

# INTERANNUAL VARIABILITY OF SUBMERGED VEGETATION IN A BRACKISH COASTAL LAGOON ON THE SOUTHERN BALTIC SEA

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## Abstract

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The annual and spatial distribution of submerged aquatic vegetation was investigated in the shallow brackish lagoon Darß-Zingst Bodden chain (southern Baltic Sea). The recent vegetation was investigated from 2001 to 2007. In addition to the vegetation, the diaspore bank in the surface sediment (upper 10 cm) was analysed in 2001. The depth distribution, density and coverage of vegetation and diaspores were analysed at five water depths along three transects. The vegetation study yielded a total of eight taxa of submerged vegetation: four angiosperms and four charophytes. The depth limit of the vegetation varied between 0.5 and 1.0 m. The cover ranged between 1 and 100%. The vegetation communities varied between the six investigated years. The diaspore bank showed a dominance of oospores of charophytes. Four species were found only in the diaspore bank, but not in the recent vegetation during the 6-year period.

The results of the vegetation analysis were compared and discussed in the framework of the abiotic parameters (salinity, secchi depth, water temperature, nutrients).

*Key words:* submerged macrophytes, Charophyta, seed bank, coastal lagoon, eutrophication

## Introduction

Coastal lagoons are characterised by unique horizontal gradients of physical, chemical, and biological parameters. Salinity is the key factor governing the distribution of flora and fauna in coastal waters and estuaries (Kautsky, 1988a; Nielsen et al., 1995).

In addition to this high natural variation of salinity, coastal lagoons have been subjected to extremely high anthropogenic impacts. Worldwide, the anthropogenic impacts on coastal lagoons have been calculated based on the nutrient and pollution input into the lagoons or on the nutrient concentration in these water bodies (Soderstrom, 1996; Howarth et al., 2002). In southern Baltic Sea lagoons, nutrient inputs have increased since the 1960s (Selig et al.,

2006). The trophic status has increased drastically during the last thirty years according to long-term monitoring measurements (Nausch et al., 1999).

Eutrophication here shows two dominant effects on the submerged vegetation: a lower distribution limit of macrophytes (Kautsky et al., 1986; Nielsen et al., 2002) and a loss of taxa (Martin et al., 2003; Schubert et al., 2007). Eutrophication has also changed the underwater light regime (Schubert, Forster, 1997). Especially the charophytes were described as sensitive and useful indicators of eutrophication in Baltic lagoons (Blindow, 2000).

Shallow lakes are ecosystems known to exhibit alternative stable-state dynamics characterized by repeated structural shifts between phytoplankton and submerged vegetation (Scheffer, 1998; Hargeby et al., 2007). We hypothesize that shallow coastal lagoons will also feature comparable stable-state dynamics. Beyond such shifts, salinity will influence the seasonal variation of phytoplankton and annual variation of submerged vegetation.

In this investigation the vegetation coverage over six years was compared with the diaspore seed bank and the abiotic parameters of the water column.

## Material and methods

### *Study area*

The study area was the Bodstedter Bodden in the middle part of the Darß-Zingst Bodden chain (DZBC, Fig. 1, and Table 1). This lagoon is located in Mecklenburg-Vorpommern on the southern Baltic Sea and is a non-tidal transition zone to the open Baltic. The chain of semi partially enclosed basins (Bodden) is characterised by changing hydrological conditions for pelagic and benthic organisms. The salinity ranged from freshwater (< 0.5 psu, westerly part near the Recknitz river) to 10 psu (eastern part, connection to the Baltic Sea).

Beside this geographical salinity gradient, salinity at a particular site shows high seasonal variability (Schumann et al., 2006). Riverine nutrient input also leads to nutrient gradients along the estuary, for example high concentrations especially in winter and spring (Selig et al., 2006). The effective water exchange is mainly determined by river inflow and changes of the Baltic Sea water level.

The sampling station for macrophytes and abiotic parameters is located in the Bodstedter Bodden, the middle part of the DZBC (Fig. 1).

