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Tiralongo, F

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Rui Rosa,
University of Lisbon, Portugal

*CORRESPONDENCE
Francesco Tiralongo
francesco.tiralongo@unict.it

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Editorial: Biological invasions in the Mediterranean Sea

Francesco Tiralongo[1,2]*, Jason Michael Hall-Spencer[3], Ioannis Giovos[4] and Periklis Kleitou[5]

[1]Department of Biological, Geological and Environmental Sciences, University of Catania, Catania, Italy, [2]Ente Fauna Marina Mediterranea, Avola, Italy, [3]School of Biological and Marine Sciences, University of Plymouth, Plymouth, United Kingdom, [4]iSea, Greece, Greece, [5]Marine & Environmental Research (MER) Lab, Limassol, Cyprus

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Editorial on the Research Topic
Biological invasions in the Mediterranean Sea

In an era of climate change and escalating transformations in ecological settings, the Mediterranean Sea is recognized as a hotspot of global biotic and abiotic changes (Moullec et al.). With a semi-enclosed-and-locked configuration affected by physical, oceanic, and atmospheric processes (Bas, 2009), the Basin is characterised by well-defined mosaics of contrasting ecosystems that make it an appealing natural laboratory for the study of natural and human-induced changes (Aurelle et al., 2022).

In the last decades, human activities have caused an imposing upsurge of Non-Indigenous Species (NIS) establishments in the Mediterranean Sea, at rates that have been unprecedented, globally (Zenetos et al., 2022). A major driver of NIS introductions are the successive enlargements of the Suez Canal, from 1960s to date, which have established a permanent sea-level waterway connecting thermophilic species of Indo-Pacific origin from the Red Sea to the Mediterranean Sea (Galil et al., 2017). Introduced species can cause a range of impacts, from ecosystem shifts and biodiversity reductions, to provision of ecosystem services and fishery benefits (Kleitou et al., 2021a; Tsirintanis et al., 2022; Kleitou et al., 2022).

Despite a growing scientific literature published in recent years (Figure 1), the absence of adequate empirical data has been emphasized as a major bottleneck for understanding the different facets and dynamics of Mediterranean bio-invasions (Galil et al., 2018; Kourantidou et al., 2021; Kleitou et al., 2021b). A bibliometric search in Scopus, using the terms "Alien Species" OR "Invasive Species" OR "non-native species" OR "non-indigenous species" OR "non indigenous species" OR "non native species" OR "Invasive Alien Species" AND "Mediterranean Sea", was made on 07 August 2022 and identified a total of 1329 references with over 80% of the references published after 2010 (Figure 1). Indeed, an analysis, of keywords with at least eight co-occurrences, using the VOSviewer software 1.6.18 (Van Eck and Waltman, 2010), extracted 106 keywords that were mostly related to countries, introduction routes, and taxonomic groups (Figure 1),

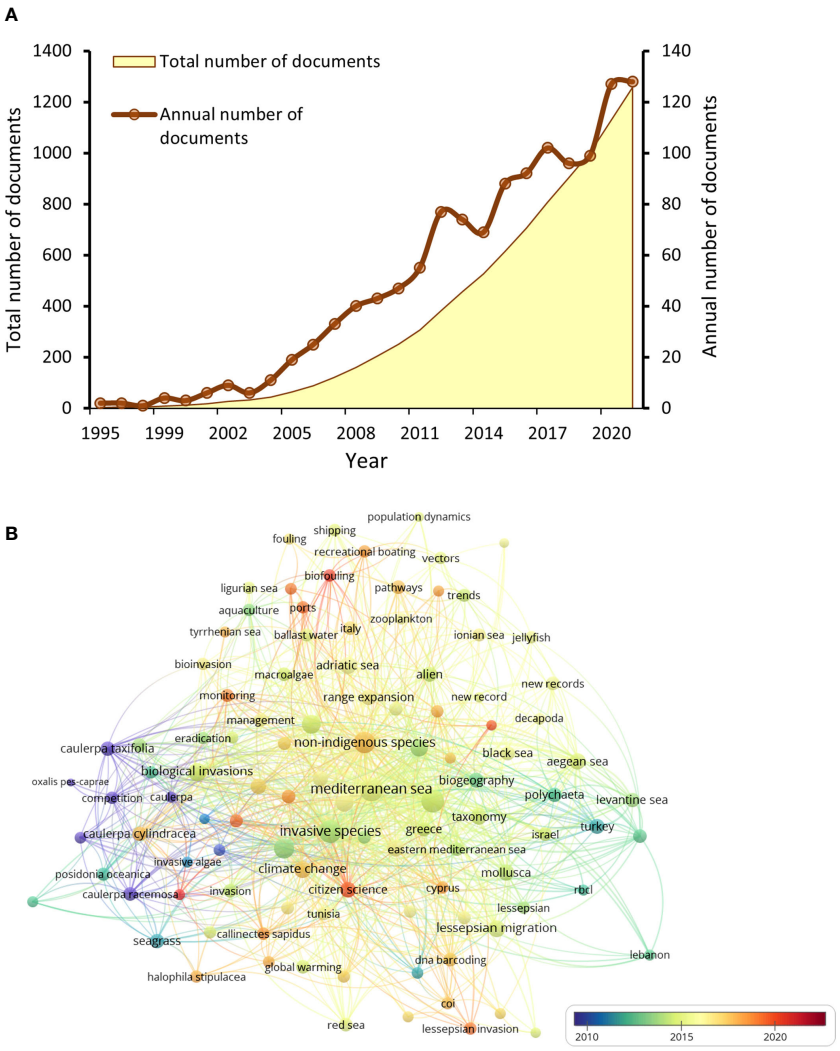

FIGURE 1
(A) Number of documents published in Scopus, extracted using the terms "Alien Species" OR "Invasive Species" OR "non-native species" OR "non-indigenous species" OR "non indigenous species" OR "non native species" OR "Invasive Alien Species" AND "Mediterranean Sea", on 07 August 2022. **(B)** Connection and average publication year for each keyword (with at least 8 occurrences) used in the extracted documents.

indicating that most studies might focused on detection and distribution monitoring with limited information to elucidate the complex dynamics of biological invasions.

