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The German procedure for the assessment of ecological status in relation to the biological quality element "Macroalgae & Angiosperms" pursuant to the European Water Framework Directive (WFD) for inner coastal waters of the Baltic Sea

Keywords: macrophytes, coastal waters, ecological assessment, water framework directive, Baltic Sea

Content

1 Motivation

The European Water Framework directive (WFD) demands that all European waters attain “good ecological status” (GES) by 2015. For coastal waters there are three mandatory “biological quality elements” (BQE) that are used to assess ecological status: phytoplankton, benthic invertebrates and macroalgae & angiosperms, the latter often summarized as “macrophytes”.

As a first step, coastal waters were divided into types on the basis of physical parameters such as salinity or exposure (“typology”). Coastal waters of the same type were then subdivided into “water bodies”, manageable units whose ecological status has to be reported to the EU every 6 years in future.

For each type and BQE a reference condition then had to be determined. The reference condition generally represents the pristine, pre-industrial condition or the status that would finally develop if all direct anthropogenic influence were to stop, taking into account, however, supra-regional factors such as global warming and species invasions. The options for determining reference conditions are, in decreasing order of reliability, reference sites, historical data, modelling and expert judgement. On the basis of the reference condition, an assessment system had to be developed for each BQE featuring 5 quality classes that classify ecological status from “high” to “bad” via “good”, “moderate” and “poor”. The reference condition is understood as the upper end of the range of the high ecological status and as such is used in the calculation of indices. The WFD only requires that good status be achieved, i.e. some deviation from pristine conditions is accepted. Normative definitions in Annex V of the WFD define the acceptable level of deviation in the BQEs for the classes high to moderate.

Assessment systems for the WFD normally consist of several parameters (“metrics”) that reflect elements of the normative definitions such as the “presence of disturbance-sensitive taxa” or “angiosperm abundance”. For each such metric and the integrated assessment an “ecological quality ratio” (EQR) has to be reported to the EU. The EQR represents the relationship between the observed value for the metric and the reference value (or the relationship between the class borders of an assessment system and the reference condition). It ranges between 0 and 1, with 0 indicating bad and 1 the reference condition. In addition to this original EQR there is a normalized EQR, also ranging between 0 and 1, but with equidistant class ranges so that 1-0.8 represents high, 0.8-0.6 good and 0.2-0 bad status, for example. The normalized EQR (unlike the original) permits comparison of the ecological status reflected by it, and the integration of the normalized EQRs of several metrics (e.g. by calculating the weighted mean or the median) makes it possible to obtain an overall assessment of the ecological status of the respective BQE.

In this report we describe the rationale behind, development and application of the German assessment system for the BQE “macroalgae & angiosperms” in the inner coastal waters of the German Baltic Sea. This system was developed mainly at the University of Rostock and, due to the German acronym of the first funding project, is generally known as the “ELBO” assessment system (Schubert et al. 2003). It was especially developed for the inner Fjords and Bodden (Figure 1), which mainly feature soft bottom communities and conditions of low exposure and low salinity, often with strong gradients and variability. Bodden systems prevail particularly in the eastern part of the German Baltic coast where the original ELBO system was developed and where, mainly due to differences in salinity, two coastal water types were distinguished (German national types B1 (oligohaline) and B2 (mesohaline), see Table 1 for physical features and Figure 1 for distribution). The system was later

extended to the western inner coastal waters (fjords such as the Flensburg and Schlei Fjord, Fig. 1) of national type B2.

In pristine times these systems were characterized by vegetation that consisted mainly of charophytes and spermatophytes and that often covered most of the mostly shallow water bodies.

Eutrophication is the most severe anthropogenic pressure to have negatively influenced these systems and the reason why all German coastal water bodies failed to obtain good ecological status in a preliminary assessment. In the fjords and Bodden, eutrophication reduced the depth distribution of the macrophyte species by enhancing the biomass of phytoplankton and, reducing the irradiance availability in the water column. It also altered the communities in such a way that with successive degradation, more and more charophyte species vanished, and at the extreme end there remained no macrovegetation at all. The ELBO assessment system was therefore developed mainly to indicate eutrophication by using the depth limits of charophytes and spermatophytes and by monitoring defined vegetation elements that depict certain degradation steps, i.e. which prevail under increasing magnitudes of eutrophication.

As it would be impossible to map the total vegetation of most water bodies, it is argued that depth distribution is the best possible approximation of total abundance as demanded by the directive's normative definition since it reflects the total bottom area of the shallow waters (without steep slopes) to offer suitable conditions for the vegetation elements. The degradation chain is believed to cover the normative definition's demands for "disturbance-sensitive taxa" since the prevailing vegetation type used for the assessment often totally dominates the vegetation of these anyway generally species-poor systems.

The assessment system was developed using historical data, (light) modelling and expert judgement. In the next chapter it will be explained how pristine light conditions were modelled and related to the light demands of vegetation elements and how certain vegetation types were defined. It has to be noted that within the set of water bodies assessed using the ELBO method considerable differences may prevail in physical conditions and, thus, in the vegetation types living there. As a result, reference and class limits and vegetation types had to be developed almost on a water body by water body basis.

2 Description of Germany's inner coastal waters

On the basis of salinity conditions, two main types of inner coastal water were defined for the German Baltic coast: oligohaline inner coastal water (German national type B1) and mesohaline inner coastal water (B2, see Fig. 1) (designation based on the salinity scale of the Venice System). In addition, a morphometric definition was used. The water bodies of the inner coastal waters are characterised by natural borders and take the form of coastal lagoons (Bodden), backwaters (Haffe), bays (Buchten) and fjords (Förden). They are characterised by abiotic conditions such as a marked but variable salinity gradient resulting.

Tab. 1 Abiotic parameters for the inner coastal waters of the German Baltic Sea.

	See Figure 1	Salinity Mean (min. – max.)	Secchi depth Mean (min. – max.)	Chlorophyll a Mean (min. – max.)	Depth Mean (max.)	Catch-ment area	Volume	Area
		[PSU]	[m]	[µg l^{-1}]	[m]	[km^2]	[km^3]	[km^2]
Flensburger Förde	FF	18.8 (11.2 - 25.3)	3.5 (1.8 - 5.9)	6.0 (0.2 - 31.4)	15 (38)	327	4.94	330
Schlei:	-	-	-	-	2.5 (13)	667	132	54
Innere Schlei	IS	7.0 (3.2 - 10.4)	0.5 (0.3 - 1.2)	66.5 (16.0 - 127.0)	-	-	-	-
Mittlere Schlei	MS	9.2 (4.4 - 14.1)	0.6 (0.3 - 1.5)	45.9 (0 -99.0)	-	-	-	-
Schleimünde	SM	14.1 (8.9 - 19.9)	1.5 (0.5 - 3.4)	12.6 (0 - 53.8)	-	-	-	-
Kieler Förde	KF	16.7	-	-	10 (22)	730	-	-
Orther Bucht	OB	13.2 (11.2 - 17.2)	-	-	3 (6)	-	-	1.8
Untertrave	UT	11.4 (6.6 - 15.1)	-	-	5.5 (20)	2.7	128	26
Wismarbucht	WB	13.7 (9.9 - 19.7)	3.3 (1.6 - 5.2)	3.5 (0.4 - 12.7)	6 (12.1)	1059	1014	186.9
Salzhaff	SH	12.7 (10.4 - 16.5)	4.2 (2.5 - 5.5)	2.8 (0.7 - 15.0)	2.3 (9.5)	271	0.06	27
Unterwarnow	UW	-	-	-	4 (14.5)	3222	49.6	12.5
Darss-Zingst-Bodden-Chain:	DZBC	-	-	-	2 (10)	1593	0.397	186.6
Saaler Bodden	SB	3.5 (2.3 - 5.7)	0.2 (0.2 - 0.3)	109.6 (38.2 - 187.0)	2.2 (4)	-	174.5	80.9
Bodstedter Bodden	BB	5.1 (3.1 - 7.9)	0.3 (0.2 - 0.3)	76.8 (20.5 - 157.0)	1.9 (10)	-	46.8	24.1
Barther Bodden	BA	6.4 (3.9 - 9.8)	0.5 (0.3 - 0.8)	53.8 (18.8 - 96.4)	1.8 (6.5)	-	34.1	19.4
Grabow	GR	7.6 (5.7 - 11.3)	0.6 (0.4 - 1.0)	37.7 (8.4 - 72.5)	2.2 (4.5)	-	93.8	41.5
Westrügener Bodden	-	-	-	-	1.8 (7.6)	238	300	236
Kubitzer Bodden	KB	8.5 (6.5 - 11.0)	1.6 (0.8 - 3.2)	9.3 (2.3 - 25.7)	-	-	-	-
Rügener Binnenbodden:	-	-	-	-	3.5 (10.3)	312	553.5	159
Wiecker Bodden	WI	9.0 (7.0 -11.8)	2.2 (0.9 - 3.2)	4.7 (1.4 - 16.4)	-	-	-	-
Breetzer Bodden	BR	8.7 (7.8 -11.9)	1.4 (0.6 - 3.4)	13.5 (2.1 - 42.6)	-	-	-	-
Großer Jasmunder Bodden	GJB	8.0 (7.4 - 8.7)	0.9 (0.5 - 1.4)	30.1 (9.3 - 66.4)	-	-	-	-
Kleiner Jasmunder Bodden	KJB	-	-	-	-	-	-	-
Strelasund	ST	7.9 (6.4 - 10.6)	1.1 (0.8 - 1.7)	12.4 (2.8 - 32.7)	-	-	-	-
Greifswalder Bodden	GB	7.1 (5.9 - 9.3)	1.4 (0.5 - 2.4)	11.7 (2.9 - 49.8)	5.8 (13.5)	659.3	2.96	510.2
Peenestrom/Achterwasser		-	-	-	2.6 (16)	5772	429	163.9
Peenestrom	PS	2.6 (0.6 - 6.9)	0.6 (0.3 - 1.6)	76.4 (11.9 - 185.3)	-	-	-	-
Achterwasser	AW	1.5 (0.4 - 3.9)	0.6 (0.3 - 1.0)	69.7 (2.7 - 233.4)	-	-	-	-
Stettiner Haff	-	-	-	-	3.4 (8.5)	122712	3310	687
Kleines Haff	KH	1.5 (0.5 - 3.5)	0.6 (0.3 - 1.0)	71.1 (11.1 - 228.0)	-	-	-	-

The reference plant community types are determined by the physiological tolerance of the species along this salinity gradient, while eutrophication reflects the degradation stages of the plant communities. Plant communities under reference conditions are characterised by charophytes, in some cases including spermatophytes. As degradation progresses only pure spermatophyte communities are found, until these degrade to rudiments of spermatophytes and eventually to a total loss of vegetation.

In contrast, the water bodies of outer coastal waters (national types B3 and B4) have arbitrary borders, 1 sm from the baseline of the coast to the open Baltic Sea. The coastal water type B3 expands along the whole German Baltic coast and the salinity gradient of its water bodies runs from NW to SE. In the west it is sometimes accompanied by type B4, which comprises inner parts of bays that are seasonally stratified. These two water types are much deeper than the inner ones and eutrophication is not expressed as a gradient along water bodies but more locally. The outer coastal waters are not inhabited by charophyte communities. The communities here, under reference conditions, are characterised by stands of the eelgrass *Zostera marina* and the bladder wrack *Fucus vesiculosus* extending to about 10 m depth, and adjacent communities of several perennial red algal species. As degradation increases, the depth limits of these forms decrease and ephemeral macroalgae dominate the communities. The outer coastal waters are mainly dominated (on hard substrata) by macroalgae and (on soft bottoms) by *Zostera marina* as the only spermatophyte.

