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Analysis of human influences and proposal of a method for assessment of ecological status

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Summary

The European Union Water Framework Directive (WFD) has a general objective that all European waters should attain good ecological status by 2015. Shallow wave-protected inlets with soft-sediment bottoms are common environments along the Swedish and Finnish Baltic Sea coastlines. However, there is no suitable method for assessing the ecological status of this biotope. The current assessment methods based on macrovegetation for coastal waters in Sweden and Finland are mainly designed for hard-bottom biotopes and function poorly for shallow soft bottoms. The aim of this study was to analyse the effects of human activities on submerged macrovegetation in shallow inlets along the Swedish and Finnish Baltic Sea coasts, and to develop a method for assessment of environmental status for the inlets.

The results of the study showed that the proportion of disturbance-sensitive species decreased with increasing total phosphorus concentration and boating activity. In addition, macrophyte cover was lower in inlets with high, as compared to low, boating pressure. Natural environmental factors were found to be very important for explaining variation in the macrophyte community. However, a large part of the variation was unexplained in the models tested, and should be examined further.

Based on the results, an assessment method for classification of environmental status was developed. The method uses a macrophyte index based on a cover proportion of sensitive to tolerant species, as well as the mean cover of all species combined. The two macrophyte responses are expressed as ecological quality ratios relative to a reference condition. Specific threshold values were developed to classify the environmental status on a five-point scale, from high to good, moderate, poor, and bad status. The method suggested can be used as a complement to the existing methods that are applied to deeper areas. The method is applicable to individual inlets and may also be suitable to larger water areas according to divisions in the WFD. It does, however, need further development and independent testing before application.

Sammanfattning

EU:s ramdirektiv för vatten har en allmän målsättning att alla europeiska vatten ska uppnå god ekologisk status senast år 2015. Grunda vågskyddade vikar med mjuka sedimentbottnar är vanliga miljöer längs den svenska och finska Östersjökusten. Det finns dock ingen lämplig bedömningsgrund av ekologisk status för denna biotop. Den nuvarande bedömningsgrunden baserad på makrovegetation är främst inriktad på hårdbotten och fungerar dåligt för grunda mjukbottnar. Syftet med den här studien var att analysera effekter av mänsklig verksamhet på makrovegetation i grunda vikar längs den svenska och finska Östersjökusten, samt att utveckla en bedömningsgrund av ekologisk status för den här typen av vikar.

Resultaten visade att proportionen störningskänsliga arter minskade med ökad koncentration totalfosfor samt ökat tryck från båttrafik. Därutöver var täckningsgraden av vegetation lägre i vikar med högt jämfört med lågt tryck från båtar. Naturliga miljöfaktorer förklarade mycket av variationen i makrofytsamhället. En betydande del av variationen kunde dock inte förklaras i de testade modellerna och bör utredas ytterligare.

Baserat på resultaten utvecklades en bedömningsgrund för klassificering av ekologisk status. Metoden använder ett makrofytindex baserat på täckningsgraden av känsliga och toleranta arter, samt täckningsgraden av alla arter kombinerat. De två indikatorerna uttrycks i form av ekologiska kvalitetskvoter i förhållande till ett referenstillstånd. Specifika gränsvärden har tagits fram för att klassificera den ekologiska statusen från hög till dålig status i en femgradig skala. Den föreslagna metoden kan fungera som ett komplement till de etablerade metoderna som tillämpas på djupare områden. Metoden är tillämpbar främst för enskilda vikar, men kan även fungera för större vattenområden i enlighet med uppdelningen i EU:s ramdirektiv för vatten. Den bör dock utvecklas och testas ytterligare innan allmän tillämpning.

