

University of Tartu
Faculty of Biology and Geography
Institute of Zoology and Hydrobiology

Tiia Möller

**Growth and community structure of *Zostera marina* L. in relation to the
environmental variables in the coastal waters of Estonia**

MSc thesis

Supervisor: PhD Georg Martin

Tartu 2007

Content

1. Introduction	3
2. Materials and methods	5
2.1. Study area	5
2.2. Fieldwork	6
2.3. Laboratory analysis	7
2.4. Data analysis	7
3. Results	9
4. Discussion	18
Summary	22
Kokkuvõte	23
Acknowledgements	25
References	26

1. Introduction

Nowadays 66 species of aquatic phanerogams are recognized as seagrasses (Larkum et al., 2006). Seagrasses are treated as an ecological group and they do not form a taxonomic group. Seagrass species inhabit the intertidal and shallow sublittoral areas along temperate and tropical coastlines (den Hartog, 1970, Larkum et al., 2006). The distribution of seagrasses is influenced by various environmental parameters (Hemminga & Duarte, 2000), such as hydrodynamic conditions, nature of the substrate, light (Peralta et al., 2002), temperature (Perez-Llorens & Niell, 1993; Marba et al., 1996), salinity (Wortmann et al., 1997), nutrient concentrations in the water column (Orth, 1977) and/or in the sediment (Viaroli et al., 1997).

The ecological importance of seagrasses is widely recognized. Among other ecological functions seagrasses stabilize the seabed in which they grow and reduce the resuspension of the sediments by currents and waves (Terrados & Duarte, 2000; Gacia et al., 2003). Dense seagrass beds formed by these plants increase the habitat complexity and thus provide better conditions for shelter and food for a great variety of plant and animal species (Rasmussen, 1973; Orth et al., 1984; Orth, 1992; Boström & Bonsdorff, 1997; Mattila et al., 1999; Heck et al., 2003). The biomass of seagrass communities may vary markedly depending on the season and is mainly regulated by changes in light and temperature (Sand-Jensen, 1975). Temperate seagrass communities show greater seasonality compared to tropical and subtropical communities (Duarte et al., 2006).

Out of known 66 seagrasses only 2 species can be found in the Baltic Sea, and due to harsh salinity conditions only one, eelgrass *Zostera marina* L. prevails in the NE part of the Baltic Sea. Eelgrass is the most common angiosperm in the temperate waters of Northern Hemisphere and due to wide distribution the species is rather well studied (den Hartog, 1970, Larkum et al., 2006). For the Baltic Sea the information on eelgrass communities originates mainly from Denmark, Sweden and Finland. Studies on long-term changes on eelgrass communities report the decrease in eelgrass distribution in Danish (Greve & Krause-Jensen 2003; Frederiksen et al., 2004) and Swedish (Baden et al., 2003) coastal waters. In Finland few studies report on long-term changes (Boström et al., 2002), the main focus is on faunal assemblage of eelgrass communities and plant-animal interactions (Boström & Bonsdorff, 2000). The information on eelgrass growth in the Baltic Sea is scarce, yet the studies have

been conducted in Denmark (Sand-Jensen, 1975; Olesen & Sand-Jensen, 1994; Krause-Jensen et al., 2000; Middleboe et al., 2003) and in the northern Baltic Sea (Boström et al., 2004).

For the north-eastern part of the Baltic Sea, including Estonian coastal waters, where the eelgrass grows at its lowest salinity limit the information on eelgrass communities is limited. For Estonian coastal waters the distribution characteristics of eelgrass can be judged based on information gathered from several inventories carried out during 1950-1980s and recent information is available also from different mapping studies as well as national marine monitoring program carried out during last decade. Available data is in most cases only qualitative, reflecting presence or absence of species while detailed information on growth dynamics and structure of eelgrass communities is missing.

The aim of current paper was to give an overview of main community characteristics and environmental settings of eelgrass communities found in Estonian coastal areas. Community parameters such as biomass, shoot density and the accompanying flora and fauna are described in relation to prevailing environmental factors in four selected locations. Analyzing the distribution pattern of eelgrass communities the working hypothesis was that presence or absence of eelgrass communities is determined by specific complex of environmental conditions (exposure, substrate type) while specific community characteristics remain similar within certain optimum of environmental forcing.

2. Materials and methods

2.1. Study area

Z. marina communities were studied at four sites – Ahelaid, Saarnaki and Sõru in the West-Estonian Archipelago Sea and Prangli in the Gulf of Finland (Figure 1). Sites were selected to represent different complexes of environmental conditions (salinity, exposure, sediment type).

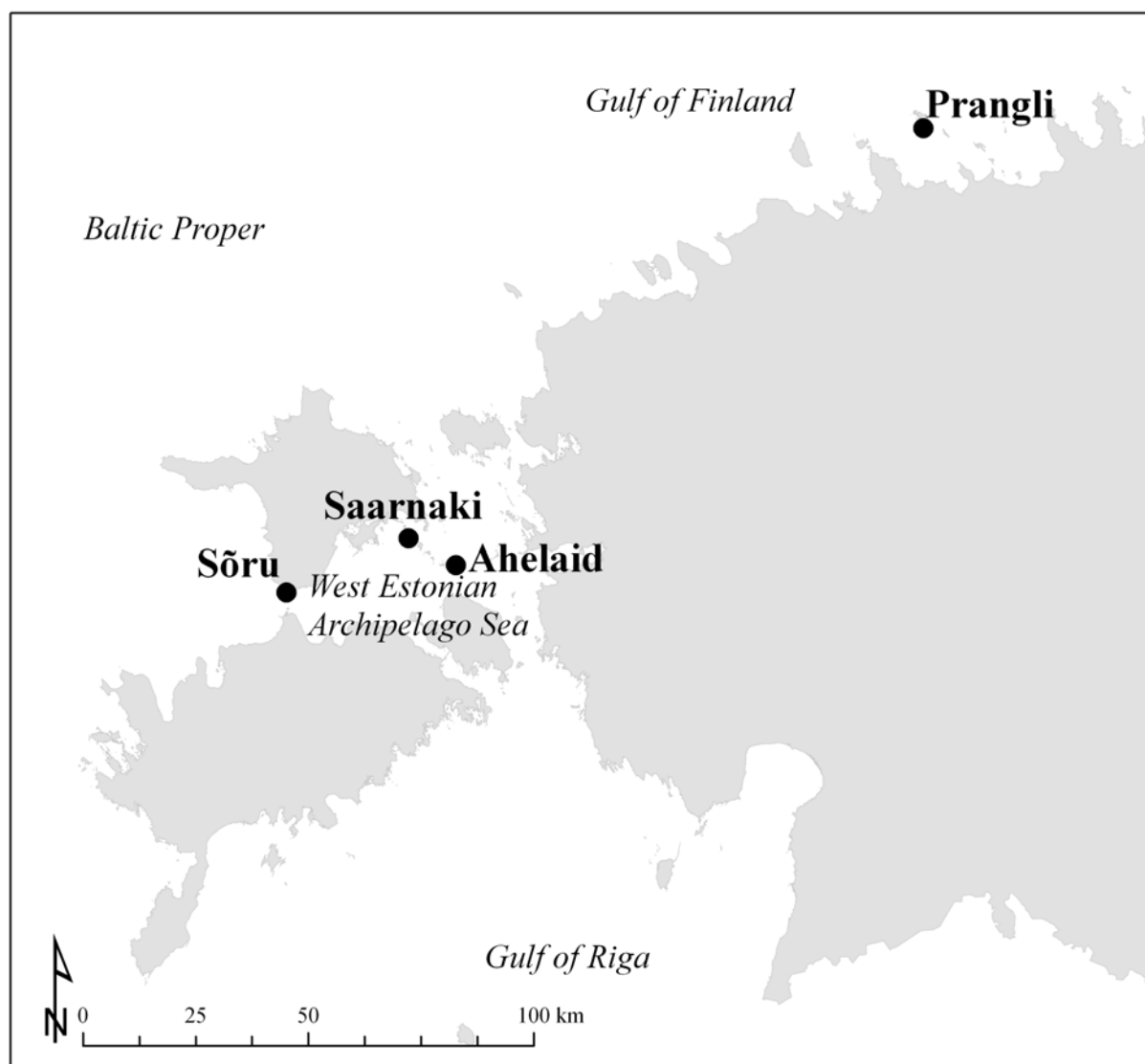


Figure 1. The four study sites of *Z. marina* communities.

