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# Restoration of Seagrass *Posidonia oceanica* in Antalya Kaş-Kekova Marine Protected Area, Northeastern Mediterranean

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**Research Article**

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## Abstract

The restoration study of *Posidonia oceanica* was carried out in the Limanağzı location of the Antalya Kaş-Kekova Marine Protected Area. The shoots collected from another donor area, approximately 300 m away from the area, were brought to Limanağzı under optimal conditions and transferred to 2 different stations in the 5-25 m depth band, 20-35 m away from the shore on the same day. Data loggers were placed in the transfer areas and physical parameters such as temperature, pH, salinity and conductivity of the water in the region were recorded regularly. In addition, the health, growth and biodiversity status of *P. oceanica* in both stations in the restoration area were monitored on-site with SCUBA dives. As a result of an 8-month monitoring, the physicochemical parameters recorded at station 1 (5 m) and station 2 (10 m) were observed to be at similar values. The lengths of the leaves at station 2 showed significant development at the end of 8 months and the rhizomes were firmly attached to the ground. The biodiversity status in the area was monitored for 9 months at both stations and during this period, 12 different species were identified, 9 of which were teleost (*Chromis chromis*, *Parupeneus forsskali*, *Siganus luridus*, *Siganus rivulatus*, *Sparisoma cretense*, *Stephanolepis diaspros*, *Torquigener flavimaculosus*, Cheilodipterus novemstriatus and *Xyrichtys novacula*) and 1 each of nudibranch (*Flabellina affinis*), echinoderm (*Synaptula reciprocans*) and tunicate (*Halocynthia papillosa*). At the end of 10 months, the most observed species in stations were Indo-Pacific alien species, *Siganus luridus*, *Siganus rivulatus*, *C. novemstriatus*, *P. forsskali* and *T. flavimaculosus*, respectively.

**Keywords:** *Seagrass, Posidonia oceanica, restoration, Kaş coasts, northeastern Mediterranean.*



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## Introduction

*Posidonia oceanica* (Linnaeus) Delile, 1813 is a seagrass species that occurs in the infralittoral zone of the Mediterranean coast in an area of approximately 50.000 km² (Pasqualini et al., 1997). The seagrass has ecological importance due to its important roles such as nursery areas, primary production, oxygenation, sediment fixation for marine and coastal systems, and economic importance due to its features such as preventing erosion in coastlines and constituting breeding areas for fish stocks (Boudouresque et al., 2016). *P. oceanica* is an effective biological indicator for estimating the status of coastal ecosystems (Ruiz and Romero, 2003). It is found at depths between 0.5 m and 30-40 m depending on environmental conditions (Okuş et al., 2006).

The geographical distribution of *P. oceanica* generally covers the Mediterranean and Aegean Seas (Boudouresque et al., 1994). In Turkish marine waters, it is distributed along the Mediterranean, Aegean and partly Marmara coasts, while it is not distributed in the Black Sea. *P. oceanica*, which is distributed in the Aegean and Western Mediterranean coasts of Türkiye, has expanded its distribution to the Mersin coast in the Eastern Mediterranean (Çelebi, 2007; Akçalı et al., 2019). Like other seagrass beds around the world, *P. oceanica* is also affected by climate change and negative anthropogenic activities. Despite being categorized as 'Least Concern' (LC) on the IUCN Red List, its populations are in decline. Due to the critical point at which the decline level has been reached, *P. oceanica* is listed in Annex II of the "Protocol on Specially Protected Areas and Biological Diversity in the Mediterranean" within the framework of the Barcelona Convention (United Nations Environment Programme [UNEP], 1995). It is also under the protection of the European Union's Habitats Directive (92/43/CEE) and *P. oceanica* beds are among the priority habitats (Boudouresque and Bianchi, 2013).

To reliably assess the global quality of the marine environment and to implement appropriate management measures for the protection of the coastal environment, information on organisms that respond rapidly and easily to ecological changes is needed (Kennedy and Jacoby, 1999). The use of biological indicators is often a suitable method for this purpose. In particular, *P. oceanica* seagrass stand out due to their wide distribution, moderate size, sedentary behaviour, easy collection and abundance, and sensitivity to coastal zone modifications, and are suitable for biological monitoring by both in situ (upper and lower depth limits, number of shoots per surface unit, surface area covered, mat structure, etc.) and in vitro (leaf biometry, temporal measurements, biochemical composition, heavy metal contamination, epiphytic cover and bacterial populations, etc.) techniques (Pergent-Martini et al., 2005). Approaches to seagrass conservation are generally local or national in nature. There is currently no international law directly applicable to seagrass (Short and Coles, 2001). However, the value of seagrass is globally recognized through international agreements such as RAMSAR, the Convention on Migratory Species (CMS), the Barcelona Convention, the OSPAR Convention, Natura 2000, CITES and the Convention on Biological Diversity (CBD) and there are arguments for their universal protection.

