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Testing and development of different metrics and indexes describing submerged aquatic vegetation for the assessment of the ecological status of semi-enclosed coastal water bodies in the NE Baltic Sea

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Abstract. A national assessment system for the classification of the ecological status of coastal waters according to the requirements of the EU Water Framework Directive was established in Estonia in the year 2007. The Estonian Phytobenthos Index was used to assess the ecological status of coastal waters based on submerged aquatic vegetation. After the testing period it appeared that the selected method did not respond to anthropogenic pressure in two national water types: the Väinameri and Pärnu Bay. During this study new indexes were developed and validated against pressure for these areas. The PCF index was combined from the proportion of perennial species, charophytes, and *Fucus* spp. This index is suitable for the assessment of the ecological status in the Väinameri area. In Pärnu Bay the depth distribution of higher plants and the proportion of opportunistic species showed the strongest correlation with eutrophication variables. These metrics were combined into the HPO index. The class boundaries for assessing the ecological status of water quality were determined for both indexes. The paper describes the calculation of the indexes.

Key words: Baltic Sea, ecological status classification, submerged aquatic vegetation, coastal water, Water Framework Directive.

INTRODUCTION

According to the European Union Water Framework Directive (EU WFD) requirements, a water quality assessment of coastal waters based on biological quality elements is to be established in all Member States. Submerged aquatic vegetation (macroalgae and angiosperms) is one of the ecological quality elements for the assessment of the status of the coastal waters (European Commission, 2000).

All indicators used for the assessment of the environmental status should be straightforward and relatively inexpensive to measure, sensitive to pressures of the system, respond to stress in a predictable manner, have a known response to disturbances, integrative with other indicators, and exhibit low variability in response (Kuuppo et al., 2006). However, it is complicated to fulfil these requirements because the effect of natural environmental conditions may exceed the influence of the anthropogenic pressure (Schramm, 1999; Carvalho et al., 2006; Kovtun et al., 2009).

A national ecological status classification system for the surface waters based on the type-specific reference conditions developed in accordance with the EU WFD was established in Estonia at the beginning of 2007. The Estonian coastal sea is divided into six national water types, which are covered by a type-specific ecological status classification system. Currently the Estonian Phytobenthos Index (EPI) is used in all coastal water types. The EPI is composed of three metrics: (1) depth distribution of phytobenthos, (2) depth distribution of *Fucus vesiculosus*, and (3) proportion of perennial plant species. Because of the scarcity of suitable substrates, the *Fucus* depth limit is not used in Pärnu Bay. The Väinameri area is too shallow to use maximum depth distribution (Torn and Martin, 2011, 2012). The EPI was developed based on the information from the literature and a limited data set covering the whole coastline. The relations between the used metrics and environmental variables were tested after a few years of experience in using the method. The relationship between the metrics and selected eutrophication variables was documented in the Gulf of Finland, Gulf of Riga, and Western Archipelago. Two water types – Väinameri and Pärnu Bay – demonstrated no significant relationships between any tested metrics and environmental variables (Torn and Martin, 2012). Both areas are characterized by complex and highly variable environmental conditions that depend on the wind direction and the amount of the freshwater inflow (Suursaar et al., 2001; Kotta et al., 2008a, 2008b). Therefore, suitable indicators needed to be developed to fulfil WFD requirements for the water quality assessment based on submerged vegetation. For the development of new indexes suitable for the Väinameri and Pärnu Bay areas an improved approach was used. First, the most indicative parameters based on submerged vegetation data and pressure parameters from a specific water type were identified. These metrics were combined into indexes. Thereafter the index values were validated against the pressure gradient in the studied areas.

The study aimed to (1) test several metrics and indexes against the most common parameters used to describe the eutrophication situation, (2) select suitable metrics and combine these to develop indexes for assessing the ecological status of coastal water bodies, and (3) determine the ecological water quality class boundaries for the selected indexes. The purpose of this approach was to develop a method for ecological status assessment based on macroalgae and angiosperms suitable for the water bodies in semi-enclosed areas with the domination of mixed or soft-bottom substrates.

MATERIAL AND METHODS

Study area

Estonia governs approximately 36 000 km^2 of the Baltic Sea area of which about 10 000 km^2 belongs to the coastal waters according to WFD definitions (sea area extending outwards up to 1 NM from the baseline). The Estonian coastal sea is divided into six national water types, which in turn are divided into 16 water bodies (Torn and Martin, 2011). The present study covers two national types, the Väinameri and Pärnu Bay (Fig. 1). These types are both characterized as shallow semi-enclosed areas, dominated by soft sediment and with only occasional stony areas.

