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WISER

Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery

DELIVERABLE

Deliverable D4.2-1: Review report/manuscript on seagrass indicator potential

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PP	Restricted to other programme participants (including the Commission Services)	
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Content

Non-technical summary

The increasing human pressure on the coastal zone is rapidly deteriorating coastal environmental quality, particularly since year 1950. Policies aiming at improving coastal water and ecosystem quality are a priority in European countries (Water Framework Directive, Marine Strategy Framework Directive, Habitats Directive) as well as in other countries and regions in the Globe (e.g. USA, Clean Water Act). Well developed seagrass beds provide many important services to coastal ecosystems, such as increased biodiversity and coastal protection, which disappear when seagrass distribution and abundance decline in response to human pressure. Seagrasses therefore have a large potential as indicators of ecological quality.

This deliverable represents a compilation of seagrass indicators included in European monitoring programs. The compilation shows that a strikingly diverse range of seagrass metrics is in use, i.e. 35 specific seagrass metrics and 20 metrics on associated vegetation, fauna and macroalgae are making part of the seagrass indicators. The widespread use of seagrass indicators in European monitoring programs reflects the value of these marine benthic vegetation components as canaries of marine ecologic status.

The metrics composing the compiled seagrass indicators describe various aspects of the seagrass community and associated flora and fauna and can, on this basis, be categorised in seven different categories: ‘distribution’, ‘abundance’, ‘shoot characteristics’, processes’, ‘chemical constituents’, ‘associated flora and fauna’ and ‘macroalgae’, of which the first five relate directly to the seagrasses.

The indicators and their metrics can typically not be extracted from the same type of raw data, and the different categories of metrics may also show different sensitivities and time scales of response to pressures. The metrics are, therefore, not directly comparable but may supplement each other in the evaluation ecological status.

The large diversity of metrics highlights a need to further explore the sensitivity and time scales of responses of metrics and indicators to pressures in order to assist managers selecting the most appropriate tools for a given purpose and type of ecosystem.

Introduction

The increasing human pressure on the coastal zone is rapidly deteriorating coastal environmental quality, particularly since year 1950. The global human population has doubled during the last four decades of the 20th Century and increasingly concentrates into cities. At present, 23% of the global human population inhabits areas located within the closest 100 km to shore, and the highest population density occurs within the closest 10 km (Nicholls and Small 2002). The concentration of the global human population in the coastal zone is transforming coastal areas, encompassing both land and marine environments. Natural ecosystems are replaced by urban areas, artificial structures (e.g. harbours, dikes, etc) and installations to produce resources (e.g aquaculture farms, desalination plants). Similarly, nutrients, organic matter and other contaminant inputs to the coastal zone have increased worldwide. As a result, there is a widespread deterioration of coastal water quality, evidenced by a decrease of water transparency, increasing nutrient and organic enrichment and coastal eutrophication, and coastal key ecosystems, such as salt marshes and seagrass meadows, are declining at an alarming rate (Duarte et al. 2008).

Policies aiming at improving coastal water and ecosystem quality are a priority in European countries as well as in other countries and regions in the Globe (e.g. USA: Clean Water Act (CWA), National Estuary Program (www.epa.gov/nep)). In Europe, the Habitats Directive (HD) sets standards to guarantee biodiversity by preserving the natural habitats of flora and fauna in the territory of European member states, and implementation of the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) set a mutual platform and obligations to ensure "good ecological status" of coastal and marine waters (Borja *et al.,* 2010). In the WFD and MSFD the assessment of ecological status of European water bodies must be conducted using indicators of biological elements that are sensitive to water quality. Seagrasses are a component, together with macroalgae, of the biological quality element "benthic vegetation" used by both European directives. Similarly, the meadows of one European seagrass species (*Posidonia oceanica*) are one of the habitats included in HD.

