Mediterranean Fisheries and Aquaculture Research

https://dergipark.org.tr/medfar

RESEARCH ARTICLE

Receive: 28 May 2025 | Accept: 12 Jun. 2025

Evaluation of the Ecological Dynamics of the Seagrass *Posidonia oceanica* in a Turkish Mediterranean Site Considering the Plant Growth

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ABSTRACT

Vascular angiosperms considered as architectures of homogeneity, dominate the composition, and ecosystem functioning in the Mediterranean Sea. Since the realisation of the factors influencing the ecological and evolutionary dynamics of seagrasses, is critical for the conservational purposes, we aimed to evaluate the ecological dynamics *Posidonia oceanica* meadows in Kızılada, Fethiye-Göcek Special Environmental Protected Area (Muğla, Türkiye) in this study. Considering growth dynamics of the plant, lepidochronological analysis using annual cycles of scale thickness, was conducted both on the orthotropic and the plagiotropic rhizomes. The upper limit of *P. oceanica* meadows, started from a depth of 18.7 m and ended at a depth of 29.7 m in the region. Development of the plagiotropic rhizomes of *P. oceanica* along a line from the upper limit to the lower limit depth, could be rarely seen in the Turkish coasts. Since the growth rates were different between orthotrophic and plagiotrophic rhizomes, the annual growth of the meadow on the line, was calculated by averaging the both of the rhizomes. Considering the results, the annual growth rate of *P. oceanica* decreased with depth and was determined to be minimum at the lower limit depth. The average rate of plagiotropic rhizome elongation, was recorded as 17.8 mm yr^{-1}, while the average of orthotrophic rhizomes was recorded as 8.8 mm yr^{-1}. Lepidochronological analyses verified that *P. oceanica* meadow was estimated to be approximately 2013 years old according to the average annual growth rate of the rhizomes.

KEYWORDS: *Posidonia oceanica*, lepidochronology, plant growth dynamics, productivity, Mediterranean Sea

How to cite this article: Taşkın, E. Bilgiç, F., Güreşen, A. (2025) Evaluation of the Ecological Dynamics of the Seagrass *Posidonia oceanica* in a Turkish Mediterranean Site Considering the Plant Growth. *MedFAR.*, 8(1):49-62. https://doi.org/10.63039/medfar.1708155

1. Introduction

Clonal vascular angiosperms considered as architectures of homogeneity, dominate the composition, biomass, and ecosystem functioning in the coasts of the Mediterranean (Trache et al., 2023). Different plant sizes among seagrasses, describe the variations of productivity between fast-growing (*Zostera*, *Cymodocea*) and slow-growing (*Posidonia*) genera (Hillman et al., 1989). In order to maintain a long life span, the endemic seagrass of the Mediterranean Sea, *Posidonia oceanica* (L.) Delile colonize monospecifically over vast areas in the littoral zones, contributing to the global primary production and to the coastal biodiversity (Ohno, 1970; Ott, 1980; Zupo et al., 1997; De Bodt et al., 2005; Lynch, 2007; Jiao et al., 2011; Van de Peer et al., 2021).

Previous studies verified that the structural species like *P. oceanica* can form continuous beds in the coastal zones from 0–40 m depths (Kuo, 2013), however facing a global regression (Bonacorsi et al., 2013; Sinclair et al., 2016; Digiantonio et al., 2020; Blanco-Murillo et al., 2022). From this point of view, *P. oceanica* is used in the studies conducted in all over the Mediterranean to evaluate its annual productivity and architectural dynamics for reproduction with the environmental variations (Boudouresque et al., 1983).

The seagrass *P. oceanica* shows development with successional morphological sections (Petersen, 1913) such as “rhizome internodes” and “leaf sheaths” (Pergent and Pergent-Martini, 1990; Duarte et al., 1994). A rhizome internode is formed with every new leaf that substituted the older leaves. When the leaf blades fall; the leaf sheath persists attached to the rhizome as ‘scales’ within the matte more than 4 600 years (Boudouresque et al., 1984). In this respect, scale thickness demonstrates the annual cycle in chronological order (Pergent et al., 1989; Pergent, 1990).