The Väinameri lies between the western coast of Estonia and the West-Estonian Archipelago. Five narrow straits connect the Väinameri area with neighbouring marine areas. The Väinameri national type with a surface area of 1700 km^2 consists of five water bodies: Väinameri, Kassari-Õunaku Bay, Väike Strait, Haapsalu Bay, and Matsalu Bay. In the Väinameri and Kassari-Õunaku Bay the depth is 6–8 m in large areas; the maximum depth is 9 m. In Haapsalu and Matsalu bays the average depth is 1.5–2 m and the maximum depth is 5 and

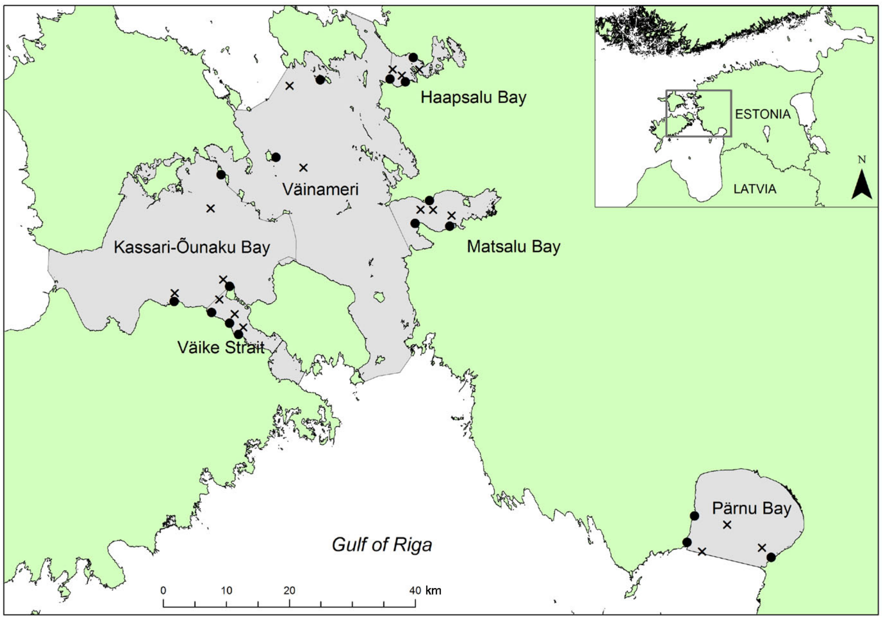

Fig. 1. Location of national types, water bodies, studied transects, and water chemistry stations in the study area. The national types covered by sampling are indicated by light grey. The Väinameri national type includes five water bodies; the Pärnu Bay national type includes one water body. Water bodies are separated by borderlines. Vegetation observation transects are indicated by black dots and water chemistry stations by crosses.

4 m, respectively (Kotta et al., 2008a). In the northern part of the Väike Strait where sampling was done the depth varies from 1.5 to 3.5 m with the maximum of 5 m. Due to the shallowness and domination of fine sediment fractions in the substrate on the bottom, the water transparency is often very poor (Suursaar et al., 2001). The Väinameri is a highly dynamic system, where the situation is mostly determined by water exchange processes forced by the inflow from the Baltic Proper and the Gulf of Riga. Regional salinity of the studied area varies from 6–7 in the western part of the water type to below 0.5 in the eastern parts of Haapsalu and Matsalu bays. Although the pollution load in Haapsalu Bay originating from the town of Haapsalu has decreased markedly after the 1990s, the concentration of nutrients in the sediments is still high. Matsalu Bay is affected by the riverine inflow from the Kasari River (Kotta et al., 2008a).

Pärnu Bay is a water basin in the north-eastern part of the Gulf of Riga, which contains one water body. The Pärnu Bay water body covers the inner part of the bay with the surface area of about 220 km^2. The maximum depth of the studied area is 7.6 m and its average depth is 5 m (Kotta et al., 2008b; Paavel et al., 2011). Hydrological conditions of the bay are formed under the complex influence of meteorological processes, river discharge, and water exchange with the Gulf of Riga. The salinity of Pärnu Bay remains between 2.5 and 5. Pärnu Bay suffers from extensive anthropogenic eutrophication. The town of Pärnu and the Pärnu River are the major sources of nutrients in the bay (Kotta et al., 2008b). Similarly to the Väinameri area, the water always contains particles of soft sediments due to the effect of waves and currents (Suursaar et al., 2002; Paavel et al., 2011).

Data collection

The vegetation of the Väinameri and Pärnu Bay areas was investigated at 17 transects in July or August from 2007 to 2013 (Table 1, Fig. 1). Several transects were visited more than once. Data were collected mainly in the frame of the Estonian National Monitoring Programme. The Estonian monitoring method was based on the HELCOM COMBINE guidelines (www.helcom.fi). Monitoring was carried out along the imaginary transect line placed at an angle of 90 degrees to the shoreline from a predetermined starting point. Observations were carried out after each 1–1.5 m of depth change. At each depth, coverage was estimated within a radius of 2–3 m around each sampling site. Observations were carried out to the deepest limit of vegetation. When the deepest limit was reached the possible occurrence of deeper vegetation was checked by a drop underwater video camera. Along the monitoring transect the total coverage of the phytobenthos community, the coverage of individual species, and the character of the substrate were registered.

