biosecurity in aquaculture, and highlight the importance of balancing the interests of food security and biosecurity for a sustainable aquaculture industry.

Beyond the cage: assessing the establishment of escaped gilthead Seabream (*Sparus aurata*) in Madeira's wild

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The gilthead seabream (*Sparus aurata*) is a prominent aquaculture species in Southern Europe. While native to the Northeast Atlantic, it was introduced to Madeira in 1997 for aquaculture, raising concerns about its potential as a non-indigenous species (NIS). Previous studies investigated the establishment and potential invasiveness of *S. aurata* in the Madeira archipelago by analyzing sport fishing contest data (2010-2019) and a custom-designed online survey targeting maritime stakeholders. Results revealed increasing occurrences and a widespread distribution of *S. aurata* sightings and captures around Madeira Island, including locations distant from aquaculture facilities, suggesting successful establishment of wild populations. Risk analysis using the AS-ISK protocol further indicated a medium to high invasiveness risk under current and future climate change scenarios, potentially due to the species' adaptability. This presentation will expand on these findings by incorporating new data and evidence regarding the causes of escape events from local aquaculture farms and preliminary observations on the life history traits and ecological interactions of escaped *S. aurata* in the wild, providing a more comprehensive understanding of this bio invasion and its potential ecological impacts in the Madeira archipelago. Further research, particularly focusing on confirming reproduction and assessing ecological impacts, is warranted.

Collaborating with mollusc farmers to tackle alien species challenges in aquaculture

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Aquaculture is a major vector for the introduction and spread of non-indigenous species (NIS), with negative ecological and economic implications. We used local ecological knowledge (LEK) to study, through questionaries, farmers' awareness of NIS and their observations of ecological changes in oyster and mussel aquaculture in the Adriatic Sea. Farmers indicated translocation practices involving seeds and adult mollusks between Italy, Greece, France, and Spain, both inside and outside the Mediterranean basin, which could facilitate the spread of NIS. Most farmers claimed to know what NIS are and reported observing them in their farms, yet only a few could precisely recognize a limited number of these species. They also noted increases in ascidians, barnacles, and hydrozoans, which they believe harm mollusks and reduce marketability. Our results show that LEK is a valuable tool for identifying issues relevant to NIS management in aquaculture. Training programs should be implemented to enhance farmers' ability to recognize alien species and contribute to their early detection. Furthermore, cross-border collaboration and partnerships between scientists, policymakers, and farmers are essential to managing the transport of alien species through aquaculture in the Mediterranean.

Transdisciplinary cross-border approach to address the problem of non-native species in mollusc aquaculture

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Aquaculture is one of the main vectors for the introduction of non-native species (NNS) in the Mediterranean. Poor knowledge about their presence in molluscs farms and insufficient legislative measures at both the national and European levels make it impossible to develop effective management strategies to contain their spread in the basin. Since 2019, the University of Bologna in Italy, has been applying a transdisciplinary approach to solve these problems in the cultivation of mussels and oysters in the Adriatic Sea, engaging also Croatian and Slovenian partners. We applied local ecological knowledge to gain access, through questionaries, to farmers' awareness of NNS, their observations of environmental changes in mollusc farms, and farming practices that promote the spread of NNS. An extensive sampling campaign and analysis of fauna associated with farmed molluscs along the Adriatic coast have provided updated information on the presence of NNS. Molecular methods have made it possible to detect new alien mudworms (Polychaeta: Polydora spp.) which are pests of oysters, and to trace their invasion routes in the Adriatic. The involvement of various stakeholders enabled to disseminate the results and open channels to address the problem of NNS spread in molluscs farming through further coordinated actions.

Lipidomic profiling of the invasive brown alga *Rugulopteryx okamurae*: insights into its biotechnological potential and invasion ecology

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Rugulopteryx okamurae, an invasive brown macroalga originally from the northwestern Pacific, is rapidly spreading across European coastal ecosystems, causing major ecological disruption and economic losses. While mechanical removal remains the primary response, its chemical composition and potential for valorisation remain underexplored. In this study, the lipidome of R. okamurae was characterised using gas chromatography–mass spectrometry (GC–MS) and C18 liquid chromatography–mass spectrometry (LC–MS). Several lipid classes, including glycolipids, phospholipids, betaine lipids, sphingolipids, acylglycerols, sterols, and oxylipins, were identified. Results provide a comprehensive overview of its lipid profile, highlighting both biotechnological potential and possible chemical drivers of invasiveness. On one hand, the presence of bioactive lipids, such as polyunsaturated fatty acids and sterol derivatives, points to promising applications in nutraceuticals, cosmeceuticals, and aquafeed. On the other hand, the detection of oxylipins, a group of lipids with known anti-herbivory effects in diatoms, suggests a role in *R. okamurae*'s ecological success. These compounds may interfere with the reproductive and developmental processes of marine invertebrates, reducing grazing pressure and facilitating invasion. Together, these findings offer new insights into the chemical ecology of *R. okamurae*, while supporting its controlled valorisation within circular bioeconomy models as a dual strategy for mitigating its impact.

Innovative detection & early warning systems

Genetic surveillance

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Assessing the effectiveness of genetic observatory networks in detecting and monitoring marine non-indigenous species

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The increasing prevalence of non-indigenous species (NIS) in marine ecosystems presents critical challenges for biodiversity conservation and ecosystem management. Advances in molecular techniques, particularly DNA metabarcoding, offer unparalleled opportunities for early detection and long-term monitoring of these taxa. The European ARMS Marine Biodiversity Observation Network (ARMS-MBON) exemplifies this approach, conducting standardized genetic sampling campaigns across Europe. We evaluated the potential of genetic monitoring networks to monitor marine NIS by analyzing ARMS-MBON data for cytochrome c oxidase subunit I (COI) and 18S rRNA markers using a custom bioinformatics pipeline. Screening against reference databases and incorporating manual curation, we detected diverse NIS across multiple locations, including taxa indicative of potential new introductions. This dataset also provides a valuable foundation for modeling NIS distributions and applying machine learning techniques to enhance predictive capabilities. Our findings highlight the efficacy of genetic observatory networks in identifying NIS distributions, mapping range shifts, and functioning as early warning systems. This talk will discuss key insights and future directions for the integration of genetic tools into NIS monitoring frameworks, emphasizing their role in addressing the growing pressures on marine ecosystems.

The Marine Biodiversity Data Portal – NI as a tool for the identification and monitoring of marine non-native species.

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The Marine Biodiversity Data Portal (MBDP–NI), is a five-year Department of Agriculture, Environment and Rural Affairs Environment Fund project based at Queen's University Marine Laboratory. The aim of the project is to build an innovative web-based portal for exploring Northern Ireland's marine biodiversity. The interactive website will incorporate recent as well as archive imagery and data from surveys in the 1980s to the present. The survey sites link through to site descriptions, photographs/video, biotopes and species lists. An important aspect of the project focusses on obtaining DNA barcodes from well curated specimens, accompanied by high quality photographs to help build identification resources. There is a particular focus on obtaining DNA barcodes and good quality images of non-native species, potential non-native species and species that could be confused with them. The availability of well curated DNA barcodes will facilitate future projects involving the monitoring of non-native species using environmental DNA.

Unravelling the temporal dimension of marine bioinvasions using sedimentary DNA and geochemical proxies: novel insights into invasion stages and community shifts

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Unravelling the historical dynamics of biological invasions is key to understand how invasive species colonise, establish and spread across ecosystems. Examining past invasion events can reveal novel mechanisms driving invasion success and impacts, as well as generate new knowledge for predicting future invasion trends and informing biodiversity management. We identified temporal dynamics of a large number of non-indigenous species (NIS), across a range of European coastal and estuarine systems, to determine their invasion stages and assess how these NIS have shaped historical community shifts. To do this, we used sedimentary ancient DNA (*sedaDNA*) metabarcoding of COI and 18S genes, and assessed sediment geochemistry in radiometrically-dated sediment cores from intertidal sediments. We found temporal variation in NIS richness and relative abundance through time that correlated with periods of increased pollutant deposition and marine traffic. Furthermore, shifts in community composition showed links between NIS presence and influences in native biodiversity. By reconstructing historical community dynamics, we unravelled temporal patterns of invasion stages, long-term ecological impacts and future dynamics of marine biological invasions. Additionally, our approach highlighted the role of key ecological mechanisms such as biotic resistance and priority effects that can be essential for understanding patterns in invasion science.

Improving eDNA detection of crab species for successful management of invasive species

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The use of environmental DNA (eDNA) for monitoring has grown, but detecting hard-shelled organisms, like crabs, remains challenging due to limited tissue exposure to water. Due to the high variability in detection within and between studies, the relatively few successful detections can be the effect of events that expose more tissue of the individuals or unintentional sampling larvae-tissue. eDNA is also sensitive to inhibitors, complicating quantification and comparisons, especially in polluted port areas. Ports are critical in preventing the spread of alien species, and false negatives could lead to mismanagement

This study explores methods to improve eDNA detection in crabs by testing different sampling techniques. We focus on detecting larvae and ovigerous stages, instead of hard-shelled adults. We prefilter the sample water to exclude whole zoeae on the filter and so reduce variability. We also test species-specific sampling and examine the influence on detection of common inhibitors like copper and TBT in port waters. Solutions such as dilution and metal extraction are tested for effectiveness. The goal is to establish a data baseline to predict false negatives, refine methods, and improve future invasive species management.

Comparing eDNA methods for assessing biofouling assemblages in the Red Sea: A case study to enhance the efficiency of NIS monitoring

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Environmental DNA (eDNA) is increasingly used to monitor biodiversity, assess species distribution, and detect the presence of non-indigenous species (NIS). However, its application is constrained by the inherent degradation of DNA in the environment and the low density of target organisms, which can limit detection accuracy. We tested the efficiency of eDNA metabarcoding (COI) for the detection of biofouling organisms from different sample types at two sites in the central Red Sea. From each site, we collected five PVC panels (deployed for three months), five scraping samples of artificial underwater structures (such as pontoon docks) and 10 seawater samples consisting of 5L each. After collection, panels and scraping samples were individually soaked for 3–5h in approximately 10L of filtered seawater. After soaking, the water was filtered and the biofouling material blended, followed by DNA metabarcoding analyses. Species present and the number and composition of NIS detected were compared among sample types to verify whether seawater filtration provides consistent taxon detection rates in comparison to panel and scraping samples (*i.e.* to the communities on artificial substrates). These findings will provide valuable insights to streamline sample processing for NIS detection and enhance the resolution and cost-efficiency of biodiversity assessments.

eDNA metabarcoding confirms NW Mediterranean ports as NIS hotspots and reveals potential spillover to surrounding natural areas

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One of the key aspects of non-indigenous species (NIS) control is preventing their establishment and further spread from areas where they have been introduced. Early detection of NIS is therefore of paramount importance. Ports (including marinas) are renowned introduction sites for NIS, which arrive as stowaways through maritime traffic. The use of environmental DNA (eDNA) metabarcoding to identify NIS in ports has the potential to enable their early detection before they spread to surrounding areas. Here we investigated community data using eDNA metabarcoding from seawater collected from triplicates collected both in 11 French Mediterranean ports and in one location in their neighbouring natural habitats. Our main goals were to assess whether artificial structures promote NIS establishment, and to estimate NIS contribution to communities in natural sites near ports. To improve species identification, we used three different genetic markers (12S, COI, 18S) and compared our species list with those listed in a custom-made comprehensive database including NIS recorded in European seas (Violet et al., *unpublished*). We confirm ports as habitats characterized by rich and distinct NIS community. Furthermore, we report a significant contribution of NIS found in ports to communities from nearby natural sites. While genetic validation is needed to confirm if these are true port escapees, this finding highlights eDNA metabarcoding's potential for detecting NIS in natural areas surrounding ports.

Scaling up the application of environmental DNA for the detection of non-indigenous species in Saudi waters

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Environmental DNA (eDNA) metabarcoding is an increasingly used tool for marine biodiversity monitoring and early detection of non-indigenous species (NIS). However, scaling up eDNA applications requires methodological standardization, including considerations of sample type, replication, and water volume. The Red Sea and the Arabian Gulf, regions of intense maritime activity, are especially vulnerable to the introduction of NIS. As part of Saudi Arabia´s first national monitoring program for NIS detection, we conducted quarterly eDNA sampling over 12 months at 11 locations (7 in the Red Sea and 4 in the Arabian Gulf). At each site, 10 replicates of 5L seawater were filtered using autonomous DNA sampler, followed by DNA extraction and amplification of 18S rRNA and COI gene regions. We aim to assess the efficiency of eDNA in detecting marine biodiversity and NIS, and to evaluate the impact of water volume on the taxonomic composition. Preliminary results identified 36 potential NIS. Community composition analyses indicated that three replicates were sufficient to resolve site-level biodiversity patterns. However, accumulation curves suggest that 20 replicates are required to detect 80% of the total biodiversity. These findings contribute to refining eDNA methodologies for targeted species detection, ultimately enhancing the effectiveness of biosecurity monitoring programs.

Assessing the spillover: metabarcoding reveals contrasting NIS dynamics inside and outside a port

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DNA metabarcoding is a powerful tool to monitor non-indigenous species (NIS) in hotspots for their introduction and spread such as harbours and marinas. However, how these species propagate their genetic variants to the natural environments remains unclear. We evaluated the genetic structure of NIS inside and outside a harbour located in the western Mediterranean (Spain). During a six-month period we placed biocollectors inside and outside the port and replaced them monthly. Metabarcoding using the COI marker of the collected samples detected a total of 1,801 Molecular Operational Taxonomic Units (MOTUs). While only 57 MOTUs were identified as NIS, they represented 54.95% of the sequences obtained from the samples collected inside but only 5.18% outside. We then analysed the community composition in terms of MOTU abundance and distribution. Finally, we assessed the genetic variability within MOTUs - the so-called metaphylogeographic approach - considering both haplotype richness and genetic differentiation. Both inter-MOTU and intra-MOTU approaches showed a clear separation of the samples inside and outside the harbour and a marked temporal structure of the community. The application of these innovative approaches has the potential to unveil key genetic attributes of marine bioinvasions, enabling a better understanding of their threats for ecosystems.

Non-indigenous species in marinas and MPAs: a metabarcoding study from two Azorean islands

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Marine non-indigenous species (NIS) can significantly impact biodiversity, disrupt ecosystem processes, and affect economic sectors, especially in remote oceanic islands.

In Azores islands, hull fouling is the main introduction vector for marine non-indigenous species, mainly by shipping and, also, by recreational boating. Marinas serve as hotspots for the presence of NIS that can spread to adjacent zones, including marine protected areas (MPAs).

Sea water samples were collected for environmental DNA (eDNA) analysis in two marinas and two MPAs, in two Azorean islands, São Miguel and Santa Maria. After DNA extraction, high-throughput sequencing (HTS) was conducted using two universal molecular markers, the V4 region of the 18S rRNA and the mitochondrial cytochrome c oxidase I (COI) genes.

Our results were consistent with previously reported biodiversity variety, including known occurring marine NIS, such as the macroalgae *Rugulopteryx okamurae* or the bryozoan *Tricellaria inopinata*. Moreover, some potential new NIS were identified, such as the barnacle *Austrobalanus imperator* in a recreational marina, and the red algae *Acrochaetium catenulatum*, inside a marine protected area. These preliminary results highlight the urge for NIS monitoring as it is crucial on promoting management strategies aiming to mitigate the impact of invasive species in vulnerable environments.

Metabarcoding surveys across harbours reveal NIS homogenisation and high genetic connectivity

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Commercial ports act as introduction spots for non-indigenous species (NIS), while smaller harbours and marinas facilitate their regional spread. Despite extensive research, genetic connectivity among harbours has not been assessed at the whole-community level. This study investigated metazoan communities over one year across four medium-sized harbours and one natural site in the NW Mediterranean. Using COI metabarcoding of artificial collectors, we identified 2,400 metazoan molecular operational taxonomic units (MOTUs), including 86 NIS detected using a custom Mediterranean NIS database. The exact sequence variants comprising each MOTU were also used as a proxy for its haplotype composition. Harbours exhibited lower species richness than the reference natural site, yet NIS comprised 34–75% of relative abundance—compared to 11% at the natural site. The southernmost harbour showed the highest NIS abundance, likely influenced by nearby aquaculture facilities. While overall community structure varied among harbours, NIS composition was more homogeneous, sharing more MOTUs across sampling sites. Notably, NIS displayed higher haplotype diversity and lower genetic differentiation between populations than native species, suggesting more effective regional dispersal via local boating. These results highlight distinct NIS dynamics in artificial environments and emphasize the importance of continued monitoring of harbours to manage coastal NIS spread.

Morpho-genetic insights into potentially dominant non-indigenous ascidians in Europe and New Zealand

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Understanding the early stages of species introductions is essential, as management efforts to prevent the establishment of non-indigenous species (NIS) are typically more effective during these stages. Surprisingly, comprehensive information on how and when NIS are first introduced remains scarce. In this paper we assess the characteristics of recent introductions of members of the widespread *Pyura stolonifera* species complex (Chordata, Tunicata). These sessile invertebrates are important bioengineers that can attain amongst the highest benthic biomass per surface area ever reported, creating extensive aggregates that can smother native species. The transient nature of their early life-history stages suggests that their introduction to distant regions can only be explained by human-mediated transport of NIS. Our genetic and taxonomic data reveal the establishment and introduction pathways of two members of the species complex - one in Europe and another in New Zealand. While an Australian species has extensively spread along the northern New Zealand coastline, an African species with considerable potential to become problematic for the aquaculture industry remains extremely rare in Europe. To prevent the harmful impacts of NIS on native biota and/or economically important anthropogenic activities, regular monitoring of recent NIS introductions, using both taxonomic and genetic approaches, is urgently required.

Development and implementation of a method for the early detection of invasive sun coral species

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Early detection and rapid response (EDRR) are essential to prevent possible large-scale ecological damage and reduce economic losses caused by marine bioinvasion. The main obstacle to implementing EDRR protocols is that monitoring programs depend on the work of taxonomists, which is considered expensive and time-consuming. Environmental DNA (eDNA) analysis offers the opportunity to identify non-native species propagules before the species are effectively established and detectable through other approaches, such as visual census. In the present study, we combined eDNA-based analyses with colorimetric loop-mediated isothermal amplification (LAMP) to develop a rapid and cost-effective detection method for *Tubastraea* spp. We also analyzed eDNA release time in microcosm experiments and compared the performance of both passive and active methods for eDNA sampling in seawater. LAMP results were validated through gel electrophoresis and qPCR. Specificity and sensitivity tests indicated the reliable detection of the *Tubastraea* genus at low DNA concentration (up to 0.5 pg/uL). The active sampling method resulted in higher eDNA concentration. No significant effects of sampling time, nor any interaction between time and method were observed. The present study provides a straightforward early detection method to monitor the spread of sun coral, requiring little laboratory infrastructure and no specific training.

Distribution and range expansion of the invasive soft coral *Chromonephthea* in the southwest Atlantic (Brazil)

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The introduction of nonnative octocorals (Octocorallia) is becoming increasingly more common around the world. In Brazil alone we know of nine nonnative or cryptogenic species of octocorals representing eight different families. The nephtheid *Chromonephthea braziliensis* (a pseudoindigenous species) was probably first introduced in Brazil in 1994 and has since appeared in three distinct regions on the northeast and southwest coast. The aims of this study were to review and describe the current distribution, verify the taxonomic composition and identify probable vectors and pathways of introduction. In 2024 we assessed seven of fourteen known populations along the entire extent of the known species distribution. Population sizes were estimated, species interactions noted and specimens collected. Colony morphology and color were assessed by examining sclerites, and DNA sequences were obtained for the mitochondrial *mtMutS* and nuclear *28S rDNA* barcode markers. Genetic and morphological analyses confirmed the presence of two different species of *Chromonephthea* in Brazil, suggesting multiple introductions through fouling on hulls of oil and gas platforms. These species can be most easily distinguished by the color of their point sclerites, which are yellow in *C. braziliensis* and red in the other species. Both negative (contact necrosis) and positive (basibiont) species interactions were recorded.

Annelida from the Red Sea: new records, non-native or just overlooked cryptic complexes?

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Molecular tools are increasingly used to assess biodiversity, detect cryptic species, and identify potential invasive species. Given marine ecosystems' vulnerability to non-indigenous species (NIS), early detection is crucial to mitigate ecological and economic impacts. However, public DNA databases remain incomplete for many marine invertebrates. The lack of detection and formal taxonomic descriptions for cryptic lineages further complicates identifying invasive species, as allegedly introduced taxa might belong to different lineages from putative originating populations. Biodiversity inventories of marine benthic invertebrates in the Saudi Red Sea are underway using DNA barcoding and metabarcoding across a range of natural and man-made habitats. Here, Annelida are used as a case study due to frequent cryptic complexes and cryptogenic status of several molecular lineages. Notable examples include *Ceratonereis tentaculata, Pseudonereis anomala* (Nereididae), Leodice antennata (Eunicidae), and *Trypanosyllis zebra* (Syllidae), which revealed overlooked hidden species often misidentified as widespread taxa. Some lineages may be native or non-native, undescribed or described species forgotten and not mentioned in regional checklists. This suggests that many potential non-native species may in fact belong to undescribed cryptic complexes, highlighting the difficulties of establishing the invasive status of a species and the need for dedicated studies following an integrative taxonomic approach.

Characterizing Bryozoan diversity to support marine biosecurity in Saudi Arabia's Arabian Gulf coast

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Bryozoans are frequently recorded non-indigenous species (NIS) in marine biofouling communities, often colonizing artificial structures in ports and marinas. As potential vectors of ecological disruption, their detection is critical to global biosecurity efforts. Despite this, bryozoan diversity along Saudi Arabia's Gulf coast remains poorly documented. This study contributes to a national initiative establishing baseline data for NIS monitoring and marine biosecurity in Saudi waters. During 2024, we surveyed bryozoan assemblages seasonally across twelve sites experiencing high disturbance and risk of NIS introduction (e.g. industrial ports and fishing marinas). Upon retrieval of PVC settlement panels, distinct morphotypes were preserved as voucher specimens (N = 117) and examined via scanning electron microscopy, representing ~15 species. DNA barcoding of a fragment of the COI marker gene is currently being performed on each species to confirm identification and develop a regional DNA reference library. Additionally, each panel's biofouling community was photographed and then homogenized for DNA metabarcoding analysis to assess species diversity and explore patterns in relative abundance of NIS versus native species. Combined, these methods and datasets significantly enhance systematic species verification, help detect introduction hotspots, and inform targeted monitoring programs aimed at early detection and prevention of NIS expansion.

Innovative detection & early warning systems

Integrated monitoring and spatial approaches

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A needed update on fouling bryozoans from the Canary Islands (North-Eastern Atlantic): new records and ecological insights

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Bryozoans are major components in fouling communities of marinas. These port environments act as reservoir and stepping-stones for further spread of non-indigenous bryozoans (NIB) to other areas. Considering that NIB management must be preventive, a deep comprehension of the diversity of bryozoans in marinas is mandatory. Furthermore, understanding the habitat preference of these NIB could be also useful for focusing monitoring efforts for their early detection. This is especially relevant in areas that rely heavily on shipping, such as the Canary Islands, where this information is still lacking. Here, we assessed the diversity of bryozoans in recreational marinas of Tenerife, Gran Canaria, Fuerteventura and Lanzarote. The diversity of bryozoan species was compared in contrasting areas within the marinas (*i.e.* interior and exterior) and types of artificial substrate (*i.e.* floating pontoons, buoys and ropes). We registered seven new records for the Canary Islands. Buoys showed the highest number of NIB, with some of them being registered only on this substrate. The bryozoan community was also very influenced by the singularity of each marina. These results emphasize the need to focus on buoys as target for monitoring, to facilitate the early detection of NIB in variable port environments.

Addressing the knowledge gap in relation to alien species in South African kelp forests

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Following establishment, the probability of successful eradication of marine alien species is unlikely. In the context of kelp forests, this is concerning as alien species can lead to dramatic changes in ecosystem structure and even the total loss of kelp. In South Africa, little is known about the status of alien species in kelp forests, nor the vulnerability of these systems to future incursions. To address the need for baseline data on alien species in this important habitat, we undertook a two-pronged approach. We developed a watch list of alien species with the potential to invade these systems using a climate-sensitive horizon-scanning approach. Temperature-matching was used to determine the suitability of South African kelp forests for the watch list species under present and future climatic conditions. In addition, the first surveys for non-indigenous species in South African kelp forests were carried out. This information will provide the foundation against which future introductions and spread can be tracked. Notably, one of the watch list species (the bryozoan *Membranipora menbranacae*) has been detected. This discovery demonstrates that routine monitoring, guided by a watch list can be an effective way to detect new incursions and track impacts.

A methodological framework: spread dynamics of invasive marine species in the Aegean Sea

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Marine biological invasions pose significant challenges to biodiversity in recipient marine ecosystems worldwide. To effectively manage impacts, it is essential to understand the complex spatiotemporal dynamics and historical expansion patterns of invasions. In this study, we introduce a comprehensive methodological framework, applied in the Aegean Sea, Eastern Mediterranean, that estimates the spatial spread of invasive marine species relying exclusively on georeferenced data records and their associated collection dates. Our approach employs spatial interpolation techniques with inverse path distance weighting, tailored to accommodate complex coastline features that shape the seascape. A sequence of maps is generated to depict the probability of species occurrence at specific time points, allowing to reveal species-specific patterns of spread. To statistically quantify the rate of spread, we employ a multi-model inference strategy that accounts for the goodness of fit of linear and non-linear models to combine their contributions and optimize predictions. Our findings reveal three main spread patterns among the studied species: 1) continuous expansion, 2) decelerating expansion suggesting a shift toward stabilization and 3) fluctuating dynamics, characterized by irregular changes in spread. The proposed methodology reveals species spread patterns and being adaptable to different areas, resolutions, and timeframes, can guide management and invasion monitoring efforts.

Hunting marine invaders with autonomous reef monitoring structures (ARMS)

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The North Adriatic Sea is one of the most bio-invaded areas of the Mediterranean, primarily due to its semi-enclosed nature and the presence of intense aquaculture activities and of major ports.
Effective management of marine bioinvasions requires accurate assessment and monitoring of Non- Indigenous Species (NIS) using standardized, integrative, and innovative approaches. In this study, we used Autonomous Reef Monitoring Structures (ARMS) to monitor the spatial and temporal changes in NIS communities across the North Adriatic Sea from 2021 to 2023. ARMS were deployed in different sites on the Italian and Slovenian coasts with varying levels of human disturbance. By comparing data from morphological identification, photo analysis and cytochrome c oxidase subunit I (COI) and 18S rRNA amplicon sequencing, we detected at least 18 NIS taxa. Furthermore, we analyzed the changes in NIS communities in ARMS over time and across different locations. The results highlight the potential of an integrative taxonomic approach for monitoring bioinvasions. However, our findings underscore the importance of harmonized protocols for ARMS deployment timing and data processing, which can be achieved only through international cooperation and long- term monitoring programs.