On the other hand, increasing anthropogenic impacts, climate change, and introduction of alien species in the Mediterranean (Turan et al., 2024) are important factors for the survival of seagrass meadows and success of artificial restoration methods (Short and Coles, 2001). Moreover, restoration is not an easy process, and many failures occur for various reasons (Race and Fonseca, 1996). It is a known fact that *Posidonia* species do not recover intact because they regrow over decades. Therefore, it is essential to first eliminate the cause of loss and then initiate restoration efforts.

During dives in the Limanağzı area in Kaş coasts of Antalya, *P. oceanica* seagrass were observed until 2009, but after a plane wreck sank into the area in 2009, *P. oceanica* have not been observed in that location since then. Therefore, in this study, it was aimed to restore Limanağzı, the old habitat of *P. oceanica*, to its pre-2009 condition through transplantation study.

**Material and Methods**

The shoots collected from the donor *P. oceanica* seagrass located approximately 300 m from the study area were stored in closed thermal baths, in a wet state and submerged in water, and then brought to the transportation area on the same day (Figure 1).

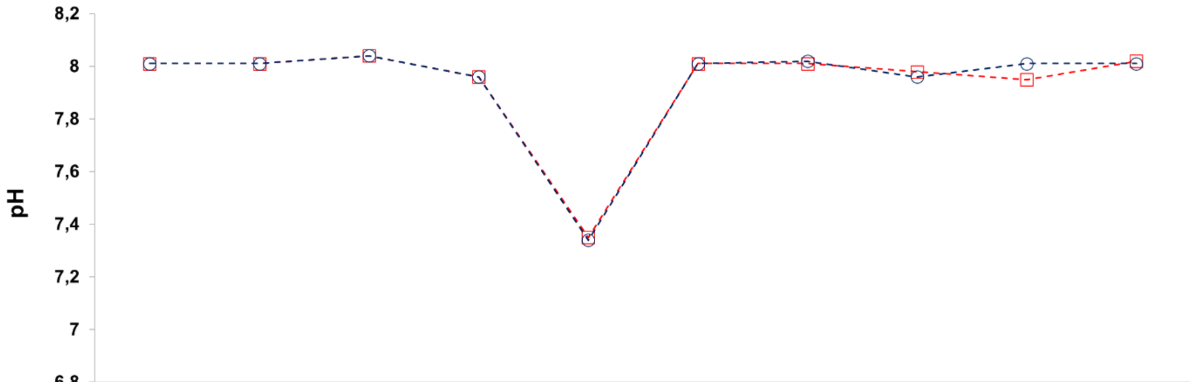

Figure 1. Satellite image and coordinates of the study area of *P. oceanica*.

While determining the study area, the fact that it was the *P. oceanica* bed before 2009 with SCUBA dives, its position where it receives sunlight, and the flatness of the ground structure were taken into consideration. To fix the rhizomes collected from the donor *P. oceanica* bed, two square frames were created with nylon rope inside 1 x 1 m iron frames. *P. oceanica* shoots were attached to these frames with plastic clamps. One of the frames was placed at a depth of 5 m (station 1) and the other at a depth of 10 m (station 2) and fixed by nailing to the ground against any threat that may arise from waves and currents (Figure 2). In addition, data loggers were placed in the transplantation areas and physicochemical parameters such as temperature, pH, salinity and conductivity of the water in the region were regularly determined. The health and growth of the transplanted *P. oceanica* were monitored on-site with SCUBA dives between November 2023 and August 2024.

Figure 2. Scuba diving deployment of *P. oceanica* rhizomes attached to an iron-grid on a sandy bottom.

