Rostock. Meeresbiolog. Beitr.	Heft 30	103 – 115	Rostock 2020

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Comparison of different methods for determination of seagrass distribution in the Southern Baltic Sea Coast

Abstract

Seagrass meadows provide fundamental ecological services including carbon export, nutrient cycling, stabilization of sediment and enhancement of biodiversity. Yet, seagrass meadows are disappearing at an alarming rate by suffering from high anthropogenic influences on coastal ecosystems. Facing the threats of the global change it is important to understand and quantify the ecological services provided by seagrass meadows for facilitating an effective monitoring and conservation efforts.

The current study uses three common survey methods: high-definition satellite imagery, sidescan sonar and scientific diving to analyse the depth distribution of *Zostera marin*a and other macrophytes in the outer coastal and lagoon waters of the southern Baltic Sea. Key parameters such as biomass, coverage, vegetation height border were determined for assessing the distribution.

The results of the current study show, that in outer coastal waters, classic parameters used for macrophyte assessment are highly influenced by physical factors such as current velocity and exposure. Given the advantages and disadvantages of the used methods, the results study show, that direct such as scientific diving and indirect methods complement each other, but on their own they are not sufficient for macrophyte assessment.

Keywords: *Zostera marina* distribution, Baltic sea, scientific diving, mapping techniques

1 Introduction

Seagrasses are a polyphyletic group of marine flowering plants. With the exception of Antarctica, this plant is common on all continents showing a distribution that ranges from the tropics and subtropics to temperate regions Short et al. 2007. In the temperate northern hemisphere plants of the species, *Zostera* spp. eelgrass, is mainly dominating the meadows of seagrasses despite their variability in composition, vegetation height and coverage. Seagrass meadows play a fundamental, ecological role in coastal areas Duarte 2002; Jackson et al. 2013 as they are habitat and breeding ground for numerous invertebrates and fish species, nutrient traps, acting against eutrophication, sediment stabilizers, replenishing against coastal erosion as well as important primary producers, storing a significant amount of CO_2. Finally, there are important food sources for migratory birds (Larkum et al. 2006).

Through the 2000/60/EG directive of October 2000, known as the EU-Water Framework Directive WFD, the European Union committed member states to achieving the good ecological status for all aquatic ecosystems, including coastal waters, by 2015. However, by 2013, nearly the entire Baltic Sea was reported to be affected by eutrophication Baltic Sea Action Plan - BSAP 2013; LUNG- MV 2013; LLUR-SH 2014, with recovery to a good environmental status projected to take as long as 20–30 years LUNG 2013.

Several studies have investigated changes concerning macrophytes during eutrophication and subsequent remesotrophication phases in the Baltic Sea in the inner coastal waters and in particular the Darß-Zingster Boddenkette (Schiewer 1998; Blindow & Meyer 2015). However, studies linking macrophyte composition with changing environmental parameters in outer coastal lagoons are rare.

The following study aims to generate a comprehensive representation of the distribution of seagrass meadows using three methods: satellite images, sidescan sonar and scientific diving. Further analyses were performed in relation to the macrophyte community composition and biomass changes with depth between inner and outer coasts.

2 Material and Methods

2.1 Survey Area

The island of Hiddensee is located in the southeast of the German Baltic Sea and northwest of the island of Rügen as well as northeast of the Darss-Zingst Bodden Chain (Fig. 1 A), in between 54° 27’ 39” – 54° 34’ 20” N and 13° 03’ 39” – 13° 09’ 28” E (Google Earth pro7.1). Since 1990, the entire area of Hiddensee and the Bodden are part of the national park “Vorpommersche Boddenlandschaft”. The water bodies around the island are the semi-enclosed Vitter-Schaproder Bodden and the open Baltic Sea. Two narrow passages, in the southwest Gellenstrom and the northeast Libben of the island connecting the Baltic Sea with the Bodden (Fig. 1 B).

The Vitter-Schaproder Bodden covers a total area of 56.1 km^2 with a maximum depth of 6.5 m, although, except for the dredged waterways, most of the area lies in a depth range of 1 – 2 m. Given limited water exchange between the Bodden and the outer Baltic Sea, the seafloor is characterised by extended, fine sediment areas with low currents, thus creating ideal conditions for the development of dense seagrass meadows.

In contrast, the outer coast is influenced by the Arkona Sea. In the survey area of the Libben bight, the depth profile reaches 9 m. A higher current exposition and the subsequent sediment transport make the occurrence of seagrass meadows patchier compared to the Bodden waters. Survey areas were located in selected areas of the sublitoral zone of the Vitter-Schaproder Bodden and the Libben bight. Six areas were selected (Tab. 1, Fig. 3), as representative of different seagrass growing conditions in the Bodden and the outer coast. Variability between the different areas covers the spectrum of abiotic conditions exposure and depth gradient found in the surveyed region (Dahlke pers. comm. May 2016).

Tab. 1: Diving transects of the survey area around the island of Hiddensee.