### *Vegetation analysis*

The vegetation was investigated once a year in either July or August from 2001 to 2007 (except 2006). The presence of submerged vegetation was described as the mean coverage in 1 m<sup>2</sup> (four or five replicates – 2004–2007) and 4 m<sup>2</sup> (one replicate – 2001–2003). The vegetation samples were taken at fixed water depths from 0.25 m, 0.5 m, 0.75 m, 1.0 m, 1.5 m. Charophytes were determined to species level following Krause (1997), Pankow (1990), and Wood, Imahori (1965); angiosperm macrophytes were identified following Rothmaler et al. (1994). The coverage of each plant species was estimated using a modified and combined Braun-Blanquet abundance-dominance scale. Values were changed into mean percent cover values: 0.1%: 1 specimen; 0.2%: 1 to 5 specimens; 2.5%: < 5% cover but < 50 specimens; 15 %: < 5% cover but > 50 specimens; 15%: 5 to 15% cover; 15%: > 15 to 25% cover; 37.5%: > 25 to 50% cover; 62.5%: > 50 to 75% cover; 87.5%: > 75 to 100% cover for the calculations (Ellenberg, 1992).

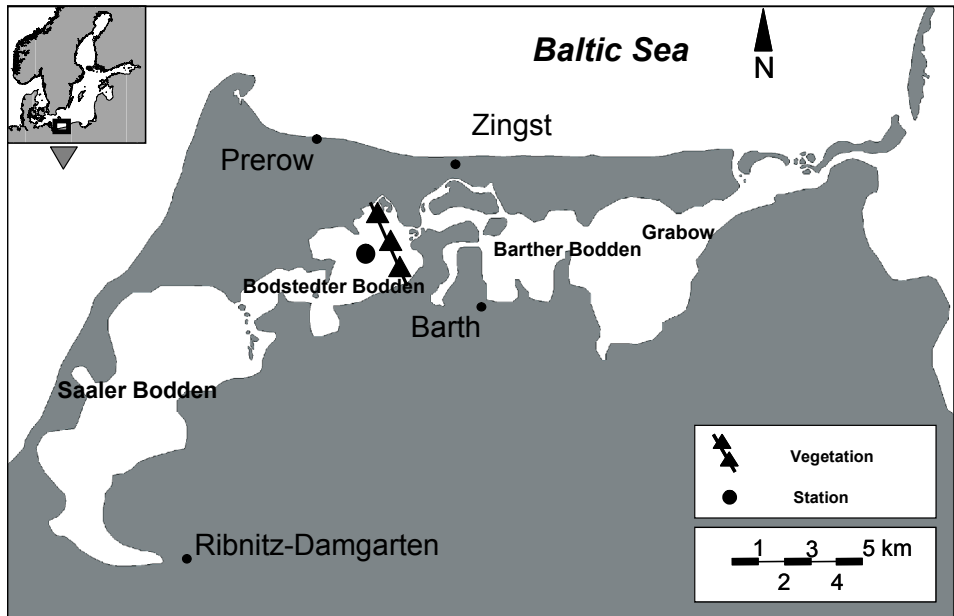


Fig. 1. Map of the Darss-Zingst Bodden chain.

Table 1. Morphometrical and physico-chemical parameters data of the four major basins of the Darß-Zingst Bodden chain – data of the study area Bodstedter Bodden bold – data from (Selig et al., 2006).

	Saaler Bodden (incl. Ribnitzer See)	<b>Bodstedter Bodden</b>	Barther Bodden	Grabow
Area [km <sup>2</sup> ]	80.9	<b>24.1</b>	19.4	41.5
Volume [10 <sup>6</sup> m <sup>3</sup> ]	174.5	<b>46.8</b>	34.1	93.8
Mean depth [m]	2.2	<b>1.9</b>	1.8	2.3
Max depth [m]	4.0	<b>10.0</b>	6.5	4.5
Salinity	mean	<b>5.4</b>	6.4	no data
	(min. – max.)	<b>(3.8-7.9)</b>	(3.9-9.8)	
Chl- <i>a</i> [µg l <sup>-1</sup> ]	mean	<b>56.3</b>	53.8	no data
	(min. – max.)	<b>(18.0-146.0)</b>	(19.0-96.0)	
Secchi depth [m]	mean	<b>0.3</b>	0.5	no data
	(min. – max.)	<b>(0.1-0.4)</b>	(0.3-1.0)	