Yhteenveto

Euroopan Unionin vesidirektiivin (WFD) tavoitteen mukaisesti kaikkien Euroopan vesialueiden pitäisi saavuttaa hyvä ekologinen tila vuoteen 2015 mennessä. Pehmeäpohjaiset, matalat ja hyvin aaltorasitukselta suojaiset lahdet ovat yleinen ympäristötyyppi Ruotsin ja Suomen rannikkoalueilla. Toistaiseksi kuitenkin keinot näiden biotooppien ekologisen tilan arvioimiseen ovat kuitenkin olleet puutteelliset. Nykyinen makrokasvillisuuteen perustuva arviointitapa on suunnattu lähinnä kovien pohjien biotoopeille ja soveltuu näin ollen heikosti matalien pehmeäpohjaisten lahtien arvioimiseen. Tämän tutkimuksen tarkoituksena olikin analysoida inhimillisen toiminnan vaikutuksia vedenalaiseen makrokasvillisuuteen matalissa lahdissa, ja kehittää parempia välineitä lahtien ympäristöarvioinnin tueksi.

Tutkimuksen tulokset osoittivat, että herkkien lajien osuus väheni fosforin määrän ja veneliikenteen lisääntyessä. Lisäksi havaittiin, että makrokasvillisuuden peittävyysprosentti oli alhaisempi vilkkaasti liikennöidyillä lahdilla. Luonnollisilla ympäristömuuttujilla havaittiin olevan suuri merkitys kasvillisuusyhteisöjen lajivaihtelun selittämisessä. Suuri osa vaihtelusta jäi kuitenkin selittämättä testatuilla malleilla, minkä vuoksi lisätutkimusta asiasta tarvitaan.

Tutkimustulosten perusteella kehitettiin ekologisen tilan luokitteluun soveltuva malli, joka perustuu makrokasvillisuuden peittävyysprosentteihin painottaen herkkien ja sietokyvyltään kilpailukykyisempien lajien osuuksia sekä koko lajiston yhteispeittävyyttä. Nämä parametrit kuvaavat alueen ekologista tilaa ilmaistuna suhteessa vertailutasoon, joka määräytyi ekologisen laadun arvioimiseen käytetyistä kynnysarvoista. Tuloksissa määritetyt vesipuitedirektiivin vesialueita koskevat luokitukset vastasivat osittain aiemmilla, vakiintuneilla menetelmillä tuotettuja luokituksia. Tässä tutkimuksessa esitettyä mallia voidaan käyttää myös syvempien vesialueiden arvottamiseen jo käytössä olevien menetelmien tukena. Ennen kuin mallia voidaan varauksetta soveltaa käytäntöön, pitää sitä kuitenkin kehittää pidemmälle ja testata riippumattomilla aineistoilla.

1 Introduction

Shallow wave-protected inlets with soft-sediment bottoms are common environments along the Swedish and Finnish Baltic Sea coastlines. This coastal biotope is naturally nutrient-rich because of hydrological conditions resulting in a large influence of run-off from land and accumulation of organic matter from the sea. Shallow and wave-protected waters, in combination with high water retention time, lead to rapid warming of the water volume during spring compared to more open coastal environments. These features generate a productive environment (Wijnbladh et al. 2006) with a rich plant community (Munsterhjelm 1997). The characteristics of the biotope also make it suitable for reproduction of many coastal fish species (Karås and Hudd 1993; Karås 1999) and as a breeding site for waterfowl.

Until the last two decades, research and monitoring in the Baltic Sea had largely overlooked shallow sheltered soft-bottom inlets, focusing on more open coastal biotopes. Swedish and Finnish monitoring of macrovegetation has, for example, concentrated on macroalgae on hard bottoms (Kautsky 1991; Kautsky 1993; Kautsky 1995; Bäck et al. 2002; Rinne et al. 2011). Monitoring and research efforts have also been allocated to macroinvertebrates in deeper soft-bottom areas (Elmgren and Cederwall 1979; Bonsdorff and Blomqvist 1992; Perus et al. 2007; Josefson et al. 2009). Studies on vegetated soft bottoms have largely been limited to the seagrass *Zostera marina* (Lappalainen et al. 1977; Boström and Bonsdorff 1997; Baden and Boström 2001; Boström et al. 2002; Krause-Jensen et al. 2005; Boström et al. 2006), while the common and widely distributed mixed vegetation communities dominated by Potamogetonaceae, *Myriophyllum* spp., *Najas marina*, and Charophyceae have received less attention.