Standardized biofouling monitoring in Monastir Bay, Tunisia

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The Mediterranean Sea, celebrated for its biodiversity, is increasingly threatened by non-indigenous species (NIS). Intensified shipping, ocean warming, and acidification accelerate these invasions, disrupting native ecosystems. While most research has focused on the northern Mediterranean, the southern region remains understudied. To address this gap, we conducted the first standardized NIS monitoring effort in the South Mediterranean using MarineGEO's fouling community protocol.

Over three months, we deployed 24 PVC settlement panels at four sites in Monastir Bay, Tunisia: an aquaculture farm, harbor, marina, and a grounded ship near a marine protected area. Monthly photographs documented biofouling succession, and panels were retrieved after three months for species identification and biomass assessment.

Our findings revealed 27 confirmed taxa, with significant variations across sites. The highest diversity occurred at the marina, while the harbor had the lowest. The bryozoan *Celleporaria inaudita* thrived in artificial settings, whereas the ascidian *Didemnum cf. perlicudum* dominated in open-water environments. These results highlight the importance of standardized monitoring protocols in tracking biofouling dynamics. By identifying high-risk areas and succession patterns, our study supports targeted management strategies for marine conservation, particularly in Kuriat Island, Tunisia.

Port environments as gateways: evaluating biotic resistance in benthic communities of the Strait of Gibraltar

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Bays, estuaries, and port zones are marine ecosystems under intense anthropogenic pressure and especially vulnerable to non-indigenous species (NIS) introduction, mainly due to maritime traffic. The Strait of Gibraltar (SoG), a major maritime route linking the Atlantic and Mediterranean, is a hotspot for NIS, particularly through its port environments. The spread of NIS from these areas can alter native community structure and composition.

This study assessed the potential biological resistance of natural benthic communities to NIS settlement. Autonomous Reef Monitoring Systems (ARMS) were used to collect standardized samples from a natural coastal area (Tarifa Island, TI) and a high-traffic port (Port of Tarifa, PTa), analyzing variability in NIS recruitment.

In July 2024, 12 ARMS were deployed—6 in PTa and 6 near TI. After 4 months, 6 units (3 per site) were analyzed. Three TI units and three new ones were then moved to PTa, joining 3 still in place (totaling 9). After 4 more months, all units were retrieved and analyzed using standardized methods.

Benthic communities differed between TI and PTa, with plate orientation also influencing composition. SIMPER analysis revealed NIS dominance in PTa and native species in TI. The study highlights the role of PTa as a key NIS entry and dispersal point in the SoG.

Spatio-temporal dynamics of fouling assemblages on Saudi Arabia ports (Red Sea and Arabian Gulf) using image analysis of settlement panels

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Coastal urbanization and maritime traffic are increasing the spread of non-indigenous species (NIS) via artificial substrates, yet baseline data from the Middle East remain scarce. This study presents the first large-scale monitoring of early fouling assemblages in the Red Sea and Arabian Gulf using a standardized PVC settlement panels methodology. Five panels were deployed every three months over a one year period at three sites nested within seven locations (four in the Red Sea, three in the Arabian Gulf), totaling 420 panels. Once retrieved, panels were photographed, and examined under a microscope to generate a species list supporting image-based analysis. The latter applied a 50-point stratified count per panel, with adjustments for non-detected and epibiotic taxa. Preliminary results from the first retrieval revealed a total of 74 taxa, including 13 NIS and 13 cryptogenic species, with 32.0% and 30.6% average cover in the Arabian Gulf, and 26.3% and 6.4% in the Red Sea, respectively. Bryozoans were more abundant in the Red Sea, whereas *Amphibalanus amphitrite,* Hydroides elegans, and massive-form ascidians were more abundant in the Arabian Gulf. This standardized approach provides a replicable framework for regional NIS surveillance and delivers essential data to inform biosecurity programs and support early detection in a rapidly urbanizing seascape.

Tracing invasion pathways to and within the Netherlands by continuous marine NIS monitoring

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Before 2009, the vast majority of marine Non-Indigenous Species (NIS) in the Netherlands were first recorded at popular diving spots by scuba-divers. Since 2009, NIS-focused surveys are conducted more widespread along the coast. These surveys in ports, marinas, and shellfish production sites resulted in the discovery of 58 additional marine NIS up to 2024. Using these surveys, nowadays organized within the marine alien species detection network, an analysis has been done to determine invasion pathways. The data showed that the Netherlands is an introduction hotspot for Europe, as about half of the species were not only new to the Netherlands but also to Europe. While most NIS are probably introduced in the port of Rotterdam, they primarily establish themselves in Zeeland, where most arrive by secondary spread. In a similar manner they arrive in the Dutch Wadden Sea, where NIS establishment is around 95%. Typically, this initially occurs in a small selection of marinas and harbours. Subsequent spread usually starts several years later, following reasonably predictable pathways, mirroring previous NIS invasions in the region. Determining and visualizing these pathways, can aid decision making by optimizing early detection monitoring and implementing measures to reduce future NIS introductions.

From ports to reefs: tracking marine invasions beyond the Panama Canal

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The Panama Canal serves as a major hub for global shipping and is recognized as a hotspot for invasions. At its Pacific entrance, we observed that 30% of sessile invertebrate species on recruitment panels were introduced. However, marine invasions are not only an urban problem. Thus, we investigated the potential spread of introduced species to more remote reef habitats on islands away from the Canal.
Using standardized experiments our aim was to: (a) detect the presence of introduced species, (b) assess the role of predation in community assembly and invasion success, and (c) determine whether upwelling modulates these processes.
We recorded at least 10 introduced species on reefs within the Pearl Islands Archipelago, approximately 60 km from the Canal, whereas reefs located further away in the Coiba Archipelago (~400 km) had fewer introduced species. In the Pearl Islands, which experiences seasonal upwelling, caged panels protected from predators exhibited higher biomass compared to open panels. This pattern was less pronounced in Coiba, a non-upwelling area.
Our results demonstrate that predation by fishes reduced prey biomass, but the effect was more pronounced in the Pearl Islands. This suggests biotic resistance and oceanographic conditions interact to shape invasion dynamics in natural reef ecosystems.

Recruitment of non-indigenous species in marinas and adjacent coastal areas: mainland vs insular patterns

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Biological invasions are a major threat to marine ecosystems, with harbors/marinas serving as key entry points due to vessel-associated vectors like ballast water and hull fouling. No updated national non-indigenous species (NIS) database is available for Portugal and invasions may be underestimated, partly due to the country's complex geography, which includes mainland and oceanic insular regions. We analyzed differences in NIS and native species recruitment in marinas versus adjacent open coasts across four sites: Azores and Madeira (oceanic islands), and Lisbon and Sines (mainland). Settlement plates were deployed for six months to allow colonization by fouling communities. Results confirmed marinas as NIS hotspots, showing greater abundance and diversity of NIS compared to open coasts, likely driven by vessel traffic and the presence of artificial structures. A higher number of NIS was detected in the mainland sites, likely reflecting higher maritime traffic. However, island sites exhibited stronger differences between marina and open coast communities. Analysis of the taxonomic diversity revealed that marina communities were more clustered, suggesting environmental filtering that may favor NIS establishment, whereas open coasts seemed to be more stable, hosting a more taxonomically diverse set of species. These findings reinforce the role of marinas/harbors as invasion hubs and highlight the ecological risks islands face due to pronounced community shifts and potential biotic homogenization, despite lower invasion levels.

Marine Non-Indigenous Species (NIS) monitoring in the Azores: achievements, knowledge gaps, and future directions

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The Azores archipelago is highly susceptible to biological invasions, with an increasing number of marine non-indigenous species (mNIS) being recorded at an unprecedented rate. The first mNIS documented in the region included species such as *Amphibalanus amphitrite* and *Balanus trigonus*, with historical observations dating back to the early 20th century. Despite these early records, references to mNIS remained scarce throughout much of the twentieth century. A turning point occurred with the invasion of Faial Island by *Caulerpa webbiana*, which galvanised local researchers, the public, and governmental bodies, leading to the implementation of targeted action plans. The publication of the first comprehensive list of mNIS for the Azores and the subsequent inclusion of the NIS descriptor in the MSFD laid the groundwork for structured monitoring programs established in 2015.

Despite these advances, significant challenges persist. Notably, critical taxonomic knowledge gaps hinder accurate identification and assessment of mNIS diversity. Monitoring efforts are further constrained by insufficient spatial coverage, leaving some islands and areas under-surveyed and potentially allowing undetected invasions. Local research has played a pivotal role in shaping both national and European guidelines for NIS monitoring and management, offering valuable models for science-informed policies.

The increasing human footprint in the Azores, including intensified maritime traffic, tourism, coastal development, and climate change, poses additional risks, potentially accelerating the introduction, establishment and spread of mNIS. Herein, we synthesise the evolution of mNIS research and monitoring in the Azores, highlighting lessons learned and discussing ongoing challenges.

Habitat specific approaches for the improved detection of NIS

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The current trend towards an increase in the introduction of non-indigenous species (NIS) on a global scale has led to the creation of specific regulations to respond to this threat. The definition of appropriate monitoring protocols for the detection of new arrivals has been one of the main measures implemented. This study evaluated how the spatial variability of available habitats in the Tagus Estuary affects the detection of NIS. Time series of the abundance of benthic communities were analysed, obtained by i) scraping hard substrates in recreational marinas, ii) using a van Veen grab and iii) towing a clam dredge. The results revealed a high heterogeneity of communities along the estuarine gradient and across different methods. Although the samples collected using a grab had a greater species richness, those obtained through the other methods allowed the detection of a higher number of NIS. There were NIS identified exclusively with the grab (1), the clam dredge (9) and scraping hard substrates (12). This methodological comparison highlights the need to use methodologies that assess multiple habitat types, to obtain a more accurate understanding of the extent and impacts of biological invasions in estuarine environments.

Integrated monitoring of biofouling assemblages with focus on non-indigenous species in the Arabian Gulf, Saudi Arabia

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Marine non-indigenous species (NIS) pose a growing threat to coastal ecosystems, yet standardized long-term monitoring remains limited. We present the first biofouling dataset from settlement panels and mature fouling communities along Saudi Arabia's Gulf coastline. PVC panels (14 × 14 cm) were deployed at 12 sites between December 2023 and March 2024, with mature communities sampled from pontoons and docks in March 2024. Panel images were analysed using the point count method to estimate coverage, and both panel and mature communities were analysed using a DNA metabarcoding approach the COI mitochondrial gene. In total, 34 NIS were identified, with mature communities exhibiting an overall higher NIS diversity than panels. Image analysis indicated an average composition of 32% NIS, while the molecular data showed 28% of NIS reads. DNA metabarcoding results showed that northern sites tended to cluster together, associated with high bryozoan abundance, predominantly the NIS *Celleporaria inaudita*, while sites in the south were dominated by the NIS ascidian *Botrylloides niger*. These results not only confirm the presence of many NIS in Saudi waters but provide critical baseline data for Saudi Arabia and neighbouring regions, offering a valuable reference for rapid assessments, and the development of proactive biosecurity strategies to manage future invasions.

Innovative detection & early warning systems

Citizens on watch

5

iNaturalist as a tool to supplement alien species monitoring: a South African perspective

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Data on the distribution of marine alien species in South Africa is scare and often outdated. This reflects the absence of national monitoring programmes, a common occurrence in developing countries. Despite these limitations, the need for accurate data on invasions persists. Crowdsourced data platforms, including iNaturalist, provide sustainable solutions by enabling large-scale data collection without requiring funding. This study assessed the status of iNaturalist records for species known to be alien in South Africa. A total of 952 records were recovered, with 568 retained for analysis following the application of a confidence metric to identify accurate records. Alien species were documented in 14 of the 29 South African coastal marine protected areas (MPAs), with most found in Table Mountain National Park MPA. This study documented three ascidians (*Ciona robusta; Clavelina lepadiformis; Styela plicata*) in natural habitats for the first time, extended the known range of the maritime earwig *Anisolabis maritima* by more than 1500km and confirmed the presence of the hydroid *Pennaria disticha* after it was last documented four decades ago. This study represents the first use of iNaturalist data in a marine invasion context in South Africa, highlighting its potential to enhance monitoring, particularly in under-surveyed MPAs.

Citizen science for early detection and monitoring of exotic species: RedPROMAR in Canary Islands

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The current state of the oceans and their biodiversity is a global concern. The introduction of exotic species is considered a major threat, with ecological, economic, and social impacts. In this context, collecting data on their presence and distribution is essential for effective management. Marine citizen science is emerging as a key tool to expand the spatial and temporal scale of species records. This study assesses the contribution of RedPROMAR as an early detection and monitoring system for exotic species in the Canary Islands. Between 2012 and 2024, nearly 190 users reported over 1,200 sightings of 52 exotic species, 45% of which are invasive or potentially invasive. Tenerife (50%) and Gran Canaria (26%) recorded the highest numbers, matching the islands with the largest port facilities and maritime traffic. In the last three years, sightings have increased, accounting for 60% of the total. Invasive species such as *Rugulopteryx okamurae* and *Cronius ruber* were frequently reported, along with new records like *Kuhlia caudavittata* and *Godiva quadricolor*. These findings highlight the value of citizen science in marine surveillance, provided it is supported by scientific validation, proper training, and integrated into management strategies that promote the conservation of native biodiversity.

Crab Alert! Engaging communities to track an invasive species in Portuguese waters

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The Chinese mitten crab *(Eriocheir sinensis*) is an invasive species established in the Tagus river basin since 1992. However, information on its distribution and impacts in Portugal remains scarce. Citizen science (CS) can help bridge these knowledge gaps, by supporting species detection and mapping. This study used CS surveys among fishing communities to assess *E. sinensis* distribution and perceived impacts. Responses were cross-checked with *in situ* sampling and records from CS platforms (iNaturalist, Biodiversity4All). Results showed that 87.8% of respondents had observed *E. sinensis*, primarily in the river, where sightings occurred year-round and peaked in spring and summer. Estuarine observations were less frequent and mostly in winter. All river fishers reported sightings, compared to ~32% of estuary fishers. Observations ranged from Belver dam to Samouco. In-situ observations and CS platforms (limited records) confirm the species presence along the Tagus River mainstem and estuary, but not in tributaries. A single CS record from Lagoa de Albufeira is the first detection in that system. Most fishers recognized the species as invasive, citing gear damage and predation as their main impacts. Overall, surveys are a valuable tool for monitoring aquatic invasions and complement traditional scientific approaches.

Eyes on the sea: uncovering Mediterranean non-indigenous jellyfish with citizen science — And where we go next

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Citizen Science (CS) plays a critical role in providing real-time alerts and enhancing long-term knowledge of species distribution and ecology. When integrated into global reporting systems, local initiatives must preserve community identity, language, and purpose to ensure meaningful CS processes. At the same time, data collection and management must follow standardised methodologies.

We present the Mediterranean-based Citizen Science Jellyfish Observation Initiatives (CS JOIs), which reveal Non-Indigenous Species (NIS) diversity and phenology. We identified 13 JOIs across 8 countries, monitoring 35 jellyfish taxa, 10 of which are NIS. Notably, several JOIs recorded first sightings of species such as *Phyllorhiza punctata* and *Rhopilema nomadica* in Malta, and revealed ecological dynamics, including *Mnemiopsis leidyi* in the Adriatic, *R. nomadica* in Israel, and *P. punctata* in Tunisia.

Data collection varied across initiatives, including differences in purpose, methodology, and community engagement, highlighting the importance of data standardisation for better integration and management. To address this challenge, we propose a three-stage approach to data management and standardisation, based on global standards

like Darwin Core and IOOS terminology. This approach aims to streamline data integration and ensure more robust, comparable citizen science efforts.

Integrating citizen science and molecular tools to enhance understanding of invasion pathways in the Eastern Mediterranean Sea

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The Eastern Mediterranean represents a hotspot for marine bioinvasions. Monitoring and management of these invasions require an integrated and multidisciplinary approach. Local Ecological Knowledge (LEK) from fishermen and citizen science initiatives are valuable tools for detecting the presence and spread of Invasive Alien Species at a local scale. Complementary, molecular tools offer insights into propagule pressure, genetic variability, and the origins and pathways of species introductions. Combining these approaches, we present results about two key invasive species in the Adriatic and Ionian Seas: the lionfish *Pterois miles* (Bennett, 1828) and the ctenophore *Mnemiopsis leidyi*A. Agassiz, 1865. Interviews with fishermen revealed that the abundance of *P. miles* has increased over time without a significant decrease in the abundance of the other commercial fish species. Conversely, the increasing presence of *M. leidyi, as shown* also by the numerous citizens' sightings collected in avvistAPP (https://segnalazioni.avvistapp.it/), caused serious damage to artisanal fisheries. The use of different molecular markers revealed that both species were introduced into the basin more than once. Our findings highlight that combining citizen science and molecular tools is a successful approach to understanding invasion dynamics and establishing more effective management and mitigation strategies.

Innovative detection & early warning systems

AI and other emerging technologies

8

Advancing marine bioinvasion monitoring: a deep learning framework for detecting invasive *Tubastraea* (sun coral) species

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The sun coral (*Tubastraea* spp.) is an invasive species that significantly threatens coastal ecosystems, making early detection essential for effective monitoring and mitigation of its impacts on marine biodiversity. This study presents a computer vision method for the automated early detection of invasive Tubastraea species in underwater images. By utilizing the YOLOv8 deep learning model, we trained and validated a manually annotated dataset, which was enhanced with synthetic images to tackle the challenge of limited training data often found in underwater environments. The model demonstrated performance metrics of precision, accuracy, recall, mAP50, and F1 scores exceeding 90%, successfully identifying both open and closed coral stages. During the testing phase, results were compared with expert validation, showcasing the model's ability for rapid detection (16 ms per image) while also highlighting some limitations in areas with dense *Tubastraea* coverage. This study emphasizes the potential of deep learning, paired with data augmentation, to facilitate quick and efficient analysis of large image datasets for monitoring sun coral bioinvasions. The proposed approach serves as a valuable tool for managers, taxonomists, and professionals engaged in controlling invasive alien species, thereby supporting more effective conservation efforts.

CANCELLED - Leveraging emerging technologies to enhance marine biosecurity: where we are now and what to be done

Marnie L Campbell, Chi T U Le, Jumana Abu-Khalaf

Edith Cowan University, Australia

Non-indigenous marine species (NIMS) incursions pose significant threats to global oceans, impacting environmental, economic, social, and cultural values. Tackling these incursions is hampered by several logistical challenges, with three primary obstacles being: limited resources for monitoring and management, difficulty in early detection and rapid response, and the complexity of data gaps and invasion pathways and vectors.

Emerging technologies offer promising solutions to these challenges. Notably, advancements in big data, machine learning, and artificial intelligence present strong opportunities for enhancing marine biosecurity efforts. While these technologies have been previously recognised, recent improvements renew their potential to significantly aid in managing NIMS.

Although artificial intelligence, in particular, has shown transformative capabilities in marine environmental management and terrestrial biosecurity, its application in marine biosecurity remains underdeveloped. Our latest research explores the utilisation of artificial intelligence, big data, and machine learning across pre-border, border, and post-border management areas. We aim to identify applicable tools for pathway and vector analyses to enhance policy and decision-making processes, thereby advancing marine biosecurity practices.

GuardIAS: emerging technologies and citizen science against aquatic invasive species in Europe

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GuardIAS is an international Horizon Europe project that leverages cutting-edge technologies and interdisciplinary expertise to tackle the growing threat of aquatic invasive alien species (IAS) within European waters. The project brings together 19 partners, including universities, research institutes, SMEs, NGOs, and the European Commission Joint Research Centre, in a three-year initiative targeting all phases of the invasion process: pre-border, border, and post-border. GuardIAS integrates artificial intelligence (AI), robotics, eDNA-based detection techniques, satellite imagery, and citizen science to enhance monitoring and inform management of IAS in marine and freshwater systems. AI-driven workflows improve species identification, risk profiling, and data harmonization, enriching platforms such as EASIN. Innovative tools include autonomous vehicles, camera traps, nanotechnology-based antifouling coatings, and sound-based species detection. Public engagement is promoted through citizen science (e.g. iNaturalist, BioArtBlitz events, Zooniverse), participatory marina events, and applied games. The project advances systematic conservation planning and prioritizes actions for Red List species and critical habitats, while assessing invasion risks under current and future scenarios. Notably, GuardIAS pioneers collaborative IAS eradication efforts with environmental managers and industry stakeholders. By combining ecological, technological, and socio-political innovation, GuardIAS delivers

scalable, policy-relevant solutions to strengthen the European capacity to prevent, control, and mitigate aquatic biological invasions.

Harnessing AI for development of novel approaches to control the spread of invasive species by marine vessels

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Bioinvasions pose a global threat to biodiversity and ecosystems. Marine bioinvasions are accelerated by maritime traffic via hull fouling and ballast water discharge. Despite extensive research, a knowledge gap remains in identifying parameters dictating which shipping routes present higher invasion risks. Factors like salinity, temperature, vessel type, duration, and port turnover likely influence the survival of transported fouling organisms. Using machine-learning classification algorithms, we investigated the parameters influencing the survival of invasive species during voyages. We conducted ~150 controlled voyage experiments using the invasive ascidian *Styela plicata*, exposing individuals to changing environments mimicking real-time voyages. Data from each route, represented as a feature vector and binary outcome, were analyzed using a Random Forest classifier to predict survival and classify shipping routes by invasion risk. Our findings reveal significant seasonal differences (winter/summer) in survival patterns, with salinity emerging as the most critical factor. Low salinity may act as a natural abiotic barrier, limiting invasive species spread without human intervention. This research provides insights into the combined effects of key environmental factors on survival and offers innovative AI-driven tools for predicting and managing marine invasions. The development of similar AI-based tools for biosecurity has the potential to inform evidence-based policy recommendations for decision-makers.

CANCELLED - Validation of an underwater laser scanner to quantify biofouling

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Biofouling burdens ships by increasing frictional drag and fuel costs, but also poses a risk of introducing invasive species to new environments when transported on ships' wetted surfaces. Hull fouling and cleaning are considered types of incidental discharges, and current guidance for vessel inspections is based on visual estimates of surface percentage covered, with no requirements for quantifiable measurements. To address this limitation, an in-situ 3D underwater laser scanner (ULS) was compared to a high-resolution, ex-situ 3D white-light scanning system, examining clusters of barnacle shells within natural seawater in Key West, FL. Replicate panels were scanned, and the biovolume (cm3) and surface profile (maximum height in mm) were calculated. The percentage difference between the two systems was assessed. Differences between the in-situ 3D ULS and ex situ 3D white light scanner were minimal: ~3% or ~5% differences in biovolume and maximum height, respectively. The high fidelity between in-and out-of-water measurements is encouraging, for research, and, potentially assessing ship conditions and submerged surfaces in a non-destructive manner. For example, the ULS system is currently used to track fouling overtime on submerged panels of test coatings. Different fouling types (coral) and other, irregular substrates (wheels, ropes) have successfully been evaluated as well.

Standardizing knowledge on the environmental impacts of marine invasive alien species – a ShinyApp database

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Managing and mitigating the impacts of biological invasions poses several challenges. To support decision making, it is fundamental to provide clear, objective, and incisive reports on the risks and impacts of invasive alien species (IAS), which is often difficult due to the lack of strong empirical evidence. The assessment of the risk posed by IAS is frequently based on expert judgement, which can be biased and misleading. This means that researchers should work towards tools and methods that express uncertainty in transparent ways, which implies designing valid, reproductible protocols to quantify the risk levels. This has long been a concern around methods to quantify the magnitude of impacts caused by IAS, with greater attention being devoted to the need for standardizing impact assessments. Impact scoring systems are an important tool in the operationalization of such assessments, and several have been developed by the scientific community. We have gathered information on the negative environmental impacts of marine invasive alien species, in Europe and beyond, and analyzed how the growing body of scientific knowledge can support stronger assessments. We present a new database, supported by a ShinyApp, that summarizes levels of impacts by taxa and by habitat, discussing impact variability and strength of evidence across habitats and geographies.

Using otolith chemistry to track a real-time marine fish invasion through the Panama Canal

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The expansion of the Panama Canal in 2016 was designed to increase canal capacity for larger ships, however, it has also led to an increase in marine fish. Currently, little is known about Panama Canal use dynamics of marine fishes, specifically whether their movements are limited to short term incursions or if some species exhibit the capacity for long-term residency. Therefore, an assessment of community wide residency dynamics is fundamental to determine species-specific residency behavior, a development expected to greatly increase interoceanic invasion likelihood. To better understand current movement dynamics in the Panama Canal, lifetime chemical exposure was analyzed for a suite of marine species via laser ablation transects along the otolith growth axis. Chemical exposure histories demonstrate break-point shifts in Sr:Ca ratios during transits through the canal locks, and indicate distinct residency patterns among taxa. Chemical histories confirm long-term residencies for Atlantic tarpon (*Megalops atlanticus*) and common snook (*Centropomus undecimalis*, while some groups, such as Carangids (jacks) and Sciaenids (drums) appear to be more limited to short-term transient movements. While populations in the Panama Canal are increasing for many species that exhibit high invasion-risk characteristics, assessments of residency dynamics indicate which species are more likely to become interoceanic invaders.

Biofouling and bioinvasion: non-native species prevention and monitoring along Brazilian coast.

