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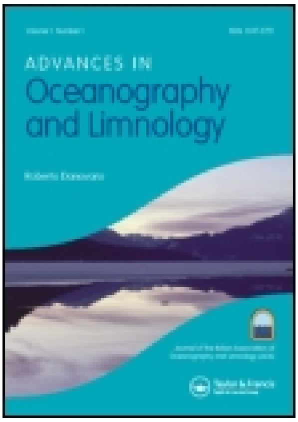

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Cystoseira species are some of the most important marine ecosystem-engineers, forming extended canopies comparable to land forests. Such forests are sensitive to human disturbances, like the decrease in water quality, the coastal development and the outbreak of herbivores. Conspicuous historical declines have been reported in many regions and several *Cystoseira* species are presently protected by European Union (EU) environmental policies. The aim of this work was to synthesize the conservation perspectives of *Cystoseira* forests in the Mediterranean Sea, focusing on the opportunities offered by artificial restoration and highlighting the potential role of Marine Protected Areas (MPAs). MPAs give a better protection to healthy forests than non-managed sites and may be a source of propagules for natural recovery and/or for non-destructive artificial restoration of nearby damaged forests. MPAs lacking *Cystoseira* forests may also represent preferential sites for reforestation. We proposed a flow-chart for the conservation and a reasoned restoration of *Cystoseira* in the Mediterranean Sea. The successful conservation of *Cystoseira* forests is still possible, via raising public awareness on the role of *Cystoseira* and reducing human impacts on coastal ecosystems. Such actions have to be coupled with more specific large-scale management plans, encompassing restoration actions and enforcement of protection within MPAs.

Keywords: *Cystoseira*; Fucales; forests; conservation; restoration; recovery; human impacts; Marine Protected Areas

1. Introduction

The genus *Cystoseira* is represented by 42 species, mostly distributed in the Mediterranean Sea, but also in the Atlantic Ocean [1], from the surface to the upper circalittoral zone [2,3]. Several species are endemic to the Mediterranean Basin, that is considered the hot-spot for *Cystoseira* species [4], some of the most important marine ecosystem-engineers, forming extended canopies comparable to land forests [5]. They increase three-dimensional complexity and spatial heterogeneity of rocky bottoms, providing refuge and food for many invertebrates and fishes at different life history stages [6–13]. *Cystoseira* forests, hence, play an important functional role in Mediterranean coastal ecosystems, sustaining complex food webs and maintaining a high biodiversity.

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Similar to other large brown seaweeds, *Cystoseira* species are highly sensitive to several human disturbances, so that conspicuous historical declines, for at least a century and especially of species thriving in rock-pools and in the infralittoral zone, have been reported in many regions of the Mediterranean Sea [14–19]. Among human impacts responsible for such regression, the increasing coastline urbanization [17] causes habitat destruction and modification of environmental characteristics (such as hydrodynamics, loads of sediments [20], nutrients [21,22] and chemical pollutants [23,24]). Proliferation of urban structures is common along the Mediterranean coasts: as an example, more than 17 km of coast close to Genoa Harbour (North West of Italy), 11.1% and 88.96% of the French whole Mediterranean and Monaco coastlines are entirely artificial (www.medam.org, last access 6 September 2013). Loss of *Cystoseira* has also been attributed to the outbreak of herbivores [15,25,26], which is a common phenomenon in many regions of the world and is sometimes caused by overfishing of their predators [27–37]. In the Mediterranean Sea, sea-urchins are considered the most important herbivores, being able to graze the macroalgal communities and to create barren grounds (i.e. rocky reef, bare or covered by encrusting coralline algae) [26,38]. High densities of sea-urchins are usually associated with over-fishing of their predators (sea-breams of the genus *Diplodus*) [38–40] and/or date mussels (*Lithophaga lithophaga*) harvest [41–45]. Although *L. lithophaga* is a protected species and its harvest banned (included in Annex IV of the Habitats Directive, in Annex II of the Bern Convention and Barcelona Convention), such fishing was very common in the past in some parts of the Mediterranean Sea and is still illegally carried on in several regions [46–50]. Another important herbivore in Mediterranean rocky bottoms is salema (*Sarpa salpa*), known to selectively graze on some *Cystoseira* species [51]. Its contribution to the general loss of *Cystoseira* in the Mediterranean Sea cannot be quantified with the present knowledge, but we cannot exclude an increase of salema abundances due to the over-fishing of their predators [52–54]. Other potential impacts causing *Cystoseira* regression that are not considered in this study, as less known and/or spread, may be agriculture, bivalve farming and scientific research in the past.