Seagrass meadows are the dominant marine ecosystem of sandy coastal areas, extending from the tropics to the poles except in Antarctica. Seagrasses are clonal plants, which encompass a limited number (50-60) of species with similar architecture but with sizes, plant growth rates, population dynamics and ramet longevity spanning across 2-3 orders of magnitude (Hemminga and Duarte, 2000). Seagrass meadows are an extremely valuable ecosystem because of the many ecological services they provide to the coastal zone. They are highly productive, influence the structural complexity of habitats, enhance biodiversity, play important roles in global carbon and nutrient cycling, stabilize water flow and promote sedimentation, thereby reducing particle loads in the water as well as coastal erosion (Jones et al., 1994; Hemminga and Duarte, 2000; Orth et al., 2006). Seagrass meadows have, in fact, been estimated to deliver the highest value, in terms of ecosystem services, of all natural ecosystems (Costanza et al., 1997). However, these ecosystems rank amongst the most vulnerable ones on the biosphere, since they experience marked global declines to a large extent due the strong human pressure to the coastal zone (Short and Wyllie-Echeverria, 1996; Schramm and Nienhuis, 1996; Walker and Kendrick, 1998; Green and Short, 2003; Orth et al., 2006; Duarte, 2009; Waycott et al., 2009). Seagrass decline is a nonlinear process that accelerates, through cascade effects, after reaching a certain level of disturbance (e.g., Duarte, 1995). Seagrass recovery can be a slow process, requiring time scales up to centuries for some species (Duarte, 1995). Hence, detection of seagrass decline at the earliest stages of the process is crucial to prevent large-scale and, at human time scales, often irreversible seagrass losses. Monitoring programs to early detect seagrass declines, as well as recoveries after cessation of disturbances, are proliferating world wide (e.g., Orth et al., 2006). These programs serve multiple purposes - they provide information on the status and trends of the vegetation, verify whether a certain target is met and provide knowledge on relationships between management measures undertaken, e.g. reductions in nutrient load, and the response of the vegetation. Moreover, the high sensitivity of seagrasses to environmental deterioration, as for instance decline of water transparency, coastal eutrophication, coastal erosion and warming, together with their widespread geographical distribution, convert them into excellent canaries of coastal deterioration (Orth et al., 2006). Indeed, one of the requirements to fulfill "Good ecological status" according to the WFD is that the level of angiosperm abundance shows only slight signs of disturbance.

The four European seagrass species grow from the intertidal (*Zostera noltii*) and down to 5-15 meter depth in North European waters (*Zostera marina*), but seagrasses may be found even deeper than 50 meter in clear Mediterranean waters (*Cymodocea nodosa* and *Posidonia oceanica*). In the Mediterranean Sea, *P. oceanica* beds cover between 25,000 and 50,000 km^2 of the coastal areas corresponding to 25% of the sea bottom at depths between 0 and 40 m (see Borja *et al.,* in press).

There is a wide repertoire of seagrass indicators, assessed at different seagrass organisation levels, aiming evaluation of plant chemical composition, individual morphology, meadow abundance and extension, and processes such as growth or population dynamics (e.g. Borum et al., 2004). Often, indicators of fauna, macroalgae and other non-seagrass flora present in seagrass communities are also considered. Seagrass indicators should be chosen accordingly to monitoring program objectives and the seagrass species growing in the region. Monitoring programs currently conducted in Europe in order to comply with WFD, as well as aiming assessing conservation status of these endangered ecosystems, therefore comprise a selected set of seagrass indicators that may vary across regions. However, an overview of the type of these seagrass indicators is lacking, and this reduces the possibility to exchange information and experience among countries on the selection and use of the indicators.

Objectives

The objective of this Deliverable is to compile the seagrass indicators available to assess ecological quality of European coastal waters and conservation status of European seagrass meadows, to (1) strengthen the evidence of the seagrass indicator potential to monitor coastal change, (2) to provide an overview of the seagrass indicators and metrics used and (3) to identify those most commonly used in Europe.