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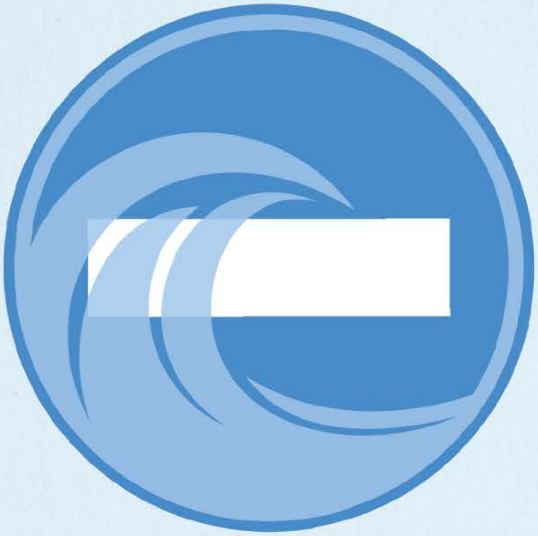
The "Biofouling and Bioinvasion" project aims to implement an innovative approach for the management of biofouling and the introduction of non-native species (NNS) along the Brazilian coast. The goal is to develop tools for the prevention and monitoring fouling NNS in eight (08) port areas along the Brazilian coastline and inland waters. The project includes surveys of fouling communities in and around these areas to establish a fouling NNS baseline. Analyses of eDNA and experimental settlement studies will be conducted using metabarcoding to monitor the NNS presence. Specimens and tissue samples will be preserved in the IEAPM Scientific Collection, and screening studies will be performed to identify natural products with potential bioactive properties. Furthermore, underwater hull inspections and ballast water sampling will be carried out on vessels anchored in port areas to detect the presence of NNS, as well as native and non-native microorganisms. Additionally, an economic impact assessment of biofouling and NNS presence in the maritime sector will be conducted. This project represents a pioneering effort and an important milestone in the management of bioinvasion through biofouling, with significant outcomes for Brazil and other countries facing similar challenges.



Marine protected areas & bioinvasions

Opportunities and challenges

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Rapid assessment of Knysna estuary identifies six species previously unknown from South Africa

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Knysna estuary is the only estuarine bay on the warm temperate south coast of South Africa. It hosts an estimated 42% of all South African estuarine biodiversity, including numerous endangered and endemic species. The estuary was declared a protected area in 1985. Despite its conservation value, no dedicated surveys for marine alien species have been conducted. In response to this need, we performed the first rapid assessment of marine alien species occurrences for Knysna. Timed interval searches for alien species in both natural (sandy shores, rocky shores, seagrass meadows and salt marshes) and artificial habitats (marinas, and bridge infrastructure) resulted in the detection of 34 alien species. Nineteen of these were new records for Knysna. Most notably, six species previously unknown from South Africa were recorded (i.e. the anemones *Diadumene lineata* and *Bunodeopsis strumosa*; the ascidian *Perophera viridis*; the crab *Paraxanthias taylori*; the polychaete *Myrianida pachycera* and the bryozoan *Tricellaria inopinata*). This study highlights the value of targeted rapid assessments in providing insights into the scale of invasions in areas of conservation importance. Additionally, this study provides important baseline data to management authorities, upon which evidence-based decisions can be made to limit spread to surrounding estuaries.

Evidence-based management of the alien bryozoan *Amathia verticillata* in a South African MPA

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Marine protected areas (MPAs) serve to protect biodiversity and the ecosystem services that flow from natural systems. With limited resources to achieve these goals, decision making by conservations agencies must ensure effective and cost-efficient outcomes. In the summer of 2023, the Spaghetti bryozoan *Amathia verticillata* was detected by researchers in Langebaan Lagoon MPA on the South African west coast. This global invader is known to be impactful in other invaded regions. A rapid survey undertaken collaboratively with South African National Parks, divided the estuary into 15 areas, each covering 3km of shoreline. *Amathia verticillata* was found in 53% of areas. In areas with low water movement the bryozoan was very abundant, with large colonies >0.2m^2 found smothering the endangered seagrass *Zostera capensis*. While recognising the threat posed to seagrass meadows, removal was considered unfeasible as *A. verticillata* was already widespread and abundant. Follow-up surveys identified a seasonal decline, with the bryozoan undetectable in winter. Based on this evidence, management actions have been focused on preventing spread to other estuaries, with strategic removal of large mats of *A. verticillata* from seagrass beds during summer to mitigate impacts. This study highlights that collaboration between researchers and conservation authorities can facilitate evidence-based decisions.

Bioinvasions in shallow water reefs of Cyprus: preliminary results from PUREEF-Y project

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The Eastern Mediterranean Sea (EMS) has one of the highest bioinvasion rates worldwide, facilitated by a rapid warming rate and the influx of Indo-Pacific Lessepsian species via the Suez Canal. Previous research has shown dramatic losses of native EMS species, driven by the synergistic effect of warming and bioinvasions, resulting in displacement and local extinctions. Marine Protected Areas (MPAs) can either mitigate bioinvasions by enhancing native biodiversity and resilience or facilitate them by providing refugia due to reduced human disturbances.

Through the PUREEF-Y project we will conduct, for the first time in Cyprus, seasonal sampling over a period of two years at different sites (including MPAs) to assess the biodiversity and the health of the intertidal and shallow subtidal reef ecosystems.

Initial collection of data from the first expeditions shows high percentages of alien fish diversity (up to 41%) and fish biomass (up to 65%) as well as alien invertebrates in the intertidal zone (up to 34%). Moreover, alien fish diversity was found to be higher outside MPAs but alien fish biomass was higher within MPAs.

By the end of the project, we plan to propose a long-term monitoring program and policy recommendations.

Marine protected areas under invasion: the eastern Mediterranean as a laboratory for monitoring and management.

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The Mediterranean Sea faces an unprecedented threat from non-indigenous species (NIS) via the Suez Canal, with most invaders exhibiting an east-to-west expansion gradient. Cyprus, positioned at the forefront, functions as an ideal “sentinel” platform for testing early-response hypotheses and management tools. Drawing on a portfolio of our projects, we (i) document current NIS patterns in Marine Protected Areas (MPAs), (ii) evaluate community-based removal techniques, and (iii) introduce novel gear tailored to MPAs. Surveys in MPAs revealed that densities of NIS are consistently higher inside no-take zones than in adjacent areas, potentially compromising conservation objectives. Community-led removal campaigns that mobilise fishers, recreational divers, and other volunteers have proved effective in reducing local NIS abundance while fostering public stewardship of MPAs. Taken together, these case studies underline the value of coupling citizen science with purpose-built gears and adaptive monitoring. We call for a coordinated eastern-Mediterranean response that shares protocols, data, and resources to maximise ecological gains and socio-economic co-benefits in the face of the region’s advancing bioinvasion front.

Biosecurity across CMAR: strengthening MPAs against marine invasions

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Marine Protected Areas (MPAs) in the Eastern Tropical Pacific, such as the Galapagos, Cocos, Coiba, Gorgona and Malpelo, are biodiversity strongholds increasingly threatened by marine bioinvasions. Through a regional analysis of case studies, existing biosecurity protocols, and structured knowledge exchange, including multi-country workshops, this study identifies patterns of species introductions, key invasion vectors, and management gaps. Findings reveal significant variation in risk and response capacity across MPAs, influenced by factors such as vessel frequency, geographic isolation, and infrastructure. Coiba experiences intense maritime pressure; Malpelo, though remote, has recorded introduced species; and Galapagos, despite strong quarantine systems, continues to face challenges from cargo vessels and international private vessels. This work proposes a coordinated regional framework emphasizing standardized monitoring, early detection and rapid response, and enhanced cross-border cooperation. Anchored within the vision of the Eastern Tropical Pacific Marine Corridor (CMAR) and supported by the Coastal Ocean Marine Biosecurity International Network of the Americas (COMBINA), the approach aims to harmonize strategies among Ecuador, Costa Rica, Panama, and Colombia, strengthening MPA resilience to biological invasions to ensure long-term biodiversity conservation in this highly interconnected and vulnerable marine region.

Biosecurity and conservation in the Ascension Island marine protected area

Tiffany Simpson

Ascension Island Government, Saint-Helena, Ascension and Tristan da Cunha

Ascension Island, located in the South Atlantic Ocean, is a unique and ecologically significant site, with a diverse range of endemic species both on land and in its surrounding marine ecosystems. As part of the British Overseas Territory of Saint Helena, Ascension, and Tristan da Cunha, the island has designated the entire EEZ (445,000 km2) as a Marine Protected Area (MPA) to conserve its rich marine biodiversity. While MPAs are increasingly central to marine conservation, their role in biological invasions is complex—they may serve as both barriers to and refuges for invasive species. While its isolation and protection offer refuge for native biodiversity, the MPA is not immune to bioinvasions, particularly from shipping-related vectors such as hull fouling and ballast water. The introduction and spread of invasive species presents one of the biggest threats and an ongoing challenge to the effectiveness of conservation efforts.

This presentation explores threats the Ascension Island MPA faces from invasive marine species as well as management challenges. We also highlight current and proposed strategies to strengthen MPA resilience, including enhanced biosecurity protocols, early detection systems, stakeholder engagement, and the development of regionally integrated management responses through the support of the UK Blue Belt Programme.

A marked increase in NIS numbers in marinas over eight years, and why that should matter.

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In 2022-24 we surveyed NIS in 51 marinas on the English and Welsh coasts of the UK that had been surveyed with the identical protocol and core staff in 2014-16. These were rapid assessment surveys, timed searches intended here to be reproducible and comparable from place to place and time to time. Over the c. 8-year interval, there was 29% growth in the number of NIS records, reflecting increases across the majority of both sites and species. Only a 6% increase resulted from species new to the surveys in 2022-24, the remaining 23% representing the spread to new sites of NIS already recorded.

Why should we care what's in marinas? One concern is that NIS propagules might 'leak' from marinas, potentially impacting adjacent marine protected areas (MPAs). To assess this possibility, we surveyed 12 marinas on the South Coast in the Solent region, each grouped with a relatively nearby and a relatively distant shore, all shores being in MPAs. There was a clear overall trend for the 'nearby' shore to host more NIS than the 'far' shore in each cluster, suggesting that NIS do 'leak' from marinas, a potential threat to the good environmental status of MPAs.

Emerging anthropogenic pathways

Vessel-mediated invasions

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Biofouling on ship hulls: a hidden risk to Galapagos marine ecosystems

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The Galapagos Islands, a globally significant hotspot for biodiversity, face growing threats from marine bioinvasions. Understanding the drivers of marine non-indigenous species dispersal is crucial for decision-makers to manage this threat. In this study, we evaluate whether ship hulls act as a vector for sessile species dispersal within the Galapagos archipelago and examine the physical characteristics and activities that promote biofouling growth. To explore this, we took photo-quadrats on 22 boats based in Puerto Ayora and performed interviews with boat owners. Results show a mean biofouling coverage of 86.1 ± 26.1%, with significantly higher coverage ($p<0.05$) on boats longer than 10 meters. These findings underscore the need for additional measures to reduce species transfer from ports to natural environments and to enhance detection and response capabilities for new incursions.

Assessing likelihood of non-indigenous species biofouling on commercial vessel arrivals to Alaska

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Biofouling on commercial shipping vessels constitutes a major vector by which marine non-indigenous species (NIS) are transported. Since 2012, commercial vessel arrivals to Alaska ports have increased by 7% annually with nearly 3,000 arrivals in 2022. While these arrivals were largely from heavily invaded ports and place this Arctic state at the leading edge of biological invasions from NIS, there has been no spatial or temporal assessment on biofouling risk from commercial vessels to Alaska. This project quantifies the likelihood of NIS introduction and survival for coastal ports in Alaska between 2012 and 2022 from biofouling on commercial vessels by assessing variability among the following risk factors for six commercial vessel groups (bulk carrier, container, passenger, tanker, roll-on roll-off, and general cargo): total WSA - a vessel's quantifiable submerged fouling habitat, residency time in arrival port, environmental similarity between ports of call, and years since last dry dock. An assessment of these risk factors is combined with a review of best practices for hull maintenance, biofouling regulations, and recommendations to refine regional and local assessments of vessel biofouling and provide critical context for proactive management and regional biosecurity at high latitudes.

Vessel haul-outs as a pathway for introducing non indigenous species at high latitudes

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Organisms may attach to vessel hulls and niche areas, reducing speed and efficiency, and resulting in unintentional transport and introduction of marine invasive species. To remove encrusting biota, commercial or recreational vessels will often be hauled from the water at shipyard facilities to be brushed, scraped, or pressure washed. The washdown pad beneath the vessel haul-out may capture biological material and wash water for disposal or drain into the adjacent intertidal. In Alaska, USA, where commercial fishing and other marine industries are common, a variety of haul-outs are used in coastal communities to facilitate upland vessel maintenance, including hull husbandry. We designed a survey of harbormasters in Alaska to inventory the number, types, usage, and cleaning practices of vessel haul-outs and associated washdown pads. We queried harbormasters on level of awareness and concern about invasive species to marine infrastructure and ecosystems. Thirty-one haul-outs were reported, mostly in larger communities, and used by approximately 2,500 vessels per year. Cleaning, collection, and disposal practices varied by haul-out type and location, with concerning biosecurity implications. Harbormasters tended to have greater awareness and concern in ports with existing invasions and/or with greater usage, and most indicated willingness to post invasive species information at facilities.

The evolution of ballast water tanks

Stephan Gollasch

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It is agreed that shipping is one of the major species introduction vectors with ballast water as key introduction pathway. However, it long remained unclear who invented to use water as ballast in shipping. The use of solid ballast was time consuming and labour-intensive so that the new idea to use water instead was most welcome. The different water ballasting approaches of vessels included water storage in bags, barrels and boxes. A real awakening happened as early as 1827, when the British naval architect Ralph Rewcastle patented the construction of a ballast water tank. This resulted in the phase out of solid ballasting in the 1850/60s. After the wooden sailing vessel times, iron ships were constructed with ballast water tanks. However, only the development of double hulled iron ships enabled to build cellular compartments along the hull as ballast water tanks. The first vessel on which dedicated ballast water tanks were installed was identified as the coal-carrier “Q.E.D.”, launched in 1844. This invention not only resulted in major improvements of naval architecture, but has also prompted species introductions by ballast water.

Evaluating operational sequences of ballast water exchange plus treatment to enhance biosecurity in Canadian freshwaters

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Ballast water is a major pathway for the introduction of aquatic invasive species (AIS) into Canadian ecosystems. Current Canadian regulations require the combined use of ballast water exchange (BWE) and ballast water treatment (BWT) for vessels discharging into freshwater ports to enhance biosecurity. However, practical challenges associated with water quality at ports and ballast water management system (BWMS) operational limitations require a re-evaluation of BWE+BWT strategies. This project examines two main operational combinations: Bypass+BWE+BWT, where BWMS treatment is bypassed at initial uptake, followed by exchange and treatment at sea, and BWT+BWE+BWT, where water is treated at uptake, exchanged at sea, and re-treated. We evaluate the effectiveness, operational feasibility, and ecological benefits of each combination based on existing field data, operational case studies, and environmental risk models. Our findings will inform best practices for ballast water management under challenging conditions and contribute to national and international discussions on future biosecurity measures.

Invertebrates in ballast tanks: morphological and genetic analyses in Brazil

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The International Maritime Organization's Ballast Water Management Convention aims to mitigate biological invasions by regulating ballast water (BW) treatment and discharge. Despite the efforts, invasive species continue to threaten marine environments, highlighting the need for enhanced global cooperation and innovative solutions. This study explores BW discharge in the major port of South America, focusing on invertebrate transfer. Sampling was conducted on fifty bulk-carriers in the port of Santos, opportunistically based on previous ports of call. BW samples were obtained from thirty-nine bulk carriers by pumping at least 700 liters of water at three different depths inside each ballast tank, filtered through a 50 µm mesh. Samples were analyzed for live specimens and preserved in 80% ethanol. Sediment samples were also collected from 16 ships and preserved. Live specimens were found across a range of BW ages, geographic sources and management approaches. Our findings revealed living invertebrate specimens in 49% of ships, with potentially 17,826 live individuals. Sediment subsamples contained 1,611 specimens, predominantly foraminiferans and mollusks. Metabarcoding confirmed eleven invertebrate taxa of concern. Our research demonstrates that many specimens are transported to Brazilian waters still alive, despite stressors. Integrated approaches are essential to effectively mitigate the risks and costs of bioinvasions.

Zooplankton survivors in treated ballast water

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Ballast water management systems (BWMS) are in routine operation on vessels to meet the D-2 Ballast Water Performance Standard of the IMO Ballast Water Management Convention. We summarize zooplankton surviving onboard treatment of 247 BWMS test samples taken from December 2005 to March 2019. Fifteen different surviving taxa were found and these were mainly copepods (including larval stages), polychaetes (including larval stages), mollusks, cirripeds and cladocerans. Approximately half of the 144 samples with surviving organisms were not compliant with the D-2 standard. In two-thirds of these failures the water was treated by BWMS using AS. Successful treatment was documented in 103 samples. We show that, despite best efforts, organisms survive the treatment meaning that biosecurity risks still exist. As BWMS wear and tear occurs, it is recommended that biological performance tests of BWMS be frequently conducted as part of surveys for certification and Port State Control inspections to check for possible performance weaknesses and improvement needs aiming to ensure compliance with ballast water management standards.

Emerging anthropogenic pathways

Debris, infrastructure, and non-traditional pathways

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Aquarium releases as an emerging bioinvasion pathway: examples from O‘ahu, Hawai‘i

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The introduction of aquatic invasive species (AIS) represents a critical threat to Hawaiian coral reefs. Currently, most aquatic introductions in Hawai‘i occur through either marine ballast water discharge or biofouling. However, an additional bioinvasion pathway is emerging, as reports of non-native aquatic species common in the aquarium trade are becoming more frequent. While records of illegal aquarium releases in Hawai‘i date back to the early 1900s, roughly 40% of all known releases have occurred in the last twenty-five years. The State of Hawai‘i Division of Aquatic Resources (DAR) AIS team regularly responds to reports of invasive species around O‘ahu that were likely introduced via illegal aquarium releases. Highlighting the increased resources and attention that must be given to these introductions are three of DAR’s recent field operations: the removal of several species of invasive coral from a reef in Kāne‘ohe Bay, the current efforts to eradicate an outbreak of *Anemonia manjano*, and the attempts at controlling the spread of *Unomia stolonifera* in Pearl Harbor. This presentation will describe the multi-agency efforts to survey, contain, and eradicate these invasive species, as well as DAR’s outreach efforts to inform the public about the dangers of illegal aquarium releases.

Anthropogenic marine debris as a source of new biodiversity records and biogeographic dispersal patterns

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Anthropogenic marine debris (AMD) acts as a species dispersal vector. As a model guild, we examine balanomorph (acorn) barnacles to discern species diversity and biogeography dispersal patterns. In the Ocean Travelers II participative science network, researchers examined AMD fouling quarterly at 112 sites across the Americas and Western Europe for one year, identifying 22 acorn barnacle species. In the northwestern Atlantic Ocean, the non-native *Amphibalanus amphitrite,* and native *Balanus crenatus, Amphibalanus venustus,* and *Amphibalanus improvisus* were dominant, while the non-native *Solidobalanus fallax* prevailed in the northeastern Atlantic. The Iberian Peninsula had the highest diversity, including the non-native species *A. amphitrite*, *Megabalanus tintinnabulum*, and *A. reticulatus*. The Eastern Pacific Ocean showed the lowest diversity, with native *B. crenatus* characterizing AMD in the Northeast Pacific, and native *Balanus laevis* in the Southeast. *A. improvisus*, *A. reticulatus*, *A. venustus*, *M. tintinnabulum* were recorded on AMD in the Iberian Peninsula for the first time. In the northeastern Pacific, the native *Chthamalus dalli*, *C. fissus*, and *Tetraclita rubescens* were found on AMD for the first time. While ballast water and vessel hull fouling have been invoked as the primary vectors to explain barnacle invasions, AMD may be playing an increasing role in the 21st century.

Drift Happens: the origin of marine litter and rafting biota on Madeira beaches

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Buoyant plastic debris is increasingly recognized as a vector for the long-distance dispersal of marine organisms, including non-native and cryptogenic species. In the North Atlantic, such debris facilitates the transport of invertebrates across oceanic currents, raising concerns about species introductions on remote islands.
This study investigated rafting biota on marine debris stranded across seven beaches of Madeira Island (Macaronesia, NE Atlantic). Objectives were to: (1) quantify debris rafts with evidence of oceanic transport based on biofouling and predation marks; (2) determine the geographic origin of items using inscriptions; (3) identify common raft types and their socio-economic sources; and (4) characterize associated communities, focusing on non-native and cryptogenic taxa.
Of 121 items surveyed, 86% showed signs of long-range oceanic transport. At least 40% originated from maritime activities, with boxes, buckets, and jerrycans being most frequent, while 30% were unidentifiable plastic fragments likely degraded during transit. Over 90% of inscribed items traced back to the North Atlantic current system, primarily the USA, Canada, and Brazil. Benthic species were found on 35% of rafts, including non-native taxa such as Isognomon radiata and *I. bicolor*, typical of Western Atlantic fauna. These findings highlight the regular arrival of biologically active debris to Madeira via transatlantic currents.

Taxonomic analysis and comparison of faunal communities associated with floating and landed anthropogenic marine debris on the Madeiran coasts

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Throughout history, natural materials like macroalgae and volcanic pumice have served as temporary rafts for coastal species, enabling short-distance dispersal despite their ephemeral nature. In contrast, today's oceans are saturated with anthropogenic marine debris (AMD). Durable and highly buoyant AMD items, especially plastics, have the potential to significantly enhance long-distance biological invasions, through direct transport between distant coastal ecosystems, and by fostering (semi)permanent "neopelagic" communities of coastal and neustonic species that thrive and reproduce in the high seas.

In this context, our study examines the arrival of floating AMD objects on beaches of Madeira Island in the Northeast Atlantic. We compare the composition of attached biotic communities between stranded and floating debris, to assess and quantify the potential loss of taxonomic and functional groups (especially mobile versus sessile species) during the stranding process. To achieve this, we are conducting species-level morphological analyses of both mobile and sessile fauna associated with these items. This integrated approach not only enhances our understanding of community composition on these novel substrates but also lays the groundwork for future research incorporating genetic tools to refine species identification and improve global monitoring efforts for invasive species.

Assessing the role of seafloor marine litter in the spread of non-native species in the Northeast Atlantic

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The increasing accumulation of marine debris poses a significant environmental threat to marine ecosystems. While the role of floating and beached litter in spreading non-indigenous species (NIS) is increasingly understood, seafloor litter remains understudied. This research examined NIS settlement on seafloor litter in the Northeast Atlantic, using samples from International Benthic Trawl Surveys. Analysis of 514 litter samples from the North Sea, English Channel, and Bay of Biscay, including colonising organisms and plastic type (via FTIR spectroscopy), revealed that 11% were colonised by five NIS: *Austrominius modestus*, *Solidobalanus fallax*, *Monocorophium sextonae*, *Styela clava* and *Crepidula fornicata*. Notably, almost all occurrences were in nearshore areas, suggesting coastal zones as potential sources, or key recipient areas. The high abundance of a few NIS on specific litter items suggests that litter characteristics like surface morphology and polymer type likely influence their settlement and secondary spread. Our findings highlight the urgent need for further research into how seafloor litter facilitates NIS proliferation and to develop effective mitigation strategies.

Exploring the early plastisphere's colonization dynamics to identify seasonal patterns, spatiotemporal drivers and invasiveness potential

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Any object submerged in the marine environment will instantly undergo a series of chemical and biological processes, leading to their subsequent colonization by biofilm forming microorganisms. These include the initial adhesion of a "conditioning film", followed by the recruitment of colonizers, growth and maturation of the biofilm architecture and community. Plastic polymers are no exception. Due to their persistence, buoyancy and dispersal potential, plastic materials can act as vectors for the spread of marine species - including invasive, toxic and antibiotic-resistant organisms. To better understand early colonization dynamics and the role of plastic in microbial dispersal, two polymers (HDPE and PET), their artificially weathered counterparts and glass controls, were submerged at two locations in Trondheim's fjord, Norway. The five substrate types were incubated at depths of 5–8 meters, during five consecutive four-week periods across seasons, from winter 2024 to winter 2025. Sampling was followed by DNA metabarcoding targeting bacteria and eukaryotes, and confocal microscopy analysis of biofilm structures. This experiment provided data on the seasonal effects of early biofilm formation, both in terms of microbial community composition and biofilm architecture. With this experimental design, we aimed to describe plastic biofouling succession dynamics and assess invasiveness of the early plastisphere.

25 years of observations on (non-)indigenous *Caprella* species on navigation buoys show important species turnovers

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All around the world, hard-substrate associated species are profiting from 'ocean sprawl', i.e. the proliferation of artificial hard infrastructure in the ocean, such as offshore energy, artificial islands, and coastal defence structures. Also floating structures, including offshore solar, aquaculture installations and navigation buoys can be added to this list. These floating artificial hard substrates are readily colonised by a fouling community, consisting of native species, introduced non-indigenous species, and range-expanding species due to climate change. Caprellid amphipods are typical representatives of this fouling community, and can reach high densities on these floating structures. We have compiled 25 years of observations on the presence of *Caprella* species on navigation buoys and aquaculture installations in the Belgian part of the North Sea. Our long-term dataset shows the turnover of several of these *Caprella* species, whereby one introduced species became dominant and was then overtaken by another range-expanding species, while at the moment other emerging species are knocking on the door. This unique dataset of long-term observations provides insights into introductions, competition and species turnovers, and might provide important insights on past and future species interactions in an warmer, busier and more cosmopolitan ocean.

Larval dispersal of invasive *Tubastraea* spp. mediated by submesoscale dynamics and wind-driven circulation off Rio de Janeiro

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This study investigates the dispersion of *Tubastraea spp.* (sun coral) larvae along the southeastern coast of Brazil, focusing on how submesoscale ocean features influence their transport and connectivity. Using a high-resolution nested ROMS model and Lagrangian particle tracking, the authors simulate larval dispersal under two wind-driven circulation scenarios: prevailing northeasterly winds and cold front-associated southwesterly winds. Submesoscale filaments narrow, intense currents play a key role in transporting larvae from coastal sites to offshore oil platforms, particularly under northeast wind conditions. Conversely, cold front winds tend to trap larvae near the coast, though intermittent changes in wind direction allow limited offshore export. The study identifies strong larval connectivity between sites like Ilha Grande Bay, Cagarras Islands, Arraial do Cabo, and offshore oil fields. Results highlight the dual influence of physical processes and anthropogenic activities (e.g., oil and gas infrastructure and vessel movement) in facilitating the spread of this invasive coral. The findings underscore the importance of incorporating submesoscale dynamics into marine spatial planning and bioinvasion control strategies. This work provides crucial insight into passive larval transport mechanisms and raises awareness about the role of offshore structures in the biogeographical expansion of invasive marine species.