For these reasons, *Cystoseira* forests are locally considered under threat. Several Mediterranean species (*C. amentacea* var. *stricta*, *C. mediterranea*, *C. sedoides*, *C. spinosa*, *C. zosteroides*) are listed in the Annex I of the Bern Convention (Council of Europe 1979). The Mediterranean Action Plan, adopted within the framework of the Barcelona Convention (1976), identifies, in an amendment of 2009 (Annex IV, SPA/BD Protocol – United Nations Environment Programme [UNEP]), the conservation of all but one Mediterranean *Cystoseira* species (*C. compressa*) as a priority. Nevertheless, the overall benefits of these protection measures have been low so far, urging for effective conservation actions.

Here we discuss how the establishment of Marine Protected Areas (MPAs) where dense *Cystoseira* forests are still present, could favour the conservation of these habitats and their recovery. In this synthesis, we only consider MPAs that are effectively enforced [55], so that illegal fishing is not carried on and predators can control densities of sea-urchins, preventing the formation of barren grounds [38].

Cystoseira species are characterized by high reproductive potential, with the production of abundant large and easily sinking eggs and zygotes [56–58]. This reproductive strategy favours the formation of dense monospecific assemblages, but limits the dispersal ability [58]. The low dispersal reduces the potential for natural recovery of wide lost/degraded areas [59,60], such that artificial restoration has been suggested to be an effective way to favour the recovery of low-dispersal/long-lived species [61]. This is the case for *Cystoseira* species, whose effective reproductive strategy would allow the use of non-destructive restoration methods such as propagules or reproductive structures [62]. On the contrary, the benefits of the restoration undertaken to restore, for instance, degraded *Posidonia oceanica* meadows have been contentious [63] because *P. oceanica* has a very low sexual reproduction potential [64] that imposes the use of techniques that may damage the source meadows [65–67]. More studies are needed to find a non-destructive technique for *P. oceanica* restoration. Finally, when *Cystoseira* forests are lost over wide areas, it may be envisaged to couple artificial restoration [19,62,68,69] with conservation and management in MPAs.

The aim of this work is to synthesize the conservation perspectives of *Cystoseira* forests in the Mediterranean Sea. We focus on the opportunities offered by artificial restoration of *Cystoseira* species, taking into account previous experiences with other large brown seaweeds worldwide, and highlighting the potential role of MPAs.

2. Restoration of marine forests

2.1. Large brown seaweeds forestation

Restoration ecology in estuarine and marine systems is a relatively recent science [61] compared to the historical restoration actions extensively carried out in terrestrial environments [70,71]. Nevertheless restoration actions have been experimented within estuarine habitats [72–75], coastal urbanized areas [76–78], wetlands [79], coral reefs [80], seagrass and eelgrass beds [81,82]. Restoration of kelp and fucoid forests has also been explored in Asia, especially China, Japan and Korea and in North and South America [83–90].

Marine forests restoration has been generally performed through three methods: transplanting juvenile or adult individuals [69,83,87,89,91], enhancing recruitment potential (by releasing a suspension of gametes/zygotes or installing fertile receptacles in the target area) [62,83,92,93] or artificially supplementing recruitment (culture of embryos/juveniles in laboratory) [83,90,94].

