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Can no-fishing zones in marine protected areas be effective for the conservation of *Posidonia oceanica* seagrass meadows?

Vahit ALAN[1], and Fikret ÖNDES[2]

[1]Department of Fisheries, Graduate School of Natural and Applied Sciences, İzmir Kâtip Çelebi University, İzmir, Türkiye
[2]Department of Fisheries and Seafood Processing Technology, Faculty of Fisheries, İzmir Kâtip Çelebi University, İzmir, Türkiye

Corresponding author: Vahit ALAN; vahitalan@gmail.com

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Abstract

This study investigated the coverage and shoot density of *Posidonia oceanica* seagrass in no-fishing zones, fishing zones, and ports within two Special Environmental Protection Areas (Gökova and Datça-Bozburun) in Türkiye that are characterized by intense boating impacts (e.g., anchor damage, mechanical disturbance). The data were collected using information based on diving observations, as well as local ecological knowledge of divers, tour boat owners, and small-scale fishers. The goal was to identify threat factors affecting *P. oceanica* meadows, evaluate stakeholder observations, interactions, and awareness regarding the species, examine the role of no-fishing zones in its protection, and better understand the potential contributions of stakeholders to its monitoring. Combining ecological metrics with stakeholder perspectives, the present study sought to contribute to the holistic evaluation of *P. oceanica* in marine protected areas. The results revealed that, in the no-fishing zones of Gökova, the coverage and shoot density of *P. oceanica* were higher than in the fishing zone, while in Datça-Bozburun; furthermore, the coverage and shoot density were found to be relatively high in the fishing zone. Nearly half of the small-scale fishers operating in permitted fishing zones reported that *P. oceanica* meadows are their preferred fishing habitat. Furthermore, 81% of tour boat owners stated that they anchor in *P. oceanica* meadows during their tours, with an average of 3 ± 1 anchorages per day. The interviewed stakeholders also reported possessing a strong awareness of the species and being well-positioned to actively contribute to its monitoring. The study concludes with a discussion of management tools needed to protect seagrass meadows in the areas requiring regular monitoring.

Keywords: fisheries management; anchoring; special environmental protection areas; local ecological knowledge; Mediterranean.

Introduction

Posidonia oceanica (L.) Delile, a flowering plant species endemic to the Mediterranean, thrives at depths extending to 40–45 meters (Telesca *et al*., 2015). Commonly known as Neptune grass, this species is a critically important element of the littoral zone as it provides barrier habitat and nursery areas for many invertebrates and fish, ensures primary production, serves as an oxygen source, and carbon storage, as well as prevents coastal erosion (Buia *et al*., 1992; Scaradozzi *et al*., 2009; Pergent *et al*., 2012; Rigo *et al*., 2020; Rotini *et al*., 2020). Owing to its ecological role, wide distribution, sedentary lifestyle, and susceptibility to changing environmental conditions, *P. oceanica* is also a good biological indicator of water quality and health (Pergent-Martini *et al*., 2005; Foden & Brazier, 2007; Rigo *et al*., 2020). Previous research also emphasized that *P. oceanica* is an effective indicator of past and present pollution of heavy metals such as mercury (Pergent-Martini, 1998). These features underscore their critical importance in monitoring marine protected areas (MPAs) and gauging ecosystem health.

This sensitive plant faces anthropogenic threats such as mechanical damage from towed mobile bottom-fishing gears, boat anchoring, water quality degradation, and coastal modifications (e.g., marina and port construction) (Boudouresque *et al*., 2009; Montefalcone *et al*., 2010; Gerakaris *et al*., 2021). Although towed mobile bottom-fishing gears are prohibited at some protected areas, set nets and demersal longlines used by small-scale fishers, lost fishing gears, anchors, and chains can damage to *P. oceanica* meadows (Fig. 1). Moreover, variations in certain environmental factors can adversely impact the distribution, density, growth, and health of *P. oceanica*. For instance, currents and waves can alter the sediment balance of *P. oceanica* meadows, thereby negatively effecting the upper depth limit of their distribution (Vacchi *et al*., 2010; Gerakaris *et al*., 2021). Similarly, some en-

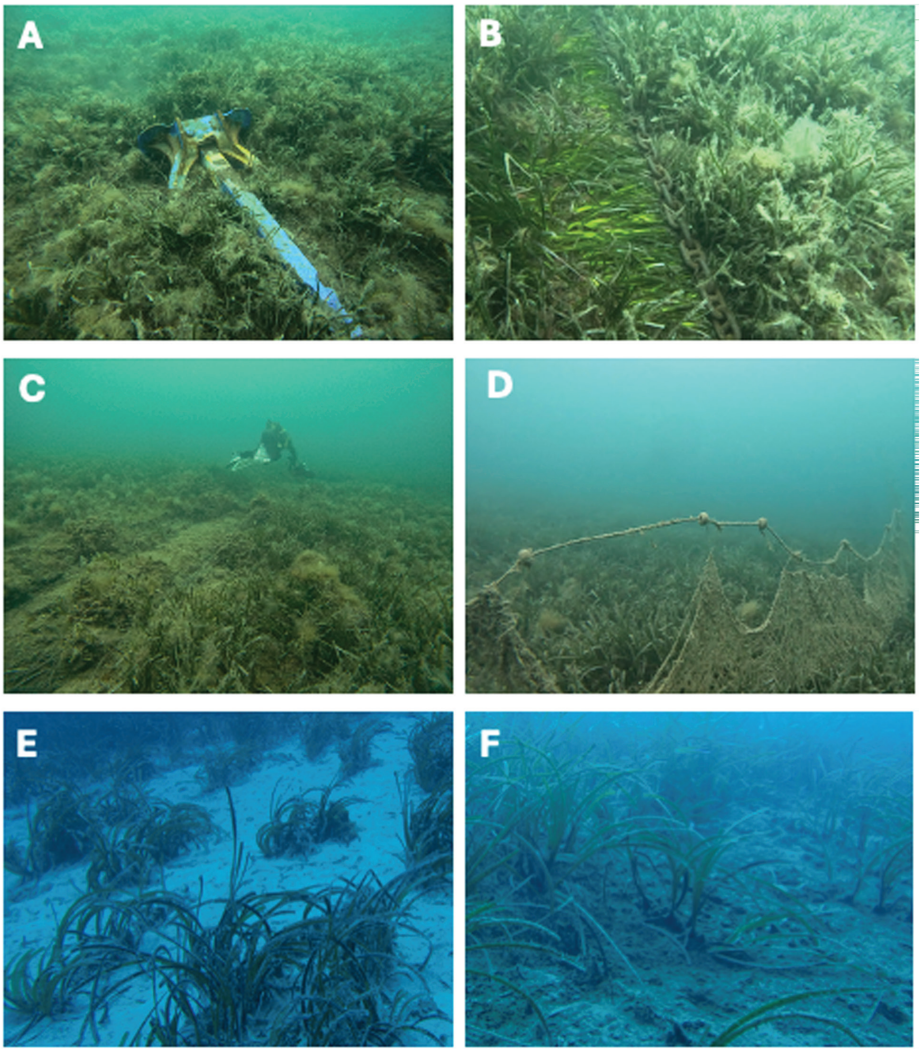

Fig. 1: Primary negative factors affecting *Posidonia oceanica* seagrass beds in the study area include a) anchor-related damage; b) chain-related damage; c) anchor dragging and retrieval that causes huge scars on the seagrass meadows, d) fishing nets, discarded fishing gears in the areas with a wide distribution of *P. oceanica* and photographs from some research stations exhibiting low coverage values (e and f) (Photo credit: Vahit Alan).