Location	Water body	Coordinates[1]	Water Depth range (m)	Salinity category (Venice 1959)
	Vitter Bodden	N54° 34'44,67" E13° 7'33,56"	1.8 – 3.2 *	b - mesohaline (Bachor 2005)
Fährinsel	Vitter Bodden	N54°33'25,15" E13° 7'57,05"	1.6 – 3.0 *	b - mesohaline (Bachor 2005)
Schaprode	Schaproder Bodden	N54°30'53,06" E13° 8'22,70"	1.9 – 5.9 *	b - mesohaline (Bachor 2005)
Libben2 (North East)	Outer coast	N54°36'13,97" E13°11'39,08"	2.4 – 9.0	b - mesohaline (Hübel 1998)
Libben (South West)	Outer coast	N54°36'23,56" E13°11'50,10"	2.3 – 5.0	b - mesohaline (Hübel 1998)
Enddorn	Outer coast	N54° 36'23,83" E13° 8'46,37"	2.4 – 4.8	b - mesohaline (Hübel 1998)

[1] coordinates for the middle point of the diving transect, for a full list of coordinates
* Depth values were corrected for the water level fluctuation.

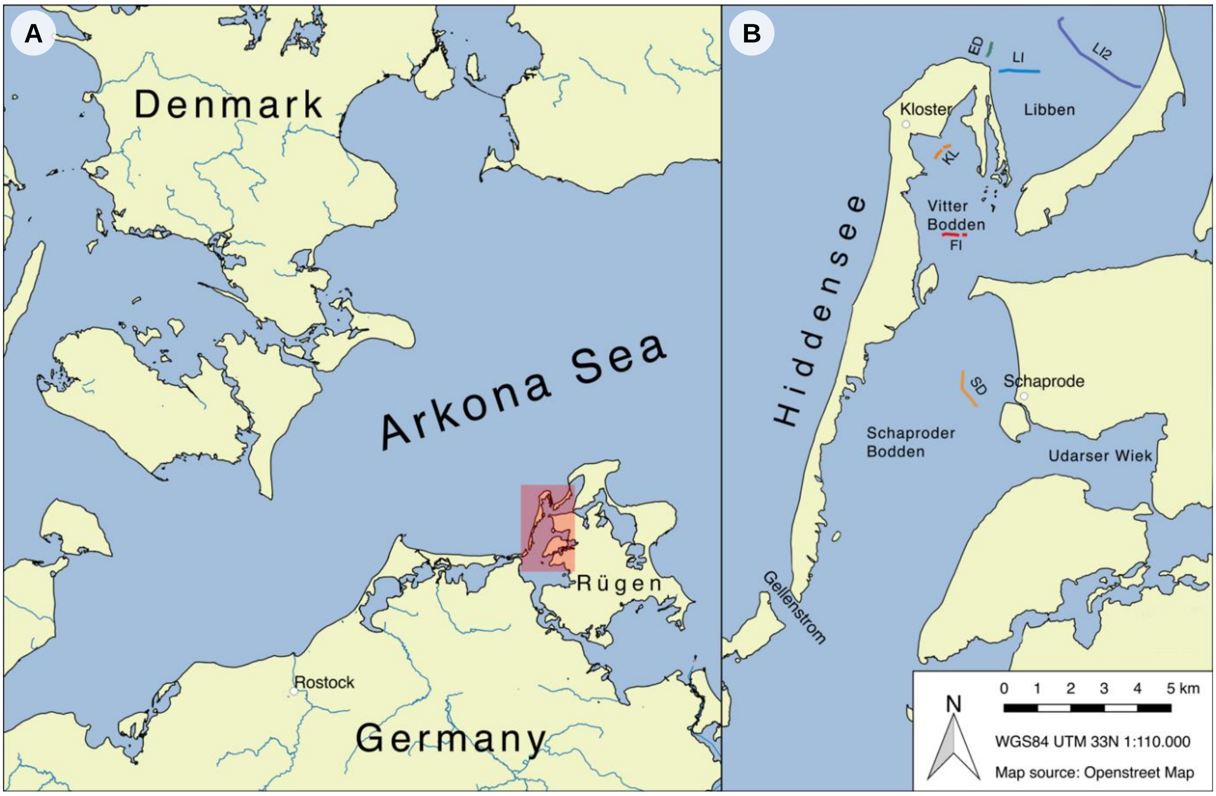

Fig. 1: Map of the survey area. A) southern Baltic Sea, B) Hiddensee island, with surveyed transects. Transect abbreviations: ED = Enddorn, LI = Libben, LI2 = KL = Klosterloch, FI = Fährinsel, SD Schaprode.

2.2 Satellite images

The use of optical images from very high-resolution satellites VHR with a maximum resolution between 0.5 – 5 m allow the recognition of seagrass meadows over a large spatial scale with very limited personnel and time. In the best scenario such as low turbidity, low sun glint and good image quality, this method can be used for a good statement considering the overall macrophyte coverage on the seafloor. Satellite images enable to gain an initial idea of the spatial distribution of macrophytes by receiving an impression of areas with a low resolution. In the highly eutrophic Baltic Sea, the main drawback of optical satellite imaging is the high turbidity of the water. This limits the maximum depth in which recognition of macrophytes is possible, which is particularly the case for internal Bodden waters. Here, the low light penetration in the water column reduces the maximum depth through which recognition of coverage is possible. Moreover, given the high heterogeneity of the macrophyte stocks no conclusions on the species compositions can be drawn only from optical images. The area of interest around the island of Hiddensee was reviewed (Fig. 2) for the occurrence of seagrass meadows using recent August 2015 high-definition satellite images.