Unravelling the impact of artificial structures on marine invasions with network theory

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In a changing climate and human-modified environment, understanding the spread and persistence of invasive marine species is crucial. The rapid offshore expansion of renewable energy, alongside the decommissioning of Oil & Gas platforms and first-generation wind farms, will significantly alter marine ecosystems over the next 30–40 years. These man-made structures (MMS) can act as stepping-stones, facilitating the spread of invasive species by enhancing ecological connectivity and gene flow. While MMS can serve as artificial reefs, supporting biodiversity and fisheries, their occurrence may also serve to accelerate biological invasions by providing shelter and substrate, threatening native ecosystems. Network analyses can identify biodiversity hotspots, stepping-stones, and critical structures that either aid or hinder the spread of invasive species. This study will reveal ecological implications of offshore MMS on connectivity and metapopulation dynamics of invasive species in the North Sea by assessing 1) possible sources of risk 2) how artificial platforms and maritime traffic contribute to the stepping stone effect and connectivity and 3) how decommissioning or building of new structures will facilitate or reduce the spread. This knowledge will help inform management decisions, balancing the benefits of artificial reef habitats with the risks of facilitating invasions, ultimately supporting biodiversity conservation in a rapidly changing seascape.

Fishes associated with oil platforms in the Western South Atlantic: are there any non-indigenous species?

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One of the suggested pathways for the recent expansion of the geographic distribution of some species of marine fish is the transport and commissioning of oil platforms and other artificial maritime structures that act as fish aggregating devices.
Among non-indigenous fish species recorded in the Western South Atlantic Ocean, there are at least five cases that were putatively linked with the oil-platform pathway: *Cephalopholis taeniops*, *Chromis limbata*, *Omobranchus punctatus*, *Pomacanthus maculosus* and *Hypsoblennius invemar*.
A review of the literature on the fish species living in some degree of association with oil platforms and other maritime structures in the WSA resulted in a list of about 130 species, among which is *H. invemar.* This small blenniid was originally described from individuals collected in the Western North Atlantic in the late 1970s. The species is commonly found in association with barnacle exoskeletons and its first records in WSA natural reefs date back to the second half of the 1990s.
Further research on WSA oil-platform ichthyofauna is currently in course aiming a better understanding of the possible role of these structures as a pathway for the expansion in the geographic distribution of fish species.

Expanding the horizons of DeNIS: a comprehensive global database on marine debris and non-indigenous species

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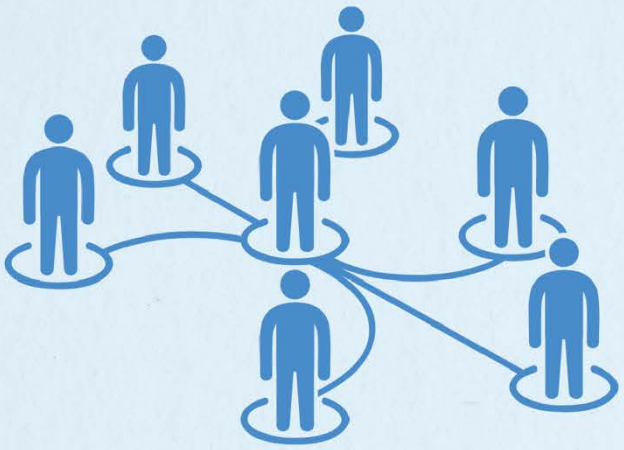
The persistent accumulation of anthropogenic marine debris (AMD) continues to pose a significant threat to global marine biodiversity. Beyond direct impacts, AMD serves as a critical vector for the long-distance dispersal of non-indigenous species (NIS), whose introduction can lead to alterations in native populations and their habitats. To comprehensively address these challenges, the Global Database for Non-Indigenous Species on Marine Debris ("DeNIS") was developed in 2024 (https://www.denis-db.com/). As of May 2025, DeNIS has 46 active users and has collected 782 reports. These reports detail 462 debris items and have catalogued 2263 species records. To date, the database includes contributions from 19 countries across all continents, from opportunistic and systematic sampling efforts.

This presentation covers the latest advances in DeNIS, featuring its newly incorporated capabilities, including new visualizations and refined data analyses. We will highlight the significant contribution of AMD to NIS proliferation and ecological invasions that continue unabated . These new features are designed to enhance global capabilities to assess the extent and impacts of AMD on marine environments, contributing to improved management and mitigation strategies. Ultimately, DeNIS aims to enable the development of more effective conservation strategies and provide insights for evidence-based policy development.



Policy & collaboration

Predictive modeling and risk assessment for policy

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Non-Indigenous marine species in Cabo Verde archipelago: dispersal mechanisms, ecological risks, and management strategies in the coastal ecosystems

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Biofouling is the process of adhesion, colonization, and growth of living organisms on hard substrates, typically artificial, such as ship hulls, piers, buoys or floating structures common on marinas and harbours. Knowledge of the biological and ecological processes occurring in the fouling community is of utmost relevance to reduce the effects associated with colonisers. In this context, the Cabo Verde archipelago plays a key role in the springboard of non-indigenous species from the north and south of the Atlantic. This study presents a comprehensive and multidimensional analysis of the introduction of non-native marine species into the coastal ecosystems of Cabo Verde, examining the primary dispersal mechanisms and the potential ecological impacts on local biodiversity. Same examples of NIS species are provided, accompanied by both quantitative and qualitative assessments of the risk levels and associated hazards of each species. Furthermore, the study discusses mitigation strategies and measures grounded in environmental management and conservation practices, aiming both to restore already degraded areas and to prevent future biological invasions, with the objective of preserving the integrity and balance of the regional marine ecosystems.

From a single invasion to multiple gateways: dispersal patterns of marine non-indigenous species in space and time.

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Understanding how marine non-indigenous species (NIS) spread after their initial introduction is crucial for effective monitoring and management. This study focuses on identifying spatial and temporal dispersal patterns of NIS along the Spanish coast to determine whether the spread of each species originates from a single invasion point or from multiple independent introductions.

Additionally, the study considers several variables that may influence dispersal patterns, such as the most probable introduction pathways and taxonomic or functional clustering. This includes examining whether certain biological traits or group classifications are associated with different expansion dynamics.

To this end, we selected NIS from our database with sufficient spatial and temporal distribution data in Spain and a minimum certainty level regarding their primary introduction pathway.

Using compiled occurrence records, we conducted chronological and spatial analyses to detect trends in the direction and pace of spread. The approach aims to shed light on the complexity of secondary dispersal and the potential influence of species traits on these dynamics.

These findings are expected to support early detection strategies and contribute to the development of more targeted risk assessments, particularly in regions subject to increasing introduction pressures.

Understanding invasion hotspots: a regional analysis of non-indigenous species in Portugal

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Increasing global trade, coupled with the absence of effective fouling monitoring and management methods, will lead to a larger impact of Non-Indigenous Species (NIS) on the ecosystems where they are introduced. To develop more targeted management measures, it is crucial to understand which factors are most relevant for NIS establishment and distribution. This study examines the distribution and drivers of NIS along the Portuguese mainland coast, focusing on marine and estuarine invertebrates. A total of 134 NIS were recorded from 1,912 occurrences, with higher richness in the southern region. Natural habitats supported more NIS than artificial ones, and wide estuaries and coastal areas were identified as invasion hotspots. Taxonomic groups such as Arthropoda, Mollusca, Chordata (Tunicata), and Rhodophyta were most common, with southern areas showing greater diversity and broader native origins. Non-metric multidimensional scaling highlighted clear community differences between artificial and natural habitats. A Generalized Linear Model revealed that habitat type, system typology, and number of harbors significantly influenced NIS richness, explaining over 91% of the observed variation. These findings highlight the role of habitat structure and anthropogenic vectors in shaping invasion patterns and provide critical insights to support region-specific NIS monitoring and control efforts along the Portuguese coast.

Developing aquatic invasive species watch lists for Canada: the role of emerging vectors

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Aquatic Invasive Species (AIS) often have significant negative impacts on invaded ecosystems, making it important to be able to restrict their arrival via regulations or policies. Given the vast number of potential species to consider, scientifically defensible prioritization exercises are essential. Here we apply a new screening assessment tool, the Non-Indigenous Species Screening Tool (NISST), to identify higher risk species. This modular tool is based on the invasion process including: 1) Invasion Potential, 2) Ecological Impacts, and 3) Socio-Economic Impacts and incorporates assessor uncertainty and climate change considerations. Although vectors are considered in the Invasion module of the tool to characterize risk, we conducted a secondary assessment to better understand the relative importance of different vectors for both species and areas. Further, we considered the strength of evidence (i.e., AIS confirmed in the vector or inferred) to identify gaps. This presentation will provide an overview of our approach, application of the tool, and identification of known and emerging vectors of concern. Since almost none of these vectors of concern are actively managed, results from our study can be used to improve AIS regulations, policies and management decisions for vectors like debris or trade.

Network analysis of vessel movements facilitates rapid response to marine pest incursion

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The world is becoming increasingly connected as human populations grow and international commerce changes. The movement of marine vessels create a complex global maritime network that is now the most significant pathway for the introduction and spread of marine non-indigenous species (NIS) to coastal ecosystems around the world. Understanding the connectivity patterns associated with these networks is crucial to inform biosecurity management. Focusing on the New Zealand seascape, we used network analysis to quantify the potential risk of NIS introductions and spread through commercial and recreational vessel pathways. Networks were constructed using vessel movements from automated identification systems (AIS), along with recreational boater surveys, and life history characteristics of the currently invading non-indigenous species of green algae *Caulerpa* (*C. brachypus* and *C. parvifolia*). Results identified the potential extent of spread and high-risk sites and were used in real-time by local managers to reprioritise current surveillance strategies and limit further spread. Our approach relies on spatial data sources that are readily available (AIS) or feasible to collect (spatially explicit online surveys) for most global coastal regions. This study serves as a transferable and adaptable model for supporting the design of future urgent, risk-based detection strategies aimed at preventing the spread of marine NIS.

Integrating macroeconomic modelling and vessel network analysis to strengthen marine biosecurity management

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With ongoing growth in global maritime trade, the associated biosecurity risks are projected to escalate. In parallel, increasing connectivity among coastal regions due to intensifying human mobility further amplifies the potential for secondary spread—yet the role of recreational vessel movements remains largely under-recognized, insufficiently quantified, and unregulated.

As part of the newly launched Horizon Europe project GuardIAS, we aim to advance predictive capacity for vessel-mediated IAS introductions and spread across European seas. Our approach integrates a Multi-Region Input-Output (MRIO) model—originally developed for macroeconomic flow analysis—with high-resolution vessel network modelling. This framework enables identification of high-risk IAS source regions and supports scenario-based forecasting of future biosecurity threats under varying socio-economic trajectories. Further, we employ network analysis to characterize the structural role of recreational vessel traffic in facilitating secondary spread. The integration of MRIO-derived exposure estimates with spatially explicit recreational vessel pathways provides a novel basis for prioritizing biosecurity interventions.

This contribution outlines our methodological framework and presents preliminary exposure risk profiles derived from trade connectivity and vessel traffic patterns. The results are designed to support long-term strategy development, informing risk-based surveillance and targeted management actions at multiple spatial and temporal scales.

Linked: network approaches offer powerful avenues for understanding and managing marine biosecurity risk

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Maritime traffic arising from global trade and tourism is the dominant pathway for the transport of marine species across domestic and international waters. Graph theory and network analysis provide powerful tools for modelling complex transport systems and quantifying the subsequent risk of bioinvasions within these systems. Using New Zealand as a case study, we developed an 'epidemiological' decision-support model (marPEST) to simulate marine invasive species spread through these vessel networks under various incursion and management scenarios. This process-based network model estimates relative incursion risks to domestic ports, aquaculture sites, and coastal destinations. We include millions of movements, many vessel types, species-specific growth, in-transit mortality, and recruitment dynamics, while tracking the flow risk through all invasion stages. We used this modelling framework to evaluate several pest control and vessel management strategies over a 10-year management horizon. We assessed (1) how initial incursion location influences spread, (2) where dominant pathways and downstream risks occur, and (3) how management interventions can impact potential detection and containment. Results highlight that vessel type and network position significantly influence translocation spread and intensity of invasions. This framework can be adapted for other regions and supports proactive management of invasive species, preserving ecological, cultural, and economic values.

Novel framework to spatially predict risk of non-native species proliferation from maritime infrastructures to neighboring natural habitats and MPAs

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The rise of non-native species (NNS) in maritime infrastructures such as ports and marinas has drawn significant attention from scientists and conservation bodies. As key entry points for biological invasions, these sites require robust monitoring to enable early detection of new arrivals, while risk assessments help flag potentially invasive taxa. Although numerous monitoring initiatives now focus on non-native presence and spread within these infrastructures, tools to assess or predict their local expansion into adjacent habitats remain limited. Ports and marinas are often the focus due to their role as introduction hotspots, linked to frequent vessel traffic from diverse regions. However, long-term monitoring is resource-intensive, especially beyond these accessible areas, leading to knowledge gaps regarding the likelihood of spread into surrounding environments. In our recent study, we developed spatially explicit risk indices to predict the potential spread of 29 observed NNS from maritime infrastructures into nearby habitats, including marine protected areas (MPAs). Incorporating factors such as distance, vessel traffic and species traits, the index maps exposure risk and categorises MPAs in a 5-level scale of exposure risk (from Very Low to Very High), identifying areas that are most at risk from general or specific NNS present in local ports and marinas.

Using biophysical modelling and marine connectivity to assess the risk of natural dispersal of non-indigenous species to comply with the Ballast Water Management Convention

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The introduction of Marine Non-Indigenous Species (NIS) poses a significant threat to global marine biodiversity and ecosystems. To mitigate this risk, the Ballast Water Management Convention (BWMC) was adopted by the UN International Maritime Organization (IMO), setting strict criteria for discharges of ballast water. However, the BWMC permits exemptions for shipping routes operating within a geographical area, known as a Same-Risk-Area (SRA). An SRA can be established in areas where a risk assessment (RA) can conclude that the spread of NIS via ballast water is low relative to the predicted natural dispersal. Despite the BWMC's requirement for RAs to be based on modelling of the natural dispersal of NIS, no standard procedures have been established. This paper presents a methodology utilizing biophysical modelling and marine connectivity analyses to conduct SRA RA and delineation. Focusing on the Kattegat and Øresund connecting the North Sea and Baltic Sea, we examine two SRA candidates spanning Danish and Swedish waters. We provide an example on how to conduct an RA including an RA summary, and addressing findings, challenges, and prospects. Our study aims to advance the development and adoption of consistent, transparent, and scientifically robust SRA assessments for effective ballast water management.

Tracking trouble: bioinvasion risk from hull cleaning near the Galápagos

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Vessel traffic has long been linked to the risk of biological invasions, yet few studies have incorporated particle tracking models to assess the potential dispersal routes taken by larvae or propagules released from ship hulls. This study focuses on hull cleaning inside and outside the Galápagos Marine Reserve (GMR), with the aim of improving marine bioinvasion management. Under current regulations, vessels that fail the Galápagos Biosecurity Agency's clean-hull assessment must exit the Reserve to clean their hulls before returning for a second inspection. However, the surrounding ocean currents may transport the removed propagules back into the GMR—some of which could pose a biosecurity risk. Using the OceanParcels particle tracking model, we have created a series of temporally varying maps of high-risk cleaning locations. Our results highlight the importance of considering seasonality and ENSO phenomena when determining invasion pathways. These findings will provide scientific support to the Galápagos Biosecurity Agency and Ecuadorian Navy in designating hull-cleaning zones that minimise invasion risk while ensuring crew safety.

Mapping the Cumulative Impacts of Invasive Alien species on Ecosystem Services (CIMPAL-ES)

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Marine invasive alien species (IAS) influence ecosystem structure and functioning, causing ecological changes and impacting socio-economic systems. Each IAS affects ecosystems uniquely, generating positive or negative impacts with varying intensity and distribution, leading to intricate cumulative effects. This research presents a comprehensive framework to systematically assess these impacts, addressing the critical need identified in existing literature for detailed evaluation of IAS impacts on ecosystem services. The developed standardized and quantitative methodology significantly addresses existing methodological gaps, enhancing the management effectiveness for IAS. The approach integrates IAS distribution data, spatially explicit ecosystem service layers, reported impact magnitudes, and evidence strength, creating the composite index CIMPAL-ES (Cumulative Impact Mapping of Alien species on Ecosystem Services). This method was applied in two case studies—the entire Mediterranean Sea (80 IAS, 10 km² resolution) and the Aegean (29 IAS, 1 km² resolution)— covering different taxonomic groups (macroalgae, seagrasses, macroinvertebrates and fish). Results highlighted considerable species variability: IAS exhibited exclusively positive (e.g., *Halophila stipulacea*) or negative impacts (e.g., *Lagocephalus sceleratus*), while others had mixed effects (e.g., *Caulerpa cylindracea*). Food provision emerged as the most affected ecosystem service, with notable positive and negative impacts. CIMPAL-ES effectively identified impact hotspots, supporting targeted IAS management interventions.

Modeling the habitat suitability of *Caulerpa* spp. across the Galápagos Islands

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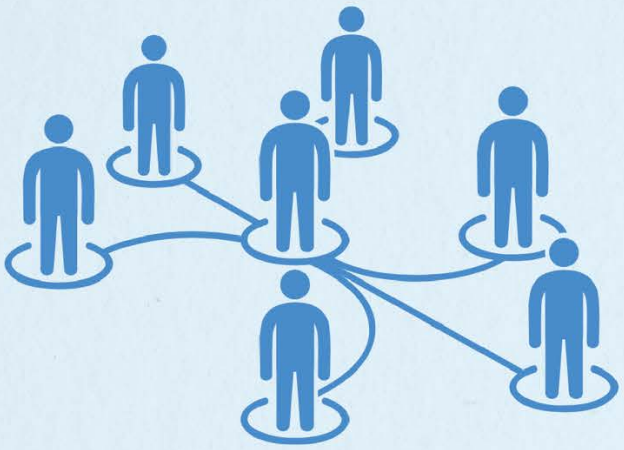
Throughout the Galápagos Islands, two species of the green macroalgal genus *Caulerpa* (*C. chemnitzia* and *C. racemosa*) exhibit competitive tendencies which threaten native biodiversity. Characterized by fast growing species that reproduce asexually via fragmentation, the genus *Caulerpa* is known for successful invasion and establishment of populations outside of their natural range. Using R packages "terra" and "sdm", we utilized geospatial (sea surface temperature, proximity to human population, and chlorophyll concentration) and presence/absence information from dive surveys to model the habitat suitability of these two *Caulerpa* species beyond their currently known ranges within Galápagos. Findings concluded that both species are highly suitable in locations far beyond their currently known ranges, suggesting a likelihood of presence in areas not yet surveyed. Comparisons between species-specific models reveal that variable importance differs between species, while niche similarity tests show high overlap (o = 0.8) and correlation (r = 0.9). We suggest conducting surveys in highly suitable areas without known presence to efficiently detect range expansions. Our study showcases how novel management techniques such as predictive modeling can be used to effectively prioritize field work throughout the Galápagos Islands.



Policy & collaboration

Cooperation, policy & management strategies

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A science-policy interface for non-indigenous species monitoring and management

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The rapid accumulation of alien species in marine ecosystems demands urgent, coordinated and cost-effective national management strategies. In Sweden, the Swedish Agency for Marine and Water Management (SwAM) with support from the Swedish Transport Agency (STA) and the local county administrative boards (LST) has established a national monitoring program for marine non-indigenous species (NIS). The aim of the program is to develop a toolbox with effective and scalable methods for early warning for NIS, understanding range shifts, predicting near-future distributions of NIS, and identifying origins and vectors of NIS. Methods currently implemented in the program include DNA-based tools (metabarcoding, quantitative PCR), citizen science campaigns, as well as species distribution modelling approaches (SDM). Here we present the results from the first two years of the national monitoring program as well as the associated development of the analytical tools for NIS management. Examples of decision support tools include early warning capabilities, range shift detectors, distribution forecasts, and connectivity maps. We explain further how these tools are used in eradication efforts, prioritization of species or habitats, as well as exemptions from ballast water treatment.

Enhancing marine biosecurity in understudied regions: the study case of Saudi Arabia

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Marine ecosystems are increasingly vulnerable to non-indigenous species (NIS), leading to significant ecological and economic impacts. To address these challenges in Saudi Arabian waters, we developed a strategic plan in collaboration with the Saudi government, focusing on three key areas: (i) knowledge acquisition through literature review and field surveys; (ii) predictive modeling of high-risk areas; and (iii) the development of a road map for a biosecurity management framework. A year-long monitoring program was launched in November 2023, covering 33 sites in the Red Sea (21) and Arabian Gulf (12). Through a multidisciplinary approach, we combined morphological and molecular tools, including PVC panel deployment, artificial surface scraping, and water environmental DNA, along with shipping traffic modelling to identify high-risk NIS introduction pathways. Preliminary findings revealed 206 potential NIS, currently under assessment. Based on these results and international best practices, we developed a biosecurity road map centered on six pillars: (i) Knowledge Consolidation, (ii) Prevention and preparedness, (iii) Capacity Building, (iv) Early Detection and Rapid response, (v) Public Awareness, and (vi) Innovation. This initiative highlights the critical role of comprehensive NIS monitoring in marine conservation, setting a benchmark for future biosecurity policies and fostering collaboration between scientific and governmental stakeholders.

Integrative monitoring of NIS in commercial ports: a case study under the MSFD in Spain

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As shipping is the prevalent vector for the introduction and spread of NIS, its control is essential for the management of biodiversity conservation and ecosystem functions. The Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC), has established the development of NIS monitoring programmes at hot-spots, such as commercial ports, recreational marinas and aquaculture facilities. The present study evaluates such monitoring programmes by sampling two ports of the Spanish Western Mediterranean subregion and two ports in the Bay of Biscay and Iberian Coast subregion, in a multifaceted approach. Planktonic, sessile macrozoobenthonic, and mobile communities were sampled throughout MSFD second cycle, with the objective of covering every level in the portuary ecosystem. This pilot study aims to be settled as a ground starting point for the revision of the NIS monitoring programmes, comparing multiple sampling methods in a wide range of spatial differentiation, being one commercial port in every continental Spanish Marine Reporting Units and taking in account physical and chemical variables, this methodology, although under continuous revision, has been proven effective for NIS detection and warning systems establishment. Increasing this knowledge is essential for the management of invasive species and contribute to biodiversity conservation.

Joining forces: advancing an integrative marine non-indigenous species (NIS) inventory through collaboration

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Effectively managing non-indigenous species (NIS) is a complex challenge that transcends boundaries and scientific disciplines. Portugal lacks a standardized inventory of NIS, limiting the ability to track introductions, assess ecological risks, and implement effective management. In this study, we present an updated inventory of

marine NIS across Portuguese waters by incorporating key descriptors such as molecular data, introduction pathways, native ranges, and year of first record. A total of 230 NIS was recorded across the three Portuguese subregions (Azores, Madeira, and mainland). NIS in mainland Portugal were mainly native to the temperate Northern Pacific, while those in the archipelagos were to the temperate Northern Atlantic. A molecular gap analysis revealed inconsistencies and uneven data coverage across regions and taxa, compromising effective management and policy response if DNA-based tools are implemented for NIS monitoring and early detection. Bridging data gaps and enhancing response capacity requires collaboration across institutions, regions, and disciplines. This work brought together taxonomists, ecologists, and geneticists in a coordinated effort to develop a harmonized inventory, providing a foundation for informed decision-making. This collaboration aligns with broader EU frameworks strengthening Portugal's capacity to anticipate ecological shifts and contribute to protect marine ecosystems from the accelerating threat of biological invasions.

Assessing introduced species for Spanish marine waters under the MSFD-D2

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The introduction of non-indigenous species (NIS) by human activities is addressed under the Descriptor 2 of the Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC). In order to achieve the good environmental status of Spanish marine waters, the primary criterion (D2C1, Commission Decision (EU) 2017/848) evaluates the number of NIS newly introduced via human activity, per assessment period for each area. Additionally, secondary criteria refer to the abundance and spatial distribution of established NIS, particularly of invasive species, contributing significantly to adverse effects on particular species groups or broad habitat types (D2C2) and their impact (D2C3), and contributing also to the assessment of the Descriptor 1 and 6.
As national coordinator of the D2, NIS records are compiled in a database fed with scientific publications, monitoring programs, data flows from regional managers, citizen science, and grey literature. Besides, the development of monitoring programs is essential to update the knowledge of state of the marine environment across the five marine reporting units of Spain in order to execute effective programs of measures in policymaking. Detection of primary introductions of NIS in hot-spot areas (e.g., ports), as well as their transfer to neighboring natural habitats are included as monitoring surveys to study invasiveness patterns and the establishment success of newly-introduced species.

COMBINA: A cross-border solution to marine invasive species

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Marine biological invasions are an escalating threat to biodiversity, fisheries, and human well-being worldwide. While terrestrial invasions have received more global attention, marine invasive species—introduced through ballast water, hull fouling, aquaculture, and floating plastic—are increasingly affecting even the most remote and protected ocean regions. Biodiversity hotspots such as the Galápagos Islands and other Marine Protected Areas are especially vulnerable, as invasive species disrupt food webs, degrade coral reef resilience, and threaten local economies. In response to this growing crisis, scientists from multiple countries and institutions have formed the Coastal Ocean Marine Biosecurity International Network of the Americas (COMBINA). COMBINA will create a collaborative, international framework for early detection, standardized monitoring, information sharing, and coordinated response to marine invasions. By building on existing biosecurity efforts and partnerships, the network will scale successful local strategies regionally through shared protocols, training programs, and citizen science initiatives. Using the Galápagos as a model of effective biosecurity governance, COMBINA aims to integrate science, policy, and public engagement to prevent the spread and reduce the impacts of invasive species. This initiative directly responds to international calls for marine biosecurity and represents a critical step toward safeguarding coastal ecosystems and sustainable livelihoods throughout the Americas.

Building a collaborative network to develop large-scale bioinvasion studies on biofouling communities

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In 2024, a marine bioinvasion research network was established within an Intensive School for Advanced Graduate Studies (ISAGS) co-organized by the University of Pavia (Italy) and the Smithsonian Environmental Research Center - SERC (USA). This initiative aimed at recruiting scientists working on marine bioinvasions in different countries, applying a standardized approach to sample biofouling communities (i.e. SERC protocol) and fostering discussions around common research goals. During the one-week intensive school held in Pavia in January 2024, training sessions and interactive discussions led to the design of an initial experiment to evaluate (i) large-scale spatial and temporal patterns of port biofouling communities and (ii) effects of simple biofouling management measures. Fieldwork was then simultaneously performed by all participants from April to October 2024 (northern hemisphere summer) in 23 European and North-African sites (spanning 13 countries) and three US sites (one on each Atlantic, Pacific and Gulf coasts).

Preliminary results illustrate strong spatial differences in both the structure of fouling communities and experimental effects of biofouling management.

We aim to expand upon this network approach, implementing further measures in collaboration with ISAGS and partners.