Methods

We compiled information on seagrass indicators used in European monitoring programmes, both implementing WFD and assessing the ecological status of seagrass meadows. We also compiled indicators that are under development to comply with WFD requirements. All WISER partners working on marine benthic vegetation contributed to the compilation by adding indicators used in their proper ecoregions: The North East Atlantic, the Baltic Sea, the Mediterranean Sea and the Black Sea. Most of the indicators are developed for or have the potential for use in monitoring according to the WFD. Many of the indicators are accordingly being discussed and attempted intercalibrated among countries of each of the four ecoregions through the geographical intercalibration groups (GIGs). The compilation of seagrass indicators used for the WFD was complemented by adding information from the metric compilation gathered by Sebastian Birk through the 'Wiser questionnaire' which was circulated among WISER partners and in GIG-groups:
http://www.wiser.eu/programme-and-results/data-and-guidelines/method-database/detail.php?id=176

The present compilation also includes additional indicators used in local monitoring programs unrelated to the WFD. The compilation was further supplemented by information from the literature.

Each of the compiled indicators includes one or more metrics describing various aspects of the seagrass bed: distribution, abundance, shoot characteristics, processes and chemical constituents. Moreover, some of the indicators combine one or more seagrass metrics with additional metrics characterising the flora and fauna associated with the seagrass bed or the macroalgal beds in the area. For each monitoring program we allocated the metrics composing the seagrass indicator to the 5 categories describing the various aspects of the seagrass bed and the two categories characterising the associated vegetation (Table 1). In some cases the same indicator was monitored by several programs and it is counted as many times as programs include it.

We use the term 'indicator' to describe a metric or a composite of metrics (an index) in a specific monitoring program. The term 'metric' is here used in a broad sense with some overlap to the term 'parameter'. For example 'seagrass depth limit' is a metric that uses e.g. the average level of the parameter 'seagrass depth limit' in an assessment of water quality. Similarly 'density' or 'aboveground biomass' are metrics that use e.g. the average level of the parameters 'density' and 'biomass' at a given water depth, and the metric 'Cymoskew' uses the skewness of the distribution of the parameter 'shoot length' in the assessment of water quality. The term 'index' refers to a composite of metrics and uses e.g. average levels of several parameters, each attributed a certain weight, in an assessment of water quality. POMI is an example of such an index which is based on several metrics/parameters belonging to various categories (Table 1).

Table 1. List of seagrass metrics and categories of metrics contained in European seagrass indicators.

Category of metric	Metric
Distribution	Seagrass area
	Depth limit
	Depth limit type
Abundance	Shoot density
	Aboveground biomass
	Cover
	Dead matte cover
	Root biomass
	Above- vs. belowground biomass
Shoot characteristics	Shoot leaf area
	No. of leaves per shoot
	Leaf width
	Leaf length
	Leaf length skewness
	Shoot height
	Shoot biomass
	Plagiotrophic rhizomes
	Leaf necrosis
	Broken leaves
Processes	Change in density
	Shoot mortality
	Shoot recruitment
	Herbivore pressure
	Flowering
	Leaf production
	Rhizome production
	Rhizome elongation
	Rhizome: baring, burial
Chemical constituents	Tissue C/N above- & belowground
	Tissue(rhizome and/or leaves) N
	Tissue(rhizome and/or leaves) P
	Tissue(rhizome and/or leaves) δ15N
	Rhizome sucrose
	Rhizome Cu Pb Zn
	Tissue (rhizome and/or leaf) δS34
Associated flora and fauna	Epiphyte biomass
	Epiphyte N
	Epiphyte cover (species & functional groups)
	Species composition
	Community components: cover or biomass
	Perennial proportion (cover)
	Opportunists abundance
	Depth limit of potameids
	Invasive species - presence
	Macrofauna abundance
Macroalgae	Depth limit of *Fucus* (belt or individuals)
	Species composition
	Macroalgae richness
	Biomass - macroalgae taxa
	Biomass - opportunists
	Cover -characteristic macroalgae
	Cover - macroalgae
	Area - opportunists
	Fraction of opportunistics

Results

We compiled a total of 118 seagrass indicators that are being monitored in European programs and 7 ones that are under development to comply with WFD requirements. The programs cover the four ecoregions: the North East Atlantic Sea, the Baltic Sea, the Mediterranean Sea and the Black Sea. All four European seagrass species are used in European seagrass monitoring programs. Most of the programs use seagrass indicators of a single species, *Posidonia oceanica* make part of 39%, *Zostera marina* of 20%, and *Cymodocea nodosa* of 2.2% of the indicators. The rest of the indicators (39%) do not specify the seagrass species monitored or they target more than one seagrass species.

