Assessment method for the ecological status of Estonian coastal waters based on submerged aquatic vegetation

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Abstract

In this paper water quality assessment system of Estonian coastal sea areas using submerged aquatic vegetation according to the Water Framework Directive of the European Community is described. Estonian coastal waters are divided to 6 national types covering 16 water bodies. The assessment system is based on three monitoring areas for each water body. Three metrics are used for water quality classification system based on phytobenthos: 1) the depth distribution of phytobenthos as the deepest occurrence of a single attached specimen; 2) the maximum depth distribution of *Fucus vesiculosus* as the deepest occurrence of singe plant specimens; 3) the proportion of perennial plant species in the observed community based on dry biomass of attached erect vegetation.
Keywords: classification, coastal water, phytobenthos, water framework directive, ecological quality.

1 Introduction

In connection with the implementation of the EU Water Framework Directive (WFD) in the area of assessment of the ecological status of water bodies, the classification system should be developed. Classification systems should be based on different biological water quality elements indicating the status of water bodies. According to the WFD, three biological quality elements (phytoplankton, benthic invertebrate fauna and aquatic flora) should be used for coastal waters [1].

The principle of the whole assessment procedure is to measure deviation from reference condition. According to the normative definition of the WFD, reference conditions represent a status with no or only minor anthropogenic

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impact. The actual description of reference conditions could be obtained from historical records, modelling exercise or even using an expert opinion. The determination of the ecological status has to be done type-specifically, which means for each type of coastal water reference conditions have to be identified. Biological indicators or metrics used in the assessment system have to react on different levels of anthropogenic pressure. Ecological status assessments shall permit classification of water bodies into five classes – poor, bad, moderate, good and high. The WFD requires that good ecological status of surface water should achieved by 2015 [1].

Aquatic vegetation is used for assessment of water quality for decades both in fresh-water and marine environment [2]. Phytobenthos is good indicator of aquatic environmental health because the autotrophic species inhabiting the phytobenthos zone respond to changes in nutrient concentrations, light climate, toxic contaminants, mechanical stress and other human induced pressures. Responses of the macrophyte community to environmental stress could be regarded as an early warning signal of the community and ecosystem impairment [3]. Eutrophication influences different aspects of underwater vegetation, well documented are the decrease of biodiversity, decrease in vegetation depth penetration, substitution of perennial species with opportunistic filamentous algae [4, 5]. As most of the anthropogenic pressures cause alterations in the physical environment characteristics followed by short- or long-term effects in benthic communities, phytobenthos has proved to be very useful as integrating (both in time and space) biological indicator for conditions of coastal environment.

A national water quality classification system for surface waters based on type specific reference conditions and fulfilling requirements of EU WFD was established in Estonia during early 2007. Here, we present an overview and description of the developed monitoring method and assessment system for implementing the Water Framework Directive based on indicators reflecting the status of phytobenthos in Estonian coastal waters.

2 Method description

2.1 Estonian national typology of coastal waters

Estonia governs approximately 50 000 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 up to 1 nm from the baseline). Estonian coastal sea is divided into six national types. Coastal water types are defined on the basis of hydromorphological conditions as salinity (< 0.5, 0.5 to 5-6, 5-6 to 18-20, 18-20 to 30, > 30), depth (< 30 m, > 30 m), exposure to waves (extremely exposed, very exposed, exposed, moderately exposed, sheltered, very sheltered), mixing conditions (fully mixed, seasonally mixed, permanently mixed), water residence time (days, weeks months), dominating substratum (mud-silt, sand-gravel, cobble-hard rock, mixed sediment) and duration of ice cover (irregular, < 90 days, 90–150 days, > 150 days (Table 1). Ranges of factors are predetermined by

Guidance document [6]. Due to the natural character of the Baltic Sea the actual salinity range of surface water in Estonian coastal area does not exceed 7.5.

Table 1: Description of national types (based on [7]).

Name of type	Southeastern Gulf of Finland	Pärnu Bay	Western Gulf of Finland
Code of type	I	II	III
Salinity (psu)	0.5-(5-6)	0.5-(5-6)	(5-6)-18
Tidal range (m)	<1	<1	<1
Depth (m)	<30 >30	<30	>30
Wave exposure	exposed	moderately exposed	exposed
Mixing conditions	seasonally mixed	fully mixed	permanently stratified
Residence time	days	weeks	days
Substratum	sand-gravel cobble-hard rock	mud-silt sand-gravel	mixed sediment
Ice cover	90-150 days	90-150 days	<90 days

