

Effects of dredging activities on population dynamics of *Posidonia oceanica* (L.) Delile in the Mediterranean sea: the case study of Capo Feto (SW Sicily, Italy)

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Abstract

Between 1981 and 1993 a methane pipeline was deployed between Sicily (Italy) and Tunisia. This involved the construction of a pipeline trench, which damaged the *Posidonia oceanica* (L.) Delile meadow at Capo Feto (SW Sicily, Italy) and disturbed the surrounding meadow. Seagrass growth and population dynamics were examined at different depth ranges and at increasing distances from the construction site outer limit (5, 15, 30, 50 m). Results showed significant differences between the shallow (10 ± 3.3 m) and the deep (20 ± 4.6 m) meadow as well as differences among distances. The age structure of *P. oceanica* varied along the distance gradient and with depth. The mortality rate decreased with distance from the trench at all depth ranges, showing that the plants close to the excavation suffered a higher level of disturbance. Turnover and annual gross shoot recruitment rate (R_{gross}) were higher in the shallow portion of the meadow than in the deep range. Forecast of future meadow development (R_{net}) close to the trench indicates that, if present conditions are maintained, shoot density will be reduced by 50% over the next 6 to 17 yrs.

Introduction

Posidonia oceanica (L.) Delile is an endemic seagrass species of the Mediterranean Sea (Pergent-Martini & Pergent, 1995) that forms extensive meadows ranging from shallow waters to depths of about 40 m (Péres & Picard, 1964), if sufficient light is available. In the last decade a decline of *P. oceanica* beds has been recorded, caused by both natural (Gallegos et al., 1993; Marbà & Duarte, 1994) and anthropogenic events (Short & Wyllie-Echeverria, 1996). Fishing pressure (mainly trawling) (Ardizzone & Migliuolo, 1982; Sanchez-Jerez & Ramos-Esplá, 1996), nutrient loading (Pergent-Martini & Pergent, 1995) and

boat anchoring (Garcia-Charton et al., 1993; Francour et al., 1999), are examples of anthropogenic factors which lead to a slow but constant decline of *P. oceanica* beds. In addition, there are marine operations which have caused negative impacts on seagrass beds such as the construction of industrial outfalls (Pergent-Martini et al., 1996), fish farms (Delgado et al., 1999; Ruiz & Romero, 2001; Ruiz et al., 2001) and dredge-fill operations (Guidetti & Fabiano, 2000; Short & Coles, 2001). Nowadays, coastal zones support an increasing number of pipes and cables for gas and water transport as well as communication, the maintenance of which entails damage to seagrass beds (Duarte, 2002).

In 1981, a submerged pipeline system (TRANS-MED) was deployed between Cape Bon (NE Tunisia) and Capo Feto (SW Sicily). Operations included the dredging of a trench through the 30 000 ha *P. oceanica* meadow at Capo Feto. In 1993, two new pipelines were laid at the same site, enlarging the previously damaged area. This operation represented a disturbance event for the adjacent seagrass meadow, as it most probably led to an increase in sediment resuspension and deposition due to dredging and backfilling activities.

The development of reconstruction techniques, useful to reconstruct historic seagrass dynamics, allows the examination of the growth of different seagrass modules, allowing the assessment of plant health (Marbà et al., 1996; Hemminga & Duarte, 2000). Such techniques can be applied to evaluate whether a population is expanding or declining, through the study of the balance between shoot recruitment and mortality (Duarte et al., 1994; Marbà et al., 1996).

Here, we report on the case study of Capo Feto where growth and shoot demography of *P. oceanica* were assessed after the perturbation caused by the nearby pipe deployment. Plant growth and demography were estimated at different depth ranges and at increasing distances from the trench. It is hypothesised that a higher shoot mortality rate and a lower shoot net recruitment will be seen in seagrass patches closest the disturbed seabed associated with the pipe trench.