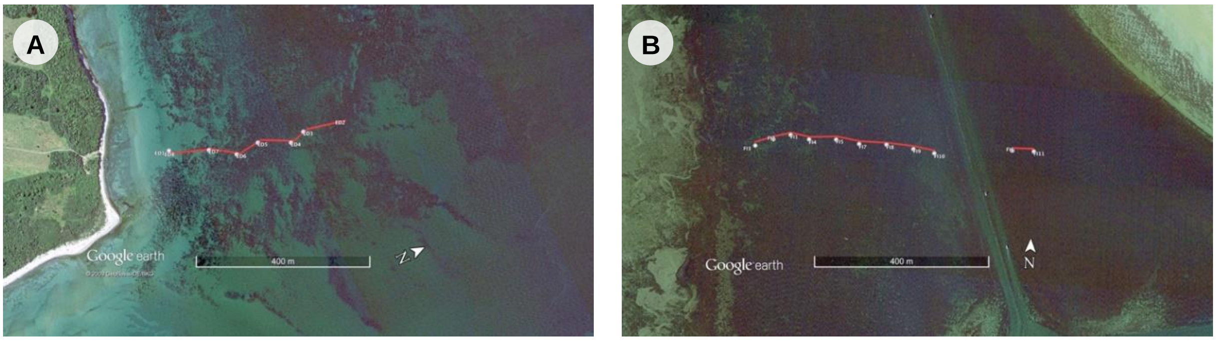

Fig. 2: Satellite images: A) outer coast ‘Enddorn’, B) Bodden waters, ‘Fährinsel’. (Google Earth pro 7.1, image date: 09/08/2015). Seagrass meadows appear as dark areas on a sandy seafloor. Red lines show dive transects.

2.3 Sidescan Sonar

The sidescan sonar is an acoustic method, which recognizes structures, such as sand ripples, rocks, vegetation, etc. on the seafloor Fig. 3. Macrophytes can be seen clearly in the lowermost area of the scan white arrows, whereas the middle is without vegetation. For this mapping project, the sidescan sonar StarFish 990F of the manufacture Tritech was used. Depending on factors such as water depth, scan speed and the selected scan width, a maximum resolution between 1 – 5 cm and a maximum lateral scan range of 70 m can be achieved. The high resolution data gained provides a good overview of the features of the sea floor at a reasonable cost. Thus the technique is a useful tool for fieldwork. For mapping work, the sidescan sonar was fixed under the hull of a metal motorboat and selected areas (Tab. 1) of the Bodden and outer coast were covered, driving parallel transects at a slow speed max. 2 Kn. The structure of the seafloor was visualized in real time during fieldwork using StarFish software. This allowed the boat driver to get a direct impression of the presence/ absence of vegetation in an area. The gained data were related with georeferenced data through StarFish GPS positioning (accuracy ± 9.1 m) and recorded. Sidescan data were used to draw plan diving operations with Google Earth pro 7.1.

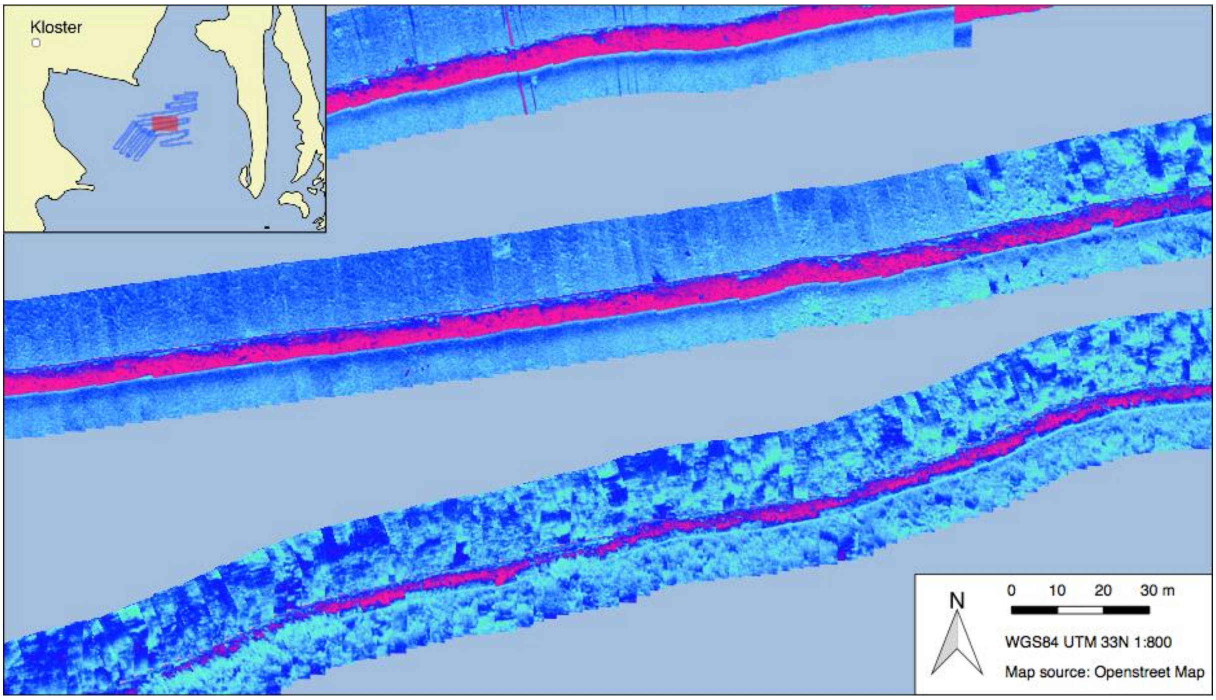

Fig. 3: Detail of the surveyed transect 'Klosterloch'. An Overview of the Position B Areas with and without vegetation.