The investigated inner coastal waters, their borders to the outer coastal waters and the abbreviations for them used in the text are presented in Figure 1.

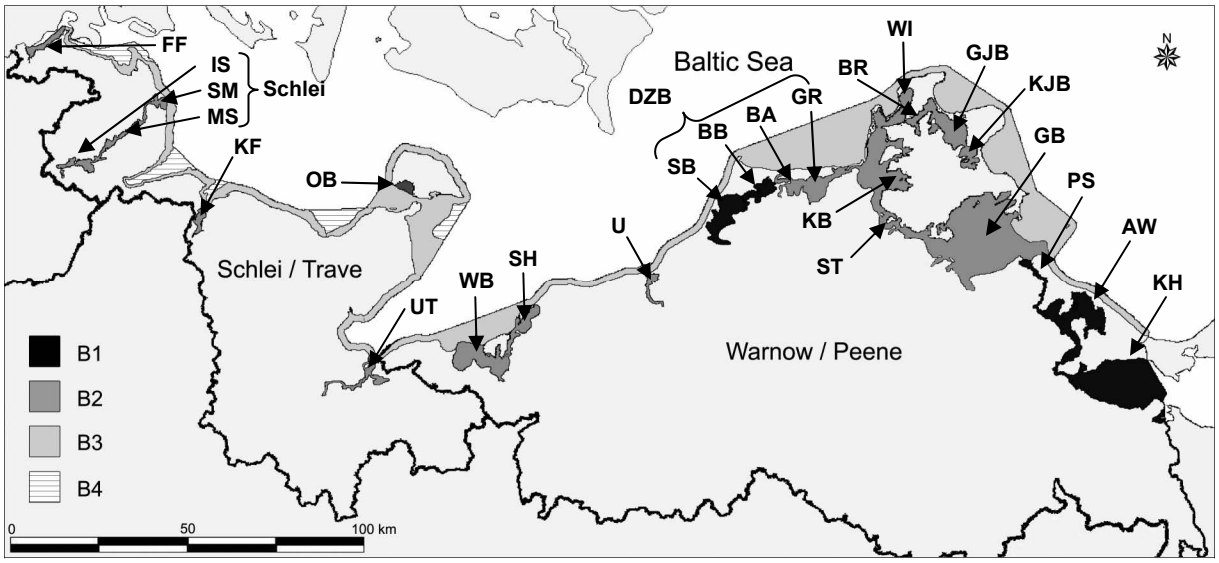

Fig. 1 Typisation of the inner coastal waters of the German Baltic Sea as B1 and B2 waters in accordance with the EU-WFD. The outer coastal waters are also given to indicate their demarcation from the inner coastal waters (FF: Flensburger Förde, IS: innere Schlei, MS: mittlere Schlei, SM: Schleimünde, KF: Kieler Förde, OB: Orther Bucht, UT: Untertrave, WB: Wismarbucht, SH: Salzhaff, UW: Unterwarnow, DZBC: Darss-Zingst Bodden Chain, SB: Saaler Bodden, BB: Bodstedter Bodden, BA: Barther Bodden, GR: Grabow, WI: Wiecker Bodden, BR: Breetzer Bodden, KB: Kubitzer Bodden, ST: Strelasund, GJB: Großer Jasmunder Bodden, KJB: Kleiner Jasmunder Bodden, GB: Greifswalder Bodden, PS: Peenestrom, AW: Achterwasser, KH: Kleines Haff.

3 Methods

The classification system for German inner coastal waters consists of three components (metrics) that are together used to assess the ecological status. The first component uses plant community types as defined degradation chains, sequences of certain vegetation types that prevail under conditions of increasing degradation. The other components are depth limits of charophyte communities and depth limits of spermatophyte communities.

Plant communities were constructed on the basis of recent evaluations of the vegetation conducted during field surveys. Multivariate statistics or further methods of classification such as plant sociological methods can be applied to these data to define distinct vegetation types. After various types of vegetation had been defined using these methods, the types were sorted in a classification system by expert knowledge reflecting degradation chains along anthropogenic degradation (eutrophication) gradients. Eutrophication was characterised using abiotic data from the monitoring programmes of the State Agencies. At the same time, historical data were evaluated to determine the reference conditions of vegetation. Multivariate statistical methods were also applied to reconstruct pristine plant communities.

Since there are no genuine data on pre-industrial depth limits of vegetation and pristine underwater light conditions, the historical depth limits of plants were estimated in several steps using modelling, under the assumption that light availability is the main factor in determining the lower distribution limit of Baltic macrophytes and that other factors, such as exposure, salinity and the magnitude of oscillation have remained similar to pristine conditions. In the first step, pristine light conditions were modelled by Domin et al. (2004) by measuring and using recent winter attenuation coefficients of least influenced water bodies under the assumption that in winter the phytoplankton concentration and their influence on light climate are at a minimum and comparable to pristine light climates. In the inner coastal waters the light-absorbing yellow materials (also cDOM: *chromophoric dissolved organic matter)* and the phytoplankton are, in addition to the absorption properties of the water itself, the main components of light attenuation (Schubert et al. 2001). cDOM mainly drains from the catchment area, especially if it consists substantially of degraded fens and mires. Domin et al. (2004) assumed that in the water of streams flowing into the Baltic Sea, cDOM is 100%, whereas in the open Baltic Sea cDOM is 0%. In the transitional zone, the respective intermediate levels of cDOM and their influence on light climate have to be calculated using salinity measurements. By using light measurements from reference years, the light climate can now be calculated for any depth of water systems of any salinity. In the final step, certain minimum light doses necessary for a positive net photosynthesis were estimated for certain vegetation components using data from the literature and our own measurements. These were then compared to the modelled pristine depth-dependent light doses to determine the depths at which specific vegetation components must have encountered their lower limit in pristine times. Depth limits were calculated for charophytes and spermatophytes as groups, because attempts to use depth limits of species proved to be unfeasible. These maximum depths are then the WFD reference levels for the two metrics “Depth limit of charophytes” and “Depth limit of spermatophytes”. To obtain the 5 classes required by the WFD, the highest ecological status, or “Reference condition”, is defined by these pristine lower distribution borders while the other class borders for the depths of spermatophyte and charophyte communities were defined with a decrease of the penetration depth of light by certain arbitrary steps (Selig et al. 2007). These calculations were carried out for all specified waters

on the basis of the respective salinity values, resulting in depth distribution class limits for every body of water which in turn permitted the calculation of EQR values. For all three metrics (plant community, depth limit of charophyte community, depth limit of spermatophyte community) five classes were defined and by using their normalized EQR they are integrated to one status class assessment for the quality element “angiosperms and macroalgae” or “macrophytes”. The steps are explained in detail again in the following section.

3.1 Determination of vegetation types

The first step in the development of an assessment procedure for the quality element macrophytes was to determine recent vegetation conditions. Plant communities were ascertained using multivariate statistics relating abiotic parameters to vegetation data and other methods of plant sociology in connection with expert knowledge.

3.1.1 Deduction of plant communities

The differentiation of plant communities is a crucial step in the evaluation of inner coastal waters. It demands the sampling of a sufficient number (several hundred) of sites to establish the “presence range” of species, i.e. the full range of abiotic conditions where a species can be found.

There are two kinds of multivariate statistical methods which can be applied to reconstruct plant communities. The first kind relates the presence of plant species to abiotic parameters and thus requires data on species presence and abundance and data on abiotic parameters from the same sites. Here, the method usually applied is CCA (Canonical Correspondence Analysis), though other statistical methods such as the BEST and LINKTREE procedures available in the PRIMER software (www.primer-e.com) directly relate environmental parameters to vegetation data. These methods are preferentially used if the environmental factors of the vegetation determination are not known. The main factors which result can then be interpreted afterwards.

The second kind of multivariate method relates the presence of plant species at different sites to reconstruct plant communities on the basis of floristic similarity. This requires data on species presence and abundance. In this case the assumption is made that species represent the underlying environmental factors behind the vegetation composition. The recommendation here is to use CA (Correspondence Analysis), nMDS (nonmetric Multidimensional Scaling) or cluster analysis.

As it is often the case that no corresponding abiotic parameters are available for historical vegetation data, only the second kind of method can be applied to historical data.

Two further methods of this second kind exist which are similar in principle to a cluster analysis except for the fact that they are not based on a mathematical algorithm but on species lists of every investigated site produced by an expert and arranged in a table according to sites which evidence similar species presence. These methods are “plant sociology” (Pflanzensoziologie; Braun-Blanquet 1964) and the “plant community concept” (Vegetationsformenkonzept; Schlüter 1984). The first method is commonly used in the classification of vegetation, but it was developed for terrestrial ecosystems and is based on the assumption of homogeneous plant

populations. The anthropogenically caused degradation stages of macrophyte vegetation evaluated by the WFD do normally not represent homogeneous plant communities with the result that this method cannot be used to reconstruct/ascertain plant communities. The WFD requires a procedure that can be used to assess anthropogenical degradation, and hence degradation as a composite parameter is used to deduce degradation stages. The multivariate statistical methods mentioned above should be used to verify the determined plant communities in relation to degradation. For the ELBO method, the “plant community concept” was used, a concept primarily based on the expert classification of species lists according to floristic similarity and degradation. Berg et al. (2001) served as orientation for the definition of plant communities in Mecklenburg-Vorpommern, and Behrens (1982) for the Darss-Zingst Bodden chain. It is well known from this and other literature that species lists featuring charophytes represent low degradation or high and good status. Moderate and advanced degradation stages are characterised by species lists without charophytes. It was possible, following this method, to distinguish both “charophyte communities” and “spermatophyte communities” (Table 2).

Using this procedure, four charophyte communities were distinguished: Bodden Large Charophyte (BLCh), Bodden Small Charophyte (BSCh), Charophyte *Ruppia cirrhosa* (ChRuci) and Charophyte *Zostera marina* (ChZoma). In the case of the BLCh and BSCh communities the plant community is defined on the basis of a minimum of two charophyte species. For the two other communities ChRuci and ChZoma only one charophyte species is required, in addition to spermatophytes (Table 2).

Among the spermatophyte communities 8 recent plant communities were distinguished: *Zostera noltii- Ruppia cirrhosa*- (ZoRu), *Najas marina*- (Nm), *Ruppia cirrhosa*- (Ruci), *Zostera marina*- (Zoma), *Ceratophyllum-Potamogeton*- (CeraPot), *Potamogeton*- (Pota), *Ranunculus*- (Ranu) and *Myriophyllum-Potamogeton* (MP) (Schubert et al. 2003). These plant communities are only valid in the absence of charophytes, as the indicative value of charophytes is regarded as higher. A spermatophyte community is constituted by one or more spermatophyte species, as indicated in Table 2.