Transplanting juvenile or adult individuals has been the most frequently tested restoration technique. Kelps and fucoids mainly thrive on rocky exposed shores, so that an efficient fixing of individuals to the rocks has been a major challenge in these forestation attempts. In Chile individuals of *Lessonia nigrescens* were transplanted using plastic nets, rubber bands or epoxy [83,91]. In Southern California *Silvetia compressa* was transplanted by attaching small pieces of rock bearing adults or juveniles to the shore [89]. In Northwestern Washington (USA), juveniles of *Nereocystis luetkeana* were embedded in a propylene rope that was successively inserted in a hard plastic clip attached to the rock with epoxy putty [87]. In Southern California, Hernández-Carmona *et al.* [85] tested, in different years, two techniques to restore *Macrocystis pyrifera*: transplantation of juveniles, by tying them to the base of previously cut *Eisenia arborea*, and the enhancement of recruitment potential, by putting reproductive blades in cage-like lobster traps. The effort required by each of the two methods was comparable, and the results suggested that combining transplantation of juveniles and seeding during spring would increase the probability of a successful restoration. The enhancement of recruitment potential was also tested for *Sargassum thunbergii* in China using a concentrated suspension of germlings [93]. In another study, such a technique was applied for increasing the recruitment potential of *Lessonia nigrescens* in Northern Chile and then compared to the use of bundles of reproductive fronds fixed to the rock [83]. The same authors also tested an artificially supplemented recruitment, by seeding spores in the laboratory on different substrata that were, afterward, fixed to the rock. Another study artificially supplemented the recruitment of *N. luetkeana* by using Petri dishes as a support, but the rate of loss was very high [87].

All of the studies discussed above considered the restoration successful when a high survival and/or density of recruits was observed at the end of the experiment. However, for restoration to be successful over time, some maintenance actions also have to be planned. For example, a suspension of germlings of *Sargassum thunbergii* was released in artificial rock-pools in China made to control water motion and nutrients and favour the settling of embryos [93]. Grazing is another factor that may need to be controlled, depending on local conditions and method applied (especially when using embryos or juveniles). Many studies on the restoration of kelps and fucoids included methods to exclude herbivores: cages [95], nets [96], antifouling paint [89] or removal by hand [88,97]. The effects of grazing may vary with the density of germlings [97] and may increase with other stressors [97–99].

2.2. **Cystoseira** ***forestation***

The restoration of *Cystoseira* forests in the Mediterranean Sea has been less well studied compared to that of kelps and fucoids in other parts of the world. Some studies used several methods for transplanting *Cystoseira* individuals in order to test ecological hypotheses (different from restoration): plants were tethered to other macrophytes [51], entangled in nets screwed into the rock [100], attached to plastic meshes fixed to ceramic plates [101], fastened to bricks with polyurethane foam [102] and fixed with epoxy putty, both detaching pieces of rocks bearing adult individuals [24] and directly in holes drilled into the rocks [58]. A few other studies explored specifically the reforestation potential of Mediterranean rocky shores (reviewed in Table 1) using different techniques depending on *Cystoseira* species. *Cystoseira barbata,* a species thriving in shallow and relatively sheltered waters, was transplanted in the Northern Adriatic Sea fastened to bricks with polyurethane foam [68], or fragments of rocks bearing juveniles were chiselled off, transferred and reattached with epoxy putty to the shore [19,62]. Attempts of *C. barbata* transplantation (together with *C. crinita* and *C. foeniculacea* f. *tenuiramosa*) were performed in the south of France, fixing adult plants with epoxy putty to boulders disposed in rock-pools [103]. *Cystoseira amentacea* var. *stricta*, a species that forms belts in the exposed infralittoral fringe, was transplanted fixing adult plants with epoxy putty in holes drilled into the rock [69]. *Cystoseira compressa,* which thrives in both exposed and sheltered shallow waters, was transplanted, in the infralittoral fringe of exposed shores, using the same technique as for *Cystoseira amentacea* var. *stricta* [58,69] or, in shallow sheltered zones, hooking the base to cubes of cork fitted in the holes of bricks [68]. For this latter species, however, there was a relatively high loss of transplants [68,69], because the morphology of the base of *C. compressa* made the fixing unstable. In most of the cited studies, transplantation success was high: more than 70% survival after six months for *C. compressa* and *C. amentacea* var. *stricta* [69] and about 30% survival for *C. barbata* after eight months [62]. More interestingly, fertile receptacles or new recruits were often observed in the same year in the case of adult transplantation and one year later in the case of juvenile transplantation [24,58,62,68,69]. Capitalising on the reproductive season of the target species of *Cystoseira* could, therefore, help optimising reforestation efforts.