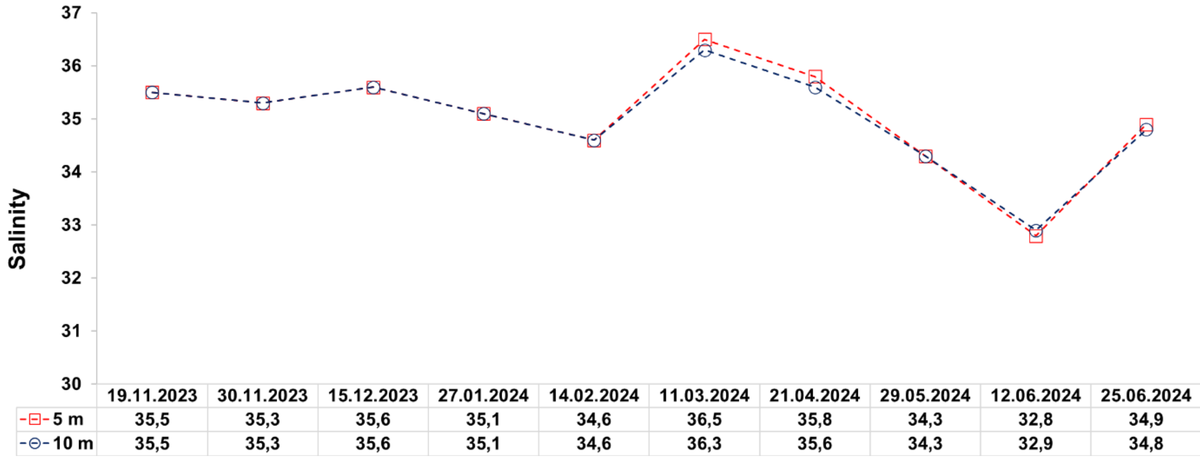
## Results

Monitoring study conducted at station 1 (5 m) and station 2 (10 m) showed that the recorded physicochemical parameters pH (Figure 3), salinity (Figure 4), conductivity (Figure 5), and temperature (Figure 6) remained similar at both stations for 8 months (temperature 10 months).




| | 19.11.2023 | 30.11.2023 | 15.12.2023 | 27.01.2024 | 14.02.2024 | 11.03.2024 | 21.04.2024 | 29.05.2024 | 12.06.2024 | 25.06.2024 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 m | 8,01 | 8,01 | 8,04 | 7,96 | 7,35 | 8,01 | 8,01 | 7,98 | 7,95 | 8,02 |
| 10 m | 8,01 | 8,01 | 8,04 | 7,96 | 7,34 | 8,01 | 8,02 | 7,96 | 8,01 | 8,01 |

Figure 3. pH changes observed in 8 months at depths of 5 and 10 meters.

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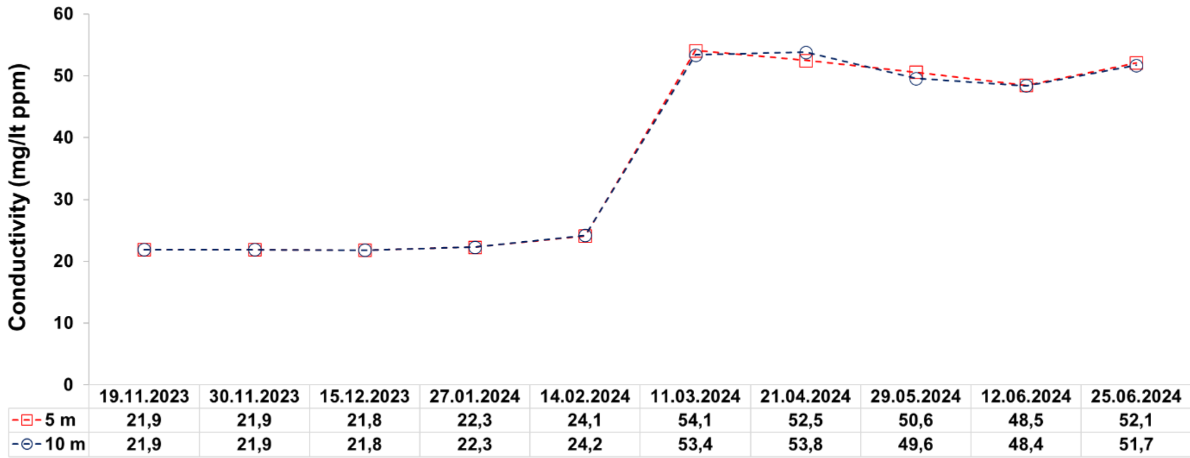
|---|---|---|---|---|---|---|---|---|---|---|
| 5 m | 35,5 | 35,3 | 35,6 | 35,1 | 34,6 | 36,5 | 35,8 | 34,3 | 32,8 | 34,9 |
| 10 m | 35,5 | 35,3 | 35,6 | 35,1 | 34,6 | 36,3 | 35,6 | 34,3 | 32,9 | 34,8 |

Figure 4. Salinity changes observed in 8 months at depths of 5 and 10 meters.

