Vegetation structure and water depth dependency of Seagrass meadows (*Posidonia oceanica* (L.) Delile) near Panarea (Aeolian Islands, Mediterranean Sea, Italy)

Vegetationsstruktur und Tiefenabhängigkeit von Seegraswiesen (*Posidonia oceanica* (L.) Delile) bei Panarea (Äolische Inseln, Mittelmeer)

Lorenz Seebauer, Elke Richert

Summary: Panarea, Aeolian Islands, is in a volcanically active area with natural gas and fluid discharges at the seafloor. In 2014 and 2015, the vegetation structure of seagrass meadows (*Posidonia oceanica*) depending on water depth and the potential influences of the gas and fluid discharges was analyzed. By scuba diving, samples and data were taken in different parts of an area with shallow-sea vents and at a reference site at depths from 11 m to 27 m. With help of transect analyses at multiple study sites the shoot density and vegetation height were measured to characterize the seagrass meadows structure. The shoot density of *Posidonia oceanica* in the area followed a well described pattern of depth dependency. The comparison with a reference curve from literature showed average or above average values in most parts of the investigation area, which indicates good habitat conditions for *Posidonia oceanica*. In contrast to the reference site (Basiluzzo), some vegetation plots with below average shoot densities were found at the sites with gas and fluid discharges, but it was not possible to proof the cause of perturbation or link it to the active hydrothermal discharges. The results indicate that no *Posidonia oceanica* growth seems possible directly at an active discharge. Own observations show that directly next to a discharge, seagrass shoots and leaves were lethally damaged. Nevertheless, at the analyzed sites with gas and fluid discharges, the amount of vegetation plots with above average shoot densities was higher than at the reference site Basiluzzo. Other authors found higher shoot densities in an area with natural carbon dioxide discharges in the Tyrrhenian Sea compared to surrounding sites.

Keywords / Schlüsselwörter: Neptune grass, shoot density, meadow height, leaf morphometric parameters, natural discharges; Neptungras, Sprossdichte, Bestandshöhe, blattmorphologische Parameter, natürliche Gasaustritte

1. Introduction

Posidonia oceanica (L.) Delile is the most widespread seagrass species in the Mediterranean Sea (Borum et al. 2004). It is an endemic sea grass that forms meadows at depths from 3 to 45 m (Borum et al. 2004). The Mediterranean Sea has an east-west alignment with many islands, which leads to a relatively long shore line with rather similar conditions. Therefore, *Posidonia oceanica* has a large potential habitat and covers huge areas, although it is limited to the Mediterranean Sea. As primary producer it has a key role in the ecosystem, as it produces biomass and oxygen (Borum et al. 2004, Garcia et al. 2012). It structures the sea floor, forms habitats and offers substrate for epiphytic organisms. Sea grass helps to protect the shoreline by increasing sedimentation and forming dense meadows with woody rhizomes and roots (Moreno et al. 2001). An increase of sedimentation can reduce the turbidity and therefore increase transparency. Unfortunately, during the last century the population of *Posidonia oceanica* is decreasing (Borum et al. 2004). The research area is in a volcanic active area north of Sicily. Panarea belongs to the Aeolian Islands, which include the active volcano Stromboli. The research area is close to the shore of Panarea and on a small archipelago east of it. Gases and fluids are known to discharge at water depths between 8 to 100 m there. Gas discharges mainly consist of carbon dioxide (> 96 %, Steinbrückner 2009) which might have a fertilizing effect on seagrass (Hall-Spencer & Rodolfo-Metalpa 2012). The discharging fluids and gases also contain sulfur compounds which might have a negative impact on the ecosystem (Fent 2013). The Scientific Diving Center (SDC) of the TU Bergakademie Freiberg is working near Panarea since 2006, mainly in the fields of geosciences (e.g. Merkel et al. 2009, Pohl et al. 2009, Sieland 2009). The idea of this work and the master thesis of the author Lorenz Seebauer (Seebauer 2015, unpubl.) was to analyse the vegetation structure of the seagrass meadows in the area, the depth dependency, and the potential influence of the gas and fluid discharges. Whereas the master thesis included the water chemistry, too, this work focuses on the results of the vegetation data taken for the thesis and beyond.

2. Study area

Panarea belongs to the Aeolian Islands in Tyrrhenian Sea north of Sicily. The Aeolian Islands are of volcanic origin and the region is volcanically active. Panarea is a small island with an area of 3.3 km^2 (Gabbianelli et al. 1990).

The study site (La) **Calcara** is located at the north-eastern shore of Panarea (Fig. 1). Basiluzzo is a small islet northeast of Panarea. On its eastern side is the study site, which is named after the islet. This site has actually no visible gas and fluid discharges and was therefore used as a reference area. At Calcara and Basiluzzo seagrass meadows at depths from 12 to 26 m were studied. At Calcara only few and small discharges can be found, therefore some meadows had discharges in several meters distance and others not.

East of Panarea, there is a submarine plateau up to 30 m water depth. It is surrounded by several islets and rocks that reach above sea surface representing the remnants of a former crater rim (Fig. 2). Most of the study sites are in this area. The study sites are in depths of 11.0 to 26.5 m. **Point 21** is a rather rocky site with very strong gas and fluid discharges in a 21 m deep depression. The main discharges are at a steep wall of this depression adjacent to a 17 m deep plateau, where sea grass was studied. The sea grass meadow starts at a distance of 10 m from the main discharges. Small discharges are scattered in the area around the depression. **Area 26** is a sandy flat site with a depth of 25 to 26 m. The discharges here are much smaller than at Point 21. The focus was on a sea grass meadow with a diameter of 12 m and one medium and several small discharges 0.5-1 m adjacent of it. Bottaro is an islet at the south-eastern part of the archipelago. **Bottaro West** is a dive site to the west of the islet whose sea floor is mainly covered by gravel. The distance from the meadow to the discharges was more than 10 m.

