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Research Article

Effect of the aquaculture on the seagrass *Posidonia oceanica*: a decade before and after in the Aegean Sea

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Abstract

Seagrass *Posidonia oceanica* is an endemic and a keystone marine plant in the Mediterranean Sea. There has been a decline in the distribution of *P. oceanica* meadows due to several anthropogenic pressures (i.e., pollution, marine transportation, intensive coastal use, overfishing by ground scanning methods, anchors, aquaculture activities, alien and invasive species, overgrazing, tourist activities). This study aims to evaluate the impact of a fish farm on an island (Kızkulesi Island, Dikili, İzmir) on the seagrass *P. oceanica* meadow from the Aegean coasts of Türkiye. Sampling was made in September 2014 and October 2023 between 0 and 30 m depth by scuba diving. *P. oceanica* meadow has been completely lost in a decade in the research site.

Keywords: Aegean Sea, fish farming, *Posidonia oceanica*, seagrass

Introduction

In total, 2 million tonnes of marine fish production in the Mediterranean Sea in 2019, 43% came from aquaculture, and the fish production is heavily made in Egypt (31%), Türkiye (29%), Greece (14%) and Italy (12%) (Carvalho and Guillen, 2021). The capture fisheries and aquaculture production (excluding aquatic plants) were estimated as 800.000 tonnes in Türkiye in 2021, with aquaculture production reaching 59% of the total, up from 27% in 2011 (Çöteli, 2022). 71% of aquaculture production occurred in the marine coastal waters and 29% in inland waters. Sea bass (*Dicentrarchus labrax*; 155.151 tonnes, 33 %) and sea bream (*Sparus aurata*; 133.476 tonnes, 28 %) are the most farmed of the aquaculture production in the Turkish coasts in 2021. Turkish marine aquaculture is dominated on the Aegean coasts, comprising 77.3% of the total production (Muğla: 36.4 %, İzmir: 33.2%, Aydın: 7.7%) (Çöteli, 2022; Comte et al., 2024).

In the Mediterranean Sea, the distribution of *P. oceanica* meadows has been declined by anthropogenic pressures (i.e. pollution, marine transportation, intensive coastal use, overfishing by ground scanning methods, anchors, aquaculture activities, alien and invasive species, overgrazing, tourist activities, global warming) (Boudouresque and Meinesz, 1982; Astier, 1984; Pérés, 1984; Gravez et al., 1992; Chessa and Fresi, 1994; Pergent-Martini et al., 1994; Bianchi and Peirano, 1995; Burak et al., 2004; Apostolaki et al., 2009; Gazioğlu, 2018; Litsi-Mizan et al., 2023; Talas and Duman, 2023). Several studies focused on the fish farm's impact on the seagrass (*P. oceanica*) meadows on the Mediterranean coasts. Delgado et al. (1997) reported that *P. oceanica* and *Cymodocea nodosa* were affected by the marine culture of gilthead seabream (*Sparus aurata*) in the Balearic Islands (Western Mediterranean) in a three-year monitoring period (1988-1990). A preliminary investigation on the impact of fish farming on *P. oceanica* in Corsica and Sardinia from the Mediterranean was carried out by Pergent et al. (1999), and they reported that the decline in density of the meadows or their total disappearance in the area influenced by aquaculture farming. Five years after the onset of fish farming in the spring of 1994, 11.29 ha of *P. oceanica* meadow has been lost, and 9.86 ha degraded in Spain (Ruiz et al., 2001). The impact of fish farming facilities on *P. oceanica* meadows was evaluated in both abiotic (light, sediment, interstitial water) and biotic variables (i.e., meadow density, leaf biometry, lepidochronology, primary production, epiphytes), and the results showed that these meadows were degraded or disappeared (Pergent-Martini et al., 2006). The effects of organic matter and nutrient input from three fish farms (Greece, Italy, and Spain) on *P. oceanica* physiology (i.e., total nitrogen content, free amino acid concentration, and composition, total phosphorus) were studied by Pérez et al. (2008). They concluded that fish farm facilities severely affect the physiological parameters of the meadows. Recently, a review study of the direct and indirect impact (such as nutrients, particulate organic carbon from pellets, chemicals) of fish farms, shellfish and sea urchin aquaculture on Mediterranean marine macrophytes (macroalgae and seagrasses), showed that *P. oceanica* seagrass meadows are degraded or ultimately loss (Okuş et al., 2004; 2006; 2010; Boudouresque et al., 2020).

