POTENTIAL EUTROPHICATION INDICATORS BASED ON SWEDISH COASTAL MACROPHYTES

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WATERS: Waterbody Assessment Tools for Ecological Reference conditions and status in Sweden

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WATERS

WATERS is a five-year research programme that started in spring 2011. The programme's objective is to develop and improve the assessment criteria used to classify the status of Swedish coastal and inland waters in accordance with the EC Water Framework Directive (WFD). WATERS research focuses on the biological quality elements used in WFD water quality assessments: i.e. macrophytes, benthic invertebrates, phytoplankton and fish; in streams, benthic diatoms are also considered. The research programme will also refine the criteria used for integrated assessments of ecological water status.

This report is a deliverable of one of the scientific sub-projects of WATERS focusing on macrophytes in coastal waters. The report presents a state-of-the-science review of macrophyte indicators used in Europe. The results will provide a basis for continued testing and evaluation of macrophyte indicators in the WATERS programme, including field studies conducted jointly with other sub-projects.

WATERS is funded by the Swedish Environmental Protection Agency and coordinated by the Swedish Institute for the Marine Environment. WATERS stands for 'Waterbody Assessment Tools for Ecological Reference Conditions and Status in Sweden'. Programme details can be found at: http://www.waters.gu.se

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Summary

This study identifies candidate vegetation indicators for use in Swedish coastal waters. The indicators should cover soft- and hard-bottoms in marine and brackish waters along the diverse Swedish coastline. The indicators should respond to anthropogenic pressure, particularly eutrophication, allow assessment of ecological status according to the demands of the Water Framework Directive (WFD) and be ecologically relevant.

We first gathered background information regarding: the response of marine vegetation to eutrophication pressure, marine vegetation along Baltic Sea environmental gradients and WFD demands regarding vegetation.

We then reviewed the vegetation indicators used in coastal soft- and hard-bottom areas in Sweden and provided an overview of the types of existing vegetation data and methods.

This was followed by a review of European vegetation indicators for areas with soft/sandy bottoms where seagrasses, angiosperms, characeans and drifting algae typically dominate and for areas with primarily hard bottoms where attached red, green and brown macroalgae dominate. Finally, we present an overview of ecologically relevant macrophyte traits (e.g. longevity, growth strategy, reproductive period and morphology) that affect the response of macrophytes to pressures and their competitive ability in various eutrophication scenarios. This overview forms the basis for classifying macrophytes in relation to their sensitivity to eutrophication.

On this basis, we produced a list of potential indicators for use in Swedish coastal waters to be further explored in the WATERS programme (Table S.1). The list suggests a set of relevant vegetation indicators for soft/sandy bottoms and for hard bottoms along the Swedish coast. The indicators reflect the distribution, abundance, diversity and composition of the vegetation and they all address WFD demands. The selected indicators also have the advantage that existing datasets can to some extent provide background information. We suggest focusing on these indicators and exploring them further through gradient studies and data analyses to be conducted in WATERS.

TABLE S.1

Selection of vegetation indicators for soft/sandy and hard bottoms to be explored through gradient studies and/or data analyses conducted in WATERS.

Soft/sandy bottom	**Hard bottom**
Distribution indicators • Depth limit of selected species (e.g. eel-grass) • Area distribution (e.g. fragmentation)	Distribution indicators • Depth limit of selected species (key macroalgae)
Abundance indicators (depth related) • Cover – macrophytes	Abundance indicators (depth related) • Cover – macroalgae (total or cumulative)
Diversity and composition (depth related) • Relative or absolute abundance of functional groups: sensitive and tolerant species • Angiosperm/characean diversity	Diversity and composition (depth related) • Relative or absolute abundance of functional groups: sensitive and tolerant species • Macroalgal diversity

The selected indicators will be explored through analyses of data from field surveys to be conducted in WATERS and through analyses of existing data. Through these analyses, we wish to address several important considerations. One is to quantify sampling uncertainty (i.e. variability between subsamples, sites, depths, years and observers) as a background for designing cost-effective monitoring schemes. Another central concern is to explore the response of indicators to pressures along spatial and temporal pressure gradients in order to assess the patterns and time scales of responses as well as the interactive effects of other environmental factors (e.g. salinity) on the responses. In testing pressure–response relationships for selected indicators, we will further explore the use of sensitive taxa as indicators of anthropogenic pressure.

Svensk sammanfattning

Målet med denna studie är att identifiera möjliga indikatorer på övergödning baserat på vegetation i Sveriges kustvatten. Indikatorerna ska täcka in vegetation på både hård- och mjukbotten och längs hela gradienten från marint till brackvatten utmed den svenska kusten. Indikatorerna ska svara på mänsklig störning, speciellt övergödning, tillåta bedömning av ekologisk status i enlighet med kraven i Vattendirektivet och vara ekologiskt relevanta.

Vi börjar med att ge en bakgrund till hur marin vegetation svarar på övergödning, hur andra miljöfaktorer påverkar vegetationen i Östersjön och Västerhavet och vilka krav som ställs i Vattendirektivet med avseende på indikatorer för vegetation. Vi presenterar sedan en översikt över vilka indikatorer för vegetation i kustvatten som används i Sverige idag, över de undersökningsmetoder som använts och används för att samla in havsvegetationsdata i Sverige, samt vilket data som finns tillgängligt.

Därefter följer en översikt över de indikatorer baserade på vegetation som används i Europa. Översikten är uppdelad i ett avsnitt för vegetation på mjukbotten (dominerad av sjögräs andra kärlväxter och kransalger samt lösliggande alger) och ett avsnitt för vegetation på hårdbotten (dominerad av fastsittande makroalger). Slutligen presenteras en sammanställning av ekologiska egenskaper som kan påverka arters respons på övergödning och annan störning (livslängd, tillväxthastighet, reproduktionskaraktärer) hos de arter som förekommer i svenska havsområden. Denna sammanställning kommer att ligga till grund för att klassificera förekommande arter utifrån om de kan förväntas gynnas eller missgynnas av övergödning och en utvärdering av möjligheten att använda sammansättningen av arter som en indikator på övergödning.

Med denna litteratursammanställning som grund har vi identifierat indikatorer som kan vara relevanta att använda i Sveriges kustvatten, och som kommer att testas inom forskningsprogrammet WATERS. Listan är uppdelad i potentiella indikatorer för mjukbotten respektive hårdbotten. Indikatorerna beskriver utbredning, abundans, diversitet och artsammansättning av vegetationen och möter alla krav från Vattendirektivet. De utvalda indikatorerna har också fördelen att nödvändiga data i viss utsträckning kan tas fram från befintliga vegetationsdata, vilket både möjliggör en vetenskaplig utvärdering av hur de svarar på övergödning och utnyttjande av befintliga tidsserier för att följa upp förändring. Fortsatt utveckling av indikatorer för vegetation i WATERS kommer att fokusera på dessa indikatorer.

TABELL S.1

De indikatorer för vegetation på mjuk- och hårdbotten som kommer att utvärderas i WATERS.

Mjukbotten	**Hårdbotten**
Utbredning • Djuputbredning av utvalda arter (t ex ålgräs) • Areell utbredning (t.ex. fragmentering)	Utbredning • Djuputbredning av utvalda arter (makroalger)
Abundans (djuprelaterad) • Täckningsgrad av rotade växter	Abundans (djuprelaterad) • Täckningsgrad av makroalger (total eller kumulativ)
Diversitet och artsammansättning (djuprelaterad) • Relativ eller absolut abundans av funktionella grupper: känsliga & toleranta arter • Diversitet av kärlväxter/kransalger	Diversitet och artsammansättning (djuprelaterad) • Relativ eller absolut abundans av funktionella grupper: känsliga & toleranta arter • Diversitet av makroalger

De utvalda indikatorerna kommer att utvärderas med analyser av befintliga vegetationsdata och data som samlas in i fältundersökningar inom WATERS. Ett viktigt mål är att testa hur dessa indikatorer svarar på störning i belastningsgradienter i tid och rum, och hur andra miljöfaktorer (t ex salinitet) påverkar responsen. Som en del av denna analys kommer vi att utvärdera möjligheten att använda arter som gynnas eller missgynnas av störning som indikatorer. Ett annat mål är att kvantifiera osäkerheten förknippad med provtagning (t ex variation mellan prov, lokaler, år och djup), vilket kan ligga till grund för att utforma kostnadseffektiva provtagningsprogram.

1 Introduction

1.1 Coastal vegetation and anthropogenic pressure

One major pressure on coastal vegetation is nutrient enrichment from anthropogenic or natural sources, resulting in increased growth of primary producers and production of organic matter. The general effect of nutrient enrichment on aquatic vegetation is well understood (review in Cloern 2001) and relates to the fact that some primary producers are more efficient in exploiting the added nutrients. One group generally favoured by nutrients is phytoplankton. A positive relationship between nutrient load and phytoplankton production or chlorophyll-a is well documented across coastal areas (references in Krause-Jensen et al. 2008). Increased phytoplankton biomass in turn increases light attenuation in the water and reduces light availability for benthic primary producers. Since light is a major limiting factor for growth of benthic vegetation, light attenuation is predicted to cause an upward shift in the distribution of benthic species. The relationship between lower depth limit of both macroalgae and seagrass species and nutrient concentrations in water and/or water turbidity is well established from findings for many coastal areas (reviewed by Krause-Jensen et al. 2008). Likewise, many studies have demonstrated that the biomass or cover at a certain depth responds negatively to increasing nutrient concentrations and/or water turbidity (reviewed by Krause-Jensen et al. 2008).

Although the depth distribution of benthic macrophytes is clearly regulated by water turbidity in many cases, it can also be affected by other factors. Macroalgae that are dependent on hard substrate are, for example, often limited by substrate availability in the deeper part of their distribution. In addition, the depth limits of macroalgae are often set by competition rather than physiological limits. One example from the Swedish coast is the downward shift of many species in the gradient from Skagerrak to the Baltic Sea, which contributes to relaxed competition in the species-poor Baltic Sea (Pedersén and Snoeijs 2001). The biomass or cover may also be affected by, for example, physical disturbance from waves or ice, especially in shallow waters (Fonseca et al. 2002).

Increased plankton production also results in increased organic matter sedimentation, which also affects the benthic vegetation. Many species are sensitive to being covered by sediment, which can act both through physical scouring and by reducing light and nutrient availability. Sedimentation can be predicted to have the largest effect in areas with low water motion (i.e. deep areas and areas sheltered from wave action). In these areas, increased sedimentation can be predicted to lead to a decrease or loss of species sensitive to sedimentation, favouring species more resistant to sedimentation. Species traits suggested to make macroalgae resistant to sedimentation are tough thalli, vegetative propagation, reproduction in periods of low sedimentation and ability to regenerate after physical damage (references in Eriksson and Johansson 2005). In the Baltic Sea, sensitivity to sedimentation has been demonstrated to differ between macroalgal species in accordance with predictions based on reproductive strategies, resulting in different macroalgal communities in different sedimentation regimes (Eriksson and Johansson 2005). Sedimentation can also reduce the extent of hard substrate, thus limiting populations of hard-substrate species such as macroalgae.

In addition to the direct effects of sedimentation organic enrichment of the seafloor increases the decomposition resulting in increased risk of water column anoxia and associated sulphide release (Howarth et al. 2011). This is known to be stressful to rooted seagrasses (e.g. Holmer and Bondgaard 2001; Pulido and Borum 2010). Oxygen deficiency in the sediment also leads to phosphate release, which can locally increase nutrient concentrations and primary production.

Apart from phytoplankton, benthic microalgae and some species of macrophytes are also favoured by nutrient addition. For macroalgae, there is a long tradition of dividing species into opportunistic and late-successional species, the former group exhibiting rapid growth and efficient nutrient uptake and being favoured under high nutrient conditions. Opportunistic species can be recognized based on life history, for example, being ephemeral and on morphological structure, for example, the functional groupings suggested by Littler et al. (1983) and Steneck and Dethier (1994). It is well supported that filamentous and foliose species, with a high surface-area-to-volume ratio, are characterized by high rates of nutrient uptake, photosynthesis and growth (e.g. Wallentinus 1984; Pedersen and Borum 1996; see Chapter 3.3 for further details). Experimental nutrient additions have been found to increase the growth of filamentous and foliose species in field and mesocosm studies (e.g. Worm et al. 2000; Kraufvelin 2007) and macroalgal blooms in response to anthropogenic eutrophication are also dominated by species from these functional groups (Valiela et al. 1997). In addition, some phanerogam species are favoured by nutrient enrichment. Species that respond positively to nutrients often have the ability to produce long shoots and thus to concentrate much of their photosynthetic biomass near the surface. Species with a high surface-area-to-volume ratio (e.g. species with dissected leaves) can also be predicted to be more efficient in taking up nutrients from the water. In the Baltic Sea, the large-growing phanerogams *Potamogeton pectinatus* and *Myriophyllum spicatum* have also been documented in heavily eutrophic areas. These species are therefore regarded as relatively tolerant of eutrophication effects or even favoured by nutrient enrichment (e.g. Wallentinus 1979; Selig et al. 2007).

Benthic microalgae and opportunistic macroalgal species often grow as epiphytes on large macrophytes and can reduce growth of the host plant through competition for light and nutrients. They can also compete with slower-growing macroalgal species for space (experimentally demonstrated by Worm et al. 2000). Excessive growth of opportunistic macroalgae can also result in the formation of drifting algal mats, which shade other species and can create anoxic conditions in the sediment and in the water near the seabed (Valiela et al. 1997). Increased occurrence of algal mats has therefore been suggested as one explanation for the decline in *Zostera marina* along the Swedish west coast (Baden et al. 2003). In soft-substrate communities, large-growing phanerogams can also shade smaller phanerogams and charophytes. This means that nutrients can have an indirect negative effect on species less able to respond to increased nutrient concentrations with increased growth, which may explain the decrease in perennial, late-successional species documented in some eutrophic areas.

Another group that can be favoured by high phytoplankton production (and by discharge of particulate organic matter) is filter-feeding animals (e.g. Kautsky et al. 1992). Sessile filter feeders can affect macrophytes by competing for space (i.e. hard substrate) and/or by living as epibionts on large macrophytes, affecting light availability and the nutrient uptake of the host. For example, animal epibionts have been demonstrated to have a negative effect on photosynthesis and growth in deep-growing *Fucus vesiculosus* in the Baltic Sea, which is suggested to affect the depth distribution of this alga (Rohde et al. 2008).

Effects of nutrient enrichment on the coastal vegetation are summarized in a simplified form in **Figure** 1.1.

Apart from nutrient enrichment, several anthropogenic pollutants have direct negative effects on coastal macrophytes. In some cases, pollutants have been demonstrated to affect specific taxonomic groups (e.g. chlorate from pulp mill effluent strongly affects brown macroalgae, Rosemarin et al. 1994). Other compounds are likely to affect all photosynthetic organisms in a similar way, though the sensitivity to such compounds likely differs between species. Differential sensitivities could lead to changes in macrophyte community composition, though this is little studied in most systems.

Physical disturbance from human activities (e.g. boat traffic, anchoring and dredging) can result in the resuspension of sediment and organic material, thereby increasing turbidity and in some cases uprooting plants. Sediment load to the coast can also increase due to changes in land use in the catchment area. The effects of sediment on vegetation are discussed above.