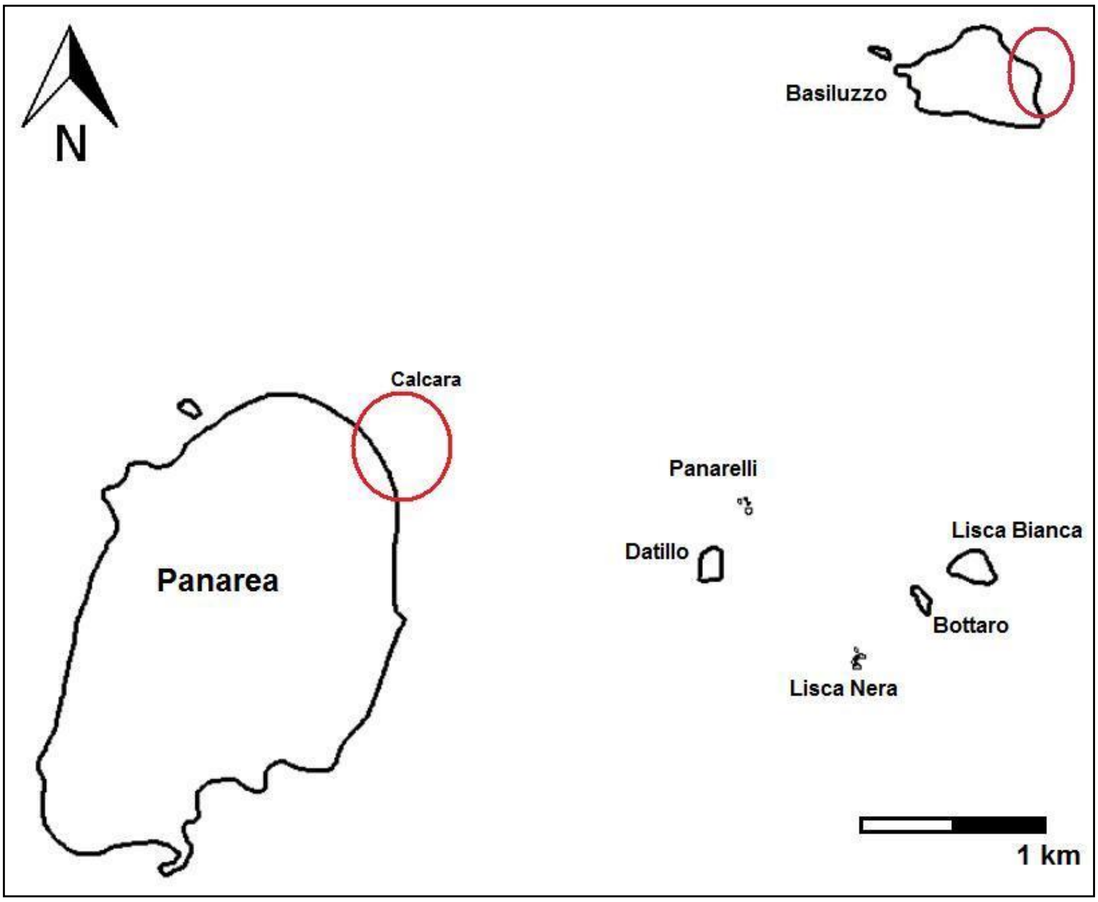

Fig. 1: Panarea Island with the study sites Calcara and Basiluzzo (red) and the islets and rocks east of Panarea.

Abb. 1: Die Insel Panarea mit den Untersuchungsgebieten Calcara und Basiluzzo (rot) und den kleineren Inseln und Felsen östlich von Panarea.

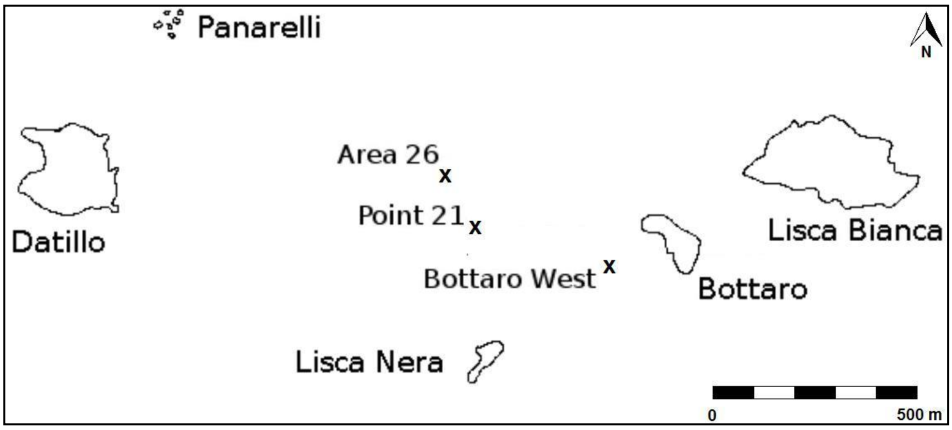

Fig. 2: Shallow area east of Panarea with the study sites Area 26, Point 21 and Bottaro West.

Abb. 2: Flachwasserzone östlich von Panarea mit den Teiluntersuchungsgebieten Area 26, Point 21 und Bottaro West.

3. Methods

The data were taken in two fieldtrips of the Scientific Diving Center (SDC) of the Technical University (TU) Bergakademie Freiberg, Germany, in 2014 and 2015 by Lorenz Seebauer and assisting divers. The vegetation data of the year 2014 were taken and used as a part of a master thesis (Seebauer 2015, unpubl.). The vegetation species were determined according to Hofrichter (2003).

The vegetation was analysed at both population and individual level. A squared frame with an inner area of 50 cm x 50 cm was used to define each vegetation plot in which seagrass samples were taken, shoots were counted and meadow height was measured. Multiple of such vegetation plots were placed along a transect line starting at the edge of the meadow towards the inner part, until the values were constant.

Shoot density is supposed to provide important information regarding vitality and dynamics of sea grass meadows (Martini et al. 2005). In order to determine the shoot density, the number of shoots was counted in a squared frame of 25 cm x 25 cm, which was placed in each vegetation plot. In 2014 the shoot density was recorded in classes (Table 1) inside the small frame mentioned above, whereas in 2015 the exact numbers were counted. The meadow height was estimated according to the method suggested by Duarte & Kirkman (2001). Hereby, a large number of *Posidonia oceanica* leafs are gathered up by hand without uprooting them and the maximum height from the bottom to the leaf tips of 80 % of the leafs was considered to be the meadow height.

Morphometric data were taken to observe the condition of single seagrass shoots. Especially the leaf area is assumed to be a good indicator for assessing the status of seagrass meadows (Calvo et al. 2010). Therefore, seagrass shoots were sampled along transects at different distances from the gas discharges and at different distances from the edge of the meadow. Furthermore, the analysed sites allowed an analysis of the dependence of the vegetation structure on water depth. The number of leafs per shoot, the length and the width of the leafs were measured. Since *Posidonia oceanica* has ribbon-shaped leafs, the approximate leaf area per shoot can be calculated by multiplying width and length of each leaf. The width was measured at the base of each leaf. The length of the longest leaf per shoot was used as the maximum leaf length per shoot and the average leaf width was calculated for each shoot. At some sites not all parameters could be measured and only seagrass shoots were sampled or only meadow height and shoot density were measured.

Table 1: Scale for estimating the shoot density in classes on the 25 cm x 25 cm plots with code replacement (oriented to Pergent et al. 1995)

Tabelle 1: Schätzskala für die Erhebung der Sprossdichte in Klassen auf den 25 cm x 25 cm großen Transektteilflächen mit code replacement (in Anlehnung an Pergent et al. 1995).

class	Shoot density	code replacement
1	< 3	2.0
2	3-10	7.0
3	11-20	15.0
4	21-30	25.0
5	31-45	37.5
6	> 45	50.0

The Kruskal-Wallis test was used to compare different sites. To check whether vegetation parameters were linked to e.g. the water depth, the Spearman rank correlation was used. The arrangement of vegetation plots along transects would cause problems due to spatial autocorrelation. Therefore, vegetation plots of each site were chosen, that are representative for the seagrass meadow, to create a new sub-dataset for the statistical tests. As the edges of seagrass meadows might be very different compared to the rest of the meadow, which is often homogenous, only vegetation plots from the inside of the meadows were considered representative. For all tests p-values < 0.10 were assumed to show significant results. For all analyses GraphPad Prism 7.03 (GraphPad Software) and Microsoft Excel 2010 with the Add-in WinSTAT (R. Fitch Software) were used.

4. Results

4.1 The vegetation structure of *Posidonia oceanica*

The dataset contains 116 vegetation plots from Point 21, Area 26, Calcara, Bottaro West and Basiluzzo, in which shoot densities and meadow height were measured (Table 2). We worked at depths from 11 to 26.5 m with a focus on around 20 m depth, because the most intensively studied sites Point 21 and Area 26 were located in this water depth. At sites apart from Bottaro West, 176 seagrass shoots were sampled and measured. The mean values and standard deviations are given in Table 2 and 3, the box plots in Figure 3 allow a general overview, and the range of values can be found in Table A1.

At **Point 21**, 27 vegetation plots were evaluated and 34 *Posidonia oceanica* shoots were sampled at depths from 16.5 to 17.5 m (Table 2). For shoot density, meadow height, average leaf width per shoot and leaf area per shoot, the widest ranges of values were found at this site. Furthermore, with 800 shoots per m^2 the highest shoot density was measured here (Table A1). **Area 26** was the deepest site. Similar to Point 21 the depth range at Area 26 was narrow with 28 vegetation plots being placed and 41 shoots being measured at depths from 23 to 26.5 m. At this site, the large range and the high maximum values of shoot density and leaf area per shoot are remarkable. Furthermore, leaf area per shoot was the highest at Area 26. With 47 vegetation plots and 60 measured shoots at depths from 13 to 24 m the dataset for **Calcara** is the largest. Therefore, the values for several parameters have large ranges (Table A1). The highest leaf length with 108 cm was measured at this site. At **Bottaro West** only 6 vegetation plots were evaluated and no shoots were measured. With 11 m depth it was the most shallow site (Table 2). At the reference site **Basiluzzo,** 8 vegetation plots were placed and 42 shoots were measured at depths from 14.3 to 22.3 m (Table A1).