## Diaspore analysis

Sediment samples were collected with Plexiglas sediment corers in July 2001. Two cores of the upper 5 cm sediment layer were extracted from each sampling point, yielding a sample volume of around 500 cm<sup>3</sup>. These cores were mixed and elutriated with a sieving machine and a jet of water through sieves of 1 mm, 0.5 mm and 0.2 mm aperture mesh. Residues were dried at 60 °C for 12 h. These three fractions were inspected under a dissecting microscope. All diaspores in the residue of the 1 mm fraction were counted. The other fractions were homogenised by cautiously mixing the residue of each fraction with a spatula to obtain random subsamples. The fraction was mixed again before taking each subsample. These subsamples of 2 to 3 g of the fraction material were spread over a Petri plate. Graph paper was glued to the bottom of the Petri plate to enable the inspection of subsamples within 1 cm sectors. As many of these subsamples were completely investigated until 10 to 20% of the whole fraction was counted (Ostendorp, 1998). The diaspore densities were calculated per 1 m<sup>2</sup> and comparisons were made between the coastal lagoons. Determination of propagules follows Steinhardt, Selig (2007).

## Abiotic parameters

The monitoring data set from the State Agency for Environment, Nature and Geology Mecklenburg-Vorpommern was evaluated. Sampling was done monthly between 2000 and 2007. The parameter salinity (psu), water temperature (°C), secchi depth (m), chlorophyll a (µg l<sup>-1</sup>), total phosphorus (µmol l<sup>-1</sup>) and nitrate concentration (µmol l<sup>-1</sup>) were used to describe the seasonal and annual variation of the abiotic parameters of the Bodstedter Bodden. The data are shown as box plot figures with the median, the 75%- and the 25%-percentile, the 90%- and the 10%-percentile, and values in the 95%- and 5%-percentile.

## Results

### Submerged vegetation

The vegetation study (2001–2007) revealed a total of eight taxa of submerged vegetation: four angiosperms and four charophytes. None of these eight species were found every year. The depth limit of the vegetation varied between 0.5 and 1 m (Fig. 2) and increased slowly in 2005 and 2007 compared with 2001 to 2004. Charophytes were found more in the shallow water between 0.25 and 0.5 m, with 25 to 90% coverage. *Chara aspera* and *C. baltica* were the two dominant taxa. *C. tomentosa* and *C. canescens* were only found sporadically.

*Potamogeton pectinatus* was the dominant angiosperm. It was found in the depth zone 0.5 to 1.0 m, especially in 2004 and 2007. In these years this species determined the depth limit of the vegetation. *Najas marina* was only observed in 2005 at 0.25 and 0.5 m. *Ranunculus aquatilis* and *Potamogeton perfoliatus* were only found in 2005 with a coverage < 5%.

### Seed bank structure

Diaspores of eight species were found in the sediment in 2001. Oospores of charophytes constituted the major part of the diaspore bank at all water depth levels (Table 2). The *Chara asperalcanescens*-group and the *C. baltica*-group were dominant in all water level

