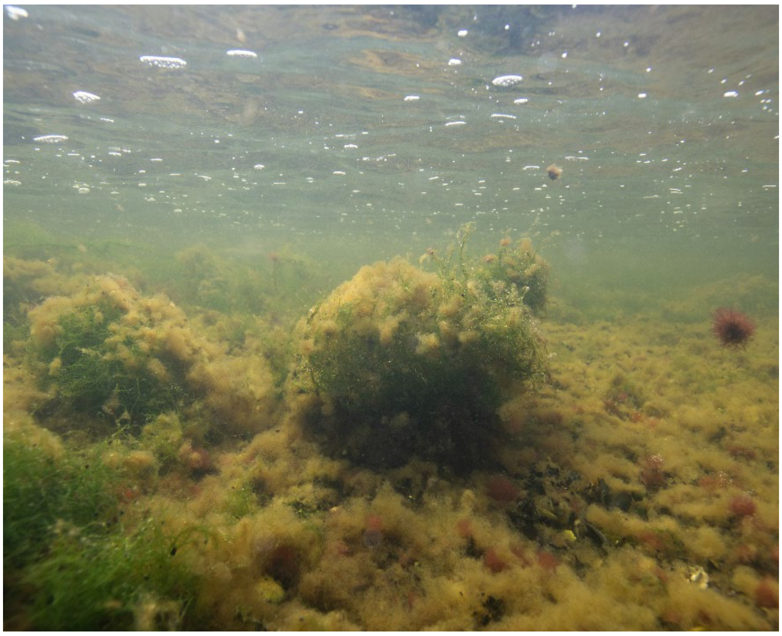
Macroalgae indicators for assessing ecological status in the Baltic and North-East Atlantic

Scientific briefing from DCE – Danish Centre for Environment and Energy Date: 27 April 2022 | **31**



AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

Scientific briefing from DCE – Danish Centre for Environment and Energy

Category: Scientific briefing

Title: Macroalgae indicators for assessing ecological status in the Baltic and North-East Atlantic

Authors: Signe Høgslund, Dorte Krause-Jensen og Jacob Carstensen
Institution: Department of Ecoscience

Referee: Karsten Dahl
Quality assurance, DCE: Anja Skjoldborg
Language QA: Anne Mette Poulsen

External comment: The Danish Environmental Protection Agency. The comments can be found here: http://dce2.au.dk/pub/komm/N2022_31_komm.pdf

Please cite as: Høgslund S., Krause-Jensen, D. & Carstensen, J. 2022. Macroalgae indicators for assessing ecological status in the Baltic and North-East Atlantic. Aarhus University, DCE - Danish Centre for Environment and Energy, 26 pp. – Scientific briefing no. 2022|31
https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2022/N2022_31.pdf

Front page photo: Karsten Dahl

Number of pages: 26

Contents

1 Introduction

This scientific briefing describes macroalgae indicators currently used for assessing ecological status in coastal waters of the Baltic and North-East Atlantic. These intercalibration areas include Danish coastal waters according to the intercalibration groups defined by the EU (EU 2005/646/EC).

The briefing is made on the request from the Danish Environmental Protection Agency (Miljøstyrelsen) and is one of tree concurrent scientific briefings concerning the development of macroalgae indicators applicable to environmental assessment of Danish coastal waters. The accompanying briefings are "Analysis of historical macroalgae data" and "Literature review of general responses of macroalgae to light, nutrient, salinity and temperature variations relevant to Danish waters".

The purpose of reviewing macroalgae indicators used by neighbouring countries is to qualify the currently suggested Danish indicators and aid the further development of the indicators, with special attention to the use of surveillance monitoring data on opportunistic algae.

1.1 Background

The management of marine waters in the EU is mainly driven by the three legal acts: The Water Framework Directive (WFD), the Marine Strategy Framework Directive (MSFD) and the Habitats Directive (HD). In addition to this, the HELCOM and OSPAR conventions also lay the foundation for monitoring and assessment activities in the Baltic and North-East Atlantic, respectively. The WFD aims to achieve "good ecological status" in all surface waters, and macroalgae are, together with angiosperms, one of the biological quality elements that, according to the directive, should be used to assess ecological status. Macroalgae are also considered as indicators for the implementation of the MSFD and HD.

Assessment of the ecological quality status in a WFD context is based on observations characterising a biological quality elements or sub-element, here macroalgae (Fig. 1.1). *Observations* like species-specific coverage are often aggregated to form indices, which express key features of the biological quality element. An example of such an *index* is the cumulative cover of all observed macroalgae species at a given location. An *indicator* built on further analysis of indices or observations sometimes acts in combination with other parameters to form a value that is sensitive to changes under a specific pressure.

The current condition, quantified by the indicator, is compared to reference conditions defined by the legislative framework. In a WFD context, reference conditions represent the state of an ecosystem when human disturbance is absent or insignificant. Reference conditions can be defined based on historical information on high ecological status, information from current ecosystems representing high ecological status, modelling or expert assessment. The result of the comparison is an environmental quality ratio (EQR), which is the ratio between the current indicator value and the reference value. EQR is thus a standardised expression of the environmental status of a given area and places the ecosystem in one of five ecological status classes: high, good, moderate, poor or bad.

The monitoring of macroalgae should thus address several needs as field data are transferred into indices and/or indicators. It should deliver information on the overall trends in ecosystem status, it should form the base of environmental assessment, and it should reveal the impact of anthropogenic pressures or natural changes and the effect of management actions. It is a prerequisite that the indicator is ecologically relevant, meaning that the pressure-response link that it describes should rely on a documented ecological theory (Borja & Dauer, 2008).