Name of type	Western Archipelago	Väinameri	Gulf of Riga
Code of type	IV	V	VI
Salinity (psu)	(5-6)-18	(5-6)-18	(5-6)-18
Tidal range (m)	<1	<1	<1
Depth (m)	<30 >30	<30	<30
Wave exposure	exposed	very sheltered	moderately exposed, sheltered
Mixing conditions	seasonally mixed	fully mixed	seasonally mixed
Residence time	days	days	days
Substratum	sand-gravel cobble-hard rock	mud-silt sand-gravel	mixed sediment
Ice cover	irregular	90-150 days	<90 days

The Estonian coastal sea area is divided into 16 water bodies (Fig.1). Among those 15 are characterised as natural water bodies and one is attributed the category of heavily modified water bodies. This is due to the dyke constructed more than 100 years ago dividing Väike Strait (strait between Muhu and Saaremaa islands) into two, more or less independent parts without actual water exchange.

In accordance with requirements of the WFD in water bodies which are identified as being at risk of failing to meet their environmental objectives, an operational monitoring programme is carried out. For this purpose, the initial assessment of the state of coastal water bodies was conducted on the bases of

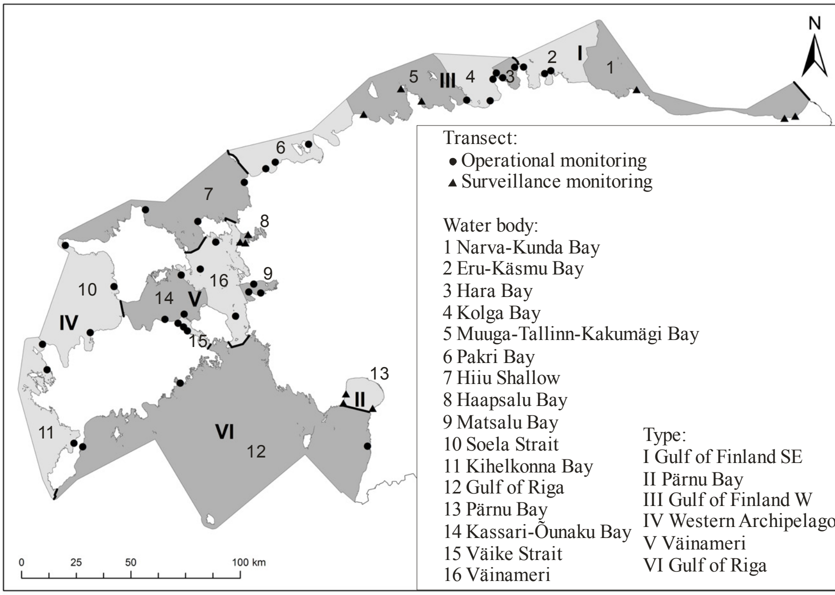

Figure 1: Location of transects, water bodies and types of coastal water in the Estonian coastal area.

previously existing information as well as data collected during the targeted monitoring programme. In Estonia 4 out of 16 water bodies are considered to be operational monitoring areas (Fig. 1). In this water bodies monitoring and assessments carried out every year during the 6 year assessment period. All other water bodies are monitored at least once during the assessment period within the surveillance monitoring programme.

2.2 Sampling procedure for phytobenthos

Each water body includes three phytobenthos monitoring areas. These areas were selected based on previous knowledge on the distribution of phytobenthic communities as well as the character of the dominating substrate. In each sampling area the monitoring transect is placed with fixed start and endpoint coordinates (Fig. 1). Monitoring activities are carried out once per year during the late summer season (July–August).

The Estonian monitoring method is based on HELCOM COMBINE guidelines [8]. Monitoring is carried out along the imaginary transect line placed at 90 degrees to the shoreline from a predetermined starting point. Observations are carried out after each 1 m of depth change. Coverage descriptions are done in a 3–4 m wide visibility corridor. Observations are carried out to the deepest limit of vegetation. When the deepest limit is reached the possible occurrence of deeper vegetation is checked by drop underwater video camera. Along the monitoring transect total coverage of phytobenthos community, coverage of individual species and character of substrate is registered.

For a quantitative description of phytobenthic communities the biomass samples are obtained from each different community type. Depending on the length of the transect biomass samples are taken from 5-7 depth intervals. Most commonly samples from depths 0.2, 0.5, 1-2, 2-3, 4-5 and 6-8 meters were collected. Quantitative biomass samples are taken always in three replicates, 20x20 cm frames with attached bag are used. Samples are stored in a deep freezer and later sorted and determined to species level in a laboratory. Each species is dried separately at 60°C until constant weight is reached and the dry weight is measured with 0.0001 g accuracy.