In addition to the charophyte communities a “charophyte remnant” (ChR) was defined which consists of just one charophyte species and no additional spermatophytes (compare to ChRuci and ChZoma, Table 2). All plant communities which do not contain charophytes and cannot be assigned to spermatophyte communities will be defined as “spermatophyte remnant” (SpR). If these remnants only exist in a rudimentary form (mean cover < 10 %), the vegetation is defined as “no plant community” (npc). If no vegetation at all is found, the vegetation is defined as “no vegetation” (nv). 16 plant communities, plant remnants and other conditions of submersed vegetation which contribute to the evaluation of the inner coastal waters resulted from these definitions (Tab. 2).

Species groups from a single survey can only be allocated on the basis that if a minimum requirement is not reached for a plant community, the survey is allocated to the next more degraded classified plant community. Allocation should start with charophyte communities. If there are charophytes in the survey it can possibly be assigned to one of the “charophyte communities”. If there are no charophytes in the survey, attempts should be made to assign the survey to a “spermatophyte community”. If there is only one charophyte or spermatophyte species, attempts should be made to allocate the survey to the “charophyte remnant” or “spermatophyte remnant”. If this is not applicable, the survey should be assigned to

“no plant community” with charophyte or spermatophyte cover < 10%. Should no species exist the survey is allocated to “no plant community”.

Tab. 2 Definition of the submersed plant communities. For each plant community a score was allocated - the “ecological value of plant community (EV_{PC})” - on the basis of the degradation chains (see Chapter 3.3.1).

Plant community	Diagnostic species	EV_{PC}
Charophyte communities		
Bodden Large Charophytes **(BLCh)**	*Chara tomentosa* and *C. liljebladii* and/or *C. baltica*, *C. horrida* (minimum 2 species)	0.8
Bodden Small Charophytes **(BSCh)**	*Chara aspera. C. baltica. C. canescens. Lamprothamnium papulosum. Tolypella nidifica* (minimum 2 species)	0.8
Charophyte-*Ruppia cirrhosa* **(ChRuci)**	*Chara aspera* and/or *C. baltica* and/or *C. canescens*, *Ruppia cirrhosa* and/or *R. maritima* (minimum 1 charophyte species)	0.6
Charophyte-*Zostera marina* (**ChZoma)**	*Chara aspera. C. baltica. C. canescens. C. liljebladii*, *Tolypella nidifica*, *Zostera marina* (minimum 1 charophyte species)	0.6
Spermatophyte communities		
Zostera noltii- Ruppia cirrhosa (**ZoRu)**	*Ruppia cirrhosa* and/or *R. marittima*, *Zostera noltii*	0.4
Najas marina **(Nm)**	*Najas marina*	0.4
Ruppia cirrhosa **(Ruci)**	*Ruppia cirrhosa* and/or *R. maritima* without indicative species	0.3
Zostera marina **(Zoma)**	*Zostera marina* without indicative species	0.3
Ceratophyllum-Potamogeton **(CerPot)**	*Ceratophyllum submersum*, *Potamogeton crispus* and/or *P. pectinatus*	0.3
Potamogeton **(Pota)**	*Potamogeton crispus*, *P. lucens*, *P. perfoliatus*	0.3
Ranunculus **(Ranu)**	*Ranunculus baudotii*, *Schoenoplectus*	0.3
Myriophyllum-Potamogeton **(MP)**	*Myriophyllum spicatum* and/or *Potamogeton pectinatus* without: charophytes, *Najas, Zostera, Ruppia*	0.2
Plant remnants		
Charophyte remnants **(ChR)**	Only one species with and without indicative species like *Ruppia* sp. und *Zostera marina*	0.4
Spermatophyte-remnants **(SpR)**	Only one species with a degree of presence > 2, cover > 10%	0.3
Other conditions of vegetation		
no plant community **(npc)**	Only single plants with a degree of presence ≤ 2, cover ≤ 10%	0.0
no vegetation **(nv)**	No species existing	0.0

3.1.2 Allocation of plant communities to the water body types B1 and B2

The communities defined above also have to be assigned to the appropriate water bodies (types B1 and B2). All recent (1999 to 2007) data records such as species lists were assigned to a plant community for every investigated site. Mean salinity could also be related to every site using data from the monitoring programmes of the State Agencies. As a result, a salinity value now exists for each plant community of a site. The allocation of salinity data to the plant communities makes it possible to calculate mean salinity and a salinity range for every plant

community. In Table 3 the occurrence of these plant communities in the water bodies of types B1 and B2 is given.

Tab. 3 Allocation of the plant communities to subtypes of water types B1 and B2. D: data situation uncertain, because there is no or uncertain historical proof, but possible according to physiological laboratory tests.

Plant community	**0.5-3 PSU (B1a)**	**3-5 PSU (B1b)**	**5-10 PSU (B2a)**	**10-18 PSU (B2b)**
Bodden Large Charophytes **(BLCh)**	X	X	X	-
Bodden Small Charophytes **(BSCh)**	X	X	X	-
Characeen-*Ruppia cirrhosa* **(ChRuci)**	D	X	X	X
Characeen-*Zostera marina* **(ChZoma)**	-	X	X	X
Myriophyllum-Potamogeton **(MP)**	-	X	X	X
Najas marina **(Nm)**	X	X	X	
Ruppia cirrhosa **(Ruci)**	D	X	X	X
Zostera marina **(Zoma)**	-	D	X	X
Zostera noltii-Ruppia cirrhosa **(ZoRu)**	-	D	X	X
Charophyte remnants **(ChR)**	X	X	X	X
Ceratophyllum-Potamogeton **(CerPot)**	X	-	-	-
Ranunculus **(Ranu)**	X	X	X	-
Potamogeton community **(Pota)**	X	X	-	-
Spermatophyte remnants **(SpR)**	X	X	X	X
no plant community **(npc)**	X	X	X	X
no vegetation **(nv)**	X	X	X	X

3.2 Reference conditions

The evaluation of reference conditions is the next step in the development of the assessment system. The WFD suggests that comparison be made with systems that have not recently been (anthropogenically) influenced. Since there are no water bodies in pristine condition on the German Baltic coast today, the other options provided by the WFD, analysis of historical data, modelling and expert judgement, had to be used to define reference status.

3.2.1 Using historical data to ascertain pristine vegetation types

Sufficient historical data are available for the Baltic Sea area as plant collecting activities date back to before Linné. The problem is that while species lists can be deduced from this material, depth distribution, lower distribution border, cover and exact location cannot. Two problems arose concerning the historical data:

1. Taxonomical changes and neophytes
2. Changes in the abiotic conditions of the sites (in addition to eutrophication)

The taxonomic problem was overcome using the checklists by Nielsen et al. (1995) and Schories and Selig (2008) which enabled us to reconstruct changes in the nomenclature**.** In the case of neophytes we referred to the data base NOBANIS (www.nobanis.org) which is updated regularly. The second problem was solved by recent typology which reflects the actual state in terms of physical and salinity conditions. By analysing herbarium material and historical literature, as much information as possible on the species, their location and the historical collection method was gathered.

The determination of pristine plant communities on the basis of historical data is a crucial step for the validation of the recently found plant communities, which determine the recent reference conditions. Four pristine communities which contain charophytes, typified by Blümel et al. (2002), validated the recent communities Bodden Large Charophyte (BLCh), Bodden Small Charophyte (BSCh), Charophyte-*Ruppia cirrhosa* (ChRuci) and Charophyte-*Zostera marina* (ChZoma) (see Chapter 3.1.1). All the pristine charophyte communities typified contained at least two charophyte species and thus characterise the upper end of the high stage of the ecological condition as reference condition.

3.2.2 Measuring pristine light attenuation coefficients along a salinity gradient

For the assumption of pristine light conditions in contemporary water bodies two conditions should be kept. Firstly, light attenuation should be measured after a cold period in winter, ideally around mid January, when the water temperature is about 4 °C and phytoplankton concentrations are at a minimum due to light limitation and low temperature. Secondly, the light measurements should be performed in a water body with a small catchment area including a low proportion of degraded bogs. In this case the cDOM inflow will be at a minimum.

Underwater irradiance should be measured with spectrophotometers using the following procedure, described by Schubert et al. (1995): measurements should be taken at a minimum of 5 depths, ideally around noon, and the number of measurements along the salinity gradient must be adapted to the particular conditions. Measurements must be taken at the points of highest and lowest salinity of the water as well at 3 to 5 sites between these salinity borders. A water system should be chosen that has a salinity gradient in the relevant range and which can be assumed to be only slightly anthropogenically influenced. For these reasons we used the water body “Salzhaff” (Fig. 1) and based the model on winter measurements along the local salinity gradient (around 10 km long). Light attenuation was measured at five places in the Salzhaff to a depth of 60 cm with a resolution of 10 cm by means of a spectrally dissolving underwater light meter (MACAM SR-9910, Macam Inc.

Livingston, Scotland). A spectrum of 400 to 700 nm (PAR: Photosynthetic Active Radiation) was measured.

The general idea is to use measurements of each wavelength of the total PAR spectrum to determine individual attenuation coefficients by means of regression analysis. This is necessary because measuring the photon flow density of the whole spectrum would lead to an overestimation of the light attenuation coefficients. Only where the regression of a single wave length lacks significance is the mean photon flow density of all measured wavelengths calculated and the regression analysis performed using this mean value (Schubert et al. 1995).

The light attenuation coefficients (k_0) were determined via linear regression of the spectral photon flow density (ln E_λ) of each wave length against water depth. The quality of the respective values can be estimated on the basis of F statistics Sachs (2002) by calculating the quotient of the squares of the standard deviations of the photon flow density and depth values. If the coefficient of determination of the regression is significantly different from zero, it can be assumed that depth has a significant influence on the photon flow density (E_λ). The next step is to calculate the mean k_0 of all these wave lengths. It should be taken into account that significance will seldom be achieved in spectral regions with low attenuation because of the high variation of values compared to the low slope of the regression line. Should the regression be of no significance (low attenuation), PAR attenuation should be calculated independently by summing up the photon flow densities (PFD) of the whole spectral range between 400 and 700 nm for each depth and then calculating the light attenuation coefficient (k_0) by linear regression of this sum against depth. The significance of the regression of the summed PFD against depth was evaluated using the F test (as described above). This means of calculating the PAR attenuation coefficient should be taken as the “minimum requirement” for the acceptance of a measurement series.

Light attenuation coefficients were obtained for various sites along the salinity gradient of the water body Salzhaff.