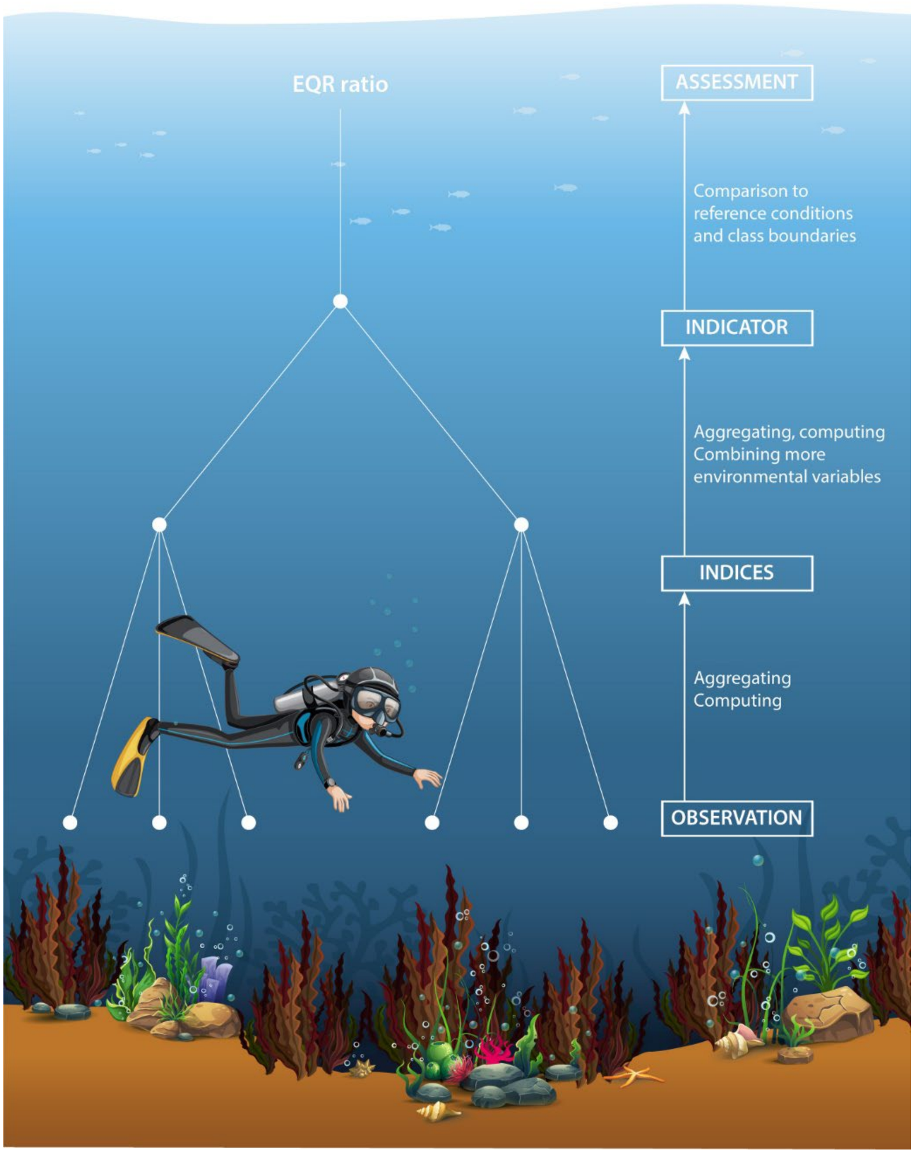


Figure 1.1. Observations within the waterbodies are transformed into indicators that form the base of the environmental assessment. See text for further explanation.

1.2 Delimitation and content

The briefing includes macroalgae indicators used by countries belonging to the same geographical intercalibration groups (GIG) as Denmark: The Baltic and the North-East Atlantic. Although Norway is not a member of the EU, Norway has adopted the WFD via the EEA agreement, and Norwegian indicators are also included in the review under the North-East Atlantic group.

The descriptions focus on the underlying indices of the indicators used in other countries with the aim to help to qualify the development of Danish macroalgae indicators. How reference conditions are set, or ecological status classes derived, for the particular indicators is described in the background literature (see table 2.1 and table 2.2) and to some extent in the WISER method database: http://www.wiser.eu/results/method-database/.

The section below, supplemented with Annex A, describes the individual indicators, and the third section relates the described international indicators to the current suggestions for Danish macroalgae indicators and discusses the possibilities for application of other methods in Danish coastal waters.

2 Macroalgae indicators in the Baltic and North-East Atlantic Geographical Intercalibration Groups

Macroalgal communities are sensitive to an array of anthropogenic pressures, they also vary due to natural environmental factors that may be major drivers of community structure. To accommodate the influence of this natural variability in the ecological assessment, the WFD divides European waters into relevant eco-regions (Mediterranean, Baltic, Black Sea and Atlantic) that form the intercalibration areas for national ecological assessment tools. In spite of this practical classification, no single indicator can account for all the particularities of an entire region, and today there is a multitude of ecological indicators based on macroalgae in the European realm (D'Archino & Piazzi, 2021; Lønborg et al.2021).

The two Danish macroalgae indicators suggested at present are based on abundance and diversity data. That is, change in cumulative cover (the sum of the cover of all erect macroalgae species at a given site) with depth and change in species richness of perennial species with depth (Carstensen 2020) (for a deeper discussion of these indicators see section 3).

2.1 Overview of indicators

The tables below list indicators in the Baltic and North-East Atlantic GIGs, respectively. The overviews include the indicators forming part of the third phase of the European intercalibration, indicators described in the WISER method database and indicators described in the scientific literature, also reviewed by D'Archino & Piazzi (2021). Indicators mainly based on rooted vegetation (charophytes and angiosperms) are not included in the overview, - for instance the German **PHYBIBCO, Sea-DE-AN-CO** and **SG** system and the **KRW-maatlatten** from the Netherlands. The French **TWOGA** system for transitional waters is also not considered. The EU indicator short name is used in cases of synonyms.

Table 2.1 Indicators used in the Baltic GIG

Baltic GIG

Indicator	Full name	Countries	Indices/observations	Habitat/ waterbody type, EU 3rd intercalibration	reference
BALCOSIS	Baltic algae community analysis system	Germany	Depth limit of *Zostera marina*. The proportion of biomass of opportunistic algae. Depth limit of *Fucus* spp. Dominance in percent cover of *Fucus* spp. Species reduction in relation to a reference species list. Proportion of biomass of *Fucellaria lumbricalis*.	Open coastal waters/ BC7,BC8	(Fürhaupter, 2015)
EPI	Estonian phytobenthos index	Estonia	Max depth of algae community, Max depth of *F. vesiculosus*, proportion of perennial plant species (dry mass of attached erect vegetation).	Open coastal waters/BC3, BC4	(Torn & Martin, 2011)
Fucus Index	Fucus index	Finland	Max depth of the continuous *Fucus* belt.	Open coastal waters/BC3,BC1	(Rinne & Salovius-Lauren, 2020; Ruuskanen, 2016)
MDFLD	Maximum depth limit of *Fucellaria lumbricalis*	Lithuania, Latvia	Max depth limit of *Fucellaria lumbricalis*	Open coastal waters/BC5,BC7	(Daunys et al., 2007)
MQAI	Assessment system for coastal and transitional waters using macrophytes	Poland	Biomass ratio of “positive taxa” and “negative taxa” and total coverage. Taxa included in the index depend on waterbody type.	Mainly in transitional waters/BC5,7	(Osowiecki et al., 2012)
MSMDI (SE-AN-CT)	Multispecies depth index	Sweden	Depth distribution (abundance) of 3 to 9 disturbance sensitive species.	Coastal waters, subtidal/ BC1,6	(Juanes et al., 2013; Kautsky et al. 2001)
PEQI	Phytobenthos ecological quality index	Latvia	Depth distribution of macroalgae community and depth limit of *F. vesiculosus*.	Open coastal waters/BC4	(HELCOM, 2015)

Table 2.2. Indicators used in the North-East Atlantic GIG.

