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The Mediterranean in check: Biological invasions in a changing sea

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Abstract

In recent decades, the high introduction rate of alien species (AS) has been mainly due to the increasingly widespread human movements, which often compromise natural barriers, facilitating the invasion of new geographic areas and environments. Being completely new in the recipient habitat, alien invasive species can often have strongly negative impacts on native communities, sometimes causing substantial and irreversible ecological and economic damage. Thus, AS have been branded as "negative" and are often targeted for eradication. However, an accurate assessment of ecological and economic impacts of alien taxa is still lacking in many species, and this is particularly true in marine environments. We focused on the Mediterranean Sea, a very important marine biodiversity "hot spot," which is among the areas that have been most influenced by the arrival of non-native species, a process also linked to global warming, leading to a deep transformation of this basin. We describe both negative and positive aspects of some well-known introductions, assuming a different view of conservation. Biological invasions are, in fact, a fundamental and integrated aspect of nature that has always been present in the history of life on Earth. Imagining that nature is static and needs to be restored to a particular state is not a reasonable way of looking at the processes of life. With this in mind, we argue that defining priorities in management and conservation is a prerogative that should not be based on the containment/eradication of one or another species, but on the conservation of those environmental conditions that are essential for the proper functioning of ecosystems. In other words, native versus non-native species distinction cannot be the main guiding principle in conservation and restoration. For this reason, great attention must be paid to the containment of those human activities that cause greater pollution and rapid changes, and therefore threaten the habitats and biodiversity that we care about most.

KEYWORDS
conservation, ecological and economic effects, impact, Marine alien species, Mediterranean Sea

1 | INTRODUCTION

In the last century, human activities led to rapid and drastic changes in global biodiversity, caused by several factors, including biological invasions by alien species (AS). Biological invasions, which have captured the attention of the scientific community since the 1990s (Carlton, 1996, 1999; Darrigran, 2002), are today considered one of the most serious threats to biodiversity, only second to habitat destruction (Davis et al., 2011; Early et al., 2016; Otero, Cebrian, Francour, Galil, & Savini, 2013; Simberloff, 2014; Simberloff et al., 2013).

Although species dispersal and invasion of new habitats have occurred throughout the history of life on Earth as a fundamental and integrated aspect of maintaining the structure of nature, an important issue is the fast rate at which invasions are today taking place facilitated by human activities (Ojaveer et al., 2018). This accelerated introduction rate does not follow the normal time scales for colonization repeated over millennia (Richardson & Ricciardi, 2013). Nowadays, human-mediated dispersal has strongly altered species distribution, converting previously separated continents and islands into one single “biological supercontinent” (Capinha, Essl, Seebens, Moser, & Pereira, 2015). Consequently, marine communities consist of both long-term native species and AS that in some regions can contribute to local biodiversity with up to more than half of all the species (Schlaepfer, 2018).

The current attention on AS is justified by pressing concerns about the consequences of their introduction to recipient environments in which they have not co-evolved with resident species. Being completely unknown to the new community, AS may become invasive, displacing native species, modifying habitat structure, producing trophic web shifts and often reducing biodiversity (Darrigran & Damborenea, 2011). Numerous studies indeed demonstrate that biological invasions drive the decline of species at local and regional scale all over the world (e.g. Gilbert & Levine, 2013; Roy et al., 2012). This is the case for terrestrial systems such as the introduction of predators and pathogens on islands (Davis et al., 2011; Sagoff, 2005). However, few extinctions of native marine species caused by AS have been reported. In this environment, newcomers seem to fit in with limited impacts on other species (Geburzi & McCarthy, 2018; Giangrande, Licciano, et al., 2014; Gurevitch & Padilla, 2004; Yapici & Filiz, 2019). Therefore, as suggested by Thompson (2014), we should determine whether a species itself is the problem and not the consequence of other problems before considering the AS as harmful by definition. Instead, the possible negative impacts of AS often mark all of them as targets for control and eradication (Russell & Blackburn, 2017), with the risk of making additional damages to the native habitat.