For the quantitative description of phytobenthic communities biomass samples were obtained from each different community type identified along the transect. Depending on the length of the transect the biomass samples were taken from

Table 1. Overview of data collection

National type	Water body	Transect	Year
Väinameri	Haapsalu Bay	Haapsalu 1	2007–2013
		Haapsalu 2	2007–2013
		Haapsalu 3	2007–2013
	Matsalu Bay	Matsalu 1	2010, 2013
		Matsalu 2	2012, 2013
		Matsalu 3	2010, 2013
	Kassari-Õunaku Bay	Rannaküla	2010, 2012, 2013
		Kõinastu	2010
		Saarnaki	2010
	Väike väin	Väike väin 1	2008, 2013
		Väike väin 2	2013
		Väike väin 3	2008, 2013
	Väinameri	Heinlaid	2010, 2012, 2013
		Pasilaid	2010
Pärnu Bay	Pärnu Bay	Liu	1995, 1997, 1999, 2000–2002, 2005–2013
		Tahkurand	2007–2013
		Audrurand	2007–2013

5–7 depth intervals. Most commonly samples from depths 0.2, 0.5, 1–2, 2–3, 4–5, and 6–8 m were collected. Quantitative biomass samples were always taken in three replicates; 20 cm × 20 cm frames with an attached bag were used. Samples were stored in a deep freezer and later sorted and determined to species level in the laboratory. Each species was dried separately at 60 °C until constant weight was reached, and the dry weight was determined.

The analyses for water transparency and the seawater samples for chlorophyll *a* (Chl *a*) content and nutrients were collected at the water chemistry monitoring stations neighbouring the vegetation sites and representing the period June–September of the same year as the vegetation data were collected. Water transparency was measured with a Secchi disc. The seawater samples were frozen immediately for further laboratory analyses. Nutrient concentrations (total nitrogen, N_{tot}; total phosphorus, P_{tot}; phosphates, PO_4; nitrites together with nitrates, NO_x) were measured in the laboratory with continuous flow automated wet chemistry analyser Skalar SAN^{plus}. Chlorophyll *a* was filtered through Whatman GF/C glass microfibre filters, extracted in ethanol, and measured using a spectrophotometer (Libra S32). Additionally, light availability at the seabed in 2012–2013 was measured with Odyssey PAR Recorders. Light sensors were kept at 3 m depth in one transect in each national water type during one month (July).

In order to study the influence of eutrophication variables on parameters of submerged macrovegetation, relationships between different environmental variables (water transparency, photosynthetically active radiation (PAR), and nutrient content in sea water) and several biological metrics and indexes (Table 2) were tested

Table 2. Description of the tested indexes and metrics based on submerged aquatic vegetation

Index	Metric	Description	Application	Reference
1. EPI	1.1. Depth distribution of phytobenthos	Deepest occurrence of vegetation	In Estonian coastal water bodies. Depth distribution of phytobenthos is one metric of German index ELBO	Torn and Martin, 2011, 2012
	1.2. Depth distribution of *Fucus*	Deepest occurrence of *F. vesiculosus* or *F. radicans*		
	1.3. Proportion of perennial plant species	Proportion of perennial plant species, calculated on dry biomass basis		
2. ELBO	2.1. Degradation of the community	Ecological value for community was given considering the occurrence and diversity of charophytes and sensitive vascular plant species	In German shallow sheltered soft-bottom lagoons	Selig et al., 2007; Steinhardt et al., 2009
	2.2. Depth distribution of charophytes	Deepest occurrence of charophytes		
	2.3. Depth distribution of higher plants	Deepest occurrence of attached higher plants		
3. MI	3.1. Macrophyte index	Calculated (Eq. 1) based on the number or abundance using coverage data of sensitive and tolerant species	In Swedish shallow sheltered soft-bottom lagoons, European lakes	Penning et al., 2008; Hansen and Snickars, 2014
4. Others	4.1. Proportion of opportunistic species	Proportion of filamentous green and selected brown algae from 0–3 m depth, calculated using coverage data or dry biomass	In German and Greek coastal waters	Kuuppo et al., 2006 and references therein
	4.2. Proportion of charophytes	Proportion of charophytes from 0–3 m depth, calculated using coverage data or dry biomass		Yousef et al., 2001; Selig et al., 2007
	4.3. Proportion of *Fucus*	Proportion of *F. vesiculosus* or *F. radicans* from 1–3 m depth, calculated using coverage data or dry biomass	In German coastal waters	Marbà et al., 2013

using Pearson correlation analysis in the statistical program STATISTICA (StatSoft, 2013). Due to the limited number of measurements in Pärnu Bay, the relationships between light availability at the seabed and macrovegetation indicators were tested in the Väinameri type only.

Description of the tested indexes and metrics

To select a suitable assessment method for the Estonian shallow semi-enclosed soft-bottom areas several metrics and indexes were tested (Table 2). If the index was composed of a complex of separable metrics (e.g. EPI, ELBO, see Table 2), the analyses were made at a metric level.

Some differences from the original method were introduced when necessary due to the local conditions. For example, the depth limit of vegetation in the ELBO approach (Table 2, rows 2.2 and 2.3) is originally based on the maximum depth of 10% of coverage (Steinhardt et al., 2009). The deepest occurrence of a single attached plant has been used in the Estonian monitoring system as it is easily identifiable in typical coastal morphological conditions. On a gentle slope the vegetation coverage decreases gradually (Torn and Martin, 2011).

The Macrophyte Index (Table 2, row 3.1) can be calculated on the basis of the number and abundance of species. In our study both options were used. The Macrophyte Index was calculated using the equation:

$$\mathrm{MI} = \frac{N_\mathrm{S} - N_\mathrm{T}}{N} \times 100, \qquad (1)$$

where N_S is the number or cumulative abundance of sensitive species, N_T is the number or cumulative abundance of tolerant species, and N is the total number or cumulative abundance of species, including indifferent species. Two options to determine sensitive, tolerant, and indifferent species were tested (Table 3): (1) species were classified based on their response to nutrient enrichment following Wallentinus (1979), and (2) species were classified based on several sources according to Hansen and Snickars (2014). Hansen and Snickars excluded filamentous ephemeral algae from calculations.

