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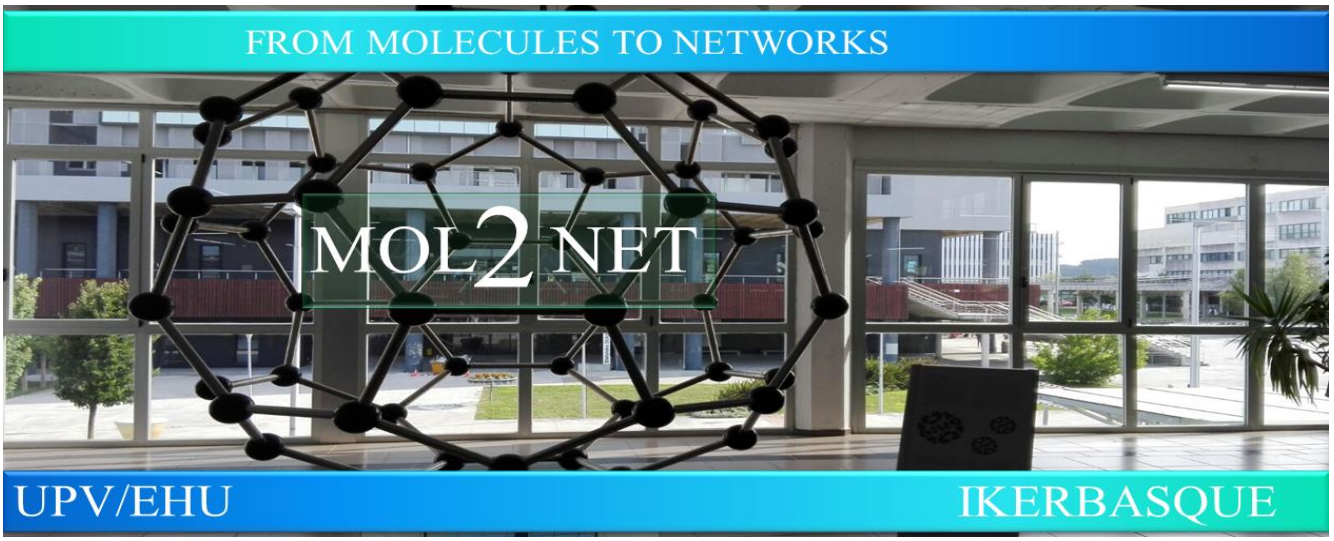

Current conservation status of autochthonous seagrasses in the Mediterranean Sea: a systematic review

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Abstract.
Seagrasses are globally declining. They form important ecosystems, providing food and shelter for other marine organisms as well as services such as protection from coastal erosion and water quality regulation. For these reasons, their conservation should be of primary concern. A critical review was conducted to determine whether conservation efforts for autochthonous marine angiosperms in the Mediterranean Sea were consistent with their status based on their distribution, habitat, population dynamics, main threats, and conservation strategies used for each one. In general, seagrasses are declining in the Mediterranean, and conservation efforts vary greatly depending on the species. Posidonia oceanica (L.) Delile and Cymodocea nodosa (Ucria) Asch were the species that were investigated the most between 2000 and 2020. On the other hand, little information about Ruppia maritima L. was available. The in situ conservation strategies implemented for these species are considerably more advanced than the ex situ. The highest level of legal protection is given to P. oceanica, whereas the remaining species are mainly protected by efforts aimed at all seagrasses in general. Not many studies were published on the ex situ conservation strategies, particularly those aimed at their long-term preservation in gene banks, which were restricted to Zostera marina L., Ruppia cirrhosa (Petagna) Grande, and R. maritima.
Keywords: *Seagrass, Mediterranean, conservation, in situ, ex situ, distribution.*