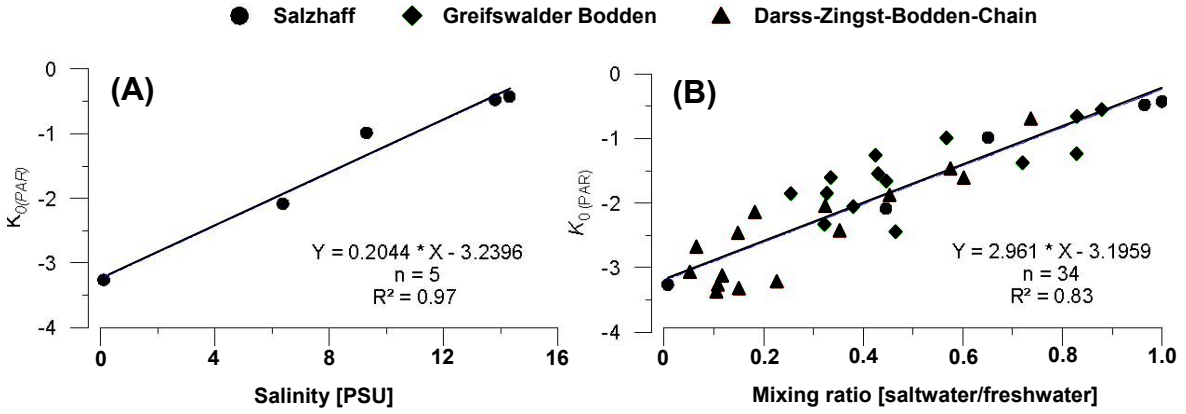

Fig. 2 Regression analysis of the salinity (A), the mixing ratio (B) and the light attenuation coefficient for three water bodies with a salinity gradient on the German Baltic Sea.

The salinity can now be plotted versus the light attenuation coefficient $k_{0\ (PAR)}$ (Fig. 2). The resulting regression for the Salzhaff was:

$$k_{0\,(PAR)} = 0.2 * \text{Salinity of the site} - 3.2 \qquad (1)$$

Using this formula (1) k_0 can be calculated for any salinity in the salinity range of the water body. The value 0.2 is the slope of the regression line and – 3.2 is the intersection point with the y-axis (see Fig. 2A). These two parameters need to be validated when this method is used in other Baltic areas.

The resulting parameter k_0 is, thus, only minimally influenced by phytoplankton, but it is influenced by freshwater runoff of cDOM.

3.2.3 The influence of cDOM on the pristine light attenuation coefficient

Because anthropogenic influences over the last centuries have been responsible for the increase of cDOM concentrations in most of the aquatic ecosystems, the least influenced systems with respect to land use changes ("melioration", drainage) should be used to reconstruct the underwater light climate. The fresh water flowing with the brooks and rivers into the inner coastal waters mixes with the water body of the open Baltic Sea. The salinity gradient can be used as an easy-to-measure approximation for cDOM towards the open Baltic Sea. As a simplification, the mixing of the waters, i.e. a change in cDOM concentration, was determined on the basis of long-term mean salinity, assuming a linear gradient of salinity from freshwater (100 % cDOM) towards Baltic Sea water (0%, reference value of cDOM concentration). This leads to a decrease in the attenuation of light as the yellow materials flowing in with the freshwater are diluted as the proportion of Baltic Sea water increases, i. e. k_0 is a function of the mixing ratio. The k_0 values measured at different sites in three water bodies were plotted against the respective mixing ratio (Fig. 2B). This method of determination of k_0 has the advantage that the mixing ratio is a relative value which is independent of the salinity range of the water and the salinity of the offshore Baltic Sea. The resulting regression for these three water bodies was:

$$k_{0\,(PAR)} = 3.0 \cdot \frac{\text{Salinity of the site}}{\text{Salinity of the Baltic Sea}} - 3.2 \qquad (2)$$

Formula (2) can now be used to calculate the attenuation coefficients (k_0) of all the inner coastal waters. The value 3.0 is the slope of the regression line and – 3.2 is the intersection point with the y-axis (see Fig. 2B). These two parameters need to be validated when this method is used in other Baltic areas.

The mean salinity was calculated for each water body and the corresponding area of the offshore Baltic Sea using the monitoring data of the State Authorities. Salinity data were then used to estimate the light climate in all inner coastal water bodies. Because it is important that a uniform data basis be used for all waters, existing data from 1990 to 2000 were used in the calculations. Some water bodies, such as Trave and Orther Bay (Fig. 1), were not allocated measuring stations during the monitoring program so we were forced to rely on the sporadic measurements available. Furthermore, the measuring stations on the outer coast are not, in every case, directly situated on the inflow of the respective internal coastal water body into the Baltic Sea, so in these cases the nearest station was selected. Where possible,

the same period was used for calculations for the Baltic Sea station and the inner coastal measuring station. On the basis of the salinity data for each water body the water-specific pristine light attenuation coefficient (k_0) was computed.

3.2.4 Pristine depth limits for certain vegetation components

The pristine downward irradiance diminished in an approximately exponential manner:

$$I(z) = SI \cdot e^{k_0 \cdot z} \quad (3)$$

where *I*(z) is the value of the downward irradiance at a depth z (m), SI is the surface irradiance of the vegetation period (µmol photons m^{-2}) and k_0 the pristine light attenuation coefficient (m^{-1}) expressed as negative values. Before the depth z can be calculated, the surface light irradiance SI needs to be obtained, and here an average seasonal irradiance cycle must be taken.

Mean surface light irradiance during the period of active growth must be calculated, i.e. the time from start of development in spring until the decay of macrophytes in autumn. This period was defined for the German Baltic coast as 15th April to 31st August. The dose can be calculated by means of on-site weather station data. These data can take the form of daily, weekly or monthly doses given in $W \cdot m^{-2}$, mol (photons) $\cdot m^{-2} \cdot s^{-1}$ or mol $\cdot m^{-2} \cdot d^{-1}$.

In cases where such data are not available, the cycle can be “constructed” with the help of the spreadsheet created by Walsby (1997), which delivers the “maximum” irradiance dose without taking into account the influence of weather conditions. It is calculated in 5 min steps based on the latitude of the investigated area and the daily changes in solar elevation. This value must be corrected for average weather conditions by determining, for a given set of meteorological conditions (rain, cloud types, extent of cloud cover etc.), the region-specific difference between the “maximum” irradiance values of the above spreadsheet and the measured ones. The results must then be applied to the whole year’s data set according to average meteorological conditions. The resulting surface irradiance value should be reduced by 5% (loss due to surface reflection) after which irradiance doses can be added up to obtain the growth-period light dose SI.

On the German Baltic coast the light dose for this period of active growth (15th April to 31st August) was 5800 mol photons$\cdot m^{-2}$. For calculations within the German Baltic water bodies the value SI can be set at 1 following formula (4). In other regions where this assessment procedure is applied the value SI must be corrected by the regional SI_R value (mol photons $\cdot m^{-2}$) for the period of active growth. The corrected value can be calculated using the following formula:

$$SI = \frac{SI_R}{5800} \quad (4)$$

If the regional surface irradiance is higher than on the German Baltic coast the SI value will be higher than 1, and it will be lower than 1 if the SI value of the region is lower than that of the German Baltic coast.

To calculate z, the downward irradiance *I*(z) has to be defined in accordance with the different light requirements of the macrophytes. Two different relative penetration depths were distinguished for each of the waters: 40% of the surface

irradiance *SI* as the propagation border of the charophytes (Yousef 1999) and 10% of the surface irradiance *SI* as the propagation border of the spermatophytes (Mur & Visser 1996). The respective downward irradiances at these depths z_{ch} and z_{sp} can be calculated as:

$$I_{ch} = \frac{SI \cdot x}{100} \qquad (5)$$

With x as the portion of underwater light for charophyte communities x = 40. The downward irradiance for spermatophyte communities I_{sp} is also calculated using formula (4), but here x = 10.

These definitions are based on the assumption that the light demand of the macrophyte vegetation is the same now as it was in pristine times.

The next step was to calculate pristine or reference depth limits for the macrophyte communities under investigation. Based on formula (3) the depths z_{ch} of 40% of the light dose of the vegetation period *SI* (charophyte communities) and the depths z_{sp} of 10% of the light dose of the vegetation period *SI* (spermatophyte communities) were calculated for all the water bodies under investigation.

$$z_{ch} = \frac{\ln \frac{I_{ch}}{SI}}{k_0} \qquad (6)$$

The pristine depth z_{sp} is also calculated using formula (6). The depth values z_{ch} and z_{sp} represent the historical (pristine) reference conditions.

3.3 Boundary setting and Ecological Quality Ratio (EQR)

The setting of boundaries for the metrics according to the normative definition of the WFD and integrating them to form a total assessment system is the last step in the development of the assessment procedure for the quality element macrophytes. An algorithm was thus developed to convert the three components plant community, depth limit of charophyte communities and depth limit of spermatophyte communities into numerical values of degradation that in turn could be converted into the (normalised) EQR requested by the WFD.

3.3.1 Degradation chain and allocation of the ecological value (EV_{PC})

The first step in degradation is the shifting of the lower depth border of plant communities. Species do not disappear and the vegetation cover remains complete. As a result only the EQR of the depth limit metrics change, while the EV_{PC} remains constant. Exceptions are formed by shallow wave-exposed areas where wave exposure diminishes macrophyte cover at all degradation stages.

The second degradation step is characterised by shifts in the lower depth border, but also by the loss of species, especially charophytes, and thus by the loss of plant communities. The vegetation cover is complete. This results in EQR_{sp} values only for spermatophyte communities, and in a different EV_{PC} value because of the changes in plant community.

The third degradation step is again characterised by shifts in the lower depth border and by the loss of species. Typically, vegetation cover is less than 50 %. Charophyte communities will not be present at this stage and thus while the EQR_{sp} value will be changed, it is not possible to calculate an EQR_{ch}. The EV_{PC} value also decreases.

The fourth and last degradation step is characterised by the lack of plant communities. Only relicts such as *Myriophyllum-Potamogeton* remnants are found. The vegetation cover is less than 10 %, making it impossible to calculate the EQR_{sp} value (because a depth limit is not measurable), and the EV_{PC} value changes to its lowest value.

The method of calculation of the changes in EQR_{ch} and EQR_{sp} values is described in Chapter 1.3.3. The EV_{PC} values resulting from the degradation of plant communities are provided in Table 1. The degradation stages are described in the following section.

In order to integrate the plant communities described in Chapter 3.1.1 into an assessment procedure and facilitate integration with the depth borders represented by EQR_{ch} and EQR_{sp} values (Chapter 3.3.3) so as to calculate an $EQR_{transect}$ (Chapter 3.3.4), the plant communities need to be transformed into a numerical value. This value is termed the ecological value, EV_{PC}. All the plant communities occurring here were assigned this value according to their stage of degradation which in turn was decided on the basis of the degradation chains, which were set up specifically for the water bodies described here. Using expert judgement, the plant communities found in the individual water bodies were arranged as degradation stages on the basis of the degradation steps described above. Figure 3 presents three examples of degradation chains in inner coastal waters.

