Bocconea 28: 77-93
https://doi.org/10.7320/Bocc28.077
Version of Record published online on 22 November 2019

Anna Maria Mannino

Human activities trigger change in marine landscape*

Abstract

Mannino, A. M.: Human activities trigger change in marine landscape. — Bocconea 28: 77-93. 2019. — ISSN: 1120-4060 printed, 2280-3882 online.

Biodiversity is undergoing rapid and worrying changes, partially driven by anthropogenic activities. Human impacts and climate change (e.g. increasing temperature and ocean acidification), which act at different spatial scale, represent the most serious threats to biodiversity and ecosystem structure and function. In this overview, the effects of anthropogenic pressures on unique and valuable Mediterranean systems, such as *Cystoseira* sp. pl. forest and *Posidonia oceanica* meadows, are examined. These complex systems, characterized by a high associated biodiversity, are regularly exposed to natural and anthropogenic pressures. Due to the central role they have for several important ecological processes in marine ecosystems, their loss can lead dramatic consequences. Since these ecosystems are often unable to recover naturally, it is necessary to reinforce their resilience. Therefore, reintroduction by transplantation and reforestation methods have been recently proposed. Considering future increase in anthropogenic and climatic pressures, understanding how these systems respond to stressors and preserving their resilience should be an essential component of any conservation management plan.

Key words: biodiversity, *Cystoseira* forest, stressors, *Posidonia oceanica* meadows, Mediterranean Sea.

Introduction

The Mediterranean Sea, even though representing a small part of the world's oceans, is inhabited by an unusually rich and diverse biota. It hosts approximately 17,000 species (Bianchi & Morri 2000; Coll & al. 2010). As a result, it is considered as a true hotspot of biodiversity (Bianchi & Morri 2000; Boudouresque 2004; Coll & al. 2010), even by virtue of the high rates of endemic species it supports (25%, Boudouresque 2004), for instance the neo-endemism (of Pliocenic origin) *Cystoseira* genus, considered a key-stone genus with 30 endemic species into the Mediterranean (Cormaci & al. 2012) and the paleo-endemism (of Tethyan origin) *Posidonia oceanica* (L.) Delile. The western basin shows a higher rate of endemism than the eastern one, appearing to be an active center of endemism (Boudouresque 2004).

*Article first published online on 20 December 2018 in Flora Mediterranea 28: 295-311.

Within the Mediterranean Sea, Sicily and circum-Sicilian Islands, as a consequence of their geographical position between the western and eastern sectors, and due to the numerous diverse habitats occurring along their coasts, which are washed by three different seas (Tyrrhenian, Ionian and South Mediterranean) are high-biodiversity areas (Coll & al. 2010; Giaccone & al. 2010; Domina & al. 2018).

At the same time, the Mediterranean Sea is among the most impacted Sea, as a consequence of different anthropogenic pressures on marine ecosystems which are significantly affecting biodiversity and are predicted to increase in the future (Coll & al. 2010, 2012; Lejeusne & al. 2010; Katsanevakis & al. 2013). The Mediterranean is currently experiencing a decline in the number of species and a deterioration of habitats, related to increase of human population, habitat modification and loss, pollution, coastal urbanization, overexploitation and the intentional or indirect introduction of Non-Indigenous Species (NIS, i.e. organisms introduced outside of their natural range) and climate changes, i.e. acidification and warming (Coll & al. 2010; Lejeusne & al. 2010; Zenetos & al. 2012; Katsanevakis & al. 2013; Bianchi & al. 2014).

In the Mediterranean Sea, several valuable, productive and unique habitats, including *Cystoseira* sp.pl. forest and *P. oceanica* meadows, supporting high biodiversity and providing essential ecological goods and services, are under threat (Coll & al. 2010; Lejeusne & al. 2010; Telesca & al. 2015; Boudouresque & al. 2017 and references therein). The sensitivity of these systems to a variety of stressors, makes them particularly vulnerable and susceptible to human pressures which can cause their decline and/or loss.