In this context, this Research Topic (RT) intended to provide novel information about NIS biology and ecology in the Mediterranean Sea and promote successful management practices. Within the RT, a total of 12 novel and impactful articles covering diverse topics were published.

Three of the articles focused on lionfish (*Pterois miles*), a recently introduced NIS in the Mediterranean Sea with the potential to cause ample negative effects in the marine ecosystems (Kletou et al., 2016). Gavriel et al. used an acoustic telemetry system to monitor the diel activity and depth preference of lionfish within its native range (Red Sea). During the study, the lionfish demonstrated flexible and wide niche-breadth characteristics that potentially facilitated its invasion success. In a global collaboration of 25 researchers, Ulman et al. reviewed and synthesized experiences from two decades of lionfish management in the Western Atlantic to give policy recommendations for their management in the Mediterranean Sea. A strong highlight of the study was the importance of participatory management to effectively tackle the invasion, including the frequent removal by SCUBA divers, the development of recreational and commercial lionfish fisheries, and the development of a market. In another article, Ulman et al. compiled data from published literature and grey literature to provide a comprehensive review of predators for lionfish and the poisonous and invasive silver-

cheeked toadfish (*Lagocephalus sceleratus*). The review identified many natural predators highlighting the importance of renewed effort towards prioritizing the rebuilding of their populations in the Mediterranean Sea. However, the low predation frequency suggested that control may require proactive, targeted human removals of the invasive species [e.g. Kleitou et al. (2021c)].

Three other articles focused on the *Caulerpa cylindracea*, a species characterised as one of the most invasive NIS in the Mediterranean with a capacity to rapidly colonize and alter native assemblages (Klein and Verlaque, 2008). Caronni et al. investigated gametogenesis and spawning events by *C. cylindracea* in the Tyrrhenian Sea using a combination of a field and laboratory experiments. The authors provided novel information about the timing, intensity, and frequency of the species' sexual reproduction showing that it can play an important role in the dynamics of the species spread. Water motion was the most important abiotic factor for gametogenesis and spawning while temperature had also a secondary additive effect. Santamaria et al. studied the diets of four of the most abundant omnivorous Sparidae species in the Mediterranean Sea to understand the foraging selectivity, magnitude and frequency on *Caulerpa cylindracea*. Low particle-size selection scores indicated that all species avoided feeding on the invasive alga. However, several individual specimens were found to have consumed high amounts of *C. cylindracea* suggesting that they could play a role in controlling its expansion. Miccoli et al. combined diet analysis, phenology, as well as biological and chemo-ecological biomarkers to elucidate potential contribution of *C. cylindracea* digestion in Abnormally Tough Specimen (ATS) anomalies of male white seabream *Diplodus sargus* in the Tyrrhenian Sea. The authors highlighted direct trophic interactions between the two species but further studies are needed to establish whether the algae or its metabolites are directly responsible of the anomaly.

Goldberg et al. used controlled mesocosm experiments and found that the invasive rabbitfish (*Siganus rivulatus*) significantly reduced its food consumption when exposed to chemical alarm cues released from a recently killed conspecific fish. The results signified that a healthy ecosystem with high density of piscivores and hence predation, or an artificial introduction of predation cues, could mitigate the impact of the herbivorous rabbitfish. Edelist et al. combined multidisciplinary approaches including citizen-science, oceanographic models, and molecular tools to track the connectivity and dynamics of the Indo-Pacific jellyfish *Rhopilema nomadica* off Israel. They produced vital information about bloom formations and found decentralized swarm origins with similar genetic structure, interannual differences, and high offshore transport of the swarms. Tamburini et al. used a standardized monitoring protocol to assess spatial and temporal changes in the structure of fouling communities in the Ligurian Sea. Through its application, authors detected many new NIS arrivals and showed its potential for upscaling in the Mediterranean Sea to provide a standard monitoring platform for long-term data collection.

In a novel work, Guastella et al. demonstrated how micropaleontologic analysis of sedimentary cores coupled with radiometric dating can be used to reliably date the first arrival and to reconstruct temporal trends of taxa having mineralized remains such as the alien foraminiferal species *Amphistegina lobifera* and its cryptogenic congener *A. lessonii*. In one of the most comprehensive studies on ascidians in the Mediterranean Sea, Virgili et al. combined bathymetric and habitat mapping, extensive transect and photo-quadrat sampling, and a morphological and molecular study to elucidate the ascidians presence in the marine reserve of the Miseno Lake. The study revealed a massive but so far overlooked presence of NIS and highlighted the importance of monitoring programs to achieve solid NIS management and protect vulnerable marine reserves. Finally, Sala et al. investigated the metabolomics of a colonial non-indigenous tunicate (*Botrylloides niger*) in the Fusaro Lake, and identified nutraceuticals and bioactive natural products that could be exploited to turn the species from a threat into a resource.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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