The West Estonian Archipelago Sea is a shallow sea area with main depth below 10 m. (Suursaar et al. 1998). The area is characterized with presence of strong temporal hydrological subfronts which move over the area according to wind-induced movement of water-masses.

Soft sediments (sand, mud, clay) prevail as the bottom substrate and hard substrate are found in shallow and exposed bays. Due to the prevalence of clay substrate and strong wave action the water transparency is often very low. The average salinity in the middle part of the West Estonian Archipelago Sea is 5.2 psu. The western ward area (Kassari Bay) is more under the direct influence of the Baltic Proper and thus is characterized by higher salinity (about 6 psu).

The Gulf of Finland is the extension of Baltic Proper and has a counterclockwise water circulation. The average salinity in Prangli area is 6 psu. Sand and gravel dominate in the area, standalone stones are found in shallow waters. Area is strongly influenced by currents and wave action. The study site near Prangli island is located in close vicinity of Muuga harbour and sand extraction area.

2.2. Fieldwork

The fieldwork was conducted in time period from 30 May to 29 September in 2005. The four study areas were visited three times in May, July and September. The study period was chosen to cover previously reported vegetation period and maximum biomass values of eelgrass in the Baltic Sea area (Sand-Jensen, 1975; Boström et al., 2004).

The community characteristics of *Z. marina* were studied at different depth intervals: in Prangli area at depth 2-3 m, 3-4 m and 4-5 m, in Sõru area at the two upper depth ranges and in Saarnaki and Ahelaid area only at 2-3 m as no eelgrass growth was recorded in other depths.

The samples of organic content in the sediment were taken in all stations in triplicates from eelgrass stand and bare sand. Samples were collected with plastic tubes (8 cm in depth, diameter 2 cm) embedded into sediment at 5 cm depth, sealed at top, pulled out, closed from the other end and transported to the boat.

The samples for shoot density, biomass and associated flora and fauna were collected by diver with 25x25 cm metal frame with attached bag on one side. At each depth three replicates were collected in eelgrass stand. In total 63 frame samples were gathered. The vegetation and 3 cm of the uppermost sediment was carefully removed. Samples were packed and stored deep-frozen until laboratory analysis.

2.3. Laboratory analysis

Sediment organic matter was determined with standard procedure (loss of ignition, 3 h at 500°C) (Rumohr et al., 1987).

The eelgrass shoots and number of leaves per shoot were counted in every sample. The length of the longest leaf of the shoot was measured from the basal meristem to the tip of longest leaf. Algae and associated fauna were separated and determined to the lowest possible taxa. Total number of individuals was counted. Plants and invertebrates were dried at 60°C for constant weight, dry weight was determined and recalculated per m².

During the statistical analysis data on invertebrates were grouped according to feeding type: herbivores, carnivores, deposit feeders and suspension feeders (Bonsdorff & Pearson, 1999). Algae taxonomy is given according to Nielsen et al., 1995.

2.4. Data analysis

Data were analyzed using PRIMER (Plymouth Routines In Marine Ecological Research), a suite of computer programs developed at the Plymouth Marine Laboratory, UK (see Clarke & Warwick, 2001) and STATISTICA 7.1 (StatSoft Inc, 2006).

The relationship between multivariate community structure and environmental variables was examined using the BIOENV procedure (Clarke & Ainsworth, 1993). A ranked similarity matrix was constructed using the Bray–Curtis similarity measure on root-transformed community data. Environmental parameters used in the BIOENV analysis were depth, slope, temperature, sediment organic matter content. The slope was calculated using ArcGIS software for each sampling point at 50, 100, 500, 1000, 2000 and 5000 m resolution. Bottom slope of different resolution were used to describe the hydrodynamic processes of different spatial scales (e.g. small scale slope is a proxy of occurrence of anoxia and large scale slope is a proxy of exposure of site). Water temperature data was provided by Estonian Meteorological and Hydrological Institute on daily bases (2 measurements per day). Nearest weather stations to the sampling sites were chosen. The mean temperature of 30 and 60 days period prior to the eelgrass sampling were calculated for further analysis.

The effect of abiotic and biotic environmental variables (shoot density, length, shoot biomass, biomass of loose algae) on macroinvertebrate community structure was analyzed by BIOENV procedure. The differences between time, depth and site were tested using the ANOSIM permutation test (Clarke and Green, 1988). The taxa contributing to any dissimilarity between samples were investigated using the similarities percentages procedure SIMPER (Clarke, 1993).

To describe the faunal composition abundance, number of species, Shannon–Weiner diversity index ($H' = -\sum p_i \log p_i$), Pielou's evenness, Margalef index were calculated and used in further analysis.

Analysis of variance (ANOVA) were applied to test the differences in sediment organic matter, in biomass of a single shoot of eelgrass, abundance of functional feeding groups within time, depth and site.

Simple correlation analyses were carried out for different parameters of eelgrass stand and environmental variables.

3. Results

The average water temperature ranged from 9-21.1 °C in time period April to September. The water temperature was slightly lower for Prangli area compared to values in the West Estonian Archipelago Sea but the differences were not significant (factorial ANOVA, $p>0.05$).

The average percentage of organic matter in the sediment varied in between 0.38-1.47 for the eelgrass bed and between 0.29-1.1 % for bare sand. The content of organic matter was significantly higher in eelgrass stand than in bare sand in Prangli and Saarnaki area (one-way ANOVA, $p<0.05$) The differences in sediment organic content of bare sand and eelgrass stand were not significant for Ahelaid and Sõru area (one-way ANOVA, $p>0.05$). Within areas the differences in the organic content of sediment content were not significant (Factorial ANOVA, $p>0.05$) (Figure 2).

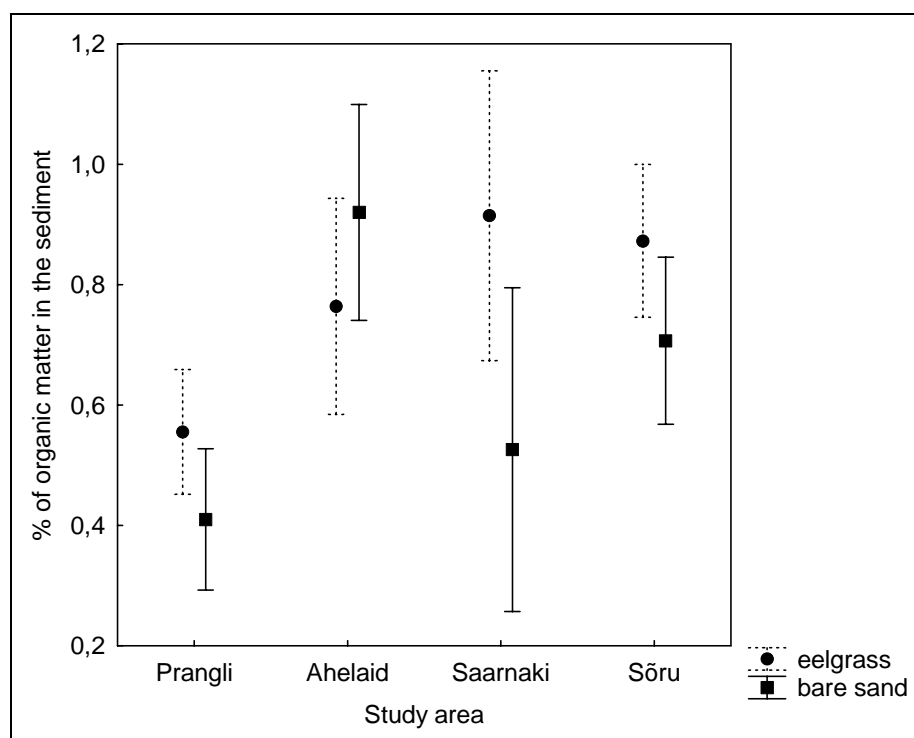


Figure 2. The organic content of sediment within eelgrass stand and in bare sand in studied areas averaged over the period of May-September 2005 (vertical bars denote 0.95 confidence intervals).