North-East Atlantic GIG

Indicator	**Full name**	**Countries**	**Indices/observations**	**Habitat/waterbody type, EU 3rd intercalibration**	**reference**
CCO (ICS)	Cover, characteristic species, opportunistic species on intertidal rocky bottoms	France	Within predefined community belts (depth intervals): total cover of the macroalgae, number of characteristic species and cover of opportunistic species.	Rocky shores influenced by tides NEA1/26 A2	(Ar Gall et al., 2016; Ar Gall & Le Duff, 2014)
CFR	Quality of rocky bottoms	Spain	Richness (number) of characteristic macroalgae species, total cover of macroalgae assemblage, cover of opportunistic species in relation to the total vegetated area, expert judgment of the physiological condition of the macroalgae community.	Rocky shores, intertidal/subtidal NEA1/26 A2	(Guinda et al., 2014; Guinda et al., 2008; Juanes et al., 2008)
CWOGA (OMBT)	Macroalgae bloom assessment	France	Cover of opportunistic species, biomass, total affected area, proportion of opportunistic algae.	Sheltered intertidal coastal waters NEA1/26	(Wilkes et al., 2018)
OMAI (DE-AL-CO)	Opportunistic macroalgae cover/acreage on soft sediment intertidal in coastal waters	Germany	Density and area cover of opportunistic algae.	Intertidal and other coastal areas NEA1/26, 3, 4	(Kolbe, 2007; Wilkes et al., 2018)
HPI	Helgoland phytobenthic index	Germany	Species richness (reduced species list), proportion of green algae, proportion of red algae, ratio of perennial forms to annual or ephemeral forms, proportion of opportunistic species, coastal factor, area with *Fucus serratus* cover > 90%, coverage of *Ulva lactuca,* depth limits of five selected species.	Intertidal rocky shores NEA 5	(Kuhlenkamp et al., 2009, 2011)
MSMDI (SE-AN-CT)	Multispecies depth index	Norway, Sweden	Depth distribution (abundance) of 3 to 9 disturbance sensitive species.	Coastal waters, subtidal NEA8a, 9, 10	(Juanes et al., 2013; Kautsky et al., 2001)
OGA	Opportunistic green macroalgal abundance	Ireland, United Kingdom	Cover of opportunistic species, biomass, total affected area.	Sheltered intertidal coastal waters NEA1/26	(Wilkes et al., 2018; Scanlan et al., 2007)
OMBT	Macroalgal bloom assessment	United Kingdom	Cover of opportunistic species, biomass, total affected area, proportion of opportunistic algae.	Sheltered intertidal coastal waters NEA1/26	(Wilkes et al., 2018; Scanlan et al., 2007; WFD-UKTAG, 2014)

pMarMAT	Marine macroalgae assessment tool	Portugal	Species richness, proportion of Chlorophyta species to the total number of species, proportion of opportunistic species to the total number of species, number of Rhodophyta species, ratio of the number of opportunistic species to the number of perennial taxa, coverage of opportunistic species, shore description. The assesment tool is based on a reduced taxa list.	Intertidal, coastal waters NEA1/26 A2	(Marques et al., 2009; Neto et al., 2012)
QI Sub Mac	Quality index of sub-tidal macroalgae of French Channel and Atlantic coast	France	14 metrics based on presence of selected perennials, structuring and other selected macroalgae species. Density of opportunistic species, total number of taxa, stipe length of *L. hyperborea* and epibiont cover of *L. hyperborea*. Depth extension of macroalgae belt.	Subtidal, hard bottom	(Le Gal & Derrien-Courtel, 2015)
RICQI	Rocky intertidal community quality index	Spain	Abundance of indicator species, presence of *Cystoseira tamariscifolia*, presence of large perennial macrophytes, species richness of algae and fauna and faunal cover of herbivores and suspension feeders.	Rocky intertidal coast NEA1/26 A2	(Diez et al., 2012)
RSL/RSLA	Rocky shore reduced species list/Rocky shore reduced species list with abundance	Ireland, Norway, Spain, United Kingdom	Species richness, proportion red algae, proportion of green algae, proportion opportunistic species, ratio of perennial forms to annual/ephemeral forms. Abundance of opportunistic species, shore description.	Coastal intertidal waters NEA1/26 A2, B21, NEA 7	(Bermejo et al., 2012; D'Archino & Piazzi, 2021; Wells et al., 2007)

.

Currently, the only commonly shared indices of ecological status in the Baltic Sea is the maximum depth limit of some perennial species (Table 2.1, Rinne et al., 2018), and there is also great diversity of the indicators in the North-East Atlantic (Table 2.2, D'Archino & Piazzi, 2021). Most of the indicators are multi-metric and combine indices in various ways, but several of the indices are shared or vary only marginally between indicators. These common elements are highlighted in the four sections below – the use of reduced species lists, indicators based on coverage of opportunistic algae, indicators based on replacement or loss of slow-growing species and the use of depth limits of selected species.

2.2 The use of reduced species lists

The WFD recommends the use of species composition of intertidal macroalgal communities for ecological quality classification, and a criterion for the reference conditions is that taxonomic composition should correspond or nearly correspond to undisturbed conditions. Using the taxonomic composition of macroalgal communities as biological indicators has some inherent problems. It is not well constrained which species are sensitive to a particular pressure under given conditions. Also, the sensitive species tend to be a less abundant part of the community and not constantly present even under good ecological conditions, and macroalgal species composition can be naturally highly variable. Species richness – the number of species - within a given habitat remains, however, broadly constant in the absence of environmental alternations and is, therefore, broadly used as an index of environmental quality (Wells et al., 2007).

A major problem in applying indicators based on species identification is the need for highly specialised taxonomists to perform the monitoring. As a solution to this, several indicators are based on reduced species lists that contain species commonly present and identifiable with reasonable certainty. The lists can encompass species across different habitats like the **RSL**, or they can be specific for a given habitat as in the **CCO**.

The reduced species lists are extensively used when forming species richness indices. The species richness indices derived from the reduced species lists are often combined with a "shore description", which acts as a type of "correction factor" for the natural variability of species richness among habitats. This allows habitats with high species richness due to favourable natural conditions to be properly compared to sites of low species richness due to unfavourable natural conditions and acknowledges the fact that both may represent a similar ecological status. Reduced species lists are used to assess species richness in different forms in the **RSLA, RSL, pMarMaT, HPI, CCO**, **CFR**, **QI Sub Mac** and **MQAI**.

The **BALCOSIS** indicator is based on lack of representative species or taxa compared to reference species lists and thus applies a variation of the reduced species lists concept. These reference lists change according to salinity gradients in the assessed waterbodies. In practice, it is evaluated how many of the species belonging to the reference list are absent at each sampling station.

In addition to examining species richness, reduced species lists are also used to assess changes in species composition, mainly reported as a change in different functional groups. An example is the ratio of opportunistic species to total number of species. These types of indices are described in section 2.4 *Indicators based on replacement or loss of slow-growing species.*

National reference conditions among these indicators are derived from existing near-natural reference sites, least impacted sites and expert knowledge. The Portuguese **pMarMaT** also adds historical data (1960-1970) to the analysis (described by Gaspar et al., 2012), and so does Ireland and the United Kingdom when assessing the **RSL** reference conditions.

2.3 Indicators based on coverage of opportunistic algae

In the North-East Atlantic GIG, the indicators **OGA**, **OMBT, OMAI** and **CWOGA** form a group that uses areal coverage of opportunistic macroalgae. High rates of nutrient uptake and growth characterise the opportunistic life strategy, and blooms of opportunistic macroalgae species are often considered to be indicative of anthropogenically elevated nutrient levels. The opportunistic bloom-forming species primarily belong to the following genera of green algae: *Ulva, Chaetomorpha, Cladophora* or brown algae *Ectocarpus* and *Pylaiella* (Boderskov & Krause-Jensen 2022). The number of species in a bloom of opportunistic macroalgae is generally limited to one or a few fast-growing species, and the taxonomic composition is therefore not considered in these indicators.

The presence of opportunistic species does not per se denote poor environmental quality, it is rather the amount of the opportunistic species that reflects the environmental quality (Scanlan et al., 2007), and the indicators therefore focus on the amount of opportunistic algae. This is quantified as cover or a combination of cover (% of suitable area), biomasses (wet weight per square meter) and total area covered by opportunistic algae (hectares).

The total area covered by opportunistic algae is used in the **OGA/OMBT** indicators. This measure was introduced to account for very large waterbodies with an overall comparable low percentage cover of opportunistic macroalgae but with dense patches of opportunistic macroalgae still covering many hectares of shallow water (Scanlan et al., 2007).