Although the scientific interest in the presence of AS in the marine environment started later than in the terrestrial environment, biological invasions are a growing concern also in the marine environment for both conservation and economic activities (Giakoumi et al., 2019; Katsanevakis et al., 2014; Occhipinti-Ambrogi & Galil, 2010; Perrings et al., 2002), and a lot of studies claim that the introduction of AS affects diversity, structure and functioning of marine ecosystems (Corriero et al., 2016; Galil, 2007; Pimentel, Lach, Zuniga, & Morrison, 2000; Stachowicz & Byrnes, 2006; Thomsen, Olden, Wernberg, Griffin, & Silliman, 2011).

In Europe, impacts of biological invasions are considered as one of the many variables to address in management decisions, and the European Commission's Marine Strategy Framework Directive addresses the issue of marine invasions, by indicating the number of introduced species as one of the descriptors needed for assessing ecological status in European marine waters (Palialexis et al., 2015), with some biological indexes proposed as well (Çinar & Bakir, 2014).

However, an accurate assessment of such ecological and economic impact is still lacking in most cases (Courchamp et al., 2017), particularly in the marine environment, where quantitative methodologies, elsewhere applicable to prioritizing management and conservation, are currently unavailable or at an early stage (Dick et al., 2014; Giakoumi et al., 2019; Ojaveer et al., 2015; Perrings et al., 2002).

An attempt to summarize the impact of AS on biodiversity and ecosystem functioning in European seas can be found in Katsanevakis et al. (2014). The authors, considering a wide range of ecological services from food provision, water purification and climate regulation to aesthetic values and recreation and tourism, found most of them negatively impacted by the presence of AS. In the present paper, we focus on the Mediterranean, a basin characterized by high biodiversity as the product of its geological history, with remarkable and consistent changes that repeatedly occurred in the past. In the Mediterranean, changes have occurred over tens of millions of years, involving the composition of flora and fauna, with historical invasions by species of both boreal and subtropical affinity (Bianchi & Morri, 2000). However, now we are witnessing changes that occur at extremely accelerated speeds (Ojaveer et al., 2018).

The general perception that AS are apocalyptic threat to biodiversity is true even for the Mediterranean. In this context, we wish to underline some specific case studies of species introductions, speculating on their possible positive effect in light of climate change and conservation, and on the possibility that in most cases the time of investigation has not been long enough to understand their real impact.

2 | DEFINITIONS AND OPERATIONAL PROBLEMS

Semantic issues often trigger or confound debates in this field. For example, the definitions of “alien” and “invasive” create some confusion because ecologists do not always define them the same way (Colautti & MacIsaac, 2004). Some works refer to non-indigenous species (NIS; Occhipinti-Ambrogi & Galil, 2004); others refer to species strongly increasing their population density and spreading widely into new habitats (Blackburn et al., 2014; Katsanevakis et al., 2011). Although the majority of invasive species are alien, some native species may also become invasive under altered environmental conditions. Jellyfish blooms in the Mediterranean Sea are a good example; such blooms are caused by both native and introduced species (Boero, 2013). It is however evident that AS have much stronger ecological and socio-economic impact than native species that, for various reasons, undergo range expansions or increase in abundance to become “weedy” (Simberloff, 2014) and the negative impacts of alien consumers generally seem to be greater than those of native consumers (Paolucci, MacIsaac, & Ricciardi, 2013).

Invasion ecology is an interdisciplinary field where ecology, social sciences, resource management and public perception overlap. The problem of bioinvasions is of regional importance, with the potential of altering the exchange patterns between regions and neighbourhoods (Corriero et al., 2016; Vanderhoeven & Branquart, 2010).

The study of new arrivals at an ecosystem level involves interdisciplinary synergism, and accurate analysis of species distributions and movements often requires international co-operation to define issues of provenance and to assess possible risks related to commercial exchanges. It is often difficult even to define the concept of “harm” for natural systems and especially difficult to predict how an introduced species will behave in its new habitat (Sagoff, 2005).

Biological invasions are effective when introduced species find favourable conditions in the new environment. Thus the success of AS depends not only on propagule pressure, but also on the presence of particular biological and ecological features of introduced species and, finally, on the ecosystem's “susceptibility,” including its abiotic (e.g. climatic similarity and resource availability) and biotic characteristics (e.g. the absence of biological enemies; Catford, Jansson, & Nilsson, 2009; Colangelo et al., 2017).