Introduction

Seagrasses are underwater marine flowering plants that tend to form extensive meadows on sandy or muddy substrates that resemble land grass fields, also known as seagrass beds (Green *et al.*, 2003). These seagrass meadows form very complex ecosystems which are extremely important to the coastal marine environment, both locally and globally (Laffoley and Grimsditch, 2009). They are very important due to their considerable contribution to fisheries production, filtering coastal waters, reducing coastal erosion, and as a great sediment anchoring system (Green *et al.*, 2003). Unfortunately, it is reported that they are declining at a global scale, in parallel to the degradation of coastal and marine environments, due to a different combination of anthropogenic and natural stressors (Green *et al.*, 2003; Orth *et al.*, 2006; Waycott *et al.*, 2009; de Los Santos *et al*., 2019).

In situ conservation strategies aim to preserve biodiversity in its natural habitat. This entails the preservation and recovery of populations in their natural habitat in order to protect, manage, and monitor population dynamics and adaptation to constantly changing conditions (Rajpurohit and Jhang, 2015). However, since *in situ* conservation measures are sometimes not enough, *ex situ* conservation strategies constitute a very valuable tool that complements *in situ* conservation measures, particularly in cases of severe population loss (Kasso and Balakrishnan, 2013).

For these reasons, this work aims to critically analyze the conservation status and actions applied to each species in the Mediterranean Sea attending to the current published information.

Materials and Methods

In order to determine the current conservation status of Mediterranean seagrasses, a database was first produced from a systematic search of the literature using the academic databases ISI Web of Science (https://webofknowledge.com/, accessed on 10 March 2020), and Google Scholar (https://scholar.google.com/, accessed on 10 March 2021). Additionally, reliable scientific information published in governmental reports or official biodiversity databases was also consulted.

The literature research was performed taking into consideration papers published between the years 2000 and 2020. This research was based on the search equation ("Posidonia oceanica" OR "Cymodocea nodosa" OR "Ruppia cirrhosa" OR "Ruppia maritima" OR "Zostera marina" OR "Zostera noltii" OR "Zostera noltei") AND (distribution OR "population dynamic*" OR regres* OR declin* OR loss OR increase* OR gain OR status OR habitat OR threat*). Different inclusion and exclusion criteria were applied and a total of 161 articles were considered to develop the database.

Results and Discussion

A remarkable amount of recently published scientific information on *C. nodosa* in the Mediterranean Sea was obtained. Along the Mediterranean-European countries' coasts, the population of *C. nodosa* appears to be declining (Chefaoui *et al.*, 2016; de Los Santos *et al.*, 2019) despite the wealth of methods applied to *in situ* conservation strategies (Zarranz *et al.*, 2010; Balestri and Lardicci, 2012; Sfriso *et al.*, 2019). The information found in these studies could also be applied to perform different *ex situ* conservation methods (for instance, *in vitro* germplasm banks) that are less developed for *C. nodosa* in comparison to other topics in conservation biology. Nonetheless, applying different *ex situ* conservation strategies might be a very good way to store and maintain the genetic diversity of the species as global warming might lead to its habitat and genetic loss (Chefaoui *et al.*, 2018).

Overall, legal protection for *in situ* conservation of *P. oceanica* is well developed, but it does not appear to be enough in order to assure its long-term survival, as obtained in the analyses of the database here produced. This species is still declining even in marine protected areas (MPAs) (Montefalcone *et al*., 2009; Burgos *et al*., 2017), primarily as a result of anthropogenic pressures (Marba *et al*., 2014). Restoration using fruits and vegetative fragments found on the shore provided a promising measure for its conservation (Balestri *et al*., 2011; Terrados *et al*., 2013), which seems to be hopeful for the recovery of damaged populations. However, the long-term survival and viability of these restored populations were not determined. Furthermore, the knowledge on *ex situ* conservation methods (micropropagation, preservation of germplasm in genebanks, etc.) for this species is severely limited. Restoration efforts have been limited by *P. oceanica*'s slow growth rate (Chefaoui *et al.*, 2018), and additional research on plant propagation procedures, as well as restoration success in the medium and long-term, is needed to ensure a more accurate long-term conservation of this species both *in situ* and *ex situ*.