Knowledge dialogue for preventive management of invasive species: a community approach in Venezuela

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Prevention is a fundamental pillar in the effective management of invasive alien species (IAS), while strategic communication and promoting active participation of local communities are key to ensuring successful implementation. As part of the project "Strengthening Management to Combat the Threats of Invasive Aquatic Species", funded by the GEF, Venezuela has developed a participatory assessment that prioritizes local knowledge and experience for designing its communication strategy. The methodology is based on ethnological and participatory approaches, highlighting the leading role of local communities as guardians of their territories. The process incorporates intergenerational and gender perspectives, systematically examining information needs, communication opportunities, and existing barriers from the community base. This approach facilitates the collective construction of knowledge, valuing and articulating ancestral and traditional knowledge alongside scientific perspectives to strengthen environmental management policies. The analysis integrates an exhaustive evaluation of communication channels preferred by 18 communities in five (5) Marine and Coastal Protected Areas (MCPAs): Cuare Wildlife Reserve, Morrocoy National Park, San Esteban National Park, Henri Pittier National Park, and Mochima National Park. Results will support the development of inclusive communication policies for IAS prevention and control, empowering communities as agents of change and strengthening their capabilities for early detection and effective response to these biological threats, thus contributing to the collective preservation of national ecosystems.

A CLIMAREST Offspring: Atlantic perceptions of marine invasive species

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Increasing public knowledge and assessing stakeholder perceptions of marine invasive species (IS) are essential first steps toward developing effective and widely supported management plans. Traditionally, research in this area has focused primarily on marine stakeholders, with limited attention given to the general public.
As part of the CLIMAREST project, we conducted a quantitative survey targeting the local populations of six demonstration areas: Svalbard (Norway), Brittany (France), Ireland, Vigo, Málaga (Spain), and Madeira (Portugal). The main objective was to assess public perceptions of marine habitats and their threats, including the presence of invasive species.
Participants were asked to evaluate the extent to which they perceive IS as a threat to their local marine environment. A total of 1045 valid responses were collected. Overall, 61.91% of respondents considered IS to be a significant pressure on the marine environment (34.64% “somewhat threatening” and 27.27% “very threatening”).
Significant differences in perception were observed across age groups, gender, and locations. Respondents aged 65–75 and women perceived IS as the most threatening or as a serious threat, respectively. Among the six regions, Madeira residents reported the highest perceived threat from invasive species, followed by Svalbard, Vigo, Málaga, Ireland, and Brittany.
Understanding how different demographic groups perceive marine invasive species is essential for developing targeted social campaigns. Such campaigns are crucial for raising awareness, encouraging behavioural change, and securing long-term public support for effective management actions.

Ocean literacy in Chilean schoolchildren - learning about biodiversity and non-indigenous species

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Ocean literacy (OL) is vital for developing sustainable interactions between society and marine environments. OL also includes knowledge about organisms and biodiversity, including basic information about native species and the arrival and colonization of non-indigenous species (NIS). Chile is an oceanic country with more than 5000 km of coastline, suggesting high OL in the population. Herein we examined OL (and knowledge about marine native species and NIS) among 527 Chilean schoolchildren (ages 9–18) from 20 coastal schools, and the learning effects of a brief in-person lecture. Utilizing a pre- and post-test design, students responded to questions about marine biodiversity, oceanographic processes, and biological invasions. After the lecture, students better understood the difference between native species and NIS, and they also improved their recognition of both native species (Chilean abalone *Concholepas concholepas,* kelp *Lessonia spp.,* red sea urchins *Loxechinus albus*, and Chilean mussels *Mytilus chilensis*) and NIS (green sea fingers *Codium fragile*). They identified cargo vessels and aquaculture as the primary dispersal of invasive species. General OL was positively correlated with students' personal experiences and motivation levels. These findings underscore the potential of brief but focused educational efforts to strengthen OL and awareness about marine bioinvasions.

Challenges in the implementation of evidence-based policy for biosecurity

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Biosecurity is lauded as being evidence-based, yet the complexities of translating and utilising evidence in policy-making persist. We examined the literature (1990-2022) to develop a systematic map of evidence presented to inform biosecurity policies across all ecosystems and identify residual gaps. Eighty-nine articles were identified with stated relevance to biosecurity policy, mostly focused on prevention and risk/surveillance. Most articles were focused on terrestrial systems. The most common policy purpose of articles was author Findings considered of relevance (31.8%) followed by work related to a defined Policy Need (30.7%). 83.5% of articles were oriented towards Operational Policies (management strategies, regulations, plans), while six focused on Government-level policies - two supporting Legislation, and six not stated. Half of articles stated Policy success/failure, identifying Poor evidence and Process most frequently. Authors stated >250 'residual' questions categorized as policy (policy-relevant research and policy/management), philosophical and research questions. Most articles had questions bordering interfaces between philosophy-policy while only a few bordering research-policy. Most philosophy questions were values based, followed by science and society considerations. Effective translation of evidence to meet the needs of policy-makers is critical, as is clarity of epistemic responsibilities of policy-makers. It remains apparent that the gap between researchers and policy-makers remains.

50+ years of keeping a finger on the invasion pulse: ICES Working Group on Marine Invasions

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The International Council for the Exploration of the Sea (ICES) is a North Atlantic Ocean intergovernmental marine science organization, meeting societal needs for impartial evidence on the state and sustainable use of our seas and oceans. Established by a Council Resolution in 1969, the Working Group on Introductions and Transfers of Marine Organisms (WGITMO) held its first meeting in 1970 in London. Since then WGITMO has typically rotated annual meetings around Europe and North America. These meetings address multiple fundamental and applied science issues related to bioinvasions and sustainable natural resource use, including early detection of non-indigenous species and alerts to potential spread; population dynamics and distribution; introduction vectors; assessment of ecological impacts; and development of non-native species risk analysis decision-support tools, from risk screening to full risk analysis schemes. The WGITMO also keeps annual records on new species introductions in the ICES area and beyond, and, upon request, provides scientific evidence to underpin management advice. In honor of the WGITMO's 50th Anniversary in 2024, we reflect on the WGITMO's role and its contributions at local, regional and global scales.

Marine non-indigenous species introductions in a rapidly changing Arctic

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Climate warming and human activity, particularly ship traffic has generated growing concern regarding potential for introductions of Non-Indigenous Species (NIS) in Arctic waters and stimulated recent increases in surveys aimed at better understanding baseline native and NIS diversity in high risk locations. Here we present updated findings on NIS in 18 Arctic Large Marine Ecosystems (LMEs) based on a comprehensive review of available information in over 60 databases and 100 primary publications. Patterns in taxonomy, broad ecological groupings and transport vectors were examined at the PanArctic scale, while spatial patterns in NIS were evaluated according to LMEs to facilitate comparisons among regions and relative to general oceanographic features. We found higher overall numbers of NIS than previous studies of Arctic waters, with Northeast Atlantic LMEs having the greatest NIS richness. Arthropods were the most dominant phylum, accounting for a quarter of NIS in the Arctic, followed by chordates and molluscs, the majority of which were zoobenthos. Taxa introduced in Arctic LMEs are primarily associated with ship-related transport vectors, followed by aquaculture and translocation. This international collaborative review is an important first step in implementing actions related to the Arctic Council Arctic Invasive Alien Species Strategy and Action Plan.

A collaborative study to assess performance of ballast water management systems in Canada's Arctic

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Ballast water discharge from ships has been identified as a primary source for aquatic non-native species (ANS) introductions globally. Shipping has increased dramatically in the Canadian Arctic since the mid-2000's with increased industry, tourism and fisheries, with potential impacts to sensitive Arctic marine species and habitats. Since September 8, 2024, international ships must comply with an international convention limiting live organisms in discharged ballast water, typically by installing ballast water management systems (BWMS). This collaborative study examines the performance of BWMS at a major Arctic port (Milne Inlet, Nunavut) and aims to develop local capacity for monitoring of ballast water discharges. Sampling occurred during the 2023 and 2024 shipping seasons (Aug–Oct). At least 1000L were filtered using a sampling device (Satake Ballast Catch) to collect large (≥50 µm) size class organisms, while additional unfiltered (raw) water was collected to enumerate the small (≥10 to <50 µm) size class organisms. Additional samples were collected to assess water quality parameters (salinity, temperature, total residual oxidants) and for later detailed taxonomic identification using microscope and molecular methods. Preliminary results will be shared to help inform discussions on future policy and monitoring efforts to prevent introduction and spread of ANS in Arctic ecosystems.

Marine and estuarine non-indigenous species in northern Central America: facing inventory and management challenges

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Marine and estuarine non-indigenous species (NIS) are a major ecological and economic threat throughout the world, but information about NIS from Central American countries is relatively limited. Here we reviewed primary and gray literature about NIS, management strategies, and the legal framework of four countries (Belize, El Salvador, Guatemala & Honduras) from northern Central America. We aim to provide a synthesis and baseline about the status of NIS in these countries. There are few reports of NIS for these countries, and most focus on lionfish (*Pterois* spp.) in the Mesoamerican Reef System of Guatemala, Belize and Honduras. Although all four countries have signed international agreements and established national strategies related to NIS (again mostly focused on lionfish), there are no systematic efforts to survey marine activities (e.g. shipping, aquaculture) in order to detect, monitor and manage NIS. This appears to be due to limited financial resources, institutional infrastructure, trained experts, and awareness about NIS. The four countries are interconnected regionally and are recognized globally for their high biodiversity, which highlights the importance to build and strengthen regional capacities and facilitate collaborative NIS monitoring and prevention to protect marine ecosystems, biodiversity and economy.

Rethinking bioinvasion pathways: vessel biofouling in policy and practice

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Global maritime traffic is one of the major drivers of marine invasive species introductions, with ballast water long recognized as the primary pathway. Hull biofouling, however, has so far, received significant research and regulatory attention. This study presents a theoretical assessment, commissioned by the Norwegian Ministry of Climate and Environment, aimed at i) identifying the key marine invasive species whose global spread has been documented to occur via fouling of maritime vessels; ii) assessing the impacts related to the spread of the different marine invasive species; iii) evaluating the potential of international policy to mitigate this risk. A total of 82 high-risk invasive species, predominantly from eight marine phyla, were identified as being transported through vessels. The impacts are primarily ecological and economic, though risks to human health may be underrepresented due to limited research on microorganisms. The study highlights the 2023 IMO Resolution MEPC.378(80) and its voluntary biofouling management guidelines as a promising but underutilized tool for global biosecurity. Findings emphasize the need for binding international measures to enhance implementation, reduce biosecurity risks, and promote cross-border policy coherence. Strengthening collaboration between science and policy is essential to address knowledge gaps, ensure adaptive management, and support global coordination.

Restoration & remediation

of invasion-impacted ecosystems

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Integrated eradication and coral restoration following *Anemonia manjano* invasion in Kāneʻohe Bay, Hawaiʻi

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Hawaii Division of Aquatic Resources, USA

The majano anemone (*Anemonia manjano*), an aggressive aquarium invader, has colonized a patch reef in Kāneʻohe Bay, Hawaiʻi, threatening coral reef ecosystems through rapid reproduction, fragmentation, and competitive overgrowth of native species. In response, the Hawaiʻi Division of Aquatic Resources (DAR) is implementing a targeted removal strategy using custom-weighted tarps and chlorine-based paste injections—an approach adapted from invasive corallimorpharian control at Palmyra Atoll and supported by laboratory lethality trials.

The infestation spans an 800 m² area adjacent to ecologically and culturally significant zones, including the Heʻeia National Estuarine Research Reserve (NERR). Removal activities will be followed by coral restoration to mitigate the necessary coral loss caused by treatment. Effectiveness will be assessed through structure-from-motion (SfM) photogrammetry and visual surveys, with continued monitoring to detect recolonization.

This response effort integrates removal, restoration, and community involvement. Public signage and training will reduce human-mediated spread and increase early detection capacity. The project demonstrates a scalable model for managing invasive cnidarians in sensitive reef habitats, emphasizing the importance of rapid intervention, interagency collaboration, and ecosystem repair. Lessons learned will inform future responses to marine bioinvasions in tropical coral ecosystems.

Increasing substrate complexity prevents sun coral establishment via diversity enhancement

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Coastal urbanization introduces structures like breakwaters, marinas, and ports into marine habitats, which often lack the complexity of natural environments. These simple surfaces may promote the establishment of invasive species, such as the sun coral (*Tubastraea* spp.), which was introduced to Brazil in the late 1980s. Since then, sun corals have spread to both natural and artificial habitats along the Brazilian coast, including marinas and shipwrecks. One way of turning artificial structures into more ecologically friendly habitats is to increase surface complexity, which potentially reduces bioinvasion risk by enhancing overall biodiversity. To test this, we conducted an experiment in a marina in Ilhabela, São Paulo, Brazil, using bricks with two complexity levels (with and without holes). We measured sun coral settlement after 15 days and morphospecies richness after 90 days. Our results showed that sun coral settlement was 3.6 times higher on more complex bricks. However, no sun coral colonies were observed at the end of the experiment, and complex bricks hosted more morphospecies. This suggests that while increased surface complexity may encourage sun coral settlement early on, which can be an issue in low diversity regions, it could ultimately prevent their establishment by fostering higher biodiversity during community development.

Funding: Fundação de Amparo à Pesquisa do Estado da Bahia - FAPESB - Edital MOVE 2025/2026

Shifting dominance of native and invasive primary producers during eutrophic estuary restoration

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The Indian River Lagoon (IRL, Florida, USA) is a shallow subtropical polluted estuary with decades of eutrophication and a history of biological invasions. Anthropogenic nutrient inputs have fueled harmful algal blooms (HABs) of phytoplankton, including the brown tide *Aureoumbra lagunensis*. HAB shading and other factors have degraded the native populations of seagrasses, including the most abundant species, *Halodule wrightii*. In the wake of numerous restoration and nutrient mitigation efforts, other types of submerged aquatic vegetation (SAV) have increased in abundance to compete with surviving native seagrasses. These include drift algae of mixed type and origin and the benthic attached algae *Caulerpa prolifera*. *C. prolifera* is a global estuarine invader but likely native to the IRL system. However, with the die-off of native seagrass competitors, *C. prolifera* has begun to creep into *H. wrightii*'s ecological niche during certain seasons and under the right conditions. The spread of *C. prolifera* is reminiscent of its success in ecosystems where it is exotic and invasive. It is possible that the ecosystem could approach a new equilibrium where seagrasses are scarce and invasive algae are the new dominant benthic SAV habitat.

Relation of *Caulerpa racemosa* with the sessile diversity and potential use of Sacoglossan molluscs as biocontrol agents in the Galapagos Marine Reserve

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The cryptogenic macroalga *Caulerpa racemosa* poses a potential invasion risk within the Galapagos Marine Reserve (GMR), where its proliferation leads to sediment accumulation, negatively affecting native benthic species by limiting growth and inducing suffocation. This study assessed the impact of *C. racemosa* on sessile community diversity by comparing Shannon-Weiner diversity, Simpson dominance, and Pielou's evenness index across three sites in Santa Cruz island. Results revealed that *C. racemosa* dominated two of the three bays, significantly reducing diversity and evenness in the affected areas. Additionally, to explore potential biocontrol measures we investigated the grazing efficiency of three sacoglossan molluscs, *Berthelinia chloris*, *Lobiger sagamiensis*, and *Oxynoe sp.*, that were collected from Tortuga Bay. Grazing rates were recorded as *B. chloris* = 0.15 $g \cdot d^{-1}$, *L. sagamiensis* = 0.21 $g \cdot d^{-1}$, and *Oxynoe sp* = 0.47 $g \cdot d^{-1}$, with water temperature significantly influencing feeding activity. Among the three species, *O. aliciae* exhibited the highest egg-laying capacity per week, with 54,320 eggs, followed by *L. sagamiensis* with 21,763 eggs, and *B. chloris* with 46,856 eggs. These findings highlight the ecological impact of *C. racemosa* on sessile communities and suggest that sacoglossan molluscs, particularly *Oxynoe sp.*, may serve as effective biological control agents.

Secret Signals: The novel use of pheromones as management for invasive marine species

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Pheromones and signalling compounds have been successfully used for the detection and control of pest species in terrestrial environments for a number of decades. Despite these successes, there are currently no pheromone or signalling compounds that have been developed for marine invasive species to assist with their management and control. The Northern Pacific Seastar (*Asterias amurensis*) is a highly invasive species that has caused significant ecological damage in South-Eastern Australia. Due to its high fecundity and dense populations, management options for control and eradication are limited. As broadcast spawners, *A. amurensis* aggregate for breeding, with pheromones and signalling compounds likely to trigger these aggregations. This talk will cover the identification and characterisation of key signalling compounds from the Northern Pacific Seastar that may be involved in spawning aggregations. Using a combination of chemical separation techniques, and controlled laboratory trials, several candidate compounds were successful tested. Further field based tests were also conducted using these compounds to demonstrate the effectiveness in a real world setting as a potential management tool to prevent *A. amurensis* from establishing in new areas, and allow for control of this highly invasive species in areas where it has currently established.

From science to solution: biology, ecology and technological advances in managing sun coral invasions

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Sun Corals (*Tubastraea* spp) have caused substantial biodiversity and ecosystem service losses along the Brazilian coast over the past two decades. Manual removal has been employed by the government agency in collaboration with NGOs, researchers, and volunteers. However, their effectiveness has been limited, mainly due to the coral's high regenerative capacity, and intrinsic underwater constraints. This study integrated new knowledge of the biology and ecology of Sun Coral (*Tubastraea coccinea)* with the development of innovative technological solutions to improve invasion control in Arvoredo Marine Biological Reserve, a Marine Protected Area (MPA) in Southern Brazil. Observations of growth patterns, and the reproductive cycle of Sun Coral, as well as actual versus predicted distributions, enabled development of new control technologies and recommendations for managers. The development and testing of new underwater tools (impact hammer and a rotating brush) have contributed to scaling up control actions at the MPA. Growth and reproduction research helped to indicate optimal management windows, and monitoring and habitat suitability models allowed a better guidance for control plan strategies at the scale of the MPA. This interdisciplinary approach has helped in optimizing species control and reducing dispersion risks.

Effect of antifouling coatings on non-indigenous species: chemical characterization, toxicity profiling and in-field performance testing

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To minimize the growth of biofouling on artificial hard substrates, antifouling coatings are usually applied. Biocidal coatings (BC) are the most widespread ones; however, there is uncertainty regarding their performance and potential indirect environmental impacts. Thus, novel coatings, such as foul-release coatings (FR), are emerging as alternative choices to BC ones. This study aimed to understand the effects of environmental conditions on the metal leaching from the coatings and to develop a screening procedure to assess their toxicity on selected marine species, known to be widespread cryptogenic or non-indigenous species.

Antifouling lixiviates were prepared from coated PVC plates with a standardized surface, under 6 different controlled incubation scenarios. Metal release was measured in water samples with inductively coupled plasma mass spectrometry (ICP-MS). Critical endpoints were assessed in three marine species: the amphipod *Monocorophium insidiosum* and the mussel *Mytilus galloprovincialis* pediveliger larvae, as biofouling target species, and the copepod *Acartia tonsa* as non-target species. Besides, previous field data was used to back up lab analysis.

Results show diverse metal release across incubation scenarios, different toxicological profiles of the selected test products and tolerance phenomena across species, findings that could have important implications for biofouling management and biosecurity.

The mirage of control through fishing: risks and recommendations for the management of invasive portunid crabs in the Mediterranean

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The growing presence of invasive blue crabs (*Callinectes sapidus* and *Portunus segnis*) in the Mediterranean Sea has prompted the promotion of commercial exploitation as a control strategy, under the premise that "if you can't beat it, eat it." However, evidence from invasion ecology warns that relying on fishing as the main management tool can trigger demographic overcompensation, foster economic incentives for persistence, and create governance traps that undermine effective population reduction. In this Perspective, we critically examine the ecological and socio-political risks of turning invasive crabs into valuable resources. We argue that management decisions must be informed by robust ecological understanding and not by market logic alone. We propose conditions under which fishing may have a role within integrated control plans, while highlighting the need for broader, adaptive, and evidence-based approaches to safeguard Mediterranean biodiversity.

CANCELLED -Engineering control of organic coatings on autonomous navy gliders (Eco-Coating) for the reduction of drag

Vanessa Molina[1,2], Scott Riley[1,2], Mohammad Elsouht[3], Rodrigo Vilumbrales-Garcia[3], Harish Ganesh[3], Diptee Chaulagain[4], Bristi Paul[4], Emma Harrington[4], Malhar Sathe[4], Skylar Leslie[4], Andrew Derasmo[4], Reece Fratus[4], David Karig[4], Matthew First[2], Jason Lee[2]

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Biofouling is well known to impact drag and fuel efficiency. While macrofouling inflicts the greatest hindrance on drag, biofilms are also impactful. This is especially important for Uncrewed, Underwater Vehicles (UUVs), where power budget limits can impede mission and deployment time. As part of the DARPA Arcadia program — aiming to build protective communities for military material using naturally occurring microorganisms on DoD assets — a test platform was developed to measure surface thin-film drag. Biofilms grown and collected from submerged UUV parts were used to construct an engineered bacterial community. The engineered community was validated for stability after temperature and shear disturbance, and the ability to maintain drag at shear rates associated with hydraulically smooth UUVs. The designed platform was used to take drag measurements using recirculating turbulent flow to measure pressure changes, and was able to detect drag penalties as low as 3% at 6 knots. Results showed no substantial drag changes associated with the engineered biofilm, suggesting the necessity for additional community structure testing. Capabilities of the designed platform allow for examining differing communities, bacterial phenotypes, and growth conditions on low-profile bacterial and algal biofilms. Improved biofilm drag detection could lead to lower operating costs and extended material lifetimes.

Restoration potential of canopy-forming *Cystoseira sensu lato* rocky reefs followed by targeted removals of invasive *Diadema setosum*

Angelos Pechlivanis[1], Andreas Akathiotis[1], George Constantinou[1], Sotia Demetriade[1], Christina Diamantopoulou[1], Ana Dinis[2], Christina Kakoulli[1], Periklis Kleitou[1], Melina Marcou[3], Christina Michail[1], João Monteiro[2], Paola Parretti[2], Ikaros Savva[1], Susanne Schäfer[2], Demetris Kletou[1]

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Cyprus has been at the forefront of the Lessepsian migration of non-indigenous species (NIS). The invasive long-spined sea urchin *Diadema setosum* has been spreading rapidly along the coast of the island. It was first sighted in 2016, on the eastern shores, and by 2021 its population had grown exponentially. The long-spined sea urchin has overgrazed *Cystoseira* forests, leaving behind barren reefs. Considering the adoption of the Nature Restoration Law and the increasing pressure of *D. setosum,* an experimental design has been created to investigate the success of *Cystoseira sensu lato* transplantation alongside targeted removals of sea urchins in the Natura-2000 site of Akamas. In June 2025, healthy *Cystoseira* thalli will be transplanted onto four 25 m² barren-reef plots. Two plots will be subjected to monthly targeted urchin removals carried out with local dive centres, while the remaining two will remain undisturbed. Transplant survival, percentage cover and associated macroalgal assemblages will be monitored quarterly for one year. We will present the preliminary findings of our study and highlight both the urgency of managing NIS that threaten future restoration efforts and the potential of citizen-science partnerships to augment conservation capacity in the eastern Mediterranean.

A bioacoustic method for the mitigation of marine bioinvasions

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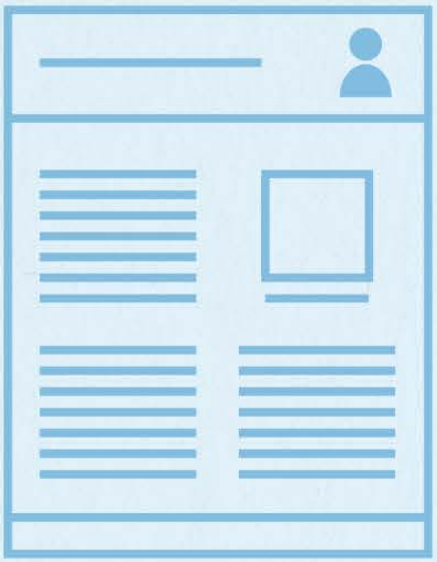
Global change is driving an increase in disturbance events affecting natural ecosystems, with biological invasions constituting a major threat to ecological integrity and function. Invasive species alter food web structures by reducing species richness and may also pose serious health risks, through the introduction of disease and parasite vectors, and economic threats, as in the case of agricultural and aquaculture pests. As observed in other marine invertebrates, sound-induced damage to the statocyst (organ responsible for equilibrium) and antenna sensory epithelia can severely impair essential biological functions, leading to a significant decline in survival capabilities. Building on its expertise in the acoustic impacts on marine invertebrates, the Laboratory of Applied Bioacoustics (LAB) has developed an innovative bioacoustic method to combat the spread of invasive species. This approach involves exposing invasive organisms to specific acoustic cues that induce pathological changes in their statocyst sensory epithelia or antenna setae. This tool has been successfully applied to various invasive marine species: i) The blue crab (Callinectes sapidus), native to the American Atlantic coast, introduced into the Mediterranean Sea during the last century. ii) The salmon louse (Lepeophtheirus salmonis), a major pest in salmon aquaculture that contributes to the decline of wild salmon populations. iii) The apple snail (Pomacea maculata), a South American gastropod, brackish-tolerant freshwater species considered a dangerous invader. It feeds on aquatic plants and serves as a vector for several parasites, including Angiostrongylus cantonensis, the causative agent of human eosinophilic meningitis. In addition, cnidarians, such as jellyfish and sea anemones, are also recognized as invasive species. Previous LAB studies have demonstrated acoustic-induced damage to the sensory epithelia in species like Cotylorhiza tuberculata, Rhizostoma pulmo, and Calliactis parasitica. These findings support the potential of this method as an effective strategy against invasive cnidarians, which prey on native fauna and negatively impact marine industries.



Posters

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Understanding the ecological dynamics and impacts of invasive marine herbivores in coastal ecosystems

Andrea Anton

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Marine invasive herbivores represent an increasing ecological threat, yet our understanding of their ecological dynamics and impacts on recipient communities remains limited. In this presentation, I will share recent findings on the ongoing invasion of the herbivorous crab *Percnon gibbesi* in shallow marine habitats across the Mediterranean basin. I will discuss its geographic spread, the speed and chronology of its expansion, habitat preferences, and its current ecological impacts. This growing body of knowledge is essential for anticipating ecological and socio-economic consequences, as well as for informing the development of proactive and effective management strategies aimed at mitigating the impacts of this and other invasive marine herbivores.