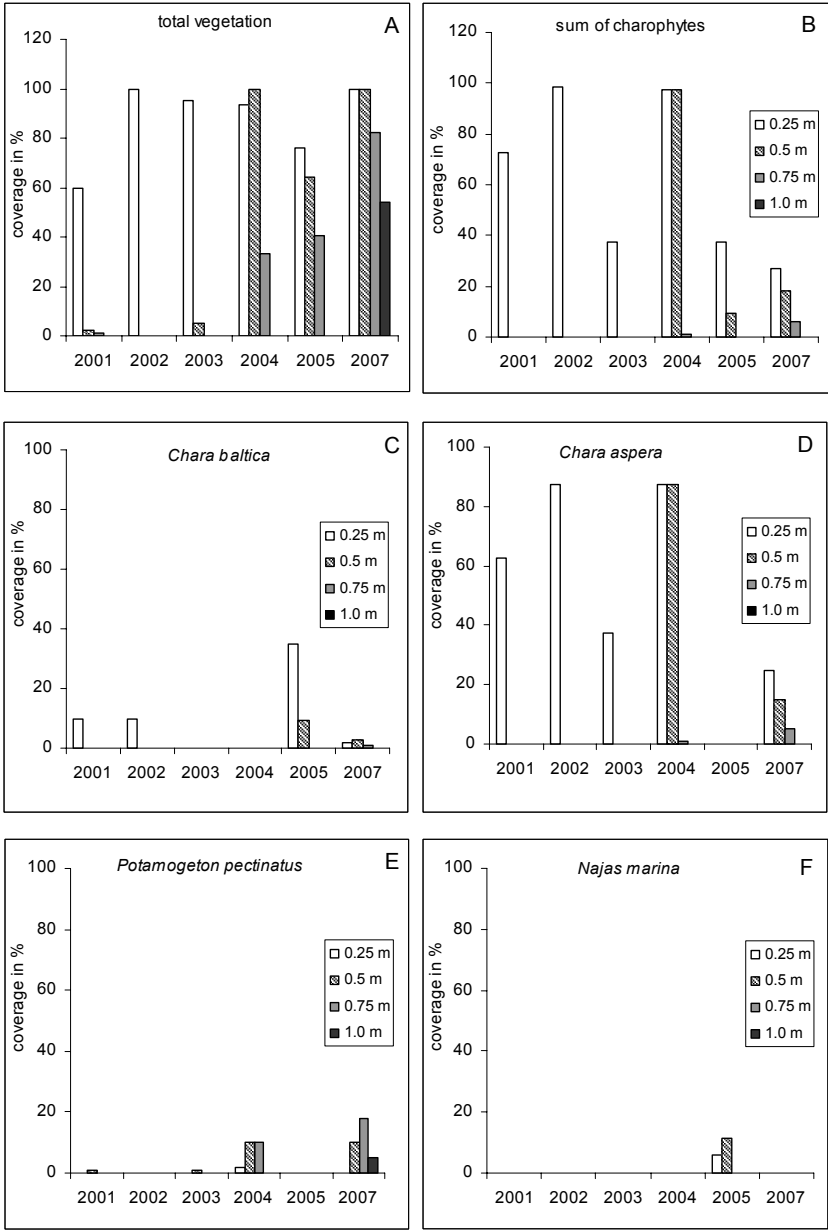


Fig. 2. Seasonal variation of coverage of the total submerged vegetation (A), charophytes vegetation (B), *Chara baltica* (C), *Chara aspera* (D), *Potamogeton pectinatus* (E) and *Najas marina* (F).

Table 2. Mean diaspore density (m<sup>-2</sup>) in the diaspore bank for different water depth levels in the Bodstedter Bodden 2001.

	0.25 m (n = 5)	0.5 m (n = 4)	0.75 m (n = 3)	1 m (n = 2)	1.5 m (n = 2)
<i>Chara asperalcanescens</i> -group	156332	65031	23715	17164	11568
<i>Chara baltica</i> -group	19277	13365	2820	2646	115101
<i>Tolypella nidifica</i>	25088	33219	85872	58602	935
<i>Najas marina</i>	254	179	0	0	6777
<i>Potamogeton pectinatus</i>	842	143	82	54	0
<i>Ruppia cirrhosa</i>	1038	1900	2123	1487	14518
<i>Ruppia maritima</i>	573	0	0	0	117
<i>Zannichellia palustris</i>	4282	2087	2214	1666	41262

depth and were also present in the deeper water, where no charophytes were observed in the recent vegetation. *Potamogeton pectinatus*, the dominant angiosperm in 2004 and 2007 in deeper water, were only found in a low density in shallow water.