Fisheries may also affect food web structure, for example, by removing top predators and thereby changing the top–down control of phytoplankton and macrophytes (Jackson et al. 2001). Changed top–down control may also interact with nutrient enrichment in affecting coastal vegetation (Baden et al. 2010).

On top of all these pressures is global warming, which may exert a complex of direct and indirect effects on coastal ecosystems.

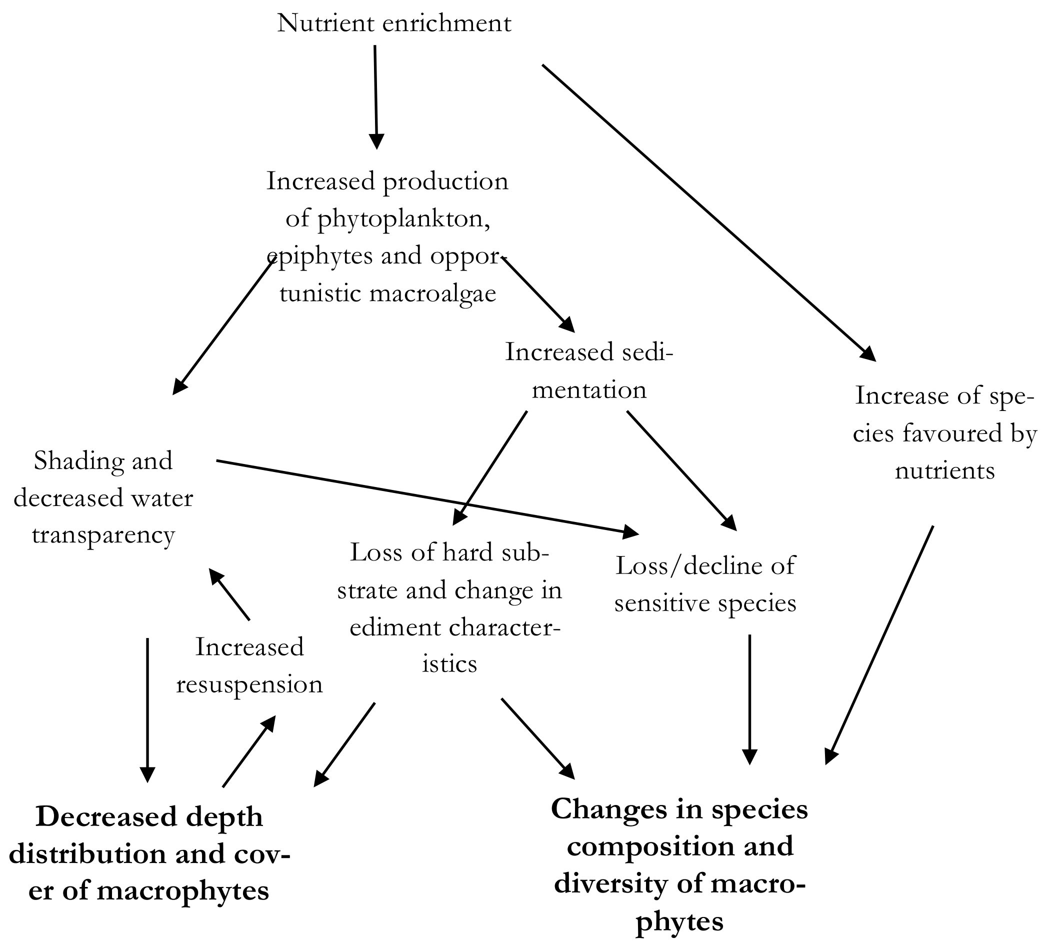

FIGURE 1.1
Direct and indirect effects of nutrient enrichment on coastal macrophytes. In practice, the effects of eutrophication interact with those of other abiotic and biotic variables, such as salinity, physical disturbance and top–down control.

1.2 Natural gradients affecting coastal vegetation in Sweden

Sweden has a long coastline along which environmental conditions differ greatly at both the large and small scales. A prominent feature is the marked gradient in salinity from the inner part of the Baltic Sea (i.e. the Gulf of Bothnia) through Kattegat to Skagerrak, which arises through the large input of freshwater to the enclosed Baltic Sea gradually mixing with the North Sea water entering Skagerrak. This gradient is reflected in the biotic communities, since most species tolerate only a certain range of salinities. The number of taxa of marine origin drops successively with decreasing salinity, while the number of taxa of freshwater origin displays the opposite pattern. In the inner Baltic Sea, the diversity of marine seaweeds is much lower than in Skagerrak and Kattegat (Nielsen et al. 1995; Middelboe et al. 1997), but this is partly counteracted by an increased diversity of freshwater phanerogams and charophytes on soft substrates. In the Gulf of Bothnia, where the surface salinity is <6 psu, there is also an increasing fraction of macroalgae of freshwater origin and freshwater mosses. Salinity thus exerts a major influence on both the species diversity and composition of macrophyte communities and must be accounted for if species composition is to be used to indicate water quality.

Salinity can also affect macrophyte tolerance of anthropogenic stressors. Since all Baltic Sea species are of either marine or freshwater origin, they are under constant osmotic stress in the brackish Baltic Sea and this can increase their sensitivity to additional stressors. For example, the toxicity of bromine and copper to the brown alga *Fucus vesiculosus* has been demonstrated to increase with decreasing salinity (Andersson et al. 1992; Andersson and Kautsky 1996). On the other hand, nutrients have been hypothesized to increase the tolerance of marine macrophytes to low salinity, possibly by decreasing nutrient limitation or increasing osmolality. The interaction between salinity and anthropogenic stressors implies that certain species' tolerance of anthropogenic pressures may change depending on the salinity gradient, which complicates the identification of tolerant and sensitive species. For example, this may restrict the possibility of applying species sensitivity classifications from marine or freshwater systems to Baltic Sea macrophyte populations.

Salinity varies not only spatially but also temporally and the temporal variability differs between geographical areas. There is a general contrast between the relatively temporally stable salinity of the Baltic Sea and the strongly variable surface salinity in Kattegat and Skagerrak. However, the variability also differs on smaller scales, being higher in enclosed areas and in areas affected by variable freshwater runoff. This variability should be considered when describing the salinity conditions at a certain site. Exactly what aspect of the salinity regime that sets the distribution limit is likely to vary between species. For many macrophytes, reproduction is the most sensitive life-history stage and the species may survive in an area where the salinity is usually too high or low, as long as occasions of suitable salinity coincide with reproduction events.

The large freshwater input from rivers to the Baltic Sea not only influences salinity but also brings large amounts of organic and inorganic matter from the catchment area. An important component of this discharge is coloured dissolved organic matter (CDOM or yellow substance), i.e. humic substances that colour the water. The CDOM concentration increases with increasing freshwater input and is thus negatively related to salinity across the Baltic Sea gradient (e.g. Kratzer et al. 2003). The discharge of CDOM in freshwater varies at both long and short timescales and affects light attenuation in the water column, which is determined by particulate organic matter (primarily phytoplankton and suspended dead organic matter), particulate inorganic matter, dissolved organic matter and the water itself (Kirk 1994).

In addition, the coastal morphology differs strongly along the Swedish coast. Much of the coast is characterized by archipelagos of islands off the mainland, creating a complex gradient in water retention time, wave exposure, salinity and influence of land runoff from the mainland to the outer part of the archipelago. In contrast, most of southern Sweden has an open coast with only a few islands. The macrophyte communities typically differ considerably between the sheltered parts of archipelagos, the exposed parts of archipelagos and more open coasts. This is the consequence of several co-varying factors and the exact mechanisms determining the distribution limits and abundances of certain species are difficult to sort out in most cases.

One of the key factors is likely the distribution of seabed substratum. The occurrence and depth extension of hard substratum and coarse sediment types increase with increasing wave exposure. The type of seabed substratum is a major determinant of macrophyte community composition: for example, macroalgal communities (with occurrences of moss in low salinity) occur on hard substrates, while rooted phanerogam and charophyte communities occur on soft substrates. These communities are likely to respond at least somewhat differently to anthropogenic stress and are typically studied separately using different indicator systems. One special characteristic, especially of the Baltic Sea coast, is that the seabed often consists of a mixture of hard substrate and sediment, resulting in mixed communities of macroalgae and rooted plants. Many current monitoring stations in the Baltic Sea are situated in areas of this kind of mixed seabed substrate.

The distribution and abundance of macrophytes are affected by different factors along depth gradients. Shallow depths are characterized by physical disturbance by waves, ice and emersion in periods of low water and these factors typically set the upper limit of macrophyte distributions. The effects of waves and ice extend deeper in more exposed than in more sheltered areas. In deeper areas, distribution and abundance are typically determined by light limitation, substrate availability or a combination of both (e.g. Kiirikki 1996; Eriksson and Johansson 2003).

Several studies have tested the relative importance of various environmental factors for the distribution and community composition of macrophytes, documenting complex regulation patterns that also depend on the scale of the study (e.g. Kautsky and van der Maarel 1990; Kiirikki 1996; Middelboe et al. 1997; Middelboe et al. 1998; Middelboe and Sand-Jensen 2004; Eriksson and Bergström 2005; Rinne et al. 2011; Sandman et al. 2012).

Besides the abiotic factors, macrophyte communities are also affected by herbivory. When abundant, herbivores can greatly affect algal community composition, reducing the abundance of grazer-susceptible species such as *Ulva* spp. and increasing the abundance of less palatable species (e.g. red algae and brown filamentous species in the Baltic Sea; Lotze and Worm 2000; Lotze et al. 2000; Lotze et al. 2001). In seagrass systems, grazers can somewhat counteract the negative effects of nutrient enrichment on seagrass, by controlling the growth of opportunistic epiphytes and drifting algae (e.g. Moksnes et al. 2008; Baden et al. 2010). Herbivore abundances can in turn be affected by top–down regulation from higher trophic levels. In Swedish waters, there are indications that a decline in large predatory fish due to high fishing pressure has promoted an increase in blooms of ephemeral macroalgae through a trophic cascade reducing the top–down regulation of mesograzers (Eriksson et al. 2009; Eriksson et al. 2011). Nutrient enrichment and fishing can have complex interactive effects on macrophyte communities, which can influence analyses of the effects of eutrophication on macrovegetation.

1.3 Coastal vegetation and the Water Framework Directive

All WATERS research relates primarily to the Water Framework Directive (WFD) (2000/60/EC). The WFD calls for the ecological status of all surface water to be assessed. Marine surface water is defined as all coastal and transitional waters inside 1 nm outside the baseline. The assessment units are water bodies representing discrete and significant stretches of coastal or transitional waters. Similar water bodies are grouped into types based on depth, stratification, water exchange, wave exposure, salinity and winter ice cover. Swedish national regulation NFS 2006:1 (Anon. 2006) defines 23 coastal and two transitional types (**Figure** 1.2 and **Table** 1.1).

The ecological status of each water body should be assessed based on four biological quality elements, i.e. phytoplankton, other aquatic flora, benthic invertebrate fauna and fish. In coastal waters, other aquatic flora is defined as one quality element, i.e. "macroalgae and angiosperms" and in transitional waters as two quality elements, i.e. "macroalgae" and "angiosperms". To comply with the Directive, a quality element assessment method must use five status classes (i.e. high, good, moderate, poor and bad) with boundaries established in accordance with normative definitions from and cover and combine all relevant parameters defined in, Annex V of the WFD. Normative definitions of vegetation in coastal and transitional waters are listed in Table 1.2.

The WFD establishes two main environmental objectives: member states shall i) prevent deterioration of the status of all surface waters and ii) achieve good ecological status in all surface waters before 2015. For artificial and heavily modified water bodies, the latter objective is to achieve good ecological potential.

TABLE 1.1

Water body typology (NFS 2006:1, Anon. 2006) used in assessing ecological status according to the WFD.

Type	Name
1	Archipelago of the West Coast, inner parts
2	Fjords of the West Coast
3	Archipelago of the West Coast, Skagerrak, outer parts
4	Archipelago of the West Coast, Kattegat, outer parts
5	Coastal waters of south Halland and north Öresund
6	Coastal waters of Öresund
7	Coastal waters of Skåne
8	Archipelago of Blekinge and Kalmarsund, inner parts
9	Archipelago of Blekinge and Kalmarsund, outer parts
10	Coastal waters of east Öland and south and east Gotland including Gotska Sandön
11	Coastal waters of the north-west part of Gotland
12	Archipelago of Östergötland and Archipelago of Stockholm, middle parts
13	Archipelago of Östergötland, inner parts
14	Archipelago of Östergötland, outer parts
15	Archipelago of Stockholm, outer parts
16	Coastal waters of the south Bothnian Sea, inner parts
17	Coastal waters of the south Bothnian Sea, outer parts
18	Coastal waters of the north Bothnian Sea, Höga kusten, inner parts
19	Coastal waters of the north Bothnian Sea, Höga kusten, outer parts
20	Coastal waters of the Quark, inner parts
21	Coastal waters of the Quark, outer parts
22	Coastal waters of north Bothnian Bay, inner parts
23	Coastal waters of north Bothnian Bay, outer parts
24	Göta Älvs and Nordre Älvs estuary
25	Archipelago of Stockholm, inner parts and Hallsfjärden

TABLE 1.2

Normative definitions of coastal and transitional vegetation according to Annex V in WFD.

Element	High status	Good status	Moderate status
Coastal water: Macroalgae and angio-sperms	All disturbance sensitive macroalgal and angiosperm taxa associated with undis-turbed conditions are pre-sent. The levels of macroal-gal cover and angiosperm abundance are consistent with undisturbed conditions.	Most disturbance sensitive macroalgal and angiosperm taxa associated with undis-turbed conditions are pre-sent. The level of macroal-gal cover and angiosperm abundance show slight signs of disturbance.	A moderate number of the disturbance sensitive macroalgal and angiosperm taxa associated with undis-turbed conditions are ab-sent. Macroalgal cover and angiosperm abundance is moderately disturbed and may be such as to result in an undesirable disturbance to the balance of organisms present in the water body.
Transitional water: Macroalgae	The composition of macroalgal taxa is con-sistent with undisturbed conditions. There are no detectable changes in macroalgal cover due to anthropogenic activities.	There are slight changes in the composition and abun-dance of macroalgal taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phy-tobenthos or higher forms of plant life resulting in unde-sirable disturbance to the balance of organisms pre-sent in the water body or to the physicochemical quality of the water.	The composition of macroalgal taxa differs moderately from type-specific conditions and is significantly more distorted than at good quality. Mod-erate changes in the aver-age macroalgal abundance are evident and may be such as to result in an undesirable disturbance to the balance of organisms present in the water body.
Transitional water: Angi-osperms	The taxonomic composition corresponds totally or nearly totally to undisturbed condi-tions. There are no detecta-ble changes in angiosperm abundance due to anthro-pogenic activities.	There are slight changes in the composition of angio-sperm taxa compared to the type-specific communities. Angiosperm abundance shows slight signs of dis-turbance.	The composition of the angiosperm taxa differs moderately from the type-specific communities and is significantly more distorted than at good quality. There are moderate distortions in the abundance of angio-sperm taxa.