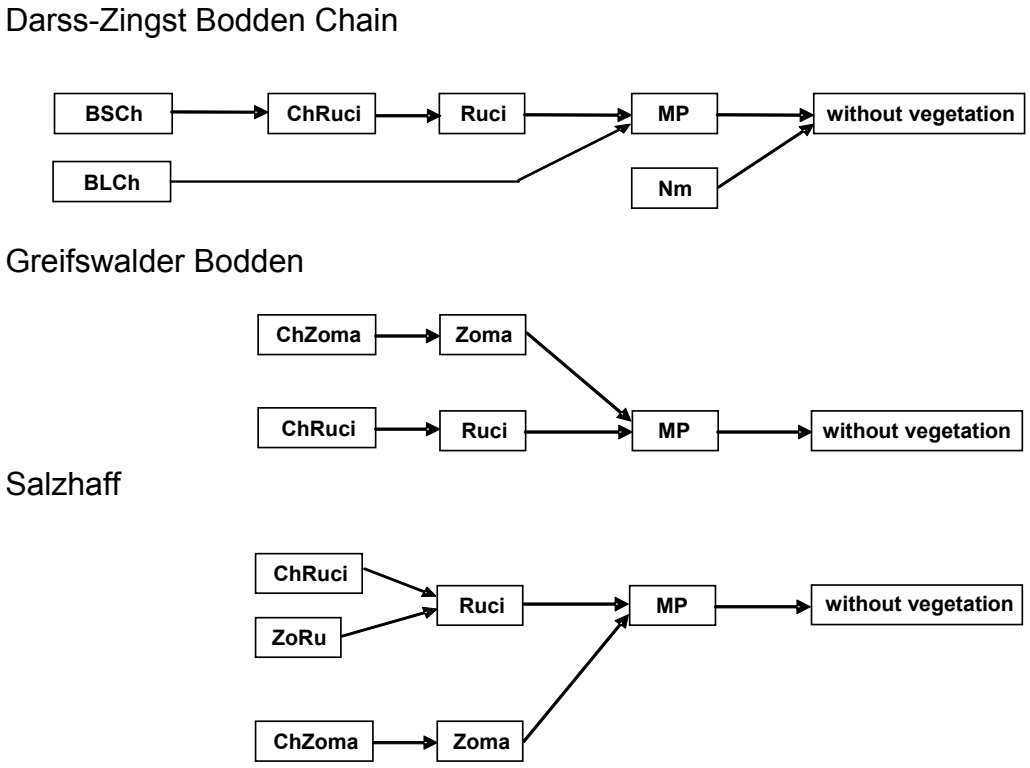

Fig. 3 Degradation chains of plant communities in three coastal water bodies (for abbreviations of the plant communities see Tab. 2).

In correspondence with these degradation chains an attempt is now made to assign to each plant community or plant remnant an ecological status value on a scale of 1 to 0, where the 1 represents the highest value.

The allocation of ecological status values to the plant communities proceeds from the premise that charophyte communities only occur down to the moderate condition and may thus not receive an EV_{PC} worse than 0.4. The worse ecological conditions are evaluated by lower EV_{PC} of spermatophyte communities. The EV_{PC} for each plant community is presented in Table 2. The charophyte communities Bodden Large Charophytes and Bodden Small Charophytes were given the highest EV_{PC} values (0.8) on the basis of the degradation chains. As last degradation stages the conditions “no plant community” (npc) and “no vegetation” (nv) were assigned to an EV_{PC} of 0. Figure 4 provides a graphical representation of the degradation stages of the vegetation in the inner coastal waters.

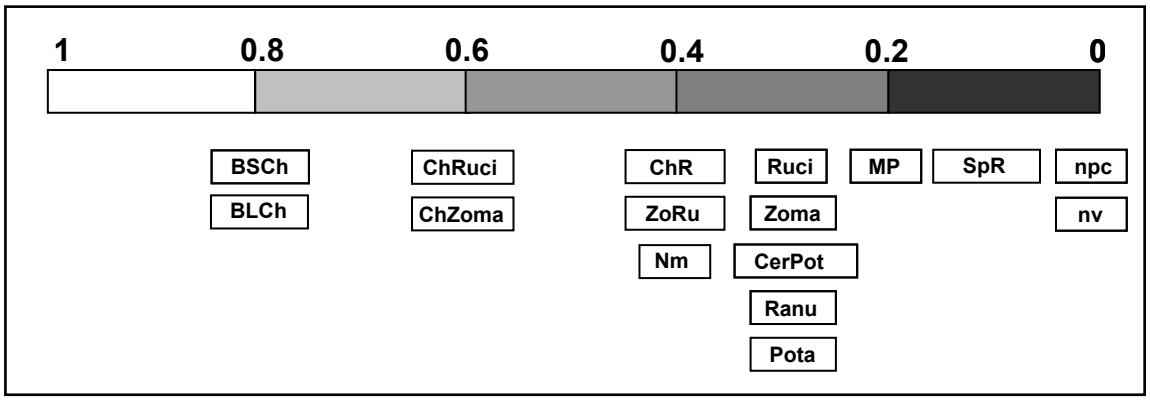

Fig. 4 Degradation stages of the plant communities in relation to the EV_{PC} value.

3.3.2 Boundary setting for $EQR_{ch(b)}$ and $EQR_{sp(b)}$

The next step is the setting of four boundaries to obtain five ecological status classes in addition to the reference condition and, thus, six EQR values. The $EQR_{ch(b)}$ and $EQR_{sp(b)}$ values of the borders between the ecological classes are indicated by a “(b)” as opposed to the interpolated EQR_{ch} and EQR_{sp} values described in Chapter 3.3.3.

The boundaries between the ecological status classes for the spermatophyte communities were set as follows: < 1% reduction of the pristine amount of underwater light I_{sp} forms the transition from high to good ecological status; < 5% reduction indicates the transition from good to moderate; < 25% reduction marks the border from moderate to poor and < 75% reduction represents the transition from poor to bad ecological status in the B1 water bodies. The latter border was set for the B2 water bodies at a depth of < 0.5 m (Table 4). This means that a spermatophyte community with a depth limit of less than 0.5 m is classified as bad ecological status (for the metric EQR_{sp}).

The boundaries between the ecological status classes for the charophyte communities were set as follows: < 1% reduction of the pristine amount of integrated underwater light I_{ch} forms the transition from high to good; < 25% reduction the transition from good to moderate and a depth limit of < 0.5 m marks the border from moderate to poor in B1 and B2 water bodies. No charophyte communities are

present where the ecological status is poor or bad because of the high light demand of charophytes.

An EQR with a value between zero and one with a gradation of 0.2 was allocated to the four boundaries and to the reference condition, as summarised in Table 4.

Tab. 4 Characterisation of the class borders according to the reduction of light penetration depth in % and lower distribution border of the macrophyte communities.

Ecological conditions and class borders	EQR	Spermatophyte communities	Charophyte Communities
		Reduced portion of light x [%] or depth limit [m]	
Reference condition	1	0%	0%
Very good/Good	0.8	1%	1%
Good/Moderate	0.6	5%	25%
Moderate/Poor	0.4	25%	0.5 m
Poor/Bad	0.2	50% B1 0.5 m B2	-

Four class borders between the five ecological classes were calculated on the basis of relative light reduction with respect to the reference conditions. The pristine amount of underwater light at the boundaries for charophyte communities $I_{ch(b)}$ is the difference between irradiance at the surface (0 m) and at the pristine depth $z_{ch(b)}$ and was calculated as:

$$I_{ch(b)} = F(0) - F(z_{ch(b)}) = SI \cdot (1 - e^{k_0 \cdot z_{ch(b)}}) \qquad (7)$$

F is the mathematical function of formula (3) for the depth given in brackets (0 and $z_{ch(b)}$). SI is the surface irradiance (see Chapter 3.2.4), k_0 the pristine light attenuation coefficient (see Chapter 3.2.2, 3.2.3) and $z_{ch(b)}$ the pristine boundary depth limit for charophyte communities being sought.

The depth limits $z_{ch(b)}$ of the four class borders were calculated for each study area as follows:

$$z_{ch(b)} = \frac{\ln\left(1 - \frac{I_{ch(b)}}{SI}\right)}{k_0} \qquad (8)$$

The amount of underwater irradiance $I_{ch(b)}$ at a boundary is calculated as follows: the difference between the surface irradiance SI and the pristine irradiance I_{ch} at the reference depth z_{ch} is calculated, then reduced by a portion x [%] (for x see Table 4) to result in $I_{ch(b)}$.

$$I_{ch(b)} = \frac{(SI - I_{ch}) \cdot (100 - x)}{100} \qquad (9)$$

The depth limits of the class borders $z_{sp(b)}$ for the spermatophyte communities are calculated accordingly. The calculated $z_{ch(b)}$ values are given in Table 5 and the $z_{sp(b)}$ values are given in Table 6 for the inner water bodies of the German Baltic Sea.

Tab. 5 Calculated distribution borders [m] for the charophyte communities in the inner coastal waters of the German Baltic Sea. Ref: Reference condition, H/G: high/good, G/M: good/moderate, M/P: moderate/poor, P/B: poor/bad. The border P/B is not calculated because charophyte communities are indicative only down to the moderate condition.

Normalised EQR	**Ref**	**H/G**	**G/M**	**M/P**
	1	**0.8**	**0.6**	**0.4**
Water bodies				
Mecklenburger Bay MV				
Wismar Bay	4.5	4.4	2.6	0.5
Salzhaff (Middle)	3.6	3.5	1.8	0.5
Unterwarnow	3.8	3.6	1.7	0.5
Nordrügensche Boddengewässer				
Libben	4.3	4.2	2.6	0.5
Vitter Bodden	4.0	3.9	2.4	0.5
Schaproder Bodden	4.0	3.9	2.2	0.5
Kubitzer Bodden	4.2	4.0	2.2	0.5
Rassower Strom	3.6	3.4	2.2	0.5
Breetzer Bodden	3.5	3.4	2.0	0.5
Gr. Jasmunder Bodden	3.5	3.3	1.7	0.5
Kl. Jasmunder Bodden	2.1	1.8	0.8	0.3
Strelasund	3.5	3.3	1.7	0.5
Greifswalder Bodden	4.3	4.1	2.2	0.5
Oder inflow				
Achterwasser	2.2	1.7	0.6	0.3
Peenestrom	2.2	1.7	0.6	0.3
Kleines Haff	2.0	1.6	0.6	0.3
Darss-Zingst Bodden Chain (DZBC)				
Grabow	3.0	2.8	1.3	0.5
Barther Bodden	2.6	2.3	0.9	0.4
Bodstedter Bodden	2.4	2.2	0.9	0.4
Saaler Bodden	2.2	1.8	0.8	0.3
Ribnitzer See	2.0	1.6	0.8	0.3
Schleswig-Holstein				
Flensburger Binnenförde	4.4	3.9	2.3	0.5
Kieler Förde	3.8	3.6	2.2	0.5
Trave	3.5	3.3	1.7	0.5
Orther Bucht	3.8	3.7	2.2	0.5
Schleimünde	3.2	3.0	1.4	0.5
Middle Schlei	2.7	2.5	1.1	0.5
Inner Schlei	2.5	2.0	0.7	0.3

The calculated depth limits correspond to the discrete borders of the ecological status classes. However, to obtain continuous normalised EQR values for depth limits measured in the WFD monitoring, the corresponding EQR_{ch} and EQR_{sp} has to be calculated by interpolation.