Despite the generally high reproductive potential of *Cystoseira* species [104,105], few studies have used gametes/zygotes for restoration purposes. Perkol-Finkel *et al.* [62] intercepted recruits of *C. barbata* in the field by using a variety of artificial plates that were located in areas with high settlement potential, but low post-settlement survival probability. They compared plates of different materials (limestone, concrete and clay) and different levels of roughness (only for the clay plates), but neither factor significantly

Table 1. Studies reporting a transplantation method used either for restoring *Cystoseira* species or for testing ecological hypotheses.

Transplanted species	Stage of transplant	Topic	References	Location
C. barbata, *C. spinosa* var. *tenuior*, *C. crinita*	Adults	Effect of pollution	[24]	Menorca Island, Spain
C. abies-marina	Adults	Effect of pollution	[100]	São Miguel Island, Azores, Portugal
C. amentacea, *C. compressa*, *C. balearica*, *C. crinita*, *C. compressa* var. *pustulata*, *C. spinosa*	Adults	Grazing	[51]	Menorca Island, Spain
Cystoseira sp.	Adults	Grazing	[101]	Medes Islands, Spain
C. barbata	Adults	Phenology	[102]	Izola, Slovenia
C. compressa, C. *amentacea*	Adults	Zonation pattern	[58]	Bogliasco, Ligurian Sea, Italy
C. foeniculacea f. *tenuiramosa*, *C. barbata*, *C. crinita*	Adults, zygotes (plates in adult canopy)	Restoration	[103]	PACA Region, France
C. amentacea, *C. compressa*	Adults	Restoration	[69]	St Jean-Cap Ferrat, South of France
C. barbata	Juveniles	Restoration	[19]	Monte Conero, Adriatic Sea, Italy
C. barbata	Juveniles, zygotes (plates in canopy of adults)	Restoration	[62]	Monte Conero and surrounding urbanized coast of the Adriatic Sea, Italy
C. barbata, *C. compressa*	Adults, cultures of zygotes	Restoration	[68]	Izola, Slovenia; Miramare Natural Reserve, Italy

affected the settlement: after four months the plates supported variable, but generally high densities of recruits that could be used for subsequent transplantation. In Menorca, Spain, fertile receptacles were directly fixed to the rocky shore, and propagules, seeded on small stones in laboratory, were transferred to the sea (M. Sales *personal communication*). These non-destructive methods allowed obtaining new recruits without damaging *Cystoseira* forests, which is essential given the critical conservation status of these species. Important knowledge on how to obtain propagules of *Cystoseira* in tanks or Petri dishes and preserve them alive for a long time, as well as on optimal culture parameters, can be deduced from laboratory cultivation experiments developed principally for industrial and medical aims [106–111]. Such propagules can be directly released at sea (through a suspension) or maintained in culture until they reach an adequate size to be transplanted, as already done for other large brown seaweeds [83,90,93,112,113].

Similar to kelps, *Cystoseira* forestation may need maintenance actions to control biotic and abiotic factors that may decrease the survival of transplants or the density of recruits. Grazing is one of the major causes of failure in restoration activities of large brown seaweeds [87,114,115]. Negative effects of grazing have been observed in almost all *Cystoseira* transplantation experiments carried out in the Mediterranean Sea ([58,62,68,69,116], Ferrario *et al*. unpublished manuscript), and experimental exclusions of herbivores have significantly increased the survival probability ([62], Ferrario *et al*. unpublished manuscript). Potential herbivores comprise species of crustaceans, molluscs, sea-urchins and fish [51,62,101,117,118] that usually graze more on *Cystoseira* juveniles than on adults [98,119]. Other factors, such as the absence of an adult canopy and the slope of the substratum, do not seem to limit the success of transplantation [19,62]. On the contrary, the zonation pattern (the position occupied by the species on the infralittoral fringe), and in particular for *C. amentacea* var. *stricta* or *C. mediterranea*, can be a determining factor [58], being related to variable abiotic and biotic pressures [51]. Locally critical ecological factors need to be identified and taken into account for a successful restoration of *Cystoseira* forests.