In the Prangli area eelgrass prevails in the southern side of the island in the sandy bottoms at depth 2-5 m (500-1200 m from the shore). In Saarnaki area the eelgrass can be found in depth range 2-3 m. This depth is reached already about 50 m from the shore and the shoreline is severely influenced by wave action. In the Ahelaid area the eelgrass is found also in the depth 2-3 m whereas the distance from shore is about 1 km. In the Sõru area eelgrass can be found in depth 2-6 m (dominates in depth 2-4 m, deeper only few specimen can be found).

The highest number of shoots per m² was recorded in Sõru area with 1725 shoots at 2.7 m depth. Similar high density (1650) was recorded for Prangli at 2 m depth. For Ahelaid the values stayed between 125-425 shoots per m² and for Saarnaki higher density was recorded at 375-825 shoots (with one exception of 175 shoots). The overview on the eelgrass communities is summarized in table 1. The lowest density (50 shoots per m²) was observed in the Sõru area at 6 m depth in May (one occasion only and therefore not included in further analysis).

The shoot biomass was significantly related to depth and time period (one-way ANOVA, $p < 0.001$ for both). No statistically significant differences were found in eelgrass shoot biomass between studied areas (one-way ANOVA, $p = 0.78$) (Figure 3).

Different eelgrass parameters: biomass, shoot density, number of leaves per shoot and length were best explained by depth and temperature (mean temperature of 2 preceding months) (BIOENV, $\rho = 0.399$, $p = 0.01$; multiple regression analysis $p < 0.001$, $R^2 = 0.494$, depth = -0.64, temperature = 0.29). The correlation matrix of different eelgrass stand parameters and depth is given in table 2. The negative correlation between shoot density and depth is shown in figure 4.

Altogether 19 macrophytobenthic taxa were recorded in the eelgrass stand (Table 3). The prevailing vascular plants were *Potamogeton pectinatus* and *P. perfoliatus*. *Zannichellia palustris* and *Ruppia maritima* were present on lower depths at lower densities. *Chara* sp was observed only in Sõru area. Most of the algae found within eelgrass stand were drifting. *Ceramium tenuicorne* and *Pilayella littoralis* were also found as epiphytes on higher plants. The presence of drifting algae was recorded throughout the study period (Table 1).

The macrophytic composition of the eelgrass stand was best explained by the combination of depth, slope at 100 m resolution, sediment organic matter and temperature (BIOENV $\rho=0.27$, $p=0.01$). Composition of macrophytes varied significantly between study areas in time and depth (ANOSIM, two-way crossed with replicates, $r=0.605$, $p=0.001$). The species contributing most to the dissimilarity were *Pilayella littoralis*, *Furcellaria lumbricalis* and *Potamogeton pectinatus* (SIMPER) (see also table 3).

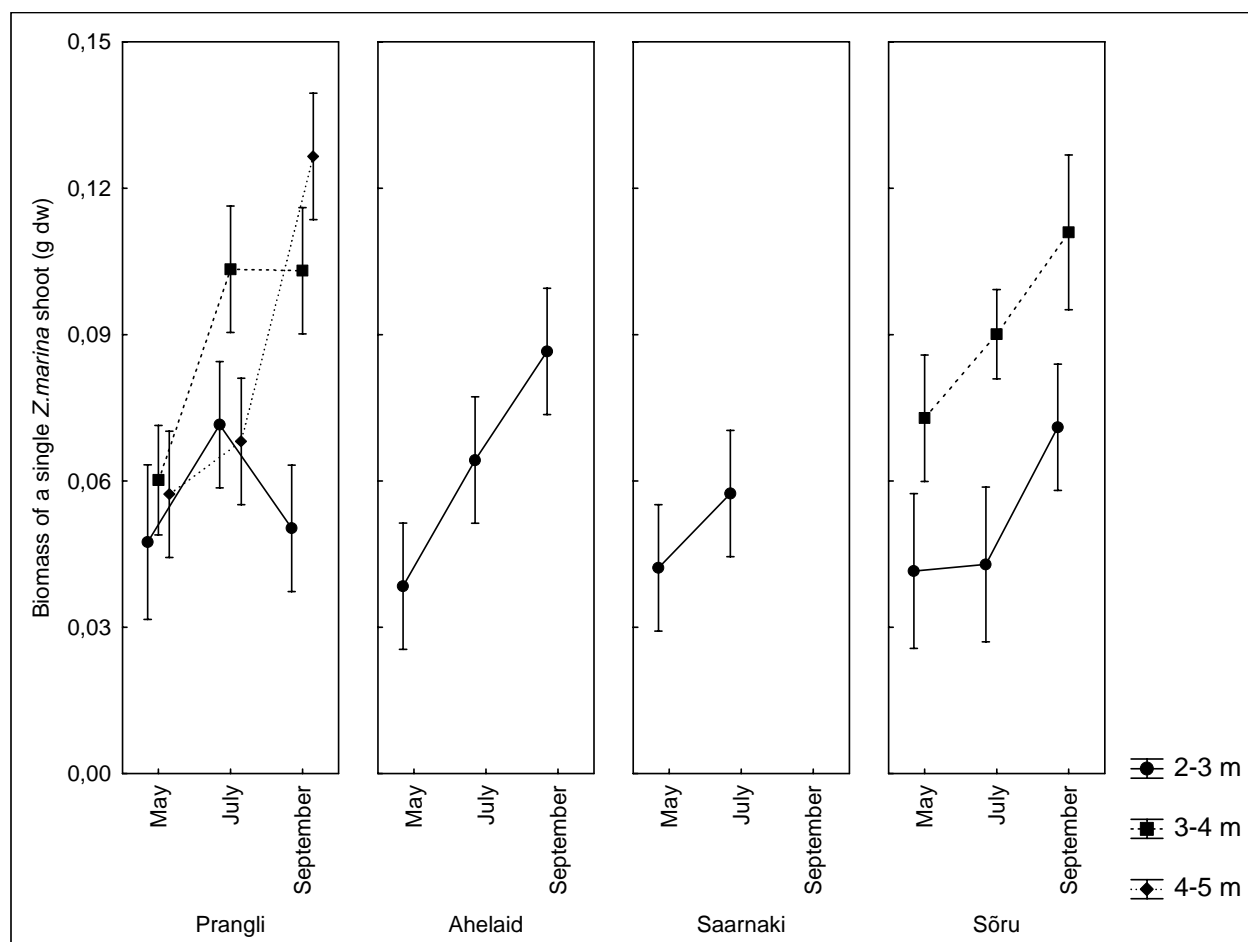


Figure 3. The biomass (g dw) of a single shoot of *Z. marina* (vertical bars denote \pm standard errors) in studied areas during May, July and September in 2005. On each sampling 3 replicates were taken randomly at eelgrass bed.

Table 1. Characteristics of eelgrass stand and standalone shoots shown for different time periods and depths in four studied areas in 2005. On each sampling 3 replicates were taken randomly at eelgrass bed.