Additionally, proportions (based both on coverage and biomass) of selected species groups were tested (Table 2, rows 4.1–4.3). An increased nutrient load often leads to an increased abundance of opportunistic macroalgae (Kuuppo et al., 2006 and references therein). All filamentous green algae and two species of filamentous brown algae (*Pilayella littoralis*, *Ectocarpus siliculosus*) were attributed to the group of opportunistic algae (Table 2, row 4.1). As a decline of the occurrence and abundance of *Fucus vesiculosus* and charophytes has been reported in several areas in the Baltic Sea, usually connected with the worsened water quality conditions (Yousef et al., 2001; Munsterhjelm, 2005; Torn et al., 2006; Rohde et al., 2008; Torn, 2008), the proportions of these groups were also tested (Table 2, rows 4.2 and 4.3).

Table 3. Species sensitivity classifications used in the Macrophyte Index calculations following Wallentinus (1979) (MI_1) and Hansen and Snickars (2014) (MI_2)

Species	MI_1	MI_2
Battersia arctica	Indifferent	
Ceramium tenuicorne	Tolerant	
Chaetomorpha linum	Tolerant	Tolerant
Chara aspera	Sensitive	Sensitive
Chara baltica	Sensitive	Sensitive
Chara canescens	Sensitive	Sensitive
Chara connivens	Sensitive	Sensitive
Chara horrida	Sensitive	Sensitive
Chara tomentosa	Sensitive	Sensitive
Chorda filum	Sensitive	Sensitive
Cladophora glomerata	Tolerant	
Cladophora rupestris	Tolerant	
Coccotylus truncatus	Sensitive	
Dictyosiphon foeniculaceus	Indifferent	
Ectocarpus siliculosus	Tolerant	
Fucus radicans	Sensitive	Indifferent
Fucus vesiculosus	Sensitive	Indifferent
Furcellaria lumbricalis	Sensitive	Indifferent
Monostroma balticum	Tolerant	Tolerant
Myriophyllum spicatum	Tolerant	Tolerant
Najas marina	Tolerant	Indifferent
Pilayella littoralis	Tolerant	
Polysiphonia fucoides	Tolerant	
Potamogeton perfoliatus	Tolerant	Tolerant
Ranunculus baudotii	Tolerant	
Ranunculus circinatus	Tolerant	Tolerant
Rhodomela confervoides	Sensitive	
Ruppia cirrhosa	Sensitive	Sensitive
Ruppia maritima	Tolerant	Indifferent
Stictyosiphon tortilis	Indifferent	
Stuckenia pectinata	Tolerant	Indifferent
Tolypella nidifica	Sensitive	Sensitive
Ulva intestinalis	Tolerant	
Zannichellia palustris	Indifferent	Tolerant
Zostera marina	Sensitive	Sensitive

Since the maximum depths of Haapsalu and Matsalu bays are very low (4–5 m), all metrics based on the depth limits of vegetation were excluded from the national water type Väinameri. Both *F. vesiculosus* and *F. radicans* were used for the calculation of metrics including *Fucus* data in the Väinameri area. In Pärnu Bay only *F. vesiculosus* was found, which occurs sparsely because the given area lacks stony substrate and is not sheltered enough for the unattached living form. Therefore all metrics based on only *Fucus* species were excluded from analyses in Pärnu Bay.

RESULTS

Coastal water type Väinameri

The shallow bays of Haapsalu and Matsalu had higher nitrogen concentrations and Chl *a* content and lower transparency compared to other water bodies in the areas included in the water type Väinameri (Fig. 2).

To develop a new index for the assessment of the ecological status of coastal waters in the water bodies belonging to the Väinameri national type several metrics were tested (Table 4). The proportion of perennial plant species was found to be statistically significantly correlated with water transparency, light availability at the seabed, and nitrogen and phosphates concentrations. The proportion of *Fucus* was positively influenced by light availability. Due to controversial effects of eutrophication parameters on the index value, the Macrophyte Index (MI) was omitted from the further index development. Based on the information from the literature (Appelgren and Mattila, 2005; Selig et al., 2007; Steinhardt et al., 2009) the abundance or depth distribution of charophytes was considered as a good metric for assessing the ecological status of a water body. Therefore the proportion of charophytes based on coverage was included in the assessment system.

Proportion of perennial plant species (based on biomass) (P), proportion of charophytes (based on coverage) (C), and proportion of *Fucus* (based on coverage) (F) were combined to form the PCF index. The calculation of the PCF