Among various methods developed to estimate the primary production, is “lepidochronological analysis”, rather performed on the the fast-growing plagiotropic rhizomes having a greater number of leaves than the orthotropics (Ott, 1980). For this purpose, measurements of leaf and rhizome growth rate and thus, age determination of *P. oceanica* were reported from Spain (Romero, 1989), France (Pergent, 1987; 1990; Pergent et al., 1989; Pergent and Pergent-Martini, 1990; Pergent et al., 1994; 1997; Pergent-Martini et al., 1994), Türkiye (Pergent and Pergent Martini, 1990), Italy (Pergent and Pergent-Martini, 1990; Pergent-Martini et al., 1994; Calvo et al., 1995; Torricelli and Peirano, 1997) and Egypt (Mostafa and Halim, 1995). Another method based on the determination of seagrass age, is the calculation of the internodal length between two successive nodes since one year periods are distinguished as marks of the scales or nodes on the rhizomes (Mossé, 1984; Duarte, 1991). The method is conducted with a standard leaf marking on the basal leaf or on the rhizome meristem (Zieman, 1974; Zieman and Wetzel, 1980; Buia et al., 1992). Moreover, calculation of the internodal length combined with plastochrone interval index (Peirano, 2002), have been performed non-destructively in situ to estimate the growth dynamics of *P. oceanica* and to compare its productivity with other seagrasses (Cebrián et al., 1994; Duarte et al., 1994; Alcoverro et al., 1995; Marbà and Duarte, 1997; Duarte, 1999).

Regarding the Turkish Aegean coasts, most of the studies focus on the relations between the environmental conditions (mainly temperature, light and nutrients) and the distribution of *P. oceanica* meadows

along the coasts (Taşkın, 2020; Taşkın et al., 2020a; 2020b). However, the realisation of the factors influencing the ecological and evolutionary dynamics of seagrasses, is critical for future planning of the conservational purposes. Therefore, in this study we aimed to evaluate the ecological dynamics *P. oceanica* meadows in the Aegean Sea considering its growth dynamics. Lepidochronological analysis using annual cycles of scale thickness, was conducted both on the orthotropic and plagiotropic rhizomes to provide data on the previous flowering occasions of *P. oceanica*.

2. Material and Methods

P. oceanica meadows were sampled from Kızılada in Fethiye-Göcek Special Environmental Protected Area (Muğla, Türkiye) (36°39'39" N, 29°03'14" E) (Figure 1). Research site was characterized with hard rocky bottom types, in the form of an almost vertical wall between 0-18 m, the upper limit of the meadows started from 18.7 m depth, and the lower limit depth ended at 29.7 m (Figure 2a-d). The meadows have been developed in the form of lines from the upper limit to the lower limit depth (Figure 3a). Only one line was sampled for lepidochronological analysis from the upper limit depth to the lower limit depth. 33 shoots (11 horizontal and 22 vertical) were collected from different depths (18.7 m, 19 m, 19.3 m, 20.8 m, 22 m, 22.7 m, 23 m, 24.1 m and 26.7 m) from the upper limit to the lower limit. Also, the total length of the same line was measured with a tape measure (Figure 3b). Lepidochronological analysis was conducted according to Pergent (1990) and Mosse (1984). The annual growth of the meadow on the line, was calculated by averaging the plagiotrophic and orthotrophic rhizomes. Spearman rank order correlations were carried out by using PAST software (Hammer et al., 2001).

Figure 1. Research site (Kızılada) in Fethiye-Göcek Special Environmental Protected Area (Fethiye, Muğla, Türkiye).