vironmental factors affecting the growth of *P. oceanica* include light availability, water temperature, sediment characteristics, and nutrient levels (Marbà *et al*., 1996; Marbà & Duarte, 2010; Hendriks *et al*., 2017). Temperatures above 27°C adversely affect photosynthesis, and hence, leaf growth reduction, leaf senescence and mortality were previously reported (Guerrero-Meseguer *et al*., 2017). Available evidence also suggests that flowering and fruiting can be negatively affected depending on the maximum sea surface temperature (SST) (Stipcich *et al*., 2024). For instance, in a study that evaluated the seagrass changes in the Mediterranean basin for the period of 1842-2009, Marbà *et al.* (2014) found that biomass declined at $-6.9\%\ yr^{-1}$. Available reported also suggest that, due to the warming of the Eastern Mediterranean Sea, *P. oceanica* production has markedly decreased in the last two decades (Litsi-Mizan *et al*., 2023). However, despite all losses and threats to *P. oceanica* meadows, this species is listed as Least Concern (LC) on the IUCN Red List (Balestri *et al*., 2017).

Posidonia oceanica is protected by the European Union Habitat Directive, the Bern and Barcelona Conventions, as well as several national- and regional-level legislations (Campagne *et al*., 2015). EU fishing regulations limit trawling activities near the shore (either above 50 m or a certain distance from the coast), which constitute an indirect protection measure for the species (EU, 2006). *Posidonia oceanica* is also protected in various MPAs in the countries along the Mediterranean Sea (UNEP-MAP-RAC/SPA, 2009). As per the Barcelona Convention, *P. oceanica* is one of the endangered or threatened species. The species is also included in the Annex I -Strictly Protected Flora Species- of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). In Türkiye, *P. oceanica* meadows are also protected within the national legal framework by the “Circular on sea and inland waters” (UNEP-MAP-RAC/SPA, 2007). As yet another attempt at the conservation of *P. oceanica* in Türkiye, Turkish fishing legislation banned *P. oceanica* harvesting and collecting on Turkish coasts (Official Gazette, 2024).

Marine Protected Areas (MPAs) are commonly defined as spatially delimited areas of the marine environment established to protect biodiversity and where certain human activities (mostly commercial fishing) are restricted (Edgar *et al*., 2007; Laffoley *et al*., 2019). These special areas have benefits such as protecting endangered species and vulnerable habitats, providing protected spawning areas, enabling the sustainable use of resources, reducing conflicts between stakeholders, and, finally, ensuring the economic development of the local people (Angulo-Valdés & Hatcher, 2010; Brander *et al*., 2020). However, the tools used to manage MPAs and their protection status (i.e., existing no-fishing or no-take zones) are important factors in achieving these benefits (Gallacher *et al*., 2016; Hall *et al*., 2023). Several previous studies demonstrated that poor management and insufficient conservation efforts in these areas cannot reduce the damage to *P. oceanica* seagrass meadows (Montefalcone *et al*., 2009; Tursi *et al*., 2022). However, the identification of the main threats and an effective management of all activities to mitigate them can have positive results in a relatively short period (Tursi *et al*., 2022). Undoubtedly, achieving these goals requires all stakeholders' awareness and contribution. Concurrently, available comparative data on the coverage, density, and health of *P. oceanica* meadows in no-fishing versus fishing zones remain scarce (Seytre & Francour, 2013). In addition, from a regional perspective, even though some studies provided information on the coverage and shoot density of *P. oceanica* in Türkiye (eastern Mediterranean) (i.e., Koçak *et al*., 2011; Dural *et al*., 2012; Akçalı *et al*., 2020; Mutlu *et al*., 2022, 2023, 2024), to the best of our knowledge, these indicators have not been investigated in protected areas with different conservation statuses. Several previous studies also called for monitoring this species in the warming Mediterranean and obtaining data from different localities (Jordà *et al*., 2012; Ruiz *et al*., 2018; Stipcich *et al*., 2022). Finally, available research examining stakeholders' awareness about this highly vulnerable species is rather limited (i.e. Ruiz-Frau *et al*., 2019; Zenone *et al*., 2021; Capasso *et al*., 2024).

In this context, the present study seeks to provide information on the coverage and shoot density of *P. oceanica* meadows in two of Türkiye's most important protected areas—Gökova Special Environmental Protection Area (SEPA) and Datça-Bozburun SEPA. To this end, we compared the coverage and shoot density of *P. oceanica* among no-fishing zones (NFZs), fishing zones (FZs), and ports. In addition, we also evaluated stakeholders' knowledge about the ecology of this endemic meadow, their awareness about its benefits, the threats they observed, as well as stakeholders' potential contributions to monitoring and protection of this species based on the local ecological knowledge.

Materials and Methods

Study area and diving surveys

In October 2024, four sampling sites (2 NFZ, 1 FZ, and 1 port area) in Gökova SEPA and five sampling sites (3 NFZ, 1 FZ, and 1 port area) in Datça-Bozburun SEPA were observed (Fig. 2). Gökova SEPA was established in 1988, and its current borders were formed in 2010. The aforementioned protected area includes a total of 82,023 ha of marine area and there are 34 protected species based on Bern and/or Barcelona Conventions and National Fisheries Circular (Official Gazette 2010; Official Gazette 2024). Hosting sensitive species and habitats, this area is an important tourism center and is exposed to heavy boat traffic, especially in the summer months. It is also an important fishing ground for both small-scale fisheries and recreational fisheries (Tunca *et al*., 2016). Small-scale fishers in the area commonly use the longlines, trammel nets, and gillnets to catch *Epinephelus aeneus*, *Mullus* spp., and *Dentex dentex* (Tokaç *et al*., 2010). Gökova Bay SEPA includes a total of 7 NFZs (Official Gazette 2024).