The aim of the present paper is to overview the effects of anthropogenic activities on these two sensitive Mediterranean coastal communities, *Cystoseira* sp. pl. forest and *P. oceanica* meadows, which are currently under threat in several areas, focusing on Sicilian habitats, also providing examples of management and conservation strategies.

Materials and methods

We looked for scientific papers, grey literature and reports, in order to obtain a representative number of relevant documents. A search was performed using standard scientific databases. The research criteria were based on a list of key terms such as "*Posidonia oceanica*" or "*Cystoseira*" or "*Cystoseira* canopies" or "Fucales" and "status" or "decline" or "regression" or "recovery" and "human impact" or "pressure" or "threat" and "restoration" or "transplantation" or "reforestation" and "Mediterranean Sea" or "Sicilian".

Results and Discussion

Cystoseira *sp. pl. forests*

In the Mediterranean Sea, species belonging to the genus *Cystoseira* (*Sargassaceae*) are the most important canopy-forming algae in shallow rocky bottoms (Ballesteros 1990a, 1990b; Giaccone & al. 1994).

Currently, 41 taxa belonging to the genus *Cystoseira* are reported for the Mediterranean Sea (Cormaci & al. 2012; Taşkin & al. 2012). These long-living brown macroalgae are ecologically relevant as keystone species (Paine 1969) and habitat-forming species (Gianni & al. 2013). They have a fundamental role in sustaining the biodiversity and performing numerous ecosystem services such as controlling spatial habitat heterogeneity, providing high primary production and food, nutrient cycling, suitable habitats, protection from predators and shelter from disturbance (Ballesteros & al. 2009; Sales & al. 2012; Mineur & al. 2015).

For these reasons *Cystoseira* species are listed as "of community interest" according to the Habitat Directive (92/43/EEC), and are considered as reliable indicators of environmental quality in Mediterranean coastal waters (Ballesteros & al. 2007), according to the Water Framework Directive (WFD, 2000/ 60/EC) and Marine Strategy Framework Directive (MSFD, 2008/ 56/EC) (Orlando-Bonaca & al. 2013). Five species are on the list of protected species (Annex I) of the Bern Convention and all the species, except *Cystoseira compressa* (Esper) Gerloff & Nizamuddin, are included in the List of endangered and threatened species of the Annex II of the Barcelona Convention (UNEP, Decision IG.21/09) and are considered vulnerable by several international organizations (i.e. IUCN, RAC/SPA, MedPan).

Anthropogenic pressures

Cystoseira species are particularly sensitive to a variety of anthropogenic stressors such as urbanization, pollution, trampling, overfishing (of large sea urchin predator fish) and climate change (Milazzo & al. 2002; Sales & al. 2011; Mineur & al. 2015; Thibaut & al. 2015; Blanfuné & al. 2016). Consequently, over the last few decades, most of the *Cystoseira* species have experienced a severe decline in many Mediterranean regions and have retracted their ranges (Thibaut & al. 2005; Mangialajo & al. 2008; Iveša & al. 2016; Bulleri & al. 2018). The causes of decline of Mediterranean Sargassaceae are multiple and act not only in a cumulative but also in a synergic way. Recently, it has been suggested the hypothesis of a possible role of the microbial communities in contributing to the declines of populations of *Cystoseira* sp. pl. in the Mediterranean Sea (Mancuso & al. 2016).

As consequence of these pressures, *Cystoseira* systems may shift from a complex and productive state to alternative states with simpler, poorly organised and less-productive communities that are able to inhibit recolonization by canopy-forming species (Connell 2005; Gorman & al. 2009; Perkol-Finkel & Airoldi 2010; Thibaut & al. 2014 and references within; Rindi & al. 2017; Chemello & al. 2018). For instance, pollution can lead to a shift to ephemeral opportunistic species and, affecting the resistance to the invasion and the resilience of the system, can enhance the growth and spread of alien species such as *Caulerpa cylindracea* Sonder (Fig. 1A) (Diez & al. 2014; Gennaro & Piazzi 2014; Gennaro & al. 2015; Piazzi & Ceccherelli 2017). In turn, opportunistic species are unable to avoid the spread of *C. cylindracea* which prevents the recovery of native populations by facilitating the persistence of alternative assemblages (Piazzi & Ceccherelli 2017). Overfishing of large sea urchin predator fish cause an increase in sea urchin density which may lead to a shift to a simpler community, dominated by turf-forming or encrusting coralline algae, the so-called 'barren ground' (Fig. 1B) (Thibaut & al. 2005; Airoldi & al. 2008; Hereu & al. 2008; Sala & al. 2012; Tsiamis & al. 2013; Templado 2014; Agnetta & al. 2015). The sea urchin *Paracentrotus lividus* (Lamarck, 1816) would have a leading role in the formation of barren areas (Agnetta & al. 2015). Indeed, by removing the base of the alga, prepares the substratum for the colonization by encrusting algae (Agnetta & al. 2013).