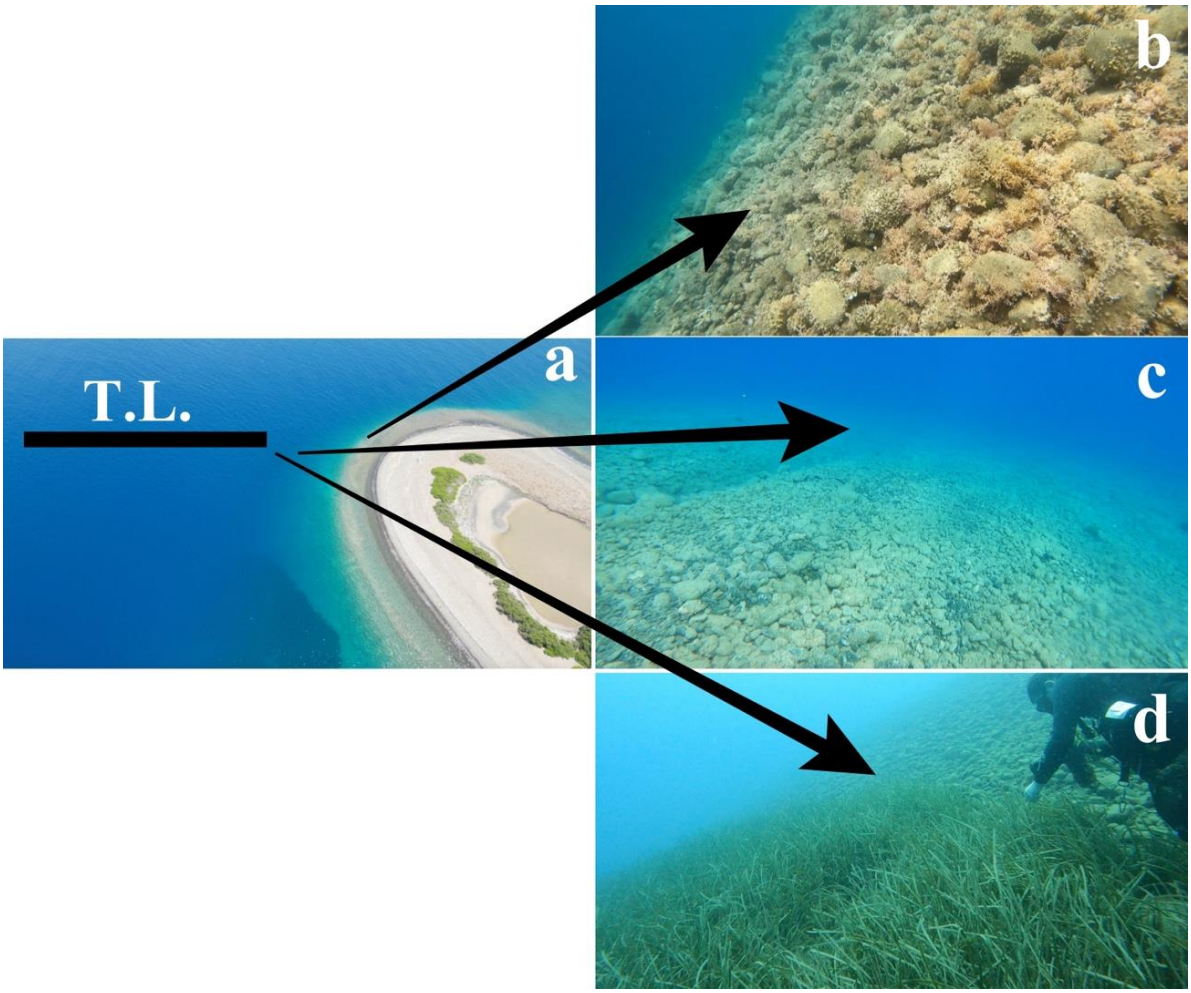

Figure 2. Sampling site (Kızılada) (T.L.: Transect Line) (a), rocky area (b-c), upper limit depth of seagrass (18 m) (d).