Location	Month	Depth range (m)	Total no of studied shoots	Average biomass (g/m ² dw)	StDev of biomass	Average no of leaves per shoot	StDev of no of leaves	Average lenght of longest leaf (cm)	StDev of lenght	Average coverage of eelgrass (%)	Average density (shoots per m ²)	StDev of density	Cover of loose algae (%)
Prangli	May	2-3	46	27.31	2.45	4.21	0.23	13.75	1.70	5	575.00	35.36	100
		3-4	48	16.21	7.64	4.68	0.19	15.63	1.61	61	300.00	220.79	0
		4-5	16	7.80	3.47	4.23	0.25	14.77	0.76	50	133.33	14.43	25
	July	2-3	116	69.42	26.71	4.17	0.21	35.25	3.82	5	966.67	354.73	5
		3-4	44	38.85	15.14	3.83	0.30	45.94	2.39	50	366.67	76.38	5
		4-5	26	15.06	5.63	4.06	0.22	39.71	4.07	80	216.67	57.74	10
	September	2-3	156	65.47	17.46	4.30	0.30	28.09	4.17	5	1300.00	326.92	20
		3-4	33	28.06	4.65	4.82	0.40	40.99	5.25	30	275.00	50.00	1
		4-5	36	37.14	12.80	4.79	0.21	42.50	1.82	70	300.00	108.97	20
Ahelaid	May	2-3	25	8.16	6.08	5.09	0.47	23.37	8.98	20	208.33	144.34	30
	July	2-3	43	23.35	9.67	4.40	0.03	27.20	5.27	50	358.33	62.92	10
	September	2-3	38	26.58	6.74	3.82	0.21	27.05	1.03	20	316.67	101.04	0
Saarnaki	May	2-3	39	14.14	9.04	4.72	0.17	18.15	3.65	60	325.00	132.29	60
	July	2-3	79	37.77	10.24	3.74	0.14	26.45	2.43	60	658.33	175.59	0
Sõru	May	2-3	64	23.97	12.23	4.41	0.29	17.53	4.49	30	475.00	319.18	70
		3-4	19	9.85	4.18	4.81	0.32	29.80	3.25	40	158.33	57.74	0
		5-6	2	0.75	0	4.00	0	9.35	0	1	50.00	0	0
	July	2-3	130	36.93	8.63	3.43	0.27	23.17	2.76	40	1083.33	566.97	20
		3-4	134	45.62	19.96	4.03	0.56	36.46	7.73	20	558.33	326.60	10
	September	2-3	128	68.59	15.30	4.15	0.16	30.32	6.52	5	1066.67	469.26	5
		3-4	13	18.42	11.25	4.97	0.75	34.05	6.26	5	162.50	88.39	5

Table 2. Results of correlation analysis between different parameters of eelgrass stand and depth, loose algae and the inhabiting macrozoobenthos (r values are shown for $p < 0.05$, ns - not significant).

	Depth (m)	Loose algae	Total species	Total individuals	Margalef index	Pielou's evenness	Shannon index	Herbivores	Deposit feeders	Suspension feeders
Total biomass of <i>Z.marina</i>	-0.3458	ns	0.4472	0.7899	0.2888	-0.3384	ns	0.3945	ns	0.3842
No of <i>Z.marina</i> shoots	-0.5608	ns	ns	0.6702	ns	-0.4231	ns	0.2607	ns	ns
Average length of <i>Z.marina</i> shoot	0.3147	-0.3471	0.5061	0.4494	0.4389	ns	0.3187	0.5281	ns	0.2664
Total coverage of macrophytobenthos	0.4855	-0.3322	0.2863	ns	0.3038	ns	0.2762	ns	ns	ns
Biomass of single <i>Z.marina</i> shoot	0.4578	-0.4251	0.3052	ns	0.2843	ns	0.2932	0.2568	ns	0.2898

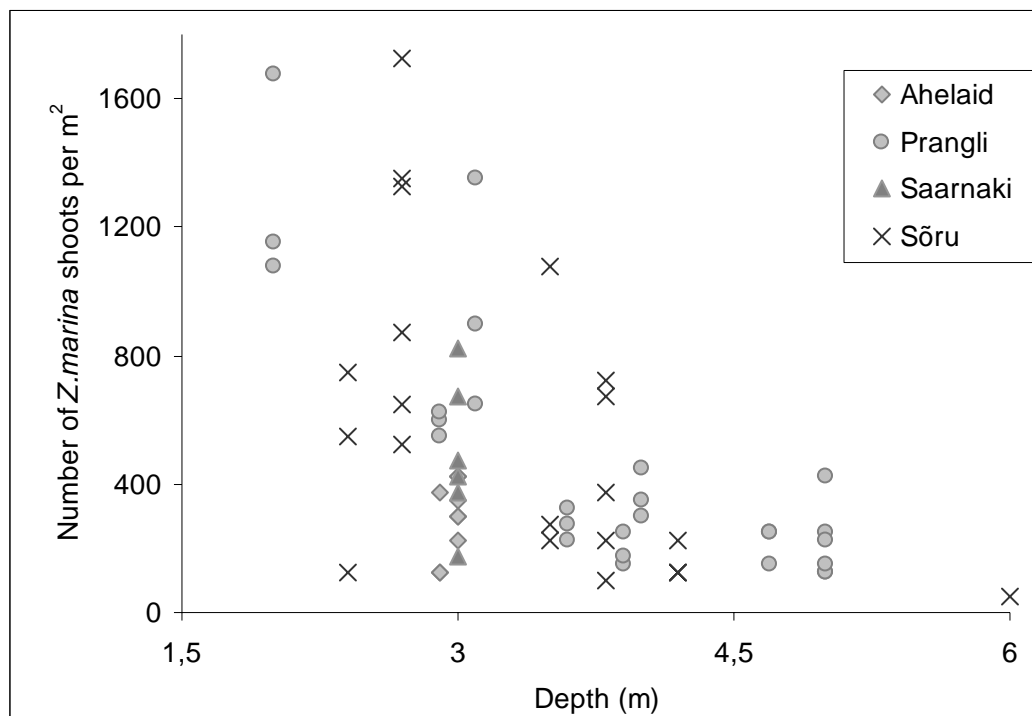


Figure 4. Correlation between depth and density of eelgrass ($r = -0.5608$, $y = 4.0039 - 0.0012 * x$).

Altogether 24 taxa of macrofauna were found inhabiting the eelgrass community (Tabel 4). The highest number of species was recorded for Sõru and Prangli area. The most common

species were *Hydrobia ulvae*, *Cerastoderma glaucum*, *Mytilus trossulus*, *Macoma baltica*, *Mya arenaria* and *Theodoxus fluviatilis*. From active swimmers the most abundant species was *Idotea chelipes*.

The faunal composition differed significantly in time and between study areas (ANOSIM two-way crossed with replicates $r=0.534$, $p=0.01$). The average abundance of *Hydrobia ulvae*, *Mytilus edulis* and *Cerastoderma glaucum* was remarkably lower in May compared to subsequent sampling times (SIMPER). These three species were also responsible for the dissimilarities between study sites (see also table 4). The differences in faunal composition among depth levels were not significant (ANOSIM, $p>0.05$).

The abundance of invertebrates correlated best to the total biomass ($r=0.790$) (Figure 5) and number of shoots of *Z. marina* per m^2 ($r=0.670$). The results of correlation analysis are presented in table 2.

The best variables explaining the faunal composition of eelgrass stand were the combination of temperature and bottom slope at 50 and 1000 m resolution and also the average length of eelgrass (BIOENV, $\rho=0.379$, $p<0.01$).

The abundance structure of macrozoobenthos functional feeding groups was best explained by combination of eelgrass biomass per m^2 , average length of shoots, slope of 50 and 5000 m and mean temperature of two preceding months (BIOENV, $\rho=0.318$, $p=0.01$).

Tabel 3. List of macroalgae and higher plants in *Z. marina* communities in the four studied areas. (+ shows average biomass. + biomass <1 g in dw per m²; ++ 1-10 g; +++ >10 g).