Tab. 6 Calculated distribution borders [m] for the spermatophyte communities in the inner coastal waters of the German Baltic Sea. Abbreviations see Tab. 5.

normalised EQR	Ref	H/G	G/M	M/P	P/B
	1.0	0.8	0.6	0.4	0.2
Water bodies					
Mecklenburger Bay MV					
Wismar Bay	7.5	7.1	6.0	3.4	0.5
Salzhaff (Middle)	5.5	5.1	4.2	2.2	0.5
Unterwarnow	6.4	5.5	4.0	1.9	0.5
Nordrügensche Boddengewässer					
Libben	7.2	6.9	6.0	3.5	0.5
Vitter Bodden	6.1	5.9	5.2	3.2	0.5
Schaproder Bodden	6.0	5.7	4.9	2.7	0.5
Kubitzer Bodden	6.5	6.2	5.3	2.9	0.5
Rassower Strom	6.0	5.8	5.2	2.9	0.5
Breetzer Bodden	5.5	5.3	4.6	2.6	0.5
Gr. Jasmunder Bodden	5.5	5.0	3.8	1.9	0.5
Kl. Jasmunder Bodden	2.7	2.2	1.5	0.7	0.4
Strelasund	5.5	5.0	3.9	2.0	0.5
Greifswalder Bodden	7.2	6.7	5.3	2.7	0.5
Oder inflow					
Achterwasser	3.2	1.9	1.3	0.6	0.3
Peenestrom	3.3	2.0	1.3	0.6	0.3
Kleines Haff	3.0	1.9	1.3	0.6	0.3
Darss-Zingst Bodden Chain (DZBC)					
Grabow	4.0	3.6	2.8	1.4	0.5
Barther Bodden	3.2	2.6	1.8	0.9	0.4
Bodstedter Bodden	3.0	2.5	1.8	0.8	0.4
Saaler Bodden	3.0	2.1	1.4	0.6	0.3
Ribnitzer See	3.0	1.7	1.1	0.5	0.3
Schleswig-Holstein					
Flensburger Binnenförde	7.6	7.4	5.7	3.0	0.5
Kieler Förde	6.0	5.7	4.7	2.5	0.5
Trave	5.4	5.0	3.9	2.0	0.5
Orther Bay	5.2	5.0	4.5	2.7	0.5
Schleimünde	5.0	4.3	3.1	1.5	0.5
Middle Schlei	3.6	2.7	1.4	0.7	0.3
Inner Schlei	2.8	2.1	1.4	0.7	0.3

3.3.3 Interpolation to obtain EQR_{ch} and EQR_{sp} values

EQR_{ch} is calculated for charophyte communities by linear interpolation between the two class borders in Table 5 in which the real depth value measured in the field is found. This calculation requires the following formula:

$$EQR_{ch} = \frac{(d_x - d_l)\cdot(e_u - e_l)}{d_u - d_l} + e_l \qquad (10)$$

EQR_{ch} EQR value of the determined depth border for charophyte communities

d_x measured depth limit (depth in m)

d_l lower class border (depth in m)

d_u upper class border (depth in m)

e_l EQR_{ch} or EQR_{sp} value of the lower class border

e_u EQR_{ch} or EQR_{sp} value of the upper class border

For the spermatophyte communities the respective EQR_{sp} values can be calculated using the values in Table 6.

3.3.4 Calculation of the $EQR_{transect}$

The final outcome of the assessment procedure is the calculation of an $EQR_{transect}$, i.e. the integration of the three metrics (EQR_{ch}, EQR_{sp} and EV_{PC}) which may stem from different frames sampled along the depth gradient (see Chapter 5.2.2):

- EQR_{sp}: represents the depth border of the spermatophyte community of a transect (equivalent to the depth border of the total vegetation)

- EQR_{ch}: represents the depth border of the charophyte community of a transect

- EV_{PC}: represents the plant community from the vegetation surveys of the different depth stages of a transect; the plant community with the highest ecological value of all depth stages is considered

$EQR_{transect}$ is calculated as the median of the three single metrics, thus reducing the influence of outliers. Using the arithmetic mean value is not recommended because normal distribution of the data cannot be assumed and there are too few values.

$$EQR_{transect} = Median(EQR_{sp}, EQR_{ch}, EV_{PC}) \qquad (11)$$

If no charophyte community is present, the EQR_{ch} is set to “0” for calculation. If the lower distribution border of the spermatophyte community corresponds to the water depth in this body of water, the parameter EQR_{sp} cannot be considered in the calculation. This can occur for some water bodies which are very shallow and where it must thus be assumed that the genuine depth limit would be deeper.

3.3.5 Calculation of the EQR_{water} and EQR_{period}

The inner coastal water bodies specified by the authorities of the Federal States differ significantly in size and are mostly characterised by a salinity gradient. The inclusion of a minimum of three transects is recommended. The number of transects depends on the size and salinity gradient of the water body. A higher number of transects will increase the precision of the evaluation of the water. Furthermore, the WFD requires sampling twice in a 6 year period. To increase the precision of the evaluation it is recommended that the water bodies be investigated more than twice in this period. Annual monitoring was recommended by Schubert et al. (2003). It is advantageous here to use the same transects each time, in order to take account of local changes in the vegetation.

The annual monitoring requires a calculation of different numbers of transects and over several years. Transects that may differ spatially and temporally need to be integrated, the number of transects per year may differ over the full 6 year period.

To integrate all these incidental transects the following approach is suggested. Firstly, all transects of a water body EQR_{water} should be integrated by calculating the median. This should be performed for each year.

$$EQR_{water} = Median\left(EQR_{transect\,1}, EQR_{transect\,2}, \ldots EQR_{transect\,x}\right) \quad (12)$$

The EQR_{period} is then calculated from the annual values of all investigation years in the investigation period (6 yr).

$$EQR_{period} = Median\left(EQR_{water,\ year\,1}, EQR_{water,\ year\,2}, \ldots EQR_{water,\ year\,x}\right) \quad (13)$$

4 Sample calculations

In the following chapter calculations of an exemplary transect are given for the different parameters using the formulas described in the method section. The example is based on part of the water body Salzhaff.

4.1 Calculation of pristine depth limits for certain vegetation components

The mean salinity of the outer part of the Salzhaff is 10.5 PSU. A mean salinity of 12.5 PSU was measured at the offshore Baltic Sea station. Using formula (2) the light attenuation coefficient k_0 is calculated:

$$k_{0(PAR)} = 3.0 \cdot \frac{10.5}{12.5} - 3.2$$

The next step is to calculate, using formula (5), the downward irradiance for the charophytes where the irradiance is 40 % of the surface irradiance. For the German Baltic coast the surface irradiance of 5800 mol photons · m^{-2} can be set as 1. In other regions the value SI must be calculated using formula (4). If, for instance, the surface irradiance in another region is SI_R = 6000 mol photons · m^{-2} in the period of active growth, the SI value is calculated as:

$$SI = \frac{5800}{6000} = 0.97$$

This value must then be taken as SI in formula (5) to calculate the pristine downward irradiance for charophytes:

$$I_{ch} = \frac{0.97 \cdot 40}{100} = 0.39$$

In this example for the German Baltic coast region the SI value is set as 1 and the pristine downward irradiance for the charophyte communities is, using formula (5):

$$I_{ch} = \frac{1 \cdot 40}{100} = 0.4$$

Now the pristine depth z_{ch} of the charophyte community can be calculated using formula (6):

$$z_{ch} = \frac{\ln(0.4)}{-0.68} = 1.35$$

The pristine depth limit for the charophyte community in this example is 1.4 m. This depth represents the reference condition with an EQR_{ch} value of 1 (Table 4).

The respective depth values for the spermatophyte communities z_{sp} can also be calculated using formulas (5) and (6). The pristine downward irradiance is:

$$I_{ch} = \frac{1 \cdot 10}{100} = 0.1$$

The pristine depth limit for the spermatophyte community is calculated as:

$$z_{sp} = \frac{\ln 0.1}{-0.68} = 3.39$$

The depth limit for the spermatophyte communities in this example is 3.4 m. This depth represents the reference condition with an EQR_{sp} value of 1 (Table 4).

4.2 Calculation of boundary depth for the setting of $EQR_{ch(b)}$ and $EQR_{sp(b)}$

In addition to the reference depths for the charophyte and spermatophyte communities, the depth borders used as the boundaries of the ecological classes need to be calculated. The first step is to calculate irradiance at the boundary using formula (9). For the charophyte community boundary high/good with x = 1 % reduction of the reference irradiance I_{ch} = 0.4, the boundary irradiance is:

$$I_{ch(b)} = \frac{(1 - 0.4 \cdot 1) \cdot (100 - 1)}{100} = 0.594$$

Using the downward irradiance at the boundary $I_{ch(b)}$, the surface irradiance SI = 1 and the light attenuation coefficient k_0 = - 0.68, the boundary depth between high and good status can be calculated for the charophyte community on the basis of formula (8):

$$z_{ch(b)} = \frac{\ln\left(1 - \frac{0.594}{1}\right)}{-0.68} = 1.33$$

The boundary depth between high and good ecological status is 1.3 m. This boundary is allocated to a normalized EQR of 0.8.

The border between good and moderate for charophyte communities can be calculated using formulas (8) and (9). In the case of the charophytes the reduction of light is 25% (Table 4):

$$I_{ch(b)} = \frac{(1 - 0.4 \cdot 1) \cdot (100 - 25)}{100} = 0.45$$

$$z_{ch(b)} = \frac{\ln\left(1 - \frac{0.45}{1}\right)}{-0.68} = 0.88$$

The depth of the border between good and moderate for the charophyte communities is 0.9 m. This boundary is allocated to a normalized EQR_{ch} of 0.6. The depth border between moderate and poor is set at 0.5 m without further calculations. This value is allocated to an EQR_{ch} of 0.4 (Table 4).

For the spermatophyte communities the border between high and good status can be calculated with the same formulas (8) and (9) using the downward irradiance I_{ch} = 0.1 as calculated above and x = 1 % reduction of the reference irradiance:

$$I_{sp(b)} = \frac{(1 - 0.1 \cdot 1) \cdot (100 - 1)}{100} = 0.891$$

Using the downward irradiance at the boundary $I_{sp(b)}$, the surface irradiance SI = 1 and the light attenuation coefficient k_0 = - 0.68, the boundary depth between high and good status can be calculated for the spermatophyte community on the basis of formula (8):

$$z_{sp(b)} = \frac{\ln\left(1 - \frac{0.891}{1}\right)}{-0.68} = 3.26$$

The depth limit between high and good ecological status for spermatophyte communities is 3.3 m. This depth limit is allocated to a normalized EQR_{sp} of 0.8 (Table 4).

The border between good and moderate for spermatophyte communities can be calculated using formulas (8) and (9). In the case of the spermatophytes the reduction of light will be 5 % (Table 4):

$$I_{sp(b)} = \frac{(1 - 0.1 \cdot 1) \cdot (100 - 5)}{100} = 0.855$$

$$z_{sp(b)} = \frac{\ln\left(1 - \frac{0.855}{1}\right)}{-0.68} = 2.84$$

The depth of the border between good and moderate for the spermatophyte communities is 2.8 m. This boundary is allocated to a normalized EQR_{sp} of 0.6 (Table 4).

In the same way, the depth border between the ecological conditions moderate and poor can be calculated with a loss of 25 % of the reference irradiance as a depth of 1.7 m, and the depth border between poor and bad can be calculated with a loss of 50 % of the reference irradiance as a depth of 0.9 m for B1 water bodies. In B2 water bodies this depth limit is set at 0.5 m (Table 4 and see Chapter 3.3.2).

4.3 Interpolation to obtain EQR_{ch} and EQR_{sp} values

If the depth limit of the charophyte communities in the field is found at 1.1 m, a linear interpolation of the EQR_{ch} value can be obtained using formula (10):

$$EQR_{ch} = \frac{(1.1 - 0.9) \cdot (0.8 - 0.6)}{1.3 - 0.9} + 0.6 \quad = 0.7$$

The EQR_{ch} value for the depth where the charophyte community was found is 0.7.