2.3 Metrics description

In Estonia three phytobenthos metrics are used for water quality classification system: 1) depth distribution of phytobenthos 2) depth distribution of bladderwrack, *Fucus vesiculosus* 3) proportion of perennial plant species in the community. To determine the depth distribution of phytobenthos the deepest occurrence of single attached vegetation is obtained by scuba-diver or by drop video camera. To determine the maximum depth distribution of *Fucus vesiculosus* the deepest occurrence of singe plant specimens are determined visually by scuba-diver. Proportion of perennial plant species in the

Table 2: List of erect annual (A) and perennial (P) plant species.

Species name	Lifetime	Species name	Lifetime
Aglaothamnion roseum	A	*Monostroma balticum*	A
Ceramium tenuicorne	A	*Myriophyllum spicatum*	A
Ceramium virgatum	P	*Najas marina*	A
Ceratophyllum demersum	P	*Percursaria percursa*	P
Chaetomorpha linum	A	*Pilayella littoralis*	A
Chara aspera	A	*Polyides rotundus*	P
Chara baltica	A	*Polysiphonia fibrillosa*	A
Chara canescens	A	*Polysiphonia fucoides*	P
Chara connivens	A	*Potamogeton pectinatus*	A
Chara horrida	A	*Potamogeton perfoliatus*	A
Chara tomentosa	A	*Ranunculus baudotii*	A
Chorda filum	A	*Ranunculus circinatus*	A
Chroodactylon ornatum	A	*Rhizoclonium riparium*	A
Cladophora glomerata	A	*Rhodochorton purpureum*	P
Cladophora rupestris	P	*Rhodomela confervoides*	P
Coccotylus truncatus	P	*Ruppia cirrhosa*	A
Dictyosiphon foeniculaceus	A	*Ruppia maritima*	A
Ectocarpus siliculosus	A	*Schoenoplectus tabernaemontanii*	A
Elachista fucicola	A	*Sphacelaria arctica*	P
Elodea canadensis	A	*Stictyosiphon tortilis*	A
Eudesme virescens	A	*Zannichellia palustris*	A
Fucus radicans	P	*Zostera marina*	P
Fucus vesiculosus	P	*Tolypella nidifica*	A
Furcellaria lumbricalis	P	*Ulva intestinalis*	A
Halosiphon tomentosus	A	*Ulva prolifera*	A
Hildenbrandia rubra	P	*Urospora penicilliformis*	A
Leathesia difformis	A		

phytobenthos community along the whole transect is calculated based on dry biomass of attached erect vegetation aggregated over the whole transect (Table 2).

2.4 Determination of reference conditions and establishments of water quality class boundaries

Type specific reference conditions were defined for abovementioned metrics mostly in combination of historical data and expert judgement. Historical data are available from years 1961-1978 for maximum depth of vegetation and *Fucus vesiculosus* [9, 10]. Unfortunately no previous datasets with acceptable data quality exist for the most of the Estonian coastline. The amount and quality of the historical data vary in different areas. For some types, where historical data was insufficient, modelling was used. In these cases data from recent monitoring surveys were used to establish functional relationships of phytobenthos parameters, water quality indicators and reference conditions of pressure variables (nutrient concentrations, Secchi depth etc.).

Table 3: Type specific reference conditions and water quality class boundaries for the single phytobenthos metrics and EPI.

Metric	**Unit**	**Ref. cond.**	**High**	**Good**	**Moderate**	**Bad**	**Poor**
EPI EQR classes	–		>0.8	0.8-0.5	<0.5-0.3	<0.3-0.1	<0.1
Type 1: Southeastern Gulf of Finland							
Vegetation depth	m	10	>8.0	8.0-5.0	<5.0-3.0	<3.0-1.0	<1.0
Fucus depth	m	5	>4.0	4.0-2.5	<2.5-1.5	<1.5-0.5	<0.5
Perennials %	%	85	>68	68-42.5	<42.5-25.5	<25.5-8.5	<8.5
Type II: Pärnu Bay							
Vegetation depth	m	5	>4.0	4.0-2.5	<2.5-1.5	<1.5-0.6	<0.5
Perennials %	%	60	>48	48-30	<30-18	<18-6	<6
Type III: Western Gulf of Finland							
Vegetation depth	m	15	>12.0	12.0-7.5	<7.5-4.5	<4.5-1.5	<1.5
Fucus depth	m	7	>5.6	5.6-3.5	<3.5-2.1	<2.1-0.7	<0.7
Perennials %	%	90	>72	72-45	<45-27	<27-9	<9
Type IV: Western Archipelago							
Vegetation depth	m	15	>12.0	12.0-7.5	<7.5-4.5	<4.5-1.5	<1.5
Fucus depth	m	7	>5.6	5.6-3.5	<3.5-2.1	<2.1-0.7	<0.7
Perennials %	%	90	>72	72-45	<45-27	<27-9	<9
Type V: Väinameri							
Fucus depth	m	7	>5.6	5.6-3.5	<3.5-2.1	<2.1-0.7	<0.7
Perennials %	%	70	>56	56-35	<35-21	<21-7	<7
Type VI: Gulf of Riga							
Vegetation depth	m	12	>9.6	9.6-6.0	<6.0-3.6	<3.6-1.2	<1.2
Fucus depth	m	5	>4	4-2.5	<2.5-1.5	<1.5-0.5	<0.5
Perennials %	%	80	>64	64-40	<40-24	<24-8	<8