2.3. Forestation on artificial structures

Many artificial reefs, already existing or especially conceived, have been used for the restoration of large brown seaweed forests degraded by human impacts [86,90,92,120–126]. Even if in many cases results have been considered as successful, the installation of new artificial structures, including artificial reefs, has some negative effects on the native habitats and their associated assemblages [127,128]. Therefore we consider a more sustainable alternative, the use of already existing coastal infrastructures deployed for other societal needs (i.e. piers, dikes, breakwaters, jetties, wharfs, seawalls, offshore platforms, etc.), as a scaffold for the forestation of threatened algal forests. Since coastal infrastructures are expected to proliferate alongside human population [128–131] and their current ecological value as habitats is often very poor compared to natural habitats [130,132–136], efforts to garden ecologically valuable species on their surfaces could help to elevate their ecological value without compromising their original function [62]. Despite the increasing interest and focus, little is still known about the factors affecting the success of these interventions.

Marine infrastructures offer atypical substrates for benthic assemblages in terms of orientation, exposure, structure, surface texture, physical and biotic disturbances [128], all of which are known to affect the recruitment, survival and growth of many large brown seaweeds [137–139]. Extensive transplantation experiments of juveniles of *Cystoseira barbata* to a number of breakwaters and natural sites along the Italian North Adriatic Sea ([19,62], Ferrario *et al*. unpublished manuscript) have given encouraging results. Transplantation proved to be technically feasible and not affected by the slope of the substratum. This suggests that coastal infrastructures could provide potentially adequate habitats despite the greater proportion of inclined surfaces compared to natural ones [130,140,141]. Moreover, the survival of transplants was not impaired by lack of surrounding adults, suggesting that this would not be a limiting factor when managing assemblages on new man-made infrastructures that would obviously lack adult canopies. Nevertheless, when structures were located in sandy areas, a typical setting of many coastal defence infrastructures, survival rate was low [132]: scouring of sediment could be an important limiting factor for algae development [20]. Grazing pressure also seems to be higher on artificial than on natural substrates ([62,129,142,143], Ferrario *et al*.

unpublished manuscript), so that grazers exclusion should be considered [68]. Finally, individuals transplanted on the seaward side of breakwaters could be subjected to a large dislodgment by wave action [62]. A broad-scale experiment is in progress on the Marseilles harbour dikes where concrete structures are tested to transplant fertile *Cystoseira amentacea* var. *stricta* (T. Thibaut, *personal communication*).

3. *Cystoseira* forests in Marine Protected Areas

Thanks to a wide array of regulations, MPAs may guarantee protection of coastal ecosystems from several kinds of direct human impacts, especially coastal development and overfishing [144–146]. Generally, in well-enforced MPAs, illegal destructive fisheries, such as date mussel harvest and blast fishing, are not practiced and high fish and macroalgal biomass are expected, as the restored/preserved high-level predators in the food webs can control the abundance of herbivores and therefore limit the grazing pressure [39,40], one of the major causes of *Cystoseira* regression [15,25,26,33,38]. Whenever released from predator control, in fact, herbivore species like sea-urchins (e.g. *Paracentrotus lividus* and *Arbacia lixula*) and fish (i.e. *Sarpa salpa*) may greatly increase in population density and overgraze erected macroalgae.