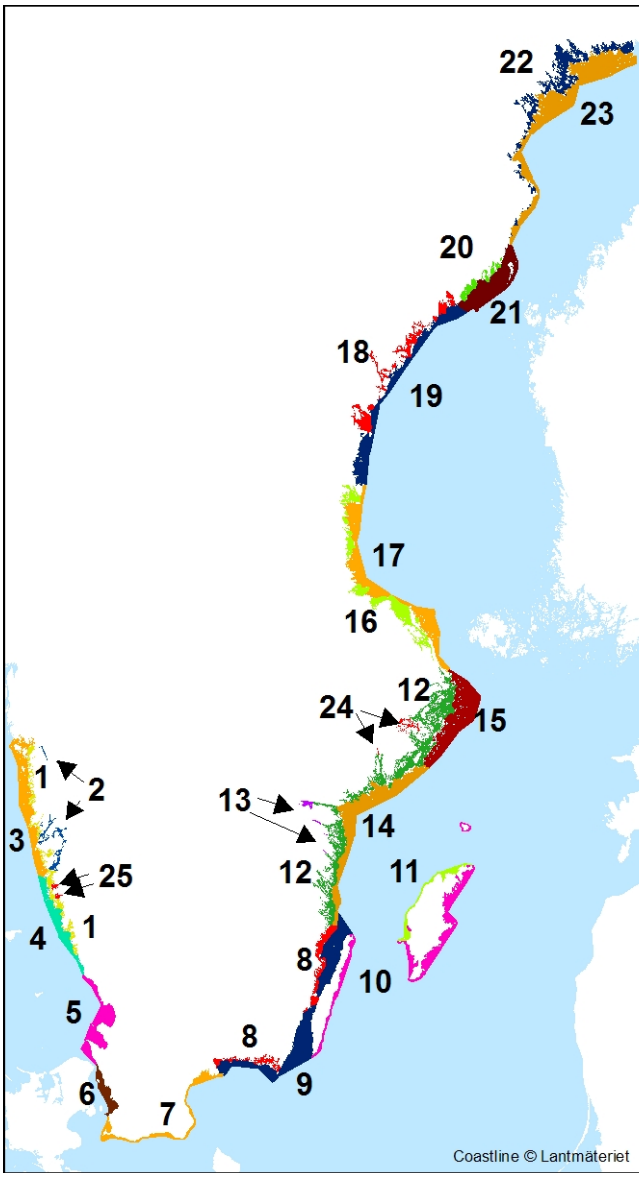

FIGURE 1.2
Water body types in Sweden: 1–23 are coastal and 24–25 are transitional types. The typology is based mainly on salinity, stratification and exposure. The map is based on data from the Swedish Meteorological and Hydrological Institute (from Leonardsson et al. 2009).

1.4 Other relevant directives and environmental objectives

There are also other directives than the WFD and national environmental objectives to which indicators of macrophyte status are relevant and applicable. In the Marine Strategy Framework Directive (MSFD) (2008/56/EC), several descriptors and suggested indicators relate to coastal macrophytes. According to the MSFD, 'good environmental status' of the marine environment should be achieved or maintained by 2020 at the latest. There are 11 MSFD descriptors each having several associated indicators. Macrophytes are most relevant as indicators for the following descriptors: 1) 'Biological diversity is maintained', 5) 'Human-induced eutrophication is minimized' and 6) 'Seafloor integrity is at a level that ensures that the structure and functions of benthic ecosystems are not adversely affected'.

The Habitats Directive (HD) (92/43/EEC) aims at achieving favourable conservation status for habitats and species. Several parts of the Directive concern the area, structure and function of habitats as related to coastal macrophytes.

The national environmental objectives (http://www.miljomal.nu) that relate to macrophyte status are mainly: 7) 'Zero eutrophication', 10) 'A balanced marine environment, flourishing coastal areas and archipelagos' and 16) 'A rich diversity of plant and animal life'. So far, no environmental indicators for assessing targets associated with these objectives involve coastal macrophytes.

Zampoukas et al. (2012) has presented helpful overviews of relationships between monitoring parameters in the WFD, MSFD and HD and the indicators of MSFD. From these overviews, it can be seen that these directives overlap somewhat and that monitoring data will be used for assessment according to several objectives. Although our work focuses on assessment according to the WFD, our results can be used in evaluating several national and international objectives.

1.5 Aim and approach

This study suggests candidate macrophyte indicators for use in Swedish coastal and transitional waters. The indicators should cover soft- and hard-bottoms in marine and brackish waters along the diverse Swedish coastline. As indicators, they should meet the following demands:

- respond to anthropogenic pressure, particularly eutrophication (the main pressure addressed by the WATERS programme)
- allow assessment of ecological status according to the WFD demands
- be ecologically relevant

We use the following approach: On previous pages we have set the scene regarding coastal vegetation and anthropogenic pressure, coastal vegetation along the Baltic Sea gradient and coastal vegetation in relation to the WFD. The next step is a review of the macrophyte indicators currently used in Sweden along with an overview of the existing Swedish vegetation data. We then review the use of European vegetation indicators in soft and sandy bottoms where seagrasses, angiosperms, characeans and drifting algae typically dominate and in hard-bottoms where attached red, green and brown macroalgae dominate. Finally, we explore the sensitivity of macrophyte taxa to eutrophication by surveying key traits (e.g. longevity, growth rate, reproduction and morphology) that will affect the competitive ability of the taxa in various eutrophication scenarios. On this basis, we generate a list of potential vegetation indicators for use in Swedish coastal waters to be further explored through the WATERS programme.

2 Review of the use of coastal vegetation as an indicator of environmental status in Sweden

2.1 Current Swedish WFD assessment method for macroalgae and angiosperms

The fact that the depth distribution of perennial species is affected by shading from the overgrowth of opportunistic species, increased phytoplankton biomass and increased siltation following eutrophication is the basis for the current assessment method. It was developed in 2006 (Kautsky et al. 2007) and implemented in Swedish law in 2008 (NFS 2008:1, Anon. 2008).

This method for assessing coastal macroalgae and angiosperms evaluates the present-day depth limit of 3–9 common conspicuous perennial eutrophication-sensitive species (**Table** 2.1) in relation to historical or maximum values observed within a water body type (reference depth limit). Each selected species found at a site is assigned a score based on the observed maximum depth limit (single specimen) in relation to the reference depth limit (example in **Figure** 2.1). The scoring boundaries for each species are established by expert judgment, with guidance from historical Secchi depth values and relationships between Secchi depths, chlorophyll-a and nutrients. The scores are 1, 0.8, 0.6 and 0.4, where 1 represents deep and 0.4 shallow depth distributions. A score of 0.2 is assigned if a species has disappeared from an area for anthropogenic reasons. Scores for all selected species at a site are weighed together by averaging into an index (i.e. the Multi Species Maximum Depth Index, MSMDI), which can thus vary between 0.2 and 1. The ecological status of a water body is assessed by comparing the average of all available MSMDI values against the boundaries for each status class. Status class boundaries are equidistant with a size of 0.2 (**Table** 2.2).

There are several rules for calculating MSMDI:

- To obtain a score, a species depth limit must not be restricted by lack of suitable substrate, i.e. suitable substrate must be recorded deeper than the deepest observation of a species.
- At least three species with scores for depth limits must be used to calculate MSMDI.
- To include a site in the assessment, the investigated depth must exceed the highest scoring (i.e. 1) depth for all selected species in the current type. Tables with

scoring depths for all selected taxa in each type are presented in NFS 2008:1 (Anon. 2008).

- Average MSMDI values must be based on at least three sites with MSMDI values in the current water body.

TABLE 2.1

Selected perennial eutrophication-sensitive taxa used for assessing ecological status in each Swedish national water body type. Types 13, 24 and 25 lack assessment method due to lack of data.

		National water body type																					
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 confer-voides*	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 pseu-doceranoïdes*	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	*Saccharina 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 perfolia-tus*													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*

TABLE 2.2

Status class boundaries for MSMDI (from NFS 2008:1, Anon. 2008).

Status class	Boundary
High	0.81–1.00
Good	0.61–0.80
Moderate	0.41–0.60
Poor	0.21–0.40
Bad	0.00–0.20

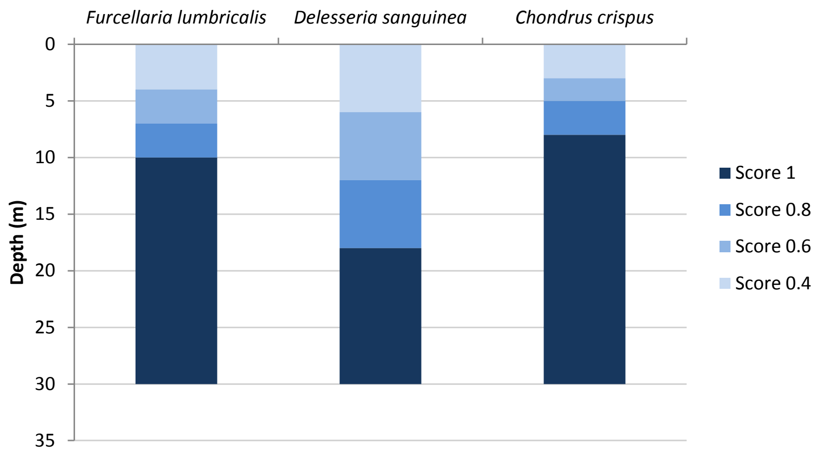

FIGURE 2.1
Examples of scoring boundaries for observed maximum depths for three species in national water body type 1 'Archipelago of the West Coast, inner parts'.

2.2 Evaluation of the current Swedish assessment method

There is a well-documented strong relationship between eutrophication and the depth limit of perennial aquatic vegetation (e.g. Krause-Jensen et al. 2008). An indicator based on depth limit should therefore, in theory, be useful in assessing eutrophication effects.

At the time MSMDI was developed, few data on macroalgae and angiosperms were available in databases, which limited the possibility of testing the usefulness of MSMDI in assessment based on existing field data. In the following years, there was a dramatic increase in the quantity of vegetation data in databases due to the development of the MarTrans database, a simple standardized database facilitating the delivery of phytobenthic data to the national data host. Based on datasets entered in MarTrans and later delivered to the national data host SMHI, the usability of MSMDI was evaluated as part of the

WFD intercalibration exercise (Mats Blomqvist unpublished). Here we extend this evaluation and report some of the findings.

To be used for assessment based on depth limits, a field method must generate data on the deepest plant specimens at a site. Large parts of the existing field data (from approximately 15% of available sites) did not capture depth limits and thus could not be used for the assessment. However, most of the remaining available data were collected according to the national monitoring methods (http://www.havochvatten.se/kunskap-om-vara-vatten/miljo--och-resursovervakning/programomraden/programomrade-kust-och-hav/undersokningstyper-inom-programomrade-kust-och-hav.html), which include recording the deepest specimens. There are two published versions of the national monitoring methods, i.e. the "east coast" and "west coast" versions. The "west coast" method is a stereo-photo method used at only six stations in Skagerrak and will not be commented on further here due to the limited number of available data. The vast majority (>95%) of available data from Bothnian Bay to Skagerrak were collected according to the "east coast" method (also described in Kautsky 1992). According to this method, a diver swims along a transect perpendicular to the shoreline from deeper to shallower water. The diver takes notes on depth, distance from shoreline, substrate cover and species occurrence along the transect measuring tape. Whenever a change in species occurring or cover of species or substrate is observed, a new section is started and a new note is made. Each section should cover an area of at least 10 m^2. Cover is estimated using a seven-point scale (i.e. 1, 5, 10, 25, 50, 75 or 100% cover) representing the cover over the whole section for both species and substrates, i.e. cover of a species is expressed in relation to the section area and not the area of suitable substrate. Observations are made in a 6–10-m wide corridor along the transect measuring tape.

From these kinds of data (i.e. obtained using the east coast method), maximum depth limits of the 3–9 selected species are extracted as the lower depth of the deepest section where each species occurs. According to MSMDI rules, a selected species depth limit can be used only if suitable substrates are recorded deeper along the transect than the species depth limit. This excludes a considerable quantity of depth limit data, either because the transect had stopped (i.e. was truncated) before the actual depth limit was reached or because the depth limit was set by lack of suitable substrate.

The MSMDI rule that the investigated depth must exceed the highest scores 1 depth for the selected species in the current type also excluded a considerable quantity of data, i.e. more than 50% of available transect data (**Figure** 2.2). Most of the sites that were too shallow for assessment were situated in inner coastal waters where ecological status assessment is greatly needed.

There were also transects that were excluded because fewer than three species with scores were present or could be assessed for the reasons mentioned above (approximately 15% of available sites). In conclusion, based on investigated data, less than 25% of available data could be used for assessment according to the demands of the current assessment method. Generally, inner (i.e. shallower) areas were underrepresented in the data and also often excluded from assessment due to MSMDI rules.

Examination of the depth limits of the selected 3–9 perennial species extracted from time series (from national monitoring in the Askö area) and of the results of one intercalibration study (Blomqvist 2008) revealed considerable variation between years and between divers in many cases. This indicates great uncertainty in each MSMDI value and hence also in the assessment. After publication of the current assessment method, there have been observations of increasing depth limits for the selected species in some areas. This could be because divers now look more thoroughly for these species (Stefan Tobiasson pers. comm.).

A final weakness of the MSMDI is that it is relatively cost-inefficient due to the considerable effort needed to sample lower depth limits using diving transects. As each transect is fairly costly and generates only one MSMDI value, there will be few index values per water body.

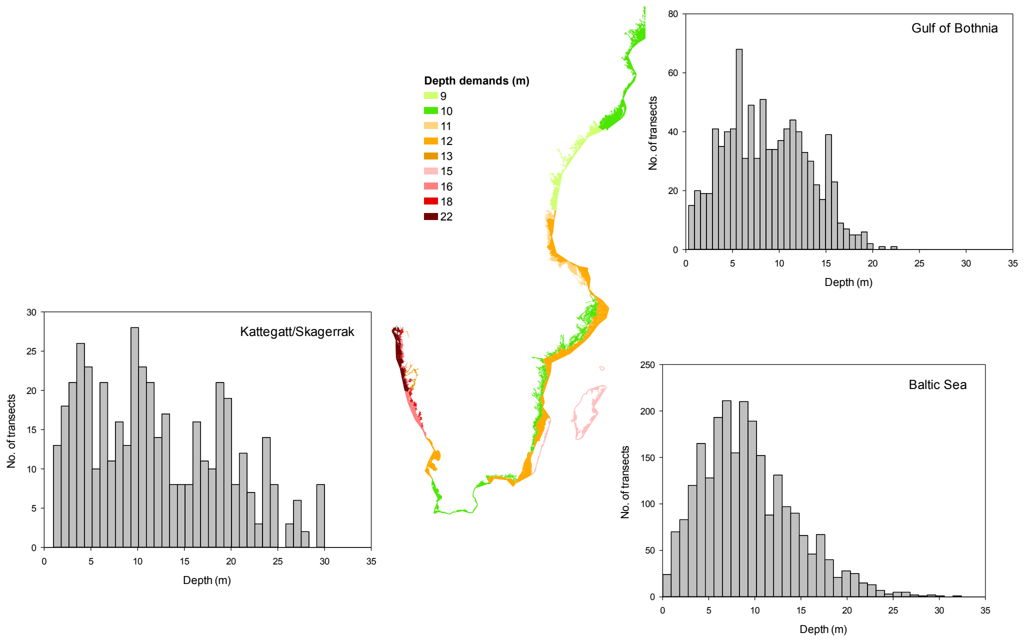

FIGURE 2.2
Map of depth demands for assessment according to the current method. Three histograms showing number of transects in various maximum investigated depth classes are also shown. Comparison of the depth demands from the map and the histograms clearly reveals the high number of transects excluded from assessment due to the depth demands of the current method.