The researchers behind the development of the **OGA/OMBT** tool stress that inter-annual variation in the spatial coverage and biomass of opportunistic algae is well documented, and the controlling factors behind these fluctuations are not always clear. To account for this, they stress the need for repeated observations over the season and recommend using rolling means or trend analyses when assessing the status by indicators based on macroalgae blooms (Scanlan et al., 2007).

There are differences among the blooming indicators of the opportunistic macroalgae, and the third EU intercalibration concluded that the **OGA/OMBT** used by the United Kingdom and Ireland was not in agreement with the **OMAI** and **CWOGA** indicators used by Germany and France (Wilkes et al., 2018). The main differences lie both in the assessment method and the frequency of assessment. The **OMAI** and **CWOGA** tools are based on remote sensing of generally unattached accumulations of green algae, whereas the **OGA/OMBT** assessments are made at the seabed (or by a combination of ground sampling and remote sensing) once during the growth season in late summer when the biomass peaks and include both the spatial cover and the biomasses of primarily attached opportunistic species.

Most opportunistic "macroalgae blooming indicators" are simple and relatively easy to apply compared to other macroalgae indicators that often combine several different types of indices and require taxonomic knowledge by the investigator. The reference conditions within this group of indicators are mainly derived from local and expert knowledge (Scanlan et al., 2007).

2.4 Indicators based on replacement or loss of slow-growing species

One impact of eutrophication is extensive growth of opportunistic algae. Those opportunists may overgrow perennial vegetation, cut off underlying vegetation from light and take up space. Several indicators therefore reflect the replacement or loss of slowly growing, predominantly perennial vegetation in one or several of the metrics included in the indicator. The **BALCOSIS, RSL / RSLA, pMarMaT, HPI, CCO**, **CFR**, **QI Sub Mac, EPI** and **MQAI** are all examples of this.

The community change is, however, assessed differently among the indicators, and both opportunistic and slow-growing species can be the main group targeted in the assessments. Indices targeting opportunists are: cover of opportunistic species in relation to total vegetated area, proportion of opportunistic algae species in relation to total species richness or in relation to perennial forms, proportion of Chlorophyta species to total number of species, density of opportunistic species, proportion of the biomass of opportunistic algae to total biomass, cover of *Ulva lactuca*. The indices targeting slow-growing species are: presence/absence of selected perennial species, density of structuring species, coverage of *Fucus sp*., area with *Fucus serratus* cover > 90%, proportion of biomass of *Fucellaria lumbricalis.*

None of these indices forms an indicator on its own but is combined with other indices like total cover of macroalgae or depth limits in the final indicator.

2.5 The use of depth limits of selected species

Depth extension of aquatic vegetation responds to changes in light regimes and depth limits of selected macroalgae are used as ecological assessment methods in several countries since light attenuation in the water column is linked to anthropogenic pressures (Krause-Jensen et al., 2021; Nielsen et al., 2002). Depth limits are the main component of the **MSMDI, MDFLD, EPI, PEQI** and the **Fucus index,** and depth limits are also included among other indices in the **BALCOSIS** and **HPI** indicators.

The indicator taxa most commonly used when assessing depth limits are *Fucus spp.*, *F. vesiculosus* and *F. lumbricalis.* The **MSMDI** includes several species specific to the individual waterbodies (Table 2.3), and the **HPI** indicator includes depth limits of *Laminaria hyperborea, Delesseria sanguinea, Plocamium cartilagineum* and *Halarachnion ligulatum*. The depth limits are defined differently among the indicators; thus, the MSMDI uses the deepest depth with 2-5% coverage, whereas other indices use the deepest occurring individual. However, the latter approach has methodological weaknesses since the individual alga gets smaller and more and more scattered with depth.

The depth limits of individual algal species are influenced by other parameters than light. Thus, temperature, exposure, salinity and substrate are other important factors structuring the algae community and influencing depth distributions. The structure of the algal community alters light availability and therefore influences the depth limits of the individual species in the community (Boderskov & Krause-Jensen, 2022). Consequently, several indicators also use the maximum depth of the total algae community as an index.

The impact of salinity on depth limits is well documented (Boderskov & Krause-Jensen, 2022), but not all of the indicators account for this. The MSMDI has an indirect salinity adjustment since boundary conditions – and thereby the assigned depth limit score – are set for each waterbody. Reference conditions are set for the **MSMDI** by using near-natural reference sites (Norway). Both Norway and Sweden use expert knowledge and historical data from the 1940s to the 1950s for setting the reference conditions in some areas (Carletii et al., 2009). German reference conditions for the depth limits indices of the **BALCOSIS** indicator rely on both expert knowledge, modelling and historical data, and the reference conditions are water type-specific (Schories et al., 2009).

Table 2.3. Taxa of macroalgae and angiosperms included in the MSMDI indicator. The waterbody type where the species are used for environmental assessment is indicated by numbers in the second row (going from the Skagerrak to the Bothnian Bay). From Juanes et al. (2013).

		North-East Atlantic						Baltic															
Group	**Taxon**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Rhodophyceae	*Delesseria Sanguinea*	x	x	x	x	X																	
Rhodophyceae	*Phycodrys rubens*	x	x	x	x	X																	
Rhodophyceae	*Rhodomela confervoides*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X						
Rhodophyceae	*Furcellaria lumbricalis*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	x	x				
Rhodophyceae	*Chondrus crispus*	x	x	x	x	x	x																
Rhodophyceae	*Phyllophora pseudoceranoides*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X						
Phaeophyceae	*Halidrys siliquosa*	x	x	x	x	x	x																
Phaeophyceae	*Fucus*															x	x	x	x	X	x		
Phaeophyceae	*Fucus serratus*								x														
Phaeophyceae	*Fucus vesiculosus*								x	x	x	x	x	x	x								
Phaeophyceae	*Sacchrina latissima*	x	x	x	x	x	X																
Phaeophyceae	*Sphacelaria arctica*								x	x	x	x	x	x	x	x	x	x	x	X	x		
Chlorophyceae	*Aegagropila linnaei*															x	x	x	x	X	x	x	x
Chlorophyceae	*Cladophora rupestris*															x	x	x	x				
Characeae	*Chara baltica*																					x	X
Characeae	*Nitella*																					x	X
Characeae	*Tolypella nidifica*														x	x	x	x	x	X		x	x
Magnoliophyta	*Potamogeton perfoliatus*														x	x			x		x	x	x
Magnoliophyta	*Zostera marina*	x	x		x	x	x			x	x		x	x									
No of taxa		9	9	8	8	9	7	4	6	5	6	6	5	8	8	8	8	7	6	3	4	5	5

3 Qualification of Danish macroalgae indicators

So far, three macroalgal indices have been evaluated based on data from the Danish monitoring program to document their applicability as indicators for environmental quality assessment in Danish coastal waters: 1) cumulative cover of macroalgae, 2) number of perennial macroalgae species and 3) relative cover of opportunistic macroalgae species.

The cumulative cover and number of perennial macroalgae species showed attenuation at deeper depths due to light limitation, and in relation to depth these indices are therefore suggested as being eutrophication-sensitive indicators. These two indicators also include a site-specific parameter (Psite) describing the max cumulative cover and max number of perennial macroalgae species, and this parameter was strongly linked to salinity. The relative cover of opportunistic macroalgae was, to a large extent, regulated by salinity, and variations in this index seemed more related to natural variation than to the level of eutrophication. This lack of eutrophication response may be caused by the design of the monitoring programme, which does not target annual fluctuations in the coverage of opportunists.

