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Contribution to the Theme Section 'Species range shifts, biological invasions and ocean warming'

INTRODUCTION

Species range shifts, biological invasions and ocean warming

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ABSTRACT: Marine species are moving beyond their native geographical ranges in response to climate change and shifts in other abiotic conditions, establishing populations at higher latitudes. At the same time, species are introduced into new marine regions as a consequence of an increasingly connected world. The success of such range expansions, whether from shifts associated with climate change or human-mediated introductions, depends on the biotic interactions and environmental conditions at the recipient site and/or the capacity of species to adapt to these new conditions. Originating from a special session held at the Association for the Sciences of Limnology and Oceanography (ASLO) Aquatic Sciences Meeting 2021, the present Theme Section (TS) brings together the current research on 2 interrelated marine ecological topics: (1) invasive species in a warming ocean, and (2) climate-mediated species range shifts. Our investigation of the temporal trends in publications highlights that only one-tenth of studies on marine invasive species examine the species' interaction with ocean warming. The topic of range shifting species receives slightly more attention than climate driven invasions, but both exhibited a comparable, similarly fast-growing publication rate. Overall, the papers in this TS provide evidence that global warming, and occasionally environmental degradation, are crucial factors altering the distribution of both marine invasive species and range-shifting species. Even though the published literature and even the contributions to this TS only infrequently focus on the interaction between these 2 topics, we propose that future collaboration between scientists from both fields would advance our understanding of the impact of global warming on the shifting distributions of native and invasive species and would allow the development of conservation and management plans in a warming ocean.

KEY WORDS: Invasive species · Exotic species · Climate change · Range expansion · Range contraction · Climate-driven shifts · Species distribution · Global change

Species moving into new geographic areas can occur through human-mediated processes, like biological introductions, or natural range shifts in response to changing environmental conditions like global warming. While humans have been moving species around the world for thousands of years, the rate of introduction has increased drastically in the past 200 yr due to globalization (Seebens et al. 2017) and is expected to continue to rise steeply within the next 3 decades (Anton 2021, Seebens et al. 2021). A changing climate may facilitate the successful establishment of introduced species, especially of those introduced to locations where thermal conditions resemble those in the species' native range (Iacarella et al. 2015, Hulme 2017, Wesselmann et al. 2020). Similarly, such environmental matching plays a role

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in climate-driven range shifts, which occur over shorter distances and at a slower pace, depending on how fast the local climate changes (Parmesan & Yohe 2003, Sorte et al. 2010, Blackburn et al. 2011).

Reconstructing the historical range of marine invaders and range-shifting species driven by ocean warming allows us to address their vulnerability, resilience and success. Ecological impacts resulting from biological invaders and range-shifting species vary. In the marine environment, around 10% of introduced species become invasive, causing significant ecological impacts (Anton et al. 2019, 2020). The impacts of range shifts are highly variable: some are comparable to those of invasive species (Sorte et al. 2010), while others are low or even absent in the recipient communities, due to shared evolutionary history with the range-shifting species (Simberloff et al. 2012).

We investigated the temporal trend in the publications listed in the ISI Web of Knowledge for 3 main themes (e.g. marine biological invasions, marine range shifts and marine invasions within the context of global warming), revealing a time lag in the increase in the number of publications between the first theme and the other two (Fig. 1; see figure legend for details on the search). The study of biological invasions began to emerge in the late 1950s (after the publication of Elton 1958), but it was not until ca. 1975 that research efforts in the marine realm expanded (Richardson & Pyšek 2007). Nowadays, there are over 7000 publications focused on marine biological invasions, but only one-tenth of these studies focuses on the interaction with ocean warming (Fig. 1). In addition, the topic of range-shifting species receives currently slightly more attention than invasions in a warming ocean (1251 and 794 publications in total, respectively), but both exhibit a comparable trend of increase in the number of publications in the past 2 decades (Fig. 1), with the first study on invasions in the 1990s (Hockey & van Erkom Schurink 1992) and earlier studies on species range shifts dating back to the late 1980s (Matsuura et al. 1988). To showcase the research advancement in the combined field of species range shifts and invasion in a warming ocean, a special session was held at the Association for the Sciences of Limnology and Oceanography (ASLO) Aquatic Sciences Meeting in June 2021, from which this present Theme Section resulted.