4.2. Variability of the vegetation structure along the transects

Considering all transects no consistent pattern of the vegetation structure parameters could be found from the edge towards the inner part of the meadows (Fig. 4). Also meadow height and shoot density differ between and within the sites. Three types could be distinguished:

A: Shoot densities and meadow heights remain more or less constant directly from the beginning (Fig. 4a, b).
B: Shoot density, height or both were much lower at the edge of the meadows (Fig. 4c-e).
C: In some transects the shoot density at the edge of the meadow was higher than in the inner part (Fig. 4f, g).

At Calcara, 13 transects were evaluated (Table 2): 3 transects had lower, 3 higher and 7 similar shoot densities at the edge of the meadow compared to the following vegetation plots. The meadow heights at the edge of the meadow were in 8 transects smaller than and in 5 transects more or less equal to the following vegetation plots.

Table 2: Overview table of the different sites and the mean values for shoot densities of *Posidonia oceanica* and meadow heights (mean ± standard deviation). n = 116

Tabelle 2: Übersichtstabelle der Teiluntersuchungsgebiete und der Mittelwerte der Sprossdichten von *Posidonia oceanica* und Bestandshöhen der Seegras-Wiesen (± Standardabweichung). n = 116.

	Discharges	Number of transects / plots	Depth range [m]	Mean depth [m]	Shoot density [1/m^2]	Meadow height [cm]
Point 21	many	1 / 27	16.5-17.5	16.9 ± 0.3	436.6 ± 207.1	54.0 ± 21.2
Area 26	many	8 / 28	23-26.5	24.9 ± 0.7	281.4 ± 133.8	55.7 ± 18.3
Calcara	few	13 / 47	13-24	19.1 ± 3.2	361.4 ± 102.1	74.2 ± 13.9
Bottaro West	few	2 / 6	11	11 ± 0.0	485.3 ± 110.7	57.0 ± 6.4
Basiluzzo	no	4 / 8	18-22	20.0 ± 2.1	348.0 ± 53.9	69.6 ± 12.8
Total		26 / 116	11-26.5	19.6 ± 4.2	365.0 ± 150.7	63.9 ± 18.8

Table 3: Overview table of the different sites and the mean values for leaf number, max. leaf length, average width and leaf area per shoot of *Posidonia oceanica* (± standard deviation)

Tabelle 3: Übersichtstabelle der Teiluntersuchungsgebiete und der Mittelwerte von der Blattzahl, maximaler Blattlänge, Blattbreite und Blattfläche pro Spross von *Posidonia oceanica* (± Standardabweichung)

	Depth (range) [m]	**Measured shoots**	**Leaf number per shoot**	**Max. leaf length [cm]**	**Average width per shoot [mm]**	**Leaf area per shoot [cm^2]**
Point 21	17-17.4	34	5.0 ± 1.5	62.0 ± 15.0	8.6 ± 0.9	183.1 ± 62.8
Area 26	22.5-25.5	41	5.9 ± 1.5	59.6 ± 14.7	9.0 ± 0.8	192.9 ± 87.0
Calcara	14.5-24	60	5.2 ± 1.6	71.5 ± 16.6	9.4 ± 0.7	213.5 ± 65.2
Basiluzzo	14.3-22.3	42	4.8 ± 1.3	58.4 ± 14.6	9.0 ± 0.5	158.1 ± 53.7
Total	14.3-25.5	177	5.2 ± 1.4	63.8 ± 16.3	9.1 ± 0.8	189.9 ± 70.8

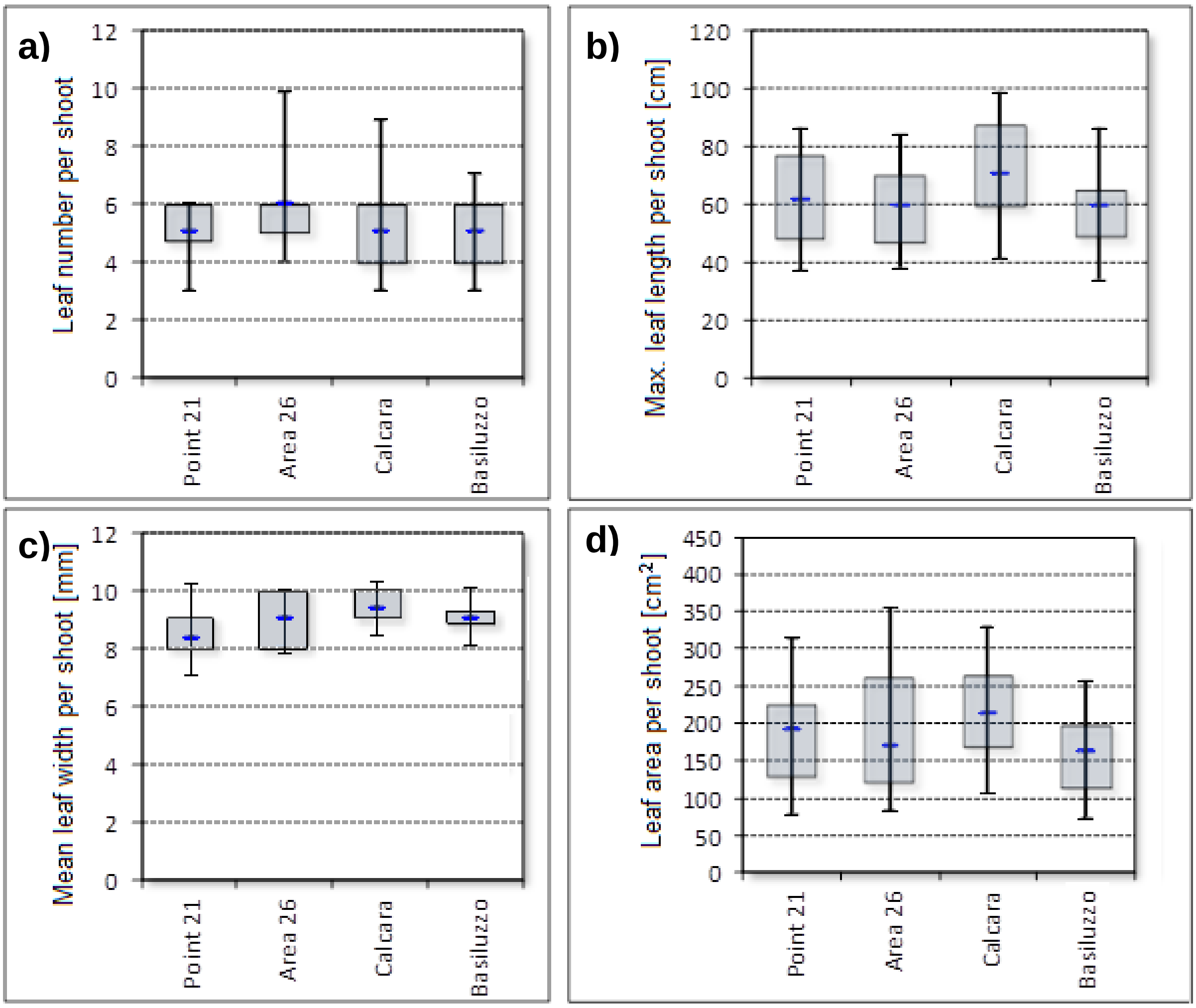

Fig. 3: Comparison of the sites Area 26, Point 21 (many gas discharges), Calcara (few gas discharges) and Basiluzzo (no discharges) regarding a) leaf number, b) maximum leaf length, c) average width, and d) leaf area per shoot from *Posidonia oceanica* (box plots without outliers).