The attenuation of cumulative cover and number of perennial species by depth was therefore proposed to be incorporated in a common indicator also including the depth limit of eelgrass (Carstensen, 2020).

3.1 The use of depth limits and opportunistic algae as indices in Danish waters

Depth limits

The proposed Danish macroalgae indices are unique in the Baltic and North-East Atlantic by applying an attenuation coefficient as a measure of status. An alternative approach could be assessments of the depth limits of the total community or selected species like in several of the European indicators. This approach has, however, two inherent problems in Danish waters: The impact of variable salinity would probably mask a eutrophication response, and the macroalgae community is often limited by substrate and does not realise the full depth potential defined by light availability.

Depth limits of macroalgae are therefore not considered suitable indices for assessing macroalgae in Danish waters. It has not been investigated if depth attenuation coefficients for individual species or taxa could reflect environmental status in Danish coastal waters. *Fucus spp.* could be considered as indicator taxon if this avenue of research is followed because of the common occurrence, easy identification and the frequent use of this taxon by other European countries. It is, however, well documented that the depth distribution of *F. vesiculosus* is impacted by altered competition within the macroalgae community when salinity changes (Torn et al., 2006), and such an index would therefore need to be adjusted for salinity effects, and possibly also the degree of exposure, or developed for specific monitoring sites. The index would also be prone to impact by competition from other macroalgae (Boderskov & Krause-Jensen, 2021), and the use of *Fucus spp.* depth attenuation would likely have a limited applicability in Danish waterbodies.

Macroalgae blooming tools
A group of European indicators focuses on the mapping of opportunistic macroalgae blooms. The current monitoring programme in Danish waters does not directly target blooms of opportunists, which most often occur in sheltered coastal stretches influenced by nutrient-rich freshwater. Mapping of the blooms by remote sensing could form a base for this type of indicator in a subset of the Danish waterbody types. The dynamics of these blooms would probably require repeated observations during the growth season.

Relative dominance of opportunists
Ecological theory predicts a shift in community composition towards increased dominance of opportunistic species in eutrophic environments, and many European indicators include a measure of this change. Some apply biomass observations, but indices based on biomasses are not relevant to the Danish monitoring programme since it is based on observations of coverage.

The relative cover of opportunists, i.e. the cumulative cover of opportunistic species relative to the total cover of all erect macroalgae species expressed in percentage of available substrate, has been proposed as an index for environmental quality in Denmark, but analyses of monitoring data showed that it did not unambiguously respond to eutrophication pressure across Danish waters. Hence, the most recent analysis of the Danish monitoring data showed a non-significant response of this indicator to nutrient concentrations when corrected for salinity (Carstensen, 2020) although earlier analyses have detected a weak response (Carstensen et al., 2014).

Cover of opportunists has also been investigated as an environmental indicator in Danish coastal waters, but temporal variability was much smaller than variability between areas and could not be predicted from variations in environmental parameters (Krause-Jensen et al., 2007).

Proportions of the number of opportunistic species to total species richness is used as an indicator in the **HPI** and **pMarMAT**. Such an index may also be derived from Danish monitoring data. However, as blooms of opportunistic algae often represent one or a few species, such an index is likely to be even less sensitive to eutrophication than the already tested index based on relative cover of opportunistic species. Also, since Denmark already has an index reflecting the change in the number of perennial macroalgal species with depth, part of the response of macroalgal community structure to eutrophication is already embedded in this.

Changing community composition or shifts in diversity can be assessed from all surveyed species or be based on reduced species lists as seen in several European indicators. The reduced species lists accommodate lack of taxonomic expertise in the monitoring. Such reduced species lists of representative species can be developed from Danish monitoring data, and indicator development can be based on these lists.

Shifts between kelps and turf algae are receiving increasing international attention, and the ratio of opportunist cover to the cover of *Laminarialis* could function as an index (Boderskov & Krause-Jensen, 2022). Other indices involve the ratio of opportunist cover to the cover of perennial species, which is similar to albeit not identical with the proportion of opportunists already investigated in Danish waters. Proportions provide a more robust index limited with the 0-1 range than ratios. While ratios have well-defined distributions for lognormal distributed variables, this is not the case for other distributions such as coverage, which may include many zero observations. Thus, it is preferable to use the proportion of opportunists instead of the ratio of opportunists to perennial species. The same argument holds for other ratios of macroalgae variables that are not lognormally distributed.

Patterns of species abundance have been investigated as a potential index of environmental quality in Danish waters (Middelboe & Sand-Jensen, 2004) and were applied by the Danish counties, which documented a change in the species distribution over time (Ellerman 2004). Such a rank-abundance index is based on the assumption that a eutrophicated environment supports few species with high abundance, whereas an undisturbed community will have an even distribution of more species. Rank-abundance indices have not been developed internationally but could potentially be explored as a measure of environmental change. However, a rank-abundance index will also depend on species richness and other specific features regulating the macroalgae community, and this may require adjustments to salinity and potentially also physical exposure.

3.2 Methods to combine indices

The Danish indicators differ from most other indicators in that they are based on few indices, which reduces the need for weighing the different indices when producing a final combined indicator for macroalgae and angiosperms. Weighing is typically based on expert judgment and therefore prone to subjectivity.

Combining indices into a composite indicator, which appears to be a common practice in other neighbouring countries, has the advantage of assembling information but also the disadvantage of lacking transparency when the underlying indices are not presented. Composite indicators such as BALCOSIS combine macroalgae and angiosperm indices, and it is not possible from the indicator itself to determine if failure to achieve good ecological status arises from the macroalgae or angiosperm indices. Moreover, such composite indicators may also be less sensitive to specific changes, particularly if the underlying indices respond to different pressures, by averaging out responses of specific indices. For example, there is a risk that a potential negative response of an eelgrass index could be averaged out by positive responses in macroalgae indices.

4 Conclusion

There are currently seven and 12 described indicators based on macroalgae in the Baltic and North-East Atlantic GIGs. The indicators differ in types and number of indices and also as to how the indices are combined. However some common elements are found among the different groups of indicators including the use of reduced species list for assessment of species richness, assessment of opportunistic macroalgae dominance, assessment of depth limits of selected species and assessment of opportunistic macroalgae blooms.

The methods used in the current Danish monitoring programme do not support the direct use of depth limits and assessments of opportunistic macroalgae blooms or biomasses; rather attenuation coefficients for the whole macroalgae community or individual species are possible indices that can be formed based on present monitoring data.

The relative cover of opportunistic species does not capture eutrophication gradients in Danish waters. This is likely partly due to the large variability in opportunistic algal cover, which is not captured by one annual sampling in the present monitoring program, and partly to the major confounding effect of salinity, which makes it difficult to identify a potential relationship with eutrophication. Other European indices follow changes in community composition by assessing the total cover of opportunistic algae or various measures of the relative occurrence of opportunistic species, and international studies present additional inspiration for such indicators. While several Danish analyses have already been conducted, the monitoring data hold possibility for further testing of some of these alternative potential indicators of the relative abundance of opportunists. Among these, rank-abundance patterns would be the most promising index to explore. New developments in remote sensing also increase the potential for generating large-scale information on, for instance, area cover of opportunists, but as area extent is site-specific, definition of a reference will be challenging.