All of these factors determine whether the newly arrived species in a geographical area may shortly disappear because of lack of adaptation to the new environment, or whether it can proliferate exponentially, becoming invasive. But species can also adapt to the new environment with neutral effect, neither beneficial nor harmful. Species may have beneficial effects in cases where they occupy a vacant niche or diversify an existing one. The impact of invasive species on biodiversity and habitats, in fact, cannot be generalized, as they cause diverse effects in different areas and at different times (Kumschick et al., 2015; Ricciardi & Cohen, 2007; Zwerschke et al., 2018), varying among recipient assemblages characterized by different biotic and abiotic conditions (Arenas, Sanchez, Hawkins, & Jenkins, 2006; Ceccherelli & Campo, 2002; Corriero et al., 2016; Grosholz, 2002; Piazzi & Balata, 2009). This last point represents one of the major operational problems, and management actions and mitigation measures are particularly problematic in the marine environment. This is partly because of the lack of historical data (Azzurro, Cerri, & Testagrossa, 2019; Dick et al., 2014; Ojaveer et al., 2018; Ojaveer & Kotta, 2015), but the problem is exacerbated in marine systems because complex life cycles facilitate connectivity among distant environments. Once species have settled, it is virtually impossible to eradicate them, and prevention of further dispersal is likely to involve a very high economic cost. Moreover, the effects of introductions are generally unknown until AS are widely spread and have a socio-economic impact (Vilches, Arcaría, & Darrigran, 2010).

A guidance to decision-makers on how to prioritize management actions for the control of marine invasive species based on the species' dispersal capacity and their distribution in the area to be managed is present in Giakoumi et al. (2019) which suggest to prioritize management actions for groups of invasive species that share similar characteristics.

3 | THE MEDITERRANEAN INVASION: SOME CASE STUDIES

The Mediterranean Sea is today among the areas most susceptible to the introduction of AS that pose a growing threat to biodiversity (Galil, 2007; Mannino, Balistreri, & Deidun, 2017; Templado, 2014), and these threats are often enhanced by the pressure of human activities (Çinar, 2013).

The number of AS in the Mediterranean is rising, with more than 5% of marine species considered non-native (Zenetos, 2019; Zenetos et al., 2012). According to these latest regional reviews, 13.5% of AS are classified as invasive and for most of them, a negative impact is recognized. Non-native macroalgae and seagrasses are dominant in the Western Mediterranean and the Adriatic Sea, whilst polychaetes, crustaceans, molluscs and fishes are the main invaders in the Eastern and Central Mediterranean (Zenetos et al., 2012).

The strongest evidence of Mediterranean invasion is linked to macroalgae and seaweeds, most of which are reported as having negative impacts on native communities by reducing biodiversity and altering ecological relationships (Boudouresque & Verlaque, 2002; Piazzi & Balata, 2009; Piazzi, Balata, Ceccherelli, & Cinelli, 2005; Thomsen, Wernberg, Tuya, & Silliman, 2009). In some cases, these species form a monospecific stratum that traps sediment particles, suffocates the underlying algae and reduces the number of species in native communities (de Caralt & Cebrian, 2013). In some cases, these effects reduce attractiveness to recreational scuba divers (Otero et al., 2013). Changes in richness and diversity with invasion status vary in magnitude and direction depending on the algae species involved (Wangensteen, Cebrian, Palacin, & Turon, 2018). One of the best-studied invasive algae is *Caulerpa cylindracea*, which forms dense canopies causing an homogenization of recipient ecosystem (Morri et al., 2019), and seems to alter native seagrass meadows and soft-bottoms, causing variable consequences both on macrofauna and meiofauna (Cebrian et al. 2012; Lorenti et al., 2011; Pusceddu, Fraschetti, Scopa, Rizzo, & Danovaro, 2016; Taylor, Bishop, Kelaher, & Glasby, 2010), negative in some sites and neutral in others (Baldacconi & Corriero, 2009).