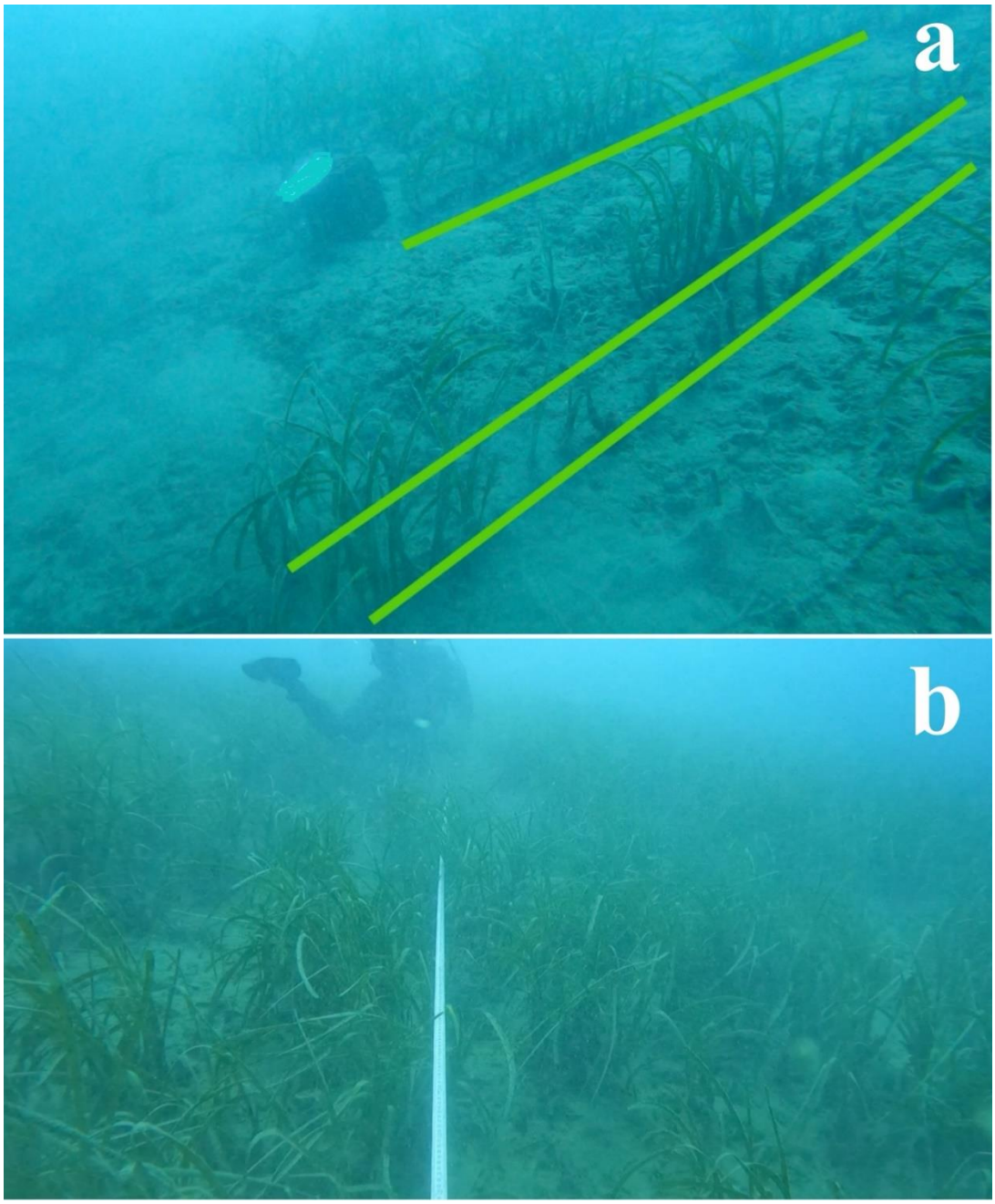

Figure 3. Line-shaped development of the meadow (26 m depth) from the upper limit depth to the lower limit depth and measurement of the meadow distance in sampling site.