Since implementation of the European Union (EU) Habitats Directive (Council Directive 92/43/EEC), the shallow, sheltered inlets of the Baltic have received much more attention, and in the Interpretation Manual of European Union Habitats (Anon 2003a), the inlets are categorised as a type of habitat prioritised for conservation. In the initial surveys for the Habitats Directive, hundreds of inlets were examined for macrovegetation by local authorities (habitats 1150, 'coastal lagoons' and 1160, 'large shallow inlets and bays'). Additional research has been conducted relating to the ecology of the inlets, focusing on macrophytes (Eriksson et al. 2004; Appelgren and Mattila 2005; Rosqvist 2010), fish (Sandström et al. 2005; Snickars et al. 2005; Snickars 2008; Snickars et al. 2009; Snickars et al. 2010), macroinvertebrates (Hansen et al. 2008b; Hansen 2010), zooplankton (Scheinin and Mattila 2010), and the food web (Hansen et al. 2012). The increased research efforts have resulted in enhanced knowledge of the ecology of shallow inlets, where the flora and fauna communities responds strongly to natural environmental gradients.

The degree of isolation from the sea has been identified as one of the most important factors explaining the composition of organisms in the inlets. Both the macrophyte community and the macroinvertebrate community change from a diverse mixture of marine and freshwater species with high total biomass in open inlets, to communities with larger proportions of a few freshwater taxa with lower total biomass in isolated bays (Hansen et al. 2008b; Hansen et al. 2012). In contrast, the abundance of zooplankton and juvenile fish increases with increasing isolation of the bays (Snickars et al. 2009; Scheinin and Mattila 2010; Hansen et al. 2012). The species composition of fish changes from a mixture of marine and freshwater species to an increased proportion of warm-water-spawning freshwater species. The degree of isolation of the inlets changes slowly over time, due to sedimentation and isostatic land uplift in the northern Baltic region. Factors related to latitude (e.g. salinity and temperature), as well as wave exposure, are also important features that affect the communities. In Swedish coastal waters, the proportion of ditch grasses (*Ruppia* spp.) is higher in the south, while some freshwater macrophytes, such as *Myriophyllum sibiricum* and *Potamogeton pusillus*, increase in abundance at higher latitudes (Hansen et al. 2008a). Increased wave exposure has a positive effect on the abundance of filamentous ephemeral algae in the Baltic Sea inlets (Hansen et al. 2008a).

A few studies have analysed effects of anthropogenic influences on the macrophyte vegetation in the shallow Baltic Sea inlets. Dahlgren and Kautsky (2004) reported lower cover of rooted macrovegetation in inlets with high concentrations of phosphorus, and general alterations in the composition of vegetation over the last decades have also been attributed to nutrient enrichment and eutrophication (Blindow 2000; Schubert and Blindow 2003; Munsterhjelm 2005). In addition, boating activities and ferry traffic have been reported to alter the species composition of macrophytes in the inlets, due to local alterations in hydrology and sedimentation, and direct mechanical impact on the plants (Eriksson et al. 2004; Henricson et al. 2006). Eriksson et al. (2004) reported reduced cover and reduced numbers of macrophyte species in inlets used as marinas or located adjacent to ferry routes. Boating activities have also been found to affect juvenile fish in the inlets, with a negative effect on species closely associated with vegetated habitats (e.g. the Eurasian pike *Esox lucius*; Fig. 1).

Figure 1. Boating activities have been found to affect fish communities in shallow inlets, with negative effects on species such as the Eurasian pike (*Esox lucius*).

Changed community composition and changed ecology of the inlets have also been suggested to be a consequence of overfishing of offshore fish populations, such as cod (*Gadus morhua*), resulting in a complex cascade at several trophic levels, with increased abundance of invertebrate-feeding fish (such as the stickleback *Gasterosteus aculeatus*), changed invertebrate composition, and reduced abundance of some herbivores—and hence increased abundance of ephemeral algae (Eriksson et al. 2009; Eriksson et al. 2011; Sieben et al. 2011). Blooms of ephemeral algae can in turn affect the composition of coarsely structured perennial plants by competing for light and nutrients, as is the case in other coastal waters (Duarte 1995; Fletcher 1996; Hemminga and Duarte 2000; Jaschinski and Sommer 2008).