In its turn, Datça-Bozburun SEPA was established in 1990 with a marine area coverage of 73,663 ha (Of-

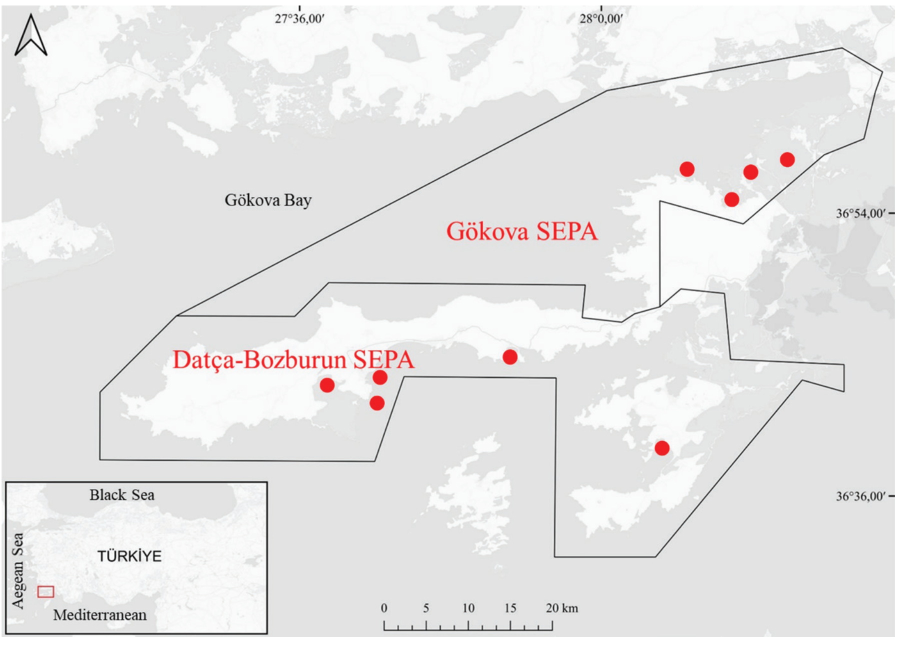

Fig. 2: Map of the study areas including Gökova and Datça–Bozburun SEPAs.

ficial Gazette, 1990). Datça-Bozburun SEPA hosts three fisheries cooperatives, and small-scale fishers target approximately 30 species, extensively fishing with longline and set nets (trammel nets and gillnets) (Ünal, 2011). Hisarönü Bay, Datça-Bozburun SEPA includes a total of 6 NFZs (Official Gazette 2024). According to the observations conducted in 2004, *P. oceanica* meadows covered an area of 4 116 ha in the Datça-Bozburun SEPA, whereas another study carried out in 2006 reported that *P. oceanica* meadows covered 690 ha in the Gökova SEPA (Okus *et al*., 2006, 2007; Akçalı *et al*., 2019). Previous research also highlighted regional differences in the health status of the meadows within the Datça-Bozburun SEPA (Okus *et al*., 2007). Specifically, *P. oceanica* meadows were found to be widely distributed in the northern part of the Datça Peninsula, whereas in the southern part of Datça and on the Bozburun Peninsula, the meadows were reported to fragmented and sparse in certain areas (Okus *et al*., 2007). Similarly, a previous studies emphasized that, in certain areas within the Gökova SEPA, *P. oceanica* meadows are also likely to be significantly damaged by boat anchoring (Okus *et al*., 2006).

In each site, three sub-regions (no-fishing zone, fishing zone, and inside the port) were studied. Two depth classes (7 m and 15 m) were investigated during each dive at each site to represent both shallow and deep areas (Guillén *et al*., 2013), except for the port area in the Gökova SEPA, where *P. oceanica* seagrass was not observed at 15 m. Based on SCUBA-diving surveys, the coverage and density (shoots.m^{-2}) data were recorded using random transects and using the quadrat method (60x60 cm) (Akçalı *et al*., 2020). Based on the monitoring protocol for *P. oceanica* of UNEP/MAP-RAC/SPA (2014), a total of 10 replicates for each sub-regions and depth classes were applied and a distance of at least one meter was left between two quadrats. In addition, after the quadrat survey, additional dives were performed to evaluate the minimum and maximum depths where *P. oceanica* meadows are located.

Local ecological knowledge (LEK)

In January 2025, questionnaire surveys were conducted with divers (n = 71) diving in the Aegean Sea, small-scale fishers (n = 21), and tour boat owners (n = 32) operating in the Gökova SEPA and Datça-Bozburun SEPA along the southwestern coast of Türkiye. In determining the sample sizes, we considered active divers and fishers, consistently engaged in the regions across all four seasons. Online surveys using Google Forms were administered to divers, while face-to-face surveys were conducted with small-scale fishers and tour boat operators. The respondents were recruited among those willing to participate in the study and the corresponding ethical permission was obtained from the Izmir Katip Çelebi University Ethics Committee. The surveys administered to divers included questions on the following topics: knowledge and awareness of the ecology, distribution, and temporal changes in the status of seagrass meadows, the main threats to seagrass meadows, perspectives on NFZs and MPAs, their potential role in seagrass meadow conservation, as well as potential tools to improve the health of *P. oceanica* meadows (see Table 1). Most of the questions were designed to be answered using a Likert scale, while several questions were open-ended (see Appendix A). While some of the survey questions were specific to the status of *P. oceanica* seagrass meadows in the Gökova and Datça-Bozburun SEPAs, the questions related to divers' awareness and potential roles in monitoring reflect the Aegean Sea more broadly, as the respondents do not dive exclusively in the aforementioned SEPAs (Appendix A). Furthermore, surveys conducted with tour boat owners inquired about the number of tours organized annually, number of anchorages per day, as well as anchorage depths during operation and habitats of fishing areas (e.g., *P. oceanica* meadows). Concerning small-scale fisheries, an applied questionnaire focused on the magnitude of fishers' activity and their interaction with *P. oceanica* meadows. More specifically, the survey questions concerned the gear used by fishers, the number of days they fished in a year, the depth range of the area they fished, and how frequently they fished in *P. oceanica* meadows in the studied protected areas (Appendix A).

Data analysis

To compare the coverage and shoot density of *P. oceanica* at two depth classes (7 m and 15 m) across three distinct areas (no-fishing zone, fishing zone, and port area), a Kruskal Wallis test followed by Dunn's post hoc test was conducted. During these analyses, the data from multiple NFZs (sub-areas) located within the special environmental protection areas were combined and used as pooled data (see Appendix B; Fig. 3). Subsequently, to interpret the dataset from a different perspective, the data from both special environmental protection areas were pooled, and the following model —Coverage × Shoot Density ~ Management (three levels: NFZ, FZ, Port)— was analysed using the Kruskal–Wallis test and Dunn's post-hoc test. In addition, to compare the density and coverage of *P. oceanica* between the two SEPAs (Gökova and Datça-Bozburun), based on two depth classes (7 m and 15 m) and three distinct areas (no-fishing zone, fishing zone, and port area), a Mann–Whitney U test was applied. In order to determine whether there was a difference between diving and survey observations regarding the maximum depths at which *P. oceanica* seagrass meadows were observed in Gökova and Datça-Bozburun SEPAs, a Mann–Whitney U test was applied. Statistical analyses were run using the SPSS package program (Ver.20) and R software (R Core Team, 2022).

Table 1. Local ecological knowledge of divers (survey data).