Several studies were made to test the effects of aquaculture on marine organisms, including *P. oceanica* and macrofauna, on Turkish coasts (Şahin, 2003; Koçak and Katagan, 2005; Keleş, 2007; Dural et al., 2007; Önen, 2008). This study aims to evaluate the impact of a fish farm on the seagrass *P. oceanica* meadow from the Aegean coasts of Türkiye.

Materials and Methods

The study was carried out in Kızkulesi Island (Dikili, İzmir, Türkiye) (38.9140º N, 26.8225º E) from the Aegean coasts of Türkiye in September 2014 and October 2023 (Figure 1). Sentinental photos were taken from Google Earth in 2006, 2010, 2013, and 2019. Sampling was made between 0 and 30 m depth along a transect method by scuba diving. Physicochemical parameters (pH, temperature, dissolved oxygen, turbidity, conductivity, and salinity) were measured by Water Quality Checker™ (DKK-TOA WQC 24). Ammonium nitrogen (Strickland and Parsons, 1972) and ortho-phosphate (Parsons et al., 1984) were also measured. The collected surface (0.5 m) and deep (20 m) water samples were preserved at +4ºC until the spectrophotometric analysis was held in the laboratory. Underwater photography and videos were taken *in situ*.

Fig. 1. Research site on the Aegean coasts of Türkiye.

Results

The results of the physicochemical parameters (pH, temperature, dissolved oxygen, turbidity, conductivity, and salinity) and nutrients (ammonium nitrogen and ortho-phosphate) of the research area are given in Table 1. Ammonium was higher in surface water in October 2023 sampling period than in-depth water sampling (2023 October) and the 2014 sampling period. However, phosphate was relatively high in 2014 sampling period. Nutrients (ammonium and phosphate) were found to be higher than two nearby research sites (Dikili and Çandarlı) given by Taşkın et al. (2023). They reported that ammonium was 24.4 µg/L and 20.0 µg/L in Dikili and Çandarlı, and phosphate was 2.1 µg/L and 2.3 µg/L in Dikili and Çandarlı, respectively.

The research site is situated on Kızkulesi Island (Dikili, İzmir, Türkiye) on the Aegean coasts, which is about 2600 m from the mainland (Fig. 1). The fish farm is 200 m away from the research area. Chroonological sentinental photos were taken in 2006, 2010, 2013, and 2019 (Figure 2A-D), and the fish farm started at the facility after 2006 (Figure 2A). The first period of the evaluated effect of the fish farm on *P. oceanica* was made in September 2014, and *P. oceanica* meadows was found from 1 m to 7 m depth (Figure 3A-C, Suppl. Video 1). Other species present at the sampling site were brown algae *Padina pavonica* (Linnaeus) Thivy and *Stypopodium schimperi* (Kützing) Verlaque & Boudouresque red algae *Amphiroa rigida* J.V.Lamouroux, *Asparagopsis armata* Harvey (as tetrasporohyte stage *Falkenbergia*) and *Peyssonnelia squamaria* (S.G.Gmelin) Decaisne ex J.Agardh, green algae *Anadyomene stellata* (Wulfen) C.Agardh, *Flabellia petiolata* (Turra) Nizamuddin, *Halimeda tuna* (J.Ellis & Solander) J.V.Lamouroux, *Codium bursa* (Linnaeus) C.Agardh and *Caulerpa cylindracea* Sonder.

The second period to analyze the impact of the fish farm on meadows was performed in October 2023, and *P. oceanica* meadows disappeared completely between 1-7 m depth (Figure 4A-C). At depths between 1 and 25 m, a dead meadow (matte) consisting of rhizomes, roots, and sediments fills the gaps (Suppl. Video 2). This dead meadow is covered with photophilic macroalgae [i.e., *Jania* spp., *Centroceras clavulatum* (C.Agardh) Montagne, *Chaetomorpha linum* (O.F.Müller) Kützing], which are found freely on the bottom zone (Fig. 4D). Three alien and invasive macroalgae, *Stypopodium schimperi*, *Asparagopsis armata* and *Caulerpa cylindracea*, were abundantly found in this area (Figure 5A-B).