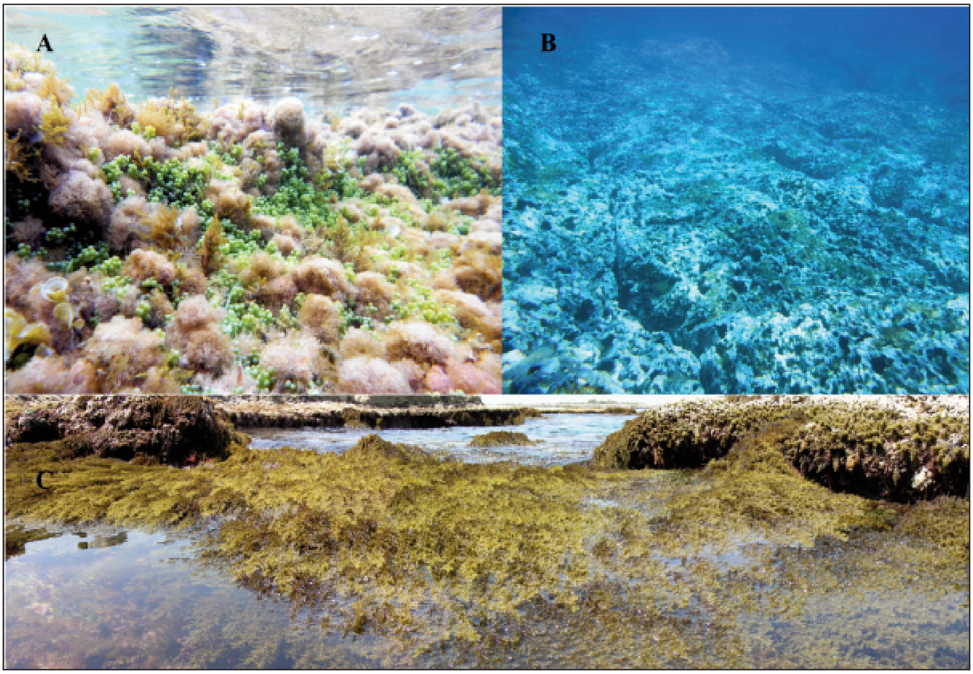

Fig. 1. A) A population of *Caulerpa cylindracea*; B) a "barren ground" (photo by Paola Gianguzza); C) the infralittoral fringe with *Cystoseira amentacea*.

Instead, the role of *Arbacia lixula* L., which settles in encrusting coralline algae, is the maintainance of 'barren ground' (Bonaviri & al. 2011; Privitera & al. 2011). At Ustica Island, a barren ground interspersed with patches of *Cystoseira* sp. pl. was recently observed by Gianguzza & al. (2010).

The regression of *Cystoseira* sp. pl. forests is mainly related to overfishing and NIS rather than to warming (Boudouresque & al. 2017 and references within). Due to the dramatically accelerating rate of NIS introductions and due to the intense shipping traffic, the Mediterranean Sea may be considered as a true hotspot of marine bioinvasions (Rilov & al. 2009). To date, almost 1000 marine NIS (equivalent to ca. 6% of the total flora and fauna) have been introduced in the Mediterranean (Zenetos & al. 2012). It has been ascertained that alien species may have significant environmental (substitution of native species; biodiversity loss; habitat modifications and alterations in community structure), socio-economic and human health impacts (Vilà & al. 2011; Jeschke & al. 2014; Katsanevakis & al. 2014), consequently they are recognized as one of the major threats to biodiversity. For instance, *Caulerpa taxifolia* (Vahl) C. Agardh, *C. cylindracea* and *Asparagopsis taxiformis* (Delile) Trevisan can outcompete with *Cystoseira* sp. pl., mainly with species growing in the infralittoral fringe such as *Cystoseira amentacea* (C. Agardh) Bory (Fig. 1C), which is a particularly vulnerable area, being subjected to a range of anthropogenic disturbances (Boudouresque & al. 1995; Thompson & al. 2002; Piazzi & Ceccherelli 2006; Mannino & Balistreri 2017; Mannino & al. 2017).