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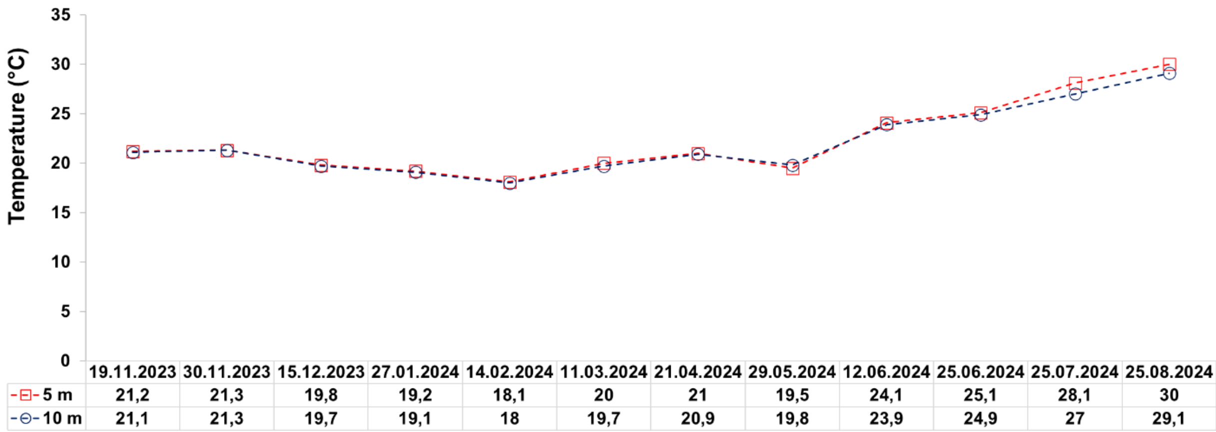
|---|---|---|---|---|---|---|---|---|---|---|
| 5 m | 21,9 | 21,9 | 21,8 | 22,3 | 24,1 | 54,1 | 52,5 | 50,6 | 48,5 | 52,1 |
| 10 m | 21,9 | 21,9 | 21,8 | 22,3 | 24,2 | 53,4 | 53,8 | 49,6 | 48,4 | 51,7 |

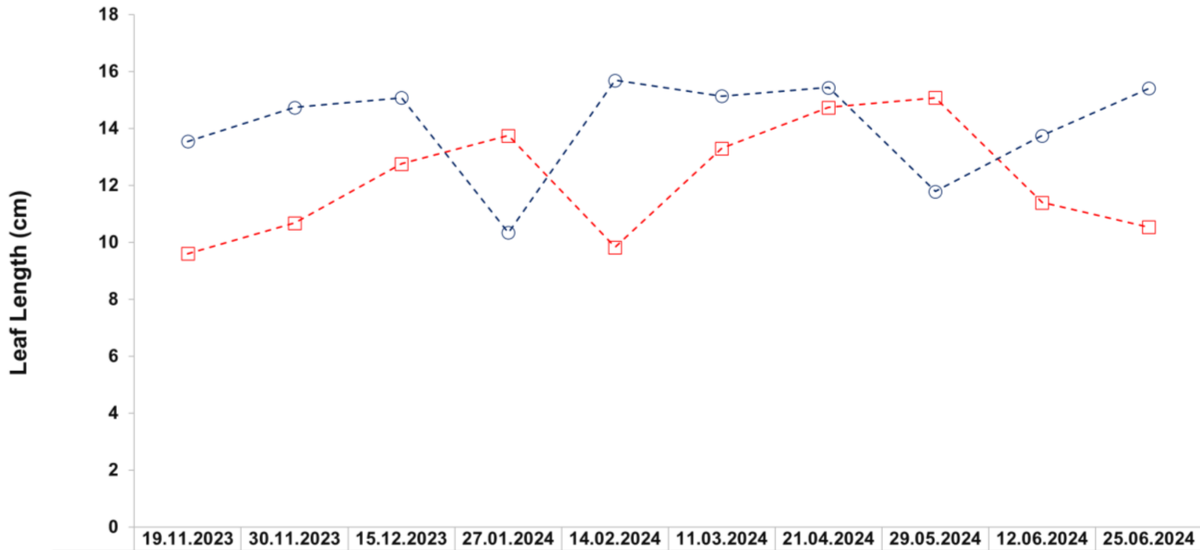
Figure 5. Conductivity changes observed in 8 months at depths of 5 and 10 meters.