The voracious carnivorous fish *Plotosus lineatus*, a species without commercial value, has spread widely along the Israeli coast, changing the native fish community structure and negatively affecting the fishing activity (Edelist, Golani, Rilov, & Spanier, 2012). Likewise, *Lagocephalus sceleratus* has become one of the most abundant fish species in the *Posidonia oceanica* beds along Greek coasts, and it is severely reducing the juveniles of local coastal fishes. The lionfish *Pterois volitans*, recently arrived in the Mediterranean (Kasapidis, Peristeraki, Tserpes, & Magoulas, 2007; Turan, Uygur, & İğde, 2017), is dangerous for the toxin contained in its spinal tissue, but its role in the community is still unknown. The introduction of herbivorous species also seems to negatively affect communities. The Red Sea rabbit fishes (*Siganus rivulatus* and *S. luridus*) have denuded large swaths of algal meadows across the Levant Basin and are one of the co-causes of the decline of *Cystoseira*, a habitat-forming alga representing a vital nursery habitat for many fish species (Sala, Kizilkaya, Yildirim, & Ballesteros, 2011). Among alien invertebrates, in the pelagic environment, the carnivorous ctenophore *Mnemiopsis leidyi* and the jellyfish *Ropilena nomadica* affect the entire zooplankton community (Boero, 2013; Öztürk & Isinibilir, 2010), causing dramatic reductions in ichthyoplankton, and zooplanktivorous fish populations (Leppäkoski, Shiganova, & Alexandrov, 2009). In the benthic environment, the gastropod *Rapana venosa*, predator of other molluscs, is responsible for the depletion of large stocks of commercial bivalves (*Mytilus galloprovincialis* and *Ostrea edulis*) and of their associated communities (Salomidi et al., 2012; Savini & Occhipinti-Ambrogi, 2006).

The aforementioned cases were all about unintentionally introduced species, but other species have been intentionally introduced by humans for productive purposes. This is the case of the penaeid species *Marsupenaeus japonicus* and *Metapenaeus monoceros* that have drastically reduced the native *Melicertus kerathurus*. Generally, the invasion of penaeids through the Suez Canal led to the rise of a lucrative industry for Levantine fisheries (Galil, 2007). *Percon gibbesi* and *Callinectes sapidus* are two invasive crustaceans which seem to be strong competitors of native crabs, feeding on native bivalves (Boudouresque, Klein, Ruitton, & Verlaque, 2011; Suaria et al., 2017) that can be used for human consumption as well. Other AS introduced by aquaculture facilities include the Asia Pacific Coast native oyster *Crassostrea gigas* and the Philippine carpet shell *Ruditapes philippinarum*, causing the drastic decline of the native species *O. edulis* and *Ruditapes decussatus*, respectively (Zwerschke et al., 2018). Both are profitable components of shellfish farming. It is also observed that in Northern Europe such alien bivalves can convey pathogens and parasites (Boudouresque et al., 2011). Other invasive bivalves are the Lessepsian species *Brachydontes pharaonis* and *Arcuatula senhousia*, the latter transported by seeds used for aquaculture, by ship's ballast waters and by fouling. Both species form dense aggregations that change the physical structure of the substratum, damage man-made structures and outcompete other filter-feeding bivalves (Mistri, Rossi, & Fano, 2004; Otero et al., 2013).

4 | THE OTHER SIDE OF BIOLOGICAL INVASIONS

Up to now, we have discussed species reported to have negative effects, most of which have been mainly investigated in Marine Protected Areas (Otero et al., 2013) although the role of MPAs in controlling biological invasions is still doubtful (Burfeind, Pitt, Connolly, & Byers, 2013; Giakoumi & Pey, 2017) and AS are likely to continue to expand in these protected sites too.

However, the most invasion-susceptible biotopes seem to be threatened, polluted and confined areas, such as ports and lagoons (Çinar, 2013), and the highest invasive potential is found in the components of fouling assemblages spread on ship hulls and in ballast water. A large majority of marine AS are associated with artificial structures that are reported to act as stepping stones or even corridors for some marine aliens, just as urban areas, roads and riparian environments function in terrestrial ecosystems (Mineur et al., 2012). In most cases, however, such foulers remain in the “confined” environments without colonizing the open sea (Shaiek & Ben Haj, 2019). The described negative impact of alien foulers is not different from that of native ones, their damage principally consisting in clogging water intakes, marine engines and aquaculture nets (Megina, González-Duarte, López-González, & Piraino, 2013). All these negative actions are usually present in the early phases of the invasion, when the species rapidly reaches high abundance. This is the case of the ascidian *Microcosmus squamiger* that competes for space with cultured bivalves (Turon, Nishikawa, & Riusa, 2007), or of the recent migrant serpulid Lessepsian *Pomatoleios kraussii* (Belal & Ghobashy, 2012), forming dense aggregations in confined environments. A similar action was also due to other “alien” serpulids such as *Hydroides elegans* and *H. dianthus*, which can only be seasonally present, and at present are considered naturalized forms.