Number of metrics included in seagrass indicators

The number of metrics included in the seagrass indicators of the various monitoring programs ranges from 1 to 18. Seagrass indicators based on just one metric are by far the most common since they constitute 79% (99 out of 125) of the indicators used in the programs compiled (Figure 1).

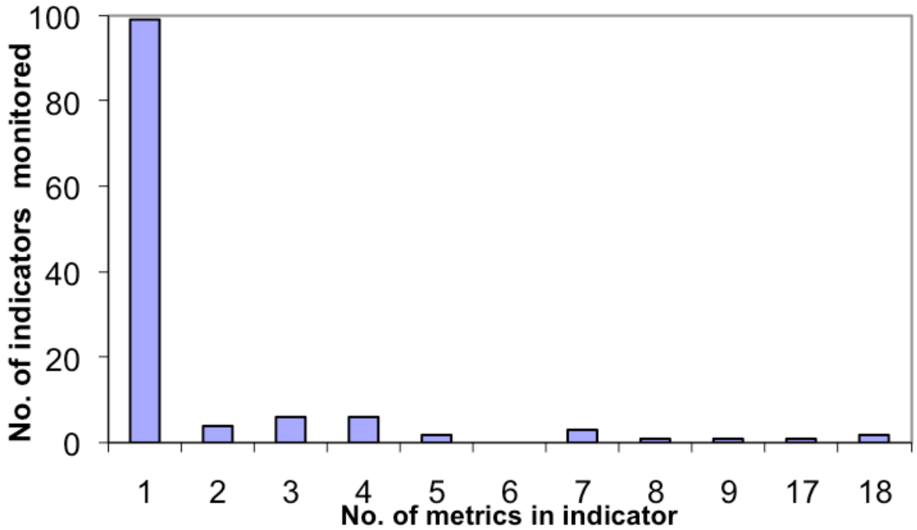

Figure 1. Number of European seagrass indicators containing one or more metrics. The same indicator can be monitored by different programs.

Categories of seagrass metrics

The diversity of seagrass metrics in use in Europe is very large. The five categories of seagrass metrics include a total of 35 different individual metrics (Figure 2), and the categories representing associated vegetation and macroalgae included an additional 20 metrics (Figure 3). A total of 55 different metrics was thus included in the various indicators.

The top-three seagrass metrics used in Europe, as evaluated based on the number of indicators including them, are: 1) shoot density (included in 27 indicators) and 2) cover (included in 26 indicators) both belonging to the category 'abundance', and 3) depth limit (included in 20 indicators) and belonging to the category 'distribution' (Figure 2).

Seagrass metrics across regions

The diversity of seagrass metrics in use is high within as well as between regions (Figure 4). The metric categories 'distribution' and 'abundance' are represented in most regions, and the same is true for the categories 'associated vegetation and fauna' and 'macroalgae'. By contrast the categories 'shoot characteristics', 'processes' and 'chemical constituents' are used in the Mediterranean Sea only, where they make part of several *Posidonia oceanica* and Cymodocea nodosa indicators.

In fact, the Mediterranean has by far the largest diversity in seagrass indicators and is the only region that encompasses the full range of metric categories. The North East Atlantic region and the Baltic Sea use indicators involving four metric categories while in the Black Sea seagrass indicators involve metrics of two of the categories (Figure 4).

Seagrass indicators for coastal versus transitional waters

Seagrass indicators are used to monitor seagrass conservation status and ecological quality of both European coastal and transitional waters. Most of the compiled indicators (90%) are used in coastal waters, while 4% exclusively monitor vegetation of transitional waters and the remaining 6% are applied in both water body types.