Materials and methods

The study area extends SW off Capo Feto coast, Sicily, Italy (37°39'N, 12°32'E) to a depth of 30 m (Fig. 1) (Tocaceli & Riggio, 1989; Orrù et al., 1993). Seagrass sampling was carried out between July and September 1998 at two depth ranges: shallow (10 ± 3.3 m) and deep (20 ± 4.6 m). Shoot density was recorded using 30×30 cm quadrates at four distances (5, 15, 30, 50 m) from the meadow edge/disturbed seabed interface (Fig. 1). For each distance, four sites were randomly chosen. Within each site, six random shoot counts were carried out.

For the population dynamics studies, six random samples were taken within a 10 m^2 area for each distance. Each sample contained between 50 and 100 living vertical rhizomes. Plant material

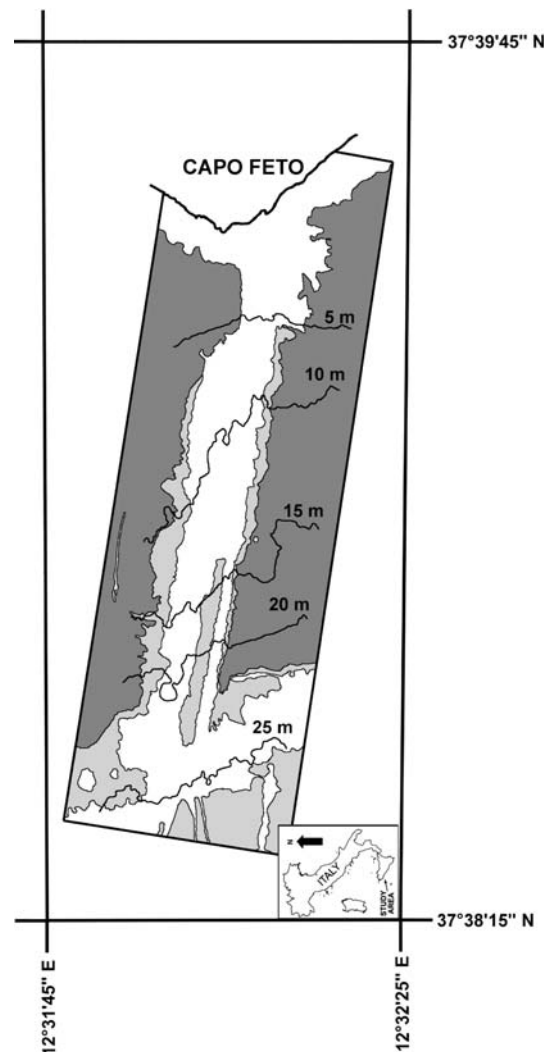


Figure 1. Side scan sonar map of study site. The area in the centre is the trench excavated for the deployment of the pipeline.

was transported to the laboratory for morphological analysis (vertical rhizome length, horizontal and vertical internode length). The age structure of living shoots was estimated (Duarte et al., 1994), allowing calculation of shoot age, shoot recruitment, mortality rate and population half-life (Duarte et al., 1994; Marbà et al., 1996).

The rate of formation of horizontal rhizome internodes was estimated using a simple regression of the number of horizontal internodes, included pairs of shoots connected by a horizontal rhizome piece, against their age difference (Duarte et al., 1994). The regression slope represented the average

number of rhizome internodes which are produced at each leaf plastochronic interval (P.I.). Once the leaf P.I. is converted into days, the inverse of this slope equals the time the plant takes to produce a horizontal internode. The vertical rhizome elongation rate was calculated by regressing the age of the rhizome (in years) against its total length. Shoot age was calculated by counting the number of nodes and the number of leaves present at sampling time. These two values were added and multiplied by rhizome P.I. to obtain rhizome age. The annual gross shoot recruitment rate (R_{gross} , \ln units yr^{-1}) was estimated as

$$R_{\text{gross}} = \ln \sum_{t=0}^{\infty} N_t - \ln \sum_{t=1}^{\infty} N_t$$

where

$$\sum_{t=0}^{\infty} N_t$$

is the number of living shoots and

$$\sum_{t=1}^{\infty} N_t$$

is the number of living shoots with age > 1 yr. Shoot mortality rate (M , \ln units yr^{-1}) was derived from the exponential decline in the abundance of living shoots (N_0) with time (t , in P.I.) as:

$$N_t = N_0 * e^{-Mt}$$

where N_0 is the number of shoots with age equal to the mode, N_t is the number of shoots older than the modal age at time t , and M is the mortality rate (\ln units yr^{-1}).