The charophyte *Tolypella nidifica* and the angiosperms *Ruppia cirrhosa*, *R. maritima* and *Zannichellia palustris* were only found in the diaspore bank, but not in the recent vegetation between 2001 and 2007. The charophyte *Tolypella nidifica* was the dominant oospore in 0.75 m and 1 m. The diaspores of *Zannichellia palustris* increased drastically at a water depth of 1.5 m.

#### *Abiotic parameters in the water column*

The data set of six abiotic parameters showed a high seasonal variability in the water column (Fig. 3). The salinity ranged from 2 to 8 psu. The secchi depth varied between 0.2 to 0.7 m. The water temperature showed a broad annual variability. High nitrate, phosphorus and chlorophyll concentrations pointed to a eutrophic coastal lagoon.

## **Discussion**

#### *Distribution of submerged vegetation*

Until the 1980s, anthropogenic nutrient loads from the catchment area increased in the DZBC.

Nausch (1981) calculated a P input between 200 t a<sup>-1</sup> P and 300 t a<sup>-1</sup> P in the 1970s and 1980s. The higher nutrient input caused an increasing phytoplankton biomass and eutrophication in the coastal lagoon (Nausch et al., 1999). Lindner (1978) described increasingly

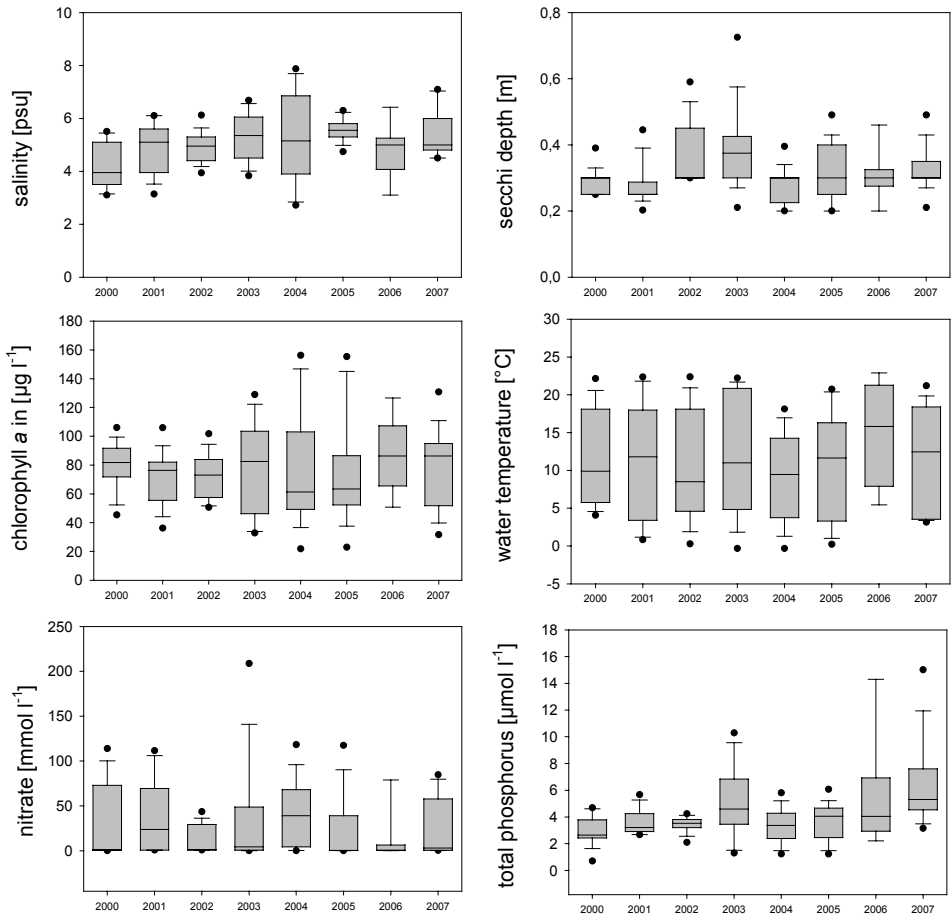


Fig. 3. Annual variation of salinity, secchi depth, chlorophyll *a*, water temperature, nitrate and total phosphorus concentration between 2000 and 2007. The diagrams show the median ( $x_{50}$  – line inside the box), the 75%- and the 25%-percentile ( $x_{75}$  and  $x_{25}$ ), the 90%- and the 10%-percentile ( $x_{90}$  and  $x_{10}$  – whisker), and values in the 95%- and 5%-percentile ( $x_{95}$  and  $x_5$  – dots).