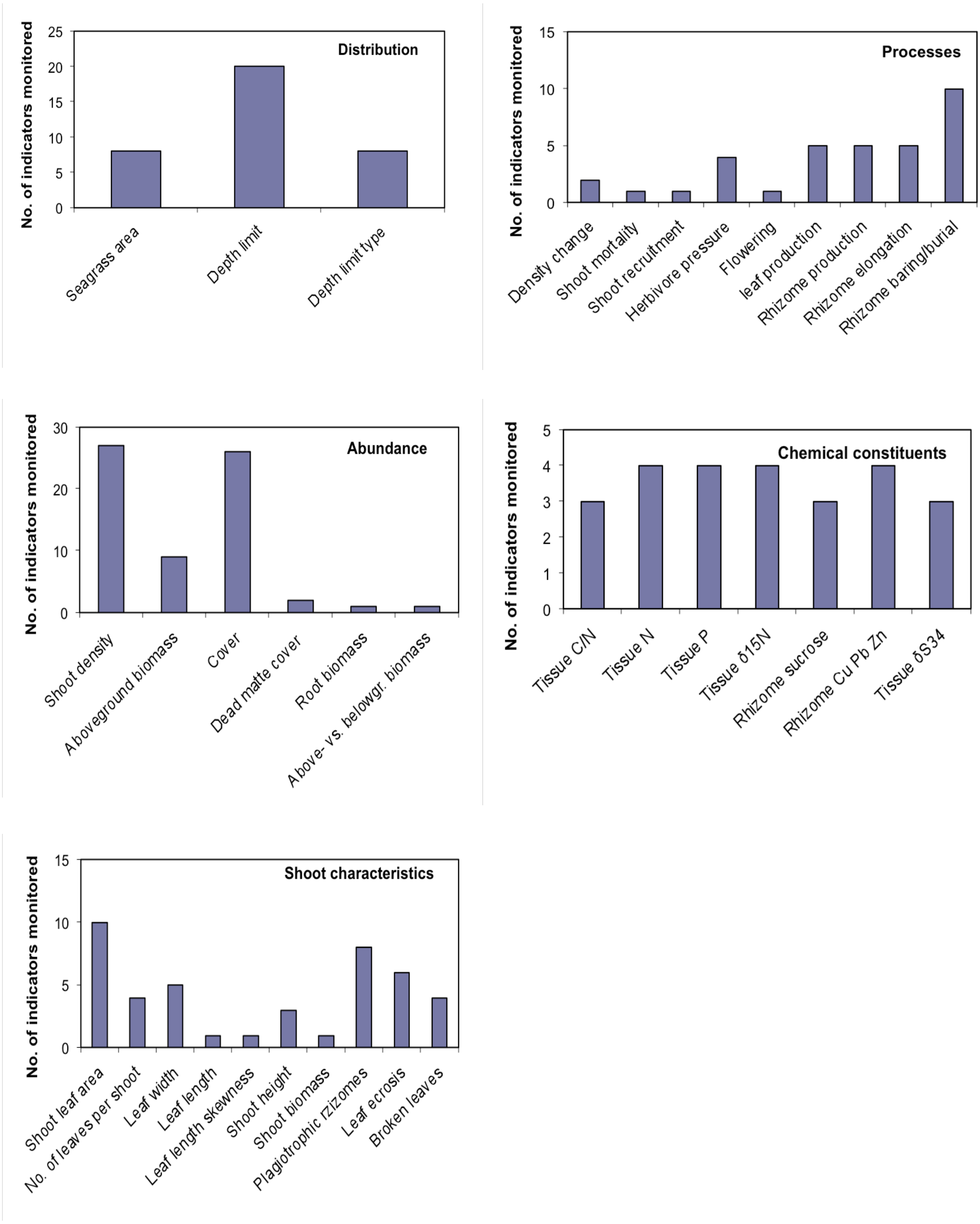

Figure 2. Number of seagrass indicators monitored which include metrics in one or more of the five categories of seagrass metrics: 'Distribution', 'abundance', 'shoot characteristics', 'processes' and 'chemical constituents'. For each of these categories the number of indicators including specific metrics was counted.