Diet composition and sex ratio of the invasive blue crab *Callinectes sapidus* in Mellah Lagoon, Algeria

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This study examines the dietary composition and sex ratio of the blue crab *Callinectes sapidus* in Mellah Lagoon (area: 865 ha, average depth: 3.5 m, temperature: 10-30.2 °C, salinity: 25-34.8 ‰), located in the far East of Algeria. The analysis was conducted on a sample of 287 individuals out of 935 (carapace length ranging from 63 to 179 mm). The results demonstrated significant seasonal variation in diet. In spring, Arthropods constituted the largest dietary component (%IRI = 43.71%), followed by Mollusks (%IRI = 22.45%). In summer, Arthropods remained dominant (%IRI = 45.14%), with the "unspecified" category comprising 43.31%. A notable shift towards Teleost Fish consumption occurred in autumn, contributing 34.25% to the diet. In winter, the "unspecified" category prevailed at 46.21%, followed by Plantae (%IRI = 20.38%). Full stomachs were more frequent in spring (75%) compared to winter. The seasonal variation in digestive vacuity was most pronounced in summer (Cv = 42.42%) and autumn (Cv = 45.74%). The sex ratio exhibited a female bias throughout the year, with a decrease in the ratio from 0.68 in spring to 0.22 in winter, deviating significantly from expected values in both autumn (χ^2 = 12.30) and winter (χ^2 = 25.81). This study underscores that *C. sapidus* is a generalist and opportunistic feeder, with dietary composition and sex ratios closely linked to prey availability and environmental conditions across different seasons, thereby highlighting the species' ecological impact in Mellah Lagoon

Population status of the invasive blue crab *Callinectes sapidus* around the Neretva River Delta, Adriatic Sea

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Institute of Oceanography and Fisheries, Croatia

The invasive blue crab (*Callinectes sapidus*) has established a significant presence along the eastern Adriatic coast, particularly around the Neretva River delta, Croatia, one of population hotspots. Specimens were collected from commercial fishermen between June 2024 and March 2025, using baited traps across six sampling events. A total of 628 individuals were captured and analyzed. The estimated catch per unit effort (CPUE) was 10.1 ± 4.4 crabs per trap. The overall sex ratio was slightly skewed toward males, comprising 52.04% of the catch, compared to 47.96% females. Average carapace width was significantly greater in females (15.86 ± 1.4 cm) than in males (14.59 ± 1.58 cm; $p < 0.05$). Average carapace length for females was 7.36 ± 0.63 cm and for males 7.28 ± 0.77 cm. In contrast, average body weight was significantly higher in males (237.3 ± 79.4 g) compared to females (197.3 ± 43.4 g; $p < 0.05$). Maturity assessments revealed that 22.3% of the sampled females were in an advanced gonadal development stage, while the majority of males (26.2%) were in the maturing stage. Despite the increasing presence of *C. sapidus*, the species remains underutilized commercially in the region, primarily due to limited market demand and unfamiliarity among local consumers.

Trap survey of blue crab, *Callinectes sapidus* in the South Adriatic Sea (Montenegro coast)

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According to local fishermen, the blue crab (*Callinectes sapidus)* was first observed in Montenegro about 20 years ago, while the first documented record dates to December 2013, when two adult males were caught by gillnet in Boka Kotorska Bay. As part of the GFCM Research Programme on blue crabs, six trap surveys were conducted from February to December 2024 at selected locations: Tivat Salina Lagoon, Boka Kotorska Bay, the open sea, the Bojana River mouth. During the six month sampling period, a total of 188 blue crabs were caught, of which 81 were females and 107 were males. Sex ratio was 1:1.32 in favour of males. Size frequency distribution were calculated per 10 mm size class intervals (CW). The mean carapace width (CW±SD) of males was 122.61±20.83 mm, while the mean size of females was 120.5±20.5 mm. Individulas from size groups from 110 to 120 mm dominating the catch. Among the females, only one was ovigerous with orange eggs, 47 were juvenile with a triangular abdomen, and 33 were adult. Juveniles representing 39.4% of the total number of captured individuals. Sex ratio in juveniles was also in favour of males (F:M=0.6:1). Juvenile females ranged from 64 to 129 mm CW while juvenile males size range extends from 62 to 120 mm CW. The length-weight relationships were studied for the overall sample, female and male. The estimated length-weight relationship for females and males was $W=0.0018CW^{2.25}$ and $W=0.0002CW^{2.75}$, respectively. The b values indicate that individuals of blue crab showed negative allometric growth in both sexes (t-test, $P<0.05$).

Early detection and habitat suitability of the global invader crab *Callinectes sapidus* in Macaronesia

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Invasive marine species prevention relies on early detection, particularly in vulnerable island ecosystems. This study reports the first occurrences of the invasive blue crab (*Callinectes sapidus*) in the Macaronesia Ecoregion, documenting captures from Gran Canaria, Tenerife, La Gomera and Lanzarote (Canary Islands) between November 2022 and April 2025, while simultaneous monitoring efforts detected no presence in Madeira. Captured specimens exhibited diverse developmental stages, suggesting multiple introduction events linked to larval dispersal from established populations along the northwest African coast. Genetic analyses revealed haplotype frequencies similar to Atlantic populations, supporting connectivity hypotheses between African coastal areas and the Canary Islands. Macaronesia hosts suitable habitats—specifically coastal lagoons and brackish-water pools—which facilitate the establishment and potential spread of this species. Considering *C. sapidus*' global invasive status and ecological impacts, our findings underscore the importance of continued surveillance and prompt management interventions. The integration of genetic and ecological approaches provides critical insights into invasion dynamics, aiding targeted "smart prevention" strategies across susceptible insular habitats.

Uncovering the colonization potential of Tanaidacea: a first look into an overlooked group in marine invasion ecology

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Anthropogenic marine environments form a mosaic of habitats where different dispersal and colonization strategies influence species success. This study investigated the colonization potential and spatial patterns of Tanaidacea—marine crustaceans often overlooked in invasion research despite documented introductions via human activity and their capacity to establish in novel habitats.

Fieldwork was conducted in nine marinas within the Strait of Gibraltar, a known hotspot for biological invasions—four in the Gulf of Cádiz (Atlantic) and five in the Alboran Sea (Mediterranean). In summer 2021, five plastic collectors based on three-dimensionally folded PVC meshes were deployed at 1 m depth in each marina for one month. Collected fauna include two tanaidacean species: *Chondrochelia savignyi*, native to the Mediterranean and adjacent Atlantic, and *Zeuxo turkensis*, a neocosmopolitan species of unknown origin. Both species occurred in three of four Atlantic marinas and in all Mediterranean sites. *C. savignyi* was nearly twice as abundant, suggesting stronger short-term colonization abilities. However, literature comparison indicates *Z. turkensis* is dominant in these marinas, highlighting its superior long-term competitive potential and success in population establishment.

These findings contribute to a better understanding of early colonization processes and can support future monitoring and management of non-native invertebrate species in coastal infrastructures.

The mysterious invader *Sinelobus vanhaareni* is successful in the Baltic Sea: Population trends over five years

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Sinelobus vanhaareni is a non-native Tanaidacea species rapidly expanding in European waters but often overlooked in invasion studies. Despite its high abundance in the Baltic Sea fouling communities, its biology and ecological role remain poorly understood. To address this knowledge gap, we examined its population structure and habitat preferences.

Specimens were collected using two PVC settlement plates (15 × 15 cm) deployed at depths of 0.5 and 1.0 m. A total of 72 sets were installed across four Polish marinas with varying salinity over three seasons in 2019. In 2024, the study was repeated in two marinas with the highest previously recorded abundances, using 27 sets.

In 2019, *S. vanhaareni* was found at frequencies of 11–100%, with abundance ranging from 0–22 individuals in salinity <4 PSU to 333–18,600 individuals at 4–7 PSU. No significant differences in abundance were observed between depths. The population was female-dominated, with copulatory females peaking in August and October, indicating reproduction in summer and early autumn. Despite ongoing reproduction, lower October abundance suggest predation pressure. In 2024, abundance ranged from 1,116 to 19,000 individuals. Comparing 2019 and 2024 data suggests a stable population, highlighting the species' successful establishment in the Baltic Sea.

Expansion of the highly invasive corals *Tubastraea* sp. and *Oculina patagonica* in the port of Santa Cruz de Tenerife

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In 2016 the presence of *Tubastraea* sp. and *Oculina patagonica* corals originating from the Indo-Pacific and South America, respectively, was first recorded in the Canary Islands within the main ports of Tenerife and Gran Canaria. Their introduction was linked to oil platforms. This study evaluated the populations changes of both species Santa Cruz de Tenerife port, comparing abundance data from 2017 and 2023 to assess the need for control measures against these highly invasive corals. Concrete blocks from pontoons were selected as sampling units. All five block surfaces were inspected for coral specimens, and block dimensions ranging (0.29 - 0.77 m^2) were recorded. Results showed a general increase in colony number for both species in 2023, suggesting sexual reproduction, particularly in *Tubastraea* sp., given to the notable rise in individual polyps. This increase could hinder manual removal, a control method used successfully in other regions. *O. patagonica* exhibited the highest abundance on shaded surfaces, indicating a preference for low-light habitats. These findings highlight the potential spread of both species and the need to consider targeted control measures to prevent further ecological impacts.

Reproductive cycle of the invasive coral *Tubastraea coccinea* in the Arvoredo Marine Biological Reserve, Brazil

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The invasive Sun-Coral *Tubastraea coccinea* threatens marine biodiversity in Brazil. This study characterizes its reproductive cycle in the Arvoredo Marine Biological Reserve, Santa Catarina, to identify critical periods of propagule development and improve management strategies. From January 2023 to January 2025, three central polyps from 10 colonies were sampled monthly to quantify propagule and polyp size and propagules abundance. The diameter of 10 propagules per polyp was measured, with the smallest and largest recorded as 0,084 mm and 1,9 mm, both in January 2025. Fecundity was analyzed correlating polyps diameter and propagules abundance. Results revealed an annual cycle, with peak propagule development between November and February and larval release intensifying from December to January. Early stages were observed from March to October. Additionally, a higher abundance of propagules was found in polyps that presented a bigger diameter. This suggests that management efforts (e.g., manual removal) should prioritize March to October and polyps with larger diameter to minimize larval release later, enhancing intervention efficacy. By aligning control strategies with reproductive biology at this invaded site, this study provides a framework for mitigating *T. coccinea* spread and safeguarding biodiversity.

Diversity analysis and trophic structure of a recently invaded tropical rocky shore

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When a nonnative species remains in an invaded community for some time, long-term effects on community diversity and ecosystem functioning are expected, as are changes in trophic interactions between species. The blue soft coral *Latissimia ningalooensis*, of Australian origin, was first detected in the wild in the tropical southeast Atlantic in Brazil in 2017. This study provides the first information on the trophic relationship that has developed between *L. ningalooensis* and 29 other benthic marine species in the food web on shallow tropical rocky reefs which have been invaded. The difference in species composition of invaded areas and control areas was also assessed. *L. ningalooensis* showed $\delta^{15}N$ values close to those of macroalgae, suggesting that its symbiosis with zooxanthellae represents an essential source of energy in addition to the suspension feeding. An apparently opportunist-generalist consumer, the crab *Stenorhynchus seticornis* showed isotopic values aligned as a probable consumer of *L. ningalooensis*. The difference in species composition between areas and an increase in the abundance of *L. ningalooensis* in shallow areas suggests that a mechanism exists which will allow its further expansion into more favorable locations, so we encourage management such as periodic monitoring of the invaded area and eradication.

The alien snowflake coral *Carijoa riisei* (Octocorallia: Alcyonacea) - A problematic NIS in marinas from São Vicente (Cabo Verde Islands)

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The snowflake coral Carijoa riisei is a highly invasive and ecologically adaptable octocoral species in coastal marine environments. Characterised by its erect, bushy colonies with flexible, hollow branches up to 30 cm in length, C. riisei forms dense carpets by attaching to hard substrates such as rocks, ship hulls, and artificial structures. Dispersal of C. riisei is primarily facilitated by anthropogenic vectors, notably ballast water discharge and hull fouling on ships, allowing rapid expansion into non-native regions worldwide, particularly around major maritime port. Earlier 2011, C. riisei was detected in Porto Grande Bay, São Vicente Island, Cabo Verde. To investigate the origin of this invasion, mitochondrial and nuclear DNA sequences from local specimens were analysed. The observed lack of genetic variation in both mitochondrial and nuclear markers suggests a recent founder event with a strong bottleneck effect, indicative of a possible introduction source. Given its capacity to alter habitat structure, out compete native species, and rapidly colonise new areas, the introduction of C. riisei in Cabo Verde represents a potential ecological threat requiring urgent monitoring and management. Genetic evidence pointing to a recent introduction event provides a critical opportunity for targeted biosecurity interventions to prevent further spread within the archipelago.

New records *Zoanthus pulchellus* (Cnidaria: Anthozoa) in the southern Madeira shallow subtidal zone

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Estimating the abundance and diversity of species, from sessile macrobenthos to pelagic fish, is crucial to assessing the structure of coastal communities. In 2023, during an underwater visual census survey, the mat-forming zoantharian *Zoanthus pulchellus* was observed for the first time on the southeastern coast of Madeira Island, Portugal. Zoantharians of the genera *Palythoa* and *Zoanthus* can act as dominant species, covering large areas in shallow rocky bottoms and proliferating in various environmental conditions. The northern limit of *Z. Pulchellus* on NE Atlantic was the Canary Islands, where studies showed impacts on native benthic communities and coastal fish populations. During our study, ten scientific dives were performed between May and July 2024 to monitor known colonies (two in Machico and one in Funchal) and look for new ones. A scale was used to measure each colony's maximum length and width. Photoquadrats were taken for area estimation (cm^2) through posterior analysis in ImageJ software. A total of five colonies have been detected on Madeira's south coast: Machico, Poças do Governador, Ponta Gorda, and Praia Formosa. Colony sizes vary between 9817 to 2267 cm^2. Preliminary results show slight differences in Machico and Poças do Governador colonies from 2023 to 2024.

Salinity tolerance assessment of *Phymactis papillosa* (Lesson, 1830), a potentially invasive sea anemone

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Biological invasions typically progress through four key stages: transport, introduction, establishment, and spread (Blackburn et al., 2011). The likelihood of successful introduction depends on the ecological and biological traits of species within specific taxonomic groups. Cnidarians possess several characteristics that make them particularly well-suited for successful invasions.

Once a non-indigenous species (NIS) is identified, the first stage—transport—has already been completed. *Phymactis papillosa* (Lesson, 1830) is a sea anemone species recently recorded on the rocky intertidal coast of Portugal (Pereira et al., 2022). Native to the Pacific coast of South America, it has not been reported outside its original range until now. Its population appears to be increasing in Portugal (Pereira et al., 2022), but information regarding its invasiveness is lacking. Previous studies indicate that this species can tolerate temperatures below 29ºC and salinities ranging from 32 to 38 PSU.

The aim of this study is to evaluate the salinity tolerance of *P. papillosa* through controlled laboratory experiments. A total of approximately 324 individuals were tested in groups of six across ten salinity treatments (38, 35, 32, 29, 26, 23, 20, 17, 14, and 11 PSU), with each condition replicated five times. Mortality was monitored daily over a two-week period.

The results show that salinity significantly affects survival at levels of 14 PSU or lower, with 100% mortality observed between days 6 and 11. These findings suggest that *P. papillosa* may have the potential to colonize estuarine and lagoon environments along the Portuguese coast.

Urea as a key nitrogen source for the invasion of the southern coast of Portugal by the seaweed *Rugulopteryx okamurae*

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The invasive macroalga *Rugulopteryx okamurae*, native to East Asia, is rapidly spreading along the western Mediterranean and southern Portugal, negatively impacting coastal ecosystems and economic sectors such as fisheries and tourism. Understanding its nutrient uptake strategies is crucial for managing its spread. This study investigates the nutrient uptake kinetics of *R. okamurae*, focusing on nitrogen and phosphorus sources. Laboratory experiments with 15N-enriched substrates revealed the highest uptake rate for ammonium (Vmax = 57.95 µmol g−1 DW h−1), followed by urea (7.74 µmol g−1 DW h−1), nitrate (5.37 µmol g−1 DW h−1), and amino acids (3.71 µmol g−1 DW h−1). Urea accounted for 70% of the species' total nitrogen uptake, with a high affinity for this form of organic nitrogen (α = 1.8). Phosphate uptake was minimal, and total nitrogen uptake exceeded the species' growth requirements, indicating its ability to thrive in environments with limited inorganic nitrogen. These findings underscore the significant role of organic nitrogen in supporting the rapid growth of *R. okamurae* and its dominance in nutrient-limited ecosystems. The study provides valuable insights for developing management strategies to control the spread of this invasive species.

Tracking vertical changes in sessile assemblages before and after *Rugulopteryx okamurae* invasion in Ceuta

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The invasion of *Rugulopteryx okamurae* is driving major shifts in marine hard-bottom communities, leading to the decline of native species and a simplification of assemblages. This invader has negatively affected several species of high conservation and commercial value across both sides of the Strait of Gibraltar. This study provides evidence of the species' differential invasive potential in relation to spatial variability, focusing on the coastline of Ceuta. We examined sessile assemblages before and after the invasion across various depths and habitat types, including natural and artificial substrates. Intertidal zones remained largely unaffected, showing temporal stability and no decline in key conservation species such as *Patella ferruginea*, which even showed local increases. In contrast, subtidal communities exhibited significant losses in diversity and species richness, along with the emergence of previously unrecorded opportunistic taxa. Changes in community structure were also most pronounced in subtidal zones, highlighting the role of environmental gradients as habitat-scale filters influencing the ecological success of the invader. Substrate type did not influence invasion dynamics, as similar colonization patterns were observed on both natural and artificial surfaces. These findings underscore the need for targeted conservation of subtidal habitats and unique assemblages to mitigate biodiversity loss in invasible coastal zones.

Expansion of the devil firefish *Pterois miles* along the Croatian Adriatic coast

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This study documents sightings of *Pterois miles* along the Croatian Adriatic in recent period (2024-2025), marking a rapid and extensive invasion four years after its first Adriatic record. Most individuals were observed via recreational diving, predominantly in shallow rocky habitats. The concentration of sightings around outer islands, mainly Vis and Lastovo, suggests larval transport by ocean currents as the primary dispersal mechanism. The dominance of small-sized individuals indicates early colonization stage. These findings highlight a critical phase in *P. miles* establishment in the Adriatic, with implications for native biodiversity and fisheries. Targeted removals, particularly in ecologically sensitive areas, is recommended, alongside raising awareness of this invasive species' ecological and economic risks and promoting its controlled removal and potential commercial exploitation. Further studies and monitoring efforts are essential to track progress of the species expanison in the Adriatic basin.

Reviewing existing knowledge on selected invasive species in the Mediterranean

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In recent decades, the Mediterranean Sea has been subjected to an invasion of alien fish species, especially Lessepsian migrants. Among them, *Pterois miles*, *Fistularia commersonii*, *Lagocephalus sceleratus*, *Siganus luridus*, and *Siganus rivulatus* have emerged as prominent examples due to their invasion rate and harmful ecological impact on native communities. This study is a review of the scientific literature on these species regarding their spatial distribution, biological parameters (length-weight relations, growth, reproduction, diet), and potential commercial uses (e.g. food, pharmaceuticals and medicine, cosmetics, biomonitoring) in the Mediterranean Sea. The goal was to synthesize the available information towards developing monitoring and management strategies, while highlighting the potential of their commercial valorisation. So far, more than 2900 records have been collected (<300 for *F. commersonii*, >1000 for *P. miles*). *Lagocephalus sceleratus* and *Pterois miles* were the most extensively studied species on every aspect of their biology. Finally, these two were the most valorized species, with applications ranging from food sources to HIV treatments (*P. miles*) and pharmaceuticals to leather exploitation (*L. sceleratus*). Our review strongly highlights an opportunity to develop Blue Economy strategies in the Mediterranean Sea by mitigating the adverse ecological and environmental impacts of these invasive species through sustainable economic initiatives.

***Acknowledgements**: This work has been funded by the following projects: (1) "4ALIEN: Biology and the potential economic exploitation of four alien species in the Hellenic Seas", funded by NRSF 2017-2020 (MIS: 5049511); (2) "VALIAS: Valorisation of Marine Invasive Alien Species a Pathway Towards the Protection of European Marine Biodiversity: From Destructive Invaders to a Source of Wealth" funded by the European Union's Horizon Europe Framework Programme (HORIZON) under the Marie Skłodowska-Curie grant agreement No 101131441; (3) The "ERASMUS+ Traineeship Programme" of the European Union, hosted at the Hellenic Centre for Marine Research (HCMR).*

Non-indigenous fish in the fresh and marine waters of the Madeira Archipelago – An update

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Over the past 65 years, several species of coastal and pelagic marine fishes from tropical and subtropical regions have been recorded from Madeira for the first time, possibly due to global warming. As a result, these new records have been expanding their distribution range, particularly its northern limit. In the present account we present an update of marine and freshwater non-indigenous fishes of the archipelago of Madeira, including what we believe are range expansions. We have identified a total of 34 fish species that were either introduced to Madeira or are considered range expansions. Three freshwater and one marine species are non-indigenous (NIS), while thirty marine fish species are range expansions. Since the last published account in 2008, seven marine fish species have been recorded for the first time from Madeiran waters, all in the last 5 years and all with tropical affinity, thus marking a tropicalization of the marine fauna, a trend also documented in the nearby southward archipelago of the Canaries. Regarding marine NIS, to the best of our knowledge, the situation is the same as reported in 2008, with only one aquaculture-escaped species regularly seen in Madeiran coastal waters. A new freshwater NIS is included in the list, despite being in Madeira for almost a hundred years as an ornamental fish in artificial ponds, because it has been caught in a natural stream on the island of Porto Santo.

Ascidian (Ascidiacea) biodiversity: non-native species in northern pacific Costa Rica

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Ascidians (class Ascidiacea) are marine invertebrates that play a key ecological role as filter feeders and are important bioindicators of environmental change. Despite their importance, the ascidian fauna of Costa Rica is poorly studied. This research provides critical baseline data on ascidian biodiversity in the Tropical Eastern Pacific, characterizing the diversity and phylogenetic relationships of ascidians along the north Pacific coast of Costa Rica using both morphological and molecular approaches. Between 2019 and 2024, 456 ascidians specimens were collected from 32 sites. From those samples 33 species representing 16 genera, seven families, and three orders were identified. Notably, introduced species such as *Polyclinum constellatum, Diplosoma listerianum, Didemnum* cf*. perlucidum, Ascidia sydneiensis, Botrylloides niger, and Polyandrocarpa* cf. *zorritensis* were found, raising concerns due to their invasive potential. DNA barcoding with mtCOI and 18S rRNA markers were used to identify species and resolve phylogenetic relationships, showing the monophyly of Ascidiacea and the effectiveness of mtCOI for identification and resolving relationships. This study improves the understanding of ascidian biodiversity in the region, validates mtCOI as a molecular identification tool, and highlights the importance of integrative approaches in tunicate taxonomy, providing valuable insights for invasive species management.

When invasion is faster than science: the long story of the flatworm who traveled across oceans

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Both scientific and policy recommendations on marine non-indigenous species agree on the importance of a rapid detection and identification of species, for a rapid action. But sometimes, detection can just be the beginning of a long investigation, longer than the invasion of the species.

In 2020, oyster farmers of the Arcachon Bay (France) noted the presence of a polyclad in cultivated oysters (*Magallana gigas*). Rapidly, special attention was paid to it because of its potential predatory behavior on bivalves. Because of its absence from public barcode databases until 2023 and from available identification keys, it was described as a new species (*Idiostylochus tortuosus*) while keeping in mind the high probability to be an introduced non-indigenous species. After several months of investigation, mainly based on molecular markers, the presence of this polyclad in Pacific areas (Australia and Japan) supported this status and finally allowed its identification as *Postenterogonia orbicularis* described from New-Zealand. Meanwhile, the species took the opportunity to proliferate both in terms of spatial expansion and population densities.

This poster aimed to detail the investigation about this traveler polyclad and first results of population dynamic in the Arcachon Bay, acquired during two successive projects, RAPSODI (IFREMER) and VISQUEUX (FEAMPA-OFB).

Exploring the sensory ecology of the invasive sea spider *Ammothea hilgendorfi* to explain its success

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Sensory perception plays an essential role in how organisms interact with their ecosystem, enabling them to respond to external stimuli. In arthropods, sensory organs and mechanisms are well described in certain taxa, such as insects and spiders, but remain poorly understood in others. It is the case for pycnogonids, or sea spiders, which have remained understudied due to low population densities. Nevertheless, the recent discovery of an invasive population of *Ammothea hilgendorfi* in Belgium has raised questions on how this species interacts with, therefore impacts, its environment, since this thriving invader is completely understudied. Indeed, recent studies have highlighted different structures of which the function remain unknown but might play a role in their success (i.e., intraspecific communication, chemical defense). The objective of this study is then to deepen our understanding on the sensory ecology of *A. hilgendorfi*. The survey will include transcriptomic analyses to characterize molecular actors of sensory perception and their expression profiles in sensory organs. In addition, it will focus on chemoreception – essential for feeding, social interactions, reproduction and predation – through the analysis of molecules potentially involved in chemical communication, such as ecdysteroids.

Stress resistance as an invasive trait - The case of *Ammothea hilgendorfi*, the first invasive Pycnogonid

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For a biological invasion to be successful, alien species must resist and adapt to all the new conditions they encounter. This ability comes from traits facilitating invasions, called invasive traits. Identifying and understanding these traits is crucial for predicting areas possibly invaded. Among the 1,400 pycnogonids, poorly studied marine arthropods, *Ammothea hilgendorfi* (Böhm, 1879) is the only invasive species to date. The present project aims to understand the success of this peculiar invasive animal, by focusing on its ability to resist a wide range of stresses. It will be divided into three axes. The first axis will focus on the physiological response and will define the limits of thermal and saline resistance by creating a Thermal Death Time (TDT) model. The second axis will aim to analyse the metabolic response to stresses with a special focus on the ability of the species to enter dormancy by using NMR techniques. The third and final axis is the construction of an ecological niche model (ENM) to predict suitable areas for invasion. In several experiments, the invasive populations will be compared with native ones and other species. The invasive population is expected to show stronger resistance, which enabled it to extend its range.