The EU Water Framework Directive (WFD, Directive 2000/60/EC) has a general objective that all European waters should attain “good ecological status” by 2015. For coastal waters, there are three required “biological quality elements” (BQEs) that should be used to assess ecological status: 1) phytoplankton, 2) benthic macroinvertebrates, and 3) macrovegetation. Macrovegetation is a promising biological element for environmental quality assessment. As most of these species are stationary (i.e. rooted in or attached to the bottom), and several are long-lived and persist over many years, their community structure integrates the environmental conditions over a long period of time. Hence, studies of macrovegetation add information to environmental monitoring as a complement to studies of chemical water properties and plankton, which change over much shorter periods of time. It has been shown that some species, often referred to as opportunists, are more tolerant to anthropogenic influences such as eutrophication, whereas other species are found less frequently in polluted areas. In the eutrophication process, slow-growing and perennial plant species decrease, while fast-growing, mainly annual algal species, but also some angiosperms, increase. It is commonly assumed that macrophyte species that are capable of concentrating much of their photoreceptive biomass near the surface are more able to compete for light with e.g. fast-growing algae, in eutrophic conditions (e.g., Barko and Smart 1981; Boston et al. 1989; Duarte and Roff 1991). High surface area to volume ratio through thin and/or dissected leaves is common in plants that can adapt to low light conditions (Sculthorpe 1967), and this growth form is also beneficial for efficient and competitive uptake of carbon and nutrients in the water (Boston et al. 1989). In European lakes, for example, many slow-growing small species, such as isoetids, water mosses, and characeans have decreased in abundance with increased phosphorus concentration, while many fast-growing tall, often delicately branched, species have increased (Blindow 1992; Penning et al. 2008b; Sand-Jensen et al. 2008). This relationship is, however, only valid for high-alkalinity lakes, as many of the more tolerant species require alkalinities above a certain threshold level (Penning et al. 2008b). In the brackish (and alkaline) Baltic Sea, charophytes have generally declined during the last half of the twentieth century (Blindow 2000), and in some areas they have been replaced by tall fast-growing angiosperms such as *Myriophyllum spicatum*, *Ceratophyllum demersum*, and *Potamogeton pectinatus* (Munsterhjelm 2005). Thus, the benthic species composition and abundance change along gradients of anthropogenic influence, and the community structure can be a strong diagnostic tool for assessment of environmental quality.

The current assessment methods based on macrovegetation for coastal waters in Sweden and Finland are mainly aimed at hard-bottom biotopes and function poorly for shallow soft bottoms (Bäck et al. 2002; Kautsky et al. 2004; Anon 2007b; Anon 2008; Vuori et al. 2010). The methods mainly use depth limitations of macrovegetation for the assessments, and they are not well developed for shallow areas since these do not allow an assessment based on depth limitations—as in the deeper vegetated areas. Thus, there is a need for development of an assessment system for the shallow inlets, which can either be single water areas or part of larger water areas in the WFD.

The first aim of this study was to analyse effects of human activities on submerged macrovegetation in shallow sheltered inlets along the Swedish and Finnish Baltic Sea coasts, using data from different sources to get a large spatial coverage. Based on previous studies, species regarded as being sensitive to human activities were hypothesised to decrease in abundance with increasing anthropogenic influence on inlets. The second aim was to develop a method for assessment of the environmental status of the inlets based on the macrovegetation. The intention was to design an assessment method that is usable both at local inlet level and at a larger water-area level in the WFD. In addition, year-to-year variation in the macrovegetation was also analysed to evaluate the performance of the assessment method over several years.