Although healthy *Cystoseira* forests can be found in MPAs, as for example in Formentera-Espardell, in Spain, and in Scandola and Port-Cros, in France [147], where an efficient fishing regulation is in force, this is not a general rule [148]. Most Mediterranean MPAs are established on rocky coasts and exposed promontories, which should be the ideal habitats for algal forests, but *Cystoseira* is often not well developed (for instance in Cap de Creus MPA, in Spain, and Piperi MPA, in Greece) [148]. Alternate states (e.g. high fish biomass and low macroalgal complexity or low fish biomass and barren grounds) are commonly observed in MPAs, probably due to other factors acting at different scales [148]. At some MPAs *Cystoseira* stands may be lacking due to natural factors, such as local physical conditions and the characteristics of the species that are locally dominant, but in other sites the lack might be related to past direct or indirect anthropogenic impacts [15]. Potentially, the date mussel harvest or the cascading effects of sea-urchins predators' overfishing may have depleted macrophyte assemblages in MPAs before the establishment of the protection regime, but historical data are generally lacking. However, at Ustica Island MPA (Sicily), extensive barren grounds appeared after the MPA establishment, likely due to the regulation of sea-urchin harvesting [149], but also to the fact that in this relatively remote island, the population density of natural fish predators (sea-breams) is low, probably due to limited juveniles' settlement [40].

Healthy dense forests can still be found in non-protected, but naturally isolated and lowly human-impacted sites, such as Bledes and Dragonera in the Balearic Islands, Kimolos in Greece or St Peter's Island and Maratea coastline in Italy (authors' *personal observation*, [148]). Such forests should be the object of priority conservation measures.

Due to the limited dispersal capability of *Cystoseira* species, the natural re-colonization of deforested areas is particularly slow [56,58,105]. To our knowledge, the only documented cases of natural recovery of *Cystoseira* have been recorded in MPAs. In the Medes MPA, *Codium vermilara* beds and some barren grounds were dominating the seascape at the moment of its establishment, and *Cystoseira* recovery started occurring only 20 years later [148,150]. In Ustica MPA, about 10 years after the disappearance of *Cystoseira* forests, a potential increase of abundance of the starfish *Marthasterias glacialis* may have contributed to the regulation of sea-urchin density and the observed natural recovery of *Cystoseira* [151]. In both cases, we suppose that fragmented reproductive populations of

Cystoseira were still present in scattered refuge areas, even if at low densities. Rare dispersal events, such as drifting or dispersal by animals ('zoochory') may be more common than generally assumed for some species [103], but it is generally assumed that *Cystoseira* natural recovery is unlikely, or very slow, and human-guided restoration could be a helpful tool. Healthy forests in well-preserved MPAs can represent the source of propagules useful to support rare dispersal events and non-destructive re-forestation programmes. Restoration of large brown seaweeds has already interested MPAs in different parts of the world (e.g. [35,36,68,83,89]) and we suggest that managers of MPAs, where the extension of such forests was reduced by human activities prior to the establishment of the protected area, should consider *Cystoseira* re-forestation. Indeed, the controlled abundance of herbivores in these sites may represent a better guarantee for a successful restoration. Unfortunately historical distribution of *Cystoseira* forests is largely unknown, also in areas hosting MPAs. Where grey literature, experts or local stakeholders knowledge is not enough to effectively assess the past presence/natural absence of *Cystoseira* forests, the decision may be based on similar neighbour sites or on modelling [152].

In conclusion, we suggest that MPAs have a strong potential for conservation and restoration of marine forests: both as a source of propagules and as priority sites for restoration activities. Nevertheless, they do not provide protection from large-scale impacts, such as global warming, biological invasions and decrease in water quality [153]. A large-scale spatial planning applied to MPAs and adjacent unprotected areas [154–156] with long-term monitoring programmes and restoration actions, where necessary, is probably the best perspective for *Cystoseira* forests preservation in the Mediterranean Sea [157].