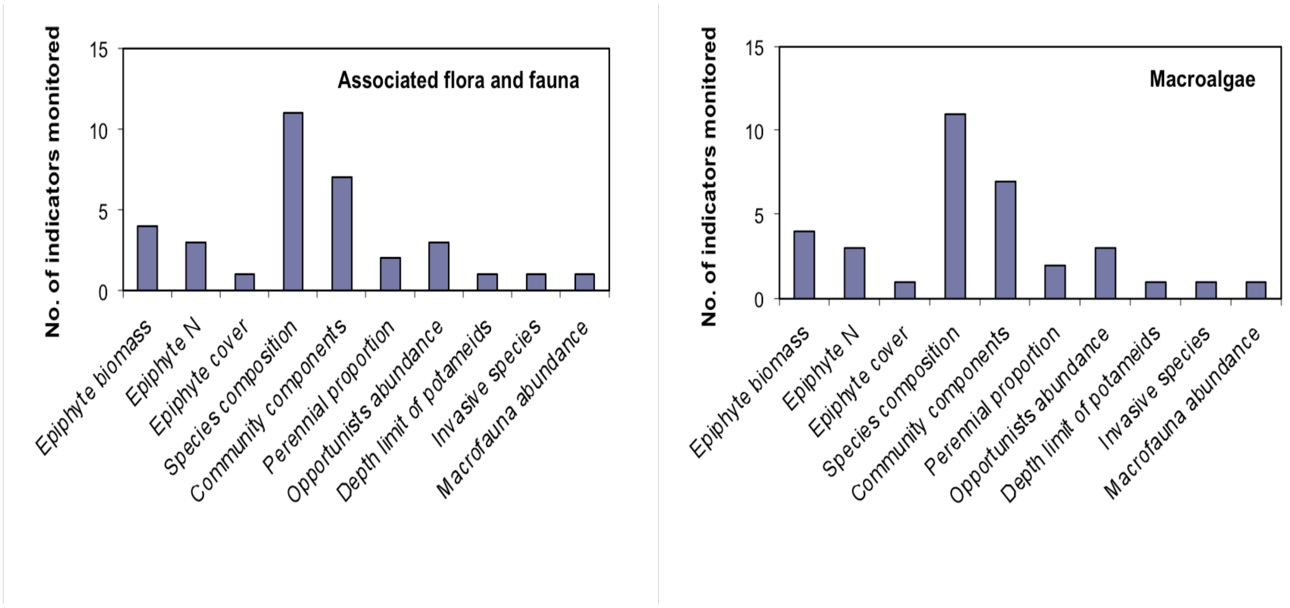

Figure 3. . Number of seagrass indicators monitored which include metrics characterising the flora and fauna associated with the seagrass bed or nearby macroalgal beds. For each of these categories the number of indicators including specific metrics was counted.