Table 1. Physicochemical parameters and concentrations of nutrients in the research site (Kızkulesi Island, Aegean coasts of Türkiye).

Physicochemical parameters and Nutrients	Sampling Seasons			
	September 2014		October 2023	
	0.5 m	20 m	0.5 m	20 m
Phosphate (PO_4-P) (μgL^{-1})	9.62	nd	5.0	5.30
Ammonium nitrogen (NH_4-N) ($x10^{-3}$ µg/L)	43.0	nd	54.23	34.78
pH	8.26	nd	8.25	8.23
Temperature (°C)	24.6	nd	21	20
Dissolved oxygen (mgL^{-1})	nd	nd	7.20	7.30
Turbidity (NTU)	20.3	nd	25.4	25.0
Conductivity (Sm^{-1})	60200	nd	50600	50700
Salinity (‰)	38.5	nd	34.3	34.4

nd: no data

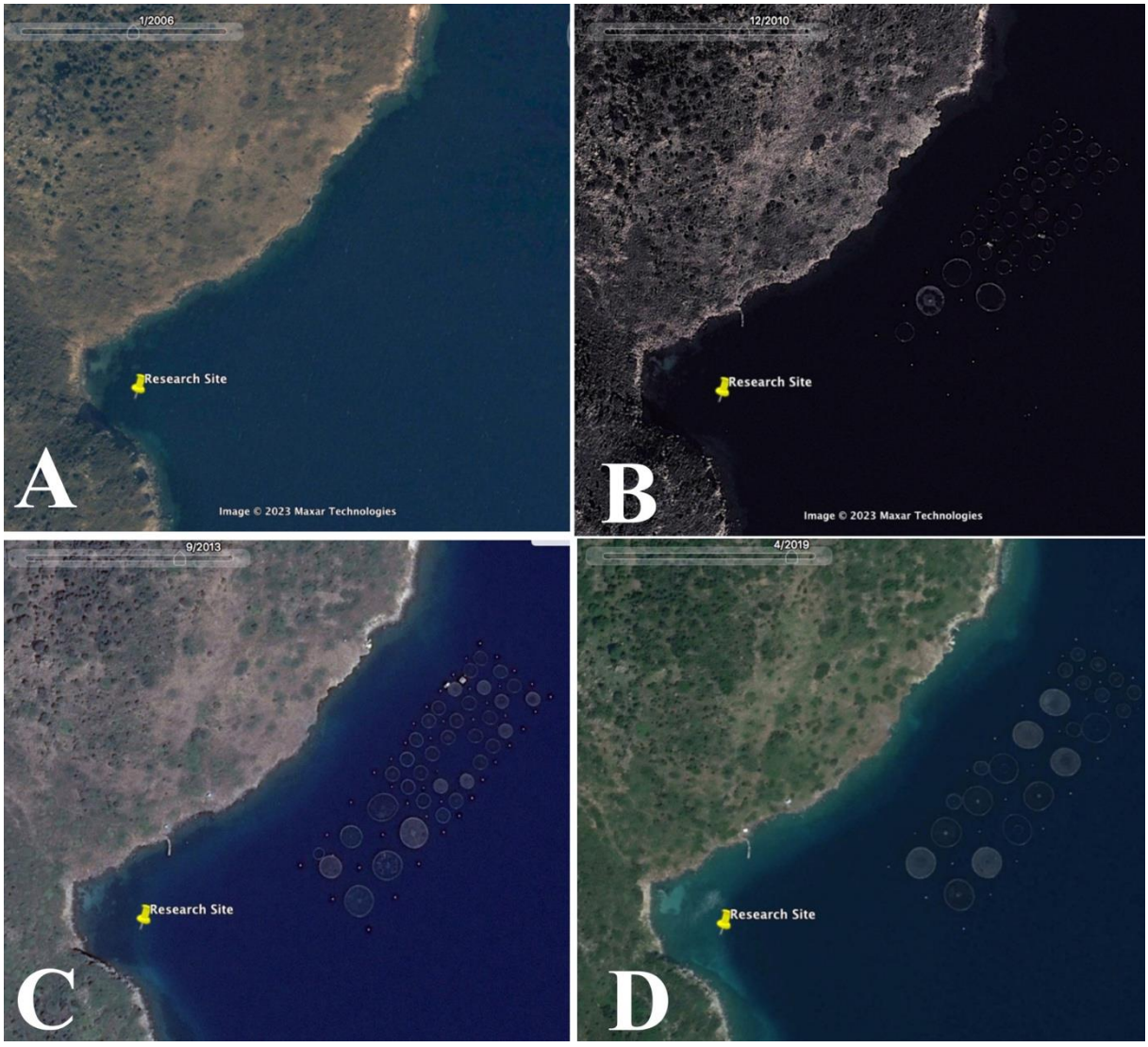

Fig. 2. Chronological sentinental photos of the research site (Google Earth).

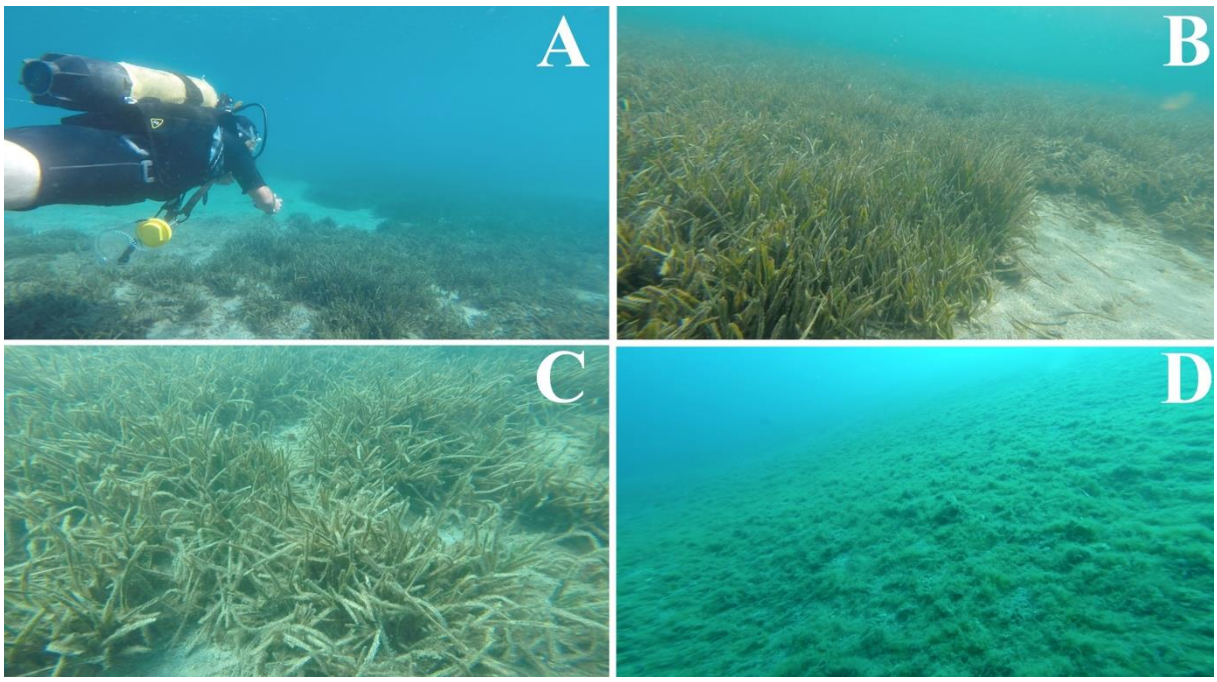

Fig. 3. *The research site's* General underwater views from different depths (3A-B: 2-3 m, 3C: 5 m, and 3D: 20 m) in September 2014.