shallower depth limits of submerged vegetation and a loss of charophytes here. Yousef, Schubert (2001) detected more charophyte species since the 1990s, but the sampling was too sporadic to detect a significant increase in the plants.

With the implementation of the EU Water Frame Directive and the development of the classification approach (Selig et al., 2007), submerged vegetation began to be investigated yearly, whereby the vegetation depth limit and coverage were measured. Charophytes were dominant up to 0.75 m in all years and formed a stable part of the submerged vegetation.

Charophytes have been described as suitable bioindicators for eutrophication in lakes (Krause, 1981; Blindow, 1992; Stelzer et al., 2005). Appelgren, Mattila (2005) also described *Chara tomentosa* as a good indicator for macrophyte communities in shallow bays of the northern Baltic Sea, similar to the freshwater investigations. This species had only a low coverage in the Bodstedter Bodden.

*C. aspera* was dominant in five of the six years. It grew in high densities (mat formation), with coverage from 40 to 90%. Only in 2005 was *Chara aspera* not found in the recent vegetation. In that year, *C. baltica* dominated. *Najas marina* was found only in 2005. Blindow, Schütte (2007) investigated the elongation and mat formation of *C. aspera* under different light and salinity conditions. They showed that *C. aspera* was absent in “double stress” environments, i.e. both high turbidity (eutrophication) and high salinity. The authors assume that the species is a poor competitor under these conditions. In 2005 the mean salinity in the Bodstedter Bodden was higher than in the years before and after. Species with a higher salinity range therefore had better conditions for development. *C. baltica* was mainly recorded in a salinity range between 2 and 10 psu, but has also been found at up to 18 psu (Olsen, 1944). *Najas marina* was recently reported at a range between 2 and 8 psu on the German Baltic Coast. Eggert et al. (2006) described, in laboratory studies, a growth of *N. marina* at low light intensities and salinities up to 8 psu.

The depth limit of charophytes varied between 0.25 and 0.75 m in the Bodstedter Bodden. Domin et al. (2004) described a light limit of 40% of the surface irradiance (SI) for this taxa group. In deeper water, with availability below 40% of SI, only *Potamogeton pectinatus* grew. The light limit of spermatophytes was defined by 10% SI (Mur, Visser, 1996). In addition to the lower light limit, *P. pectinatus* has an elongation. Nonetheless, *P. pectinatus* did not form stable mats in deeper water. In only two of the six years was coverage over 10% recorded in 0.75 m water depth.

In 2005 and 2007, a lower vegetation depth limit was observed. The secchi depth and the chlorophyll a concentration showed no decrease of phytoplankton biomass in those years. Selig et al. (2006) discussed a re-mesotrophication of this coastal lagoon after a drop in nutrient inputs in the 1990s. This interpretation is confirmed by the long-term analysis of Secchi-depth measurements over 20 years. The development of the last five years alone indicates not an improvement in Secchi-depth. The variation of the underwater light regime in itself cannot explain the variation of the vegetation depth limit or the variability in the coverage change between the charophytes and angiosperms in the lagoon.

#### *Distribution of the diaspore bank*

In addition to dominating the vegetation, charophytes also dominated the diaspore bank in the sediment of the Bodstedter Bodden. This reflects the charophyte life strategy. Kautsky (1988b) described this group as stunted plants with various types of vegetation diaspores, whereas other plants showed other life strategies with few diaspores (e.g. *Zostera marina* or *Potamogeton pectinatus*).

Steinhardt, Selig (2007) described the spatial distribution patterns and relationship between recent vegetation and diaspore bank in the Salzhaff, another Southern Baltic lagoon.