2.3 Available vegetation data along the Swedish coast

In a review, Blomqvist and Olsson (2007) described various macrophyte field methods used in national and regional monitoring, conservation surveys and other large investigations in Sweden. We will continue this review with a focus on the types of vegetation data generated by these field methods and the implications for the possibility of using them in our work. The data used are the same as Blomqvist and Olsson (2007) used, combined with recent vegetation data extracted from the national data host SMHI and some datasets from investigations not yet delivered to the data host by the data owner. We know that more data exist, but these have not yet been collated.

As demonstrated in later chapters, assessment based on coastal vegetation relies mainly on vegetation depth distribution, cover and taxonomic composition/diversity. Here we try to categorize data into types based on these features together with sampling methodology.

Initially, we look at how the data are collected, i.e. the field method, diving, snorkelling and various video techniques being the most common methods. The distinction between these methods is important, since it determines the possibility of observing different dimensions of the vegetation community (i.e. canopy, sub canopy and basal layer) and also sets the limit of taxonomic resolution. Data interpreted from video are often restricted to the uppermost layer; they also offer reduced taxonomic resolution and greater taxonomic uncertainty. Video data collection, however, is a less costly field method and has been used extensively in habitat monitoring in recent years, resulting in large datasets. In a few instances, handheld cameras are used by divers and taxa are identified from images and not in the field. For this reason, we also distinguish whether substrate and taxa cover are determined in the field or from images or video recordings in the laboratory. Divers commonly collect samples of taxa difficult to identify in the field for later determination in the laboratory, which increases the accuracy of species determinations made by divers in the field.

We also take account of how the cover is recorded, since there are several ways of doing this. The prevalent method used is to estimate cover using a slightly modified seven-point Braun–Blanquet scale (i.e. 1, 5, 10, 25, 50, 75 and 100%). Several different four-point scales are also used (e.g. <5, 5–25, 25–75, >75% or <5, 5–20, 20–60/70, >60/70%). In a few investigations, cover is determined in the field as absolute cover without use of a scale. When cover is estimated from image or video, the same cover estimation methods are used, except in some recent studies using a point method in which cover is expressed in per cent based on 100 points equally distributed over the image. The cover estimation method is important, especially when considering cover composition in terms of the combination of taxa.

The current assessment method is based on recordings of the lower depth limit of 3–9 selected species. As already mentioned, the lower depth limits are not recorded in all investigations, but in some investigations using transects running perpendicular to depth contours, the diver specifically records the exact upper and lower depth limits of certain taxa. In other investigations, the maximum depth limit of recorded taxa can be extracted as the lower depth of the deepest section where each taxon occurs. In our categorization of types, this is an important feature for all assessment methods that require data on the lower depth limit of vegetation or specific taxa.

Finally, we have noted whether observations are made along a transect or in a sample or a combination of samples taken along a transect, how long the transects or how large the samples are and how the measurements are recorded along the transect or in the sample.

Dedicated sampling of eelgrass (*Zostera marina*) is grouped into one data type irrespective of the sampling methodology. Several sampling methods are used, resulting in several types of data. Since all of these types of data are quite local with limited numbers of data, it is difficult to develop an assessment method based on them, so we choose not to distinguish between them in this overview. If possible, the data will still be used in our work.

Table 2.3 lists the most common types of vegetation data. Some very rare types of data are excluded. The types are generalizations; for the older data in particular, exceptions and variations are included within each type. **Figures** 2.3–2.8 show the geographic extent of each type. Most data, from both the Swedish east and west coasts, are categorized as type A data and follow the national "east coast" method.

TABLE 2.3

Categorization of vegetation data available in databases into types based on features relevant to assessment. The methodologies used in types A and B “east coast” and F “west coast” are described in standardized national monitoring methods; the remaining methods do not follow national monitoring standards and are described in reports or are undescribed.

Type	Taxon determination	Substrate determination	Max. depth	Field method	Transect/ sample	Effort	Measurements
A	Field, cover 7-point scale	Field, cover 7-point scale	Extracted from data	Diving	Transect	Commonly 20–100 m transect, section	Continuous, new section when change occurs
B	Laboratory, biomass (fauna and flora) and abundance (fauna)	Field, cover 7-point scale	No	Diving	Samples in depth intervals along transects	3 × 0.04 m^2 in each depth interval	Per sample area
C	Field, cover 7-point scale	Field, cover 7-point scale	Separate measurements, not all taxa	Diving	Transect	Commonly 20–100 m	Continuous in fixed depth or length intervals
D	Field, cover 4-point scale	Sometimes field, cover 7-point scale	Separate measurements, not all taxa	Diving	Transect	Commonly 20–100 m	Continuous in fixed depth intervals
E	Field, cover	Field, cover	No	Diving	Samples in depth intervals along transects	3 × 25 m^2 in 2-m depth intervals	Substrate-specific taxa cover in sample area
F	Image, cover	No, only hard substrates monitored	Separate measurements, not all taxa	Diving	Photo at fixed depths along transects	2 × 0.25 m^2 in each depth interval, 5 transects per site	Per sample area
G	Field, cover	Field, cover	No	Diving	Sample	10 × 10 m square	Per sample area
H	Field, cover 4-point scale	No, mainly hard substrates monitored	Separate measurements, not all taxa	Diving	Cover at fixed depths along transects	Commonly 20–100 m	Around fixed depths every meter

Type	Taxon determination	Substrate determination	Max. depth	Field method	Transect/ sample	Effort	Measurements
I	Video, cover 7-point scale	Video, cover 7-point scale	No	Dropvideo	Sample	Approx. 25 m^2	Per sample area
J	Video, cover 7-point scale	No	No	Dropvideo	Sample	Variable, approx. 100 m^2	Per sample area
K	Image, cover point method	Image, cover point method	No	Dropvideo	Sample	0.5 m^2	Per sample area
L	Video, cover 7-point scale	Video, cover 7-point scale	No*	Towed video	Transect	Commonly 50–1000 m	Continuous, new section when change occurs
M	Image, cover point method	Image, cover point method	No	Remotely operated vehicles (ROV)	Sample	0.5–3 m^2	Per sample area
N	Field, cover 7-point scale in sample, 4-point scale in section	No	No*	Snorkelling	Transect and sample	0.25 m^2 + 10-m sections	Per sample area or continuous in section
O	Field or video, eelgrass cover, depth and sometimes shoot density	Varying	Deepest plant or deepest finding of specific cover. Sometimes missing.	Snorkelling, diving, dropvideo, towed video or aquascope	Transect, sample or area	Varying	Varying

* Data are often collected without the aim of finding the deepest specimen, since transects are not always perpendicular to the depth contours. In some cases a lower depth limit can be determined for some taxa.

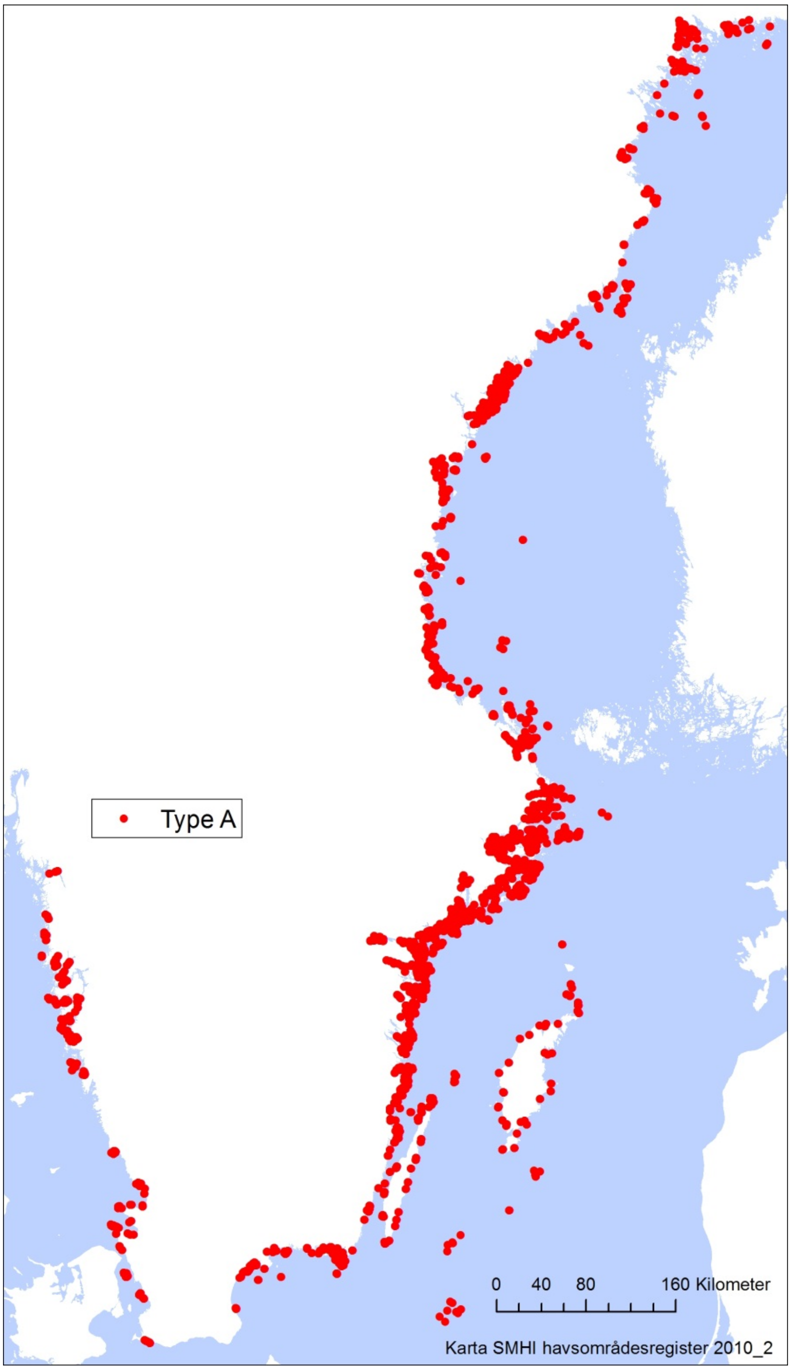

FIGURE 2.3
Sites with type A data obtained from diving transects. Methodology follows the national "east coast" monitoring method.

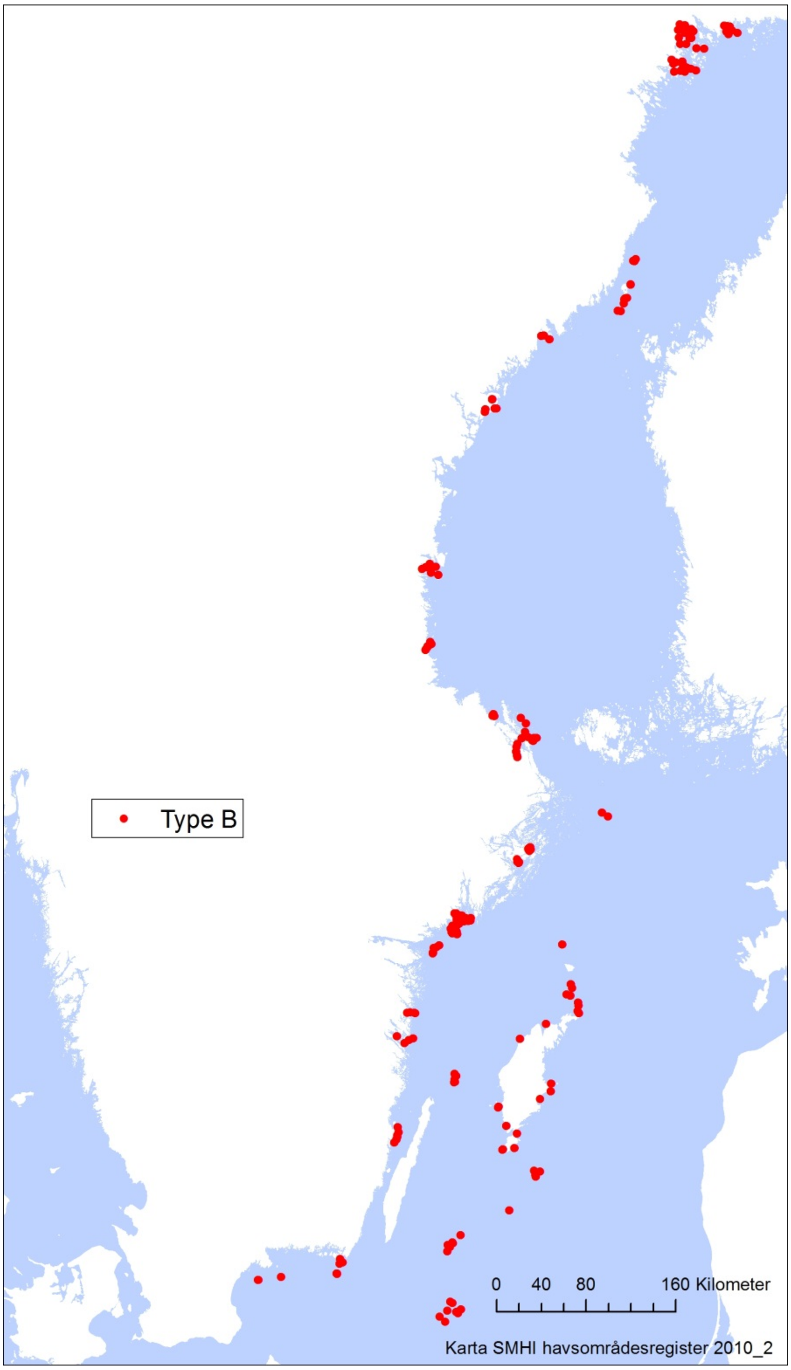

FIGURE 2.4
Sites with type B data obtained from quantitative biomass samples collected by means of diving. Methodology follows the national "east coast" monitoring method.