4. Conservation and a reasoned forestation of *Cystoseira* species

In synthesis, *Cystoseira* forests have already suffered widespread and apparently irreversible loss, much of which may have gone unnoticed. The Mediterranean Action Plan, adopted within the framework of the Barcelona Convention (1976), identifies the conservation of *Cystoseira* species as a priority and several large brown seaweeds are listed in the Red Books of Mediterranean and Black Seas (IUCN, www.iucn.org), but very few tangible focussed actions have been established (no institutional actions have been undertaken in the Mediterranean Sea to our knowledge). Therefore, the overall benefits of these protection measures have been low so far [17] and we do not have information on *Cystoseira* distribution, even in MPAs. Also little information is available about their recovery potential, and possibly, over a certain deterioration threshold, these systems may not be able to recover at all [19,34,158,159]. A correct conservation of Mediterranean marine forests should therefore rely firstly on the protection and management of existing healthy forests and secondly on the restoration of fragmented/lost ones. Some guidelines for hypothetical conservation/non-destructive restoration actions of *Cystoseira* forests can be summarized by a flow-chart (Figure 1).

The first step would be to collect information on the distribution and status of the existing forests. If forest is present, healthy and already protected (e.g. in a MPA), it would be useful establishing a regular monitoring to detect early signals of regression. If the forest is not protected, setting effective conservation actions should be considered, in addition to a regular monitoring. If instead the forest is unhealthy, management actions (including forestation) should be planned.

When the site is not forested, it is important to search for historical data: if *Cystoseira* was previously present, an artificial restoration plan should be considered, after removing

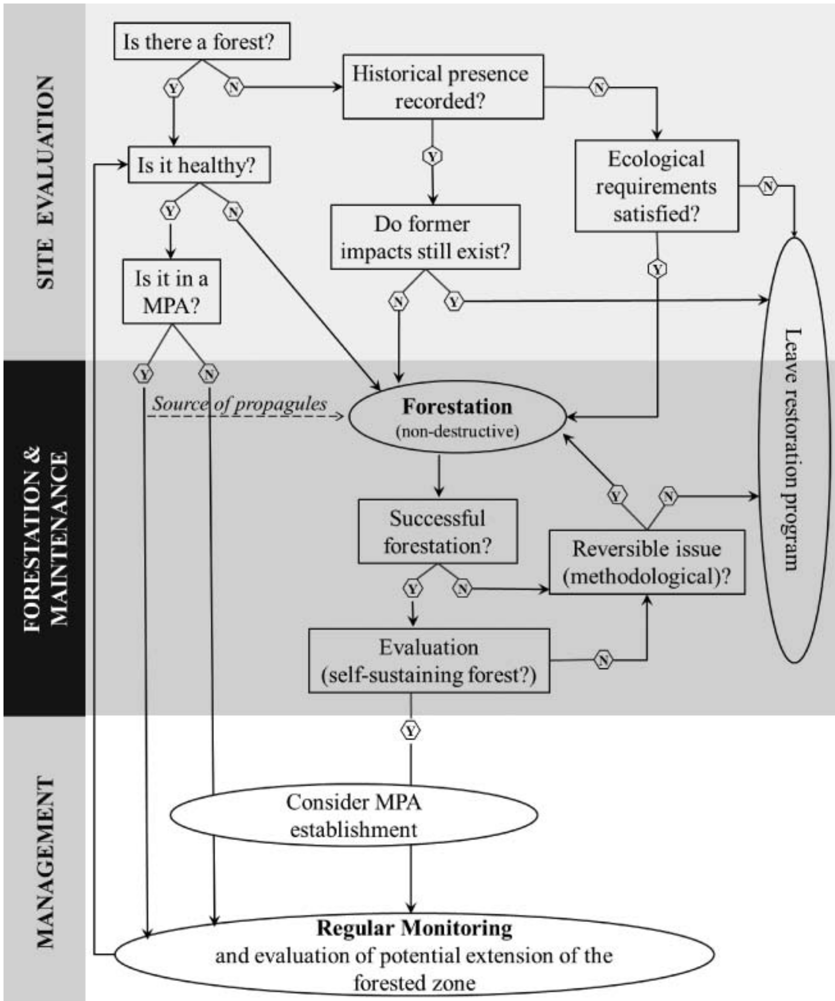

Figure 1. Flow-chart for conservation and reasoned forestation of *Cystoseira* species in the Mediterranean Sea.

the impacts that generated the loss of the forest. If such impacts are still present in the area, no forestation action should be undertaken. If no historical data are available, evaluating the local and regional environmental conditions and anthropogenic pressures could help to understand if *Cystoseira* ecological requirements are satisfied, the likelihood that *Cystoseira* forests might have occurred in the region (e.g. [152]) and if a restoration programme could succeed.