Species	Prangli	Ahelaid	Saarnaki	Sõru
<i>Ceramium tenuicorne</i> (Waern) Kütz.	+	+	+	+
<i>Cladophora glomerata</i> (L.) Kütz.	+	+	+	+
<i>Cladophora rupestris</i> (L.) Kütz.	+			
<i>Coccotylus truncatus</i> (Pallas) Wynne & Heine		++	+	+
<i>Dictosiphon foeniculaceus</i> (Huds.) Grev.	+			
<i>Furcellaria lumbricalis</i> (Huds.) Lamour	++	+++	+	++
<i>Pilayella littoralis</i> (L.) Kjellm.	++	++	++	+++
<i>Polysiphonia fucoides</i> (Huds.) Grev.	+	++	+	++
<i>Polysiphonia fibrillosa</i> (Dillwyn) Spreng.				+
<i>Potamogeton pectinatus</i> L.	++	+	+	+++
<i>Potamogeton perfoliatus</i> L.	+			++
<i>Rhodomela confervoides</i> (Huds.) Silva				+
<i>Ruppia maritima</i> L.			++	+
<i>Sphacelaria arctica</i> Harv.	+	+		
<i>Styctosiphon tortilis</i> (Rupr.) Reinke sensu Rosenv.	+		++	
<i>Zannichellia palustris</i> L.	+			+
<i>Zostera marina</i> L.	+++	+++	+++	+++
<i>Tolypella nidifica</i> (Müller) Leonhardi			+	+
<i>Chara</i> sp				+
Total	12	9	11	14

Tabel 4. List of macrofauna species within *Z.marina* communities in the four studied areas. Numbers indicate on average abundance of individuals per m² over the study period.

Species	Prangli	Ahelaid	Saarnaki	Sõru
<i>Cerastoderma glaucum</i> Brugue	18	228	121	436
Chironomidae	14	11		5
<i>Corophium volutator</i> Pallas	57	36		
<i>Crangon crangon</i> L.				1
<i>Gammarus</i> juv	59	19		7
<i>Gammarus oceanicus</i> Segerstråle	3			1
<i>Gammarus salinus</i> Spooner	7			2
<i>Gammarus zaddachi</i> Sexton	18			
<i>Hediste diversicolor</i> Müller	12		4	27
<i>Hydrobia ulvae</i> Pennant	306	58	25	144
<i>Idotea baltica</i> Pallas	56	19		52
<i>Idotea chelipes</i> Pallas	173	11	4	27
<i>Idotea granulosa</i> Rathke	1			1
<i>Jaera albifrons</i> Leach	10			4
<i>Leptoheirus pilosus</i> Zaddach		3		1
<i>Macoma baltica</i> L.	56	25	21	71
<i>Mya arenaria</i> L.	63	28	38	12
<i>Mytilus trossulus</i> Gould	150	214	46	382
<i>Neomysis integer</i> Leach	1			2
<i>Palaemon adspersus</i> Rathke				1
<i>Praunus flexuosus</i> Müller	1			1
<i>Radix peregra</i> L.				15
<i>Saduria entomon</i> L.	4			2
<i>Theodoxus fluviatilis</i> L.	47	50	17	56
Total no of species	20	12	8	22

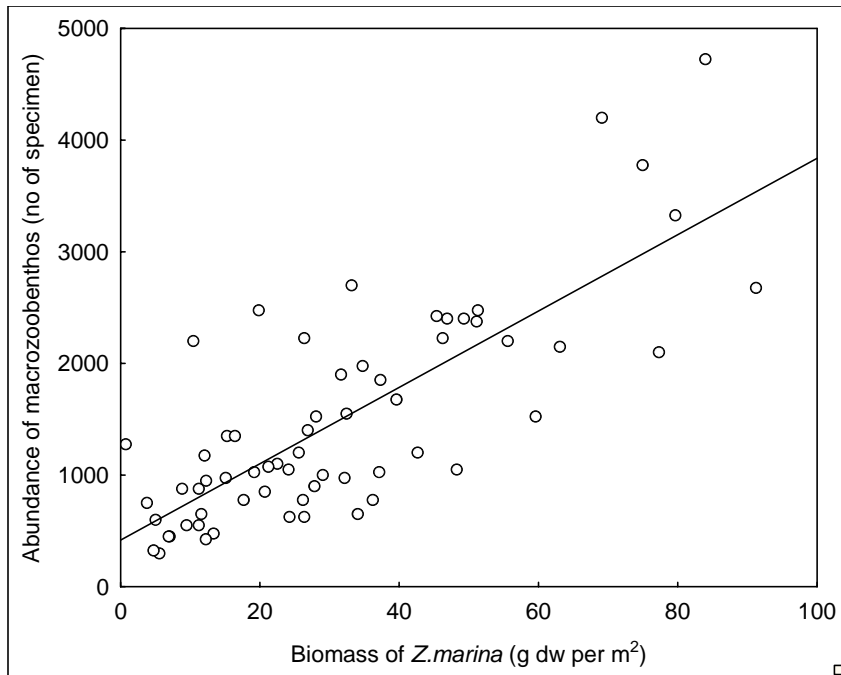


Figure 5. The correlation between the abundance of macrozoobenthos specimen inhabiting the eelgrass stand and the biomass of eelgrass ($r=0.78191$, $y=417.75 + 34.191*x$).

4. Discussion

The organic content in the sediment was higher in the eelgrass stands compared to unvegetated areas. In exposed areas such as Saarnaki and Prangli where the sand is washed through rather intensively the eelgrass presence contributes significantly to sediment organic matter by reducing sediment erosion. Ahelaid and Sõru represent the moderately exposed habitats and sediment organic values between eelgrass stands and areas without vegetation do not differ. The measured values of the sediment organic content within eelgrass stand are in good accordance with the ones determined for in the Finnish Archipelago Sea (0.5-1.5%) (Boström et al., 2003).

Generally, the eelgrass depth distribution is determined with a set of environmental variables of which light and substrate are the most important ones. The change in light climate along the depth gradient controls the photosynthesis activities and thus growth (Moore & Short, 2006). In the West Estonian Archipelago Sea inner parts the prevalence of clayish substrate unsuitable for eelgrass growth in deeper areas and fluctuations in water transparency due to wind-induced water movement (Suursaar et al., 1998) are considered to be responsible for the shallow depth distribution of eelgrass. In Sõru and Prangli deeper areas sand is the dominant substrate and light conditions vary less as the water-masses movement is not as restricted as in the inner West Estonian Archipelago Sea. Substrate and light are not limiting in these areas and this suggest the overall lower depth limit of eelgrass beds in Estonian coastal waters at 6 m depth with the main distribution depth at 2-4 m. Few specimen of eelgrass have been found up to depth 8.4 m but they do not form a distinguishable stand (unpubl. data). In Danish and Swedish waters the reported depth range of eelgrass is 1-10 m with main distribution estimated similarly at 2-5 meters depth (Boström et al., 2003).

In our study sites the eelgrass depth distribution follows the same pattern as presented in Øresund Denmark (Krause-Jensen et al., 2003) – eelgrass creates many small shoots in dense patches in the exposed shallow waters with high light intensity. In deeper areas larger but fewer shoots are found in sparse coverage. The upper limit is controlled mainly by wave action and ice-scouring (Middelboe et al., 2003).

The density of eelgrass in all our study sites varied in between (50)133-1300 shoots per m². The density values are somewhat higher compared to ones reported in Finland where the shoot range is estimated to 50-500 per m² (Boström et al, 2003; Boström et al, 2004) and lower compared to Swedish (maximums reported 1573 and 3600) (Krause-Jensen et al., 2000; Boström et al, 2003) and Danish waters (550-3500 shoots) (Sand-Jensen, 1975; Wium-Andersen & Borum, 1984). Compared to the whole Baltic range the density of eelgrass is surprisingly high especially in Prangli and Sõru where the density at 2-3 m depth exceeds 1000 shoots per m².

The four monitored populations of eelgrass showed similar temporal changes with regard to several parameters. The shoot biomass and length showed a strong seasonal component with minimum in spring and maximum in late summer. The temporal pattern observed proved to be depth and not site specific. Differences within depth ranges were recorded for the Prangli area where the biomass of shoots varied most. The decrease in eelgrass shoot biomass in Prangli shallow area may be a result of self-shading effect on high densities. The density-dependent draw-back in production has been shown by Sand-Jensen and Borum (1983). For the Baltic Sea area the maximum biomass of eelgrass is observed in July and August (Duarte 1989, Olesen & Sand-Jensen, 1994, Boström et al., 2004). Thus it was surprising to discover that the shoot biomass as well as length show a constant increase in most cases till September.