2.4 Scientific diving

To compare the results of the sidescan sonar, a team of three scientific divers were employed in the areas previously surveyed with sonar. All dive operations were conducted according to German scientific dive regulations GUV-R 2112.

Water depth measurements were taken using the echo sounder of the motorboat. Values of the Bodden area were corrected for water level fluctuations and related to mean water level (Wasser- und Schifffahrtsverwaltung des Bundes, Germany, www.pegelonline.wsv.de). Transects were established from shallow 1.6 m to deeper areas making sure to cover the depth gradient of the region until the lower macrophyte border was reached. Dive stations were established at a regular distance of 50 – 60 m along transects to gain quantitative information about vegetation distribution. Positions were marked using a handheld GPS Garmin etrex legend Hcx (accuracy ± 2 m). To gather quantitative data about macrophytes coverage, vegetation height, species composition and biomass, a 0.1 m^2 steel frame (33 × 33 cm, Fig. 4), similar to those used in EU-WFD surveys, was chosen for comparisons between surveys in other areas.

Coverage was estimated by using a scala from 0 – 100 % in steps of 5 %. To account for the canopy effect of tall macrophytes *Zostera marina* and *Stuckenia pectinata*, coverage was distinguished between upper and lower layers. Thus, in some cases, the total coverage can exceed 100 %. Mean vegetation height was measured for each taxon in cm. Before sampling, calibration dives were conducted at the same station with different divers from the team to assure agreement in terms of the judgment of coverage, vegetation height and species. At each station, the frame was used to determine vegetation coverage %, vegetation height and species composition. Additionally, vegetation samples, including rhizomes of macrophytes, were taken and transported in plastic bags for further laboratory analysis. For interpretation of the data, a picture of each steel frame and its vegetation was taken

Fig. 4: A 0.1 m^2 (33 × 33 cm) steel frame for evaluation of % coverage, vegetation height and taxonomic composition

In the laboratory, the collected samples were taxonomically sorted according to Pankow 1976 for macroalgae and Weyer & Schmidt 2007 determination keys. If necessary species that were determined with the use of a microscope Olympus SZX12.

For dry weight biomass determination, samples were placed in labelled, aluminium foil cups and put in a dry oven at 105 °C for 24 h. Biomass was determined using standard laboratory scales Kern PCB max 3500 g ±0.01 g, Sartorius BP310 S max 310 g ±0.01 g and RADWAG AS220.R2 max 220 g ±0.001 g. Species with a biomass below the measurement uncertainty were qualitatively recorded. In further statistical analysis, these species were given a biomass value of 0.001 g, corresponding to the measurement uncertainty of the scale.

2.5 Statistical analysis and cartography

The recorded macrophyte parameters % coverage, species biomass and vegetation height were analysed for similarity between the different survey regions using Cluster analysis, non-metric Multidimensional Scaling MDS with the program ‘PRIMER-e v6’ (Clarke & Gorley 2006). Survey stations without vegetation were not considered in the statistical analysis. All raw data were transformed using the ‘squareroot option’ prior to analysis. Similarity matrices for Cluster analysis and MDS were built using the Bray-Curtis index. The Cluster analysis was tested for the occurrence of significant clustering using the SIMPROF test. Differences were set significant at $p < 0.05$.

To simplify interpretation of the change in macrophyte communities along the depth gradient, the multivariate data set was transformed in a univariate data set. Therefore, data concerning biomass and coverage for single species were considered in three classes: macrophytes as a whole, spermatophytes and macroalgae. Given the low information density on vegetation height, only a median height between all macrophytes was considered. Moreover, to get a representation of macrophyte community diversity, the biomass data set was transformed in a presence/absence matrix. A Shannon diversity index H’ was then calculated. To visualize how different vegetation groups, change along the depth gradient, the recorded depth values were grouped in classes and plotted in a series of whisker box-plots.

A Mann-Whitney U-Test was performed to see if the recorded parameters significantly differed between Bodden and the outer coast. For the analyses the program ‘IBM SPSS Statistics v22’ was used. Differences were considered significant at $p < 0.01$. Cartographic illustrations were made using the program ‘QGIS v2.14.0 - Essen’.

3 Results

3.1 Macrophyte biomass

The MDS plot of the macrophyte species biomass (Fig. 5), show three significant groupings with fair discrimination between the inner and outer coast. The stress value of 0.16 in the 2D-MDS is average, signalling some distortion in the graphical representation compared to the raw multivariate data. Similarity within single groups is low and varies between 37 % in the cluster dominated by the Bodden stations, 36 % and 57 % in the other two clusters dominated by outer coastal stations. This suggests a high variance between the different sampling stations. Also noticeable is the presence of two outliers ‘LI5’ and ‘KL7’, this can be explained due to low biomass at these stations.