The net rate of shoot population growth

$$R_{\text{net}} = R_{\text{gross}} - M$$

was used to make predictions about the future development of the meadow. Turnover rate and the ratio between recruitment and mortality rates ($R:M$) were also calculated. This ratio indicates whether a population is expanding ($R:M > 1$), declining ($R:M < 1$) or it is in equilibrium ($R:M = 1$) (Duarte & Sand-Jensen, 1990; Duarte et al., 1994; Marbà et al., 1996).

Data were analysed using a multifactorial multivariate design with both factors (depth and dis-

tance) fixed and orthogonal. The analysis included eight variables (vertical rhizome growth, modal, mean and median age, R_{gross} , R_{net} , shoot mortality and shoot turnover). Analysis was carried out using the FORTRAN Programme NP-MANOVA (Anderson, 2001). Shoot density data were analysed using a three-way analysis of variance. Treatment factors were: depth (two levels), distance (four levels), site (four levels). The first two factors were considered as fixed and orthogonal, while sites were taken as random and nested in the interaction of the fixed factors. Homogeneity of variance was checked for both statistical tests, using Cochran's test. When necessary, data were transformed using $\ln(X+1)$ (Underwood, 1997). When significant differences were found in the ANOVA, they were compared *a posteriori* using a Student–Newman–Keuls (SNK) test (Underwood, 1981, 1997).

Results

Posidonia oceanica shoot density was found to be significantly higher in shallow water (10 ± 3.3 m) than in deep water (20 ± 4.6 m) (Table 1), with mean values of 452.6 ± 53.62 and 254.2 ± 45.45 shoot m^{-2} respectively ($\text{df}_{1,24}$; $F = 1035.94$; $p < 0.001$). A significant increase in shoot density was found at increasing distances from the trench ($\text{df}_{3,24}$; $F = 4.50$; $p = 0.01$; SNK test: $5 < 15 < 30 < 50$ m). In shallow water, at a distance of 5 m from the trench, density was 392.6 ± 67.8 mean shoot m^{-2} , whilst at 15 m this variable had increased to 439.8 ± 48.0 shoot m^{-2} . Further from the trench, values averaged at 483.3 ± 43.9 at 30 m distance and 494.6 ± 54.8 shoot m^{-2} at 50 m distance. At 20 m depth, shoot density showed a similar pattern with increasing values from 5 m distance (213.9 ± 50.8 shoot m^{-2}) to 50 m distance (302.2 ± 45.8 shoot m^{-2}).

Seagrass dynamics data are reported in Table 1. NP-MANOVA analysis showed significant differences between depths and distances (Table 2). Pairwise comparisons (Table 3) indicated a significant difference between depth for all variables, whilst significant differences among distances were only found for mean shoot age, shoot mortality and net recruitment rate (Table 3). Leaf P.I. attained 53.39 days for the whole meadow, a higher value than shoot P.I. which averaged at 46.8 days (Table 1). Vertical rhizome growth rates ranged between 0.67

Table 1. Average (\pm SD in brackets) of population dynamics variables of *Posidonia oceanica* at Capo Feto at different depths (10 and 20 m) and distances (5, 15, 30, 50 m) from the trench