Status along the Sicilian coasts

According to Giaccone & al. (2010), who depicted the ecological status of coastal waters around Sicily, in Tyrrhenian areas (e.g. Ustica Island, the Aeolian Islands) communities with *Cystoseira* sp. pl. (*C. amentacea*, *C. brachycarpa* J. Agardh, *C. sauvageuana* Hamel, *C. spinosa* Sauvageau, *C. zosteroides* (Turner) C. Agardh) were well structured. Conversely, in the Straits of Sicily (e.g. Pantelleria Island and Linosa Island) and the Ionian Sea (Maddalena Peninsula), disappearance of the above-mentioned species of *Cystoseira* and the resulting communities (excluding those occurring in shallow water), and their substitution by less-structured communities of *Dictyotaceae*, *Sphacelariaceae* and *Udoteaceae* were observed. The disappearance of *Cystoseira* in these areas was related by the authors to an increase in the temperature of superficial waters caused by global climate change, together with changes in the deep circulation of the eastern Mediterranean basin recorded in the last 30 years. More recently, Mancuso & al. (2018) observed at Portopalo di Capo Passero the loss of *Cystoseira humilis* Kützing and a notable decrease in the cover of *C. compressa* with respect to previous data (Giaccone & al. 1992).

Management and restoration strategies

The threat of declining/losing *Cystoseira* species is increased by the low dispersal capacity of most *Cystoseira* species, due to rapid egg fertilization and zygote sinking, which makes difficult natural recovery. To stimulate the natural restoration of lost populations, the setting up of Marine Protected Areas (MPAs) could be certainly useful but probably not sufficient. Therefore, artificial reforestation may be a valuable tool to improve the restoration of extinct populations (Falace & al. 2018 and references within).

Nowadays, the interest in habitat restoration is increasing according to the Biodiversity Strategy to 2020 (Target 2; European Commission, 2011), which recommends the restoration of valuable species, such as *Cystoseira* sp. pl. forests, into areas where their historical presence is recorded and the pressures that led to their loss are no longer acting (Mangialajo & al. 2013; Falace & al. 2018).

For *Cystoseira* reforestation, among the techniques now available, transplantation of juveniles or adult thalli is the most used method (Falace & al. 2006; Susini & al. 2007; Sales & al. 2011; Perkol-Finkel & al. 2012; Gianni & al. 2013). Outplanting (culturing germlings, obtained from fertile receptacles, in the laboratory and transferring them into the field), providing many healthy specimens without depleting natural populations, appears to be a more ecologically sustainable technique (Falace & al. 2006; Sales & al. 2015). Since large numbers of germlings are necessary for outplanting in large-scale restoration actions, efficient and cost-effective seedling production system must be planned (Falace & al. 2018). However, restoration of canopy forests makes sense only within the framework of an effective and rapid management of local stressors. Reducing local human impacts would represent the most effective strategy for the conservation and recovery of these systems, but, whenever this is not sufficient, restoration projects can help.

Posidonia oceanica *meadows*

Mediterranean seagrass meadows, such as *P. oceanica*, constitute a major component of coastal marine ecosystems, which provide goods and services in coastal areas (Pergent & al. 2014).

P. oceanica is a slow-growing species endemic of the Mediterranean Sea, where it is the dominant seagrass and it can form meadows or beds extending from the surface to 40–45m depth (Fig. 2A).