The depth limit of the spermatophyte communities in the field was found at 3.0 m. Using formula (10) the EQR_{sp} value for the spermatophyte community is calculated as follows:

$$EQR_{sp} = \frac{(3.0 - 2.8) \cdot (0.8 - 0.6)}{3.3 - 2.8} + 0.6 \quad = 0.68$$

The EQR_{sp} value for the depth at which the spermatophyte community was found is 0.7.

In a final step, the EV_{PC} value of the best-valued plant community of a transect is found by referring to Table 2. The following example is based on a Bodden Large Charophyte community with an EV_{PC} of 0.8.

On the basis of the EQR_{ch} and EQR_{sp} values along with the EV_{PC} value from Table 2, the $EQR_{transect}$ is then calculated using formula (11):

$$EQR_{transekt} = \text{Median}(0.7, 0.7, 0.8) \quad = 0.7$$

This hypothetical transect receives an $EQR_{transect}$ value of 0.7 - its ecological status is thus good.

Calculating the median of several $EQR_{transect}$ values of a water body using formula (12) results in the EQR_{water}. If we extend our example by taking another two transects with $EQR_{transect}$ values of 0.4 and 0.5, the EQR_{water} value is calculated using formula (12) as follows:

$$EQR_{water} = \text{Median}(0.4, 0.5, 0.7) \quad = 0.5$$

The water body receives an EQR_{water} of 0.5, giving it an ecological status of moderate.

Finally, the median EQR_{water} over several years, calculated using formula (13), results in the EQR_{period}. Assuming that EQR_{water} values of 0.5, 0.7 and 0.8 are obtained over three years, the EQR_{water} is then calculated using formula (13):

$$EQR_{period} = \text{Median}(0.5, 0.7, 0.8) \quad = 0.7$$

For the investigated period of three years, an EQR_{period} of 0.7 is calculated, indicating that the overall ecological condition of the water body was good over this period.

5 Procedure/Protocol

This section provides detailed information on the preparation and execution of those aspects of the field investigations which are not described in Chapter 3 (Methods). It also explains in detail the process used to evaluate water body-related data in some parts of the assessment procedure. This information is necessary for the success of the assessment procedure.

5.1 Preparation, equipment and selection of investigation sites

The field investigations need to be prepared thoroughly and the sampling sites selected with great care because field work is known to be a time-consuming process. The amount of work must be proportionate to the benefit it brings. The choice of sampling sites is a crucial step for effective work in the field. The sampling sites in the coastal waters are investigated using transects. The vegetation at the different transect depths is investigated using frames. The cover of a single species is estimated using an ordinal scale. A lot of equipment is necessary for aquatic investigations and it must be in good condition. The following chapters provide useful information for fieldwork preparation.

5.1.1 Instruments and equipment

The following instruments and equipment are necessary:

- Boat with safety equipment complying with the national and international specifications
- Nautical charts (with bathymetric information)
- Chest waders and/or ABC equipment (fins, mask, snorkel), neoprene suit and, if necessary, weight belt - for work in the shallow water area (down to approx. 1.5 m)
- Diving equipment complying with national and international specifications (starting from water depths of 2 m)
- Underwater viewer, rake (weighted with diving lead on both sides)
- Mapping minutes (minutes sheets)
- Cool box with thermal pack to transport samples
- Bags, labels, sample containers to transport plants for identification or biomass estimation
- Equipment for measuring depth by hand: lead weight (sinker) or digital depth-sounder (depth gauge)
- Salinity measuring device or sample bottles for later salinity measurement in the laboratory
- GPS or DGPS equipment (data output format NMEA 0138, coordinate systems WGS84 or ETRS89
- Secchi disk (EU standard EN 27027 3/94) / light measuring instrument
- Sample frame 1x1 m (with partitioning into at least 4 squares)

- Digital camera for photo documentation of the sampling locations and species identified
- Pencils or water resistant felt-tip pens, protocol, literature for identification, magnifying glass

5.1.2 Literature for identification

The following literature is recommended for the identification of species in German Baltic coastal areas. In other Baltic areas locally available literature may be more useful.

Burrows, E. 1991. Seaweeds of the British Isles. Volume 2. British Museum London.

Kornmann, P. & P. H. Sahling 1983. Meeresalgen von Helgoland. Biologische Anstalt Helgoland. Hamburg.

Kornmann, P. & P. H. Sahling 1994. Meeresalgen von Helgoland. Zweite Ergänzung. – Helgoländer wissenschaftliche Meeresuntersuchungen 48. 365-406.

Krause, W. 1997. Charales (Charophyceae), Band 18, In: Ettl H et al. (1997) Süßwasserflora von Mitteleuropa, Gustav Fischer Verlag, Jena.

Pankow, H. 1990. Ostsee-Algenflora, 1. Edition., Gustav Fischer Verlag. Jena.

Preston, C. D. 1995. Pondweeds of Great Britain and Ireland. – B.S.B.I.-Handbook no. 8: 352 pp. London.

Rothmaler, W. & E. J. Jäger 2005. Exkursionsflora von Deutschland 4. Gefäßpflanzen: Kritischer Band.

Schubert, H. & I. Blindow 2004. Charophytes of the Baltic Sea. Baltic Marine Biologists Publication No. 19. Koeltz Scientific, Königstein.

Triest, L. 1988. A revision of the genus Najas L. (Najadaceae) in the Old World. – Academie Royale des Sciences D'Outre-Mer, Classe des Sciences naturelles et medicales, Mem. 8, Book 22: 1-172.

Van de Weyer, K. & C. Schmidt 2007. Bestimmungsschlüssel für die aquatischen Makrophyten (Gefäßpflanzen, Armleuchteralgen und Moose) in Deutschland. Nettetal. www.mluv.brandenburg.de/cms/detail.php/bb2.c.416666.de

5.1.3 Investigation period

The vegetation should be investigated once a year between 15th June and 15th August. In water bodies where the charophyte species *Tolypella nidifica* belongs to the character species of the plant communities, sampling must take place before 15th July, because this species is then displaced in the course of the vegetation period by other species.

5.1.4 Geographical location of the investigation sites

The location of the sampling sites must be precisely recorded topographically using GPS equipment to permit resampling and presentation of the data in maps. Each depth step has to be recorded separately along the transects.

5.1.5 Definition of the sampling sites

The investigation transects in the water bodies are defined annually by the Federal State Offices (clients) according to the requirements of the WFD.

When selecting investigation areas it must be ensured that sheltered sites with low exposure are sampled, where submerged vegetation can form on the soft bottoms. Furthermore, the maximum depths of transects should be greater than the depth limits of the macrophytes. If appropriate transects are known already from earlier surveys, they can be considered in the selection of sampling sites.

5.2 Execution of the field investigations

To minimise personal error when field work is carried out by different people, a detailed description of the investigation steps is invaluable. Mistakes made during this process cannot be corrected later, so particular attention to accuracy is called for.

5.2.1 Collection of abiotic parameters

The specified abiotic parameters are collected only once at an investigated transect. Sampling should take place at the deepest point or in the centre of the transect in the case of sampling from shore to shore. Here, the following parameters should be documented:

- Maximum water depth and/or deepest examined/measured location along the transect
- Meteorological data (cloud coverage, wind force, wind direction)
- Salinity (measured directly on site or later in the laboratory)
- Secchi depth, if technology available: surface light and light measurements in water
- Estimation of wind and wave exposure of the investigation site
- Estimation of the anthropogenic influence on the investigation site (swimming area, boat traffic, tourism, fishery)

In Germany a standard operating procedure (SOP) entitled “macrophytobenthos investigations on marine substrates: sampling in the sublitoral” exists including a protocol sheet that can be used as the basis for the documentation of the data (Quality Assurance Panel of the GMMP at the FEA (2009 a, b).

5.2.2 Collection of vegetation data

Selection of transects

The mapping of the macrophyte vegetation is performed by transect mapping in defined depth stages. A transect can be surveyed from the shore to the maximum depth, but as far as the size of a water body permits, mapping should be done from shore to shore (transect across entire water body).

In shallow water, sampling can be performed with ABC equipment, and at greater depths by diving from a boat. All submerged vegetation as well as macrophytes rooted below mid water level (Chlorophyceae, Charophyceae, Phaeophyceae, Rhodophyceae, Spermatophyta) have to be recorded.

Earlier surveys of the vegetation in the inner coastal waters revealed rather patchy distribution. This spatial heterogeneity relates primarily to the occurrence of the vegetation in general, however, not to its species composition. It should therefore be ensured that the spatial heterogeneity is recognized and taken into account and that surface mapping is carried out at representative sites before starting the transect sampling. For this reason an initial inspection of the investigation area with a boat is suggested.

To determine the depth limit by means of an underwater viewer the water body should be traversed with a boat (inflatable dinghy). After the depth limit has been ascertained the water body should be crossed parallel to the shore line but approximately 300 to 400 m out to ensure that the genuine maximum depth has been determined. If poor visibility does not permit use of the underwater viewer, the vegetation border should be determined roughly by means of a rake and examined by a diver. It can generally be assumed in such cases that the depth border is very low, which usually necessitates diving with ABC equipment and/or walking along the vegetation border.

If investigation data on the submerged vegetation at these transects already exist from previous years, the transect can be found and surveyed again on the basis of the available GPS data. Before the vegetation is mapped, however, it is important to double check that the specified transect is still representative of the water body.

Definition of investigation sites on the transects

If a transect is set from shore to maximum depth, the depth stages are investigated once. If the transect is set from shore to shore, each depth stage is investigated twice along the transect. The following depth stages are sampled down to the depth limit:

B 1 water bodies and inner and mid Schlei (Fig. 1):
0.25; 0.5; 0.75; 1.0; 1.5; 2.0; 2.5; 3.0 m

B 2 water body:
0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0 m, thereafter in 1 m depth stages down to the lower depth border.

In addition to these depths, the depth border good/moderate specific to the water body in question must also be sampled (see Tab. 5, 6).

Five frames with a surface of 1 m2 are sampled per depth stage. The sampling of the first frame is performed directly on the transect. The four other survey areas are chosen as 2 on the left and 2 on the right of the transect with a distance of

approx. 5-10 m between the frames. The GPS coordinates are taken at the mid frame on the investigation transect.

If, due to the very patchy distribution of the vegetation, there is significant heterogeneity between the frames (difference of over 50 % of the total vegetation cover) and/or if frames without or with low vegetation coverage (less than 5%) have to be sampled, the number of frames should be increased to 8 per depth stage.

Data collection on the lower distribution border of the vegetation

After the depth limit has been ascertained approximately by boat and underwater viewer (see above), the exact depth border of the vegetation is recorded at the beginning of transect sampling. The depth borders of the charophyte and spermatophyte communities must be recorded separately.

The vegetation surveys are initially carried out at the given depth stages. If charophytes cease to be found between two depth stages further sampling should be performed between these two stages to obtain more precise information about the lower depth border of these plants.

The depth limit of spermatophytes is then determined in the same way. If at the intended sampling depth no more vegetation is found, the exact depth border of the vegetation has to be determined between the two last depth stages. If, for instance vegetation is still found at 1.0 m but no longer found at 1.5 m, the exact depth limit has to be ascertained between these two depth stages as the last vegetation survey at this transect.