3. Results and Discussion

It is possible to obtain data from the shoots of *P. oceanica* meadow to estimate its annual growth rate and age (Christrine Pergent, pers. Comm.). In this study, it was determined that plagiotropic rhizomes of *P. oceanica* meadows in Kızılada, Fethiye-Göcek SPA (Muğla, Türkiye) have been developed along a line from the upper limit to the lower limit depth. This phenomenon could be rarely seen in the Turkish coasts. The upper limit of the meadow started from a depth of 18.7 m, and the lower limit depth was recorded at 29.7 m. The total length of the sampling line was recorded as 26.8 m. Lepidochronological years, rhizomes elongation rates (mm yr^{-1}) and scales thicknesses (µm), were given in Table 1. The average elongation rate of vertical rhizomes (mm/$year^{-1}$) was calculated as 8.82 mm

year^{-1}, while that of horizontal rhizomes, was calculated as 17.81 mm year-^{1}. In order to estimate the annual growth rate and the age of the meadows, the average values of plagiotrophic and orthotrophic rhizomes, were given in Table 1. The highest growth rate (45.7 mm) of plagiotrophic rhizomes, was recorded at 22 m depth, and the highest growth rate (29.2 mm) of orthotrophic rhizomes, was recorded at 19.3 m depth. It was determined that the average annual growth rate of the meadow, decreased from the upper limit depth to the lower limit depth. The highest growth rate of rhizomes in 2025 were measured at 19.3 m depth (22.56 mm year^{-1}), followed by 20.8 m (15.54 mm year^{-1}), 18.7 m (14.94 mm year^{-1}), 22 m (10.98 mm year^{-1}), 24.1 m (7.87 mm year^{-1}), 22.7 m (6.24 mm year^{-1}), and 26.7 m (6.65 mm year^{-1}). As a result of measurements performed by lepidochronological analyses in the research area, it was calculated that the meadow was approximately 3038 years old according to the annual average growth rate of only the orthotropic rhizomes and approximately 1504 years old according to the annual average growth rate of only the plagiotrophic rhizomes. However, in this study, the average annual growth rate of both vertical and horizontal rhizomes, was preferred and accordingly, the meadow was calculated to be approximately 2013 years old.

In total, 412 scales were measured from different depths (18.7 m: 76 scales, 19.3 m: 40 scales, 20.8 m: 85 sclaes, 22 m: 43; 22.7 m: 82 scales, 24.1m: 51 scales, and 26.7 m: 23 scales) in May 2025, and scales thickness were recorded as 482,54 μm, 551,81 μm, 565,08 μm, 495,58 μm, 581,51 μm, 636,25 μm and 643,75 μm, respectively. It was determined that the scale thickness increased towards the lower distribution limit depth of the meadow.

Table 1. Rhizome elongation rate (mm yr^{-1}) and scales thickness (μm) of the horizontal and vertical rhizomes of *P. oceanica* from the sampling site (Kızılada, Fethiye, Türkiye).

Sampling	**Number of shoots examined**		**Av. Rhizome elongation rate (mm yr^{-1})**			**Av. Scales thickness (μm)**		
Year/Depth	**P**	**O**	**P**	**O**	**Av.**	**P**	**O**	**Av.**
2025 / 18,7 m	1	3	25.33	4.55	14.94	438.89	526.19	482.54
2025 / 19,3 m	3	1	15.92	29.20	22.56	603.61	500.00	551.81
2025 / 20,8 m	3	3	24.85	6.22	15.54	564.58	565.58	565.08
2025 / 22 m	2	1	16.28	5.68	10.98	500.16	491.00	495.58
2025 / 22,7 m	0	4	nm	6.24	6.24	nm	581.51	581.51
2025 / 24,1 m	0	4	nm	7.87	7.87	nm	636.25	636.25
2025 / 26,7 m	2	0	6.65	nm	6.65	645.83	nm	645.83
2024 / 19 m	0	3	nm	5.33	5.33	nm	437.33	437.33
2024 / 23 m	0	3	nm	5.48	5.48	nm	424.03	424.03
	11	**22**	**17.81**	**8.82**	**13.31**	**550.61**	**520.24**	**535.43**

P: plagiotrophic rhizome, O: orthotrophic rhizome, Av.: average, nm: not measured.

