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**EDITORIAL**

# Biological Invasions in Marine Ecosystems: Amphipods (Crustacea: Amphipoda) as a Model Group

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The introduction of non-indigenous species (NIS), deliberately or unintentionally, by means of human action, is considered one of the major threats to biodiversity and ecosystem functioning worldwide [1]. Some of these species successfully establish, spread rapidly into new locations, and become invasive, altering ecosystem services and causing both significant ecological and socio-economic impacts [1,2].

In the marine environment, the number of NIS has increased dramatically in the last decades [3] driven particularly by the intensification of shipping (both commercial and recreational), aquaculture activities, aquarium and life seafood trade, and the construction and formation of new transportation corridors [1,4]. Consequently, regulations and policies (e.g., the Marine Strategy Framework Directive, the GloBallast Programme, the EU Biodiversity Strategy, the Invasive Alien Species Regulation (EC 1143/2014)) have been adopted to ensure the prevention and early detection of these species, which have been recognized as the only viable and cost-effective strategies for their control and management [5,6].

Crustaceans are among the most successful aquatic invaders around the world [7,8], mainly due to their ability to colonize and easily adapt to different substrata, their high plasticity in trophic strategies, and their broad tolerance of a wide range of environmental conditions [8]. Among marine crustaceans, one of the taxa most frequently recorded outside of their native ranges is amphipods [8], small in-

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vertebrates that form an important trophic link between primary producers and higher trophic levels [9]. Amphipods live mainly as epibionts of a wide variety of natural substrata (e.g., macroalgae, ascidians, hydrozoans, sponges, etc.) [10,11], but are also very successful colonizers of artificial ones (e.g., buoys, ropes, wheels, vessel hulls, and pontoons), being frequently associated with fouling communities of ports and marinas, where they can reach high densities under optimal environmental conditions [12,13]. Like other peracarid crustaceans, amphipods have direct development, i.e., they lack a pelagic planktonic larval stage, and have also limited swimming capabilities [12]. However, despite this, they can be dispersed over long distances by rafting on floating substrata [12] or by anthropogenic vectors (such as ballast water and vessel hull fouling) [14,15], favoured for their small body size and morphology, which is well adapted to strongly cling to these types of substrata. In addition, these marine invertebrates are characterized by high fecundity and growth rates, have broad environmental and trophic plasticity, and some species show aggressive intra- and interspecific behaviour [16-19]. All these biological traits seem to facilitate the colonisation of new areas and competition with native species, therefore, making amphipods a good model group to understand marine invasions.

In the last two decades, introduced amphipods have been reported with increasing frequency around the world [6,20-22]. However, the number of introduced species is still underestimated due to the presence of cryptogenic species (those that cannot be demonstrably classified as native or non-native in a region) and because these marine organisms are easily overlooked due to their small size and complex identification [20]. An accurate morphological identification of amphipod species requires examination of numerous characters, some of which are difficult to observe and generally show a considerable amount of intraspecific variation (e.g., ontogenetic variation and sexual dimorphism) [23,24]. Furthermore, amphipods are easily mistakenly identified due to the morphological uniformity between some closely related species [6,20], but also due to the existence of cryptic species (those that are genetically distinct but lack morphological differentiation), which has been widely reported for these organisms [23,25-27]. Consequently, the identification of NIS amphipods using only morphological approaches presents significant challenges to ensure an early detection of these species and, thus, to control their establishment and further spread. For this reason, the use of an integrative approach, i.e., combining morphological and molecular methods (e.g., DNA barcoding and (e)metabarcoding), has been suggested as the most reliable and cost-effective approach to managing biological invasions [28]. In this context, these analyses have allowed the recognition of cryptic species and NIS present at low abundances [23,27,29,30], but also have helped to unravel the likely origin and introduction pathways of these marine species [22,26,29].

Despite the research advances, knowledge on amphipod invasions is far from being complete. Further studies involving scientific collaboration among experts from different disciplines (taxonomists, molecular scientists, and invasion ecologists) are needed to fill the existent gaps and, therefore, guarantee the proper identification and management of these important marine crustaceans.

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