| | 19.11.2023 | 30.11.2023 | 15.12.2023 | 27.01.2024 | 14.02.2024 | 11.03.2024 | 21.04.2024 | 29.05.2024 | 12.06.2024 | 25.06.2024 | 25.07.2024 | 25.08.2024 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 m | 21,2 | 21,3 | 19,8 | 19,2 | 18,1 | 20 | 21 | 19,5 | 24,1 | 25,1 | 28,1 | 30 |
| 10 m | 21,1 | 21,3 | 19,7 | 19,1 | 18 | 19,7 | 20,9 | 19,8 | 23,9 | 24,9 | 27 | 29,1 |

Figure 6. Temperature changes observed in 10 months at depths of 5 and 10 meters.

In the 8-month monitoring study conducted at station 1 (5 m) and station 2 (10 m) of the *P. oceanica* restoration area, the average length measurements of leaves randomly selected from each station with SCUBA dives showed significant changes over the 8 months (Figure 7). Especially in station 2, a visible growth in leaf length was observed and it was also noted that the rhizomes, which were firmly attached to the ground, physically responded strongly to the current.




| | 19.11.2023 | 30.11.2023 | 15.12.2023 | 27.01.2024 | 14.02.2024 | 11.03.2024 | 21.04.2024 | 29.05.2024 | 12.06.2024 | 25.06.2024 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 m | 9,60 | 10,68 | 12,76 | 13,74 | 9,82 | 13,30 | 14,73 | 15,08 | 11,40 | 10,53 |
| 10 m | 13,54 | 14,73 | 15,08 | 10,34 | 15,69 | 15,13 | 15,43 | 11,79 | 13,74 | 15,41 |

Figure 7. Average length measurements taken from randomly selected leaves at depths of 5 and 10 meters during 8-month monitoring.

Biodiversity observations at stations 1 and 2 were carried out over a 10-months period (Figure 8). A total of 12 different species were identified through SCUBA dives, 9 of which were teleosts (*Chromis chromis*, *Parupeneus forsskali*, *Siganus luridus*, *Siganus rivulatus*, *Sparisoma cretense*, *Stephanolepis diaspros*, *Torquigener flavimaculosus*, *Cheilodipterus novemstriatus* and *Xyrichtys novacula*), 1 nudibranch (*Flabellina affinis*), 1 echinoderm (*Synaptula reciprocans*) and 1 tunicate (*Halocynthia papillosa*). Of these species, *S. luridus*, *S. rivulatus*, *C. novemstriatus*, *P. forsskali*, *T. flavimaculosus*, *S. diaspros* and *S. reciprocans* are Indo-Pacific origin, while *C. chromis*, *S. cretense*, *X. novacula*, *F. affinis* and *H. papillosa* are native species of the Mediterranean from the Atlantic.