Depth	Distance	Shoot density (shoot m ⁻²)	Median shoot age (yr)	Maximum shoot age (yr)	Shoot recruitment rate (ln units yr ⁻¹)	Shoot mortality rate (ln units yr ⁻¹)	Net recruitment rate (ln units yr ⁻¹)	Shoot turnover (yr)	R_{gross}/M	Vertical rhizome growth (cm yr ⁻¹)	Shoot P.I. (days)
Deep	5	213.9 (50.8)	4.2 (0.8)	17.0 (2.8)	0.07 (0.02)	-0.21 (0.00)	-0.14 (0.05)	14.5 (10.4)	0.32	0.70 (0.14)	42.6
Deep	15	222.2 (35.5)	4.5 (1.6)	20.5 (4.7)	0.07 (0.02)	-0.18 (0.02)	-0.11 (0.03)	10.3 (4.3)	0.39	0.86 (0.18)	42.6
Deep	30	278.6 (49.7)	5.3 (1.0)	26.0 (11.2)	0.06 (0.04)	-0.17 (0.04)	-0.11 (0.06)	21.1 (13.4)	0.35	0.84 (0.12)	54.9
Deep	50	302.2 (45.8)	3.9 (1.4)	14.6 (4.6)	0.11 (0.10)	-0.15 (0.03)	-0.04 (0.00)	11.1 (5.3)	0.71	1.00 (0.35)	48
Shallow	5	392.6 (67.8)	1.9 (0.8)	19.3 (6.0)	0.40 (0.20)	-0.30 (0.03)	+0.10 (0.03)	2.6 (1.7)	1.32	1.00 (0.31)	40.7
Shallow	15	439.8 (48)	3.0 (1.1)	18.5 (4.1)	0.20 (0.10)	-0.21 (0.04)	-0.01 (0.00)	4.1 (1.8)	0.94	1.12 (0.2)	47.2
Shallow	30	483.3 (43.9)	3.1 (1.7)	16.7 (5.4)	0.26 (0.10)	-0.21 (0.03)	+0.05 (0.00)	2.5 (0.7)	1.25	0.96 (0.12)	49.7
Shallow	50	494.6 (54.8)	2.9 (0.7)	18.8 (5.2)	0.15 (0.06)	-0.23 (0.05)	-0.08 (0.00)	5.1 (2.0)	0.64	0.99 (0.21)	44.1

Table 2. NP-MANOVA results for the seven variables included in the statistical test

Source	Df	EMS	Perm. Units	SS	MS	F
Depth	1	RES	32	1241.20	1241.2	20.6 ^{***}
Dist	3	RES	32	498.55	166.18	2.75 ^{**}
Dexdi	3	RES	32	133.16	44.29	0.73 ^{ns}
RES	40			2409.57	60.23	
TOT	47					
Data not transformed				Unrestricted permutation of raw data		
No standardisation				Integer used as seed = 5		
Analysis based on Euclidean Distances				No. of permutations used = 4999		

Differences are shown both for depths (shallow and deep) and distances (5, 15, 30, 50 m).

*** $p < 0.001$; ** $p < 0.01$; ns = not significant.

and 1.57 cm yr^{-1} , with an average value of 0.88 ± 0.22 in the deep meadow, and $1.04 \pm 0.22 \text{ cm yr}^{-1}$ in the shallow meadow. Shoot maximum age averaged between 12 and 41 yr in the deep meadow, whilst values for the shallow meadow ranged between 6 and 28 yr, indicating that the latter presents young patches with higher recruitment.

The age structure of *P. oceanica* varied along the distance gradient and with depth (Figs. 2, 3). In the shallow meadow, the population showed a significantly lower modal age ($0.93 \pm 0.32 \text{ yr}$) than in the deep meadow ($2.44 \pm 1.92 \text{ yr}$) (Table 3). Shoot recruitment (R_{gross}) rate was found to be significantly higher in the shallow meadow (on average, $0.25 \pm 0.19 \text{ ln units yr}^{-1}$), than in deep meadow ($0.07 \pm 0.05 \text{ ln units yr}^{-1}$; Table 1). However, the recruitment rate recorded in shallow water was balanced by a higher mortality rate found at this depth range ($-0.23 \pm 0.04 \text{ ln units yr}^{-1}$). At 10 m depth, at 5 m distance

Table 3. Pair-wise comparisons, made with NP-MANOVA and SNK tests, indicating differences within treatments for each variable