5 References

Ar Gall, E., Le Duff, M., Sauriau, P. G., de Casamajor, M. N., Gevaert, F., Poisson, E., . . . Miossec, L. (2016). Implementation of a new index to assess intertidal seaweed communities as bioindicators for the European Water Framework Directory. Ecological Indicators, 60, 162-173. doi:10.1016/j.ecolind.2015.06.035

Ar Gall, E. & Le Duff, M. (2014). Development of a quality index to evaluate the structure of macroalgal communities. Estuarine Coastal and Shelf Science, 139, 99-109. doi:10.1016/j.ecss.2013.12.028

Bermejo, R., Vergara, J. J. & Hernandez, I. (2012). Application and reassessment of the reduced species list index for macroalgae to assess the ecological status under the Water Framework Directive in the Atlantic coast of Southern Spain. Ecological Indicators, 12(1), 46-57. doi:10.1016/j.ecolind.2011.04.008

Boderskov, T. & Krause-Jensen D. (2022). Literature review of general responses of macroalgae to light, nutrient, salinity and temperature variations relevant to Danish waters. DCE - Danish Centre for Environment and Energy, Scientific briefing no. XX

Borja, A. & Dauer, D. M. (2008). Assessing the environmental quality status in estuarine and coastal systems: Comparing methodologies and indices. Ecological Indicators, 8(4), 331-337. doi:10.1016/j.ecolind.2007.05.004

Carletii, A. & Heiskanen A.S. (2009). Water Framework Directive intercalibration technical report report part 3: Coastal and transitional waters, European commision – Joint Research Centre, Luxembourg.

Carstensen, J. (2020) Macroalgae indicators for assessing ecological status in Danish WFD water bodies. Aarhus University, DCE – Danish Centre for Environment and Energy, 74 pp. Technical Report No. 170.

Carstensen, J., Krause-Jensen, D. & Josefson A. (2014). Development and testing of tools for intercalibration of phytoplankton, macrovegetation and benthic fauna in Danish coastal areas. Aarhus University, DCE – Danish Centre for Environment and Energy, 85 pp. Scientific Report No. 93.

D'Archino, R. & Piazzi, L. (2021). Macroalgal assemblages as indicators of the ecological status of marine coastal systems: A review. Ecological Indicators, 129. doi:10.1016/j.ecolind.2021.107835

Daunys, D., S. Olenin, R. Paskauskas, P. Zemlys, I. Olenina & M. Bucas. (2007). Typology and classification of ecological status of Lithuanian coastal and transitional Waters: an update of existing system. Technical Report for Transition Facility project No. 2004/016-925-04-06:

Diez, I., Bustamante, M., Santolaria, A., Tajadura, J., Muguerza, N., Borja, A., . . . Gorostiaga, J. M. (2012). Development of a tool for assessing the ecological quality status of intertidal coastal rocky assemblages, within Atlantic Iberian coasts. Ecological Indicators, 12(1), 58-71. doi:10.1016/j.ecolind.2011.05.014

Ellerman, I. (red) (2004). Overvågning af kystvande 2003. Vejle Amt Teknik og Miljø Hav- og Kystafdelingen.

EU 2005/646/EC. Commission decision of 17 Augus 2005 on the establishment of a register of sites to form the intercalibration network in accordance with Directive 2000/60/EC of the European Parliament and of the Council (2005/646/EC)

EU 2018/229/EC Commission Decision of 12 February 2018 establishing, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, the values of the Member State monitoring system classifications as a result of the intercalibration exercise and repealing Commission Decision 2013/480/EU (notified under document C(2018) 696). Text with EEA relevance.

Fürhaupter, K. (2015). Guidance document of the assessment system BALCOSIS, Ecological status assessment of macrophytes in the open coastal waters of the German Baltic Sea according to WFD requirements.

Gaspar, R., Pereira, L. & Neto J. M. (2012). Ecological reference conditions and quality of marine macroalgae sensu Water Framework Directive: an example from the intertidal rocky shores of the Portuguese coastal waters. Ecological Indicators, 19, 24-38.

Guinda, X., Gracia, A., Puente, A., Juanes, J. A., Rzhanov, Y. & Mayer, L. (2014). Application of landscape mosaics for the assessment of subtidal macroalgae communities using the CFR index. Deep-Sea Research Part Ii-Topical Studies in Oceanography, 106, 207-215. doi:10.1016/j.dsr2.2013.09.037

Guinda, X., Juanes, J. A., Puente, A. & Revilla, J. A. (2008). Comparison of two methods for quality assessment of macroalgae assemblages, under different pollution types. Ecological Indicators, 8(5), 743-753.
doi:10.1016/j.ecolind.2008.01.004

HELCOM (2015). Eutrophication Assessment Manual. Retrieved from https://helcom.fi/helcom-at-work/publications/

Juanes J.A., Bartsch, I., Karup, P.H….Birk, S. (2013). Intercalibration of biological elements for transitional and coastal water bodies. Nort East Atlantic GIG: Coastal Waers - Macroalgae and Angiosperms.

Juanes, J. A., Guinda, X., Puente, A. & Revilla, J. A. (2008). Macroalgae, a suitable indicator of the ecological status of coastal rocky communities in the NE Atlantic. Ecological Indicators, 8(4), 351-359. doi:10.1016/j.ecolind.2007.04.005

Kautsky L., Wibjörn, C. & Kautsky, H. (2001). Bedömningsgrunder för kust och hav enligt krav i ramdirektivet vatten - makroalger och några gömfröiga vattenväxter. Report to Swedich EPA (Naturvårdsverket).

Kolbe, K. (2007). Intercalibration Report (NEA GIG). Assessment of German coastal waters (NEA1/26, NEA3/4) and transitional waters (NEA11) by macroalgae and angiosperms. NLWKN Wilhelmshaven.

Krause-Jensen, D., Carstensen, J. & Dahl, K. (2007). Total and opportunistic algal cover in relation to environmental variables. Marine Pollution Bulletin, 55(1-6), 114-125. doi:10.1016/j.marpolbul.2006.08.019

Krause-Jensen, D., Duarte, C. M., Sand-Jensen, K. & Carstensen, J. (2021). Century-long records reveal shifting challenges to seagrass recovery. Global Change Biology, 27(3), 563-575. doi:10.1111/gcb.15440

Kuhlenkamp, R., Schubert P. & Bartsch, I. (2009). Marines Monitoring Helgoland: Benthosuntersuchungen gemäss Wasserrahmenrichtlinie. Handlungsanweisung Makrophytobenthos. Version2 /06.2009. NMH-Report 13.

Kuhlenkamp, R., Schubert P. & Bartsch, I. (2011). Water Framework Directive monitoring component macrophytobenthos N5 Helgoland EQR Evaluation 2010. MMH-Report 17.

Le Gal, A. & Derrien-Courtel, S. (2015). Quality index of subtidal macroalgae (QISubMac): A suitable tool for ecological quality status assessment under the scope of the European Water Framework Directive. Marine Pollution Bulletin, 101(1), 334-348. doi:10.1016/j.marpolbul.2015.10.053

Lønborg, C., Thomasberger, A., Staehr, P. A. U., Stockmarr, A., Sengupta, S., Rasmussen, M. L., . . . Timmermann, K. (2021). Submerged aquatic vegetation: Overview of monitoring techniques used for the identification and determination of spatial distribution in European coastal waters. Integrated Environmental Assessment and Management. doi:10.1002/ieam.4552

Marques, J. C., Patricio J., Teixeira, H. & Neto. J. M. (2009). Ecological Indicators for coastal and estuarine environmental assessment. A user guide. UK: WIT Press.