Abb. 3: Vergleich der Untersuchungsgebiete Area 26, Point 21 (viele Gasaustritte), Calcara (wenige Gasaustritte) and Basiluzzo (keine Gasaustritte) hinsichtlich a) der Blattzahl, b) maximaler Blattlänge, c) mittlerer Blattbreite und d) Blattfläche pro Spross von *Posidonia oceanica* (Boxplots ohne Ausreißer).

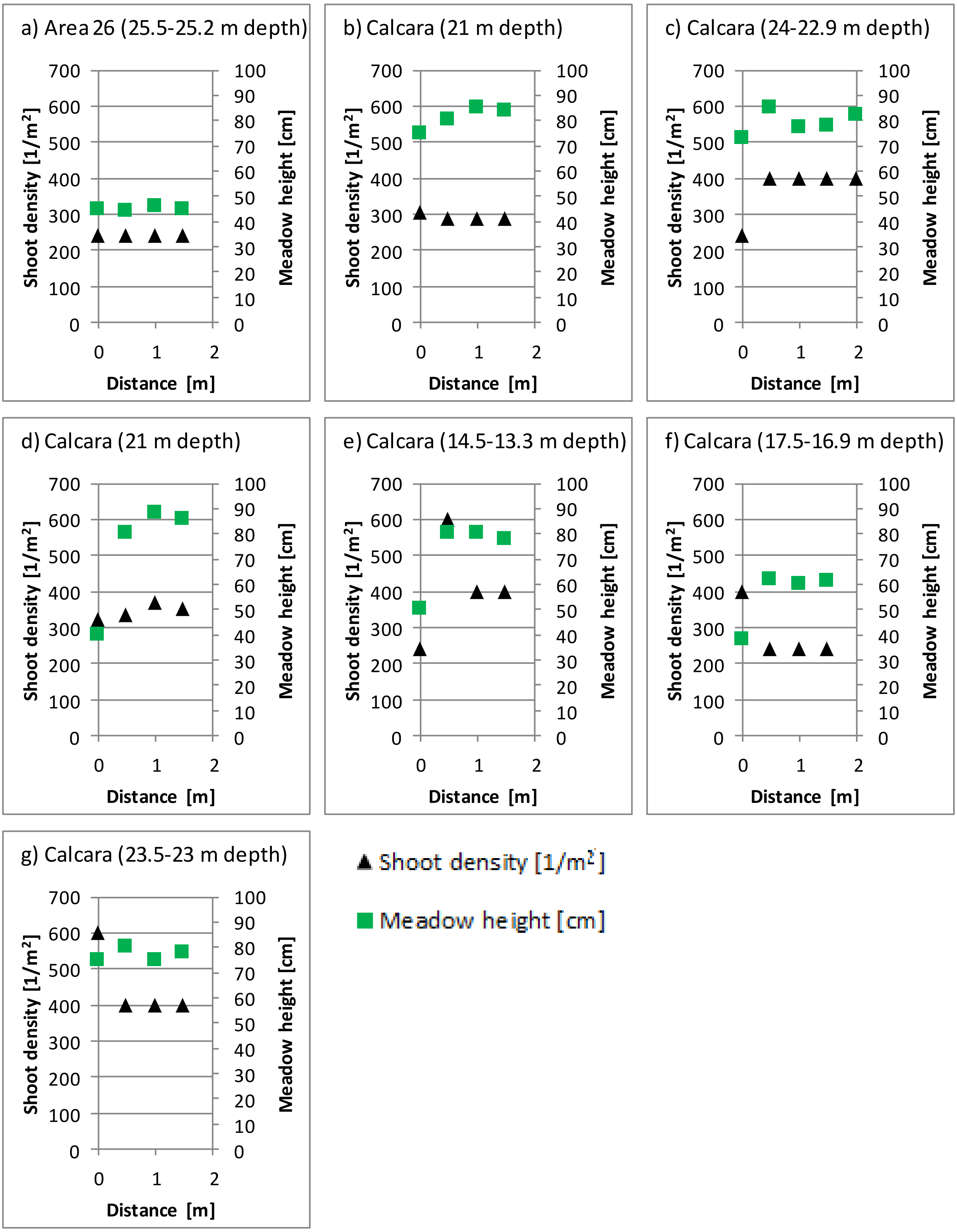

Fig. 4a-g: Shoot density (triangle) and meadow height (square) along several selected transects at Area 26 and Calcara from the edge of the *Posidonia oceanica* meadow towards the inner part (13.3-24.0 m water depth).

Abb. 4a-g: Sprossdichte (Dreieck) und Bestandshöhe (Quadrat) entlang ausgewählter Transekte bei Area 26 und Calcara vom äußeren Rand der *Posidonia oceanica*-Wiesen in Richtung Bestandesinnere (13,3-24,0 m Wassertiefe).

4.3 Dependence of the vegetation structure of *Posidonia oceanica* on water depth

The shoot density was negative correlated with water depth (dataset representative plots; $r_s = -0.41$, $p = 0.01$, $n = 33$; Fig. 5). No significant correlation was found for water depth and meadow height. Reference values provided by Pergent et al. (1995) were used to assess if the shoot densities at a certain depth were below, within or above the medium range of shoot densities described by Pergent et al. (1995). To improve the figure the given values by Pergent et al. (1995) from 1 to 40 m depth in 1 m steps were joined to two uniform lines, which show the upper and lower limit of the medium range of shoot densities (Fig. 6).

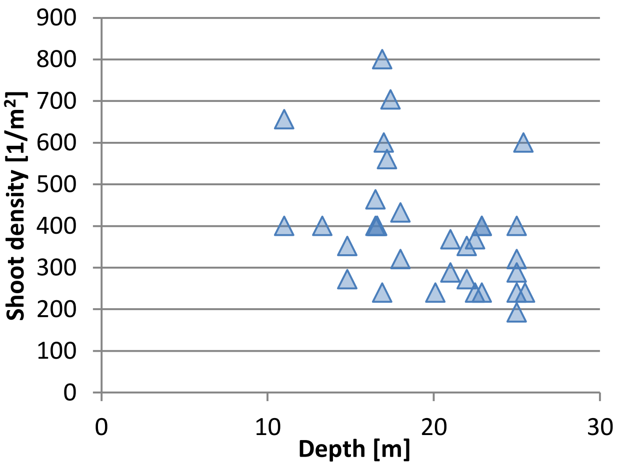

Fig. 5: Relationship between shoot density and water depth (reduced dataset with representative plots; Spearman, $r_{sp} = -0.41$, $p = 0.01$, $n = 33$).

Abb. 5: Zusammenhang zwischen der Sprossdichte und der Gewässertiefe (Datensatz mit repräsentativen Transektteilflächen; Spearman, $r_{sp} = -0,41$, $p = 0,01$, $n = 33$).