Variables	Depth	Distance
Modal shoot age	Shallow < deep	ns
Mean shoot age	Shallow < deep	5 < 15 = 30 = 50
Median shoot age	Shallow < deep	ns
R_{gross} (ln units yr^{-1})	Shallow > deep	ns
Shoot mortality (ln units yr^{-1})	Shallow > deep	5 > 15 = 30 = 50
Shoot turnover (yr)	Shallow > deep	ns
R_{net}	Shallow < deep	5 > 15 = 30 = 50
Vertical rhizome growth (cm yr^{-1})	Shallow > deep	ns

ns = not significant; < and > $p < 0.05$.

from the trench, M averaged $-0.30 \pm 0.03 \text{ ln units yr}^{-1}$, a significantly higher value than mortality rates reported for the other three distances (15, 30 and 50 m; Table 1). Indeed, moving further from the trench, mortality rates decrease to $-0.21 \pm 0.04 \text{ ln units yr}^{-1}$ (15 m distance), -0.21 ± 0.03 (at 30 m distance) and -0.23 ± 0.05 at 50 m distance. A similar trend was observed at 20 m depth ($5 > 15 = 30 = 50 \text{ m distance from trench}$; Table 3). In this depth range, mean values of M at 5 m distance equal $-0.21 \pm 0.004 \text{ ln units yr}^{-1}$, while average values at further distances were -0.18 ± 0.02 , -0.17 ± 0.04 and $-0.15 \pm 0.03 \text{ ln units yr}^{-1}$ at 15, 30 and 50 m respectively.

A significantly shorter turnover rate was reported for the shallow meadow (average 3.2 ± 1.8), than the deep meadow, mean value of 14.2 ± 9.6 . The net recruitment ratio, derived from the ratio between recruitment and mortality, suggested that in the shallow meadow R_{net} is almost in equilibrium or slightly increasing (mean $0.015 \pm 0.078 \text{ ln units yr}^{-1}$) whilst *P. oceanica* patches found in the deep meadow ($20 \pm 4.6 \text{ m}$), are declining (average $-0.1 \pm 0.04 \text{ ln units yr}^{-1}$) but at a slower rate. These findings were confirmed by the relationship between R_{gross}/M which is < 1 at all distances in deep water; in shallow water, R_{gross}/M is > 1 at a distance of 5 and 30 M, ~ 0 at 10 m distance and < 1 at 50 M distance.

Discussion

The population dynamics variables measured at Capo Feto fall within the range of those obtained for other Mediterranean meadows (Marbà et al., 1996). For example, shoot density varied with