Category of collected data	Specific information collected
Knowledge of divers on the species' ecology and its temporal changes in the sampling sites	-Depth distribution -Health status -Temporal/historical changes in health status, density and distribution
Divers' awareness of the benefits of this species to the ecosystem and related sectors	-*Posidonia oceanica* meadows are important habitats for fish and invertebrates. -*Posidonia oceanica* meadows are habitats hosting economically important species that help us find food. -*Posidonia oceanica* meadows are important habitats for primary production. -*Posidonia oceanica* meadows play a role in carbon sequestration. -*Posidonia oceanica* meadows significantly contribute to improving water quality. -*Posidonia oceanica* meadows play an important role in preventing coastal erosion. -*Posidonia oceanica* meadows are important habitats for fisheries. -*Posidonia oceanica* meadows are important habitats for diving tourism.
Determination of threat factors by divers	-Boat anchoring -Fishing gears -Water pollution -Sedimentation -Temperature anomalies -Invasive species -Diving activities
Divers' perspectives on NFZs and MPAs	-Satisfaction
Potential roles of divers to monitoring *Posidonia oceanica* meadows	-Mobile application -Social media -Diving notebooks, logbooks
Divers' perspectives on potential tools to improve status of seagrasses	-Eco-mooring systems -Restoration -Reducing boat capacity

Results

Coverage and shoot density of **P. oceanica** *in fishing zones, no-fishing zones, and ports based on direct diving observations*

Significant differences in the coverage and shoot density values of *P. oceanica* seagrass were found between the two SEPA across different depth classes (7 and 15 m) and sampling zones (NFZ, FZ, and port). The mean values for each area with standard deviation (SD) are presented in Table 2.

In the Gökova SEPA, the coverage was higher in NFZ than in the FZ and port (Fig. 3a), while the highest coverage was found in the FZ in the Datça-Bozburun SEPA (Fig. 3a). Coverage was higher at 7 m than at 15 m in the Gökova SEPA, while similar mean values were observed between the two depth contours in the Datça-Bozburun SEPA (Fig. 3b). The results of the Kruskal–Wallis test and Dunn's post hoc test, conducted for a comprehensive comparison of the coverage in the three distinct zones (NFZ, FZ, and port) across different depth contours, are summarized in Table 3.

Regarding shoot density, the highest mean value in the Gökova SEPA was observed in the NFZ, followed by the FZ and port areas. By contrast, in the Datça-Bozburun SEPA, the highest mean shoot density was observed in the FZ (Fig. 3c). The mean shoot density was higher in

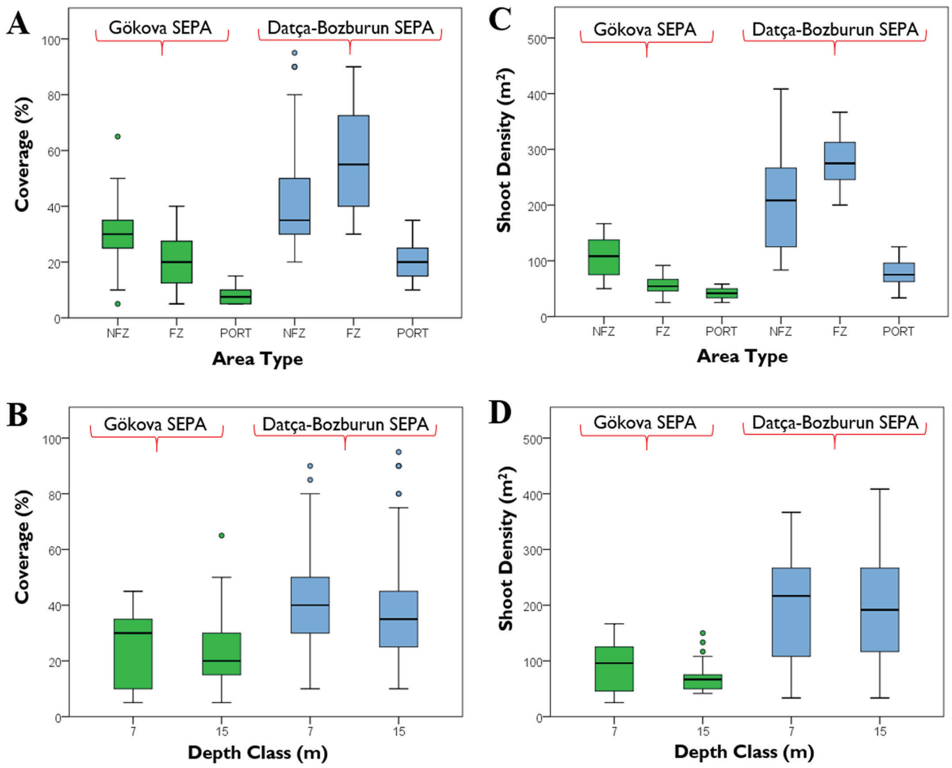

Fig. 3: a) The coverage (%) of *Posidonia oceanica* in different areas (no-fishing zone (NFZ), fishing zone (FZ), and port; b) coverage (%) of *P. oceanica* in different depth classes (7 and 15 m); c) shoot density of *P. oceanica* in different areas; d) shoot density of *P. oceanica* in different in Gökova and Datça-Bozburun SEPAs, Aegean Sea.

Table 2. Results of the Mann-Whitney U test comparing *P. oceanica* coverage and shoot density across different protection statuses and depth contours between two SEPAs (Gökova and Datça-Bozburun).

	Gökova SEPA	**Datça-Bozburun SEPA**	**Mann-Whitney U Test**	
Test Variable	**Mean ± SD**	**Mean ± SD**	**U value**	**P-value**
Coverage in the NFZ	31 ± 11	43 ± 19	707.500	<0.001
Coverage in the FZ	20 ± 10	57 ± 18	11.000	<0.001
Coverage in the Port	8 ± 3	20 ± 7	14.500	<0.001
Coverage at 7 m depth	25 ± 12	42 ± 20	460.500	<0.001
Coverage at 15 m depth	24 ± 13	40 ± 23	384.000	<0.001
Shoot density in the NFZ	106 ± 35	209 ± 83	341.500	<0.001
Shoot density in the FZ	57 ± 18	282 ± 48	<0.001	<0.001
Shoot density in the Port	42 ± 10	79 ± 25	18.500	<0.001
Shoot density at 7 m depth	91 ± 45	196 ± 97	402.500	<0.001
Shoot density at 15 m depth	72 ± 26	198 ± 95	113.500	<0.001

shallow areas in the Gökova SEPA, whereas similar mean values were observed between the two depth contours in the Datça-Bozburun SEPA (Fig. 3d). Furthermore, the results of the Kruskal–Wallis test and Dunn's post hoc test, conducted for a comprehensive comparison of the shoot density in the three distinct zones (NFZ, FZ, and port) across different depth contours, are presented in Table 4. According to the model based on the pooled data from both SEPAs, the interaction of *P. oceanica* coverage and shoot density significantly differed between the port area and the FZ and between the port area and the NFZ; however, no significant difference was observed between the FZ and the NFZ (Table 5).