P. oceanica is a long-lived and slow-growing seagrass species, and the colonization rate of this species, is extremely slow (Marbà et al., 2004). Therefore, based on rhizome growth, a 15 m wide clone of *P. oceanica* would take 350 years to reproduce. The Mediterranean seagrass *P. oceanica* forms a biological structure called a "mat", where it accumulates vast amounts of organic debris (Mateo et al., 1997). Radiocarbon dating of the samples revealed a range of 0-3370 years before present, with average deposition rates of 0.175 cm yr^{-1}. It has been reported that *P. oceanica* meadows can grow continuously for more than 6000-7000 years (Mateo et al., 1997), suggesting that clones can reach a life span of thousand years (Arnaud-Haond et al., 2012).

The growth rates and scales thickness of the horizontal and vertical rhizomes of *P. oceanica* are given in Table 2. Plagiotrophic rhizomes in Corsica have average annual growth rates ranging from 32 to 45 mm yr^{-1} (Gobert et al., 2016). Neither the growth rate nor the primary production of rhizomes of the meadow, were dependent on depth up to 14 m, but a significant decrease in shoots was reported at depths greater than 14 m (Tomasello et al., 2016). In the present study, the annual growth rate of *P. oceanica* decreased with depth and was determined to be minimum at the lower limit of distribution (Table 1). It is thought that the decrease in the annual average growth rate of the meadow from the upper limit depth to the lower limit depth may be related to light penetration. The growth rates of plagiotropic rhizome were given by Mosse, 1984; (as 32.43 mm yr^{-1}), Marbà et al., 2004 (as ave. 20.00 mm yr^{-1}), and Tomasello et al., 2016 (as 40.25 mm yr^{-1}) (Table 2).

Table 2. The growth rates of the horizontal and vertical rhizomes of *Posidonia oceanica* in the Mediterranean coasts.

	Rhizome elongation rate (mm yr^{-1})	
Reference	**P**	**O**
Mosse, (1984) (France)	32.43	5.54
Pergent and Pergent, (1990), Urla (Türkiye)	nd	5.90
Pergent and Pergent, (1990), Banyuls (France)	nd	7.45
Pergent and Pergent, (1990), Port-Cros (France)	nd	5.75
Marbà et al., (2004)	20.00	10.00
Calvo et al., (2006), Sicily (Italy)	nd	19.70
Marbà et al., (2006) (Cyprus, Greece, Italy and Spain)	nd	6.15
Maida et al., (2013), Sicily (Italy)	nd	8.20
Gobert et al., (2016), Corsica (France)	40.25	nd
Tomasello et al., (2016), Sicily (Italy)	nd	10.26
Güreşen et al., (2020), Corsica (France)	nd	4.74
Güreşen et al., (2020), Gökçeada (Türkiye)	nd	6.07
Taşkın et al., (2025), Marmara Sea (Türkiye)	nd	7.02
Taşkın et al., (2025), Kaş (Türkiye)	nd	10.72
Average of rhizome elongation rate (mm yr^{-1})	**30.89**	**8.27**

P: plagiotrophic rhizome, O: orthotrophic rhizome, nd: no data.

P. oceanica plagiotrophic rhizomes show elongation rates 20 (10-60 mm yr^{-1}) much higher than those of orthotrophic rhizomes 10 (1- 40 mm yr^{-1}) in the Mediterranean Sea (Marbà et al., 2004). However, plagiotropic rhizome elongation rate was recorded as 17.81 mm yr-^{1} from the Turkish coasts (Table 1). While the average value of orthotrophic rhizomes in the Mediterranean was stated to be 8.27 mm $year^{-1}$ (Table 2), this value was calculated as 8.82 mm year-1 in the study obtained from Fethiye (Türkiye). In the Mediterranean, the meadow was calculated to be approximately 3240 years old according to the annual average growth rate of the orthotrophic rhizome, and approximately 867 years old according to the annual average growth rate of only the plagiotrophic rhizome (Table 2). However, when the annual average growth rate of vertical and horizontal rhizomes, was taken into account as in this study, the meadow was calculated to be approximately 1368 years old.