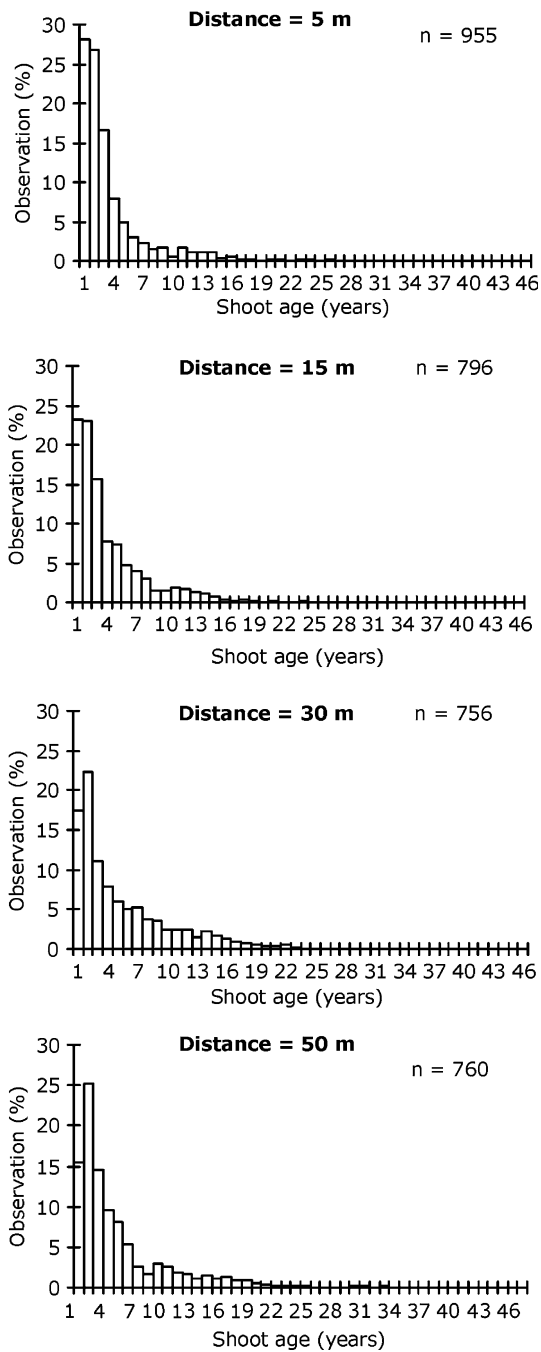


Figure 2. Shoot age structure of living shoots of *Posidonia oceanica* in the shallow (10 ± 3.3 m) meadow at increasing distances (5, 15, 30 and 50 m) from the trench.

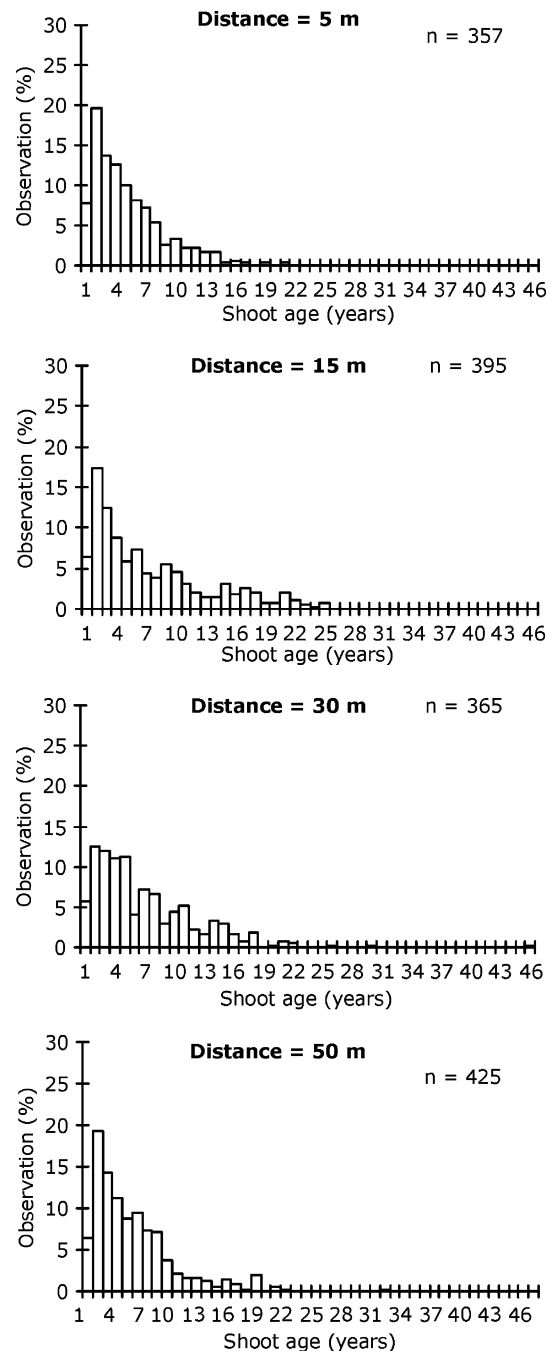


Figure 3. Shoot age structure of living shoots of *Posidonia oceanica* in the deep (20 ± 4.6 m) meadow at increasing distances (5, 15, 30 and 50 m) from the trench.