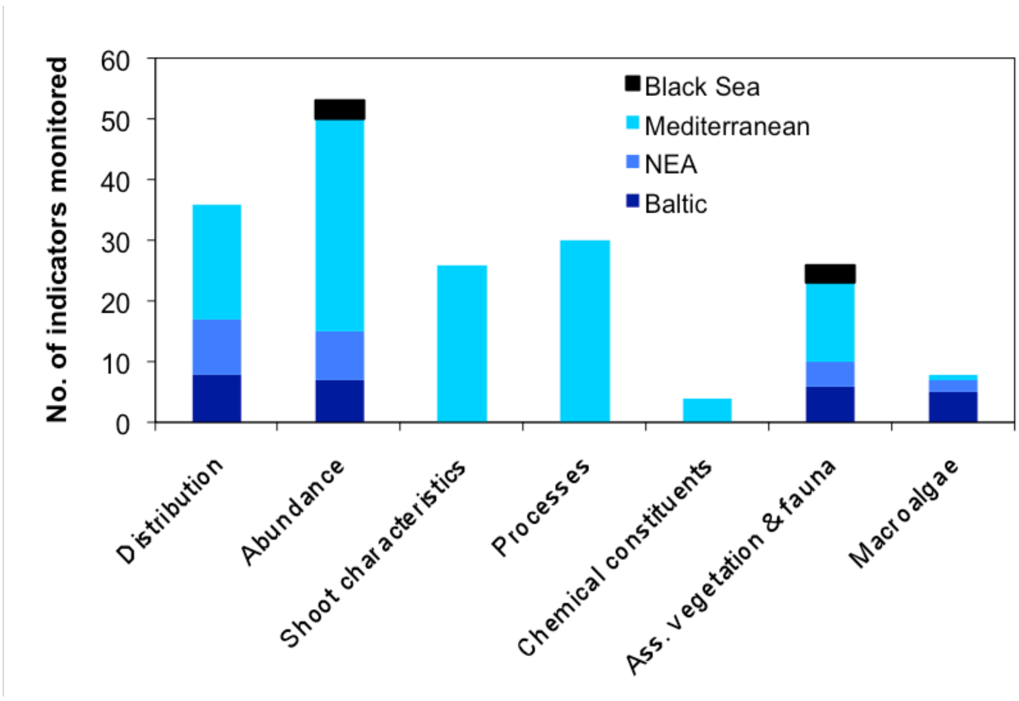

Figure 4. Number of seagrass indicators that include the various categories of metrics in each of the European regions: North East Atlantic (NEA), Baltic Sea, Mediterranean Sea, Black Sea.

Discussion

Seagrasses are excellent canaries of ecological quality because well developed seagrass beds provide many important services to coastal ecosystems, such as increased biodiversity and coastal protection, which disappear when seagrass distribution and abundance decline in response to human pressure (Erftenmeijer and Robin Lewis, 2006).

The compilation shows that a strikingly diverse range of seagrass metrics is in use to monitor ecological quality in Europe, i.e. the compiled seagrass indicators included 35 specific seagrass metrics and 20 metrics on associated vegetation and macroalgae. The diversity of seagrass metrics is even larger than the compilation immediately suggests since some of them can be assessed in different ways: e.g. the metrics relating to chemical constituents may represent either leaves or rhizomes/roots, and the metric ‘opportunists abundance’ may be assessed as either biomass or cover. Moreover, as the benthic vegetation extends from the intertidal and far into the subtidal, most of the metrics exhibit depth-dependent differences in response to e.g. changes in light and physical exposure with depth (e.g. Krause-Jensen et al., 2000) which must be considered.

The compiled metrics describe various aspects of the seagrass community and the associated flora and fauna and can, on this basis, be categorised in the seven different categories: ‘distribution’, ‘abundance’, ‘shoot characteristics’, processes’, ‘chemical constituents’, ‘associated flora and fauna’ and ‘macroalgae’, of which the first five relate directly to the seagrasses.

The metric category ‘abundance’ relates directly to the part of the WFD definition of good ecological status, which states: ‘the level of macroalgal cover and angiosperm abundance show only slight signs of disturbance’. The metric category ‘distribution’ also relates to this definition since it describes extent of the seagrass area. Moreover, metrics of the category ‘processes’, such as change in shoot density’, ‘shoot recruitment’ and ‘mortality’, also address this part of the WFD definition of good ecological status by indicating whether the seagrass bed is in a stable state, is improving or degrading (e.g. Marbà et al., 2005). The metric categories ‘associated flora and fauna’ and ‘macroalgae’ also contribute to characterize this part of the definition of ecological status.