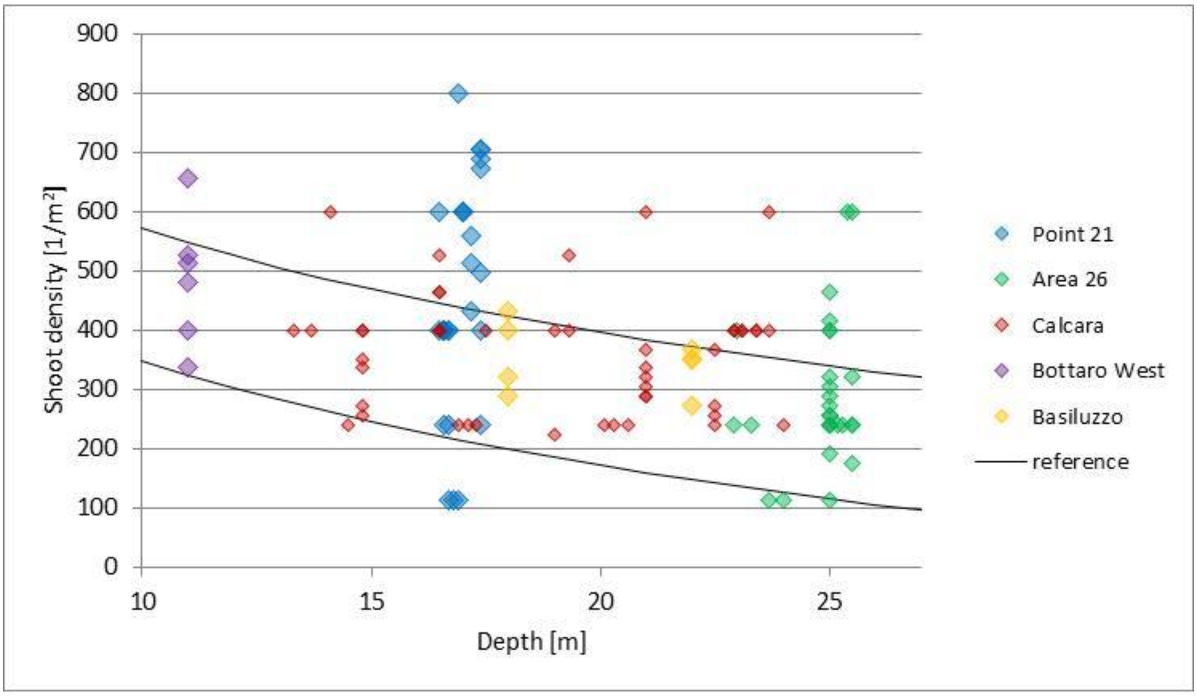

Fig. 6: Shoot densities [1/m²] at Point 21, Area 26, Calcara, Bottaro West and Basiluzzo with a graph showing the medium range of shoot densities at different depths approximated from values in steps of 1 m by Pergent et al. (1995).

Abb. 6: Sprossdichte [1/m²] bei Point 21, Area 26, Calcara, Bottaro West und Basiluzzo bei unterschiedlichen Wassertiefen. Die zwei Linien grenzen die von Pergent et al. (1995) beschriebenen mittleren Sprossdichten bei unterschiedlichen Tiefen (abgeleitet von Werten in 1 m Tiefenschritten).

Most shoot densities were within or above the medium range of shoot densities approximated from values by Pergent et al. (1995, Fig. 6). 64 % of the shoot densities were within, 30 % above and 6 % below the mentioned range of average values. The shoot densities at Basiluzzo and Bottaro West were mainly in the reference range and a couple were above, whereas at Point 21, Area 26 and Calcara more shoot densities than at the other sites were above and a few below the reference range. At Point 21, the 3 vegetation plots with shoot densities below the reference range were at a distance of around 16 m from the beginning of the transect near the crater-like structures mentioned above (Fig. 6). At Area 26, all vegetation plots except 4 were placed at the sea grass meadow where most data were taken. Those four vegetation plots were placed along a short transect far away from discharges and two of them had a shoot density below the reference range. The third vegetation plot with shoot densities below the reference range was directly next to a discharge.

Leaf number, maximum leaf length and leaf area per shoot were not correlated with water depth (reduced data set with representative plots; $p > 0.10$, $n = 24$). The average width (Fig. 7a) increased with increasing depth (Spearman, $r_{sp} = 0.12$, $p = 0.06$, $n = 24$). Some reference values for average width from the south-east coast of Spain (Moreno et al. 2010) were similar and others were higher (Fig. 7b). The reference values at around 20 m depth are higher.

To compare the data with reference values, the whole dataset was split in classes of 2 m depths and the mean values of the leaf number, leaf width, leaf area and depth for each class were calculated. The reference values of leaf number per shoot (Fig. 8) and leaf area (Fig. 9) were similar.

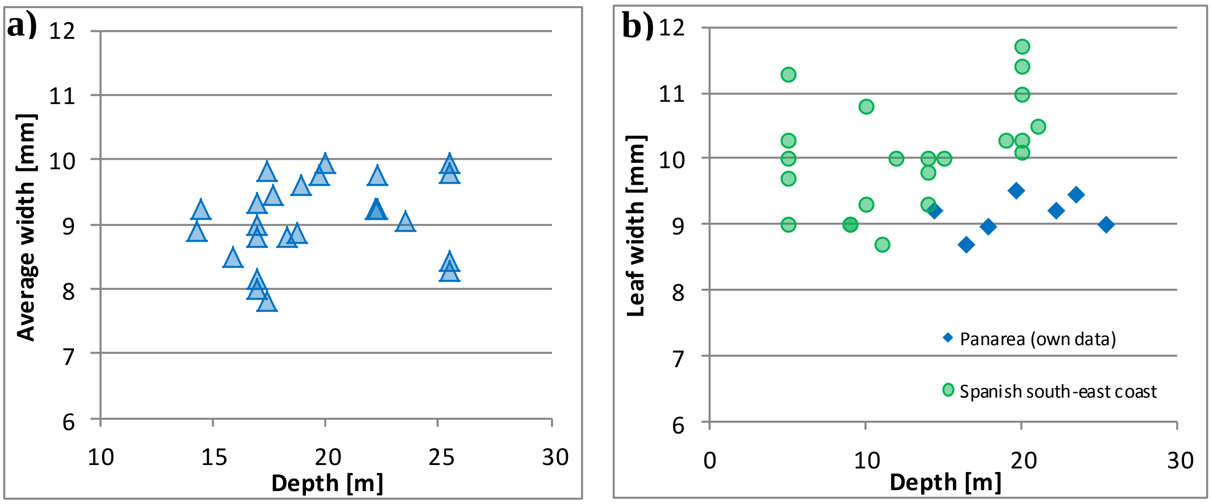

Fig. 7: a) Average leaf width (in mm; mean values of selected sampling sites) in dependence of the water depth (Spearman, $r_{sp} = 0.12$, $p = 0.06$, $n = 24$) and b) Mean values of leaf width at different depths (in classes of 2 m depth) at Panarea and mean values from the south-eastern shore of the Iberian Peninsula (Spain; Moreno et al. 2010).

Abb. 7: a) Mittlere Blattbreite (in mm; Mittelwerte von ausgewählten Probenahmestandorten) bei unterschiedlichen Wassertiefe (Spearman, $r_{sp} = 0{,}12$, $p = 0{,}06$, $n = 24$) und b) Mittelwerte der Blattbreiten in unterschiedlichen Tiefen (in Klassen von 2 m Tiefe) bei Panarea mit Mittelwerten von der Südostküste der Iberischen Halbinsel (Spanien; Moreno et al. 2010).

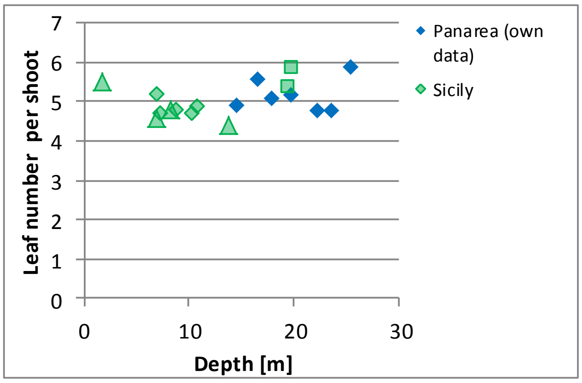

Fig. 8: Mean values of leaf number per shoot at different depths (classes of 2 m depth) at Panarea (own data) and mean values from Sicily (Calvo et al. 2010), the Mediterranean Sea (Calvo et al. 2010), and Mallorca (Castejon-Silvo & Terrados 2012).