Apart of seasonal maximum of shoot biomass the comparison of our results with the data from the literature on the eelgrass populations in the Baltic Sea on the density, aboveground biomass and length does not show any major differences (Boström et al., 2003; Boström et al., 2004). The biomass values are similar to those estimated also by Trei (1973) for some eelgrass communities in the West Estonian Archipelago Sea (128-300 g/m² (wet weight)). The values below 100 g per m² are typical for the northern and north-eastern part of the Baltic Sea (Boström et al., 2004).

A total of 19 macrophytobenthic taxa were found in samples from eelgrass stand. The vascular plants occurring together with eelgrass are all common on the soft substrate of Estonian coastal waters and can be found also in single-species stands in depth range 1-7 m. (Trei, 1991). The most common species co-occurring with eelgrass are *Potamogeton pectinatus* and *P. perfoliatus*. *Zannichellia palustris*, *Tolypella nidifica* and in some occasions

Chara sp are also rather common. *Ruppia maritima* inhabits mostly more shallower areas (Trei, 1991) and thus is found within eelgrass rarely. The species responsible for the differences in macrophytic composition were the ones found in all study sites. The most variance was related to occurrence of *Pilayella littoralis* which is one of the most common species found in loose algal mats. The growth of algae follows the seasonal pattern and “blooms” in spring (Wallentinus, 1984; Lotze et al., 1999). This is one of the reasons why the coverage of loose macroalgae was greater in May compared to following months.

Macroalgal mats are seen as a sign of the eutrophication and their presence has been mapped in many regions of the Baltic Sea (Kiirikki & Blomster, 1996, Bäck et al., 2000, Vahteri et al., 2000). The shallow coastal waters of Estonia are not an exception (Paalme et al., 2004, present work). The macroalgal blooms can reduce not only eelgrass shoot density (Nelson & Lee, 2001) but also shoot size and biomass and distribution area (Burdick et al., 1994; Bintz et al., 2003; overview in McGlathery, 2001). The negative impact of loose algae on seagrass communities was not highlighted in our studies. But the presence of loose algae can be one of the factors triggering the high abundance of herbivores (Philippart, 1995; Drury, 2005; Gil et al., 2006) and other epibenthic fauna (Pihl et al., 1995). This has been observed in the Wadden Sea where the increase in the abundance of *Hydrobia ulvae* correlated to the increase in periphyton and epiphytes in the *Z. noltii* bed (Philippart, 1995). The herbivores control the epiphyte biomass and thus mitigate the deleterious effects of epiphytes on eelgrass (Montfrans et al 1982; Williams & Ruckelshaus, 1993; Philippart, 1995).

In the studied areas altogether 25 faunal species were found within eelgrass stand. The total number on invertebrates found in the shallow coastal areas of Estonia (depth range 2-5 m) is 74 (raw data, Estonian Marine Institute). Altogether 86 invertebrate species have been recorded in these waters. The average density of benthic invertebrates in the eelgrass stand was estimated 475-3158 specimen per m². Dense eelgrass stands support higher diversity of invertebrates (Homziak et al., 1982; Boström and Bonsdorff, 2000; Moore & Short, 2006; this study). The eelgrass stands support higher abundance and diversity of faunal species compared to bare sand (Sogard and Able, 1991; Curras et al., 1993; Heck et al., 1995). The latest overviews suggest that structure per se rather than the type of structure is important for invertebrates in determining the habitat value of eelgrass stands (Heck et al., 2003).

This study also indicates that abiotic factors rather than biotic interactions control the faunal composition within the eelgrass stand as the variance in faunal communities in observed depths and sites was best explained by seasonality and small-scale slope. It has been proposed that the stressful physical environment of the Baltic sea decreases the importance of biotic interactions in the benthic communities (Kautsky & van der Maarel, 1990; Lotze et al., 2001).

General conclusion on dependence of physiological characteristics of eelgrass communities on prevailing environmental conditions is that certain complex of environmental settings influences the presence or absence of eelgrass community while the growth rate of dominant species and other qualitative community characteristics are not site specific within investigated sea area.

Summary

Seagrasses are marine angiosperms providing important ecological components of coastal ecosystems worldwide. Out of 66 known seagrass species only two inhabit the Baltic Sea and only one, eelgrass *Zostera marina* L. is found in the NE part of the Baltic Sea. Due to wide distribution in temperate coastal waters of Northern Hemisphere eelgrass is rather well studied. For the Baltic Sea studies have been carried out mostly in western part of the sea. In the coastal waters of Estonia where eelgrass grows at its salinity tolerance limit no information on community exist. The aim of this study was to give an overview of main community characteristics and environmental settings of eelgrass communities found in Estonian coastal waters.

Eelgrass communities were studied at four sites – Ahelaid, Saarnaki and Sõru in the West-Estonian Archipelago Sea and Prangli in the Gulf of Finland. Fieldwork was carried out in time period from May to September in 2005. The study period was accordingly to reported eelgrass (maximum) growth period in the Baltic Sea. Sampling was conducted by scuba diving. In total 63 frame samples of eelgrass and associated flora and fauna were collected.

The organic content in the sediment of eelgrass bed was considerably higher compared to unvegetated areas. The eelgrass grew in depth 1.8 to 6 m with main distribution depth at 2-4 m. The eelgrass shoot biomass show constant increase till September. The overall growth pattern was similar for all studied areas but varied within depth. The average shoot density was 50-1300 shoot per m², biomass ranged from (0.75) 7.8 to 37.31 g per m² in spring and from 18.42 to 68.59 g per m² in autumn.

Altogether 19 macrophytobenthic taxa and 24 invertebrate species were recorded in the eelgrass stand. The prevailing vascular plants were *Potamogeton pectinatus* and *P. perfoliatus*. The drifting algae was recorded through out the study period. Most common invertebrate species inhabiting eelgrass stand were *Hydrobia ulvae*, *Cerastoderma glaucum*, *Mytilus trossulus*, *Macoma baltica*, *Mya arenaria*, *Theodoxus fluviatilis* and *Idotea chelipes*. Dense eelgrass stands supported the higher diversity of inhabiting fauna. Structure per se rather than the type of structure seems to be important for invertebrates inhabiting eelgrass stand.

Kokkuvõte

Pika meriheina *Zostera marina* L. kasv ja koosluse struktuur ning nende seos keskkonnateguritega Eesti rannikumeres.

Merelise levikuga õistaimed ei moodusta ühtset taksonoomilist grupeeringut, kuid on vaadeldavad ühtse ökoloogilise grupina. Taimed stabiliseerivad substraati, kus nad kasvavad, suurendavad elupaigalist mitmekesisust ning seega pakuvad paremaid varje- ning toitumistingimusi mitmetele taime- ning loomaliikidele. Teadaolevatest 66 liigist vaid kaks esinevad Läänemeres ning vaid üks, pikk merihein *Zostera marina* L., kasvab ka mere kirdeosas. Merihein on laialt levinud põhjapoolkera rannikuvetes ning seetõttu on liigi bioloogia suhteliselt hästi uuritud. Samas Eesti rannikumeres, kus merihein kasvab oma soolsustaluvuse piiril, on andmeid meriheina koosluste kohta vähe ning piirduvad peamiselt vaid andmetega esinemise/mitteesinemise kohta. Käesoleva töö eesmärgiks on anda ülevaade meriheina kooslustest ning struktureerivatest keskkonnateguritest Eesti rannikumeres.

Meriheina kooslusi uuriti neljas piirkonnas – Ahelaiu, Saarnaki laiu ning Sõru piirkonnas Väinameres ning Prangli saare lähistel Soome lahes. Välitööd teostati ajaperioodil maist septembrini 2005. aastal. Vaatlusperiood valiti vastavalt Läänemere piirkonnas teadaolevale meriheina kasvuperioodile. Proovide kogumine toimus sukeldumise abil, meriheina kooslusest koguti kokku 63 proovi.