However, often, the increases in abundance and the negative action are recorded only at the first stage of introduction. This can be, however, different in different species. In the Gulf of Taranto, 15 years of observations showed the dynamics of some aliens that at first were considered highly invasive. The cold-temperate brown seaweed *Undaria pinnatifida* had a boom-and-bust path, ending in apparent local extinction, whilst the tropical red seaweed *Hypnea cornuta* has shown a steadily invasive path since its introduction (Cecere, Alabiso, Carlucci, Petrocelli, & Verlaque, 2016).

More often, however, within disturbed environments, introduced species seem to have positive effects. For example, the alien seagrass *Halophila stipulacea*, growing on dead *Posidonia* mat, seems to enhance local diversity and recently its consumption by a native herbivorous fish was also documented (De Martino, Stancanelli, & Molinari, 2007; Rindi, Maltagliati, Rossi, Acunto, & Cinelli, 1999; Gambi, Gaglioti, & Barbieri, 2018). Likewise, the serpulid *Ficopomatus enigmaticus*, native of the Indian Ocean, is considered a habitat-forming species able to build large reefs in brackish waters, so providing shelter and resources for other invertebrates and also attracting fish with high conservation value (Nonnis Marzano, Baldacconi, Fianchini, Gravina, & Corriero, 2007). This is an interesting issue because *Ficopomatus* reefs are included in the European Red List of Threated Marine Habitats and have been suggested for a protection measure (Gubbay et al., 2016).

An example of positive effects comes from our studies conducted in the Gulf of Taranto (Ionian Sea, Italy), which is considered a “hot spot” for biodiversity of NIS, also referred as biological pollution (Cecere, Petrocelli et al., 2016). A study conducted by means of artificial panels in this biotope showed a higher fouling diversity linked to the abundance of AS. In particular, two congener polychaete sabellids, *Branchiomma luctuosum* and *B. boholensis*, together with the colonial ascidian *Polyandrocarpa zorritensis*, hamper the dominance of *M. galloprovincialis* at the surface of the system, so fostering a more diverse benthic assemblage (Lezzi & Giangrande, 2018). Our monitoring studies in the area have been going on for 30 years (Giangrande, Licciano, et al., 2014). Both polychaete species are Lessepsian migrans, and *B. luctuosum* were introduced in the Mediterranean in the 1970s, whilst *B. boholensis* became widespread only recently (Del Pasqua et al., 2018). As occurred for the already mentioned macroalga *U. pinnatifida* (Cecere, Alabiso, et al., 2016), at first, both alien sabellids appeared highly invasive, but then they reached an equilibrium and at present they form a characteristic fouling assemblage co-existing with the native sabellid *Sabella spallanzanii*, that in the studied area remained the most abundant sabellid species, so increasing the local biodiversity (Pierri, Colangelo, Del Pasqua, Longo, & Giangrande, 2019). In particular, in the long term, *B. luctuosum* reached a "naturalized" condition, so becoming a part of the fouling community everywhere along the Mediterranean coast, without negative impacts. On the contrary, at the moment *Branchiomma boholense* is restricted to the southern Mediterranean and was proved to be one of the few species naturally growing and reproducing in the highly acidified area at the Castello CO_2 vent system of the Ischia Island (Del Pasqua, Gambi, Caricato, Lionetto, & Giangrande, 2019), so promoting this species as a possible candidate for survival in future ocean acidified conditions.