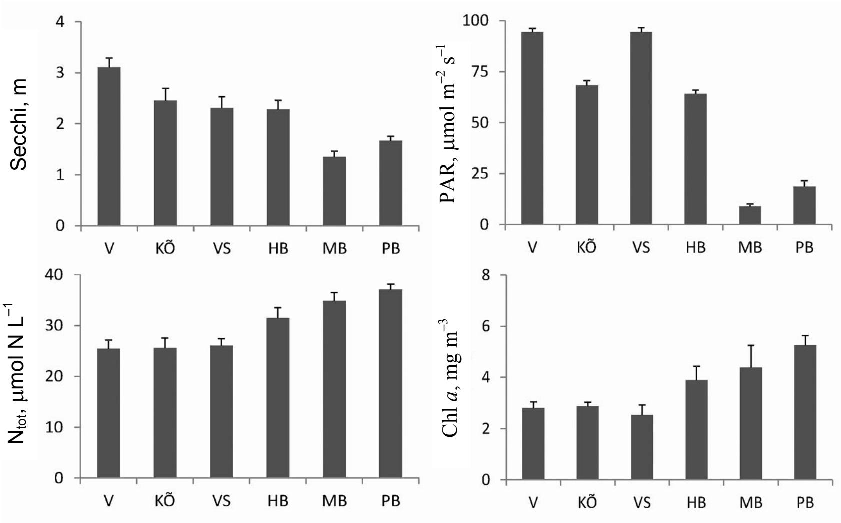

Fig. 2. Values of basic environmental characteristics (average Secchi depth, PAR, and N_{tot}; median Chl *a*; ±SE for all parameters). PAR at the seabed was recorded only in 2012–2013, other parameters are from the time periods listed in Table 1. Water bodies: V – Väinameri, K – Kassari-Õunaku Bay, VS – Väike Strait, HB – Haapsalu Bay, MB – Matsalu Bay, PB – Pärnu Bay.

Table 4. Results of Pearson correlation analysis between metrics of submerged aquatic vegetation and selected eutrophication variables based on data from the Väinameri national type. Statistically significant relationships ($p < 0.05$) are in bold

Metric	Secchi, m	PAR, µmol m^{-2} s^{-1}	NO_x, µmolN L^{-1}	N_{tot}, µmolN L^{-1}	PO_4, µmolP L^{-1}	P_{tot}, µmolP L^{-1}	Chl *a*, mg m^{-3}
Proportion of perennial plant species (biomass)	**0.49**	**0.68**	−0.30	**−0.50**	**−0.35**	−0.04	−0.30
Degradation of the community	−0.08	−0.06	0.14	−0.01	0.19	0.14	−0.04
MI_1 (species count)	0.10	0.11	0.14	−0.05	0.06	−0.01	0.03
MI_1 (coverage)	−0.31	−0.21	0.32	0.29	0.32	0.19	**0.42**
MI_2 (species count)	−0.05	−0.09	0.24	0.18	0.22	−0.13	0.01
MI_2 (coverage)	**−0.35**	−0.32	**0.35**	**0.32**	**0.38**	0.15	0.30
Proportion of opportunistic species (coverage)	−0.09	−0.15	−0.07	0.10	0.06	0.12	−0.08
Proportion of opportunistic species (biomass)	−0.08	−0.01	−0.18	0.09	0.05	−0.05	−0.10
Proportion of charophytes (coverage)	−0.37	−0.35	0.29	0.43	0.30	0.09	0.40
Proportion of charophytes (biomass)	−0.33	−0.42	0.29	0.33	0.15	0.04	0.29
Proportion of *Fucus* (coverage)	0.09	**0.58**	−0.19	−0.20	−0.06	0.24	−0.05
Proportion of *Fucus* (biomass)	0.17	0.21	−0.26	−0.37	−0.22	0.37	−0.11
EQR_{PCF}	**0.41**	**0.63**	−0.27	**−0.42**	−0.29	0.03	−0.19

index followed the principles of the CFR index. The CFR index has been used for the assessment of ecological status based on submerged aquatic vegetation in Spanish coastal areas (Juanes et al., 2008; Carletti and Heiskanen, 2009). For each metric the quality score was given (Table 5). As the proportion of perennial plant species showed the strongest correlation with eutrophication parameters, this metric obtained the highest importance among the selected indicators.

Summed scores of single metrics were used to find the final value of the PCF index:

$$\mathrm{PCF} = \mathrm{P}_{\mathrm{SCORE}} + \mathrm{C}_{\mathrm{SCORE}} + \mathrm{F}_{\mathrm{SCORE}}. \tag{2}$$

The maximum value and therefore also the reference value of the index can be 100. According to the EU WFD requirements, the ecological status of coastal waters should be expressed as the Ecological Quality Ratio (EQR). The EQR is the ratio of the actual level of a biological indicator and the reference value of the metric (European Commission, 2000). For the final EQR of the PCF index, the index value was divided by the reference value (PCF/100) (Table 6). In the PCF index the 50% deviation from the reference condition determines the border between the good and the moderate ecological quality class (Torn and Martin, 2011).

Table 5. Thresholds for proportions of metrics and the corresponding scores for the PCF index

Proportion of metric, %	Score		
	Perennial species (P), %	Charophytes (C), %	*Fucus* (F), %
60–100	60	20	20
40–59	50	15	15
20–39	40	10	10
10–19	10	5	5
0–9	0	0	0

Table 6. Ecological quality class borders for the PCF index

PCF score	EQR	Ecological quality class
>80–100	>0.8–1	High
50–80	0.5–0.8	Good
<50–30	<0.5–0.3	Moderate
<30–10	<0.3–0.1	Poor
<10	<0.1	Bad