Based on the diving surveys at our sampling stations, the shallowest and deepest locations where seagrass meadows are found are presented in Appendix B. The mean coverage (%) and shoot density values of the sub-areas (diving stations) are also presented in Appendix C.

Table 3. Results of Kruskal-Wallis and Dunn's post-hoc tests comparing *Posidonia oceanica* coverage at different dept across areas with varying protection statuses in the Gökova and Datça-Bozburun SEPAs.

Area	Sample1-Sample2	Coefficients	T value	P-value (Adj. Sig)
Gökova SEPA	Port (7 m) – FZ (15 m)	11.950	1.325	1.000
	Port (7 m) – FZ (7 m)	28.000	3.105	0.019
	Port (7 m) – NFZ (15 m)	30.750	3.937	0.001
	Port (7 m) – NFZ (7 m)	42.200	5.403	<0.001
	FZ (15 m) – FZ (7 m)	-16.050	-1.780	0.751
	FZ (15 m) – NFZ (15 m)	-18.800	-2.407	0.161
	FZ (15 m) – NFZ (7 m)	-30.250	-3.873	0.001
	FZ (7 m) – NFZ (15 m)	-2.750	-0.352	1.000
	FZ (7 m) – NFZ (7 m)	-14.200	-1.818	0.691
	NFZ (15 m) – NFZ (7 m)	-11.450	-1.795	0.726
Datça-Bozburun SEPA	Port (15 m) – Port (7 m)	-2.450	-0.190	1.000
	Port (15 m) – NFZ (15 m)	40.333	3.827	0.002
	Port (15 m) – NFZ (7 m)	41.900	3.975	0.001
	Port (15 m) – FZ (15 m)	46.050	3.567	0.005
	Port (15 m) – FZ (7 m)	74.800	5.795	<0.001
	Port (7 m) – NFZ (15 m)	37.883	3.594	0.005
	Port (7 m) – NFZ (7 m)	39.450	3.743	0.003
	Port (7 m) – FZ (15 m)	43.600	3.378	0.011
	Port (7 m) – FZ (7 m)	72.350	5.605	<0.001
	NFZ (15 m) – NFZ (7 m)	-1.567	-0.210	1.000
	NFZ (15 m) – FZ (15 m)	5.717	0.542	1.000
	NFZ (15 m) – FZ (7 m)	34.467	3.270	0.016
	NFZ (7 m) – FZ (15 m)	4.150	0.394	1.000
	NFZ (7 m) – FZ (7 m)	32.800	3.122	0.027
	FZ (15 m) – FZ (7 m)	-28.750	-2.227	0.389

Local ecological knowledge of divers and boat owners on Posidonia oceanica

The divers who responded to the survey had an average age of 46 ± 12 years and an average diving experience of 21 ± 13 years. Most divers demonstrated a strong awareness of the benefits of *P. oceanica* meadows to the ecosystem and their contributions to related sectors (see Table 6).

Using the local ecological knowledge of the divers, we found that the maximum depth at which *P. oceanica* was encountered is 35 meters in Gökova and Datça-Bozburun SEPAs and 43 meters on the other coasts of Aegean Sea, Türkiye. In Gökova and Datça-Bozburun SEPAs, there was no statistically significant difference between diving and questionnaire survey observations in terms of the maximum depths at which *P. oceanica* seagrass meadows were observed ($P > 0.05$). Furthermore, 45 % of the divers indicated that the deepest location at which they observed *P. oceanica* meadows exceeded 30 meters in the Aegean Sea. Most of the experienced divers surveyed noticed both a decline in the abundance of *P. oceanica* and a deterioration in their health status over the last 5 years (see Table 7). Moreover, 25% of the surveyed divers reported a considerable contraction in the depth range of *Posidonia oceanica* meadows in the region in recent years (see Table 7).

Conversely, 89% of the divers indicated that *P. oceanica* meadows appeared to be in better condition in no-fishing zones than in areas where fishing is permitted (Table 7). Similarly, 10% of the divers agreed and 87% strongly agreed with the view that the density of meadows is higher in no-fishing zones (Table 7). The proportion of respondents who strongly endorsed the view that marine protected areas in the region are sufficiently managed was notably low (Table 7).

Furthermore, in response to the question "What are the top three main threats to *Posidonia oceanica*?", 89% of the survey participants identified boat anchoring as a threat, followed by 63% citing fishing gear, and 58% mentioning water pollution. In addition, the rate of the respondents who agreed that these three threat factors adversely affect *P.* meadows was higher than those who absolutely agreed that other factors (e.g., invasive species, temperature anomalies, divers' impacts) have a negative effect (Table 7). The divers conducting dives in Körmen FZ (Gökova SEPA) highlighted that, particularly in recent years, there has been a notable increase in the presence of fishing boat anchors and ghost nets, especially in

Table 4. Results of Kruskal-Wallis and Dunn's post-hoc tests comparing *Posidonia oceanica* shoot density at different depths across areas with varying protection statuses in the Gökova and Datça-Bozburun SEPAs.

Area	Sample1-Sample2	Coefficients	T value	P-value (Adj. Sig)
Gökova SEPA	Port (7 m) – FZ (15 m)	8.400	0.926	1.000
	Port (7 m) – FZ (7 m)	14.750	1.626	1.000
	Port (7 m) – NFZ (15 m)	27.200	3.462	0.005
	Port (7 m) – NFZ (7 m)	47.850	6.091	<0.001
	FZ (15 m) – FZ (7 m)	-6.350	-0.700	1.000
	FZ (15 m) – NFZ (15 m)	-18.800	-2.393	0.167
	FZ (15 m) – NFZ (7 m)	-39.450	-5.022	<0.001
	FZ (7 m) – NFZ (15 m)	-12.450	-1.585	1.000
	FZ (7 m) – NFZ (7 m)	-33.100	-4.214	<0.001
	NFZ (15 m) – NFZ (7 m)	-20.650	-3.219	0.013
Datça-Bozburun SEPA	Port (7 m) – Port (15 m)	5.700	0.440	1.000
	Port (7 m) – NFZ (7 m)	43.350	4.095	0.001
	Port (7 m) – NFZ (15 m)	45.150	4.265	<0.001
	Port (7 m) – FZ (15 m)	62.600	4.828	<0.001
	Port (7 m) – FZ (7 m)	69.200	5.337	<0.001
	Port (15 m) – NFZ (7 m)	37.650	3.556	0.006
	Port (15 m) – NFZ (15 m)	39.450	3.727	0.003
	Port (15 m) – FZ (15 m)	56.900	4.389	<0.001
	Port (15 m) – FZ (7 m)	63.500	4.898	<0.001
	NFZ (7 m) – NFZ (15 m)	1.800	0.240	1.000
	NFZ (7 m) – FZ (15 m)	19.250	1.818	1.000
	NFZ (7 m) – FZ (7 m)	25.850	2.442	0.219
	NFZ (15 m) – FZ (15 m)	17.450	1.648	1.000
	NFZ (15 m) – FZ (7 m)	24.050	2.272	0.346
	FZ (15 m) – FZ (7 m)	-6.600	-0.509	1.000

Table 5. Results of the Kruskal–Wallis test and subsequent Dunn's post-hoc comparisons examining differences in *Posidonia oceanica* coverage × shoot density across areas with different protection statuses (No-Fishing Zone [NFZ], Fishing Zone [FZ], and Port Area), based on pooled data from the Gökova and Datça-Bozburun Special Environmental Protection Areas (SEPAs).