According to Telesca & al. (2015), the total known area of *P. oceanica* meadows in the Mediterranean Sea was found to be 1,224,707 ha (12,247km^2). In Italy (337,611 ha) it was characterized by a rather continuous distribution along continental and insular coasts, and it covers 76,000 ha of Sicilian coastal areas (Calvo & al. 2010; Telesca & al. 2015).

Seagrass meadows are presently experiencing a decline globally (Orth & al. 2006), as consequence of several threats, which places them among the most threatened ecosystems (Waycott & al. 2009). Since *P. oceanica* is also susceptible to regression as response to specific impact (Orth & al. 2006; Marbà & al. 2014), its presence and abundance is considered as an indicator of the environmental quality of the coastal zone. Therefore, *P. oceanica* has become one of the main targets of the protection and management of the Mediterranean marine environment (Pergent 1991; Boudouresque & al. 2012). Indeed, the European Union's Habitat Directive (92/43/ CEE) included *P. oceanica* beds among priority habitats (Habitat 1120), and more recently, the Marine Strategy Framework Directive (MFSD) (2008/56/EC) selected *P. oceanica* as representative species of the angiosperm quality elements for the Mediterranean marine environment.

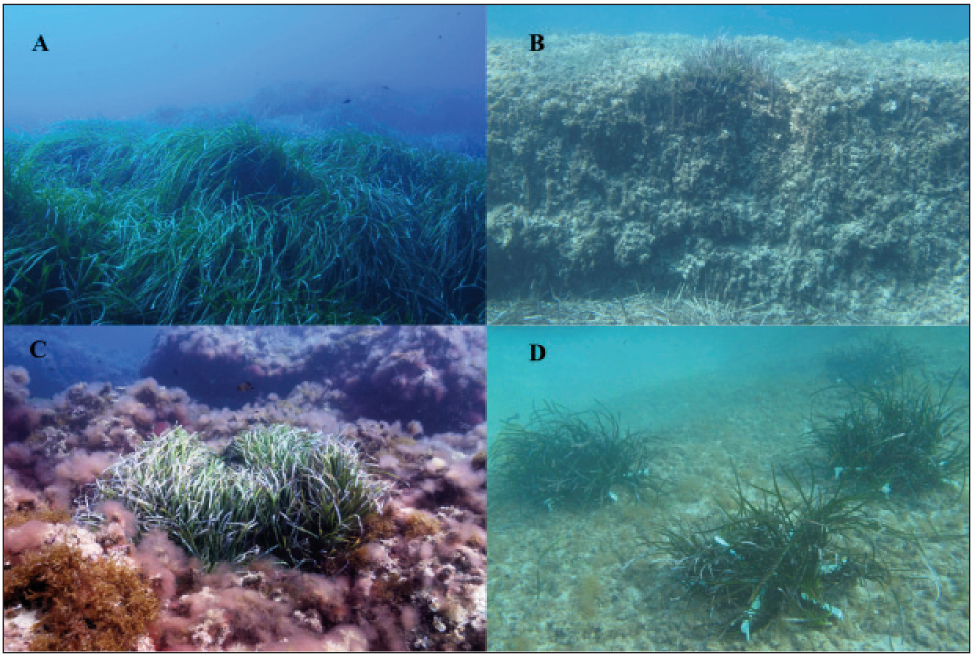

Fig. 2. A) *Posidonia oceanica* meadow; B) *Posidonia oceanica* dead *matte* (photo by Antonino Scannavino); C) the NIS *Lophocladia lallemandii*; D) an underwater anchor modular system for restoration of *Posidonia oceanica* meadows (photo by Antonino Scannavino).

P. oceanica is listed as a species of Least Concern within the International Union for the Conservation of Nature Red List of Threatened Species (IUCN 2015) and included in Annex I of the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats, 1979) as a protected species. The habitat has been also identified as a priority under the European Commission Habitats Directive (92/43/EEC), and in several European countries the species and/or the habitat are under specific legal protection (Boudouresque & al. 2012).