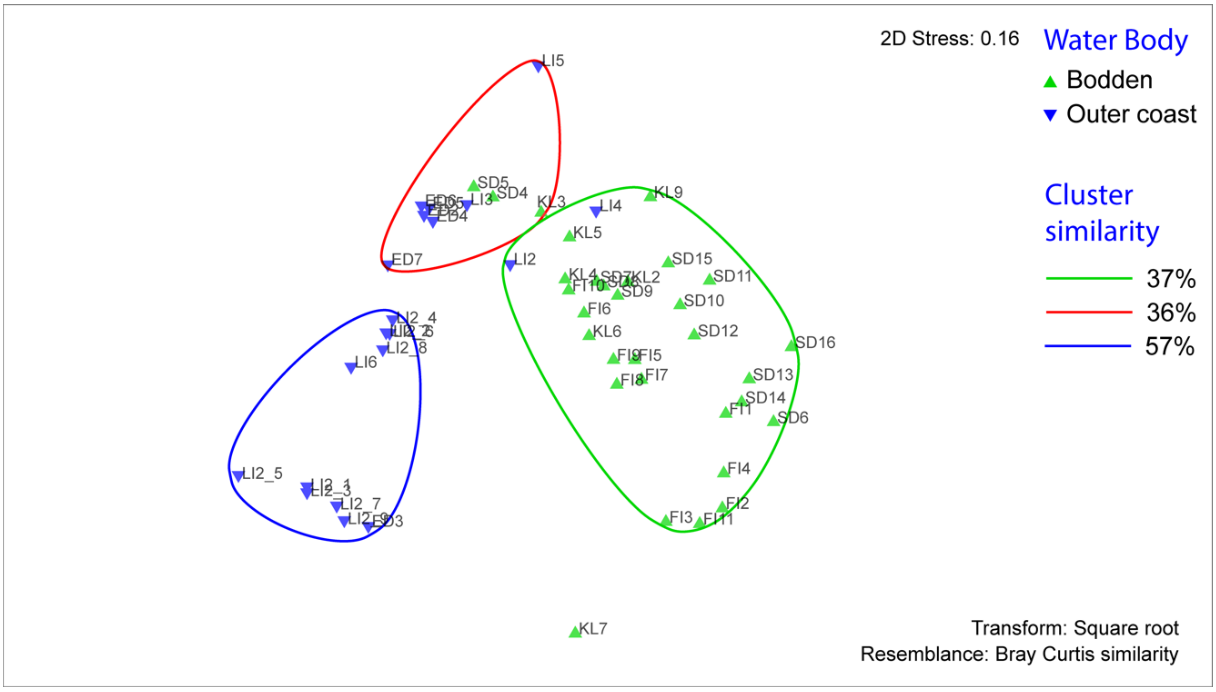

Fig. 5: Multi-dimensional scaling (MDS) analysis of macrophyte species biomass. Circles show overlaid clusters of cluster analysis at $p < 0.05$. Transect abbreviations: ED = Enddorn, LI = Libben, LI2 = Libben2, KL = Klosterloch, FI = Fährinsel, SD = Schaprode.

3.2 Macrophyte percentage species cover

The MDS plot of the percentage of macrophyte species cover (Fig. 6), show three significant groupings. While the distinction between the inner and outer coast appears evident in two of the clusters, the third is less clear, with an equal number of Bodden n = 9 and outer coastal n = 9 stations. The stress value of 0.12 in the 2D-MDS is average, signalling some distortion of the graphical representation, compared to the raw multivariate data. Analogous to the biomass, similarity within the single clusters is low, varying from 29 % in the Bodden cluster, 36 % and 57 % in the other two clusters. This suggests a high variance between different sampling stations. Also noticeable is the presence of one outlier ‘KL7’. This can be explained due to the low percentage of coverage at this station.

The ANOSIM permutation test displays a significant difference p = 0.001 between Bodden and the outer coast, with a calculated Global-R value of 0.438.

Analogous to the biomass, the percentage of coverage of macroalgae on the outer coast and water depth shows a significant, positive correlation *rho* = 0.617, p = 0.004. All other recorded parameters do not show a significant correlation with depth.

Noticeable is the high variation of percentage of coverage of spermatophytes. This can be explained due to the high heterogeneity of the sampling stations. Remarkably, in the Bodden, the percentage of coverage of spermatophytes is up to 70% at the lower macrophyte border 3.8 m.

The Mann-Whitney test only shows a significant difference between the inner and outer coast only for the percentage coverage of spermatophytes, with the Bodden showing a significant higher value p = 0.011 than the outer coast.