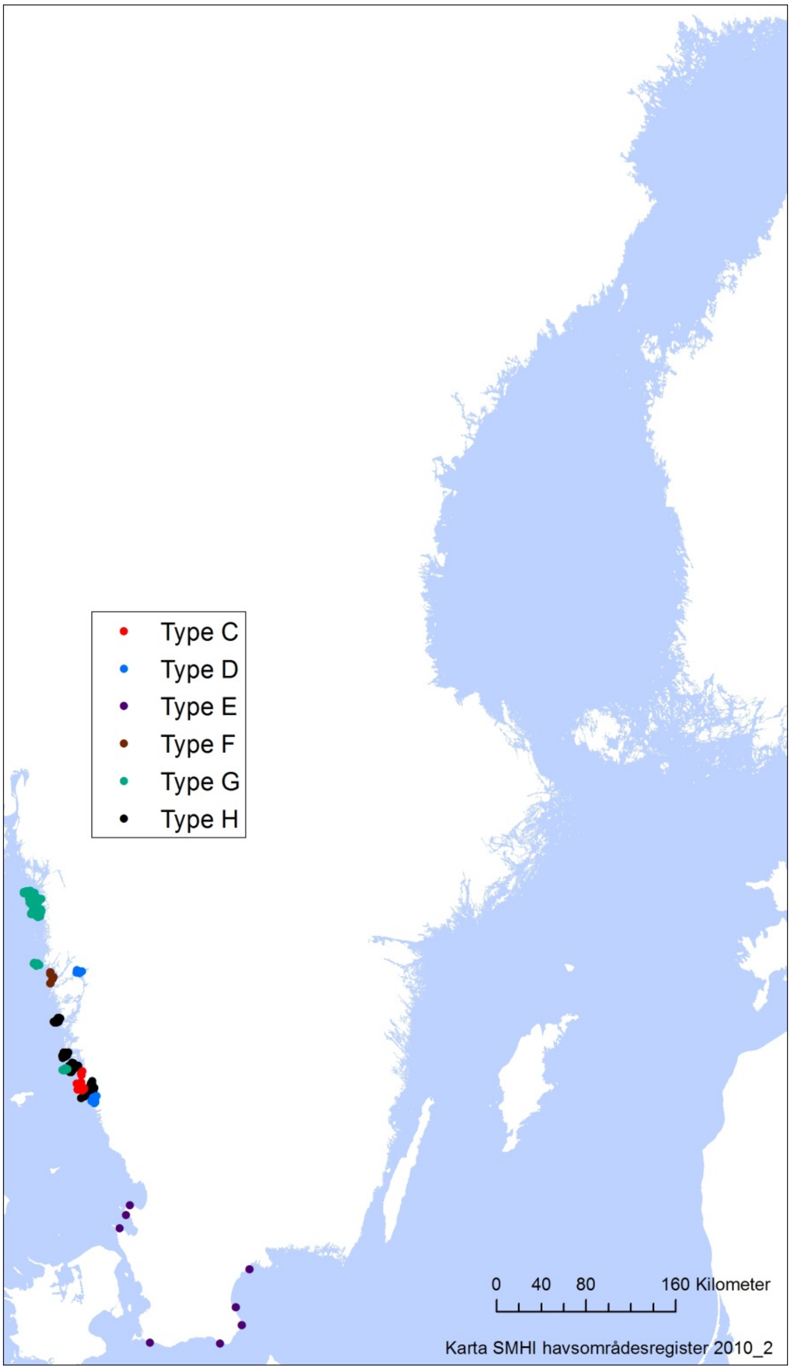

FIGURE 2.5
Sites with types C–H data obtained by means of diving. Type F data are obtained using the national “west coast” monitoring method.

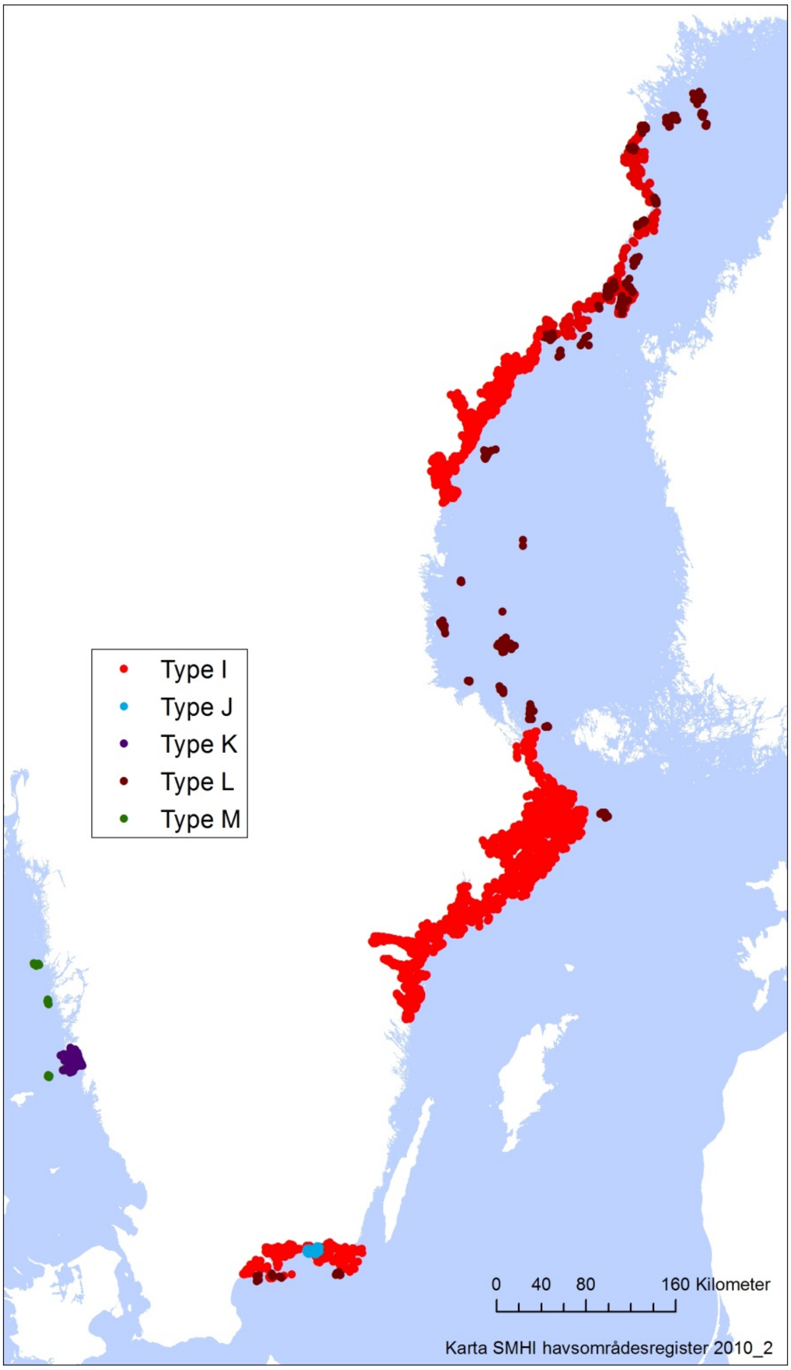

FIGURE 2.6
Sites with types I–M data obtained by means of video analysis.

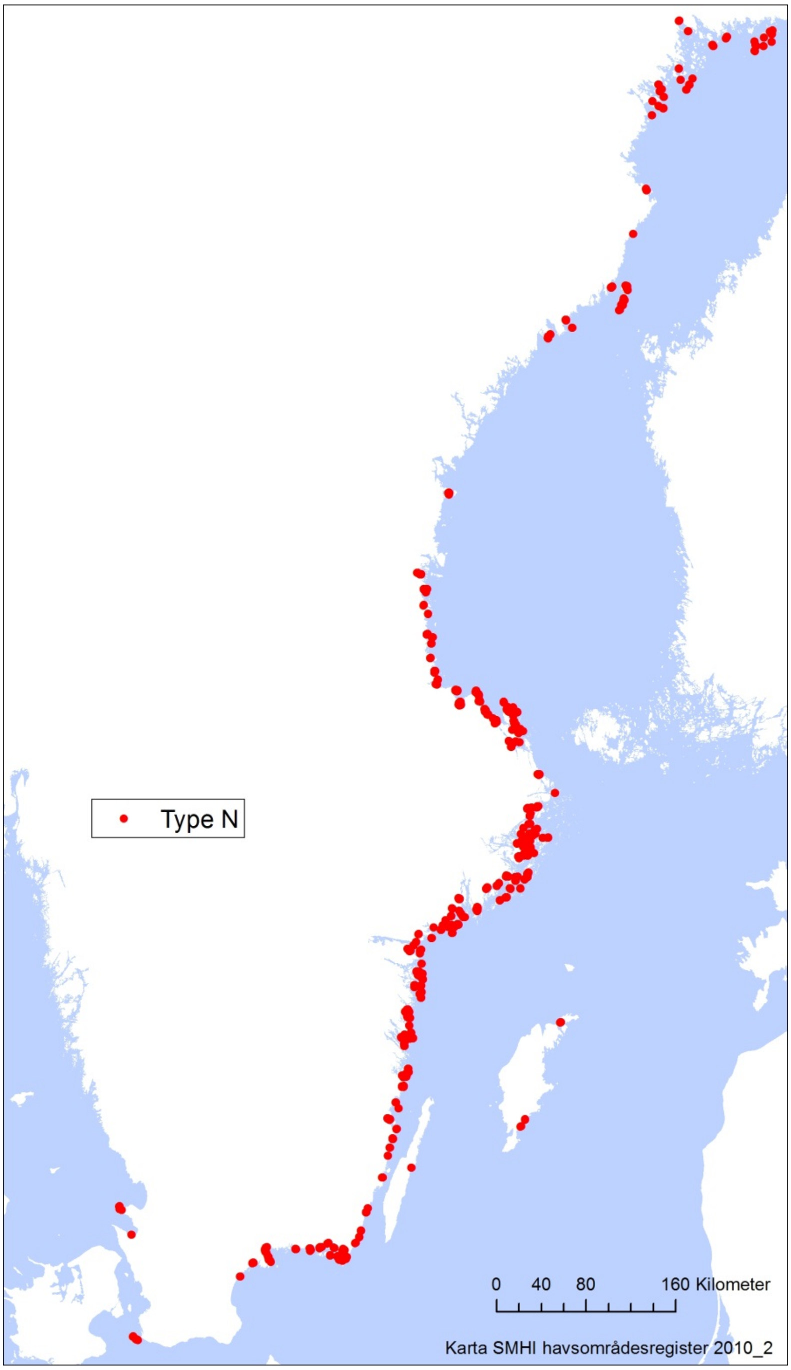

FIGURE 2.7
Sites with type N data obtained by means of snorkelling using the “shallow bay” method.

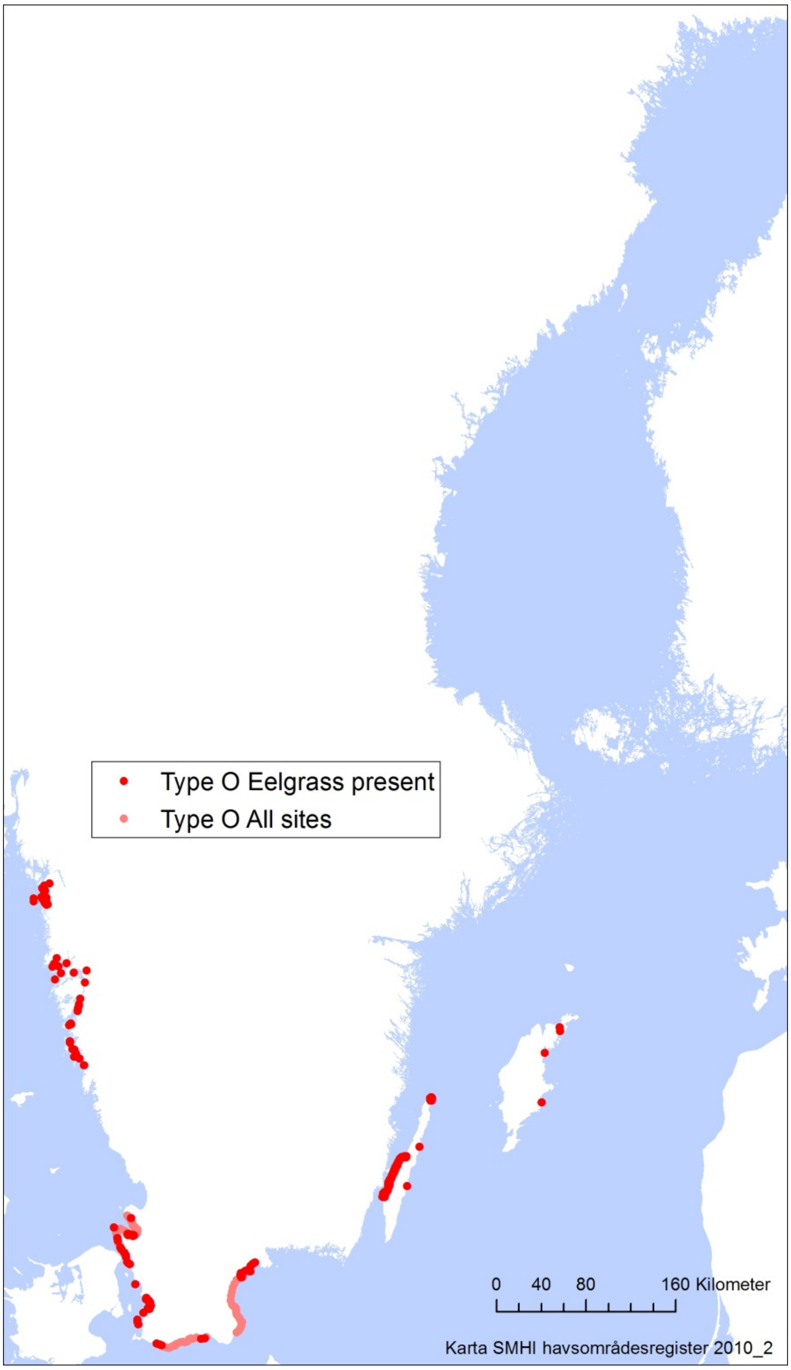

FIGURE 2.8
Sites with type O data obtained by means of dedicated eelgrass (*Zostera marina*) sampling. These include sites sampled using several different methods. Light red indicates sites where no eelgrass has been found.

3 Review of the use of coastal vegetation as indicator of ecological status in Europe

3.1 Overview of seagrass and other soft-bottom vegetation indicators

Macrophytes colonize the soft and sandy seafloor along Sweden's coastline where light reaches the bottom and where other habitat characteristics are conducive. These macrophytes include seagrasses (primarily eelgrass, *Zostera marina*), other angiosperms, characeans and drifting and epiphytic macroalgae. In most marine areas along Sweden's west coast, eelgrass is the dominant vegetation type, whereas other angiosperms and characeans are more important in the more brackish regions on the south and east coasts. Mats of drifting macroalgae and epiphytes on the leaves of angiosperms can also be important components of the soft-bottom vegetation.

As the Swedish coast includes marine to almost freshwater habitats, inspiration for proposing candidate Swedish macrophyte indicators can be found in both the marine and freshwater literature. This chapter therefore explores the use of vegetation indicators on soft and sandy habitats in marine, brackish and fresh waters.

Seagrasses and associated coastal vegetation indicators

Seagrasses are experiencing a global crisis due to anthropogenic pressure (Waycott et al. 2009), so efficient management and monitoring in combination with increased awareness of seagrass ecosystems are crucial (e.g. Borum et al. 2004; Orth et al. 2006; Boström et al. in review). In recent years, many new seagrass monitoring programmes have been developed, particularly in response to the WFD and a variety of seagrass indicators and indices have been developed. These have recently been compiled and characterized (Marbá et al. in review) and are summarized in this section. This seagrass indicator review is based primarily on information gathered through the EU FP7 project WISER (http://www.wiser.eu/results/method-database/; Birk et al. 2010 and 2012). The review considers seagrass indicators used alone and indicators used in combination to form indices. All indices containing at least one seagrass indicator were included in the review, as were all indicators contained in a given seagrass index.