Collection of data on the species inventory and vegetation coverage

For the purposes of the species inventory and degrees of coverage, only those plant parts which root within the investigation surface (frame) are considered. Plant parts which extend into the frame from outside are not counted.

Another important environmental factor which should always be determined is the sediment. The categories here are stones, gravel, sand and mud. The proportion of hard substrate (stones) in the investigation area is recorded in percent. Detailed description and/or distinction of sandy and muddy sediments is not necessary. The sampling surface (1 m2) should be partitioned into four subsamples (0.25 m2) in cases of very high substrate heterogeneity (e.g. if there are stones in the square).

For the plant types total coverage, if possible in percent, is recorded (at least 5-15 % gradation, 2-3 % scaling for the smaller degrees of coverage is desirable, Table 7). If only single specimens (< 5 plants) are available, this must be noted.

Other estimate classes (see Table 7) should only be used if it is impossible to estimate coverage more precisely due to a lack of visibility. This is likely to apply to water bodies with very low Secchi depths (< 0.5 m). In such cases it is suggested that the Braun-Blanquet scale (1964), extended by Wilmanns (1998) to nine classes, is used. In cases of very bad visibility it is necessary to ascertain the degree of coverage by raking and/or harvesting the areas parallel to or instead of estimation by sight.

The individual species and their degree of coverage are recorded in the sampling sheet. All species should be recorded under their taxonomically valid species name. A data base by Selig et al. (2008) records all species occurring on the German coast under their currently valid scientific names and synonyms. All species are provided with an ID number which should, if possible, be used for the digital data acquisition. This data base is administered by the quality assurance office of the

Federal Office for Environmental Protection (UBA, Berlin, Germany) and must be acquired there.

Samples featuring species difficult to identify in the field must be identified later under the stereo and/or optical microscope. One specimen of all species should be stored in a herbarium. It is recommendable to keep samples in the herbarium for at least five years, after which they should be made available to botanical collections (herbariums) for long-term documentation.

Tab. 7 Comparison of different estimate classes to determine the degree of coverage (ind.: individual).

Frequency	Londo	Cover [%]	Braun-Blanquet	Transformed cover grade according to Ellenberg [%]	Kohler
Very seldom	1	<1	R (= 1 ind.) + (= 2-5 ind.)	0.1 0.2	1
Seldom	2 4	1-3 3-5	1 (= <5% / <50 ind.) 2m (= <5% / >50 ind.)	2.5 5	2
Common	1- 1+ 2	5-10 10-15 15-25	2a (= 5-15%) 2b (= 15-25%)	10 20	3
Frequent	3 4 5-	25-35 35-45 45-50	3 (= 25-50%)	37.5	4
Mass	5+ 6 7 8 9 10	50-55 55-60 60-75 75-85 85-95 95-100	4 (= 50-75%) 5 (> 75%)	62.5 87.5	5

5.3 Evaluation of water bodies

Water bodies are evaluated while the assessment procedure is being developed. This includes the process of ascertaining plant communities described in Chapter 3.1.1. In the further application of the developed assessment procedure in the monitoring the evaluation of water bodies is performed by allocation of plant communities, a procedure explained in Chapter 3.3.1.

5.3.1 Deduction of plant communities

All data recorded in the field protocols have to be digitised and entered into Excel sheets. This also applies for the abiotic parameters, which should be specified in an extra sheet. For each water body the transects investigated, depth stages and any appropriate vegetation subsamples (at least 5 mapping squares per depth stage) are listed in a table (Table 8).

If the degree of coverage was not determined in percent but according to other estimate scales (including Braun-Blanquet 1964), the coverage values must be transformed into numerical values (%) in accordance with Ellenberg (1992) (Table 7).

Tab. 8 Example of an excerpt from a table digitally compiling the vegetation data. The degrees of coverage in % are highlighted (bold numbers) after transformation in accordance with Ellenberg (1992).

Code	Date	Depth	Cover								
		[cm]	[%]								
			total macrophytes	*Chara aspera*	*Chara baltica*	*Chara canescens*	*Chara liljebladii*	*Chara tomentosa*	*Potam. perfoliatus*	*Ruppia cirrhosa*	*Zannichellia palustris*
DS-01-1	28.07.2005	25	50		**10**	**10**				**10**	**37.5**
DS-01-2	28.07.2005	25	75		**2.5**	**0.2**				**10**	**10**
DS-01-3	28.07.2005	25	100		**10**	**2.5**				**37.5**	**10**
DS-01-4	28.07.2005	25	100		**10**	**0.1**				**10**	**2.5**
DS-01-5	29.07.2005	25	100		**2.5**	**0.2**				**37.5**	**10**

These degrees of coverage in percent, directly estimated or transformed, form the basis for the calculation of the mean cover of a depth stage. The cover values of the subsamples are added together and divided by the number of subsamples (n=5 or 8) to obtain one degree of coverage per depth stage. The mean cover values from all surveys are then arranged in an Excel worksheet. The individual surveys (as the mean of five subsamples) can now be arranged according to floristic similarity. Surveys with the same species combination are arranged side by side. In cases where diverging species are also present, cover is the determining factor in finding similarities. Species with low cover are treated as absent species and a resulting suitable species combination should be defined. During this process it is important to consider indicative species such as charophytes. Plant communities are determined on the basis of the calculated values for degree of presence and coverage for all investigation sites of a floristically similar part of the table. The degree of presence refers to how often a species was found in individual surveys compared to all surveys of the plant community in question (e.g. the species X was found in 30 of 150 single surveys: 30 * 100/150 = 20 [%]). The original data on the cover and degree of presence of each species in each plant community are used to derive a transformed value ranging from 0 to 7 in accordance with Ellenberg (1992) (Table 9).

Tab. 9 Class borders for the calculation of the degree of presence and mean degree of coverage.

Category	Degree of presence [%]	Cover [%]
7	> 95	> 87
6	> 80	> 62
5	> 60	> 37
4	> 40	> 19
3	> 20	> 9
2	> 10	> 2
1	> 5	> 0.15
0	< 5	< 0.15

Sixteen rooted plant communities were defined for soft grounds in the inner coastal waters of Germany (Chapter 3.1.1, Table 2). The results are shown in Table 10.

The plant communities given in Table 2 are derived from Table 10, where the diagnostic species are listed.

5.3.2 Allocation of plant communities in monitoring

In the later monitoring process the plant community has to be defined for each examined depth stage of a transect. The subsamples of a depth stage (Table 8) are combined to obtain mean values as described above. A cover/degree of presence table then has to be calculated for each depth stage of a transect (Table 11).

Allocation can be made to the plant communities given in Table 10 if the minimum requirements specified in Table 2 are met. Otherwise the plant community of this depth stage is assigned to the next plant community along the degradation chain. Vegetation surveys where allocation of the plant communities was difficult and/or did not clearly match the definitions of the 16 plant communities are recorded separately and declared as such accordingly in the monitoring report.

Tab. 10 Cover/degree of presence for all vegetation sites (excerpt, complete table in Schubert et al. 2003) - highlighted are diagnostic species combinations. The first digit is the transformed value for the cover and the second one is the transformed value for the degree of presence (Table 9). In the Bodden Large Charophyte community for instance, *Chara liljebladii* has a transformed cover of 7, the cover is higher than 87 %. This species has a transformed degree of presence of 5, the degree of presence is higher than 60 %. For abbreviations of the plant communities see Table 2.

Plant community	BLCh	BSCh	ChRuci	ChZoma	MP	Nm	Ruci	Zoma	ZoRu
number of surveys	12	37	49	30	61	14	70	25	16
min. water depth [m]	0.3	0.0	0.3	0.2	0.2	0.3	0.3	0.3	0.3
max. water depth [m]	1.5	1.0	2.0	4.0	2	1	2.5	4	3
min. light [%]	1	5	40	15	1	1	20	15	65
median light [%]	15	20	60	40	20	10	60	35	75
max. light [%]	45	100	90	80	45	45	90	80	80
mean species number	3	4	6	5	2	2	4	4	6
rooting									
Chara liljebladii	**75**	11	31	51	.	.	.	.	.
C. tomentosa	**55**	53	11	.	.	30	.	.	.
C. aspera	51	**65**	**11**	.	.	33	.	.	.
C. baltica	.	**65**	**61**	51	.	10	10	.	51
C. canescens	51	**53**	**51**	51	.	53	11	11	51
Tolypella nidifica	.	.	31	**51**	.	.	11		31
Zostera marina	.	.	51	**75**	11	.	11	**75**	50
Najas marina ssp. *marina*	53	31	.	.	11	**75**	.	.	.
Ruppia cirrhosa	.	13	**75**	31	.	.	**75**	33	**75**
Zostera noltii	.	.	.	.	.	.	10	10	**71**
Myriophyllum spicatum	51	31	31	.	**55**	10	33	.	.
Potamogeton pectinatus	65	65	75	63	**75**	61	65	55	61
Zanichellia palustris ssp. *pedicellata*	.	35	51	63	31	11	53	73	51
drifting									
Chaetomorpha linum	.	11	35	53	13	.	33	53	31
Monostroma oxyspermum	.	.	13	11			33	.	.
epilithic									
Cladophora sericea	.	.	.	.	11	.	11	.	.
Enteromorpha spec.	.	.	.	.	11	.	15	10	50
E. intestinalis	.	15	.		11	.	10	.	.

Tab. 11 Example of a plant community table featuring values of coverage (first digit) and degree of presence (second digit) for the occurring species.

WB-Code	Water body	Transect	Transect part	Water depth	*Chara aspera*	*Chara canescens*	*Lamprothamnium papulosum*	*Potamogeton pectinatus*	*Ruppia cirrhosa*	*Tolypella nidifica*	*Zannichellia palustris*	*Zostera marina*
WP_02	Wismarbucht	KIR-1	A	0.50		20			55			
WP_02	Wismarbucht	KIR-1	A	0.75	43	32			76		32	
WP_02	Wismarbucht	KIR-1	A	1.00	74	32	31		55		73	
WP_02	Wismarbucht	KIR-1	A	1.50	33			42	43	20	33	45
WP_02	Wismarbucht	KIR-1	A	2.00	20			33	20	21	33	33
WP_02	Wismarbucht	KIR-1	A	3.00				20			23	33
WP_02	Wismarbucht	KIR-1	B	0.50				20	76			
WP_02	Wismarbucht	KIR-1	B	0.75				52	76		20	
WP_02	Wismarbucht	KIR-1	B	1.00				42	75		33	
WP_02	Wismarbucht	KIR-1	B	1.50				75	33		34	33
WP_02	Wismarbucht	KIR-1	B	2.00	20			22		20	53	75
WP_02	Wismarbucht	KIR-1	B	3.00				22		20	33	34

Finally, on the basis of Table 2, the ecological values (EV_{PC}) for each depth stage of a transect are allocated. In calculating the ecological condition of the investigation transect ($EQR_{transect}$), the highest ecological value of all plant communities of the transect is used and integrated with the two depth limits (charophyte and spermatophyte communities) to obtain the final total assessment of ecological status. This calculation is described in Chapter 3.3.4.

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