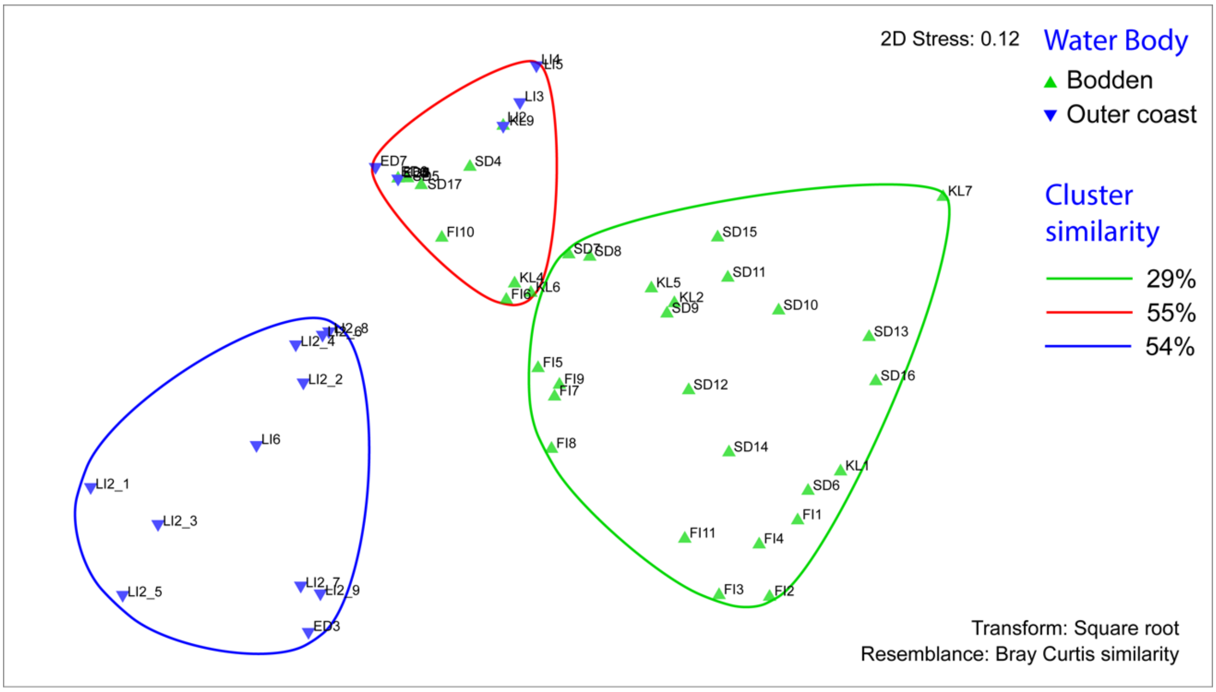

Fig. 6: Multi-dimensional scaling analysis of the percentage of macrophyte species cover. Circles show overlaid clusters of the cluster analysis at $p < 0.05$. Transect abbreviations: ED = Enddorn, LI = Libben, LI2 = Libben2, KL = Klosterloch, FI = Fährinsel, SD = Schaprode.

3.3 Macrophyte vegetation height

On the outer coast, a low number of samples n = 14 due to the high patchiness of the seagrass meadows makes a statement about the parameter challenging. High dispersion of the data signals a high heterogeneity between sampling stations. Given this, a comparison between Bodden and outer coast does not appear viable. For this reason, further analysis concerning this parameter only considers data about the Bodden.

The median macrophyte vegetation height shows a significant positive correlation *rho* = 0.572, p= 0.001 with water depth in the Bodden (Fig. 7). Remarkably, in the Bodden, the median vegetation height can be up to 110 cm at the lower macrophyte border 3.8 m.

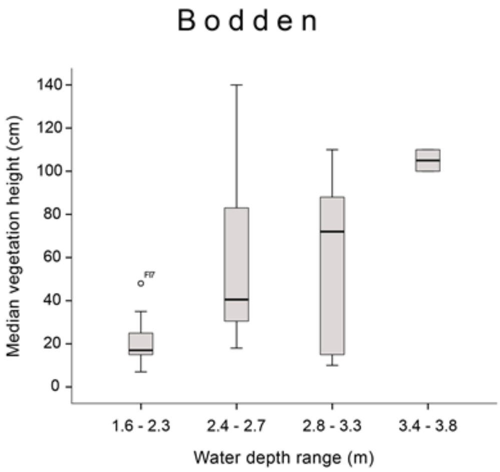

Fig. 7: Boxplot of the median vegetation height in Bodden at different depth classes.

3.4 Macrophyte community analysis

The Mann-Whitney test shows only a significant difference between inner and outer coast for the H', with the Bodden showing a significant higher diversity (p = 0.013) than the outer coast.

In the euphotic zone no evident correlation appears between the recorded vegetation classes, neither for biomass or percentage coverage. Only vegetation height and the Shannon diversity Index H' showed significant opposite correlations with increasing depth. This could be explained by the fact that small, growing macrophytes may have a competitive disadvantage compared to canopy-forming spermatophytes, such as *Z. marina* and *S. pectinata*. The negative correlation of H' x median vegetation height supports this statement, as with increasing depth, spermatophytes outcompete small macrophytes.