Once restoration action is deemed necessary and likely successful, a forestation method should be chosen. Several approaches have been presented and discussed here and there is not a best technique, as recovery is context-dependent, relying on life-history characteristics of the target species and on the local environmental conditions [159]. Restoration should not involve the transplantation of adults or juveniles collected from healthy forests [68,69]. This approach, although successful, should be avoided and preference should be given to non-destructive techniques based on the enhancement of natural ([62], M. Sales *personal communication*) or artificial supplemented recruitment [68].

After the first forestation phase, the established setup should be maintained (e.g. cages cleaning, nutrients supply and regulation or exclusion of herbivores) and regularly monitored to assess its success. If the forestation is not successful due to high mortality of transplants or absence of recruitment, additional forestation activities could be planned, but only in case the failure is related to reversible issues (e.g. catastrophic events, inadequate choice of the forestation or the maintenance actions). The outcome of restoration should be regularly evaluated by quantifying different variables, in the function of the chosen species/technique: survival of transplants, density and mortality of recruits and/or fertility of second generation individuals. When such variables are comparable to those measured in healthy forests, we may consider the forest as self-sustaining. Afterwards, eventual cages installed for excluding herbivores can be removed, unless they were made from biodegradable materials [84]. Successive monitoring programmes should be undertaken to detect eventual impacts affecting such a forest. If the restored area is not protected, any kind of effective management action devoted to protect the forest may be considered. A successful restoration can be also applied on the adjacent coasts, so to increase the extension of *Cystoseira* stands.

5. Conclusions

Marine forests of large brown seaweeds are locally disappearing in many regions of the world, together with the increase of human activities [17,160]. This trend is also occurring in several areas of the Mediterranean Sea [15], where healthy *Cystoseira* forests are highly threatened and not adequately protected [148]. An important role for forest conservation may be played by MPAs that guarantee protection from various human impacts (e.g. overfishing, urbanization) and that can reduce other ones through an integrated large-scale ecosystem-wide management with adjacent non-protected areas [155,156]. The protection of existing forests should be coupled to regular monitoring programmes in order to promptly highlight potential threats and early signs of regression. Current recovery potential for lost marine forests seems to be limited, even when the proximate drivers of loss are removed [60,161]. An active restoration represents a valuable alternative to assist the conservation of *Cystoseira* forests, but a costs/benefits assessment should be done to evaluate if protection of marine forests would be a better alternative to restore already degraded forests. This should account the economic value of direct, indirect and ‘non-use’ goods furnished by marine forests, a practice already performed with services provided by MPAs [162].

Several restoration techniques have been presented and discussed here and the choice is species/site dependent. Whenever possible, non-destructive techniques and biodegradable materials should be preferred and, in some cases (e.g. highly variable environments where failure could be higher) the integration of different techniques could enhance success probability [87]. The restoration of *Cystoseira* forests is particularly recommended where historical presence is recorded and the impacts that led to its loss are no longer acting in the area. Nevertheless, forestation could also be considered at sites where the previous distribution cannot be documented, but is likely, based on the local and regional environmental characteristics. Also existing artificial substrata could be considered for forestation, whenever the biotic and abiotic environmental factors are compatible, as this would enhance the ecological value of these artificial substrata without compromising their engineering function. Restoration actions should be preferentially performed in MPAs that can give a better protection than non-managed sites and guarantee the source of propagules for the recovery and/or restoration of close damaged forests.

A successful conservation of *Cystoseira* forests is still possible, as shown by the encouraging results discussed in this synthesis [19,62,68,69]. Reducing cumulative human impacts would still represent one of the most important strategies for the successful conservation and recovery of these systems, but, whenever this alone cannot reverse the loss, well-designed restoration projects can assist. Other important drivers of success would include raising public and political awareness, legal actions and enforcing MPA management plans [159,163].

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