Sample1-Sample2	Coefficients	T value	P-value (Adj. Sig)
Port – FZ	59.929	5.042	<0.001
Port – NFZ	70.237	6.856	<0.001
FZ – NFZ	-10.308	-1,120	0.789

areas where *P. oceanica* meadows are densely located. Besides, the divers with extensive experience in Gökova SEPA (Karacasöğüt NFZ, Boncuk NFZ, Körmen FZ) have reported "a significant rise in water temperatures in recent years" and "the whitening of seagrass meadows in certain areas". The respondents attributed these changes primarily to "the rise in water temperature, along with the impact of terrestrial inputs."

With regard to the potential role of divers in monitoring seagrass meadows, 68% of the surveyed participants identified the mobile application as a tool they could use to contribute to the monitoring efforts. In addition, over half of participants reported that they could contribute to monitoring efforts by social media platforms, while 44% reported that they could contribute by their dive notebooks (Table 7). Concerning potential protection and recovery tools, over half of the respondents absolutely agreed that the eco-mooring system would be effective in reducing mechanical damage on *P. oceanica* meadows (Table 7). In addition, most (85%) of the respondents indicated that they believed seagrass restoration was essential, and even more (86%) asserted that reducing the number of boats in the area would be an effective measure to improve *P. oceanica* meadows (Table 7).

The average annual number of daily tours organized by boats for swimming or fishing purposes in the region amounted to be 43 ± 18 days (Gökova SEPA = 53 ± 26 days, Datça-Bozburun SEPA = 38 ± 10 days). The number of stations visited by these boats daily, or the average number of anchorages, was 3 ± 1. We also found that the depths at which the boats anchored during the tour ranged from 10 to 35 meters, with an average depth of 21 ± 7 meters. Furthermore, 81% of the tour boat owners who

Table 6. Divers' awareness of the contribution of *Posidonia oceanica* meadows.

Opinions on the contribution of seagrass meadows to the ecosystem and stakeholders	Category	Percentage (%)
Posidonia oceanica meadows are important habitats for fish and invertebrates.	Absolutely agree	99
	Agree	1
	Relatively agree	0
	Disagree	0
	N/A	0
Posidonia oceanica meadows are habitats hosting economic species that help us find food.	Absolutely agree	86
	Agree	11
	Relatively agree	0
	Disagree	0
	N/A	3
Posidonia oceanica meadows are important habitats for primary production.	Absolutely agree	86
	Agree	6
	Relatively agree	0
	Disagree	0
	N/A	8
Posidonia oceanica meadows play a role in carbon sequestration.	Absolutely agree	91
	Agree	3
	Relatively agree	0
	Disagree	0
	N/A	6
Posidonia oceanica meadows significantly contribute to improving water quality.	Absolutely agree	94
	Agree	3
	Relatively agree	0
	Disagree	0
	N/A	3
Posidonia oceanica meadows play an important role in preventing coastal erosion.	Absolutely agree	89
	Agree	3
	Relatively agree	0
	Disagree	0
	N/A	8
Posidonia oceanica meadows are important habitats for fisheries.	Absolutely agree	83
	Agree	13
	Relatively agree	1
	Disagree	3
	N/A	0
Posidonia oceanica meadows are important habitats for diving tourism.	Absolutely agree	69
	Agree	17
	Relatively agree	7
	Disagree	1
	N/A	6

participated in the survey declared that they anchored in *P. oceanica* meadows during their tour activities.

In addition, 43% of small-scale fishers operating in areas where fishing is permitted within the Gökova and Datça-Bozburun SEPAs reported that their preferred habitat is the *P. oceanica* meadows. They reported that they intensively fished in this habitat with longlines, trammel nets, and gillnets. The minimum depth of the fishing area varied between 10 and 60 meters, and the average minimum depth was determined to be 30 ± 15 meters. Finally, according to the results, small-scale fishers in the mentioned protected areas fished for an average of 88 ± 78 days per year.

Discussion

This study aimed to provide data on the coverage and shoot density of *P. oceanica*, distributed within two SEPAs located along Türkiye's southwestern coast and characterized by intense tourism-related boating activity. Our specific focus was on no-fishing zones (NFZs), fishing zones (FZs), and port areas. In addition, using local ecological knowledge, we explored the threats to *P. oceanica* meadows, stakeholder awareness, and the potential contributions of stakeholders to monitoring efforts. The present study revealed that in both SEPAs, coverage and shoot density values in the port areas were lower as compared to those in the NFZs and FZs. On the other hand, in

Table 7. Divers' perceptions regarding recent changes in *Posidonia oceanica* seagrass meadows, the role of no-fishing zones in supporting seagrass meadows health, the main reported threats to seagrass meadows, and potential contributions to the monitoring and conservation of seagrass meadows.

Perceptions regarding recent changes in seagrass meadows	Category	Percentage (%)
The density of the meadows has decreased over the past five years.	Absolutely agree	62
	Agree	24
	Relatively agree	4
	Disagree	6
	N/A	4
The health of the meadows has deteriorated over the past five years.	Absolutely agree	68
	Agree	15
	Relatively agree	6
	Disagree	4
	N/A	7
In recent years, there has been a narrowing of the depth range of the meadows.	Agree	25
	Disagree	58
	N/A	17
Perceptions regarding the role of no-fishing zones in supporting seagrass meadow health and in the management of marine protected areas	Category	Percentage (%)
The health of *Posidonia oceanica* meadows is higher in no-fishing zones.	Absolutely agree	80
	Agree	8
	Relatively agree	1
	Disagree	1
	N/A	10
Densities of *Posidonia oceanica* meadows are higher in no-fishing zones.	Absolutely agree	87
	Agree	10
	Relatively agree	0
	Disagree	0
	N/A	3
Marine Protected Areas in the region are adequately managed.	Absolutely agree	14
	Agree	29
	Relatively agree	30
	Disagree	23
	N/A	4
The main reported threats to *Posidonia oceanica* in the Gökova and Datça–Bozburun SEPAs, Aegean Sea	Category	Percentage (%)
Boat anchoring has a negative effect on *Posidonia oceanica.*	Absolutely agree	93
	Agree	6
	Relatively agree	1
	Disagree	0
	N/A	0
Fishing gear has a negative effect on *Posidonia oceanica.*	Absolutely agree	78
	Agree	18
	Relatively agree	1
	Disagree	0
	N/A	3
Water pollution negatively affects *Posidonia oceanica.*	Absolutely agree	82
	Agree	14
	Relatively agree	0
	Disagree	0
	N/A	4
Sedimentation negatively affects *Posidonia oceanica.*	Absolutely agree	59
	Agree	21
	Relatively agree	3
	Disagree	1
	N/A	16