As an example, the calculation of the PCF index based on data from the Haapsalu Bay water body (national type Väinemari) is presented. In transect Haapsalu 1, the proportion of perennial plant species (P) was 25, the proportion of charophytes (C) was 0, and the proportion of *Fucus* (F) was 60 in 2013. The proportions were calculated based on biomass samples from five depths (three replicates from each depth) (P) and on eight coverage estimations (C and F). Data from depths 0–3 m were used for the calculation of C, and data from depths 1–3 m were used for the calculation of F. The scores for certain proportions of these metrics are presented in Table 5. For example, if $P = 25$, then $P_{SCORE} = 40$; if $C = 0$, then $C_{SCORE} = 0$; if $F = 60$, then $F_{SCORE} = 20$. Now the EQR for transect Haapsalu 1 can be calculated: $EQR_{PCF\,TR1} = (40 + 0 + 20)/100 = 0.6$. For the final result at water body level the average value of three transects should be used. In our example, in addition the data from transects Haapsalu 2 and 3 were used: $EQR_{PCF\,TR2} = 0.8$, $EQR_{PCF\,TR3} = 0.7$. According to this calculation, the ecological quality class of the water body Haapsalu Bay was good $(EQR_{PCF} = \mathrm{average}(0.6; 0.8; 0.7) = 0.7)$.

A statistically significant correlation was detected between water transparency and nutrient concentration in the water column and the EQR of the PCF index (Table 4).

Coastal water type Pärnu Bay

Pärnu Bay showed the highest total nitrogen and Chl *a* concentrations among all studied water bodies. Its water transparency remained below 2 m (Fig. 2).

To develop a new index for the assessment of the ecological status of the coastal water in Pärnu Bay several metrics were tested (Table 7). A statistically significant correlation was found between the proportion of opportunistic species (calculated based on biomass data) and the concentrations of total nitrogen and Chl *a*. With increased light availability an increase in the depth distribution of higher plants was observed (Table 7).

The depth distribution of higher plants (HP) and the proportion of opportunistic species (O) were combined into the HPO index. The good/moderate class border was determined as an acceptable deviation of 25% from the reference condition (Table 8). Due to the lack of historical data the 5% elevated value from the maximum value registered during the study period was chosen to represent the reference condition for each metric. The reference condition for the depth distribution of higher plants was set as 6 m. The proportion of opportunistic species was subtracted from the maximum proportion and the opposite value of the proportion was used for EQR calculations. The reference condition was set as 80% for the opposite proportion of opportunistic species. The final EQR is calculated as the mean of the normalized EQR values of the two selected metrics:

$$EQR_{HPO} = \frac{EQR_{HP} + EQR_{O}}{2}. \tag{3}$$

Table 7. Results of Pearson correlation analysis between metrics of submerged aquatic vegetation and selected eutrophication variables based on data from the national type Pärnu Bay. Statistically significant relationships ($p < 0.05$) are in bold

Metric	Secchi, m	NO_x, µmolN L^{-1}	N_{tot}, µmolN L^{-1}	PO_4, µmolP L^{-1}	P_{tot}, µmolP L^{-1}	Chl *a*, mg m^{-3}
Depth distribution of phytobenthos	0.25	−0.05	−0.14	−0.30	−0.10	0.31
Proportion of perennial plant species (biomass)	0.08	−0.15	−0.37	−0.11	−0.19	−0.13
Degradation of the community	−0.12	0.27	0.14	−0.04	0.26	0.49
Depth distribution of charophytes	−0.28	0.18	0.28	0.12	0.10	0.46
MI_1 (species count)	0.28	0.06	−0.19	−0.21	−0.34	0.18
MI_1 (coverage)	−0.15	0.10	0.26	0.32	0.30	0.04
MI_2 (species count)	0.04	0.13	−0.03	−0.08	−0.22	0.10
MI_2 (coverage)	−0.24	0.24	0.37	0.22	0.12	0.32
Proportion of opportunistic species (coverage)	−0.07	−0.12	0.17	−0.15	−0.08	0.33
Proportion of opportunistic species (biomass)	−0.28	−0.10	**0.41**	0.08	**0.42**	**0.43**
Proportion of charophytes (coverage)	−0.07	0.01	0.42	0.23	0.34	0.16
Proportion of charophytes (biomass)	0.10	0.21	0.03	−0.04	0.05	0.34
Depth distribution of higher plants	**0.43**	0.03	−0.27	−0.18	0.09	0.17
EQR_{HPO}	**0.48**	0.21	**−0.45**	−0.10	−0.37	−0.18

Table 8. Ecological quality class borders for single metrics and the HPO index

Depth distribution of higher plants, m	Proportion of opportunistic species, %	EQR	Ecological quality class
≥5.4	<8	0.9–1	High
<5.4–4.5	<20–8	<0.9–0.75	Good
<4.5–3.3	<36–20	<0.75–0.55	Moderate
<3.3–1.8	<56–36	<0.55–0.3	Poor
<1.8	≥56	<0.3	Bad

As an example, the calculation of the PCF index based on data from the Pärnu Bay water body from 2013 is presented. In the Liu transect the maximum depth distribution of higher plants (HP) was 2.5 m, the proportion of opportunistic species (O) was 30 (based on biomass data from the depth interval 0–3 m). Reference conditions and data on the sensitivity of species presented in Table 3 were used to calculate the normalized EQR values:

$\mathrm{EQR}_{\mathrm{HP\,TR1}} = 0.3 + (2.5 - 1.8) \times (0.55 - 0.3)/(3.3 - 1.8) = 0.42;$

$\mathrm{EQR}_{\mathrm{O\,TR1}} = 0.55 + (30 - 36) \times (0.75 - 0.55)/(20 - 36) = 0.63.$

The EQR of the transect was (Eq. 3):

$\mathrm{EQR}_{\mathrm{HPO\,TR1}} = (0.45 + 0.63)/2 = 0.54.$

For final assessment the average value of three transects should be used. According to this calculation, the ecological quality class of the water type Pärnu Bay was poor:

$\mathrm{EQR}_{\mathrm{HPO}} = \mathrm{average}(0.54; 0.39; 0.31) = 0.41.$

A statistically significant correlation was detected between the water transparency and the EQR of the HPO index (Table 7).