depth as in many other Mediterranean meadows (Pergent et al., 1995). However, in the area closest to the disturbed seabed associated with the trench,

average shoot density, shoot age and R_{net} values decreased, while mortality rate increased, most likely as a result of the construction work. Coastal

engineering and the maintenance of pipes and cable for water and gas supply often change seagrass habitat or they alter the physical characteristics of water (Hemminga & Duarte, 2000). One of the consequences of construction operations is the increase in water turbidity (Onuf, 1994), due to dredging and filling operations (Guidetti & Fabiano, 2000). Such operations do not only involve the alteration of water properties but often lead to an increase in the sedimentation rate as well as sediment movements (Orrù, pers. comm, 1994). These consequences may cause the burial of seagrass stands, with subsequent shoot death and low shoot density (Marbà & Duarte, 1994; Duarte et al., 1997; Hemminga & Duarte, 2000).

In most seagrass species, both in and outside the Mediterranean basin, rhizome growth has been demonstrated to be sensitive to sediment dynamics (Marbà & Duarte, 1994; Marbà et al., 1996; Duarte et al., 1997) and, in some cases, vertical rhizomes may overcome the burial process by increasing internodal length (Duarte & Sand-Jensen, 1990; Vidondo et al., 1997). Internodal length was demonstrated to be strictly related to the degree of burial and erosion experimentally imposed on a number of Philippine seagrass species and on the Mediterranean seagrass species *Cymodocea nodosa* (Ucria) Ashers (Duarte et al., 1997; Marbà & Duarte, 1994). Similarly, several seagrass including *P. oceanica* in natural environments display fluctuations in the rhizome elongation rate as a consequence of sediment dynamics (Marbà et al., 1996; Marbà & Duarte, 1997). At Capo Feto, vertical rhizome growth was fairly low at all depths and was found not to be affected by dredge-fill activities. This finding is in accordance with previous work by Guidetti (2001) who reported no significant differences in rhizome elongation rates of *P. oceanica* after beach replenishment. Guidetti (2001) highlighted an increased leaf production rate. On the other hand, our data shows a higher mortality and net recruitment rate in the meadow area closest to the trench. In this area, sediment deposition may have been so high that rhizome growth could not compensate for the burial process, leading to a complete disappearance of seagrass in this area. In this case, recovery, if ever possible, will require a long period of time (Talbot et al., 1990; Hemminga & Duarte, 2000).

Population variables differed between the shallow and deep meadow. A general trend was

found in the age structure of the meadow, with a decline of shoot abundance with age, possibly due to shoot mortality. Plants living in deeper water tended to show a higher mortality and a lower recruitment, hence a longer turnover rate. Plants living in deep water generally showed longer recovery times as growth was reduced possibly due to light limitation. On the other hand, the shallow meadow displayed a shorter turnover rate and a lower mortality, and hence shorter recovery times may be hypothesised. At 10 m depth, a higher recruitment rate was also recorded, which may imply shorter recovery times. With regard to mortality, plants closer to the excavation site seem to be the most affected. At 5 m distance in shallow water, *P. oceanica* shoots showed the highest mortality rate, which may also be linked to low shoot density and patch size. Further from the construction site, seagrass shoots experienced a lower mortality suggesting a lower sedimentation rate hence a lower level of disturbance. The combination of increased mortality and low recruitment rates reflects an overall decline of the meadow if present conditions are maintained. Even though the source of disturbance at Capo Feto has been eliminated from the scenario, forecast of future meadow development (R_{net}) indicates that shoot density close to the trench will be reduced by 50% over the coming 6–17 yrs. *P. oceanica* has the slowest elongation rate of all seagrasses (between 1 and 6 cm yr⁻¹), with patch formation rates averaging around 3×10^{-4} ha⁻¹ yr⁻¹ (Meinesz & Lefèvre, 1984). This entails recovery times that generally exceed a century. Capo Feto represents a unique case study as the disturbance events were well defined and have stopped, and are not to be repeated. This cessation of disturbance should allow seagrass recovery, at least in shallow meadow areas, even if over a long decadal time period. Further studies will be necessary to evaluate the resilience of the recovering *P. oceanica* over time.

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