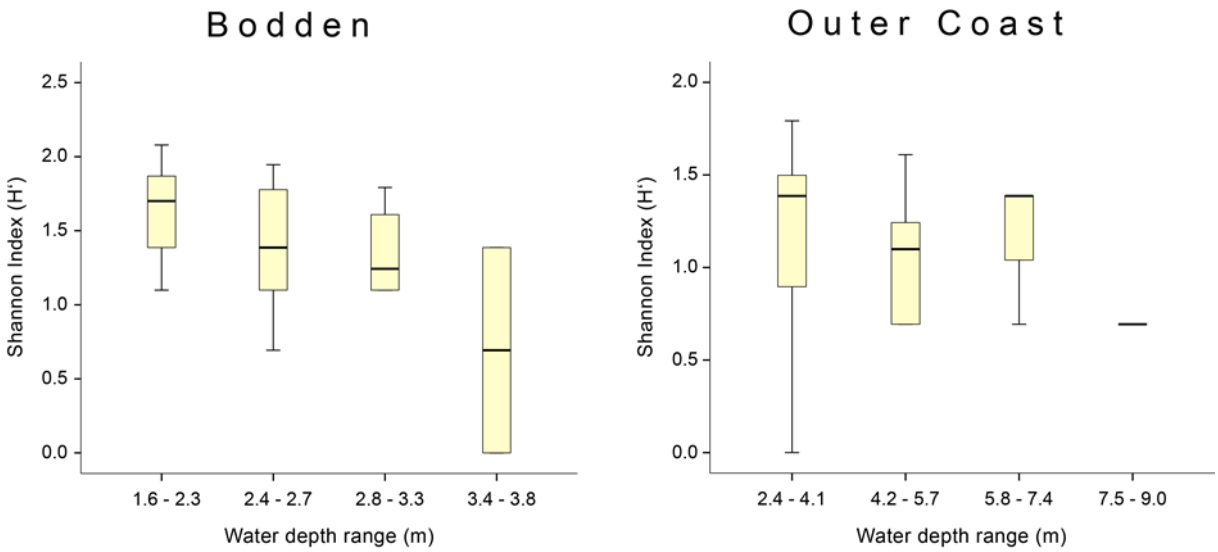

Fig. 8: Boxplot of the Shannon diversity index (H') at different depth classes.

4 Discussion

For coastal waters, there are three mandatory biological quality elements (BQEs) that are used to assess ecological status: phytoplankton, benthic invertebrates and macrophytes. Options for determining reference conditions were, in decreasing order of reliability: reference sites, historical data, modelling and expert judgement. Due to different characteristics of different water bodies the data were normalized for a comparison between ecological statuses Domin et al. 2004.

The current classification of the ecological status for inner coastal waters PHYBIBCO (Fürhaupter & Meyer 2015a) is based on the evaluation of three parameters: 'naturalness' of the community composition and the lower distribution borders of charophytes and spermatophytes. According to this model, different ecological values are given to different macrophyte species, from '4 - high' to '0 - low', depending on their tolerance to light attenuation (Fürhaupter & Meyer 2015a). For example, charophytes are considered indicators of a good ecological status and are therefore given a high 'ecological value'.

In outer coastal waters the evaluation of ecological status BALCOSIS (Fürhaupter & Meyer 2015b) differs slightly as many plant communities, such as charophytes and most spermatophytes are naturally not present in these ecosystems. Therefore, the lower distribution limit and proportion of opportunistic macroalgae were evaluated for three macrophyte classes: *Zostera marina*, *Fucus* spp. and *Rhodophyta* (Fürhaupter & Meyer 2015b).

As shown in the results, the Bodden and outer coast are significantly different, both for the macrophyte species biomass and percentage species coverage. The Bodden was characterized by a species composition that is typical for brackish transitional waters, with representatives of limnic ecosystems, such as *Stuckenia pectinata, Myriophyllum spicatum, Ruppia cirrhosa* and marine ecosystems such as *Zostera marina, Fucus vesiculosus f. balticus* (Athanasiadis 1996).

Shallow areas depth class 1.6–2.3 m were characterized by high patchiness, high diversity, low biomass and low vegetation height. The most common species were *Polysiphonia* sp., *F. vesiculosus f. balticus* (Athanasiadis 1996), and *S. pectinata.* Furthermore, occasional finds included single spots of *Z. marina, Furcellaria lumbricalis*. Blindow et al. 2016 reported a somewhat different vegetation composition for the shallowest parts water depth up to 0.8 m of the northern Vitter Bodden. Here, the most common species were *Ruppia* spp., *S. pectinata, F. vesiculosus f. balticus* and *Chara* spp. Below 1 m water depth, *S. pectinata*, *Ruppia* spp. and *F. vesiculosus f. balticus* were considered the most common macrophytes for this area.

In deeper areas depth classes 2.4 – 2.7, 2.8 – 3.3, 3.4 – 3.8 m, the proportion of spermatophytes to macroalgae increased, as well as the median vegetation height. In particular, the coverage, vegetation height and biomass of Z. marina increased. The most common species at these depths were *Z. marina* and *S. pectinata*, forming mixed and dense stocks. Furthermore, *Polysiphonia* sp. was found under these canopy forming macrophytes. The lower border for *S. pectinata* was determined at 3.0 m water depth, with occasional finds at 3.2 m (pers. Obs. May 2016). This is well below the results of Blindow et al. 2016 which considered this species the most common in between 1.0 – 2.0 m depth.

The lower border for *Z. marina* was determined at 3.8 m in the Schaproder Bodden, validating signals from the sidescan sonar with scientific divers. This species was dominant below 3 m from the 1930s to the 1960s Müller 1932; Müller-Stoll &

Künzenbach 1956; Overbeck 1965, whereas now it is considered dominant below 2.0 m Blindow et al. 2016.