We have also studied the role of all the filter feeder species in the fouling community, highlighting as both *Branchiomma* species have a filtration rate that is several times higher than that of mussels and of the native *S. spallanzanii* (Licciano, Stabili, & Giangrande, 2005). The co-occurrence of these filter feeders furnishes relevant ecosystem services, in that they effectually clear particulate organic matter and also pseudofeces produced by mussels, which are cultured intensively in the area, acting as bioremediators (Giangrande, Pierri, et al., 2014). Moreover, sabellids are promising even from an economic point of view; owing to their conspicuous and attractive features, their biomass could be employed in aquaculture food production (Stabili et al., 2019) or as ornamental invertebrates for aquariums in order to reduce the unsustainable trade of species imported from tropical areas (Murray, Watson, Giangrande, Licciano, & Bentley, 2013). This is an interesting and relevant case study that shows the potential positive ecological (bioremediation) and economic impact of some AS, as already proposed by Fanelli (2016), and calls for European regulations in this regard, as, at the moment, the use of AS is not permitted by current European regulations.

Of course, these are only isolated cases, but the *Branchiomma* case study, with its long-term record, is very useful to discuss about the multiple and diversified destinies of AS and their relationship with native species within local communities.

5 | GLOBAL CHANGES AND CONSERVATION QUESTIONS

Although issues triggered by biological invasions are very complex in the marine environment, they remain a priority in planning the conservation and protection of habitats and biodiversity. The protection of certain natural elements has had a long history, marked by the change in time of concepts and values regarding conservation initiatives (Mace, 2014). Ecosystem preservation from human impact, including the erosion of biodiversity the protection of rare species from extinction, has been the prevailing goal of conservation efforts during the 20th century. Conservation has become more socially inclusive especially in the last 20 years, with also particular attention to the contribution of "nature services" to human well-being (Costanza et al., 2017; Diaz et al., 2018).

Conservation approaches strictly based on human perception often neglect the fact that changes are an intrinsic aspect of life. It is generally known that the distribution of species naturally changes over time; species dispersal and invasion of new regions are survival mechanisms adopted by organisms, and, as such, they are as old as life itself. Processes in ecology and evolution are dynamic; imagining nature being a static old master that needs to be restored to a particular state is just not a reasonable way of looking at the processes of life. The issue is that what we wish to preserve has already been modified time and time again. The introduction of species may, in fact, be viewed as part of a dynamic process that has been going on for millennia. Indeed, the "pristine" condition is already a modified stage with respect to the historical process (Ojaveer et al., 2018).

We suggest, therefore, that it is essential to define a "temporal baseline" that can be used in order to distinguish early AS from "naturalized" species. Clarifying these concepts will help to address our conservation priorities and to make decisions about what to keep in a moment, like the one we are experiencing, characterized by such accelerated changes.

Mediterranean invasions have been recorded since the early 20th century, and they promoted and hastened changes in Mediterranean since the 1950s (Ojaveer et al., 2018). Invasions were mainly fostered by the breaking of barriers, including man-made canals digging, such the Suez Canal; the most spectacular worldwide invasion of marine AS is the Lessepsian migrations, which are continuing and have increased in the last decades, partially including the Mediterranean Sea into the Indo-Pacific region (Galil et al., 2015).

Only a few decades ago, when no particular attention was paid to biological invasions, we were not concerned about introducing species for aquaculture. In many cases, these almost completely supplanted native species, fact that does not worry us even now! We also do not consider as negative the invasion of *Ficopomatus*, which, after its involuntary introduction into the Mediterranean a century ago, has spread widely in brackish environments, giving rise to a bioconstruction that is very important from an environmental and biological point of view and supporting the biodiversity of habitats of hard substrate of such environments. At present, anthropogenic climate change affects the vulnerability of a region to biological invasions (Gravili, 2017; Masters & Norgrove, 2010; Occhipinti-Ambrogi & Galil, 2010). The rising of world temperatures strongly influences species' geographical ranges. In the northern hemisphere, native species are forced to move towards the north or to shift into deeper waters (Ponti et al. 2014) or they may be replaced by invasive AS

(Cox, 2004; Dukes & Mooney, 1999). Mediterranean thermophilic species are in fact rapidly spreading northwards, whilst some tropical species find suitable environmental conditions in the Eastern Mediterranean basin (Boero, 2015). Global warming is leading the Mediterranean into a new state with an increase in the number of AS with warm-water affinities AS (Mannino et al., 2017; Zenetos et al., 2012).

Mediterranean is changing, and seawater warming is impacting marine ecosystems, but as pointed out by Bianchi et al. (2019), proper evaluation of change requires the availability of long-term biological data series. These authors demonstrated as a novel community emerged from the climate shift occurred in the 1990s, with the loose of many native species, reduced complexity, biotic homogenization, greater diversity and domination by aliens.