Middelboe, A. L., & Sand-Jensen, K. (2004). Patterns of species number and abundance in macroalgal communities in coastal waters. Hydrobiologia, 511(1), 173-183. doi:10.1023/B:HYDR.0000014039.00942.8c

Neto, J. M., Gaspar, R., Pereira, L. & Marques, J. C. (2012). Marine macroalgae assessment tool (MarMAT) for intertidal rocky shores. Quality assessment under the scope of the European Water Framework Directive. Ecological Indicators, 19, 39-47. doi:10.1016/j.ecolind.2011.09.006

Nielsen, S. L., Sand-Jensen, K., Borum, J. & Geertz-Hansen, O. (2002). Depth colonization of eelgrass (*Zostera marina*) and macroalgae as determined by water transparency in Danish coastal waters. Estuaries, 25(5), 1025-1032. doi:10.1007/bf02691349

Osowiecki, A., Lysiak-Pastuszak, E., Kruk-Dowgiallo, L., Blenska, M., Brzeska, P., Krasniewski, W., . . . Krzyminski, W. (2012). Development of tools for ecological quality assessment in the Polish marine areas according to the Water Framework Directive. Part IV - preliminary assessment. Oceanological and Hydrobiological Studies, 41(3), 1-10. doi:10.2478/s13545-012-0022-2

Rinne, H., Korpinen, S., Mattila, J., & Salovius-Lauren, S. (2018). Functionality of potential macroalgal indicators in the northern Baltic Sea. Aquatic Botany, 149, 52-60. doi:10.1016/j.aquabot.2018.05.006

Rinne, H. & Salovius-Lauren, S. (2020). The status of brown macroalgae *Fucus* spp. and its relation to environmental variation in the Finnish marine area, northern Baltic Sea. Ambio, 49(1), 118-129. doi:10.1007/s13280-019-01175-0

Ruuskanen, A. (2016). The occurrence and monitoring of macroalgae in the coastal waters of Uusimaa. The description of national macrophyte monitoring and application in Uusimaa 1993-2016. In Finish. Centre for Economic Development, Transport and the Environment. Report 100.

Scanlan, C. M., Foden, J., Wells, E. & Best, M. A. (2007). The monitoring of opportunistic macroalgal blooms for the water framework directive. Marine Pollution Bulletin, 55(1-6), 162-171. doi:10.1016/j.marpolbul.2006.09.017

Schories, D., Pehlke, C. Selig, U. (2009). Depth distributions of *Fucus vesiculosus* L. and *Zostera marina* L. as classification parameters for implementing the European Water Framework Directive on the German Baltic coast. Ecological indicators, 9, 670-680.

Torn, K. & Martin, G. (2011). Assessment method for the ecological status of Estonian coastal waters based on submerged aquatic vegetation. Conference paper, WIT transactions on Ecology and the Environment, Vol 150 doi:10.2495/SDP110371.

Torn, K., Krause-Jensen, D. & Martin, G. (2006). Present and past depth distribution of bladderwrack (*Fucus vesiculosus*) in the Baltic Sea. Aquatic Botany, 84(1), 53-62. doi:10.1016/j.aquabot.2005.07.011

Wells, E., Wilkinson, M., Wood, P. & Scanlan, C. (2007). The use of macroalgal species richness and composition on intertidal rocky seashores in the assessment of ecological quality under the European Water Framework Directive. Marine Pollution Bulletin, 55(1-6), 151-161. doi:10.1016/j.marpolbul.2006.08.031

WFD-UKTAG, Water Framework Directive – United Kingdom Advisory Group. (2014). UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. UKTAG report.

Wilkes, R., Best, M.., Scanlan, C., Rossi, N., Kolbe, K. & Salas Herrero, F. (2018). Coastal and transitional waters North East Atlantic geographic intercalibration group. JRC Technical Report. Publications Office of the European Union, Luxembourg.

Annex A: Basic concept of macroalgae indicators

Baltic

BALCOSIS *Baltic Algae Community analysis System*. Used in German Baltic open coastal waters. Combines evaluation of soft and hard bottom vegetation and includes both angiosperms (mainly seagrasses) and macroalgae. It consists of seven individual parameters that reflect different impacts of eutrophication. On soft bottom: 1) Depth limit of *Zostera marina* and 2) proportion of biomass of opportunistic algae. On hard bottom: 3) depth limit of *Fucus* spp. 4) Dominance in percent cover of *Fucus* spp. 5) Proportion of biomass of opportunistic algae. 6) Species reduction in relation to a reference species list. 7) Proportion of the biomass of *Fucellaria lumbricalis*. The last (5, 6 and 7) are only used in the 5 to 8 m depth range since structural changes with environmental pressure are less obvious in deeper waters. The biomass proportion of *Furcellaria lumbricalis* is used since it is a widely distributed and conspicuous red algae and often overgrown by epiphytes. Each metric has its own classification. The final value of **BALCOSIS** is obtained by calculation of a weighted mean from the normalised results of the individual parameters.

Inner coastal waters of the German Baltic are assessed using the **PHYBIBCO** system, which is not considered in this context since it is based on rooted vegetation of Charophytes and angiosperms.

Literature: Fürhaupter et al. (2015).

EPI *Estonian Phytobenthos Index*. Used by Estonia. It is based on three metrics: 1) The deepest occurrence of single attached vegetation observed by diver or video camera, 2) the maximum depth of *Fucus vesiculosus* and 3) the proportion of perennial species in the macroalgae community determined as dry biomass of attached erect vegetation aggregated over the whole transect. The scores of the three metrics are averaged for each transect to form the indicator value.

Literature: Torn & Martin (2011).

Fucus Index. Used by Finland. Primary description by Ruuskanen is in Finnish. Rinne et al. (2020) state that the lower limit of the continuous *Fucus spp.* belt is measured. They highlight that higher nitrogen concentrations seem to have positive rather than negative effects on the lower limit of the *Fucus* belt and that high nutrient concentrations do not have direct negative effects on the depth penetration of *Fucus*. Rather the negative effect of eutrophication is expressed indirectly via increased sedimentation and decreased water transparency, which lower the depth limits of the *Fucus* belt.

Literature: Ruuskanen (2016) and Rinne & Salovius-Lauren (2020).

MDFLD. *Maximum depth limit of Fucellaria lumbricalis.* Used by Lithuania and Latvia. Primary literature was not available.

Literature: Daunys (2007).

MQAI. *Assessment system for coastal and transitional waters using macrophytes.* Used by Poland. Based on biomass ratio of "positive taxa" and "negative taxa" and total coverage of macroalgae. The "positive taxa" consists of vegetation which occur naturally under only slight anthropogenic pressure, and "negative taxa" consists of taxa considered as indicators of eutrophication. The taxa included in the index depend on waterbody type. Lists of included taxa are only available for transitional waters.

Literature: Osowiecki et al. (2012).

PEQI *Phytobenthos Ecological Quality Index.* Used by Latvia. Based on two metrics: Depth distribution of macroalgae community and depth distribution of *Fucus vesiculosus*. It resembles the **EPI** but does not consider the proportion of perennial species.

Literature: Original literature not available, description according to HELCOM (2015).