Behavioral & physiological responses of invasive sea spider *Ammothea hilgendorfi* to environmental stressors in Belgium

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Ammothea hilgendorfi (Böhm, 1879), the first documented invasive sea spider worldwide, has become as the dominant pycnogonid in Knokke-Heist, Belgium, comprising approximately 97% of the local community. This overwhelming presence raises concerns regarding its impact on native biodiversity. In this study, we employed controlled laboratory experiments to investigate the responses of *A. hilgendorfi* to multiple environmental stressors. Four scenarios were examined: (1) the influence of low-frequency underwater noise on aggregation behavior; (2) the effects of climate change on parameters such as movement speed, depth distribution, thermal tolerance, and substrate preference; (3) the modulation of behavior in the presence of predators; and (4) the ability to withstand polluted water characterized by heavy metals and eutrophication. Specimens were exposed to each stressor individually, and their movement patterns, spatial distribution, and interactions were rigorously recorded and quantified. Expected results suggest that *A. hilgendorfi* exhibits a preferred substrate, increased temperatures affect its activity, noise disrupts aggregation, predators trigger defensive responses, and polluted conditions reduce mobility and habitat fidelity. Such results would offer valuable insights into the plasticity of *A. hilgendorfi* and contribute to our understanding of how invasive marine species adapt to anthropogenic and natural disturbances, thereby informing future conservation and management strategies.

From baseline to biosecurity: Saudi Arabia's pioneering marine bioinvasion research in the Red Sea and Arabian Gulf

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Saudi Arabia faces increasing exposure to marine non-indigenous species (NIS) in both the Red Sea and Arabian Gulf. To address this challenge, the National Center for Wildlife (NWC), in collaboration with KAUST, launched the first phase of a long-term national program on marine invasions - the Kingdom's first coordinated effort to establish a baseline inventory of NIS, identify introduction pathways, and design a national marine biosecurity framework aligned with international conventions and protocols. Using a multi-method approach (*literature review*, *field surveys with standardized protocols*, *morphological species identification*, *DNA barcoding*, *eDNA monitoring*, *maritime traffic risk modeling*, and *stakeholder engagement*), the program identified 181 potential NIS in the Red Sea and 168 in the Arabian Gulf, while developing the first regional NIS DNA barcode library. Spatial analyses showed stronger NIS signals near major ports and coastal development sites. This first phase also strengthened national capacity through training and fostered regional and international collaborations to harmonize monitoring standards. The next phase will expand habitat coverage and deliver a **National Biosecurity Toolkit**, including species-specific molecular probes for early detection, outreach products, predictive modeling, and a **rapid response framework co-developed with stakeholders ensuring effective the protection of** biodiversity and coastal economies in the region.

Influence of temperature on the abundance and impacts of the invasive foraminifer *Amphistegina lobifera*

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Amphistegina lobifera is a highly invasive non-indigenous species in the central and eastern Mediterranean Sea, where it has become the most numerically dominant shallow-water benthic foraminifer and is displacing native species. It is largely absent from the western Mediterranean basin, but modelling studies predict an increase in habitat suitability there as a consequence of seawater warming due to ongoing climatic changes. Working in Malta (central Mediterranean) where *A. lobifera* is already well-established, we compared a site subjected to elevated sea temperature due to a thermal effluent from a power plant that has been operating for over three decades, serving as a proxy for long-term effects of climate-driven temperatures increase, with two nearby reference sites having ambient sea temperatures. Our results show that both the absolute and relative abundance of *A. lobifera* were significantly higher at the impacted site, whereas the abundance of other Foraminifera was markedly lower, confirming that increases in temperature can facilitate proliferation and hence ecological impacts of *A. lobifera.* These results predict a future scenario where rises in seawater temperature in the coming decades will further enhance the invasion by *A. lobifera* and facilitate its monopolisation of infralittoral benthic foraminiferal assemblages.

Development of a species-specific molecular markers for a rapid detection of the Asian mussel, *Arcuatula senhousia* (Benson, 1842)

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The Asian mussel*, Arcuatula senhousia*, is an invasive alien species in Europe with a capacity to form dense populations rapidly. This species can severely modify the ecosystem altering habitat and community structure, but also functioning. While invasive alien species are one of the major threats to biodiversity, it is widely assumed that it is essential to detect these invaders as soon as possible.
In this context, we propose here molecular markers and a protocol allowing for the detection of this species in the environmental DNA (eDNA) with a targeted approach using quantitative PCR (qPCR).
Primers and probe specificity was checked *in silico* and *in vitro* and detection in eDNA applied both experimentally and *in situ*. This poster presents results of each steps of development, until *in situ* detection of *Arcuatula senhousia* in water and sediment with eDNA, in areas with variable densities.
This tool could be used in monitoring programs, particularly in territories where the question of the presence of this invasive mussel arises. Without sequencing step, the results can be obtained rapidly, always with the aim of early detection.

High-throughput detection of marine invertebrate NIS via DNA metabarcoding: a 2-year survey in recreational marinas

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Early detection of non-indigenous species (NIS) is vital to mitigate their ecological and economic impacts, especially in vulnerable coastal areas. Traditional methods often fall short due to slow processing and limited taxonomic resolution. This study used DNA metabarcoding to monitor invertebrate communities across four Portuguese recreational marinas - Viana do Castelo (VC), Porto Atlântico (PA), Costa Nova (CN), and Jardim Oudinot (JO) - over two years (2021-2022), in summer and autumn, using three sample types and two genetic markers (COI and 18S rRNA genes). A total of 797 taxa from 21 phyla were detected, including 37 NIS. Some were consistently detected (e.g., *Austrominius modestus* in all marinas; *Balanus trigonus* in all PA time-points), while others showed seasonal or sporadic patterns (e.g., *Musculus lateralis*, *Potamopyrgus antipodarum*). Several NIS detected in 2022 (4-8 per marina) had not been previously recorded at those locations, suggesting early detection events - e.g., *Acartia (Acanthacartia) tonsa* in VC and PA, *Styela clava* in PA and CN, *Didemnum vexillum* in CN, and *Molgula manhattensis* in JO. In contrast, some NIS detected in 2020 were not found again, such as *Amphibalanus eburneus* (VC/PA) or *Eriocheir sinensis* (JO). These results highlight DNA metabarcoding potential for sensitive, early, and site-specific NIS surveillance.

Tracing the intruders: a global perspective on marine invasive species through eDNA

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Early detection of non-indigenous species (NIS) is crucial to prevent their establishment and reduce ecological and economic impacts. DNA-based tools, particularly environmental DNA (eDNA), have revolutionized NIS surveillance by enabling the detection of cryptic, rare, or early-stage invaders with higher sensitivity than traditional methods. This study presents the first global synthesis of NIS detected using eDNA in coastal ecosystems, based on 150 published studies. Europe was the most surveyed region (69 studies), while the African coast, Antarctica, and the Arctic were the least (<10 studies). Most studies used DNA metabarcoding (48%) or single-species PCR (42%), with some applying both (10%). A total of 753 NIS was detected using eDNA tools, including 465 Animalia, 209 Chromista, 78 Plantae, and 1 Protozoa. The most frequently detected groups were Dinophyceae (136 species), Copepoda and Malacostraca (94), Teleostei (59), and Ascidiacea (44). Globally, COI was the most widely used marker (110 studies), followed by 18S (48) and 16S (12) rRNA genes. Water was the most common sample type surveyed (93 studies), followed by plankton (31) and fouling communities (20). Notably, ~30% of NIS detections in these studies represented new regional records, highlighting the strong potential of eDNA-based approaches for early NIS detection in coastal environments.

First application of BRUVS for monitoring NIS fish in Tunisia

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Non-indigenous species (NIS) pose a significant threat to marine ecosystems, particularly in the Mediterranean Sea, where they disrupt native biodiversity and ecological balance. Monitoring NIS is critical for understanding their impacts, especially in areas around Marine Protected Areas (MPAs) vulnerable to bioinvasions. This study marks the first application of Baited Remote Underwater Video Systems (BRUVS) in Tunisia to monitor NIS fish populations.

BRUVS were deployed at 14 stations with varying depths and substrates, resulting in 93 videos recorded over 1024 minutes. A total of 37 fish species were identified, including two NIS: Siganus luridus and Fistularia commersonii. Compared to traditional Underwater Visual Census (UVC) methods, BRUVS provided consistent results, recording an average of 16 species per station and capturing elusive predators. Statistical analyses identified ecological groupings based on depth and substrate. Stations with poor ecological status showed low fish diversity, while those with fair status exhibited medium diversity, highlighting the link between ecological health and biodiversity.

This first application of BRUVS in Tunisia demonstrates its effectiveness as a scalable, non-invasive tool for long-term NIS monitoring. Its ability to provide revisitable data offers MPA managers and researchers a reliable method to detect and manage bioinvasions while supporting ecosystem resilience.

Strengthening aquaculture impact assessment through benthic biodiversity monitoring: A Norwegian Case Study

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Biodiversity assessment, particularly of organismal community composition, is a vital tool for detecting early warning signals of ecosystem shifts driven by human use of marine resources. It plays a key role in supporting environmental governance and sustainable ocean management. This Norwegian case study implements existing biodiversity-related regulations targeting the aquaculture sector and aims at comparing traditional taxonomic methods with emerging monitoring technologies, including molecular (eDNA), imaging, and acoustic tools, to evaluate the benthic community structure and presence of shifts in ecological functionality. A key objective is to determine whether these innovative monitoring methods offer more time-, cost-, and labor-efficient alternatives to traditional assessments, and whether they can be integrated into ecological indices required by national regulations. By exploring the compatibility of data from different monitoring approaches with established biodiversity metrics, this research contributes to the development of next generation monitoring systems. It also provides insight into the potential of new technologies to enhance efficiency, resolution, and scalability in marine biodiversity assessment. Using a Norwegian case study, this work supports the advancement of effective, science-based monitoring tools that promote the sustainable use of marine resources and contribute to the long-term development of a resilient and responsible blue economy.

Monitoring non-indigenous species in port habitats in the Estonian coastal waters of the Baltic Sea

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The role of commercial harbours and recreational marinas in the spread of non-indigenous species (NIS) has increased globally. Harbour monitoring is important for assessing NIS introduction and spread, as maritime transport – particularly via ballast water tanks (containing both water and sediments) and biofouling on vessel hulls – is the primary pathway for their dispersal. In Estonian coastal waters, regular monitoring of harbours (including quays and surrounding waters) has been conducted since 2012 in the marine areas around the Port of Muuga and near the Port of Sillamäe in the southern Gulf of Finland (Baltic Sea). The monitoring assesses species composition, abundance, and biomass of mobile epifauna and fish, fouling organisms, benthic infauna, and plankton. Species-specific monitoring of NIS targets species such as the round goby, Chinese mitten crab, and Harris mud crab. The surveys follow the HELCOM and OSPAR port survey protocols. Additionally, NIS studies using the same methodology have been conducted at the Old Port of Tallinn (2022), Paldiski South Harbour (2022), and Roomassaare Harbour (2024). In recent years, one new regional NIS – cumacean *Nippoleucon hinumensis* – was first detected through harbour surveys in 2022.

Assessing marine bioinvasions in the Greater Bay Area of China

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Coastal cities in the Greater Bay Area, such as Hong Kong, are busy ports with extensive man-made marine structures, making them hotspots for bioinvasions. Previous studies on marine macrobiota have identified 18 non-indigenous species (NIS) and eight cryptogenic species in Hong Kong. These records primarily come from outdated studies or casual observations, leaving current bioinvasion trends unclear. To update the understanding of bioinvasions in Hong Kong and the Greater Bay Area, a literature review of fouling species recorded in the region is currently underway. This review is complemented by field surveys in man-made structures, which include taxonomic identification and DNA barcoding of fouling species. By cross-referencing species with global databases, we aim to identify NIS and cryptogenic species in the region. This baseline, combined with DNA barcoding information, can aid biodiversity surveys to better understand bioinvasion status in the region. The findings of this study will update Hong Kong's Marine Biodiversity Database and contribute to local efforts for biodiversity conservation. Additionally, this study will provide critical baseline information for stakeholders to mitigate bioinvasion risks and safeguard regional biodiversity.

Hotspots of non-indigenous species in the southern Adriatic Sea (Montenegro)

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Non-indigenous species (NIS) represent a global phenomenon that significantly alters local biodiversity, often with negative ecological consequences. This study identifies the main hotspots of NIS along the Montenegrin coast through field surveys conducted by autonomous diving at marina (Porto Montenegro), port (Port of Bar), and aquaculture site. Biofouling communities on submerged structures were analyzed to assess NIS presence and abundance. Results reveal a substantial number of mostly established NIS at all surveyed locations, with *Styela plicata*, *Botryllus schlosseri*, *Amathia verticillata*, and *Ciona robusta* being the most abundant. These findings highlight the urgent need for continuous monitoring of NIS population dynamics to enable timely implementation of effective management and protection measures, thereby mitigating their impact on native marine ecosystems.

A decade of monitoring non-indigenous species recruitment on artificial substrates in the Madeira Archipelago

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The diversity and abundance of fouling marine non-indigenous species (NIS) in the Madeira Archipelago have received increasing attention through regular monitoring, especially in four marinas along Madeira Island's southern coast. This study examined sessile fouling assemblage recruitment using artificial settlement panels, assessed every four months over an 11-year period (2013–2024). Seawater temperature data across three seasonal intervals (T1: Winter/Spring, T2: Spring/Summer, T3: Summer/Autumn) were used to analyse temporal and spatial trends in assemblage composition, focusing on NIS. Preliminary results showed clear seasonal and interannual variability, with recruitment peaking in warmer seasons (T2, T3). A total of 68 species were recorded across eight taxa, including 29 NIS, 21 cryptogenic, 10 unresolved, 7 native, and one range expansion species. Species richness and abundances varied by site. Overall, NIS richness nearly doubled over the study period, indicating a steady rise in introductions and establishment. Long-term monitoring is crucial for early detection of NIS and effective biosecurity measures. These findings highlight the importance of site-specific surveillance for managing biofouling communities and limiting the spread of NIS in island marine ecosystems.

Comparing experimental settlement panel methods from global fouling NIS monitoring programmes

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Globally, settlement panels have been adopted as a method to carry out baseline monitoring for fouling marine non-indigenous species (NIS). A standardized protocol developed by the Smithsonian Environmental Research Centre (SERC) using PVC plates is widely used across North and South America and has recently been adopted and trialled across European and Mediterranean locations. In the United Kingdom, standardized monitoring using another type of settlement panel made from black plastic CoreX, has taken place for over 10 years in the Shetland and Orkney Islands. As part of a wider experiment coordinated by SERC and the University of Pavia, 10 panels of each type were deployed for a 3- and 6-month period in May to October 2024 in marinas in Shetland and in Orkney. This study compares the fouling community composition and NIS detection between the two panel types. The findings of this study will inform the relevance of cross-comparisons between two different long-term monitoring programmes and methods.

The monitoring of Sicily's coast (southern Italy) reveals the most representative NIS invertebrates of the central Mediterranean

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Sicily, the largest island in the Mediterranean Sea, occupies a strategic position regarding the dispersal routes of marine species entering the basin from the Atlantic Ocean and the Red Sea. Through case studies pertaining to activities conducted under the NBFC framework, this contribution aims to test this assertion. The fouling communities on nautical ropes were examined in three harbours (Trapani, Palermo, and Licata). New occurrences of non-indigenous species (NIS) or cryptogenic isopods (*Paranthura japonica*, *Mesanthura* cf. *romulea*, *Paracerceis sculpta*), amphipods (*Caprella scaura*, *Jassa slatteryi*, *Laticorophium baconi*, *Stenothoe georgiana*), pycnogonids (*Anoplodactylus californicus*), bivalves (*Isognomon* sp., *Brachidontes pharaonis*), and tunicates (*Microcosmus squamiger*, *Styela plicata*, *Distaplia bermudensis*) were identified in Trapani, while the isopod *Mesanthura* cf. *romulea* and the amphipod *Laticorophium baconi* were reported for the first time in Licata. Additionally, the latter species and the pycnogonid *Achelia sawayai* were also newly recorded in Palermo. Contextually, new records of species previously undetected in this area were compiled, which included two copepod species parasitic on ascidians (a botryllophilid in *Polyclinum aurantium* and *Bonnierilla similis* in *Styela plicata*) and the marine mite *Litarachna duboscqi*, whose record marks the first sighting in the central Mediterranean.

Systematic map: approaches to identifying pathways of marine non-native species spread

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Invasive non-native species (INNS) are a pervasive threat to global biodiversity and economy. There is increasing concern surrounding the spread of marine INNS to more remote and higher latitude areas in Scotland and the Arctic, attributed to the globalisation of trade and climate change effects[1]. Arctic sea ice melt could facilitate INNS spread through changing ocean biogeochemistry, currents and opening areas for ship movement[2], threatening one of the most climate modified environments globally[3].There is a possibility that Arctic micro-climates could enable INNS to persist[4]. Anthropogenic modifications from Scotland to Arctic states such as the deployment of renewables, harbour use changes and vessel traffic increase could remove barriers that previously prevented INNS spread[5]. We present a systematic map exploring the modelling methods used to quantify pathways of primary and secondary INNS spread and to identify current and future hotspots. The systematic map findings will give an overview on the current use of modelling to inform biosecurity protocols and prevent catastrophic bio-invasions. The results will identify ecological and spatial modelling approaches that could be applied to research pathways, INNS arrival hotspots and connectivity between Scotland and the Arctic to potentially provide an early warning system for vulnerable Arctic States.

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Hidden frontiers of invasion: patterns, hotspots, and management gaps in the marine Arctic

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The rapid environmental and anthropogenic changes unfolding in Arctic marine systems are reshaping the region's vulnerability to biological invasions. As sea ice retreats and human activities expand, Arctic marine ecosystems, once isolated, are now becoming increasingly exposed to the introduction and establishment of invasive species. This study systematically assesses the presence and potential spread of invasives across the 18 Arctic Large Marine Ecosystems. Drawing on global biodiversity and invasion databases, we map invasion occurrences and overlay these with jurisdictional boundaries, taxonomic classifications, and invasion status data to identify spatial and temporal trends. The analysis highlights ecological and socioeconomic risks posed by selected species, based on a review of documented impacts both within the Arctic and in comparable ecosystems. Emphasis is placed on species likely to become invasive under continued warming and increased propagule pressure, as well as the challenges posed by limited Arctic baseline data. Against this backdrop, the study aims to inform proactive, science-based management strategies and to support circumpolar cooperation. In doing so, the study aims to identify emerging hotspots of concern and inform policy responses at regional and international levels, in line with the Arctic Council's priorities.

Project strengthening management to combat threats from aquatic invasive alien species in Venezuela

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Venezuela, recognized as one of the ten countries with the greatest biological diversity on the planet, is currently facing the invasion of the species *Unomia stolonifera*, an Indo-Pacific octocoral, in important marine-coastal protected areas. In response, the Venezuelan government, through the Ministry of Ecosocialism (MINEC), has designed a five-year strategy to strengthen governance on this issue, with financial support from the GEF and technical assistance from the FAO. The project aims to reduce biodiversity loss and the impact on globally important ecosystem services by strengthening institutional and community capacities for the prevention, early detection, control, and eradication of aquatic IAS in Venezuela, with an emphasis on marine and coastal species. For this purpose, four components were developed: 1) Strengthening of institutional and community capacities for the management of aquatic IAS with a gender perspective; 2) An aquatic IAS monitoring and control system developed with community participation; 3) A pilot project for participatory community control and eradication of aquatic IAS, with sustainable socio-productive alternatives to contribute to habitat restoration and food security; and 4) A strategy for knowledge management, information dissemination, and project learning. Eight outcomes and 18 key outputs are expected to be achieved through the implementation of the project.

Experimental design as a tool for properties mapping in hydrogels and foams for large-scale application in the control of Orange Cup Coral

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The Brazilian government classified the Orange Cup Coral (*Tubastraea coccinea)* an invasive species in the Brazilian coastline. Thus, efforts in preventing further degradation of local fauna are being gathered on multiple fronts. Currently, divers are the main resource for cleaning ships and other maritime devices, being a laborious, slow, and dangerous process. Also, it has been reported that the removal of coral by divers increases the spread of the species as it releases their larvae in the water. The development of biodegradable and biocompatible hydrogel and foams aims to substitute divers by applying the product with a Remote Operated Vehicle (ROV). However, properties of gels like its viscosity at higher (70 °C) or lower temperature (25 °C), G', G", and tgδ can very widely depending on its components. The same can be said of foam for its viscosity, stability in sea water, and foam height. In this context, experimental design such as Box-Behnken, central-composite, and Doehlert can be valuable tools for variables screening and formulation optimization. Nonetheless, the statistic approach can assess quantitatively the impact of each component on the properties, its interactions, and assist the development of field-ready formulations with the controlled variations imposed on the system.

Adapting rapid response protocols to combat the spread of *Unomia stolonifera* in Hawai‘i

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Since 2020, multiple high-risk aquatic invasive species (AIS) have been detected in Hawai‘i, prompting the Division of Aquatic Resources (DAR) to adapt rapid response protocols to address these unique challenges. One such species, the invasive octocoral *Unomia stolonifera*, has been found in Pearl Harbor, Hawai‘i. This highly prolific species has caused widespread reef degradation in the Caribbean, and after colonizing over 82 acres within Pearl Harbor, it poses a serious threat to broader Hawaiian marine ecosystems. To combat *U. stolonifera*’s spread and regenerate native habitats, the Hawai‘i Invasive Octocoral Working Group is aiding the Navy’s eradication efforts within Pearl Harbor. DAR is also preparing for potential expansion into state waters by refining its rapid response framework for faster and more effective action. When DAR was alerted to a potential sighting in state jurisdiction, the agency collaborated with partners to expand survey efforts within the Navy’s security zone. By targeting areas adjacent to the known population, this approach helped determine whether the species had spread beyond established boundaries, demonstrating the effectiveness of DAR’s adaptive response framework. As collaborative efforts continue, these protocols will be crucial for protecting native species and mitigating ecological damage caused by *U. stolonifera*.

Rapid response to Octocoral spread at Kualoa Beach in Kāneʻohe Bay, Oʻahu

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On June 17, 2024, the State of Hawaiʻi Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR) Aquatic Invasive Species Team (AIS) received reports from partners at the Hawaiʻi Institute of Marine Biology (HIMB) of a potentially non-native invasive octocoral growing near Kualoa Beach and Mokoliʻi in Kāneʻohe Bay. The octocoral was observed growing in large patches near native stony coral colonies and did not immediately resemble any known octocorals native to Hawaiian waters. Colleagues at HIMB and Bishop Museum conducted morphological and genetic identification, while DAR AIS conducted delimiting surveys. Collected octocoral samples were genetically identified as *Sarcothelia edmonsoni*, a native Hawaiian octocoral. However, the sample's morphology did not resemble typical S. edmonsoni colonies. Genetic testing was repeated, confirming the identification. Concurrently, the AIS Team surveyed ~300 acres of benthic habitat near Kualoa Beach Park. Survey areas located ~800m offshore and around Mokoliʻi exhibited the highest concentration of *S. edmonsoni* growing near native stony coral and overgrowing coral skeletons. Delimiting surveys concluded following genetic identification. However, concerns still surround the anthropogenic influences that may have caused the invasive tendencies.

Utilizing urchin biocontrol and manual removal to manage invasive algae in Kāneʻohe Bay, Hawaiʻi

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Kāneʻohe Bay, the largest embayment in Hawaiʻi, is comprised of patch reefs, lagoons, and fringing reefs with abundant coral reef habitat. In the 1970s, the algal taxa *Eucheuma spp*. and *Kappaphycus spp.* were introduced for aquaculture purposes and later spread throughout the Bay, overgrowing and smothering native corals. Since 2007, the State of Hawaiʻi Division of Aquatic Resources (DAR) has managed invasive algal spread in Kāneʻohe Bay using mechanical removal via hand-pulling and an underwater vacuum (Super Sucker) paired with biocontrol using native Hawaiian collector urchins (*Tripneustes gratilla*). Annual benthic surveys are conducted to monitor invasive algae, assess management effectiveness, and determine the appropriate number of urchins needed to maintain low algal abundance. From 2016-2023, invasive algal abundance was relatively low, such that urchin biocontrol was sufficient to prevent significant overgrowth of corals. However, recent trends on several managed reefs indicate invasive algal abundance is on the rise, necessitating manual removal. At present, DAR is restarting the Super Sucker program to reduce invasive algal abundance to levels such that urchin biocontrol can effectively prevent algal overgrowth of native corals. These methods, coupled with watershed and herbivore management, show promise in restoring and protecting coral reef habitats in Kāneʻohe Bay.

Can a pest become an opportunity for exploitation? The case of tunicate ascidians

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Ascidians are among the most abundant taxa in marine biofouling communities and include some very widespread invaders, with well-known impacts on biodiversity and local economy. Ascidians have potential of use in various applications, although their current exploitation is geographically scattered and their exploitation has not been explored yet as a possible management option. This study aims to investigate the nutritional characteristics and heavy metal content of three non-indigenous ascidian species present in the Lagoon of Venice (Mediterranean Sea), namely *Styela clava*, *Styela plicata* and *Ciona robusta*. Two native ascidian species (*Phallusia mammillata* and *Ascidiella aspersa*) were also included in the analysis for comparison. Standard analytical chemistry and biochemistry procedures to determine proximate composition, fatty acid (FA) profile and mineral content, including heavy metals, showed that *C. robusta* and *P. mammillata* have high-quality fatty acids comparable to edible ascidians. However, these species, along with *A. aspersa*, show high heavy metal concentration, especially in V and Fe. Considering their long-chain n-3 FAs, ascidians commonly found in the Venice lagoon can be considered for commercial exploitation as possible ingredients in the formulation of animal feeds and for human consumption.

Weaving a national network to protect our natural heritage: science, communities, and government in action

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The fight against invasive alien species (IAS) requires collaborative approaches, where the integration of local, national and international efforts is key to protect biodiversity and ecosystem services. The project “Strengthening management to combat threats from aquatic invasive alien species in Venezuela”, led by the Government of Venezuela with FAO support and GEF funding, establishes the creation of the Intersectoral Coordination Group on Invasive Alien Species (GCIEEI) as a mechanism for national coordination. This group integrates public institutions, academia, scientists and local communities under a unified legal framework, with a gender perspective. The GCIEEI comprises the National Environmental Authority and twenty-three State bodies and entities responsible for managing IAS. It was structured into four working groups tasked with coordinating policies, plans, programs, and projects related to the prevention, early detection, control, and eradication of IAS. This strategy strengthens national capacities and positions the country as a key actor in the global fight against biological invasions, promoting the resilience of marine-coastal ecosystems and fostering international cooperation and information exchange, especially with neighboring countries, for the transboundary control of species such as *Unomia stolonifera* (Cnidaria, *Xennidae*), among others, through technical cooperation mechanisms.