The metric categories ‘shoot characteristics’ and ‘chemical constituents’ address the definition of good ecological status more indirectly as their level may indicate whether the seagrass bed is affected by disturbances and thereby likely to change in the future. Thus, the skewness of length distribution of seagrass leaves, reflected in the metric ‘Cymoskew’, has been suggested to reflect the degree of disturbance of seagrass beds (Orfanidis et al., 2009). The rationale of using the length distribution is that body size of organisms correlates with many life history and plant functional traits, e.g. carbon turnover, production, growth, metabolism, and phenotypic features of plants can therefore help understand ecological processes (Brown *et al*., 2004; Marbà *et al*., 2007). High contents of nutrients or contaminants in the seagrass tissue may likewise indicate that the area is eutrophic or affected by contaminants that may eventually lead to a decline in seagrass abundance (e.g. Martínez-Crego et al., 2008)

The WFD further describes that good ecological status requires that 'most disturbance sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are present'. As the seagrasses are sensitive to disturbances, any metric describing their presence relate to this part of the definition. The metric categories 'associated flora and fauna' and 'macroalgae' also contribute to characterize this part of the definition of ecological status.

The various metrics can typically not be extracted from the same type of raw data, and the different categories of metrics also show different sensitivities and time scales of response to pressures. Indeed, it is likely that the impact of a same given pressure may take years-decades to be detected using indicators in the category distribution, years in indicators of abundance, and one year or less in indicators of processes or chemical constituents. Time scales and pathways of responses also depend strongly on whether the ecosystems have undergone regime shifts in response to pressures, which may delay the restoration of the ecosystem (Duarte, 1995; Duarte et al., 2009). Significant reductions in nutrient loads in Danish coastal waters over the last decades have, for example, not yet led to marked improvements in the depth distribution of eelgrass, most likely because the water remains turbid (Markager et al., 2010).

Moreover, the intrinsic characteristics of the different European seagrasses constrain the time scales of indicator responses to pressures as well as to the cessation of them. The four European seagrass species thus exhibit growth rates and population dynamics that range across 2 orders of magnitude (e.g. Hemminga and Duarte, 2000). For instance, *Zostera marina* clones may spread at rates of 30 cm yr^{-1}, whereas those of *Posidonia oceanica* spread at rates of 2-6 cm yr^{-1}. These differences imply that changes in distribution or abundance, particularly during recovery, would be detected at different time scales depending on the species used, and for some species (e.g. *P. oceanica*) may take longer than the managerial requirements. Hence, the assessment of ecological status using benthic vegetation requires the use of different seagrass indicators depending on the species to assess responses at similar time scales. The metrics are, therefore, not directly comparable but may supplement each other in the evaluation of ecological status.

In summary, our results demonstrate that seagrasses are good indicators of ecological status of coastal and transitional waters and that they are commonly used in European monitoring programs (see Borja *et al.,* in press). There is a wide diversity of seagrass indicators aiming to detect responses to pressures at physiological, individual, population and community levels, allowing identification the impact of pressures at different time scales.

Because the pressures along European coasts are multiple and occur simultaneously (Claudet and Fraschetti, 2010), some monitoring programs include assessment of several individual seagrass indicators or multimetric indices, that are designed to respond to the various types of pressures. Moreover, the use of several seagrass indicators in a monitoring program also allows detection of pressures that impact seagrasses at different time scales. There is a need to further explore the sensitivity and time scales of responses of metrics and indicators to pressures in order to assist managers selecting the most appropriate tools for a given purpose and type of ecosystem. In this process it is also relevant to examine whether some of the metrics used in multi-metric indicators and monitoring programs assessing multiple indicators are redundant and could be omitted in order to decrease the cost of the program. There are indicators for monitoring the ecological status of all four European seagrass species (*Z. marina, Z. noltii, P. oceanica, C. nodosa*) and the set of applied indicators varies across GIGs, mostly because the different intrinsic characteristics of the seagrass species present in the regions. This largely prevents to define a common seagrass indicator able to monitor ecological status of coastal and transitional waters across the entire Europe. The set of applied indicators also varies within GIGs for the same seagrass species, and at this level it should, in principle, be feasible to use common seagrass indicators.

Acknowledgments

We thank Sebastian Birk for providing an overview of the vegetation indices and metrics compiled across regions through the ‘WISER questionnaire’, which helped complete our compilation and linking it with the larger compilation of metrics across quality elements, water bodies and regions conducted in the WISER project.

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