DISCUSSION

There have been several discussions and attempts to develop a common metric all over the Baltic Sea or even Europe but with no success. A decrease in the depth distribution or abundance of *F. vesiculosus* and *Z. marina* was previously detected in many areas along the Baltic coast (Torn et al., 2006; Carstensen et al., 2013). These species are supposed to be affected by eutrophication, being therefore considered as disturbance-sensitive species and are included in the water quality assessment systems of several countries around the Baltic Sea (Selig et al., 2007; Carletti and Heiskanen, 2009; Balsby et al., 2013). Although different indicators based on seagrass species have been widely used in European seas, the uneven distribution of the species and differences in their dynamics and longevity have caused usage of different assessment methods (Marbà et al., 2013). Differences in the distribution patterns have been hindering the development of a common metric for the whole Baltic Sea area. The Baltic Sea cannot be regarded as a uniform water body, and area-specific ecological responses should be described. Despite the fact that more or less the same ecological parameters are involved in the processes in the different parts of the sea, the severity of the changes may differ between regions. Since the effects and consequences may vary, the area-specific approach to the assessment is advisable (Rönnberg and Bonsdorff, 2004 and references therein).

The assessment method currently used in Estonia, which is based on the quality element of submerged aquatic macrophytes, was shown to have no relation to anthropogenic pressure in two national water types out of six (Torn and Martin, 2012). These two are semi-enclosed coastal areas with soft or mixed substrate. For such areas the assessment method had to be reviewed. During this study, two new indexes were developed to fulfill the requirements of the EU WFD. The PCF index was developed to classify the ecological quality of the coastal water in the national type Väinameri. The HPO index was developed for the national type Pärnu Bay. These indexes have two main strengths: (1) development was based on real measured time series and spatial data, and (2) a relationship with pressures was established. According to Mascaró et al. (2013), responses to pressures may considerably differ from responses along spatial gradients in pressures over time. Temporal data are needed to detect changes in macrophyte communities caused by changes in water quality. Spatial data reduce the uncertainty of the classification of the water bodies. Spatial replication reduces errors by covering a larger area with heterogeneous communities (Mascaró et al., 2013).

The PCF index was composed on the basis of three metrics: proportion of perennial species (calculated from biomass data), proportion of charophytes, and proportion of *Fucus* species (the last two calculated from coverage data). Among the index components greater importance was given to the proportion of perennial species. The proportion of perennial species was correlated with water transparency and nutrient content as demonstrated by data collected from the national type Väinameri. Considering previous findings we concluded that the proportion of perennial species was a suitable metric to be used as part of the assessment method in all areas in the Estonian coastal waters except Pärnu Bay (Torn and Martin, 2011, 2012).

In other studies species composition, depth distribution, and abundance of charophytes are reported as suitable indicators that characterize the ecological quality of coastal waters in the Baltic Sea (Appelgren and Mattila, 2005; Selig et al., 2007; Steinhardt et al., 2009). In our case the proportion of charophytes did not show statistically significant correlation with pressure variables, which is most probably due to the specific environmental conditions of shallow sheltered sea areas. At the same time charophytes were widely distributed and were dominant species in the Väike Strait, Matsalu Bay, and Haapsalu Bay water bodies (Torn and Martin, 2003; Torn et al., 2014). The two last mentioned bays are under the influence of freshwater inflow from rivers, which affects water transparency and nutrient content; water transparency is also influenced by resuspension of soft sediments. Although resilience to the reduced light availability of the production of charophytes has been detected by different authors before (Marquardt and Schubert, 2009; Kovtun-Kante et al., 2014), the loss or degradation of charophyte communities is detected under severe eutrophication pressure (Schubert and Blindow, 2003; Selig et al., 2007). An example from our study area shows that charophyte communities disappeared from Haapsalu Bay under the influence of sewage inflow during the 1970s (Trei, 1984). Communities were recovered after the sewage treatment system had been improved (Trei, 1991).

The HPO index includes two metrics: depth distribution of higher plants and proportion of opportunistic species calculated using coverage data. The depth distribution of higher plants was positively related with water transparency in our data set. In other areas the depth distribution of higher plants is currently used as a part of the German assessment system (Selig et al., 2007; Steinhardt et al., 2009). Based on the current study an increase in the nutrient content in the water column favours the abundance of opportunistic species. It has been shown experimentally that an increase of nutrients does not affect all species of filamentous algae in the same way. Green filamentous algae are affected most severely while there is no influence on the biomass of red filamentous algae (Karez et al., 2004). In our study all filamentous green algae and two species of filamentous brown algae (*P. littoralis*, *E. siliculosus*) were considered as opportunistic species.