The review identified 42 monitoring programmes that together used 51 seagrass indicators either alone or in various combinations of up to 14 indicators per unit/index and yielding a total of 49 indicator units/indices. The monitoring programmes spanned four European Seas, i.e. the North-East Atlantic Sea, the Baltic Sea, the Mediterranean Sea and the Black Sea and involved all four European seagrass species, i.e. *Zostera marina*, *Z. noltii*, *Cymodocea nodosa* and *Posidonia oceanica*. Only *Z. marina* and *Z. noltii* occur along the Swedish coast, but as all seagrasses are relatively similar in structure and growth form, indicators developed for southern European seagrasses could, in principle, be relevant to their north European counterparts.

The compiled seagrass indicators were grouped in six broad categories covering various organizational levels of seagrasses and various spatial scales: distribution, abundance, shoot characteristics, processes, chemical constituents and associated flora and fauna (distribution, abundance, diversity and composition) (**Table** 3.1). The first five categories relate directly to seagrasses while the last relates to the flora and fauna associated with the seagrasses. The indicators capture structural aspects, ranging from large-scale distribution patterns of seagrass meadows in a water body, though abundance patterns within meadows, to small-scale characteristics of individual shoots. They also capture biochemical and physiological aspects such as chemical constituents and process rates at the shoot level and meadow scales.

The distribution indicators include the lower depth limit of seagrasses, which is regulated primarily by light (Duarte 1991; Duarte et al. 2007). The depth limit can be assessed by diver or underwater video and the reference level can be defined based on, for example, historic data or the modelled relationship with pristine light levels. Another index in this group is the seagrass distribution area, which also responds to human disturbance (Short and Burdick 1996; Waycott et al. 2009), especially in the deeper light-limited depth range, while shallow populations are also governed largely by, for example, physical exposure (e.g. Fonseca et al. 2002). Area distribution can be assessed by, for example, underwater video or remote sensing procedures. In some cases, historical data also allow the reference situation for this variable to be defined by, for example, overlaying the time series of distribution maps and defining their union area as the potential distribution/reference area (Steward et al. 2005) or the reference can be defined as a certain percentage cover of the seafloor within a specified depth range, as is done for macrophytes in lakes (e.g. Søndergaard et al. 2010).

The abundance indicators target the cover, biomass or shoot density of seagrasses at given water depths and reflect human pressure by being light-limited in deeper water (e.g. Krause-Jensen et al. 2000, 2003). Some abundance indicators are sampled non-destructively, for example, cover can be assessed by diver or underwater video, while biomass sampling is destructive and creates small gaps in the meadows. When meadows are not too dense, shoot density can be assessed non-destructively by divers counting the shoots in small frames in situ, although this is quite resource intensive.

The indicators related to shoot characteristics, chemical composition and, to some extent, processes, do not directly reflect WFD demands as they describe none of the distribution, abundance or composition of the vegetation. They still constitute parts of several seagrass indices, as they are likely to respond relatively quickly to pressures and may therefore provide an early warning of responses that may appear too late in the larger-scale distribution and abundance indicators for managers to react in time. Such faster-responding indicators are especially relevant supplements for the monitoring of slow-growing and long-lived seagrass species such as *Posidonia oceanica* in the Mediterranean Sea and typically constitute parts of the seagrass indices for *Posidonia*. There is less need for such additional seagrass indicators for faster-growing eelgrass, such as *Zostera marina*, the dominant seagrass species of Sweden. All indicators in these categories are strongly dependent on water depth, so sampling must be carried out in well-defined depth zones.

The indicators related to associated flora and fauna were included because they constitute parts of some of the identified seagrass indices. The associated flora represents angiosperms other than seagrasses as well as various macroalgae. This category of indicators primarily characterizes diversity and composition aspects based on taxa or functional groups (e.g. tolerant versus sensitive species and the presence of epiphytes) as well as distribution and abundance patterns of species associated with the seagrasses or occurring separately on rocky substrate in the same water body (e.g. depth limits of other angiosperms or macroalgae). Grouping species as tolerant or sensitive based on functional traits and quantifying their absolute or relative importance is an approach widely used in monitoring programmes. For example, the Ecological Evaluation Index was developed and applied as an ecological status indicator for the coastal waters of Greece (Orfanidis et al. 2001, 2003, 2011) and of other European countries and has also to some extent been analysed and discussed in Sweden. A recent study testing the use of a related macrophyte index on shallow, brackish creeks and inlets of Sweden and Finland also found a significant response to anthropogenic pressure, though with considerable unexplained variation (Kautsky and Anderson 2005; Joakim Hansen pers. comm.). Species traits and sensitivity are explored in more detail in Chapter 3.3.

The three seagrass indicators most widely used in Europe, evaluated based on the number of monitoring programmes using them, are shoot density (included in 24 programmes plus two programmes that use the indicator ‘change in density’), cover (included in 18 programmes) and depth limit (included in 16 programmes) (Marbá et al. in review).

TABLE 3.1

Compilation of European seagrass indicators used alone or in combinations of up to 14 to form indices. The table includes all compiled indices containing at least one seagrass indicator as well as all indicators contained in those indices. The first five categories of indicators relate directly to seagrasses while the last category relates to the associated community. Indicators marked by asterisks relate directly to the WFD as they describe the abundance (in absolute terms or by delineating abundance limits) or presence of disturbance-sensitive taxa. Indicators marked in bold can, to some extent, be assessed based on existing Swedish monitoring data. Indicators in grey are irrelevant to Swedish seagrasses. Dead matte = dead mat of *Posidonia* remains; plagiotrophic rhizomes = horizontally oriented *Posidonia* rhizomes. Macroalgal indicators are discussed further in section 3.2. Redrawn from Marbá et al. (in review).

Category of indicator **Indicator**	**Category of indicator** **Indicator**
Distribution	Chemical constituents
• **Depth limit***	• Rhizome N
• Depth limit type	• Rhizome P
• **Area***	• Rhizome δ15N
Abundance	• Rhizomes δ34S
• **Cover***	• Rhizome sucrose
• **Shoot density***	• Rhizome Cu
• Aboveground biomass*	• Rhizome Pb
• Above/belowground biomass*	• Rhizome Zn
• Dead matte cover	**Associated flora** and fauna
Shoot characteristics	*Diversity and composition*
• Shoot biomass	• **Diversity – soft-bottom sp.***
• Shoot leaf area	• **Diversity – macroalgae***
• No. of leaves per shoot	• **Diversity – all flora***
• Leaf width	• **Tolerant sp. – proportion, abundance or area***
• Leaf length skewness	• **Sensitive sp. – proportion or abundance***
• Leaf necrosis	• **Fucus abundance***
• Broken leaves	• **Furcellaria proportion***
• Plagiotrophic rhizomes	• **Invasive sp. presence***
Processes	• Epiphytes – N, biomass*
• Leaf production	*Depth limits of associated species*
• Rhizome production	• **Depth limit – Fucus***
• Rhizome elongation	• **Depth limit – Characeans***
• Change in density*	• **Depth limit – selected sp.***
• Shoot recruitment*	*Overall abundance*
• Shoot mortality*	• **Vegetation abundance***
• Flowering	• Macrofauna abundance
• Shoot burial, rhizome baring	
• Herbivore pressure	

Notes on terms used in the compilation: Indicators that largely overlap but have different names are conflated: 'Sensitive species' also covers the terms ‘Ecological Status Group 1 (ESG 1)’, 'perennial species', 'good ecological status species', ‘positive taxa', 'characteristic species' and 'reference species'. 'Tolerant species' also covers the terms ‘Ecological Status Group 1 (ESG 1)’, 'opportunists' and 'negative taxa’. ‘Depth limit type’ is an indicator used in referring to the Mediterranean Sea to characterize the shape of the meadow near the depth limit and on this basis evaluate whether it is progressing or regressing.

Freshwater angiosperms and characeans

The use of lake macrophytes as indicators of ecological status has recently been reviewed and tested through comparative analyses of many lakes at the national and European scales (Penning et al. 2008a, b; Søndergaard et al. 2010). These reviews identified a number of relevant macrophyte indicators displaying considerable overlap with those identified in **Table** 3.2.

Søndergaard et al. (2010) explored the use of lake macrophytes as indicators of the ecological quality of lakes by analysing the distribution, abundance and composition (of sensitive and tolerant species) of macrophyte communities in 300 Danish lakes in relation to nutrient enrichment and phytoplankton abundance. Based on their analysis, they suggested a macrophyte index comprising species richness, presence of indicator species, cover and depth extension.

In a larger European review of lake macrophytes, taxa were identified as sensitive to or tolerant of eutrophication pressure and ranked according to their sensitivity (Penning et al. 2008a). Three macrophyte indices comprising the indicators ‘species richness’ and ‘abundance of sensitive and tolerant species’ were subsequently chosen for a pan-European analysis of their indicator potential: 1) the simple ‘total species richness’, 2) the more complex ‘trophic index (TI)’ based on the relative abundance of sensitive and tolerant species, calculated by subtracting the abundance of tolerant species from that of sensitive species and dividing by the total abundance and 3) the most complex ‘lake trophic ranking (LTR)’, calculated from the species composition of a lake in combination with the trophic rank of the species (**Table** 3.2). The response of the indices to eutrophication pressure (i.e. total phosphorus concentration) was tested at the European, regional and national scales (Penning et al. 2008b). Species richness was found to be highest at intermediate nutrient concentrations and thus did not display a clear negative response to eutrophication pressure; TI correlated well with total P in Northern European lakes but less so in Central European ones and the same was true for LTR, though considerable variation around the regression line limited the possibility of precise ranking (Penning et al. 2008b). The response of individual lakes to changes in eutrophication was sometimes not well captured by the indices and it was argued that the use of multiple indicators would improve the assessment of ecological status.

TABLE 3.2

Lake macrophyte indicators developed and tested at the national and European scales. All indicators relate directly to WFD demands (marked by asterisks), i.e. presence of disturbance-sensitive taxa, levels of cover and abundance (depth limit is included here as it defines the deepest occurrence of vegetation cover/abundance). Indicators marked in bold can, to some extent, be assessed based on existing Swedish coastal monitoring data.

Category of indicator Indicator	Reference
Distribution	
• **Depth limit***	Søndergaard et al. (2010)
Abundance	
• **Vegetation cover***	Søndergaard et al. (2010)
• Plant volume*	Søndergaard et al. (2010)
Diversity and composition	
• **Species richness***	Søndergaard et al. (2010), Penning et al. (2008 a and b)
• **Sensitive species***	Søndergaard et al. (2010), Penning et al. (2008 a and b)
• **Tolerant species***	Søndergaard et al. (2010), Penning et al. (2008 a and b)

3.2 Overview of macroalgal indicators

Attached macroalgae occur on hard substrates across all Swedish coastal areas, from the marine areas in the northern Skagerrak, through the Baltic proper, to the increasingly brackish areas of Bothnian Bay. While some areas represent rocky coasts entirely dominated by hard substratum, other areas are characterized by moraine coasts with scattered stones colonized by macroalgae. In recent years, a wealth of indicators has been developed for monitoring macroalgae in order to fulfil the demands of the WFD. We searched for macroalgal indicators used across Europe, based primarily on information gathered through the EU FP7 project WISER (http://www.wiser.eu/programme-and-results/data-and-guidelines/method-database; Birk et al. 2010 and 2012). Some indicators are used individually in monitoring programmes while others are used in combination, forming indices. All indices containing at least one macroalgal indicator were included in the survey as were all indicators contained in a given index. As some vegetation indices contain both angiosperm and macroalgal indicators, there is some overlap with the survey of indicators for soft-bottom vegetation presented in the previous chapter.

Thirty monitoring programmes using macroalgal indicators were compiled (see Annex): 19 of these addressed macroalgae alone, while 11 addressed macroalgae and seagrasses/angiosperms in a combined index. Three of the programmes addressed transitional waters solely, while the rest addressed coastal waters solely (20) or coastal as well as transitional waters (7). The programmes represented all European ecoregions: seven were developed for the Baltic Sea (two of these also addressed the North-East Atlantic Sea), nine additional programmes were developed for the North-East Atlantic Sea, 11 for the Mediterranean Sea and two for the Black Sea. Tidal as well as subtidal macroalgae were addressed by five programmes, while nine programmes addressed tidal macroalgal solely and the rest (16) addressed subtidal macroalgae solely (see Annex).

We categorized the indicators contained in the 30 monitoring programmes into three categories of macroalgal indicators, i.e. distribution indicators, abundance indicators and diversity and composition indicators, plus a category relating to associated species (addressing their distribution, abundance and diversity composition) (**Table** 3.3). The macroalgal indicators thus stand in contrast to the compiled seagrass indicators by representing just three categories, while the seagrass indicators represent five categories. Thus, all macroalgal indicators were structural ones operating at relatively high organizational levels (e.g. population and community) and relating more or less directly to WFD demands. In contrast to the seagrass indicators (**Table** 3.1), none of the macroalgal indicators were based on characteristics of individual specimens, processes or chemical constituents.

The distribution indicators included the depth limit of the entire vegetation, overall macroalgal vegetation and selected species (e.g. in the existing Swedish index), all of which are expected to respond to eutrophication pressure via changes in the light climate and in the competitive ability of the involved species. Another distribution indicator described the length of coastline occupied by given vegetation types – an indicator developed for intertidal macroalgae in areas with large tidal range, but irrelevant to the Swedish microtidal coast, which is, moreover, affected by ice scouring. For the same reason, the depth limits of littoral algal belts are an irrelevant indicator along the Swedish coast. The area extent of tolerant species, for example, macroalgal mats, also makes part of the category distribution indicators and is expected to increase with increasing eutrophication (**Table** 3.3).

The abundance indicators describe the overall abundance of the entire vegetation, macroalgal community and selected key species such as *Fucus vesiculosus* at specific water depths.

Diversity and composition indicators were the indicators most frequently used in the compiled monitoring programmes. They focus on the entire community, functional groups represented by tolerant and sensitive species, taxonomic groups represented by the three large classes of attached macroalgae (i.e. green, red and brown algae) and selected key species (**Table** 3.3). The rationale is that anthropogenic pressure will reduce overall diversity, favouring tolerant species, often dominated by green algae, at the expense of sensitive species, often dominated by perennial brown and red algae and representing key species such as *Fucus vesiculosus* and *Furcellaria lumbricalis*. As for the soft/sandy-bottom vegetation indicators, several macroalgal indicators thus rely on the different sensitivities of taxa to human disturbance, an aspect further explored and discussed in Chapter 3.3. Important considerations regarding the sampling of tolerant macroalgae (e.g. drifting macroalgal mats and epiphytes) are the high temporal variability in their occurrence due to high rates of growth and decomposition (Valiela et al. 1997) and their drifting nature making them highly dependent on exposure and weather conditions. Sampling should therefore be conducted at large spatial scales so that algal mats drifting from one side of a bay to another are still included in the survey; ideally, sampling should take place several times during the growth season, though this is often not feasible for cost reasons.

Important points regarding sampling and analysis of the macroalgal indicators

As mentioned for the soft/sandy-bottom vegetation, all indicators related to abundance, species diversity and composition are strongly dependent on water depth, so sampling must be carried out in well-defined depth zones.

The substratum also affects abundance and species composition as, for example, mobile substratum may not allow time for dense communities of perennial algae to develop (see Chapter 1). Therefore, specified substratum types should preferably be sampled to reduce the variability among samples and increase the chance of detecting responses to pressures.