Regression of *Z. marina* has been observed at both local (Boudouresque *et al.*, 2007; Bull *et al.*, 2010), and Mediterranean scales (Boudouresque *et al.*, 2009; Pergent *et al.*, 2014). A high number of restoration protocols have been developed using sods, shoots, rhizomes, and seeds, but unfortunately, only one was conducted in the Mediterranean region (Sfriso *et al.*, 2019). No results were obtained for the *ex situ* conservation strategies such as preservation of germplasm in genebanks , in contrast to what was obtained for those *in situ*, which is a common finding for the species studied in this work. The same situation was observed for *Z. noltii*, whose *in situ* conservation strategies are far more extensive than those *ex situ*. Research on this species in the Mediterranean Sea is also very limited since the majority was carried out in other regions (e.g. Paulo *et al*., 2019). A decreasing population trend was last assessed by the IUCN Red List of Threatened Species in 2013 (Pergent-Martini *et al.*, 2015). This conclusion, however, does not appear to be consistent with the trend described by Garrido *et al.* (2013), Pergent *et al*. (2014), De Los Santos *et al.* (2019), and Espel *et al.* (2019). These findings highlight the necessity for additional scientific research on global population dynamics (and particularly, at a Mediterranean scale) to draw accurate conclusions and adopt effective conservation and management strategies.

Furthermore, the scarcity of data prevents a comprehensive understanding of both *Zostera* species in the Mediterranean, which may be contributing to the species' present population decline.

The distribution of *R. cirrhosa* in the Mediterranean Region is still not very clear. The main reason seems to be derived from the problems with the taxonomic identification of this genus' species (Boudouresque *et al.*, 2009; Triest and Sierens, 2009; Mannino *et al.*, 2015). The fact that the genus *Ruppia* was just recently recognized as a marine angiosperm (Short et al., 2016) could explain the dearth of knowledge about the species, and the same should be considered for the closely related *R. maritima.* Different *in situ* conservation measures for these species were listed. However, none of them were carried out in the Mediterranean basin. As far as *ex situ* conservation actions concerns, *R. maritima* is stored in four separate gene banks according to PlantSearch (https://tools.bgci.org/plant_search.php, accessed on 3 April 2020). Also, several procedures for *in vitro* propagation were developed (Bird *et al.*, 1993; De Leon *et al.*, 1997; Bird *et al.*, 1996) which could be applied to both *ex situ* and *in situ* conservation plans. However, these two species do not appear to be under significant conservation pressure, as is the case for *P. oceanica.*

Conclusions

Depending on the species, the results collected for each seagrass differ substantially. The species for which the greatest information is available are *P. oceanica,* followed by *C. nodosa*. It is safe to state that these two species were the most investigated in the Mediterranean Sea between the years 2000 and 2020. On the contrary, there are few investigations on *R. maritima*, although the conservation seems not to be compromised as revealed in the works developed in other biogeographic regions. However, a better taxonomic understanding of the complex would be desirable to finally draw conclusions on the conservation status of these species. The information provided for the species belonging to the genus *Zostera* was also rather limited. A similar situation can be found for *R. cirrhosa*.

Overall, *P. oceanica* is the species that benefits the most from *in situ* conservation strategies, followed by *C. nodosa* and *Z. marina*. The two species in the genus *Ruppia* are the only ones that are simply protected by general legal action rather than species-specific legislation. Restorations and transplantations are the main strategies for *in situ* reinforcement observed in the Mediterranean.

However, *ex situ* conservation measures are quite rare. *In vitro* cultures are the most common procedures used, but not for all species, and only *Z. marina, R. cirrhosa,* and *R. maritima* benefit from conservation in gene banks.

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