Continued

Table 7 continued

Perceptions regarding recent changes in seagrass meadows	Category	Percentage (%)
Temperature anomalies have a negative effect on *Posidonia oceanica.*	Absolutely agree	66
	Agree	21
	Relatively agree	6
	Disagree	0
	N/A	7
Invasive alien species have a negative effect on *Posidonia oceanica.*	Absolutely agree	44
	Agree	27
	Relatively agree	4
	Disagree	4
	N/A	21
Diving activities have a negative effect on *Posidonia oceanica.*	Absolutely agree	18
	Agree	32
	Relatively agree	34
	Disagree	15
	N/A	1
Divers' potential contributions to the monitoring and conservation of *Posidonia oceanica* meadows.	Category	Percentage (%)
Which tool can you use to contribute to the monitoring of *Posidonia oceanica* meadows?	Mobile application	68
	Social media platforms	58
	Diving notebook	44
Eco-mooring systems are necessary to reduce mechanical damage to *Posidonia oceanica* meadows in this area.	Absolutely agree	51
	Agree	30
	Relatively agree	6
	Disagree	6
	N/A	7
Restoration of *Posidonia oceanica* is necessary in this area.	Absolutely agree	61
	Agree	18
	Relatively agree	6
	Disagree	7
	N/A	8
Reducing boat capacity is necessary to protect *Posidonia oceanica* meadows	Absolutely agree	49
	Agree	24
	Relatively agree	13
	Disagree	10
	N/A	4

the Gökova SEPA, coverage and shoot density of *P. oceanica* were higher in NFZs as compared to FZs, whereas in the Datça-Bozburun SEPA, relatively higher mean coverage and shoot density values were observed in the FZ. These findings indicate that not only fishing restrictions, but also tourism-related boating activity in the regions should be considered meaningful factors. Similarly, LEK indicated that other concerns include anchoring and pollution related to boats in the Datça-Bozburun NFZs. It is known that over 10,000 boats including fishing, private and tour boats (data obtained from the Bodrum, Marmaris, and Datça harbor master's on January 21, 2025) can be found in the Datça-Bozburun SEPA. Based on the LEK, the survey results showed that many boat owners in the Datça-Bozburun SEPA anchored in *P. oceanica* meadows throughout their tour activities. In addition, NFZs in the Datça-Bozburun SEPA were established later than NFZs of Gökova SEPA. A previous study indicated that it may take at least 7 years to observe the positive effects in NFZs and this period may vary from region to region (Ziegler *et al*., 2022).

Our findings highlight that there can be differences in *P. oceanica* coverage (%) across different geographical areas and regions with varying conservation statuses. The results related to *P. oceanica* coverage and shoot density reported in previous studies conducted in various regions are summarized in Table 8. Although direct comparisons may not be entirely appropriate due to the differences in depth contours and management zones (e.g., fishing zones, marine protected areas), this evidence provides a valuable basis for evaluation across different parts of the Mediterranean.

Previous studies reported that shoot density decreases with increased depth (Çelebi, 2007; Holzknecht & Albano, 2022), and this is associated with different levels of solar irradiation (Pergent *et al*., 1995). However, according to our results, this situation can sometimes vary. In the areas with differing conservation status and levels

Table 8. Studies conducted on *Posidonia oceanica* coverage and shoot density across different geographical regions of the Mediterranean and the mean values obtained.

Study	Area	Depth (m)	Mean coverage (%)	Mean shoot density (m^{-2})
Dural *et al*. (2012)	Aegean Sea, Türkiye, Eastern Mediterranean	8-10	n/a	261-848
Duman *et al*. (2019)	East Aegean Sea, Türkiye, Eastern Mediterranean	n/a	2.7-37.3	n/a
Akçalı *et al*. (2020)	Aegean Sea, Türkiye, Eastern Mediterranean	25.1-32.9	13.4-26.8	50.9-87.9
Güreşen *et al*. (2020)	North Aegean Sea, Türkiye, eastern Mediterranean	6-28	37-89	75-207
Gerakaris *et al.* (2021)	North Aegean Sea, Greece, Eastern Mediterranean	n/a	60	333
Gerakaris *et al.* (2021)	South Aegean Sea, Greece, Eastern Mediterranean	n/a	87	403
Gerakaris *et al.* (2021)	Ionian Sea, Greece, Eastern Mediterranean	n/a	89	469
Bacci *et al*. (2015)	Italy, Central Mediterranean	15	n/a	112-1059
Llorens Escrich *et al*. (2021)	Spain, Western Mediterranean	4.5-12.5	n/a	326-1109
Pergent-Martini *et al*. (2021)	Corsica Island, Western Mediterranean	5-30	n/a	106-551
This study	Gökova, South Aegean Sea, Türkiye, Eastern Mediterranean	7 and 15	24	83
This study	Datça-Bozburun, South Aegean Sea, Türkiye, Eastern Mediterranean	7 and 15	41	197

of anthropogenic impact, shoot density may not decrease with increasing depth. Furthermore, the relatively small depth difference between the selected shallow and deep contours in our study may have also contributed to this. Besides, Mutlu *et al*. (2024) noted that shoot density did not show significant differences among seasons in the north-eastern Mediterranean coasts of Türkiye.

In our study, one-fourth of the surveyed divers reported a narrowing in the depth distribution range of *P. oceanica*. Similarly, Taşkın & Bilgiç (2024) reported that the lower depth limit of the meadow, which was approximately 25-26 meters in 2019 at a different location (Çeşme) in the Aegean Sea, had receded to 19-20 meters by 2024. Another recent study from Northwestern Alboran Sea by Mateo-Ramírez *et al*. (2023) reported a decrease trend in the depth range within the 1 to 6 m.

According to several recent estimates, anthropogenic impacts have caused a rapid decline in seagrasses in the Mediterranean, with approximately 34% lost over the past 50 years (Marbà *et al*., 2014; Telesca *et al*., 2015). Another study conducted in the region reached similar conclusions, determining that intense human pressure threatens local seagrasses (Duman *et al*., 2019). In the present study, based on unofficial observations, many divers noticed that the density of *P. oceanica* has decreased and its health has deteriorated over the past five years in these two SEPAs. Factors such as herbivory, especially by invasive herbivores in the study areas, water temperature, epiphytes, and water quality (i.e., increased turbidity) may also cause to seagrass mortality (O'Brien *et al*., 2018; Sagerman *et al*., 2020; Ruiz & Romero, 2003).