Number, length and width of leaves in per shoot from the sampling site are given in Table 3. Spearman rank order correlations were used to study the relationship between the metrics (Table 4), and marked correlations are significant at $p < 0.05$.

Table 3. Number, length and width of leaves in per shoot from the sampling area.

Sampling Year/Depth	Number of Leaves	Length of Leaves	Width of Leaves
2025 / 18.7 m	4.0 ± 1.0	259.3 ± 67.6	7.6 ± 0.6
2025 / 19.3 m	4.7 ± 2.1	265.2 ± 21.8	7.8 ± 0.7
2025 / 20.8 m	5.7 ± 0.6	344.9 ± 54.4	8.9 ± 0.3
2025 / 22.0 m	6.5 ± 0.7	282.1 ± 59.1	8.1 ± 0.3
2025 / 22.7 m	6.0 ± 0.8	354.6 ± 66.8	8.8 ± 0.6
2025 / 24.1 m	5.7 ± 1.2	338.4 ± 78.5	8.8 ± 0.23
2025 / 26.7 m	7.0 ± 0.0	344.1 ± 9.6	9.2 ± 0.2
2024 / 19.0 m	5.4 ± 1.2	305.5 ± 103.5	8.6 ± 0.9
2024 / 23.0 m	5.0 ± 0.7	255.7 ± 63.1	8.4 ± 0.8

Table 4. Spearman rank order correlations. Bold correlations are significant at $p < 0.05$.

	Growth rate of plagiotrophic rhizome	Growth rate of orthotrophic rhizome	Scales thickness of plagiotrophic rhizome	Scales thickness of orthotrophic rhizome	Number of leaves	Length of leaves	Width of leaves
Growth rate of plagiotrophic rhizome		0.0833	**0.0167**	0.3333	0.2333	0.5167	0.2333
Growth rate of orthotrophic rhizome	-0.8		0.0833	0.1966	0.4867	0.2675	0.3894
Scales thickness of plagiotrophic rhizome	**-0.9**	1		1	0.2333	0.4500	0.2333
Scales thickness of orthotrophic rhizome	0.6	0.5238	0		0.4867	0.0576	0.2162
Number of leaves	-0.7	0.2874	0.6000	0.2874		**0.0470**	**0.0438**
Length of leaves	-0.3	0.4286	0.5000	0.6905	**0.6860**		**0.0138**
Width of leaves	-0.6	0.3333	0.7000	0.4762	**0.6946**	**0.7833**	

4. Conclusion

The distinction between the two types of rhizomes is never clear-cut, therefore an orthotrophic rhizome may morph into a plagiotrophic again to recolonize an empty area (Mosse, 1984). Most of the lepidochronological studies are performed on orthotrophic rhizomes and since the growth rate will be different, we considered to take the plagiotrophic rhizomes growth into account. Thus, the annual growth of the meadow on the line was calculated by averaging the plagiotrophic and orthotrophic rhizomes.

Acknowledgements

The present study had been carried out with the Project "Mavi Nefes-Göcek" supported by Garanti BBVA and DenizTemiz Derneği / TURMEPA Foundation. Also, we would like to thank to Republic of Turkey Ministry of Environment, Urbanization and Climate Change, General Directorate of Protection of Natural Assets, and to Esra Merve Taşkın (Eser Deniz Ltd. Şti, Manisa) for laboratory analyses support.

Compliance with Ethical Standards

Conflict of interest

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

Ethical approval
Ethics committee approval is not required.

Funding
Financial support was received for this study.

Data availability
Not applicable.

Consent for publication
Not applicable.

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