Abb. 8: Mittelwerte der Blattzahlen pro Spross in unterschiedlichen Tiefen (in Klassen von 2 m Tiefe) bei Panarea (eigene Daten) und Mittelwerte von Sizilien (Calvo et al. 2010), dem Mittelmeer (Calvo et al. 2010) und Mallorca (Castejon-Silvo & Terrados 2012).

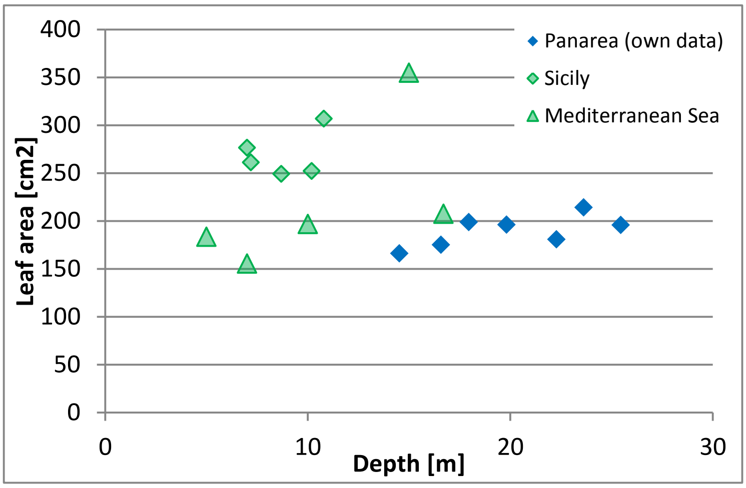

Fig. 9: Mean values of leaf area per shoot at different depths (in classes of 2 m depth) at Panarea (own data) and mean values from Sicily and the Mediterranean Sea (Calvo et al. 2010).

Abb. 9: Mittelwerte der Blattflächen pro Spross in unterschiedlichen Tiefen (in Klassen von 2 m Tiefe) bei Panarea (eigene Daten) und Mittelwerte von Sizilien und dem Mittelmeer (Calvo et al. 2010).

4.4 Relations between vegetation structure of *Posidonia oceanica* and occurrence of discharges

In order to analyse the impact of discharges on the structure of seagrass, transects were placed at seagrass meadows close to discharges to assess the vegetation at different distances from the discharges. At Point 21 we studied a transect line of a length of 26 m which started next to the main discharges and led into a seagrass meadow. The first part of the transect (9.5 m) had a rocky substrate with a small amount of fine sediment and without seagrass. From 9.5 to 14.5 m there was a seagrass meadow with a sharp edge at the beginning (Fig. 10). At the edge of the meadow several lethally damaged seagrass shoots were found directly at a small discharge in 2014 (Fig. 11). In comparison to other seagrass meadows (Fig. 4) the meadow height and shoot density of the first plots (9.5–17 m) was average, except on the second vegetation plot with *Posidonia oceanica*, which had a higher shoot density than all the surrounding plots. From 15 to 23 m the vegetation was not homogenous. Vegetation-free crater-like holes were observed with patches of seagrass in different conditions around them. Three vegetation plots were placed at such a hole at a distance of around 16 m from the transect beginning. Shoot density und meadow height was low. At a distance of 24 m from the large discharges the seagrass meadow became dense and high. The area was basically one contiguous and homogenous meadow. The meadow height and shoot density were comparable to the seagrass meadows shown in Fig 4. No further vegetation plots were placed beyond a distance of 25.5 m from the beginning of the transect because the vegetation structure showed no visible change.

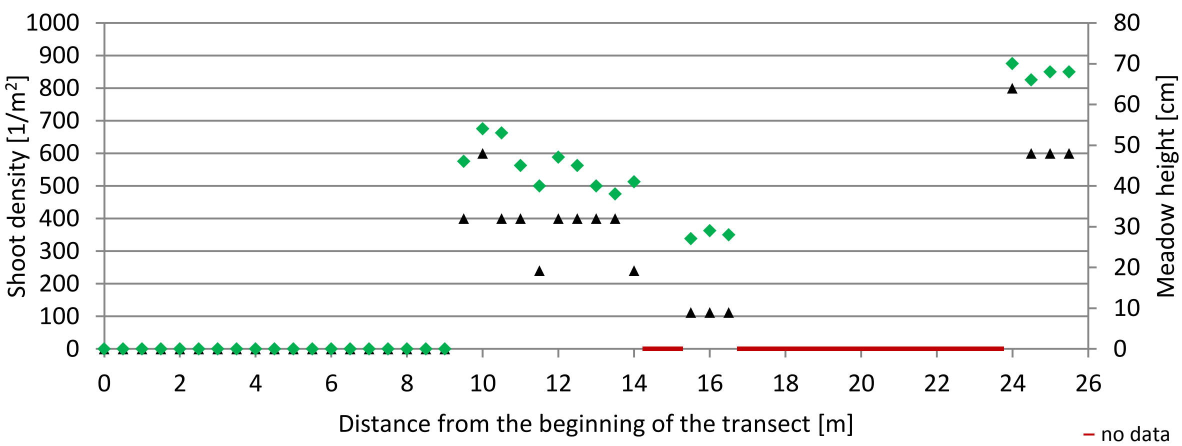

Fig. 10: Shoot density (triangle) and meadow height (square) of *Posidonia oceanica* along the transect line at Point 21 (16.5-17.5 m water depth). The transect started next to large discharges. The red marked parts of the transect (14.5-15 m and 17-23.5 m) were not analysed.

Abb. 10: Sprossdichte (Dreieck) und Bestandshöhe (Quadrat) von *Posidonia oceanica* im Verlauf des Transektes bei Point 21 (16,5-17,5 m Wassertiefe). Das Transekt startete an großen Gasaustritten. Die rot markierten Abschnitte (14,5-15 m und 17-23,5 m) wurden nicht analysiert.

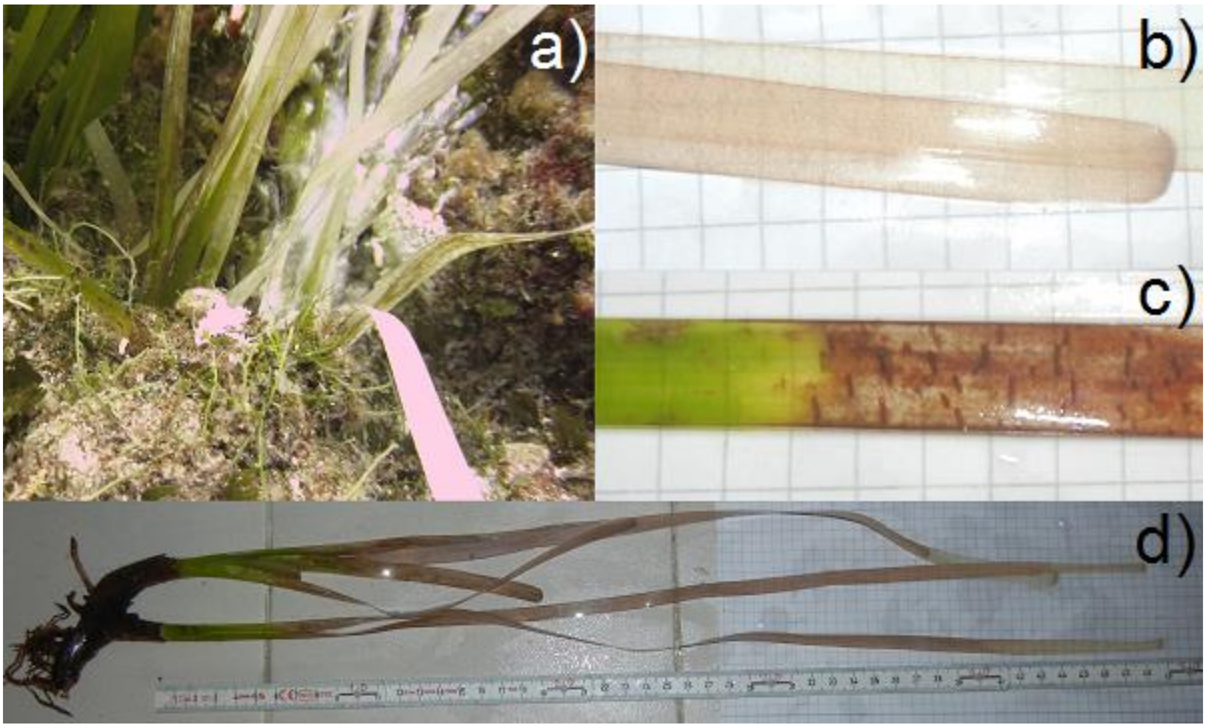

Fig. 11: (a) Lethally damaged seagrass shoots at Point 21 directly next to a little discharge, (d) sampled *Posidonia oceanica*-shoots with (b) the discolored tip and (c) base section (Photos: L. Seebauer)

Abb. 11: (a) Abgestorbene Seegrassprosse unmittelbar an einem kleinen Austritt bei Point 21, (d) entnommene *Posidonia oceanica*-Sprossen mit (b) entfärbten Spitzen und (c) Unterteil (Fotos: L. Seebauer).