The boundary setting system is based on the reference condition and a deviation of the acceptable reference conditions. According to OSPAR Common Procedure for Identification of the Eutrophication Status of the Maritime Area, the generally acceptable deviation from background concentrations or reference conditions is 50% [11, 12]. Boundaries between classes are determined according to scenario C (acceptable deviation from reference conditions 50%) [13]. The deviations from reference conditions and boundaries for all parameters and classes are given in table 3.

2.5 Assessment method

For the calculation of the Estonian Phytobenthos Index (EPI) the average values of parameters of each transect are used (Fig. 2). Normalized EQRs of three metrics were calculated using the formula:

$$EQR_{metric} = \frac{(P_x - P_l) x (E_u - E_l)}{(P_x - P_l)} + E_l$$

P_x – measured value of parameter
P_l – lower class border of parameter
P_u – upper class border of parameter
E_l – lower class border of EQR value
E_u – upper class border of EQR value.

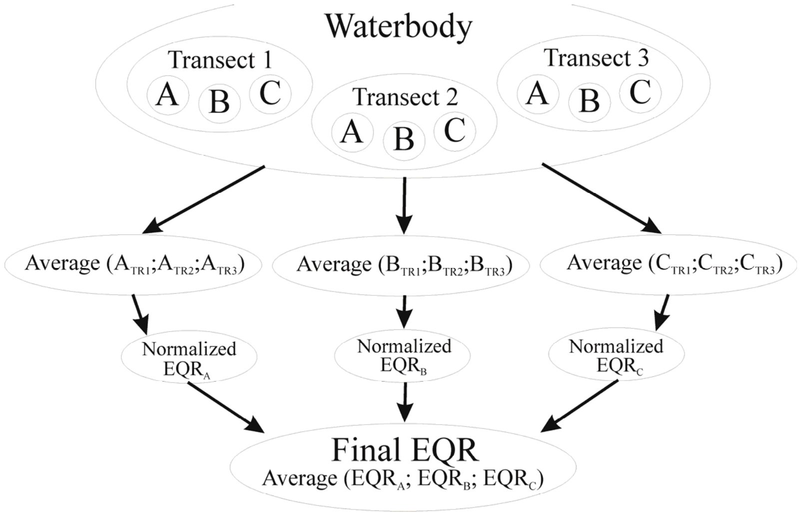

Figure 2: Conceptual scheme of EPI for final EQR calculations. Metrics: A – vegetation depth limit, B – *Fucus* depth limit, C – proportion of perennials.

For the final EQR average of metrics EQRs were used (Fig. 2). So the final assessment is performed using the aggregated data from two to three metrics and three monitoring areas from each water body.

3 Discussion

Currently, most EU countries have implemented the requirements of WFD and have established the water quality classification schemes for their coastal waters [14]. There is no unified guidance and methodological conditions set harmonising the actual monitoring methods and monitoring parameters/metrics but at the same time the results of the assessment and assessment schemes are going to be intercalibrated between countries. Special focus is set to ensure comparability of assessment results between countries. In the Baltic Sea variety of approaches is currently used in phytobenthos monitoring systems and water quality assessment schemes developed for the purpose of the WFD. These approaches differ between the countries and the regions of the Baltic Sea [14]. Estonian phytobenthos monitoring scheme was developed in the middle of 1990ies in close cooperation with Swedish and Finnish experts and was based on methodological guidelines published by Kautsky [15–17]. Monitoring methods follow the principles of the Phytobenthos Monitoring Guidelines adopted by HELCOM [8]. The results of Estonian phytobenthos monitoring programme showed the suitability of these methods for use in water quality assessment schemes already before the implementation phase of WFD [18]. So, for the purpose of the water quality assessment scheme required by the WFD the theoretical background proved to be relevant for the particular sea area was used (e.g. [19, 20]) and the formalised assessment system created following the normative definitions of WFD.

The established assessment system follows all the requirements set by the WFD, describing the changes in distribution pattern, structure of the communities and variability of sensitive species in relation to changes in water quality characteristics. In the case of the Baltic Sea, in most cases the ruling anthropogenic pressure is eutrophication and the described assessment system responds well to the changes in the eutrophication level [8].

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