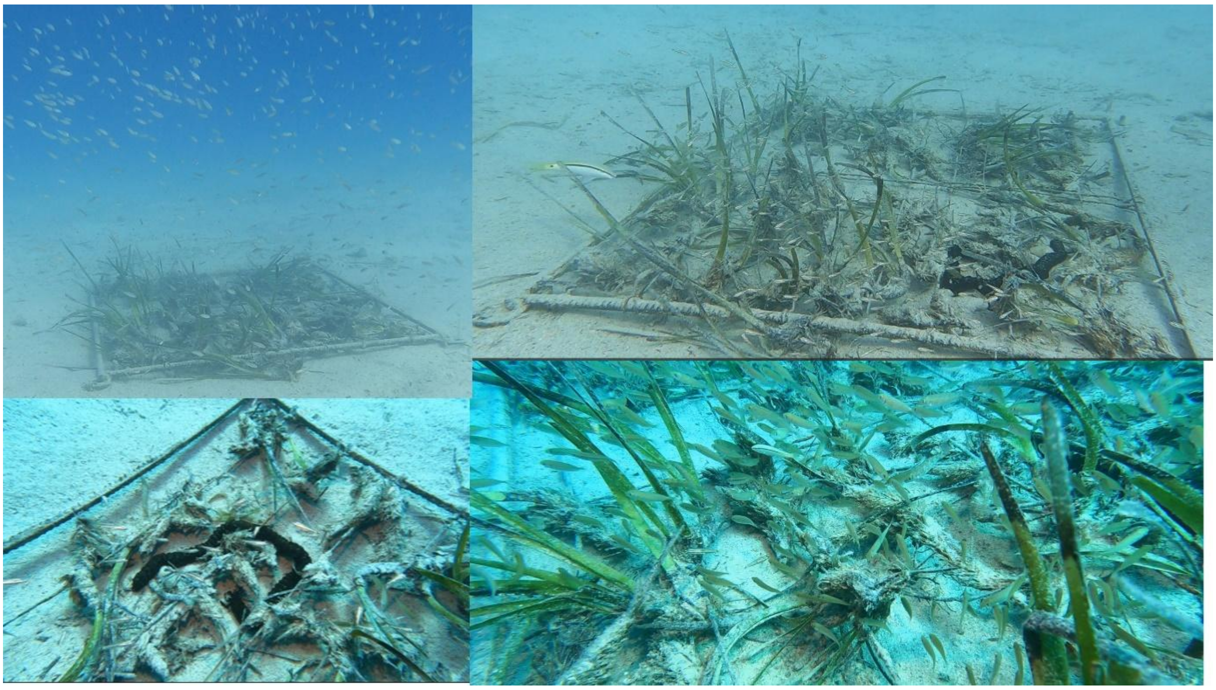


Figure 8. Transplanted *P. oceanica* seagrass appears to be under attack (or inhabiting) by hundreds of individuals of many species, mostly invasive alien species.

Following 10-month monitoring, the most frequently observed species in total at station 1 and 2 were *S. luridus* and *S. rivulatus*, followed by *C. novemstriatus*, *P. forsskali* and *T. flavimaculosus*. *C. chromis* was the only Mediterranean species to rank 6$^{th}$ in this ranking. Only nudibranch (*Flabellina affinis*), 1 echinoderm (*Synaptula reciprocans*) and 1 tunicate (*Halocynthia papillosa*) species were monitored along the experimental period (Figure 9). The number and abundance of each species was higher at station 2 than at station 1.

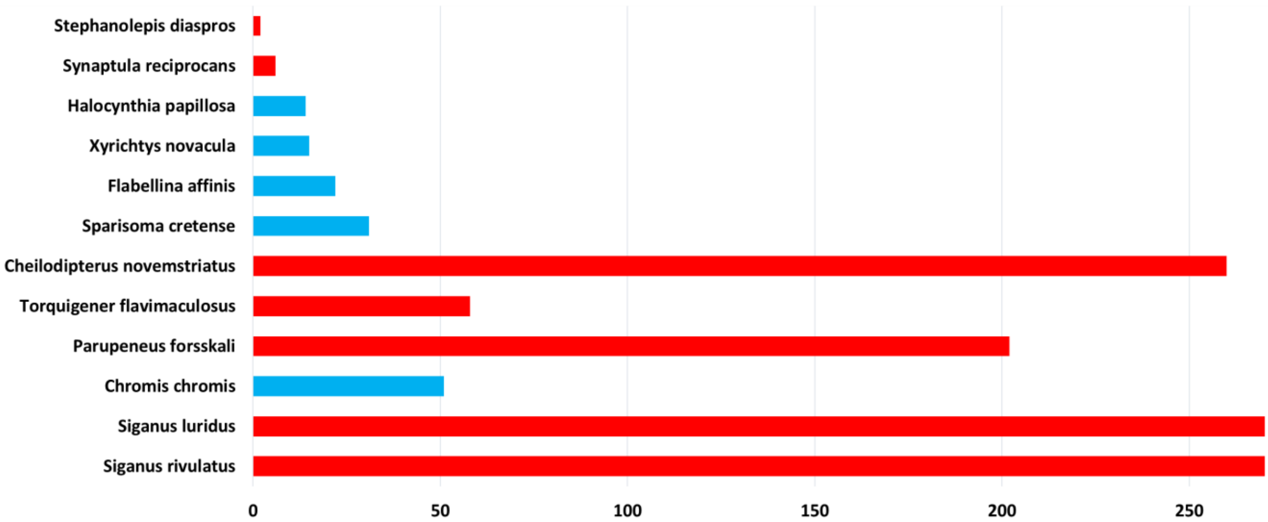



Figure 9. Distribution of species in number observed at station 1 and 2. Red bars indicate alien Indo-Pacific originate species and blue bars Mediterranean-originate species.

When the origin or species was investigated 94 % of the abundance constitute from alien species and remaining 6% Mediterranean originated species. On the other hand, although alien species have a very high abundance in seagrass meadows, in terms of number of species, alien species are slightly higher, and the number of Mediterranean endemic species is 5 while the number of alien species is 7 (Figure 10A). In the classification of observed species at stations 1 and 2, fish species accounted for 79%, nudibranch 7%, echinoderm 7% and tunicate 7% (Figure 10B).