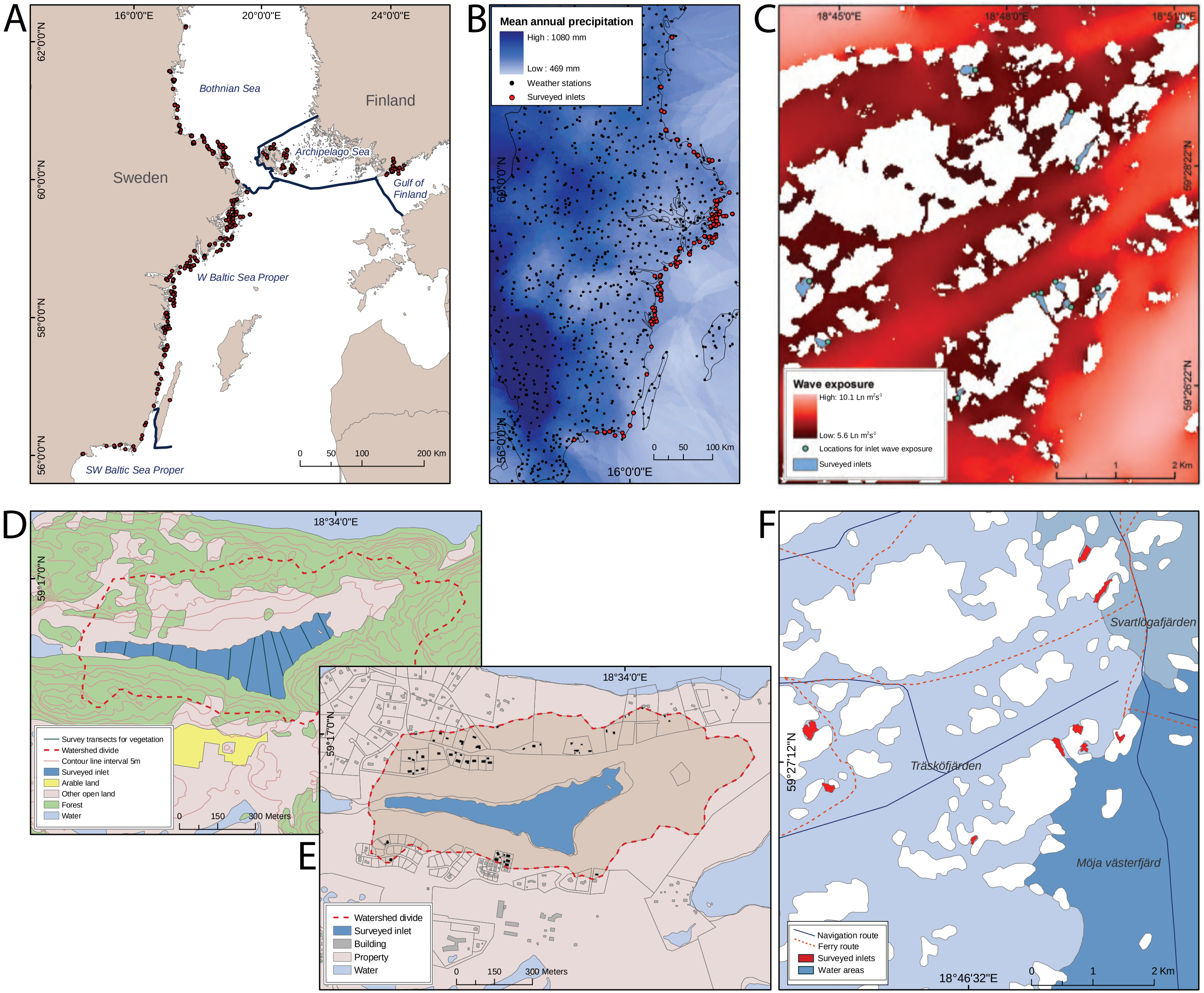
2 Methods

2.1 Vegetation data

I used data from several vegetation surveys of small shallow Baltic Sea inlets ($\bar{x}$ ± SD; 1.2 ± 0.6 m depth and 5.6 ± 0.1 ha surface area). The surveys were conducted during different projects from 2001 to 2010 by the County Administrative Boards of Sweden, the Uppland Foundation, the Swedish Board of Fisheries, the Government of Åland, Åbo Akademi University, and Stockholm University. All projects used a similar survey method and I combined the data into one dataset. Data were excluded if the method deviated from the one described below. The final dataset included 350 inlets (Fig. 2A and Appendix 1). The survey method that was used was the method for vegetation surveys of the EU Natura 2000 habitats ‘lagoons’ and ‘large shallow inlets and bays’ in Sweden (Persson and Johansson 2007), which is similar to the method used in Finland (e.g. Snickars et al. 2009; Rosqvist et al. 2010). Percentage cover of coarsely structured aquatic macrophytes was surveyed by a free diver along parallel transect lines that extended perpendicular to the length axis of the inlets (Fig. 2D). The number of transect lines depended on the surface areas of the inlets, with a minimum of three transects. The first transect line was located 10 m from the innermost shore (outside reed belts, if present) and the other transect lines were located 50–200 m apart (depending on inlet area) until the entire inlet was surveyed. A final transect line was (in most cases) located across the opening(s) of the inlet.

The percentage cover of coarsely structured macrophytes was estimated visually every 10 m along the transect lines within a 0.5 × 0.5-m square (Fig. 3). If a transect was more than 120 m, estimates in sample squares were done every twentieth meter when the distance to the shore was more than 50 m.

Figure 2. A. Map of the central Baltic Sea with divisions into regions, and with all 350 surveyed inlets shown with solid red circles. **B.** Locations of weather stations, interpolated mean annual precipitation, and 139 of the surveyed inlets selected for detailed environmental analysis (dataset A). **C.** Example of modelled wave exposure with locations of wave-exposure estimates for a few surveyed inlets. **D.** Topographic and land-use map, and **E.** property map for one of the surveyed inlets. **F.** Example of navigation and ferry routes adjacent to a few surveyed inlets. This map also shows divisions of water areas according to divisions in the WFD.