Climate change, is, however, a worldwide phenomenon, and we should consider the possibility that some endangered species could also benefit from their transport towards different environments. In other words, some introductions could survive better than local species in changing environments and could compensate for the decrease in species caused by climate changes, so also acting as a reservoir of diversity (Walther et al., 2009), just as rare species sometimes do (Boero, 1996).

As pointed out by Davis et al. (2011), nativeness is not a sign of evolutionary fitness or of having positive effects. The effects of AS vary in time, and species that are not causing harm now might do so in the future. But, the same could be true of natives, particularly in rapidly changing environments.

6 | CONCLUSIONS

In the era of global changes, humans have broken ecological barriers; they have excavated canals connecting different marine basins, multiplied shipping and sea routes between far-flung geographical areas, created mariculture with exotic species, replaced native shellfish with more productive ones and transferred propagules and larvae by shipping. All of these activities promote species dispersal, breaking down geographical barriers. At a local scale, the introduction of AS can actually increase biodiversity, but on the global scale this process could hamper biodiversity by levelling species composition. As regards the Mediterranean, global warming and uncontrolled introductions are leading the basin to a new state.

In a moment like the present one, in which the changes are particularly accelerated, it seems more urgent and necessary than ever to reflect on the problem of biological invasions which, in turn, represents one of the effects of human activities that are the very cause of acceleration of the environmental changes we are experiencing.

However, notwithstanding the mechanisms and the magnitude of the impact of AS on ecosystem services and on biodiversity, such impact is a prerequisite for the efficient prioritization of mitigation measures. Unfortunately, for most marine alien taxa this impact remains unknown or it is still the subject of debate and probably the time to study it is not sufficient to describe the real behaviour of the species in the recipient habitat. In the few cases with existing long trend data, it has been observed that species often integrate themselves into the community.

There is no doubt that human activities are eroding the tree of life and that this requires us to prioritize research and conservation. Animals and plants are also disappearing faster than at any time. The survivors, however, are taking advantage of human-mediated new opportunities; some are spreading into new parts of the world and adapting to new conditions, whilst others can cause extinction of native ones. These last cases seem, however, to be fairly rare especially in the marine environment where most of the newcomers seem to fit in with limited impacts on other species. It is therefore also possible to see in many countries that, as a result, many more species are arriving than are dying out.

Today, in fact, most human and natural communities consist of both of residents and of new arrivals, and in some areas, the latter correspond to a large part of local biodiversity, leading to the emergence of ecosystems that never existed before.

Now that we are more aware about the danger and the damage we have caused before, we must be proud about our past control of introductions but, however, as the climate shifts, we must allow animals and plants to shift as well. This kind of intervention runs contrary to the rules and regulations designed to prevent invasive species. It is true that the rate at which we are transporting species is unprecedented. However, we must consider that also the rate of environmental changes is now accelerated and that many species do not have a generation span to respond with adaptation/climatization.

It is impractical to try to restore ecosystems to some optimal or pristine historical state, and instead of concentrating our attention on some single species, our real objective could be focused on the functioning of the entire ecosystems, preventing their collapse in a world that is too rapidly changing. We cannot rewind history. It might be more effective for us to not regard change per se as negative, but to accept biological gains if this can assure the sustainability of natural resources for future generations. In other words, instead of focusing on preserving past ecosystems, we should concentrate on preserving biodiversity, so that living beings can flexibly respond to future challenges. We must think in terms of maintaining the biodiversity that we currently have, accepting that it is a dynamic system rather than a static one, and be prepared to accept biological gains as much as we regret losses, with a much more optimistic view of conservation. With this in mind, we believe that defining priorities in management and conservation is a prerogative that should not be based on the containment/ eradication of one or another species, but on the conservation of those environmental conditions that are essential for the proper functioning of ecosystems. In other words, the native versus non-native species distinction cannot be a guiding principle in conservation and restoration management and conservationists should assess organisms with respect to their environmental impact rather than on whether they are native. For this reason, the focus must be on the containment of those human activities that cause greater pollution and therefore threaten the habitats and biodiversity that we care about.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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