Anthropogenic pressures

P. oceanica meadows are presently experiencing significant regression generally linked to anthropogenic pressures, such as coastal development, pollution, turbidity, resuspension of sediments, boat anchoring, fish trawling, dredging (Milazzo & al. 2002; Boudouresque & al. 2009; Badalamenti & al. 2011; Abadie & al. 2016). Pressures linked to global change, i.e. the introduction of NIS, warming and sea level rise, can be considered to be among the main responsible of *P. oceanica* regression (Short & Neckles 1999; Boudouresque & Verlaque 2002; Marbà & Duarte 2010; Pergent & al. 2014, 2015). As consequence of its regression, *P. oceanica* may be substituted by "warm" affinity species of lower structural complexity, such as *Cymodocea nodosa* (Ucria) Ascherson (which is also a pioneer species in the succession, allowing for the settlement of *P. oceanica* meadows), *Halophila stipulacea* (Forsskål) Ascherson, or other NIS. Warming is responsible for a reduction of its range near its warm limit and an increase of its range near its cold limit, whereas sea level rise causes a reduction of its lower limit (Boudouresque & al. 2017 and references within). Trawling removes the upper layer of rhizomes of the dead *matte* (Fig. 2B). Anchoring of small leisure boats scars the dead *matte*, whereas the anchor of large boats may remove huge blocks of *matte* (Ganteaume & al. 2005; Boudouresque & al. 2012). Anchoring has a direct adverse effect on cover and shoot density of *P. oceanica* meadow (Francour 1994; Francour & al. 1999; Milazzo & al. 2002). The introduction of NIS, such as *C. taxifolia* and *C. cylindracea*, able to enter into competition with native seagrasses, is a major concern (Boudouresque & al. 2009). Stressed and degraded meadows constitute a very favorable environment for the development of NIS, and this development could in turn exacerbate the regression of seagrass meadows (Fig. 2C). Both invasive *Caulerpa* species are able of invading sparse *P. oceanica* meadows, but fail when shoot density of *P. oceanica* is high (Meinesz & Hesse 1991; Klein & Verlaque 2008).

Status along the Sicilian coasts

P. oceanica is the most common seagrass along Sicilian coasts, whose meadows show the most extensive bottom coverage of all the Italian regions after Sardinia (Calvo & al. 2010).

According to these authors, along the Sicilian coasts, *P. oceanica* is commonly found in a good condition in respect to average Mediterranean conditions. This is demonstrated by the high levels of productivity, leaf biometry and flowering performance which have been recorded. Genetic diversity is also high, with the exception of isolated meadows such as the *Posidonia* banks and the Stagnone of Marsala. Several factors may explain the health status of Sicilian meadows, such as relatively low anthropogenic pressure, sedimentation rate and favourable temperature and photoperiod (Calvo & al. 2010 and references within). In particular, along the western coast of Sicily favorable ecological conditions and highly pristine natural conditions have allowed the development of one of the largest *P. oceanica* meadows in the Mediterranean. Wide and dense *P. oceanica* meadows are present on the sea floor of the calcareous Egadi Archipelago and the island of Lampedusa. In the volcanic islands (Aeolian, Ustica, Pantelleria and Linosa Islands) *P. oceanica* beds settle on rock or volcanic sands mixed with biogenic calcareous detritus. A decline of *P. oceanica* meadows has been observed in "Stagnone di Marsala" (Tomasello & al. 2009; Calvo & al. 2010), a semi-enclosed coastal lagoon along the western coasts of Sicily (Italy), where seagrass forms reef, atoll and tiger meadow types. Signs of evident regression have been also found for meadows close to urban and industrial areas (e.g. Gulfs of Palermo and Augusta).