As salinity also exerts a major influence on vegetation (see Chapter 1), it must be taken into account in data analysis to be able to distinguish between the effects of salinity and of eutrophication pressure. The number of macroalgal species thus declines from 293 on the Swedish west coast (Kattegat east) to 42 in the brackish Bothnian Bay and the relative importance of green algae increases along the salinity gradient (Nielsen et al. 1995). Moreover, the reduced species diversity changes the competition pressure among macroalgae enabling the deeper depth colonization of several species, for example, *Fucus vesiculosus*, in the more brackish areas (Waern 1952; Pedersén and Snoijs 2001; Torn et al. 2006).

Sampling effort in terms of the size of the examined area, sampling intensity/time and diver experience are other important factors especially affecting detected species richness. To take this into account, all sampling must be conducted within well-defined sampling areas by, for example, using a certain number of frames of a given size. Moreover, we must define the level of precision needed in species identification. This can be done, for example, by producing a species list for each water body type indicating the species that must be known by the diver and be recorded if present, as well as mentioning the species that need not be considered, for example, due to their tiny size. Such a list would also take into account the change in species occurrence along the salinity gradient.

TABLE 3.3

Compilation of European macroalgal indicators based on http://www.wiser.eu/results/method-database. Some indicators are used alone while others are used in combinations to form indices. All indices containing at least one macroalgal indicator were included in the compilation as were all indicators contained in a given index. Indicators marked by asterisks relate directly to the WFD as they describe the abundance (in absolute terms or by delineating abundance limits) or presence of disturbance-sensitive taxa. Indicators marked in bold can, to some extent, be assessed based on existing Swedish monitoring data.

Category of indicator **Indicator**	**Category of indicator** **Indicator**
Distribution	Diversity and composition (continued)
• **Depth limit – Selected species***	• **Green macroalgae – sp. richness, proportion***
• **Depth limit – Fucus belt or individuals***	• **Red macroalgae – sp. richness, proportion***
• **Depth limit – Furcellaria individuals***	• **Green and red macroalgae – proportion***
• **Depth limit – Vegetation***	• **Brown macroalgae – sp. Richness***
• Length of coastline – Macroalgal community types*	• **Furcellaria – proportion***
• Area extent – Tolerant species*	
Abundance	Associated flora
	Distribution
• **Cover – macroalgae***	• **Depth limit – *Zostera marina******
• **Cover – all vegetation***	• Area extent – Seagrasses*
• **Cover – Fucus***	• Area extent – Tidal marsh*
Diversity and composition	*Abundance*
• **Species diversity – macroalgae***	• **Cover – seagrasses***
• **Species richness – macroalgae***	• **Density – seagrasses***
• **Species richness – all vegetation***	*Diversity and composition*
• **Species richness reduction***	• **Composition – seagrasses***
• **Sensitive sp. – presence, cover, biomass, richness, proportion***	
• **Tolerant sp. – cover, biomass, richness, proportion***	

Notes on terms used in the compilation: Indicators that largely overlap but have different names are conflated: 'Sensitive species (sp.)' also covers the terms 'Ecological Status Group 1 (ESG 1)', 'perennial species', 'good ecological status species', 'positive taxa', 'characteristic species', 'reference species' and 'structuring species'. 'Tolerant species' also cover the terms 'Ecological Status Group 2 (ESG 2)', 'annual species', 'opportunists' and 'negative taxa'. In some indicators/indices, the terms 'sensitive' and 'tolerant' species refer to macroalgae only while in others they also refer to angiosperms and some indices describe the proportion of groups as the ratio of the abundance (or species richness) of tolerant to sensitive species, while others describe it as the difference between the groups in relation to the total abundance (or species richness).

3.3 Species traits and sensitive versus tolerant vegetation taxa

Overview of species trait database

Many macrophyte indicators are based on species traits such as longevity, morphology, opportunistic capability and habitat preferences. To have a solid basis for ongoing work on indicator construction, a database was developed for internal use in WATERS, summarizing recordings of species in Swedish waters and their traits. This database (TaxonTraits) is based on records extracted from the national data host SMHI originating from the MarTrans (mainly phytobenthic transect data) and Grunda (vegetation in shallow bays) databases. These records provide an overview of the distribution of macrophyte species in Swedish water body type areas based on occurrence along coastal transects and in shallow bays. They also include information on taxa occurrence on different substrate types and in different wave exposure classes.

The species trait database (TaxonTraits) was designed to combine information on the *occurrence* of species/taxa with information on characteristic traits of the recorded species/taxa. Thus, for each taxon, a list of traits has been created derived from current knowledge in the literature. To date, the focus has been on a number of key traits considered vital in applying many potential indicators. The identified key traits are longevity, functional groups based on morphology, reproduction period, growth strategy (i.e. opportunist versus late successional) and eutrophication response. Other traits, such as growth rate and response/sensitivity to other stresses, have also been added to the database when information has been found.

Occurrence of species/taxa

The TaxonTraits database includes all vegetation data from the national data host SMHI originating from the MarTrans and Grunda databases up to May 2011 and forms the basis of the distribution overview. These data indicate a total of 456 taxa, including bacteria, diatoms, algae, charophytes and angiosperms, recorded in macrophyte inventories from Swedish waters. The records are at different taxonomic levels but include 311 species of red, brown and green algae, charophytes, bryophytes and angiosperms (including Lycopodiophyta). The algae are the most species-rich group with 189 recorded species followed by the angiosperms with 101 species. The charophytes are represented by 16 species and the bryophytes by five.

Based on their occurrence, some of these recorded species may be more or less interesting than others for indicator application. A species occurring along all or most of the coast may, for example, provide a basis for an indicator applicable in many water body types. In contrast, a species that is rare along the coast but common in one or a few water body types may prove to be an important indicator in these particular types. A species that is generally rare, on the other hand, is probably not very suitable as an indicator, as its recorded occurrence likely depends largely on coincidence.

To obtain a general overview of how common a species is in the Swedish coastal aquatic flora, three occurrence traits were calculated based on the existing data. The first occurrence trait, i.e. Occurrence COAST, is based on the number of water body types in which the species has been recorded. This gives a general idea of how common the species is along the long, diverse Swedish coastline. Each species was classified as: 1) rare (occurs in less than 5% of the water type areas), 2) unusual (5–10%), 3) relatively unusual (10–25%), 4) less common (25–50%), 5) common (25–75%), 6) very common (75–90%) or 7) Extremely common (occurs in >90% of the water type areas).

The second occurrence trait, i.e. Occurrence TRANSECT, refers to the number of transects on which the species has been recorded in each water body type. Each species was classified into one of seven (ranging from rare to extremely common) classes based on the type with maximum occurrence. The third occurrence trait, i.e. Occurrence BAYS, is similar to the second but instead based on occurrence in shallow bays. A species can thus be rare based on Occurrence COAST (occurring in only one type) but very common based on Occurrence TRANSECT.

Longevity

Knowledge of species longevity is central in determining many species characteristics and responses. For example, annuals are usually fast growing and more opportunistic than are perennial slower-growing species, a trait that can be beneficial in disturbed environments and may govern responses when species are exposed to stress. Information on longevity was extracted from articles, floras, databases and other work (mainly Wallentinus 1979; Mossberg et al. 1992; Tolstoy and Österlund 2003; the MarLIN database online; the Swedish Virtual Flora online, PLANTS database online). A concluding decision regarding species longevity was then made based on all information found for each species. Each species was placed in one of the following six groups: annual, perennial by overwintering parts, perennial, persistent perennial, A/P (i.e. the literature states it can be both annual and perennial) and biennial. Currently, the longevity of 218 of the 311 macrophyte species recorded in Swedish waters (including 10 hybrids, subspecies or variations) has been determined.

Each grouping into a specific trait was coupled with a confidence value to provide some information on the reliability of the group determination. The highest confidence value, "A", was generally assigned when all found (at least three) references agreed on the trait. The slightly lower confidence value of "B" generally indicates that the two references found are in agreement. A trait determination followed by the confidence value "C" indicates that it is based on only one reference, but of good quality (i.e. based on experimental evidence, reviewed text or in agreement with other references concerning the trait assignment of other species). The confidence value "D" is indicative of a determination based on only one, less certain reference, for example, one that often disagrees with other references or is from unreviewed text or information. Trait determinations based on references in disagreement were assigned confidence values of 1–3, a value of "1" indicating a determination based on more than two references in agreement versus one in disagreement.

A confidence value of "2" was assigned to traits for which two references were in agreement but one was not. If no majority existed, the conclusion on trait was determined based on reference reliability (see explanations on confidence values C and D above) and the confidence value "3" was assigned. In general, references concerning Swedish conditions were given more weight, as different environmental conditions can cause differences in species characteristics.

Functional grouping based on morphology

Communities constitute an ecologically relevant level for investigating long-term anthropogenic stress (e.g. Odum 1985; Crowe et al. 2000), but natural variability causes spatial and temporal variation at the community level as well, making it difficult to evaluate a stress response based on species composition. A functional approach, i.e. grouping functionally similar species together, arguably gives a more temporally stable and predictable view of communities (Littler and Littler 1980; Steneck and Watling 1982; Steneck and Dethier 1994).

Functional grouping based on morphology was identified as another key "trait". The macroalgal taxa recorded in Swedish waters were each assigned a morphological functional group according to Steneck and Dethier (1994) based on a classification conducted by Karsten Dahl and Steffen Lundsteen of Aarhus University (AU) (Carstensen et al. 2008). The AU classification was compared with literature and other classifications according to morphology (mainly Eriksson et al. 2002; Kraufvelin et al. 2009; Kautsky unpubl.; several floras and algal websites with photographs). Taxa were classified into the following groups: 2) Filamentous algae (i.e. uniseriate and uncorticated), 2.5) Filamentous algae (i.e. sparsely corticated and polyseriate), 3) Foliose algae (i.e. leaf shaped), 3.5) Corticated foliose algae (i.e. leaf shaped and sturdy), 4) Corticated algae (i.e. coarsely branched), 5) Leathery algae, 6) Calcareous algae or 7) Crustose algae.

A confidence value was coupled with each morphological functional group classification to indicate the reliability of the group determination. The highest confidence value designated "A" was generally assigned when the AU classification was supported by other references or directly from photographs. The confidence value "B" indicates that the AU classification was accepted without further verification, while "N" indicates a new classification usually based on photographs and floras. Almost all (182) of the 189 recorded algal species were placed in a functional group according to morphology.

The 101 angiosperm species were roughly classified according to morphology based on two floras (Mossberg et al. 1992; the Swedish Virtual Flora) as follows: 2) Helophytes (emerges from the water), 3) Nympheids (plants with floating leaves), 4) Elodeids (submerged, long plants), 5) Isoetids (submerged, short <10 cm) and 6) –Lemnids (free floating/unrooted plants). The inventory data include species described (e.g. in floras) as growing on beaches, periodically submerged areas or moist soil. These 27 angiosperm species were classified as 1) Land plants. Of the remaining 74 species, 69 were classified.

Sensitivity to eutrophication

There are two basic theoretical approaches to identifying sensitive species with regard to eutrophication. One that has been applied mainly in lakes identifies a large number of lakes with different nutrient (mainly P) concentrations and then classifies the occurring species as sensitive or tolerant based on their occurrence in this nutrient gradient. Another approach is to base the classification on the literature, with references including actual experimental evidence considered most reliable. Various kinds of information found on eutrophication response have been added to the database. Our classification was then done in several steps. In the first step, separate classifications were made based on freshwater (lake) references or brackish and marine water references. In the second step, the classifications were compared with other information on nutritional preferences (oligotrophic or eutrophic waters).

In the first step, 54 angiosperms, four bryophytes and eight charophytes were classified based on freshwater references (Melzer 1999; Ecke 2007; Penning et al. 2008a; Søndergaard et al. 2010) as sensitive, possibly sensitive, possibly tolerant or tolerant. Each classification was coupled with a confidence value as described above for the longevity trait. Based on marine and brackish water references (e.g. Wallentinus 1979; MarLIN database), 90 taxa were grouped, based on eutrophication response, as most sensitive (S++), very sensitive (S+), sensitive (S), tolerant (T), slightly favoured (T+) and favoured (T++) and coupled with confidence values. Also based on marine and brackish water references, 31 species were classified according to sensitivity to changes in nutrient level.

These classifications were then compared with information on nutritional preferences (Mossberg et al. 1992; Kautsky and Andersson 2005; the Swedish virtual flora) for 58 species and a combined classification of sensitive or tolerant was made for each species. The confidence values for the combined classification generally rated references regarding Swedish coastal waters slightly higher than references regarding lakes or remote marine water.

On this basis, we created an initial list of species potentially sensitive to or tolerant of eutrophication in Swedish coastal waters (**Table** 3.4). The list provides a starting point for testing indicators based on sensitive/tolerant species represented in current data. The lists will be revised based on further literature reviews and on the results of tests of current data. **Table 3.5** summarizes some of the identified key traits and the current number of species classified according to the traits based on the literature.

TABLE 3.4

A preliminary list of species classified as sensitive to or tolerant of eutrophication based on the literature. The most reliable classifications as either tolerant or sensitive are indicated by species names in bold text and the letter A (at least three references in agreement). Slightly less reliable classifications are denoted by the letter B (two references in agreement). The other classifications were based on either one reference or several disagreeing references. The 40 taxa classified as potentially sensitive or potentially tolerant are not shown here.