The estimations of cover differed between Sweden and Finland. In Sweden, a continuous percentage scale was used individually for each taxon, meaning that the total cover could exceed 100% if the macrophytes overlapped. In Finland, cover of each taxon was estimated as a continuous fraction of a maximum cover of 100%. The Finnish and Swedish data were therefore analysed separately.

Abundance of ephemeral, mainly epiphytic filamentous, algae was estimated using a 5-point scale. As the criteria for this scale differed slightly between surveys, I used the percentage of squares in an inlet with a high abundance of epiphytes (grades 4 and 5) in the present study. Data on epiphytes were not available for 23% of the inlets. Depth at the position of each square was measured to the nearest 0.1 m and used for calculations of mean and maximum inlet depth (after adjustment in relation to mean seawater level; Appendix 1).

Figure 3. Percentage cover and species composition of macrophytes was estimated visually by a free diver using a 0.5 × 0.5-m survey square.

In addition, vegetation between the squares was estimated using a 5-point scale for each taxon. These estimates between squares were not recorded or available for all the inlets that were surveyed. As the observations between squares covered a much larger area than the square observations, the data were used to examine the accuracy of species richness in the square data. There was a clear correlation between the number of species found (per inlet) in the squares and the number of species found between squares (Fig. 4). A list of all macrophyte species in the data is given in Appendix 2.

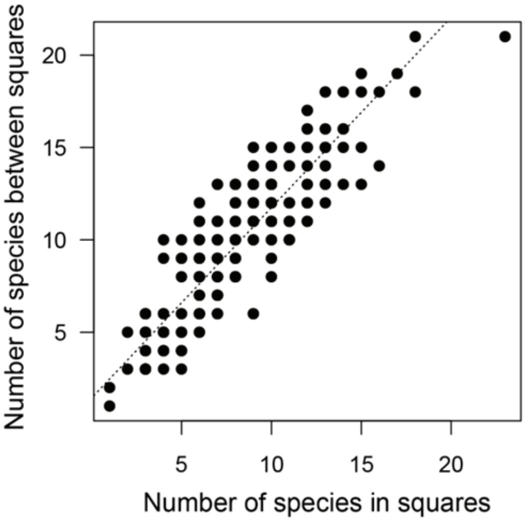


Figure 4. Correlation between the number of species recorded (per inlet) between survey squares and the number of species recorded in the squares (r = 0.89, *t* = 31.7, *p* < 0.001, *df* = 263).