Vaatlusalustes piirkondades kasvas merihein sügavusel 1.8-6 m, peamine kasv sügavus oli 2-4 m. Meriheina võsundi maksimumbiomassid registreeriti septembris. Kasv oli sarnane kõikidel uuritud aladel, kuid varieerus erinevatel sügavustel. Keskmise tihedus oli 50-1300 võsundit, biomassi väärtused varieerusid vahemikus (0.75) 7.8-37.31 g m² kohta kevadel ning 18.42-68.59 g m² kohta sügisel. Keskmise pikkus septembris jäi vahemikku 27.05-42.5 cm.

Meriheina koosluses leiti kokku 19 taime- ning 24 selgrootu looma liiki. Kõige sageli esinevateks taimedeks koosluses olid kamm-penikeel *Potamogeton pectinatus* ning kaeluspenikeel *P. perfoliatus*. Lahtine vetikas esines meriheina kooslustes kogu vaatlusperioodi jooksul. Enim levinud selgrootud olid ümarkeermene vesitigu *Hydrobia ulvae*, südakarp *Cerastoderma glaucum*, söödav rannakarp *Mytilus trossulus* ning roheline lehtsarv *Idotea*

chelipes. Tihedad meriheina kooslused toetavad suuremat loomastiku mitmekesisust. Struktuur *per se* pigem kui struktuuri tüüp näib olevat oluline meriheinaga assotsieerunud loomastikule.

Acknowledgements

I am very grateful to my supervisor PhD Georg Martin for support and help in the work process. My deepest gratitude belongs to Kaire Kaljurand, Jonne Kotta, Kristjan Herkül, Priit Kersen, Teemar Püss and Martynas Bucas who contributed to the fieldworks, shared their chocolate and were a great support during the writing period.

References

- Baden, S., Gullstroem, M., Lunden, B. & Rosenberg, R., 2003. Vanishing seagrass (*Zostera marina* L.) in Swedish coastal waters *Ambio* 32: 374-377.
- Bintz, J.C., Nixon, S.W., Buckley, B.A. & Granger, S.L., 2003. Impacts of temperature and nutrients on coastal lagoon plant communities. *Estuaries* 26: 765-776.
- Bonsdorff, E. & Pearson, T.H., 1999. Variation in the sublittoral macrozoobenthos of the Baltic Sea along environmental gradients: A functional-group approach. *Australian Journal of Ecology* 24: 312-326.
- Boström, C. & Bonsdorff, E., 1997. Community structure and spatial variation of benthic invertebrates associated with *Zostera marina* (L.) beds in the northern Baltic Sea. *Journal of Sea Research* 37: 153–166.
- Boström, C. & Bonsdorff, E., 2000. Zoobenthic community establishment and habitat complexity—the importance of seagrass shoot density, morphology and physical disturbance for faunal recruitment. *Marine Ecology Progress Series* 205: 123–138.
- Boström, C., Baden, S.P. & Krause-Jensen, D., 2003. The seagrasses of Scandinavia and the Baltic Sea. In *The World Atlas of Seagrasses*, pp. 27-37. Edited by Green, P. Short, F.T. University of California Press, Berkeley, USA. 298 pp.
- Boström, C., Bonsdorff, E., Kangas, P. & Norkko, A., 2002. Long-term changes of a brackish-water eelgrass (*Zostera marina* L.) community indicate effects of coastal eutrophication. *Estuarine, Coastal and Shelf Science* 55: 795-804.
- Boström, C., Roos, C. & Roennberg, O., 2004. Shoot morphometry and production dynamics of eelgrass in the northern Baltic Sea. *Aquatic Botany* 79: 145-161.
- Burdick, D.M., Kaldy, J.E. & Short, F.T., 1994. Nuisance algal blooms in estuarine waters are a major disturbance to eelgrass communities. IAGLR, BUFFALO, NY (USA). 166 p.

Bäck, S., Lehvo, A. & Blomster, J., 2000. Mass occurrence of unattached *Enteromorpha intestinalis* on the Finnish Baltic Sea coast. *Annales Botanici Fennici* 37: 155-161.

Clarke K. R. & Warwick, R. M., 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Plymouth Marine Laboratory, Plymouth, 2nd edn.

Clarke, K. R. & Green, R. H., 1988. Statistical design and analyses for a “biological effects” study. *Marine Ecology Progress Series* 46: 213-226.

Clarke, K. R., 1993. Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18: 117-143.

Clarke, K.R. & Ainsworth, M., 1993. A method of linking multivariate community structure to environmental variables. *Marine Ecology Progress Series* 92: 205-219.

Curras, A., Sanchez-Mata, A. & Mora, J., 1993. Comparative study of benthic macrofauna collected from sediments within a seagrass bed (*Zostera marina*) and an adjacent unvegetable area. *Cahiers de Biologie Marine*. 35: 91-112.

den Hartog, C., 1970. The Seagrasses of the World. North Holland Publ. Co, Amsterdam, 275 pp.

Drury, D.M., 2005. Effects of grass shrimp (*Palaemonetes* spp.) density manipulations and nutrient enrichment on widgeongrass (*Ruppia maritima*) condition, epiphyte load, and epiphyte functional groups. *Dissertation Abstracts International Part B: Science and Engineering* 65: 4381.

Duarte, C.M., 1989. Temporal biomass variability and production/biomass relationships of seagrass communities. *Marine Ecology Progress Series* 51: 269-276.

Duarte, C.M., Fourqurean, J.W., Krause-Jensen, D., Olesen, B., 2006. Dynamics of seagrass stability and change. Chapter 11, 271-294. In Larkum, A.W.D.; Orth, R.J.; Duarte, C. (Ed.). 2006. *Seagrasses: biology, ecology and conservation*. Springer: Dordrecht, Netherlands, 691 pp.

Frederiksen, M., Krause-Jensen, D., Holmer, M. & Laursen, J.S., 2004. Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. *Aquatic Botany* 78: 167-181.

Gacia, E., Duarte, C.M., Marba, N., Terrados, J., Kennedy, H., Fortes, M.D. & Huang, N., 2003. Sediment deposition and production in SE Asia seagrass meadows. *Estuarine, Coastal and Shelf Science* 56: 909-919.

Gil, M., Armitage, A.R. & Fourqurean, J.W., 2006. Nutrient impacts on epifaunal density and species composition in a subtropical seagrass bed. *Hydrobiologia* 569: 437-447.

Greve, T.M. & Krause-Jensen, D., 2005. Stability of eelgrass (*Zostera marina* L.) depth limits: influence of habitat type. *Marine Biology* 147: 803-812.

Heck Jr., K.L., Hays, G. & Orth, R.J., 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253: 123-136.

Heck, K.L. Jr., Able, K.W., Roman, C.T. & Fahay, M.P., 1995. Composition, abundance, biomass, and production of macrofauna in a New England estuary: Comparisons among eelgrass meadows and other nursery habitats. *Estuaries* 18: 379-389.

Hemminga, M. A. & C. M. Duarte, 2000. *Seagrass Ecology*. Cambridge University Press, 298 pp.

Homziak, J., Fonseca, M.S. & Kenworthy, W.J., 1982. Macrobenthic community structure in a transplanted eelgrass (*Zostera marina*) meadow. *Marine Ecology Progress Series* 9: 211-221.

Kautsky, H. & van der Maarel, E., 1990. Multivariate approaches to the variation in phytobenthic communities and environmental vectors in the Baltic Sea. *Marine Ecology Progress Series* 60: 169-184.

Kiirikki, M. & Blomster, J., 1996. Wind induced upwelling as a possible explanation for mass occurrences of epiphytic *Ectocarpus siliculosus* (Phaeophyta) in the northern Baltic Proper. *Marine Biology* 127: 353-358.

Krause-Jensen, D., Middelboe, A.L., Sand-Jensen, K. & Christensen, P.B., 2000. Eelgrass, *Zostera marina*, growth along depth gradients: upper boundaries of the variation as a powerful predictive tool. *Oikos* 91: 233-244.