Innovating post-invasion strategies: a transdisciplinary approach to marine invasive species management

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Marine ecosystems are increasingly threatened by the introduction and spread of invasive species, which disrupt native biodiversity and alter food web dynamics. In particular, gelatinous zooplankton such as invasive ctenophores and jellyfish have been observed to expand rapidly under changing environmental conditions, posing challenges for monitoring, impact assessment, and long-term management. These impacts are compounded by knowledge gaps in post-invasion responses at regional scales. In this presentation, outcomes from an international workshop held in Denmark will be shared. The workshop brought together scientists and stakeholders to explore interdisciplinary approaches for mapping invasive species hotspots, developing early-warning frameworks, and evaluating opportunities for sustainable biomass utilization. The results highlight the urgent need for adaptive, science-based governance tools that support integrated marine biodiversity management. It is concluded that coordinated regional efforts, including stakeholder participation and innovation-driven solutions, are essential for mitigating the long-term ecological and socio-economic impacts of marine invasive species.

Towards regional management of door-knocking invasive aquatic species - example from Scandinavian waters

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A regional approach is proposed for effective management of Invasive Aquatic Species that is of concern for several neighbouring countries. The overall goal of the Biodiversa+ project CLIMATE INVASIVES is to reach joint management for IAS in the Scandinavian countries where the national borders of Denmark, Sweden and Norway meet in the Baltic Transition (sea areas Kattegat and Skagerrak). The spread of IAS with changing climate is predicted using oceanographic dispersal modelling. Further, characteristics for specific species are used in connectivity analyses and combined with remote sensing data to localize habitats or geographic areas of interest. Early identification of IAS is crucial and within the CLIMATE INVASIVES project an array of novel molecular as well as traditional taxonomical sampling and detection methods has been performed.

A risk scenario workshop will be held with responsible authorities for sharing of knowledge and experience, and to identify the work ahead needed. Finally, a management approach that minimize spread of IAS with allocated resources and joint efforts via regional networks will be presented.

An early warning system based on a community collaboration network for coastal marine protected areas in Venezuela

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Early detection and rapid control of alien species is crucial for preventing biological invasions, especially in marine ecosystems where management options are limited and expensive. Within the framework of the project "Strengthening Management to Combat the Threats of Aquatic Invasive Alien Species in Venezuela", funded by the GEF, a mobile application will be designed in collaboration with the national environmental authority. This application will enable the generation of reports on sightings, geographic coordinates, photos, descriptions, and spotter data, along with a module that will serve as a repository for information on marine invasive alien species detected in the country and their status. A network of community organizations will be formed, including fishermen, recreational divers, park rangers, and tour operators, who will be trained in the use of the application and the identification of alien species present or likely to be sighted in the country. A local training program will also be developed for environmental authorities, who will be responsible for validating the findings. An effective link between community environmental action and national authorities aims to provide a valuable and innovative contribution to the preventive management of these threats.

“What’s growing under your boat? Alien species: intruders that travel with you”

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Within the framework of the HORIZON EU GuardIAS project (Guarding European Waters from Invasive Alien Species), new citizen science activities are planned to engage a wider community in addressing IAS challenges. Among these, we will organize at least twenty marina events targeting specific audiences, i.e. Italian boaters and marina managers, in the 3-year period 2025-27. The aim of the events is to raise public awareness on biofouling as a vector for IAS and actively engage this audience in biofouling prevention and IAS monitoring.
The marina events follow a two-tier approach using a pre- and post-test setting to measure the effectiveness of our communication activities. The first step is to screen the perceptions and awareness of participants (prior to the activities), who are then informed and involved in expert-guided rapid assessments of alien species in interactive open labs set up in the marina. We then use post-activity questionnaires to measure the impact of the event. Lastly, a call to action is made to further involve participants in long-term monitoring by ‘adopting’ a passive habitat collector for fouling species. Long-term participants commit to regularly sending pictures of the biofouling species community growing on the collector, hence becoming true ‘citizen scientists’

Restoring the heart of the Caribbean: a community-led battle against the invasive soft coral *Unomia stolonifera*

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A coral reef restoration program is being implemented in Mochima National Park, Venezuela, to address the impacts of the invasive octocoral *Unomia stolonifera*. This initiative is part of the project “Strengthening management to combat the threats from aquatic invasive alien species in Venezuela,” funded by The Global Environment Facility (GEF). Given the limited national experience in coral restoration, successful strategies from the Caribbean were analyzed to design a comprehensive approach based on the propagation and transplantation of native coral species. Pilot site selection was conducted through a multi-criteria analysis incorporating technical, economic, and community-based factors, with active participation of experts and local stakeholders. To support these efforts, community-based coral nurseries will be established, prioritizing species with high growth rates and resilience. A continuous training program will be implemented to ensure the project's sustainability, including the development of standardized restoration protocols and a business plan. Restoration activities will be monitored by marine biologists and ecologists from various universities and research centers across the country, generating technical and scientific reports to optimize methodologies and enhance environmental management. This initiative contributes to biodiversity conservation, coastal protection, and local economic development through sustainable tourism and responsible fisheries.

Concomitant effects of algae invasion and sea urchin mass mortality drive the shift from barrens to turf grounds

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The current invasion of the brown macroalgae *Rugulopteryx okamurae* poses a major threat to native coastal communities in southern European waters, with major socioeconomic implications. This species was first detected in the archipelago of Madeira in December 2021 and has since been expanding along the coast of Madeira Island. Later, in 2022, a mass mortality event (MME) of the main grazer species in the region, the sea urchin *Diadema africanum*, was detected. We investigate the direct effects of these two events, the arrival and proliferation of *R. okamurae* and the MME of *D. africanum*, on the coastal rocky systems along the southern coast of Madeira Island. Surveys were conducted at four sites along the south coast, assessing *D. africanum* densities and benthic species cover at two depths (5 m and 15 m) over two years (2021 and 2023). Results revealed drastic community changes, as *D. africanum* densities dropped to zero and barren systems transitioned from dominant to absent within two years. This shift facilitated the rise of turf and erect algae (including *R. okamurae*) as dominant functional groups. *R. okamurae* became the dominant species at both depths in two of the surveyed sites. A general increase in species richness and Shannon's diversity indices was observed at 15 m in 2023, whereas at 5 m, both indices showed different patterns across locations. These changes reflected a shift in community structure between 2021 and 2023, which was more evident at 15 m depth. The expansion and proliferation of *R. okamurae* are expected to continue in Madeira Island, potentially leading to the homogenisation of the coastal systems. Continuous monitoring of the region´s coastal ecosystems is crucial to assess their long-term response to the invasion, the potential recovery of *D. africanum* populations, and the associated ecological consequences.

Native macroalgae: Refuge for macroinvertebrates against the invasions of *Rugulopteryx okamurae*?

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Rugulopteryx okamurae, a brown algae native to the northwestern Pacific, has become a prolific invasive species in the marine ecosystems of the Western Mediterranean, Northeastern Atlantic and Macaronesia region since its arrival in the Strait of Gibraltar (SdG) in 2014. Its rapid spread promotes high species richness and abundance in the core areas of native population's distribution, while diversity is reduced at the invasion front. Its extensive spatial coverage allows *R. okamurae* to dominate substrates, altering habitat complexity and nutrient cycling. Furthermore, its chemical defenses—particularly the production of the secondary metabolite dilkamural—hinder grazing by native herbivores and lead to cascading ecological changes by reducing fitness and increasing mortality in key species such as sea urchins. Experimental evidence also suggests that prolonged exposure to *R. okamurae* weakens native populations and disrupts community dynamics. Effective management of this invasive species requires a comprehensive, multi-scale approach combining biological control, habitat restoration, and continuous monitoring. In this context, algal epifauna were monitored in two locations within the SdG: one on the Mediterranean side, which is highly invaded, and another on the Atlantic side, where the invasion rate is low, to compare the effects of the algae on native epifaunal species in terms of biomass loss and biodiversity decline.

How does habitat complexity impact biodiversity and the presence and success of invasive species on eco-engineered seawalls

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Hong Kong's coastline, largely modified by seawalls, epitomizes the global issue of habitat homogenization. These artificial seawalls, with their flat, thermally stressful surfaces, often favor resilient non-indigenous species while diminishing native biodiversity. Currently, Hong Kong has implemented several eco-engineering trials to enhance the habitat complexity of seawalls and increase biodiversity. However, the effect of eco-engineered habitats on non-indigenous species remains to be understood. This study aims to investigate how varied levels of artificial habitat complexity affect thermal buffering, native biodiversity, and non-indigenous species success. By conducting field surveys on ongoing eco-engineered seawall trials, manipulative field experiments, and complementary laboratory experiments, the study examines the role of habitat complexity on the presence, abundance, and survival of native and non-indigenous species in intertidal seawalls. Mussels are used as model species due to their role in structuring intertidal communities and the increasing presence of the non-indigenous species *Xenostrobus securis* and *Mytella strigata* on Hong Kong's seawalls. The findings from this study will enhance our understanding of how habitat complexity affects non-indigenous species and native biodiversity, providing valuable insights for stakeholders involved in the implementation of eco-engineered seawalls in Hong Kong.

Latitudinal patterns of biotic resistance to marine bioinvasions in the Macaronesian Islands

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Settlement and survival of non-indigenous species (NIS) are strongly influenced by interactions with native communities, particularly through predation and competition. While latitudinal biodiversity gradients suggest that more diverse communities may exert stronger biotic resistance to invasions, the role of predation remains understudied. Here, we present the first experimental investigation in the Macaronesian region to assess how predation influences NIS settlement along a latitudinal gradient, spanning temperate to tropical island climates. We conducted a standardized three-month predation-exclusion experiment across Macaronesia—Azores, Madeira, Canary Islands, and Cabo Verde—using settlement panels subjected to four treatments: Control (open panels), caged panels (full predator exclusion), cage-control (half cage over panels), and delayed exposure of caged panels (to examine effects on established communities). Benthic communities were compared across treatments, focusing on NIS presence and abundance. Preliminary results reveal clear spatial variability in community composition and NIS incidence, with a total of 151 species recorded across eight major taxonomic groups. Species richness ranged from 51 in Madeira to 82 in the Canary Islands. Ongoing analyses aim to clarify how predation influences NIS success across this biogeographic gradient. Our findings will provide critical insights into the role of insitu biodiversity and trophic interactions in shaping biotic resistance to marine bioinvasions.

Less is more: Minimizing disturbance boosts native seagrass resilience against invasive Caulerpa

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The invasive alga *Caulerpa cylindracea* poses a serious threat to Mediterranean seagrass ecosystems, particularly where native *Cymodocea nodosa* meadows prevail. This ongoing pilot study—initiated in May 2024 and continuing through May 2026 on Kuriat Island—aims to evaluate whether physical removal of *C. cylindracea* inadvertently promotes its rapid regrowth and undermines the resilience of native seagrass beds. A total of 18 fixed quadrats were established to capture three distinct community compositions: low (25% Caulerpa, 75% C. nodosa), medium (50% Caulerpa, 50% C. nodosa), and high (75% Caulerpa, 25% C. nodosa) Caulerpa cover, with six quadrats per composition. For each composition, three quadrats were randomly assigned to the removal treatment—where manual extraction (with a 10-cm algae-free buffer zone) was conducted every three weeks—and the remaining three quadrats served as undisturbed controls.

Preliminary first-year results indicate that active removal triggers a rapid regenerative response in *C. cylindracea*, while undisturbed patches maintain a more stable algal cover. Moreover, minimal disturbance appears to provide *C. nodosa* with a better opportunity to compete against the invader. These early findings suggest that reducing disturbances—both from deliberate removal and incidental trampling—may enhance the resilience of native seagrass meadows and help them better counteract the invasive pressure. Full results will be shared as the study continues, offering valuable insights for managing invasive *C. cylindracea* and preserving Mediterranean seagrass ecosystems.

Non-indigenous species in the transitional water: analysis of impacts in the Lesina Lagoon (Italy)

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The Transitional ecosystems are particularly susceptible to biological invasions. The presence of non-indigenous species causes a serious impact not only on the biodiversity of these habitats but also on the economy. In the Lesina Lagoon (Apulia Region, Italy), over the last 20 years 14 Alien species have been identified: *Mnemiopsis leidyi* A. Agassiz, 1865, *Ficopomatus enigmaticus* (Fauvel, 1923), *Hydroides dianthus* (Verrill, 1873), *Anadara transversa* (Say, 1822), *Arcuatula senhousia* (W. H. Benson, 1842), *Crassostrea gigas* (Thunberg, 1793), *Amphibalanus eburneus* (Gould, 1841), *Amphibalanus improvisus* (Darwin, 1854), Penaeus (Farfantepenaeus) *Aztecus Ives*, 1891, *Callinectes sapidus* Rathbun, 1896 *Dyspanopeus sayi* (Smith, 1869), Procambarus clarkii (Girard, 1852), *Oreochromis niloticus* (Linnaeus, 1758), *Gambusia affinis* (Baird & Girard, 1853). In recent years large blooms of *M. leidyi* and an increase in the presence of *C. sapidus* have been recorded. Recent observations ecological have highlighted a contraction of the fish population and the macrozoobenthic community with negative repercussions on the small-scale artisanal fishing widely practiced in the lagoon. In the future, a long-term strategy will need to be implemented, which includes a thorough understanding of all potential socio-economic and ecological benefits and risks and the possibility of developing fishing activities for alien species with commercial purposes.

Shifting shell occupation: how an introduced gastropod alters hermit crab resource use

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Hermit crabs depend on gastropod shells for protection and survival in rocky coastal habitats. This study examines how the arrival of the non-native gastropod *Phorcus sauciatus* has influenced shell selection by the hermit crab *Clibanarius erythropus* along the southern coast of São Miguel Island, Azores (NE Atlantic). Field surveys at four intertidal sites revealed that *P. sauciatus* shells comprised 22.4% of those occupied by hermit crabs, indicating a significant shift in shell usage since the species' introduction in 2013. Morphometric analyses comparing *P. sauciatus* shells with four commonly used gastropod shells showed that *P. sauciatus*offers favorable characteristics, including a high internal-to-mass ratio, likely enhancing hermit crab survival and mobility. Temporal comparisons with data from 2000 and 2009 highlight substantial changes in shell utilization, with *P. sauciatus* emerging as a key resource. Its establishment has increased shell diversity for *C. erythropus*, illustrating how non-native species can alter resource availability and create new ecological opportunities for native species in rocky shore environments.

Do two species of introduced crab predators smell different, and can their prey tell the difference?

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In the Gulf of Maine, the intertidal snail *Littorina obtusata* is threatened by two non-native predators: the European green crab, *Carcinus maenas*, present since ~1900, and the Asian shore crab, *Hemigrapsus sanguineus,* present since ~2000. Snails detect chemical cues released by crabs, and can respond behaviorally or morphologically to avoid predation. *H. sanguineus* is expanding north, and it is unclear whether snails currently exposed to only *C. maenas* will recognize cues from this new predator. Previous studies suggest that snails can differentiate cues from different crab species. In this project, we used metabolomics to determine the extent to which chemical cues differ by species, and a behavioral assay to determine whether snails respond to species differences. The snails came from a population exposed to both species. We found that 77% of the features detected with mass spectrometry were shared by both species, but 17% were unique to *C. maenas* and 6%, to *H. sanguineus*. Snails actively avoided cues from *C. maenas* but not *H. sanguineus,* implying that snails recognize species-specific metabolites. This snail population might not have been exposed to *H. sanguineus* long enough to recognize its cues. Alternatively, snails might recognize *H. sanguineus* but not perceive it as threatening.

Impact of sexually dimorphic asian shore crabs and dogwhelk morphology and size on predation by winkling

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The Asian shore crab, *Hemigrapsus sanguineus* is native to the western Pacific Ocean, and was introduced to the east coast of North America beginning in New Jersey prior to 1988. In the Northwest Atlantic *H. sanguineus* preys on native dog whelks, *Nucella lapillus*. The foraging strategy “winkling” (i.e. probing by the crab to remove gastropod tissue without breaking the shell) is most effective for crabs when snails have relatively large apertures. Consumption of larger gastropods through winkling by the crabs is well-documented, however, male *H. sanguineus* have claws about 5x larger than females and the impact of this sexual dimorphism on winkling behavior is not well understood. Here we investigated whether *N. lapillus* with larger aperture and lower retraction ability were more susceptible to winkling. Male and female crabs were given a choice of three *N. lapillus*, ranging in size (small, medium and large), each trial lasting 3 d. Our results indicate that female *H. sanguineus* more likely to winkle *N. lapillus* than male *H. sanguineus*. Additionally, smaller *N. lapillus* having a lower retraction ability and larger aperture width were more vulnerable to winkling. We discuss how the winkling foraging strategy by this invasive crab may be a novel selective force on *N. lapillus* shell morphology.

Behavioural assessment of a sea anemone impact - an example using *P. papillosa* and native sea anemone species

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Human activities and environmental changes have significantly increased the introduction of non-native species (NIS) into marine habitats, posing serious challenges to biodiversity conservation and ecosystem management. This study adopts a comprehensive approach to assess the invasive potential of a recently introduced sea anemone species on the Portuguese intertidal zone, through behavioral analysis of its interactions with native species under controlled conditions.

Restricted to the rocky intertidal zone, *P. papillosa* is likely to compete with native species, particularly those within the same functional group. Aggressive interactions with six native sea anemone species were observed, with *P. papillosa* dominating three species of the genus *Actinia* and exhibiting comparable behavior to *A. viridis*. This behavioral dominance may adversely affect the spatial distribution of native *Actinia* species.

Testing marine alien biofouling detection devices in poorly investigated Sardinia sites (Mediterranean Sea)

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The assessment of marine alien species distribution, areas at high risk of introduction, pathways and vectors of introduction are essentials for effective management and conservation programs. Sardinia in the second biggest island of the Mediterranean Sea, with a coastline of about 1,850 km, located in the centre of the Western basin influenced by maritime traffic and natural larval dispersal. In the framework of an Interreg Marittimo Italy-France project devoted to limit, manage and survey actions related to the introduction of invasive alien species in this area, we tested the applicability and feasibility of marine alien detection devices. Despite biofouling studies have been performed in north side in the past, paucity of data is available in the Gulf of Oristano (Western Mediterranean, Sardinia, Italy), where many potential alien species "entry gates" are present, such as: marina, commercial harbour and aquaculture plants. The early warning proposed protocol focuses on about 20 target species thriving on PVC panels (both sessile and vagile), from 3 different sites and 4 seasons. Results revealed the occurrence of 16 species reported for the first time in the study sites. The standardized approach aims to be replicated cross-border in order to simplify the detection of potential invasive species.

Recruitment rates of non-native fouling species in one-year survey in the Gulf of La Spezia (Ligurian Sea, Italy)

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In the marine environment, the introduction of non-native species (NNS) is strongly associated with the maritime traffic, making port monitoring crucial for the early detection of NNS. Surveys conducted in ports are usually carried out in summer to collect samples during the maximum growth of fouling, but the recruitment rate of NNS during the different seasons is poorly investigated.
In this context, a study of the succession of fouling communities was carried out for a whole year in three marinas within the Gulf of La Spezia (Western Mediterranean Sea, Italy) with the aim of testing the best period to detect the maximum number NNS. The fouling communities were assessed monthly by using PVC panels following a standardized protocol developed by the Smithsonian Environmental Research Center. One set of panels was immersed for a full year (May 2021-April 2022), while another set was replaced every 3 months. After one year, the total number of species was higher than in the first three months, but the number of NNS was comparable. On the other hand, the fouling communities recruited in the autumn period recorded the higher number of NNS, with a new record for the area, namely the serpulid *Spirobranchus tetraceros*.

Characterization of marine macrofauna on floating pontoons in harbours of the Canary Islands

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The current state of the oceans and their biodiversity is a global concern. Species introductions are considered one of the main threats, capable of generating significant ecological, economic, and social impacts. The Canary Islands, a strategic hub for both recreational and commercial maritime traffic, have harbour environments that act as key entry, establishment, and dispersal points for non-native species—particularly in the main islands of Tenerife and Gran Canaria. This study focuses on the submerged sections of floating pontoons, common harbour structures in the region that support diverse and distinctive marine communities. Surveys were conducted across harbours on Tenerife, Gran Canaria, La Palma, and El Hierro. This work presents the first illustrated taxonomic catalogue of marine macrofauna inhabiting floating pontoon harbours in the Canary Islands, documenting over 140 species across 12 phyla. Among these, at least 20 are currently classified as non-native, including several first records for the archipelago. Additionally, marine citizen science data from the Canary Islands Marine Environment Observers Network (RedPROMAR) were integrated to expand the spatiotemporal scope of exotic species records. The findings provide a valuable tool for decision-making in harbour management and non-native species monitoring across the archipelago.

First record of cup orange coral *Tubastraea coccinea* Lesson, 1829 and other non-indigenous species transported by Offshore Supply Vessel (tugboat type)

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In the southwestern Atlantic, the invasive cup orange coral, *Tubastraea coccinea*, was first recorded fouling an oil platform off the Brazilian coast before spreading to natural habitats, with an estimated expansion rate of 2.1 km yr^{-1} on marginal reef systems. Its rapid spread along the Brazilian coast is widely attributed to hull fouling, as *T. coccinea* has already been detected on distinct oil and gas structures. This is a novel record of nine colonies found on the hull of an offshore supply vessel in dry dock on May 9, 2024, in Niterói, Brazil (-22.87727, -43.12882). The colonies were documented on the underside, with diameters ranging from 1.2 cm to 5.4 cm. In addition, five other non-indigenous species were recorded: octocoral *Carijoa* sp., green mussel *Perna viridis*, bivalve *Isognomon bicolor*, cirripedium *Megabalanus cocopoma* and bryozoan *Schizoporella errata*. To date, there have been no recorded instances of *T. coccinea* presence on a vessel of the tugboat type, which typically operates at an average speed of 10 knots. This finding underscores the role of vessels as primary vectors for the dispersal of non-indigenous species, emphasizing the importance of implementing biofouling control measures across various types of vessels.

Aquaculture and non-indigenous species: an overview of the introductions, impacts, and regulations

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Aquaculture plays a pivotal role in global food production, yet it is also a significant pathway for the introduction of non-indigenous species (NIS) into aquatic ecosystems. These introductions (both intentional and accidental) can have severe cross-sectoral consequences, ranging from ecological to socioeconomic.

Although regulatory frameworks have been established at local, national, regional and international levels to prevent new introductions and mitigate NIS risks, their effectiveness remains inconsistent. Examples of measures to reduce potential risks associated with NIS introductions include the ICES *Code of Practice on the Introductions and Transfers of Marine Organisms* and the *EU regulation No 708/2007* concerning the use of alien and locally absent species in aquaculture.

This review identifies key NIS cultivated and hitchhiker species linked to aquaculture, their major impacts, and current regulations and management measures. A systematic literature review was performed using keywords associated with NIS and aquaculture. Policy strengths, weaknesses, and opportunities wereaddressed through the analysis of case studies to derive lessons learnt from both successful and unsuccessful examples. Our conclusions highlight the importance of harmonized approaches and adaptive management to ensure aquaculture sustainability alongside ecosystem preservation.

Aquaculture under stress: the arrival and expansion of invasive tunicates in a coastal lagoon mussel production area

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Aquaculture is a vector for the introduction of non-indigenous species (NIS), but is also one of the economic sectors that suffers most from the negative impacts caused by biological invasions. This work was developed in Lagoa de Albufeira, a semi-enclosed coastal lagoon located on the southwest coast of Portugal. Traditional small-scale mussel aquaculture has been practiced in the lagoon since 1980 but in 2017 the aquaculture producers reported high production losses, associated with the arrival of invasive species, namely Styela plicata and Ciona robusta. Seasonal sampling surveys were conducted to assess the % cover of fouling communities on mussel rafts in 2019-2021 and in 2025. Of the 120 species identified, 25% were NIS, with tunicates and bivalves with a higher number of NIS. The results of a PCO ordination and PERMANOVA tests showed that the fouling communities changed between years and seasons, but also between mussel rafts in productive activity and others inactive, in which there was no replacement of mussel seeds or cleaning of the fouling communities. A major change was the arrival of Didemnum vexillum in 2020. This study showed that the translocation of shellfish might be the transport vehicle for NIS, which cause damage to aquaculture production.

Marine debris as substrate and dispersal vector for non-indigenous species in Madeira Archipelago

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Marine debris (MD) is a transport vector for diverse marine communities, including non-indigenous species (NIS). This study investigated the role of MD as a substrate for NIS colonisation and dispersal vector in Madeira waters by examining three MD categories: floating (FMD), seafloor (SMD), and beached (BMD). Opportunistic sampling, conducted in collaboration with local maritime stakeholders, recorded MD sightings with photographs and GPS coordinates. 92 MD items were inspected, revealing 108 fouling species from 11 phyla, 13% of which were identified as NIS. SMD hosted the highest proportion of NIS (9.6%), followed by BMD (4.4%) and FMD (3.9%). The study confirms FMD as both a substrate and a vector for NIS dispersal in the region. Biogeographic analyses, oceanographic modelling, and identification marks highlighted the North Atlantic Subtropical Gyre as a significant pathway, transporting MD from the Wider Caribbean, North America, and the Iberian Peninsula to Madeira within 2–3 years. These findings underscore Madeira's role as both a recipient and source of MD, with clear implications for NIS introductions and secondary spread. The study highlights the need for standardised monitoring, stronger stakeholder collaboration, and proactive MD management to mitigate NIS risks and safeguard Macaronesian marine ecosystems.

NUI-PLASTIC: Impact of marine plastic debris on the settlement and dispersion of nuisance species in Portuguese coastal ecosystems

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Plastic pollution and non-indigenous species (NIS) are major threats to marine ecosystems, often acting synergistically to disrupt biodiversity and ecosystem function. The NUI-PLASTIC project introduces a pioneering, interdisciplinary approach to assess the role of plastic debris as a vector for NIS in Portugal's coastal ecosystems. Focusing on recreational marinas - known hotspots for both plastic litter accumulation and biological invasions - the project spans mainland Portugal and São Miguel Island (Azores), capturing regional ecological differences. The project aims to: (1) conduct extensive, seasonal sampling of floating plastic litter in six marinas over two years; (2) test how different plastic types influence biofouling by deploying panels made of various polymers (e.g., polyethylene, PVC); (3) use deep learning, including convolutional neural networks, to detect and classify plastic litter efficiently; (4) apply morphological and DNA-based methods to characterize the biota colonizing plastics, from microbes to invertebrates; and (5) analyse seasonal and geographic patterns in species colonization, with a focus on nuisance and invasive taxa. This novel methodology will generate unprecedented data on species-plastic interactions and inform evidence-based strategies for managing marine litter and biological invasions. The outcomes will support conservation, policy, and public engagement, promoting healthier and more resilient coastal ecosystems.

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