North-East Atlanti

CCO/ICS *Cover, characteristic species, opportunistic species on intertidal rocky bottoms.* Used by France and based on assessments along a depth gradient where distinct algae communities are identified. Within each of the communities, three indices are calculated: 1) Total cover of the macroalgal communities, 2) number of characteristic species within a defined community belt/depth interval and 3) cover of opportunistic species. The final indicator score is obtained by adding the scores of the three indices. It resembles the CFR indicator used by Spain (see below).

Total cover of all seaweed and lichens are scored in % and assigned a value that also takes the surface available for colonisation on the particular site into account. The number of characteristic species is assessed in each community belt/depth interval. These belts are characteristic of shorelines strongly influenced by tides. For each community belt, a reduced species list is developed and the number of species are scored on the list. Different lists have been assigned to each geographical region. Species below a coverage of 2.5% are not included. The total cover of opportunistic species is determined in each community belt according to a species list of opportunistic species. The indicator builds on the previous ICS Index of community structure.

Literature: Ar Gall et al. (2016) and Gall & Le Duff (2014).

ICS. *Index of community structure.* Used by France. It combines the three indices macroalgae cover, taxonomic stratification and functional groups. See above.

CFR *Quality of Rocky Bottoms.* Used by Spain and is a precursor for the CCO. Based on the general coverage of large characteristic macroalgae and opportunistic species. It combines 1) the richness (number) of characteristic macroalgae species with a coverage above 1% according to a previously established list for each geographical region, 2) total cover of the macroalgae assemblage, taking the morphological characteristics of the substrate into account, 3) cover of opportunistic species in relation to the total vegetated area and 4) an expert judgment of the physiological condition of the whole macroalgal community by observations of, for instance, depigmentation, level of epiphyte coverage etc. The four metrics result in a score with a maximum of 25, 40, 30 and 15, respectively. The indicator value is calculated as the sum of these four metrics.

Literature: Guinda et al. (2014), Guinda et al. (2008) and Juanes et al. (2008).

CWOGA *Macroalgae Bloom Assessment (Opportunistic Green Macroalgae)*. Mentioned in the EU Commission decision of the third intercalibration (EU/2018/229) and by Wilkes et al. (2018). No background literature was available, but the indicator is based on the OGA principle described below.

HPI. *Helgoland Phytobenthic Index*. Used by Germany on Helgoland. The metrics are based on a reduced species list, and some of the RSL metric are also used in this indicator: species richness, proportion of green algae, proportion of red algae, ratio of perennial forms to annual or ephemeral forms (ESG1/ESG2), proportion of opportunistic species and a coastal factor. The indicator also includes the area where *Fucus serratus* covers > 90%, the coverage of *Ulva lactuca* in % and the depth limits of five selected species.

Literature: Kuhlenkamp et al. (2009, 2011).

MSMDI. *Multi Species Maximum Depth Index*. Used by Norway and Sweden. The depth distributions (abundance) of 3 to 9 disturbance sensitive species are measured. The species are common conspicuous perennial species sensitive to eutrophication, and the species selection depends on the specific waterbody type. Each selected species gets a score from 0.2 to 1 based on maximum depth distribution in relation to a reference depth limit for the particular species. The value 0.2 is assigned if a species has disappeared from an area. The average score of the species denotes the MSMDI value.

Literature: Juanes et al., 2013) and Kautsky et al. (2001).

OMAI (DE-AL-CO). *Opportunistic Macroalgae cover/acreage on soft sediment in intertidal coastal waters*. Used by Germany. Original literature (Kolbe, 2007) was not accessible. A short description is given in Wilkes et al. (2018), which states that the indicator is primarily used in intertidal habitats but can be applied to other coastal systems. The total area covered by opportunistic algae and the density of the algae are assessed by aerial mapping.

Literature: Wilkes et al. (2018) and Kolbe (2007).

OMBIT and **OGA** *Macroalgal Bloom Assessment (opportunistic macroalgae)* and *Opportunistic green macroalgal abundance.* Used by Ireland and United Kingdom. Methods for monitoring blooms of opportunistic macroalgae such as *Ulva*, *Chaetomorpha* etc. Abundance is measured as a combination of spatial cover (% of suitable area) and biomass in wet weight per area, forming the base of the indicator. Total area covered by opportunistic algae can also be included in the assessment. Biomasses and coverage are evaluated against expert-derived boundary conditions.

Literature: WFD-UKTAG (2014), Wilkes et al. (2018) and Scanlan et al. (2007).

pMarMAT. *Marine Macroalge Assessment Tool.* Used by Portugal. It is based on even different metrics: 1) Species richness, 2) proportion of Chlorophyta species to the total number of species, 3) proportion of opportunists species to the total number of species, 4) number of Rhodophyta species, 5) ratio of the number of opportunistic species to the number of perennial taxa, 6) coverage of opportunists and 7) shore description. The assesment tool is based on a reduced taxa list (in principle similar to the reduced species list) adapted to different shore typologies. The metrics are given different weights to produce the **pMarMAT** score, and the shore description serves as a correction factor for the species richness score to make shores with different substrata comparable.

Literature: Marques et al. (2009) and Neto et al. (2012).

QI Sub Mac. *Quality Index of subtidal Macroalgae*. Used by France. A composite indicator based on 14 metrics: 1) Presence/absence of selected perennial macroalgae specific for each ecoregion. 2 and 3) In the upper and lower infralittoral, depth, extension of subtidal zone supporting macroalgae communities (infralittoral). 4) Density (individuals per m^2) of structuring species. 5 and 6) In the upper and lower infralittoral, number of characteristic species defined for each ecoregion with occurrences above 10%. 7 and 8) In the upper and lower infralittoral, mean density (individuals/m^2) of opportunistic species. 9 and 10) In the upper and lower infralittoral, total number of taxa. 11 and 12) In the upper and lower infralittoral, mean stipe length of *Laminaria hyperborea* in 10 randomly selected individuals. Longer stipes result in higher scores and are considered to express better environmental conditions. 13 and 14) In the upper and lower infralittoral, mean quantity of epibionts growing on the 10 stipes measured in 11 and 12 expressed as cm^2 epibionts/ m stipes. Different scores are assigned to the 14 metrics and summed to form the index. The calculation is carried out for each algae belt – upper and lower infralittoral – and the mean of the score for the two belts is used as the final score.

Literature: Le Gal & Derrien-Courtel (2015).

RICQI. *Rocky Intertidal Community Quality Index*. Used by Spain. Based on abundance of indicator species, presence of the disturbance sensitive *Cystoseira tamariscifolia*, presence of large perennial macrophytes, species richness of both algae and fauna and faunal cover of both herbivores and suspension feeders. Each metrics is assigned a score, which is summed to form the final index.

Literature: Diez et al. (2012).

RSL and **RSLA** *Rocky shore reduced species list* and *Rocky shore reduced species list with abundance*. Developed for the intertidal seaweeds of the British Isles and also used by Ireland, Norway and Spain. The method is based on a scoring system for basic shore description of physical parameters and a list of commonly present and identifiable macroalgae species that are assessed in the area. The changes in the number of Rhodophyta and the proportions of Chlorophyta and opportunistic species are considered to be indicative of anthropogenic influence and shifts in quality status, showing an increase in Rhodophyta species number with increased environmental quality and an increasing number of Chlorophyta taxa and opportunistic species with decreasing quality status. The indicator has later been modified to also include the ratio of perennial forms to annual or ephemeral forms. The indicator is focused on areas of rocky intertidal coastline.

Literature: Bermejo et al. (2012), D'Archino & Piazzi (2021) and Wells et al. (2007).