To reduce a potential effect of water depth, the reduced dataset with representative plots was split into two depth ranges from 14 m to 20 m and 20 m and below. For both depth classes no significant differences of the mean values of leaf number, maximum leaf length, average width, leaf area per shoot were found, when comparing the sites with no, few and many gas discharges (Kruskal-Wallis test; $p > 0.10$, $n = 15$ (shallow sites) and $n = 9$ (deep sites)). No such differences were found for shoot density, too (Kruskal-Wallis test; $p > 0.10$, $n = 16$ (shallow sites) and $n = 17$ (deep sites)). On the deep plots of the representative dataset (20 m and below) the meadow heights differed between the sites with no, few and many discharges (Kruskal-Wallis test; $p < 0.01$, $n = 17$). The plots at the sites with few discharges had a significant higher meadow height than the plots with many discharges (Dunn's multiple comparison test; $p < 0.01$, $n = 15$).

5. Discussion

The aim of this work was to analyze the vegetation structure of seagrass meadows and leaf morphology of *Posidonia oceanica* in the investigation area depending on water depth and potential effects of hydrothermal gas discharges. Therefore, sites with discharges of different size and at different distances from the discharges were investigated. Furthermore, we compared our data to reference values and known relationships e.g. between water depth, shoot density, and morphometric parameters.

Leaf width, leaf number and leaf area per shoot (Fig. 7, 8 and 9) were similar to reference values from the literature (Moreno et al. 2001, Calvo et al. 2010 and Castejon-Silvo & Terrados 2012); shoot densities were mainly inside the reference range given by Pergent et al. (1995; Fig. 6). At the reference site Basiluzzo, no shoot densities below the reference range were found, which suggests that there is no significant negative influence in the area. This hypothesis is supported by Calvo et al. (2010) who describe the commonly good condition of the *Posidonia oceanica* meadows on the nearby Sicilian coast, except close to the main urban and industrial centers. Probable reasons were the low anthropogenic pressure and the pristine conditions compared to other parts of the Mediterranean Sea (Calvo et al. 2010).

The transect analyses showed that different types of edges of seagrass meadows were observed in the investigation area (Fig. 4). In other studies, edges of seagrass meadows are described as progressive, sharp, erosive or regressive (e.g. Pergent et al. 1995). At Calcara, at 10 out of 13 transects the shoot density was equal or higher on the first vegetation plot, at the edge of the meadow, compared to the following plots (Fig. 4). Therefore, it can be assumed that these edges are sharp (example in Fig. A2a). Straight from the data a differentiation into the other classes is not possible, but based on own field observations and photo documentation it can be stated that none of the studied edges were erosive. At the reference site Basiluzzo, the evaluated edges were either sharp or seemed progressive (Fig. A1).

Dalla Via et al. (1998) analyzed two *Posidonia oceanica* meadows at 3 m and 10 m depth. At the deeper stand they found a lower average and maximum leaf length, but a larger average leaf width, leaf number per shoot and leaf area. Only the depth dependency for the leaf width was found in the evaluated dataset of representative shoots for Panarea. Moreno et al. (2001) describe mean leaf widths of *Posidonia oceanica* at similar depths from the Spanish south-east coast, which were a bit higher than the values of this work (Fig. 7). The authors calculated a "conservation index", which is a ratio of living and dead *Posidonia* meadows, to measure the alteration of meadows. Moreno et al. (2001) described a positive correlation of their conservation index with leaf width and leaf length. The slightly lower average leaf width at Panarea (Fig. 7) might be a result of the high water transparency in this region, which – together with depth – influences the irradiation.

The widest range of shoot densities and leaf area per shoot were observed at Point 21 and Area 26 (Table A1 and A2). Especially in the case of shoot density this is interesting, as the depth ranges at these sites are very limited (Table A1 and A2) and a negative correlation of shoot density and water depth was found in the whole dataset (chapter 4.3) and is well described in the literature (e.g., Pergent et al. 1995). The range of meadow height, average leaf width and maximum leaf length per shoot were widest at Point 21. The wide ranges of values at the sites with more and larger discharges (Point 21 and Area 26) suggest that the differences there are more important than the water depth.

As shown above, no significant differences or general trends in leaf morphology were found when comparing the sites with large discharges (Point 21 and Area 26) with sites with less and smaller discharges (Calcara and Bottaro West) and with the reference site Basiluzzo (Seebauer 2015, unpubl.).

All vegetation plots at the end of the transect at Point 21 had a very high shoot density and meadow height (Fig. 10), which led to the assumption that the habitat conditions for *Posidonia oceanica* are better there than closer to the discharges. At Point 21, the rocky seafloor close to the discharges at the beginning of the transect was problematic. As seagrass prefers soft substrate (Borum et al. 2004) it is impossible to conclude whether the absence of seagrass at the transect beginning is linked to the discharges or rather to the substrate.

The lower values of shoot density and meadow height in the middle of the transect at Point 21 (Fig. 10) can be assumed to be linked to the crater-like structures, which might be the result of eruption-like discharging events as described for 2002 by Capaccioni et al. (2005), Esposito et al. (2006) and Vizzini et al. (2010). After this event, many 1 m wide craters were found in the area (Esposito et al. 2006). Vizzini et al. (2010) suggest that the temperature at nearby seagrass might have been higher than its tolerance limit. Capaccioni et al. (2005) described the discharging of colloidal sulfur and fine substrate from the sea floor, which might have caused seagrass die-offs. A decrease in rhizome growth was observed in this time, too (Vizzini et al. 2010). Since *Posidonia oceanica* spreads mainly vegetative and has a slow horizontal growth rate (Duarte 1991), it seems plausible that some of the died-off seagrass might have been a result of strong discharging events in the past. In 2015, the vegetation along the transect at Point 21 near the crater-like structures seemed more dense compared to 2014 which suggests that the vegetation recovers at this location.

We assumed that potential effects of the discharges would be higher at Area 26 and Point 21 than at Calcara (and Bottaro West), because of the differing size and number of discharges (Tab. 2). However, the results showed only few significant differences between locations, but no general trends (chapter 4.4). It is possible that potential differences are masked by other effects. As the dataset was split into two depth ranges of around 6 m each, it seems unlikely that differing water depth was responsible for the results.