All EU Member States need to identify indicators that respond predictably to the changes in the water quality to assess the ecological quality of water bodies according to the EU WFD requirements. However, various difficulties have been faced in fulfilling this task (Carletti and Heiskanen, 2009; Willby et al., 2014). All currently used metrics and indexes were developed based on information gathered from previous investigations, modelling, literature, expert judgement, or a combination of these (Nijboer et al., 2004; Carletti and Heiskanen, 2009). The EU WFD requires that the boundaries between the ecological quality classes should be verified through intercalibration exercises (European Commission, 2000). During the intercalibration exercise a strong correlation between indicators and pressures is needed to be established (Willby et al., 2014). In several countries intercalibration between methods has been delayed due to weakness or lack of statistically sound relationships between developed indicators and common pressure indicators (European Commission, 2013). Therefore accurate corrections of indicators should be imposed (Carletti and Heiskanen, 2009).

There are several reasons for difficulties in finding good indicators that would reflect the ecological status based on macrovegetation. For example, perennial benthic macrophytes have a long lifetime and their growth pattern may therefore reflect the changes of the habitat and water quality conditions with a considerable delay (Scheffer et al., 2001; Kuuppo et al., 2006). It is also a challenge to separate natural variability from human-induced changes in the environment (Kotta et al., 2012). In the Baltic Sea all communities are under the influence of multiple stressors such as variations in oxygen, salinity, weather, riverine inflow, pollutants and contaminants, ship and boat traffic, pressure from fisheries, introduction of non-native species, which all have effects hardly separable in many cases (Rönnberg and Bonsdorff, 2004). The cumulative effect of natural and anthropogenic impacts is higher in sheltered coastal areas such as the Väinameri and Pärnu Bay.

Establishment of the reference conditions required by the EU WFD can be made in a number of different ways for the coastal water bodies. The best option would be to define the reference conditions on the basis of undisturbed or minimally disturbed sites. However, according to common understanding, the Baltic Sea is heavily impacted by the human activities and that is why isolated and undisturbed sites are not currently available (Andersen et al., 2004). If historical data are not available, then an alternative option is to determine the reference conditions based on current data and expert judgement (Carletti and Heiskanen, 2009). In the PCF index the maximum possible value of the index was set as the reference value. The pristine status of water quality in the Baltic Sea is assumed to date as far back as 1900 (Conley et al., 2007; Henriksen, 2009). A systemic investigation of aquatic macrovegetation in the Estonian coastal waters started in the 1960s (Martin, 2000). Thus, the historical approach is not applicable, and we used current data to derive reference condition values for our indicators. Although in some cases the highest present-day values were used as reference cite (Carletti and Heiskanen, 2009), in this study a somewhat strict approach was used. In the HPO index the reference conditions were set as the maximum value registered during the study period elevated by 5%.

Determination of class borders for the assessment of ecological quality is based on the normative definition that characterizes the good class status because in that case most disturbance-sensitive macroalgal and angiosperm taxa associated are present and only a slight sign of disturbance is observed (European Commission, 2000). Boundaries between classes were determined according to the OSPAR Common Procedure for the Identification of the Eutrophication Status of the Maritime Area (Andersen et al., 2004). In the PCF index class borders between the ecological quality classes were determined similarly to the method used for the rest of the Estonian coastal water types, where the 50% deviation from the reference condition determines the border between good and moderate ecological quality classes (Torn and Martin, 2011). The Väinameri area belongs to the good ecological quality class as most of the macrovegetation biomass is formed by perennial species supported by high coverage of charophyte communities or *Fucus* spp. In the sheltered soft-bottom bays *Fucus* occurs as a round-shaped unattached form floating between higher plants and charophytes.

Considering that the natural variability of the HPO index is lower, the boundaries between classes were determined according to the scenario B based on the OSPAR Common Procedure for the Identification of the Eutrophication Status of the Maritime Area (Andersen et al., 2004). According to this scenario, the good/moderate class border is determined as an acceptable deviation of 25% from the reference condition. In Pärnu Bay the ecological quality is of good class as the share of opportunistic species in the vegetation biomass remains below 20% and higher plants extend at least down to 4.5 m depth.

The Macrophyte Index, which is based on the sensitive and tolerant species, has been tested previously for water quality assessment in shallow soft-bottom lagoons in the northern Baltic Proper and the Archipelago Sea (Hansen and Snickars, 2014) and European lakes (Penning et al., 2008). Surprisingly, the

Macrophyte Index showed controversial results between the index and pressure in Estonian semi-enclosed shallow water bodies. There can be several explanations for that. One reason could be that the currently used sensitivity classification is not directly applicable to the conditions of western Estonia. Secondly, for some species used in this classification, the interval of variability of environmental conditions observed in our test sites is not large enough to cause an adequate response to eutrophication pressure. For example, it is known that charophytes can be indifferent to fluctuations in nutrient concentrations up to a certain threshold (Kovtun-Kante et al., 2014).

Our conclusion is that in the case of sheltered, low-salinity and soft-bottom conditions as observed in some limited areas of western Estonia, the standard, widely applied metrics do not work. Instead multimetric indexes such as the HPO and PCF should be used. The applicability of these metrics in other areas has to be tested further, but the principles used in their development could have wider geographical application.

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