Furthermore, in our survey data, most of the stakeholders (divers) showed a high awareness of the benefits of the species on the ecosystem. Undoubtedly, their high awareness and knowledge of the ecology of the species can facilitate an effective application of management tools. Moreover, most divers declared that they could take an active role in monitoring this sensitive species by using some tools (e.g., mobile application, social media, and dive logbooks). Similarly, several previous studies highlighted the importance of stakeholder engagement in improving the management of sensitive species (e.g., vulnerable or endangered species) and ecosystems (Sawchuk *et al*., 2015; Fontaine *et al*., 2022). One of the most important activities supporting the management and effective conservation of MPAs is the use of eco-mooring systems, which serve as alternatives to traditional boat anchoring. Available evidence suggests that eco-mooring systems help to protect benthic habitats, such as seagrass meadows (Solandt *et al*., 2024). The MPAs where eco-mooring systems are used were reported to be characterized by a reduction in mechanical damage to seagrass meadows, along with an increase in their distribution area (Solandt *et al*., 2024). Previous studies on restoration in recent years reported promising results (Piazzi *et al*., 2021; Escandell-Westcott *et al*., 2023; Bacci *et al*., 2025). Similarly, in our study, stakeholders emphasized that habitat restoration efforts could bring significant benefits to the region. In addition, most stakeholders stated that reducing the number of boats could be an important management tool to minimize damage caused by anchoring. Protected areas must simultaneously maintain their protective function while allowing for tourism development. Based on this evidence, a practical recommendation suggested by our results is that carrying capacity assessments should be conducted in these areas and, if necessary, restrictions should be imposed on the number of visitors to reduce destructive anthropogenic impacts and ensure the sustainable use of resources (Llausàs *et al*., 2019). In addition, considering that many protected areas in Türkiye, particularly along the Aegean and Levantine coasts, are under intense tourism pressure, it is important to conduct up to date carrying capacity studies not only for the two SEPAs analyzed in the present study, but also for other areas. In the light of the impacts of global warming, it is essential to monitor changes in vegetative growth parameters in the Mediterranean Sea (González-Correa *et al.*, 2007). The corresponding data should be regularly collected.

In conclusion, the present study provides baseline data on the coverage and shoot density of *P. oceanica* meadows within two SEPAs located along the southwestern coast of Türkiye. Although comparisons were made among zones with different protection statuses, the sampling was conducted during a short time frame—specifically, at the end of the tourism season when fishing activity tends to increase. In addition, we focused on a relatively small geographic area. For that reason, future research that would cover a broader area and include year-round seasonal sampling would offer a more accurate understanding of temporal variation and provide a stronger basis for the evaluation of the effectiveness of marine protected areas. Finally, our findings that the stakeholders have a high level of awareness about the species and can thus play an active role in its monitoring highlights the potential value of stakeholder contributions in improving management strategies in marine protected areas.

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Appendix A. The English version of the surveys administered in the study.

Survey questions directed to divers

Question	**Answer**
What is your age?	
How many years of diving experience do you have?	
Which locations do you usually dive in?	
Based on your observations, what is the greatest depth (max) at which *Posidonia oceanica* occurs within the Gökova SEPA or Datça-Bozburun Special Environmental Protection Area (SEPA)?	
Based on your observations, what is the deepest limit of *Posidonia oceanica* distribution in regions of the Aegean Sea outside of the Gökova SEPA and Datça-Bozburun SEPA?	

Opinions on the contribution of seagrass meadows to the ecosystem and stakeholders	**Absolutely agree**	**Agree**	**Relatively agree**	**Disagree**	**N/A**
Posidonia ocenica meadows are important habitats for fish and invertebrates.					
Posidonia ocenica meadows are habitats that host economic species that help us find food.					
Posidonia ocenica meadows are important habitats for primary production.					
Posidonia ocenica meadows have a role in carbon sequestration.					
Posidonia ocenica meadows contribute significantly to improving water quality.					
Posidonia ocenica meadows play an important role in preventing coastal erosion.					
Posidonia ocenica meadows are important habitats for fisheries.					
Posidonia ocenica meadows are important habitats for diving tourism.					
Perceptions regarding recent changes in seagrass meadows					
The density of meadows has decreased over the past five years.					
The health of the meadows has deteriorated over the past five years.					
In recent years, there has been a narrowing of the depth range of the meadows.					
Perceptions regarding the role of no-fishing zones in supporting seagrass meadow health and in the management of marine protected areas					
The health of *Posidonia oceanica* meadows is higher in no-fishing zones.					

Densities of *Posidonia oceanica* meadows are higher in no-fishing zones.					
Marine Protected Areas in the region are adequately managed.					
The main reported threats to *Posidonia oceanica* in the Gökova and Datça–Bozburun SEPAs, Aegean Sea					
What are the top three main threats to *Posidonia oceanica*?					
In recent years, have you observed any serious threats in the areas where you dive? If yes, please give information.					
	Absolutely agree	**Agree**	**Relatively agree**	**Disagree**	**N/A**
Boat anchoring has a negative effect on *Posidonia oceanica.*					
Fishing gear has a negative effect on *Posidonia oceanica.*					
Water pollution negatively affects *Posidonia oceanica.*					
Sedimentation negatively affects *Posidonia oceanica.*					
Temperature anomalies have a negative effect on *Posidonia oceanica.*					
Invasive alien species have a negative effect on *Posidonia oceanica.*					
Diving activities have a negative effect on *Posidonia oceanica.*					
Divers' potential contributions to the monitoring and conservation of *Posidonia oceanica* meadows					
Eco-mooring systems are necessary to reduce mechanical damage to *Posidonia oceanica* meadows in this area.					
Restoration of *Posidonia oceanica* is necessary in this area.					
Reducing boat capacity is necessary to protect *Posidonia oceanica* meadows.					
Which tool can you use to contribute to the monitoring of *Posidonia oceanica* meadows? (Can select two or more options)	Mobile application	Social Media Platforms	Diving notebooks		

Survey questions directed to tour boat owners/operators

Question	Answer
How many days per year do you organize tours (how many days did you organize tours last year)?	
On average, how many stations are anchored at during a typical daily tour?	
What is the typical depth range (in meters) at which anchoring is carried out during your tours?	
What is the average anchoring depth during your tours?	
Which habitat types do you usually anchor in during your tours?	

Survey questions directed to small-scale fishers

Question	**Answer**
On average, how many days per year do you engage in fishing activities within this area?	
What is the minimum depth (in meters) at which you conduct fishing activities?	
In which types of habitats do you typically prefer to carry out fishing activities?	
What types of fishing gear do you typically prefer to use when operating in these habitats?	

Appendix B. The shallowest and deepest locations where *Posidonia oceanica* seagrass was recorded at the sampling stations.

Station	Min. depth (m)	Max. depth (m)
Bozburun Söğüt NFZ	7	31
Datça Aktur NFZ	2	16
Datça FZ	7	34
Datça Kargı NFZ	4	18
Datça Port	6	15
Boncuk NFZ	7	25
Karacasöğüt NFZ	6	23
Karacasöğüt Port	2	8
Körmen FZ	7	31

Appendix C. a) The coverage (%) of *Posidonia oceanica* in sampling sites, b) the shoot density of *Posidonia oceanica* in sampling sites, Gökova and Datça-Bozburun SEPAs, Aegean Sea. Abbreviations: NFZ = no-fishing zone; FZ = fishing zone.