The shoot density of *Posidonia oceanica* is known to be a good indicator for the condition of seagrass meadows (Moreno et al. 2001, Romero et al. 2007, Fernández-Torquemada et al. 2008). Seagrass meadows with shoot densities close to or above to the reference range provided by Pergent et al. 1995 are considered to be in a healthy condition. This is the case at most of the studied sites which are not directly adjacent to discharges, and for the reference site Basiluzzo. The higher abundance of shoot densities that are above the reference range provided by Pergent et al. (1995) at Point 21, Area 26 and Calcara compared to Basiluzzo are a hint on good habitat conditions for *P. oceanica*. This suggests that there might be a positive effect of the discharges on *P. oceanica* as described by Hall-Spencer & Rodolfo-Metalpa (2012) for another area in the Mediterranean Sea: In a study area in the Tyrrhenian Sea the authors observed higher shoot densities at sites which were influenced by natural CO_2 discharges. Finally, one can conclude that most *Posidonia oceanica* meadows in the investigation area are generally in a good condition. Especially the high number of shoot densities that are above average in the areas with large discharges are positive and might even support the hypothesis of an positive effect due to the CO_2 enrichment by the hydrothermal discharges.

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6. Zusammenfassung

Im Rahmen von Tauchexkursionen des Scientific Diving Centers (SDC) der TU Bergakademie Freiberg in den Jahren 2014 und 2015 wurden verschiedene Parameter zur Wuchsstruktur von Seegras (*Posidonia oceanica*) aus verschiedenen Bereichen des Untersuchungsgebietes bei Panarea, Äolische Inseln, Italien, analysiert. Insbesondere wurden Bestandshöhe und Sprossdichte erhoben, um die Seegraswiesen zu charakterisieren und zu vergleichen. Für die Sprossdichte konnte die in der Literatur vielfach beschriebene Tiefenabhängigkeit nachgewiesen werden. Im Vergleich zu Referenzkurven der Literatur zeigte sich in weiten Teilen des Untersuchungsgebietes eine durchschnittliche oder überdurchschnittliche Sprossdichte, die auf einen guten Zustand der Seegraswiesen schließen lässt. Einige Aufnahmeflächen mit unterdurchschnittlichen Sprossdichten in den Untersuchungsgebieten mit Gas- und Fluidaustritten deuten auf Störungen, die räumlich allerdings nicht mit aktiven Austritten in Verbindung gebracht werden konnten. Anhand der Ergebnisse ist zu vermuten, dass ein Teil dieser „gestörten“ Seegrasflächen auf eruptive Entgasungsereignisse zurückzuführen ist, die es in der Vergangenheit in Teilen des Untersuchungsgebietes gab. Lediglich unmittelbar an den Gas- und Fluidaustritten scheint keine dauerhafte Besiedlung durch *Posidonia oceanica* möglich. In den Teiluntersuchungsgebieten mit Gasaustritten war der Anteil der Aufnahmeflächen mit überdurchschnittlichen Sprossdichten höher als im Referenzgebiet Basiluzzo ohne solche Austritte. Dies stimmt mit anderen Untersuchungen überein, die von einer Förderung des Seegrases durch die höhere CO_2-Konzentration im Wasser und damit von einer „Düngerwirkung“ des in den austretenden Gasen enthaltenen Kohlendioxids ausgehen.

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Appendix

Table A1: Range of values for shoot density and meadow height at the different sites.

Tabelle A1: Wertebereiche der Sprossdichte und Bestandshöhe an den unterschiedlichen Standorten.

	Depth [m]	Vegetation plots	Shoot density [1/m^2]	Meadow height [cm]
Point 21	16.5-17.5	27	112-800	27-92
Area 26	23-26.5	28	112-600	27-80
Calcara	13-24	47	224-600	38-100
Bottaro West	11	6	336-656	50-65
Basiluzzo	18-22	8	272-400	45-80
Total	11-26.5	116	112-800	27-100

Table A2: Range of values for the leaf morphometric parameters at the different sites (no data available for Bottaro West).

Tabelle A2: Wertebereiche der blattmorphometrischen Parameter an den unterschiedlichen Standorten (für Bottaro West liegen keine Werte vor).

	Depth [m]	Measured shoots	Leaf number per shoot	max. leaf length [cm]	average width per shoot [mm]	Leaf area per shoot [cm^2]
Point 21	17-17.4	34	3-6	36-90	7-10.67	65.8-323.5
Area 26	22.5-25.5	41	4-10	38-84	7.75-10.75	70.4-393.3
Calcara	14.5-24	60	3-11	35-108	7.5-10.67	86.8-334
Basiluzzo	14.3-22.3	42	3-7	21-88	8-10	45.6-270.7
Total	14.3-25.5	177	3-11	21-108	7-10.75	45.6-393.3

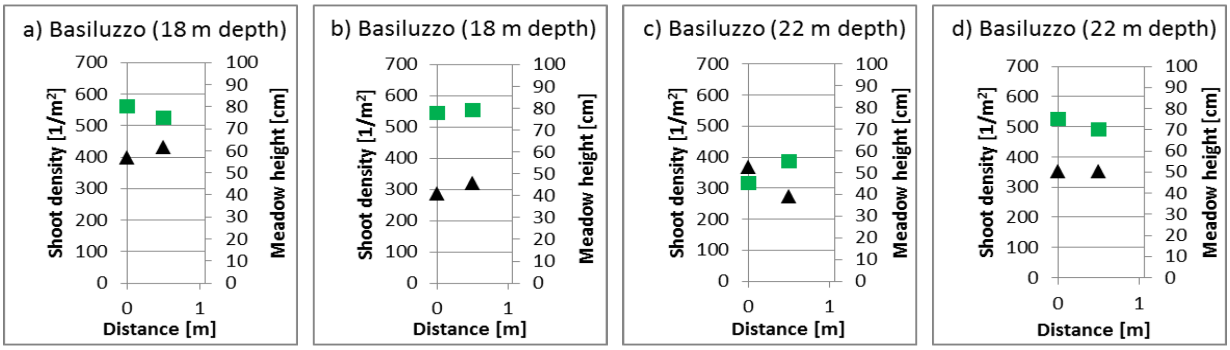

Fig. A1: Shoot density (triangle) and meadow height (square) along several selected transects at Basiluzzo from the edge of the *Posidonia oceanica* meadow towards the inner part (18 m and 22 m water depth).

Abb. A1: Sprossdichte (Dreieck) und Bestandshöhe (Quadrat) entlang ausgewählter Transekte bei Basiluzzo vom äußeren Rand der *Posidonia oceanica* Wiesen in Richtung Bestandesinnere (18 m bzw. 22 m Wassertiefe).

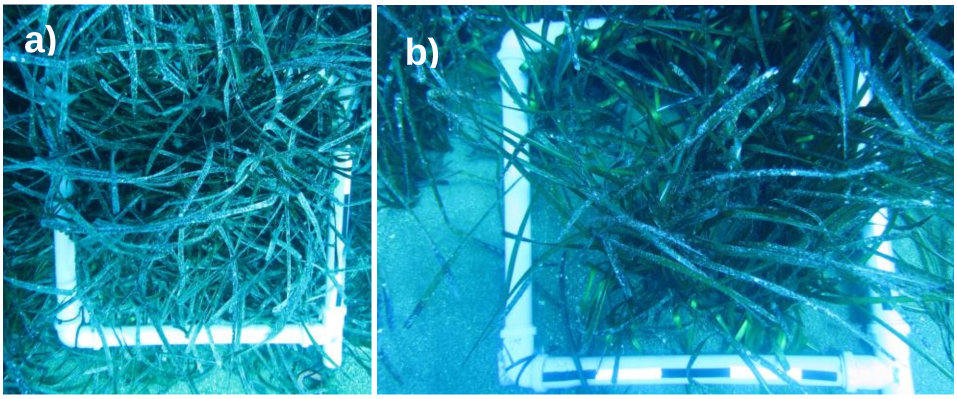

Fig. A2: a) Straight edge of a *Posidonia oceanica* meadow with high shoot density and b) progressive edge with a lower shoot density than at the inner part of the meadow.

Abb. A2: a) Gerader Rand an einer *Posidonia oceanica* Wiese mit hoher Sprossdichte und b) in die offene Substratfläche fortschreitender Bestand mit geringerer Sprossdichte im Vergleich zum Inneren des Bestandes.