Krause-Jensen, D., Pedersen, M.F. & Jensen, C., 2003. Regulation of eelgrass (*Zostera marina*) cover along depth gradients in Danish coastal waters. *Estuaries* 26: 866-877.

Larkum, A.W.D.; Orth, R.J.; Duarte, C. (Ed.). 2006. *Seagrasses: biology, ecology and conservation*. Springer: Dordrecht, Netherlands, 691 pp.

Lotze, H. K., Schramm, W., Schories, D. & Worm, B., 1999. Control of macroalgal blooms at early developmental stages: *Pilayella littoralis* versus *Enteromorpha* spp. *Oecologia* 119: 46–54.

Lotze, H. K., Worm, B. & Sommer, U., 2001. Strong bottom-up and top-down control of early life stages of macroalgae. *Limnology and Oceanography* 46: 749-757.

Marba, N., J. Cebrian, S. Enriquez & C. M. Duarte, 1996. Growth patterns of Western Mediterranean Seagrasses: species-specific responses to seasonal forcing. *Marine Ecology Progress Series* 133: 203–215.

Mattila J., Chaplin G., Eilers M.R., Heck K.L., O'Neal J.P. & Valentine J.F., 1999. Spatial and diurnal distribution of invertebrate and fish fauna of a *Zostera marina* bed and nearby unvegetated sediments in Damariscotta River, Maine (USA). *Journal of Sea Research* 41: 321-332.

McGlathery, K.J., 2001. Macroalgal blooms contribute to the decline of seagrass in nutrient-enriched coastal waters. *Journal of Phycology* 37: 453-456.

Middelboe, A.L., Sand-Jensen, K., Krause-Jensen, D., 2003. Spatial and interannual variations with depth in eelgrass populations. *Journal of Experimental Marine Biology and Ecology*: 1-15.

Moore, K.A. & Short, F.T., 2006. *Zostera*: Biology, Ecology, and Management. In *Seagrasses: biology, ecology and conservation*. pp 361-386. Larkum, A.W.D., Orth, R.J. & Duarte, C. (Ed.). Springer: Dordrecht, Netherlands, 691 pp.

Nelson, T.A. & Lee, A., 2001. A manipulative experiment demonstrates that blooms of the macroalga *Ulvaria obscura* can reduce eelgrass shoot density. *Aquatic Botany* 71: 149-154.

Nielsen, R., Kristiansen, A., Mathiesen, L. & Mathiesen, H. (eds), 1995. Distributional index of the benthic macroalgae of the Baltic Sea area. *Acta Botanica Fennica* 155. The Baltic Marine Biologists Publication No. 18, 51 pp.

Olesen, B. & Sand-Jensen, K., 1994. Demography of shallow eelgrass (*Zostera marina*) populations - shoot dynamics and biomass development. *Journal of Ecology* 82: 379-390.

Orth, R. J., 1977. Effect of nutrient enrichment on growth of the seagrass *Zostera marina* in the Chesapeake bay, Virginia, USA. *Marine Biology* 44: 187-194.

Orth, R.J., Heck, Jr., K.L. & van Montfrans, J., 1984. Faunal communities in seagrass beds: a review of the influence of plant structure and prey characteristics on predator-prey relationships. *Estuaries* 7: 339-350.

Orth, R.J., 1992. A perspective on plant-animal interactions in seagrasses: physical and biological determinants influencing plant and animal abundance. In: John, D.M., Hawkins, S.J., Price, J.H. (Eds.), *Plant-Animal Interactions in the Marine Benthos*. Systematics Association Special Volume 46, Clarendon Press, Oxford, pp. 147-164.

Paalme, T., Martin, G., Kotta, J., Kukk, H. & Kaljurand, K., 2004. Distribution and dynamics of drifting macroalgal mats in Estonian coastal waters during 1995-2003. *Proceedings of the Estonian Academy of Sciences. Biology, Ecology* 53: 260-268.

- Peralta, G., Perez-Llorens J. L., Hernandez I. & Vergara J. J., 2002. Effects of light availability on growth, architecture and nutrient content of the seagrass *Zostera noltii* Hornem. *Journal of Experimental Marine Biology and Ecology* 269: 9–26.
- Perez-Llorens, J. L. & Niell, F. X., 1993. Temperature and emergence effects on the net photosynthesis of 2 *Zostera noltii* Hornem. morphotypes. *Hydrobiologia* 254: 53–64.
- Philippart, C.J.M., 1995. Effect of periphyton grazing by *Hydrobia ulvae* on the growth of *Zostera noltii* on a tidal flat in the Dutch Wadden Sea. *Marine biology* 122: 431-437.
- Pihl, I., Isaksson, I., Wennhage, H. & Moksnes, P.-O., 1995. Recent increase of filamentous algae in shallow Swedish Bays, effects on the community structure of epibenthic fauna and fish. *Netherlands Journal of Aquatic Ecology* 29: 349-358.
- Rasmussen, E., 1973. Systematics and ecology of the Isefjord marine fauna (Denmark). *Ophelia* 11: 1–495.
- Rumohr, H., Brey , T. & S. Ankar, 1987. A compilation of biometric conversion factors for benthic invertebrates of the Baltic Sea: BMB Publ. No. 9: 69 pp.
- Sand-Jensen, K., 1975. Biomass, net production and growth dynamics in an eelgrass (*Zostera marina* L.) population in Vellerup Vig, Denmark. *Ophelia* 14:185-201.
- Sand-Jensen, K. & Borum, J., 1983. Regulation of growth of eelgrass (*Zostera marina* L.) in Danish coastal waters. *Marine Technology Society Journal* 17: 15-21.
- Sogard, S.M. & Able, K.W., 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. *Estuarine, Coastal and Shelf Science* 33: 501-519.
- StatSoft, Inc., 2006. STATISTICA (data analysis software system), version 7.1. www.statsoft.com.

Suursaar, Ü., Astok, V. & Otsmann, M., 1998. The front of Väinameri. EMI Report Series 9: 23-33.

Terrados, J. & Duarte, C.M., 2000. Experimental evidence of reduced particle resuspension within a seagrass (*Posidonia oceanica* L.) meadow. *Journal of Experimental Marine Biology and Ecology* 243: 45-53.

Trei, T., 1973. The phytobenthos of West-Estonian coastal water. Dissertation. Eesti Mereihüloogia laboratoorium. Tallinn. 164 pp + app. *In Estonian* (Lääne-Eesti rannikuvete fütobentos).

Trei, T., 1991. Plants in the Baltic Sea. Tallinn, Valgus. 144 pp. *In Estonian* (Taimed Läänemere põhjal).

Vahteri, P., Maekinen, A., Salovius, S. & Vuorinen, I., 2000. Are drifting algal mats conquering the bottom of the Archipelago Sea, SW Finland? *Ambio* 29: 338-343.

Wallentinus, I., 1984. Partitioning of nutrient uptake between annual and perennial seaweeds in a Baltic archipelago area. *Hydrobiologia*, 116/117: 363–370.

van Montfrans, J., Wetzel, R.L. & Orth, R.J., 1984. Epiphyte-grazer relationships in seagrass meadows: Consequences for seagrass growth and production. *Estuaries*.

Viaroli, P., M. Bartoli, I. Fumagalli & G. Giordani, 1997. Relationship between benthic fluxes and macrophyte cover in a shallow brackish lagoon. *Water Air Soil Pollution* 99: 533–540.

Williams, S.L. & Ruckelshaus, M.H., 1993. Effects of nitrogen availability and herbivory on eelgrass (*Zostera marina*) and epiphytes. *Ecology* 74: 904-918.

Wium-Andersen, S. & Borum, J., 1984. Biomass variations and autotrophic production of an epiphyte-macrophyte community in a coastal Danish area: I. Eelgrass (*Zostera marina* L.) biomass and net production. *Ophelia* 23: 33-46.

Wortmann, J., J. W. Hearne & J. B. Adams, 1997. A mathematical model of an estuarine seagrass. *Ecological Modelling* 98(2–3): 137–149.