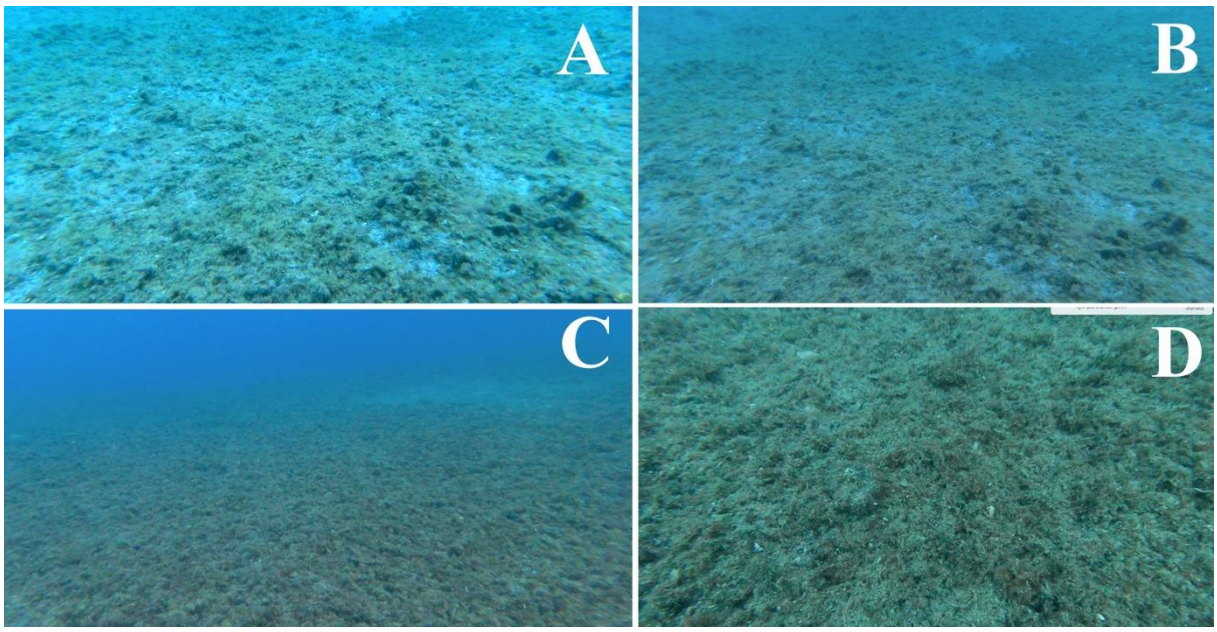

Fig. 4. *The research site's* general underwater views from different depths (4A-B: 3-4 m, 4C: 10m, and 4D: 15 m) in October 2023.

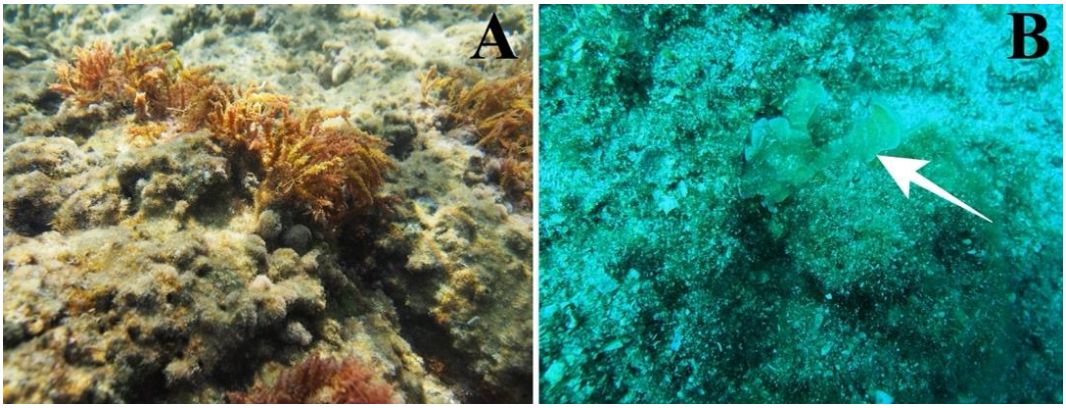

Fig. 5. Alien species in the research site (5A: *Asparagopsis armata*, 5B: *Stypopodium schimperi*, arrow)