ANGIOSPERMS, BRYOPHYTES AND CHAROPHYTES	
Tolerant of eutrophication	**Sensitive to eutrophication**
(A) ***Callitriche hermaphroditica***	(A) ***Zostera marina***
(A) ***Ceratophyllum demersum***	(A) ***Subularia aquatica***
(A) ***Ceratophyllum submersum***	(A) ***Eleocharis acicularis***
(A) ***Elodea canadensis***	(A) ***Ranunculus reptans***
(A) ***Lemna trisulca***	(B) *Zostera noltii*
(A) ***Myriophyllum verticillatum***	(B) *Utricularia intermedia*
(A) ***Potamogeton compressus***	*Isoëtes echinospora*
(A) ***Potamogeton crispus***	*Isoëtes lacustris*
(A) ***Potamogeton friesii***	*Callitriche hamulata*
(A) ***Potamogeton pectinatus***	*Plantago uniflora*
(A) ***Ranunculus aquatilis***	*Myriophyllum alterniflorum*
(A) ***Ranunculus circinatus***	*Ruppia cirrhosa*
(A) ***Stratiotes aloides***	
(A) ***Typha angustifolia***	*Fontinalis dalecarlica*
(A) ***Zannichellia palustris***	
(B) *Elodea nuttallii*	(A) ***Tolypella nidifica***
(B) *Najas marina*	*Chara baltica*
(B) *Ranunculus peltatus ssp. baudotii*	*Chara canescens*
Elatine hydropiper	*Chara tomentosa*
Myriophyllum spicatum	
Persicaria amphibia	
Potamogeton berchtoldii	
Potamogeton filiformis	
Potamogeton obtusifolius	
Potamogeton perfoliatus	
Potamogeton praelongus	
Potamogeton pusillus	
Ruppia maritima	
Sagittaria sagittifolia	
Zannichellia palustris var. pedicellata	
Zannichellia palustris var. repens	

(A) > 3 references in agreement, (B)= 2 references

MACROALGAE Tolerant of eutrophication	Sensitive to eutrophication
(A) ***Pylaiella littoralis***	(A) ***Ascophyllum nodosum***
(A) ***Ulva intestinalis***	(A) ***Ceramium tenuicorne***
(B) *Ceramium virgatum*	(A) ***Chondrus crispus***
(B) *Halidrys siliquosa*	(A) ***Chorda filum***
(B) *Polysiphonia fucoides*	(A) ***Laminaria hyperborea***
(B) *Prasiola stipitata*	(A) ***Saccharina latissima***
(B) *Ulva lactuca*	(B) *Fucus serratus*
Acrosiphonia arcta	(B) *Fucus spiralis*
Aglaothamnion roseum	*Aegagropila linnaei*
Blidingia minima	*Ahnfeltia plicata*
Chaetomorpha linum	*Chaetomorpha melagonium*
Cladophora fracta	*Coccotylus truncatus*
Cladophora glomerata	*Delesseria sanguinea*
Cladophora pachyderma	*Dictyosiphon chordaria*
Ectocarpus siliculosus	*Dictyosiphon foeniculaceus*
Hildenbrandia rubra	*Elachista fucicola*
Leathesia marina	*Eudesme virescens*
Monostroma grevillei	*Fucus vesiculosus*
Percursaria percursa	*Halosiphon tomentosus*
Pilinia rimosa	*Laminaria digitata*
Punctaria tenuissima	*Lithothamnion glaciale*
Rhizoclonium riparium	*Palmaria palmata*
Stictyosiphon tortilis	*Phyllophora pseudoceranoïdes*
Ulothrix flacca	*Phymatolithon calcareum*
Ulothrix zonata	*Polyides rotundus*
Ulva clathrata	*Polysiphonia fibrillosa*
Ulva compressa	*Rhodochorton purpureum*
Ulva linza	*Rhodomela confervoides*
Ulva prolifera	*Scytosiphon lomentaria*
Urospora penicilliformis	
Hildenbrandia	
Oedogonium	
Rhizoclonium	
Spirogyra	
Spongomorpha	
Stigeoclonium	
Ulva	
Vaucheria	

(A) > 3 references in agreement, (B)= 2 references

TABLE 3.5
An overview of some of the identified key traits of macrophytes along the Swedish coast and the current number of species classified for each trait.

Trait	Longevity	Reproduction period	Functional group (morphology), macroalgae	Functional group (morphology), angiosperms	Sensitive to/ tolerant of eutrophication
Groups	1. Annual 2. Perennial by overwintering parts 3. Perennial 4. Persistent perennial 5. A/P 6. Biennial	1. Episodic 2. Protracted	2. Filamentous (uniseriate) 2.5 Filamentous 3. Foliose 3.5. Corticated foliose 4. Corticated 5. Leathery 6. Calcareous 7. Crustose	1. Land plants 2. Helophytes 3. Nympheids 4. Elodeids 5. Isoetids 6. Lemnids	- Tolerant - Potentially tolerant - Potentially sensitive - Sensitive
Current status					
- No. classified sp.	*218*	*59*	*182*	*96*	*137*
- Total no. sp.	*311*	*311*	*189*	*101*	*311*

4 Conclusion: Potential vegetation indicators for use in Sweden

4.1 Vegetation indicators in soft/sandy habitats

Based on the review (Chapter 3), we find that the following list of vegetation indicators in soft/sandy habitats could be relevant in Sweden. We suggest focusing on these and exploring them further through gradient studies and data analyses to be conducted in the WATERS programme:

Distribution indicators

- Depth limits of selected species (e.g. eelgrass)
- Area distribution (e.g. fragmentation)

Abundance indicators (depth related)

- Macrophyte cover

Species composition/diversity (depth related)

- Relative or absolute abundance of functional groups: sensitive & tolerant species
- Macrophyte diversity

This list of indicators relates directly to the ecological status definitions and demands of the WFD and targets relatively large spatial scales and high organizational levels, i.e. the population and community levels. These indicators also have the advantage that they can, at least to some extent, be described using existing Swedish monitoring data, which can then provide some background information. As the angiosperms characteristic of the Baltic Sea are relatively fast growing, there is less demand for supplementary, faster-responding indicators (i.e. in the categories shoot characteristics, process rates and chemical constituents) than, for example, in the Mediterranean Sea where slow-growing seagrasses dominate.

The prioritized indicators have the further advantage of being relevant to habitats ranging from marine to freshwater ones and thus to most of the Swedish coastline, reflecting that the benthic vegetation of shallow coastal and lake habitats has many commonalities in structure, function and response patterns to eutrophication pressure. Thus, the reduction in water clarity as eutrophication increases and the ensuing effects on the depth distribution, abundance and performance of macrophytes at specific depths occur across all these habitats, as does stimulation of the growth of tolerant species at the expense of sensitive ones.

Of the distribution indicators, depth limits and area distribution, including the degree of fragmentation of meadows, are in the priority list. This latter aspect may merit further exploration through the WATERS programme, as the degrees of cover and fragmentation of meadows affect the functionality and services of coastal ecosystems in terms of nutrient retention, carbon sequestration, particle sedimentation and biodiversity (Carr et al. 2010; Boström et al. 2011; McGlathery et al. 2012). This is a new field likely to gain importance in the future.

Of the abundance indicators, we prioritize those that are non-destructive, i.e. cover rather than biomass measures. Cover measures also have the advantage that they can be obtained by underwater video, which is relatively cost-efficient and can be used not just to assess the abundance of seagrass stands and meadows, but also to describe the depth distribution and large-scale distribution patterns of seagrasses, including the degree of fragmentation of the meadows. As the shoot density of dense meadows is difficult to assess non-destructively and demands intensive diver investigation, we chose not to include it in the list of candidate indicators, even though it does respond very clearly to changes in light (e.g. Krause-Jensen et al. 2000).

Indicators based on the presence and abundance of sensitive versus tolerant species appear to be a promising field meriting further exploration in the WATERS programme. Along the more saline northern parts of the Swedish west coast, seagrass communities are often monocultures of eelgrass (*Zostera marina*), which is a sensitive species, but mats of drifting opportunistic macroalgae can occur in large quantities (Pihl et al. 1999) and shading the seagrasses (e.g. Rasmussen et al. 2012). Drifting *Fucus* has also been observed in large quantities in some soft-bottom habitats, for example, in Denmark, with associated negative effects on eelgrass (Valdemarsen et al. 2010). Along the northern Swedish west coast, evaluation of the importance of tolerant versus sensitive species therefore primarily reflects the balance between seagrasses and drifting macroalgae. Towards the more brackish areas along the east coast of Sweden, the relative importance of *Zostera* diminishes and *Zostera* is absent in the Gulf of Bothnia. The brackish soft-bottom habitats are often covered by mixed meadows of angiosperms (e.g. *Zostera*, *Ruppia*, *Potamogeton* and *Zannichellia*), characeans and mosses (at very low salinity), with some of the species regarded as tolerant and others as more sensitive (see section 4.2). The mixed communities may also be affected to varying extents by drifting algal mats. Therefore, along the east coast, the importance of tolerant versus sensitive species largely reflects the balance between sensitive angiosperms and tolerant angiosperms and macroalgae.

4.2 Vegetation indicators in hard-bottom habitats

In summary, we find that the following list of vegetation indicators in hard-bottom habitats could be relevant in Sweden. We suggest focusing on these and exploring them further through gradient studies and data analyses to be conducted in the WATERS programme:

Distribution indicators

- Depth limits of selected species (i.e. key macroalgae)

Abundance indicators (depth related)

- Cover of macroalgae (total or cumulative)

Diversity and composition (depth related)

- Relative or absolute abundance of functional groups: sensitive & tolerant species
- Macroalgal diversity

All the compiled macroalgal indicators relate to the ecological status definitions and demands of the WFD and most are, in principle, applicable to the Baltic Sea, as long as, for example, the marked salinity gradient of the Baltic Sea is taken into account in the data interpretation. Indicators focusing on the intertidal zone (e.g. depth limits of littoral belts) are of limited relevance in the Baltic Sea, where the tidal range is small in relation to irregular water level fluctuations driven by air pressure and strong winds.

Of the distribution indicators, the depth limits of selected macroalgae merit further exploration. As discussed in Chapter 2, this indicator has some severe limitations as, for example, the lack of stable substratum rather than light limitation often sets the depth limit and determining the depth of the deepest occurring individuals is associated with considerable uncertainty. To be useful, this indicator would therefore need modification and redefinition. For example, including the depth limits of macroalgae only in areas with sufficient hard substratum availability in deep areas should be considered. Moreover, it may be useful to combine this indicator in an index along with other indicators in the priority list.

Closely related to the depth limit of the vegetation is the cover at a given depth along the light-limited part of the depth gradient, which may be useful even in areas where hard substratum is lacking in the deepest depth intervals. We have placed this indicator in the abundance indicators category and intend to explore it in the WATERS programme with respect to total macroalgal abundance (having a maximum of 100%), cumulative abundance of macroalgal species (which can be >100%) and abundance of key species. As for the soft-bottom vegetation, we prioritize assessing the abundance of the vegetation through cover measures rather than biomass samples as the biomass samples are destructive and also costly.

As discussed for the soft- and sandy-bottom vegetation, the indicator category diversity and composition seems promising also with respect to macroalgae and will be explored further in the WATERS programme. The focus will be on the aspects of sensitive versus tolerant taxa rather than on algal classes, as form and functional traits are more closely related to eutrophication pressure than is taxonomy.

In sampling and data analysis, substratum composition will be emphasized. Separate sampling schemes should be developed for soft/sandy habitats and hard-bottom habitats.

4.3 Points to address in analyses of vegetation indicators in WATERS

The selected indicators will be explored by analysing data from field surveys to be conducted in the WATERS programme and by analysing existing data. Through these analyses, we wish to address the following considerations:

- Responses of the selected indicators to pressures
- The potential for using species traits in indicator development
- Quantification of sampling-related uncertainties

Responses of the indicators to pressures

Knowledge of the pattern of indicator responses to pressure and of the time-scales of such responses is essential for optimal indicator use and interpretation.

Most pressure–response relationships reported in the literature have been established based on spatial gradients, i.e. various ecosystems describing a range in pressures (e.g. Carstensen et al. 2011 and references therein). Analyses of responses to changes in pressure over time are less common, as good long-term datasets are rare. It has been assumed that spatial pressure–response relationships could be used as a proxy for responses to changes in pressure over time. However, this is not necessarily the case, as recently illustrated through spatio–temporal analyses of relationships between nutrient concentration and chlorophyll-a (Carstensen et al. 2011).

It has often been assumed that an increase in pressure causes a gradual degradation of an ecosystem, reflected in a linear response of the indicators and that, upon release of the pressure, the ecosystem would gradually return to its original state. However, recent evidence challenges these assumptions (e.g. Duarte et al. 2009; Kemp et al. 2009; Taylor et al. 2011; Carstensen et al. 2011, 2012). For example, there are indications that trajectories of ecosystem response to pressure are not necessarily gradual and linear but may be abrupt and non-linear, as the ecosystem may display delayed (hysteresis) response to nutrient enrichment (Duarte et al. 2009; Kemp et al. 2009; Taylor et al. 2011; Carstensen et al. 2012). Ecosystems may thus be capable of absorbing disturbances up to a certain threshold level, but then suddenly exhibit an abrupt state shift upon exceeding the threshold, and the new state/regime may display inherently different functionality and responses to pressures. Moreover, the trajectories of ecosystem response to an increase in pressure do not necessarily match those of their response to a release of the pressure (e.g. Duarte et al. 2009; Kemp et al. 2009; Carstensen et al. 2011). For example, the threshold nutrient concentration triggering a regime shift may be higher during the eutrophication phase than during the oligotrophication phase; this puts increased demands on nutrient load reductions in order to flip the ecosystem back into a desirable state, because feedback mechanisms tend to maintain the system in the undesired state (Krause-Jensen et al. 2012). As a further complication, baselines may change so that the system may not necessarily return to its original state upon release of the pressure (e.g. Duarte et al. 2009).

Data analyses in the WATERS programme will be conducted with these considerations in mind. The gradient study to be conducted in WATERS will establish a dataset for exploring the response of indicators to eutrophication across spatial scales. The existing Swedish data include additional spatial gradients in pressures and environmental conditions as well as some time series, allowing some combined spatio–temporal analyses of indicator response to pressures.

As data from the gradient study and the existing dataset will represent eutrophication gradients across estuarine ecosystems varying, for example, in salinity, they take account of several combinations of nutrient levels and salinity, which should allow the analysis to distinguish between indicator response to salinity and eutrophication, respectively.

The potential for using species traits in indicator development

The potential for using species traits in indicator development, which is introduced in Chapter 3.3., will be further explored through analyses of existing datasets over the next year of the WATERS programme. For example, the presence and abundance of various taxa can be related to ranges of habitat conditions and combinations of these across the Baltic Sea.

Quantification of sampling-related uncertainties

The potential of an indicator to reflect changes in pressure is tightly connected with the uncertainty connected with sampling the indicator. Low sampling uncertainty increases the chance of detecting a response to pressure and vice versa. The sources of sampling-related uncertainty include spatial variation at different levels (e.g. between subsamples at a given site, between sites in a water body and between water bodies), temporal variation (e.g. between seasons and between years) and variation between observers. Knowledge of the various sources of uncertainty can be applied when planning sampling programmes to reduce overall indicator variability. For example, if variability between sites or observers is important and variability between subsamples is not, then the overall variability of sampling can be reduced by increasing the number of sites in an area at the expense of the number of subsamples and by involving more than one observer. Comparative studies of uncertainty connected with vegetation indicators are relatively few, but the EU project WISER is now yielding results indicating how to apply knowledge of uncertainty in the planning of sampling design (Bennett et al. 2011; Mascaró et al. 2012 and submitted; Balsby et al. submitted).

Field surveys were conducted in summer 2012 and are being planned for summer 2013 along gradients of eutrophication on the Swedish west and east coasts. These surveys will include all biological quality elements relating to the WFD, i.e. macrophytes, benthic fauna, fish and phytoplankton, as well as physicochemical conditions representing the water bodies. While the primary goal of these studies is to assess the responses of various quality elements to gradients in eutrophication, the gradient studies will also allow the quantification of various sources of sampling-related uncertainty (e.g. spatial variation between subsamples at a given site between sites in a water body).

As well as specially designed field studies, such as the WATERS field studies, large monitoring datasets also allow the estimation of various sources of variability in indicator assessment. For example, existing Swedish monitoring data on macrophytes allow analyses of variability between water bodies, between sites within water bodies and between years.

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Annex

See excel file 'WATERS D1 Annex' at: http://www.waters.gu.se/publikationer/

Potential eutrophication indicators based on Swedish coastal macrophytes

This study suggests candidate vegetation indicators for use in assessing the ecological status of Swedish coastal waters. The indicators cover soft- and hard-bottoms in marine and brackish waters along the diverse Swedish coastline. The indicators are selected based on their responses to anthropogenic pressure (in theory or practice). They reflect the distribution, abundance, diversity and composition of the vegetation and are ecologically relevant. They all address the demands of the Water Framework Directive regarding the assessment of ecological status and also have the advantage of being able, to some extent, to use background information obtained from existing datasets. The candidate indicators will be further explored in the WATERS programme based on analyses of existing vegetation data and data from new field studies along gradients of eutrophication.

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