Management and restoration strategies

Due to the fundamental role played by *P. oceanica* meadows along Mediterranean coasts, and the obvious regression to which they have been subjected, it is crucial to undertake actions to mitigate the threats, promote conservation practices and restore the previous conditions. For seagrass habitat recovery it is necessary to identify and limit and/or eliminate the causes of degradation (Hobbs & Norton 1996). The management of direct impacts, certainly helping recovery and promote resilience, can take an extremely long time from dozens to hundreds of years (González-Correa & al. 2005; Badalamenti & al. 2011; Fraschetti & al. 2013). Full recovery of *P. oceanica* meadows is considered irreversible in human time-scale, because it is a slow-growing species with a low recovery rate a low recovery rate, low flowering and high rates of fruit abortion and predation (Balestri & Cinelli 2003; Díaz-Almela & al. 2006). Transplantation is considered a possible option for speeding up seagrass habitat restoration (Fonseca & al. 1994). The use of vegetative fragments as planting units has proved more effective than seeds, which are less available (Balestri & Cinelli 2003; Díaz-Almela & al. 2006; Terrados & al. 2013). Transplant donor populations of *P. oceanica* with the highest genetic variability showed the best growth performance (Procaccini & Piazzi 2001). Terminal plagiotropic cuttings with three leaf bundles resulted suitable material for transplanting (Piazzi & al. 1998). A careful habitat selection for seagrass transplantation is also needed (van Katwijk & al. 2009). Dead *matte* results the most suitable substratum for *P. oceanica* planting (Di Maida & al. 2013; Terrados & al. 2013). Another focal point of marine restoration projects is monitoring of transplant performance. A monitoring period should last at least 3 years for the selection model outcome and at least 6 years for evaluating the effectiveness of restoration projects (Pirrotta & al. 2015). Limiting anchorage and craft fishing to protect transplants, at least until their stabilization, is also needed.

A new transplantation technique, based on anchor modular system with six arms constructed of starch-based biodegradable materials (bioplastic Mater-Bi), may be an effective technique to successfully restore *P. oceanica* habitat (Fig. 2D) (Scannavino & al. 2014). Cultivated seedlings of *P. oceanica* can be also transplanted in the field with relatively high success and thus can be an important management tool for seagrass restoration (Balestri & al. 1998; Domínguez & al. 2012; Terrados & al. 2013). Since *P. oceanica* fruits are increasingly available in many countries, they may be planted in selected suitable areas to create reservoirs of juveniles for future restoration activities.

Conclusions

Unhealthy *Cystoseira* assemblages and *P. oceanica* meadows are at high risk from anthropogenic and climatic stressors. Since anthropogenic stressors and global change are expected to increase in the coming decades, a strong effort at global scale is required in order to establish and/or implement effective conservation plans for these valuable ecosystems.

A successful conservation plan is possible by reducing anthropogenic stressors and improve the resilience of these systems to future anthropogenic and climatic pressures (Folke & al. 2004; Boudouresque & al. 2009; Sales & al. 2011; Pergent & al. 2014; Strain & al. 2014, 2015).

Additional management strategy can be restoration and protection within MPAs (Susini & al. 2007; Gianni & al. 2013). MPAs are without any doubt precious tools for the management and governance of biodiversity in the Mediterranean (IUCN 2010). For decades the creation of marine reserves has been considered the only means to restore natural communities and protect marine ecosystems.

MPAs may play a fundamental role in the conservation of *Cystoseira* sp. pl. forests and *P. oceanica* meadows, guaranteeing protection from several impacts and representing the source of propagules for the restoration of lost or degraded systems. Unfortunately, the aesthetic appeal of reserves and the facilities provided, together with the increased public awareness of nature, contribute to creating massive tourism in MPAs (Badalamenti & al. 2000).

Moreover, monitoring plans are also required in order to describe how these populations are changing over time, and implement integrated coastal zone management actions for the protection, conservation and/or restoration of these unique, valuable and unfortunately sensible ecosystems (Calvo & al. 2010; Pergent & al. 2014; Mancuso & al. 2016). The creation of early-warning systems, able to valuate early signs of suffering or decline, could be crucial for monitoring these habitats. Since intensive scientific monitoring programs are very expensive, Citizen Science (involvement and active participation of volunteers: tourists, fishermen, divers) could be a useful tool for providing information and scientific data and also to improve the communication between scientists and citizens (Mannino & al. 2018).

Acknowledgements

The author thanks Paola Gianguzza and Antonino Scannavino for providing photos.

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Address of the author:
Anna Maria Mannino,
Department STEBICEF, Section of Botany and Plant Ecology, University of Palermo, Via Archirafi 38, I - 90123 Palermo, Italy. E-mail: annamaria.mannino@unipa.it