Blindow et al. 2016 reported in the northern Vitter-Bodden that a maximal macrophyte coverage of 70 % was reached at 1.0 m and maintained up to 2.8 m water depths. This is in agreement with the results of the current study, as in the shallower areas depth classes 1.6 – 2.3, 2.4 – 2.7 m, the median macrophyte coverage was found to be 75 % and 85 % respectively. Overall, previous surveys in the Schaproder Bodden show a similar species community over the last years, with low change in depth distribution. Moreover, the highest overall coverage has been consistently found at intermediate depths of 2.0 – 3.8 m.

Weather conditions, wave action and the mechanical disturbance of ice in winter are considered to have the highest impact on biomass and species composition in the shallow, wind-exposed environments of the Baltic Sea (Idestam-Almquist & Kautsky 1995; Idestam-Almquist 1998). This is particularly the case for the Bodden, where large areas are shallower than 1.5 m, therefore determining the upper distribution limit of tall macrophytes. Moreover, the prevailing wind direction can generate temporary ‘wadden’ areas that are exposed at lower water levels. This is frequent in the shallowest parts of the lagoon water depth < 0.5 m around the peninsula of Bessin and the Gellen area. These areas are not relevant for the current study, rather wind fetch and consequent wave action certainly affect the shallowest parts of the investigated areas. This explains that the highest coverage and biomass is found at intermediate depths.

Other factors anthropogenic influences on macrophytes in this area are dredged waterways, frequent ferry traffic and harbours (Fürhaupter et al. 2009).

These results suggest that in the Bodden, light is not a major limiting factor for the dominant canopy forming spermatophytes *Z. marina* and *S. pectinata*. This is in contrast with other water bodies in the area, like the Greifswalder Bodden or the Darß-Zingster-Boddenkette, where the coverage of macrophytes decreases continuously with increasing depth, indicating significant light limitation (Blindow & Meyer 2015). Nevertheless, Blindow et al. 2016 reports that eutrophication affected also the WRB, as there has been a shift from charophytes to more resistant species such as *Z. marina* and *S. pectinata*. A reduction in eutrophication remesotrophication neither brought an improvement in water transparency nor in the depth distribution of macrophyte species. It has also been speculated that the relatively high frequency of mild winters in recent years, combined with eutrophication, excludes annual macrophytes, such as charophytes, from recolonizing shallow, coastal ecosystems (Blindow et al. 2016).

Compared to the Bodden, the outer coast had a lower species number, as most macrophyte groups are not adapted to higher exposure. For example, charophytes were completely absent and other spermatophytes such as *S. pectinata* or *R. cirrhosa* were found only occasionally. Moreover, exposure generated extreme patchiness in the seagrass meadows. Only one out of three transects ‘Enddorn’ had relative dense patches of eelgrass. This can be attributed both to the relative protection from land and the prevailing.

The shallow areas depth class 2.4 – 4.1 m were characterized by the highest biomass and coverage. Deeper areas depth classes 4.2 – 5.7, 5.8 – 7.4, 7.5 – 9.0 m showed little change in community diversity. While a measurement of vegetation height did not prove representative, probably due to higher degrees of exposure. An increase of height with depth, as it is the case in the Bodden, is not possible.

The percentage coverage and biomass of macroalgae increased significantly with depth. While this may seem counter-intuitive, it can be explained by the fact that, here, macroalgae are made up of mats of the rootless genus *Pylaiella* sp. Their distribution is therefore mainly determined by the local current regime, wave exposure and seafloor slope.

The limiting factor for the lower border of macrophytes is difficult to determine because of the low number of observations and the combination of exposure and potential light limitation. Even the determination of the lower border for *Z. marina* was not possible due to the extreme patchiness of the meadows. Nevertheless, eelgrass was found at 7.1 m with 25 % coverage in one transect and at 7.6 m depth in the following year (pers. obs. May 2016), which is a value that is close to the reference value of 7.2 m for a good environmental status of this water body (Fürhaupter & Meyer 2009). On the other hand, high proportions of opportunistic macroalgae *Pylaiella* sp. was found, which is a clear sign of eutrophication. In fact, the closest WFD stations in the Libben bight, 'Hiddensee' HID and 'Dranske' DRA, were given a bad and a poor ecological status, respectively, (Kuhlmann et al. 2015). The reason can be assigned to the fact that the Libben bight has prevailing westerly wind direction and is located directly downstream of the WRB. Therefore, this area receives nutrient rich waters from the WRB, thus enhancing the growth of opportunistic macroalgae.

Comparing the recorded parameters between inner and outer coast, only the spermatophyte biomass $p = 0.011$ and percentage coverage $p = 0.011$ proved to be significantly higher in the Bodden, whereas macrophytes as a whole and macroalgae were not significant. Therefore, we can assume with good confidence that the driving factor behind this difference is higher exposure on the outer coast, rather than different eutrophication levels.

The study shows that a combination is necessary for assessment of macrophyte distribution. Single methods cannot deliver the necessary overview and knowledge about the coverage to assess the ecological status. Best resolution for the distribution of macrophytes is the combination of the use of indirect methods such as satellites and sidescan sonar, which allow a great coverage, with little time spent in the field and validation in the field by diving to receive a high resolution with as quantitative and taxonomic statements.

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