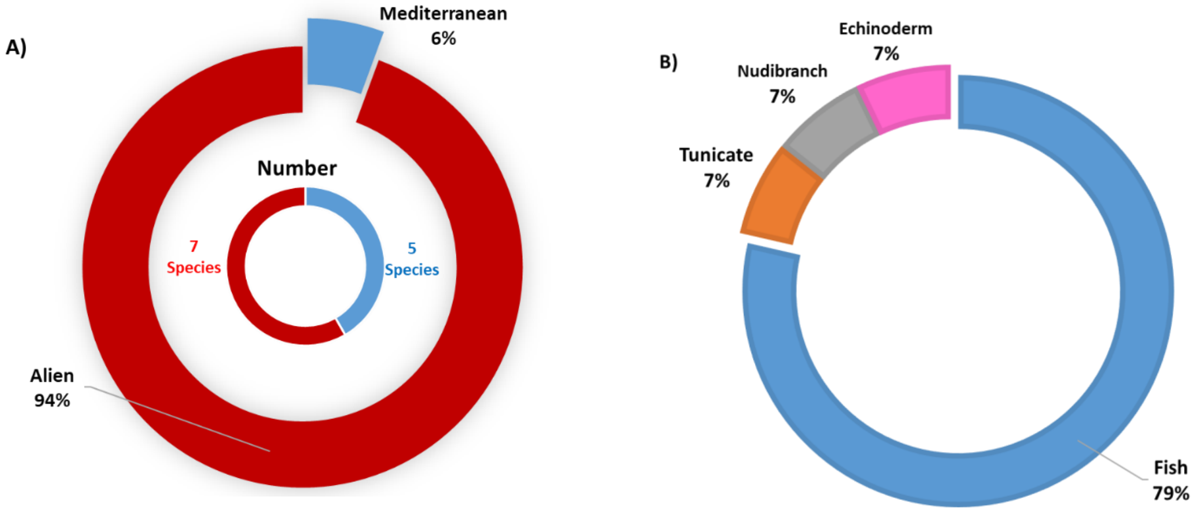



Figure 10. Abundance and number of Alien (red) and Mediterranean (blue) species (A) and classification of observed species (B) in Station 1 and 2.

**Discussion**

During the monitoring of *P. oceanica* restoration at depths of 5 m (station 1) and 10 m (station 2) in Limanağzı, similar trends were observed in the recorded physicochemical parameters (pH, salinity, conductivity, surface temperature, and bottom temperature) at both stations. The average leaf lengths, randomly selected from each station, were tracked over time with SCUBA dives. The maximum average leaf length recorded was 15.08 cm at station 1 and 15.69 cm at station 2 after transplanting. On the other hand,

On the other hand, the most frequently encountered species in the biodiversity monitoring study conducted in both sites were alien species. The fact that the top 5 species and 94% of the numerical abundance of species in the observations made were alien species. Therefore, the most important finding determined in this study is that the biggest obstacle to restoration efforts in degraded ecosystems or habitats requiring restoration is alien species. Thus, the biggest problem to the development of seagrass meadows in damaged habitats is alien species. For this reason, we should protect the existing seagrass meadows very well, otherwise it is seen that when they turn into fragile habitats, it is very difficult for them to return again due to alien species.

*P. oceanica* habitats have increased in protection and restoration efforts in recent years due to their wide range of benefits for marine ecosystems. Various studies have been conducted with different techniques and strategies to improve restoration activities to offset the decline in the populations of this seagrass in the Mediterranean, and similar development findings have been obtained in this study (Balestri et al., 1998; Piazzi et al., 1999; Çelebi et al., 2007; Domínguez et al., 2012; Alagna et al., 2013; Terrados et al., 2013; Pereda-Briones et al., 2018; Castejón-Silvo and Terrados, 2021; Zenone et al., 2022).