The diaspore distribution in the sediment in this lagoon was dependent on all tested factors: wave exposure, diaspore mass, vegetation cover, nutrient level and water depth. Beside depending on the above factors, the diaspore distribution also depended on the transport processes of particles and sediment in the lagoon.

Despite the high oospore abundance of *Tolypella nidifica* in the sediment, this species was not found in the recent vegetation. The low salinity of the Bodstedter Bodden may explain the absence of *T. nidifica*: this species prefers coastal areas of the German Baltic Sea with higher salinity (Selig et al., 2007). Olsen (1944) described the salinity range of *T. nidifica* as 4 to 18 psu. The mean salinity in Bodstedter Bodden (2000 to 2007) was 5.4 psu, with a range of 3.8 to 7.9 psu (10% and 90% percentile).

The present study examines the generative potential of the diaspore bank. The lack of data on both the vegetative diaspores and the germination rates of the generative diaspores somewhat limits the interpretation. Charophytes mainly reproduce by their oospores. The generative potential of the diaspore bank cannot explain all the dispersal strategies in the investigation area and beyond, but does demonstrate some basic relationships.

Generally, two main factors – salinity and nutrient gradient – shape the vegetation and therefore the diaspore bank in coastal lagoons. Steinhardt, Selig (2008) investigated the variability of the vegetation and seed bank along the salinity gradient in three coastal lagoons. Their results showed no significant differences between the diaspore banks of transects along the salinity gradient in the DZBC. Accordingly, the nutrient gradient influences the difference between the recent vegetation and diaspore bank.

#### *Interannual variability of vegetation*

The monthly data of abiotic parameters insufficiently explain the interannual variability of the submerged vegetation. Our understanding of changes in the submerged macrophytes is limited. Beside salinity, nutrient load and diaspore bank, several other factors like water level fluctuations, fish abundance and certain weather conditions may also affect the submerged plant communities. Our study did not address these aspects. In our opinion, future research on the variability and stability of submerged macrophytes should focus more these aspects and integrate two new aspects: diaspore germination and the affect of the waterfowl community.

Baldwin, Mendelsohn (1998) described a significant role in species richness for the interaction between germination, salinity and inundation – an aspect not investigated in our study. The variability of salinity, light and temperature in the spring could also potentially influence the recent vegetation. Petr, Tielbörger (2008) described the effect of climate change on the germination of annual plants. Altered water temperatures will influence the time and rate of germination. The variability of species richness and coverage between the years may therefore reflect the influence of abiotic parameters on germination. The measurement of abiotic parameters once a month is insufficient to investigate the influence of germination.

In addition to abiotic parameters, the presence of water birds influences the distribution of submerged vegetation. The area of the DZBC is a stopover and resting site for water birds. Over 120,000 birds were counted around the DZBC (Nels, 2005). In mild winters, most of the birds winter in this area. Milberg et al. (2002) expected that food availability was more important for water birds. The stopover time of waterfowl in spring might essentially influence the submerged vegetation in the following season. Detailed information about the stopover site over the years or about the development of submerged macrophytes is not available, so that the role of water birds of the development of submerged vegetations cannot be determined.

## Conclusion

The recent vegetation changed during the six investigation years. Charophytes dominated the coverage at 0.5 m water depth. The submerged vegetation showed interannual variability between the species. Its depth limit varied between 0.5 m and 1.0 m.

The diaspore bank showed a high recolonisation potential of some species of (charophytes) of the submerged vegetation, even at the deeper water level without recent vegetation. The combination of vegetation and diaspore bank analyses yields the best results when studying current and former vegetation states with regard to salinity and nutrient variability. Charophytes have a higher recolonisation potential than angiosperms because they have a life strategy with high oospore production.

The monthly data on abiotic parameters are insufficient to explain the interannual variability of the submerged vegetation. Especially the variability of abiotic parameters in the spring must be investigated in greater detail. Future research should also focus on the germination of the recent diaspore bank and the role of this area as a stopover site for water birds on the development of the submerged vegetation.

*Translated by the authors*

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