The contributions in this Theme Section (TS) show how the distribution of native or invasive species may change following climatic events or environmental degradation. These results are based on different methodological approaches, including genetic techniques and transplant experiments with the gorgonian coral *Paramuricea clavata* to evaluate local adaptation (Sartoretto et al. 2024, this TS). Additionally, emerging methodologies like digital methods for passive data mining were employed to track the northward distributional range shift of the white grouper *Epinephelus aeneus* (Sbragaglia et al. 2024, this TS). Extensive fieldwork surveys were conducted of two range-expanding whelk species (Waite et al. 2024, this TS), while laboratory experiments and modelling were utilized to examine the westward expansion of the jellyfish *Rhopilema nomadica* and loggerhead turtles *Caretta caretta* in the Mediterranean Sea (Dror & Angel 2024, Santidrián Tomillo et al. 2024, both this TS). The studies span a variety of bioregions, including Arctic (focus on marine mammals; Land-Miller et al. 2024, this TS), tropical and temperate environments. Studied taxa involve several sessile or mobile species (including economically valuable species such as American lobster *Homarus americanus*; Huizenga & Oviatt 2024, this TS) that change their distribution through different dispersal mechanisms, such as adult movement and larval dispersal (Aceves-Medina et al.

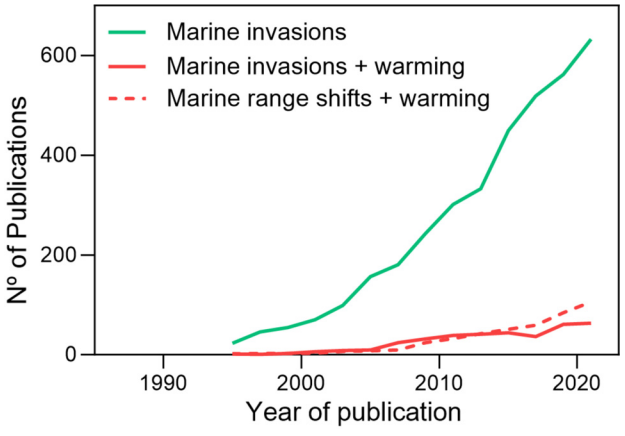

Fig. 1. Change over time in the number of publications between 1985 and 2023 on marine invasive species, marine invasions fuelled by warming, and climate-driven range shifts. Literature search on ISI Web of Science: Results for marine (Topic) AND species (Topic) AND invasi* OR exotic OR 'non native' OR 'non-native' OR 'non indigenous' OR 'non-indigenous' OR introduced OR alien (Topic) = 7641 publications. Results for marine (Topic) AND species (Topic) AND invasi* OR exotic OR 'non native' OR 'non-native' OR 'non indigenous' OR 'non-indigenous' OR introduced OR alien (Topic) AND 'temperature' NEAR/3 'increase*' OR 'temperature' NEAR/3 'rise*' OR warming OR 'marine heatwave' (Topic) = 1251 publications after screening the abstract. Results for marine (Topic) AND species (Topic) AND 'shift*' NEAR/5 'distribution*' OR 'shift*' NEAR/5 'range*' OR 'range expansion' OR 'range extension' (Topic) AND 'temperature' NEAR/3 'increase*' OR 'temperature' NEAR/3 'rise*' OR warming (Topic) = 794 publications after screening the abstract for suitability

2024, Adams et al. 2024, both this TS). Notably, the articles published in this TS do not reflect the trends in the research interest of authors in the topic of invasions and range shifts driven by ocean warming (Fig. 1), as 90% of the contributed papers were dedicated to range shifts, and only one paper studies marine invasions (Dror & Angel 2024). Instead, they highlight global warming, occasionally coupled with environmental degradation, as a significant driver reshaping the distribution of both marine invasive species and range-shifting species. While the interaction between these topics is infrequently the focus in the current literature (Lo Bruto et al. 2011, Parravicini et al. 2015, Figueira et al. 2019, Pessarrodona et al. 2019), including the contributions to this TS, we propose that an increase in the collaboration between scientists from both disciplines would enhance our understanding of the impact of global warming on the shifting distributions of native and invasive species and would allow the development of conservation and management plans, to assure a sustainable future of a warming ocean.

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