Balestri et al. (1998) transplanted two-month-old *P. oceanica* seedlings grown in an aquarium to two different substrates (matte and gravel) in a damaged coastal area of the Ligurian Sea, Italy, and observed the highest survival and growth in seedlings grown on matte. Piazzi et al. (1999) studied the sexual reproductive success, seed germination and seedling development of *P. oceanica* along the Tuscan coast of Italy over a two-year period and found that seedling density decreased from approximately 3 to 1.9 per square meter, rhizome length increased from approximately 2 cm to 5 cm, leaf length was maximum in summer and minimum in autumn, and leaf number remained constant. Çelebi et al. (2007) transplanted *P. oceanica* shoots collected from the Bozyazı coast of Mersin to the eastern Erdemli and Samandağ regions, where they are not naturally found, and reported that *P. oceanica* meadows maintained their vitality despite high sea water temperatures at the end of 2 years in the regions where the shoots were transplanted.

Domínguez et al. (2012) evaluated the support status of *P. oceanica* seedlings in a degraded area due to fish farm activities in Hornillo Bay, Spain, in a 1-year study in which they found that the survival rate of seedlings was significantly higher in the dead matte area (75%) than in the meadow area (20%) and the average leaf length was similar in both substrates. Alagna et al. (2013) studied the early life stages of *P. oceanica* in the Egadi archipelago in northwestern Italy, examining the effects of microhabitat factors such as substrate type and algal cover on seedling persistence and growth over two years and found that seedlings persisted longer on rocky substrates covered with vegetation, especially those covered with Cystoseira species, with an 81% survival rate, and that they grew better on rocks covered with Halopteris and Dilophus species than on those covered with Cystoseira species. Terrados et al. (2013) planted seedlings produced in laboratory conditions from washed-up *P. oceanica* fruits on different substrates (dead matte and meadow) and at different levels (on and in the bottom) in the fish farm-damaged areas of Hornillo Bay, Spain, and followed their survival and leaf development for 3 years. They reported that the seedlings planted on the dead matte substrate had a 44% survival rate after 3 years and that the seedlings planted below the surface branched and produced additional shoots.

Pereda-Briones et al. (2018) investigated the success of *P. oceanica* seedlings after they were planted in a 6-month experiment in the Gulf of Alcudia, Spain, in a region with dense sediment and invasive *Caulerpa cylindracea*. They suggested that 1-year-old seedlings successfully survived and grew in the area and that this benefited from the presence of *C. cylindracea* in the short term. Castejón-Silvo and Terrados (2021) transplanted 468 rhizome fragments and 450 seedlings into *P. oceanica* beds disturbed by power line laying and excavation works in Santa Ponsa Bay, Mallorca, Spain, and found that rhizomes had higher survival rates than seedlings. Zenone et al. (2022) investigated the hydrodynamic factors affecting the propagation of *P. oceanica* seagrass via propagules. They found that seedlings transplanted to Carini Bay, Italy, could withstand current speeds of up to 70 cm/s and orbital flow speeds of up to 25 cm/s on rocky substrates and had anchor strengths ranging from 3.92 to 29.42 N, suggesting that propagules can tolerate high hydrodynamic stress once they are anchored to solid substrate.

In conclusion, *P. oceanica* seagrass are exceptional ecosystems that are extremely sensitive and vulnerable to natural and anthropogenic pressures. Therefore, they need to be protected and preserved not only because of their great ecological heritage value but also for economic reasons. In restoration works, choosing transplantation techniques that are suitable for local environmental conditions is of vital importance to increase the probability of success of the project and to minimize costs. Involving the community and local authorities in restoration works can increase awareness and thus encourage the development of permanent protection strategies and ensure their strengthening with legal bases. On the other hand, alien species such as *S. luridus* and *S. rivulatus*are most important factor to the development of seagrass meadows in damaged habitats. *C. novemstriatus* was also present in high numbers as an omnivorous species that lives in seagrass meadows and should be further investigated for its impact on seagrass meadows. This also raises the question of whether seagrass meadows are a good habitat for alien species, increasing the number of alien species. The number of alien species are getting increased in Turkish marine waters in last two decades (Turan et al., 2024), thus, there seems to be no other way to eliminate this factor than to fight climate change. Considering the importance of *P. oceanica* seagrass as carbon sequestrants, restoration works should be considered as a vital tool in combating climate change and these projects should be included in both national and international climate strategies. Consequently, this study shows that restoring *P. oceanica* beds is difficult especially due to negative impacts of alien species, but not impossible.

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**Conflict of Interest**

The authors declare that for this article they have no actual, potential or perceived conflict of interest.

**Author Contributions**

Ö.D. and C.T. performed all the experiments and drafted the main manuscript text. Authors reviewed and approved the final version of the manuscript.

**Ethical Approval Statements**

No ethics committee permissions are required for this study.

**Data Availability**

The data used in the present study are available upon request from the corresponding author.

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