Discussion and Conclusion

Four native marine phanerogams (seagrasses) are known along the Turkish coasts: *P. oceanica* (Marmara Sea, Aegean coasts, and Mediterranean coasts of Türkiye), *C. nodosa* (Black Sea coasts, Marmara Sea, Aegean coasts and Mediterranean coasts of Türkiye), *Zostera marina* (Black Sea coasts, Marmara Sea, Aegean coasts and Mediterranean coasts of Türkiye) and *Zostera noltii* (Black Sea coasts, Marmara Sea, Aegean coasts and Mediterranean coasts of Türkiye) (Taşkın, 2018). *P. oceanica* is affected by different anthropogenic pressures on the coasts of Türkiye. For example, there is pollution (domestic and industrial discharge) with global warming in the Marmara Sea. At the same time, there is pollution and increased salinity with global warming (increasing surface water temperature) in the Mediterranean Sea (E. Taşkın, pers.comm.). *P. oceanica* is under pressure from pollution and sedimentation in the northern Aegean coasts, pollution and aquaculture in the central Aegean coasts, and discharge-induced pollution and anchoring pressure on the coasts of the southern Aegean coasts.

A study conducted on a small facility in İzmir Bay (Aegean coasts of Türkiye) reported that the fish farm's effect on the seagrass *P. oceanica* was low (Keleş, 2007). However, in another study, some phenological parameters of the seagrass (shoot density, leaf length, leaf surface, leaf area index) were reported to be more sensitive indicators of changing environmental conditions, and the meadows were declined by near fish farming facilities in İzmir Bay (Koçak et al., 2011). Later, this area was impacted by aquaculture facilities (Dural et al., 2012).

A total of 2 216 116 ha was reported (estimated 2 794 861 ha) for *P. oceanica* meadows coverage area along the Mediterranean coasts, 39 983 ha (estimated 68 937 ha) of which are found in the Turkish coasts (Pergent-Martini et al., 2021). Increased light attenuation, sedimentation rates, and grazing pressure have been proposed as key factors causing seagrass decline, and *P. oceanica* was affected more severely and rapidly than *C. nodosa* (Delgado et al., 1997). It has been reported that the decline in seagrass meadows continues even if fish farming is stopped (Delgado et al., 1999). About 21 ha of *P. oceanica* meadow (53% of the former meadow) was destroyed or degraded in Spain (Ruiz et al., 2001). Pergent-Martini et al. (2006) reported that the meadow is severely disturbed or destroyed when fish farm cages are placed on *P. oceanica* beds. The resulting sediment can lead to anoxia phenomena. Pérez et al. (2008) concluded that fish farming activities strongly influence the physiological parameters of nearby *P. oceanica* meadows and suggested that changes in these physiological parameters could be useful indicators of marine environmental degradation for the studies monitoring the effects of fish farming. The remote impact of off-shore fish farm effluents on *P. oceanica* meadows was investigated by Ruiz et al. (2010) and concluded that waste delivered by off-shore farms has a wide impact area affecting meadows in remote environments near the coast. The study's result in spatial analysis of marine fish farming shows that the risk of eutrophication in the marine coastal zone should be attributed to the impact of aquaculture along with all other coastal activities (Yucel-Gier et al., 2013). Moving fish farms farther from *P. oceanica* meadows has been reported to help meadows recover at the deepest edges of their distribution (Kletou et al., 2018).

In conclusion, *P. oceanica* meadows are decreasing in the Mediterranean Sea because of anthropogenic activities, including aquaculture. The present study showed that fish farming affects *P. oceanica*, and the meadows are entirely lost (about 1 ha). Some protection strategies are suggested as follows: using ecological mooring methods instead of traditional mooring, collection of wastewater from boats (especially in tourism areas) to reduce turbidity, ports and marinas should not be built above the *P. oceanica* meadows, fishing (trolling, dredging, etc.) should not be done in areas where *P. oceanica* meadows exist, aquaculture activities should not be carried out in areas where meadow exists, turbidity and sediment load should be limited.

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