Of the 350 inlets included in the study, 67 had been surveyed for vegetation for more than one year, and 43 had been surveyed for three years or more. For analysis, an average cover over the years was calculated for each macrophyte species in each inlet and for all species combined in each inlet. To examine inter-annual variation, an average cover for each year was calculated for inlets that had been surveyed for three years or more.

To develop and test a univariate response for bio-assessment, and to analyse effects of human-induced pressures on the vegetation, a macrophyte index (MI) was applied. The index is based on a classification of species as being either sensitive or tolerant to anthropogenic pressures. The equation has previously been applied to European lakes (Penning et al. 2008a) and streams (Fabris et al. 2009). In the index, the number or abundance of tolerant species in an inlet is subtracted from the number or abundance of sensitive species, and the result is divided by the number or abundance of all species, including indifferent species. The index can be computed either by using species counts (presence/absence, Eq. 1) or abundance (Eq. 2):

$$\mathrm{MI_c} = \frac{N_S - N_T}{N} \times 100 \qquad \text{(Eq. 1)}$$

$$\mathrm{MI_a} = \frac{\sum_{i=1}^{N_S} A_i - \sum_{j=1}^{N_T} A_j}{\sum_{k=1}^{N} A_k} \times 100 \qquad \text{(Eq. 2)}$$

where N_S is the number of sensitive species recorded in an inlet, N_T is the number of tolerant species, and N is the total number of species (including indifferent species), and A is a measure of abundance—in this study, mean cover in inlets. Both versions of the index produce values from -100 (all species tolerant) to +100 (all species sensitive). Species were classified as sensitive or tolerant (Table 1, Fig. 5) using published studies from the Baltic Sea Proper and the Gulf of Finland. Species were classified as being sensitive if the previous studies had found negative effects of nutrient enrichment, marinas, or ferry traffic (regardless of the level of effect). Similarly, species were classified as being tolerant if the previous studies had found positive effects of nutrient enrichment, marinas, or ferry traffic (regardless of the level of effect). When response of the species differed depending on pressure, it was not classified (which was the case for *Fucus vesiculosus*, *Najas marina*, *Potamogeton pectinatus*, and *Ruppia maritima*). The classification partly coincides with results from inner coastal waters along the German Baltic Sea coast (Selig et al. 2007).

Table 1. List of Baltic Sea inlet macrophytes that have been examined in relation to nutrient enrichment and boating activities. A plus-sign (+) denotes a positive relationship and a minus sign (–) denotes a negative relationship. The last column indicates the classification used in the macrophyte index presented in Eq. 1 and Eq. 2. Epiphytic ephemeral algae are not included, as they were not identified to taxa in surveys of the inlets.

Species	**Response to nutrient enrichment[1]**	**Response to marinas[2]**	**Response to ferry traffic[2]**	**Classification in macrophyte index**
Chorda filum	–	–		Sensitive
Fucus vesiculosus	–		+	
Chaetomorpha linum	+			Tolerant
Monostroma balticum	+			Tolerant
Chara aspera	–[3]	–		Sensitive
*Chara baltica/horrida/liljebladii**	–			Sensitive
Chara canescens	–	–		Sensitive
*Chara connivens***				Sensitive
Chara globularis	–			Sensitive
Chara tomentosa	–	–[4]	–[4]	Sensitive
*Chara virgata***				Sensitive
Tolypella nidifica	–			Sensitive
Callitriche hermaphroditica	+			Tolerant
Ceratophyllum demersum	+	+		Tolerant
Myriophyllum spicatum	+	+		Tolerant
Najas marina	+		–	
Potamogeton pectinatus	+	–		
Potamogeton perfoliatus	+		+	Tolerant
Potamogeton pusillus	+			Tolerant
Ranunculus circinatus	+			Tolerant
Ranunculus peltatus	+			Tolerant
Ruppia cirrhosa	–	–		Sensitive
Ruppia maritima	+	–		
Zostera marina	–			Sensitive

[1] Wallentinus 1979.
[2] Eriksson et al. 2004.
[3] Blindow and Schütte 2007.
[4] Henricson et al. 2006.

*Treated as one taxon since genetics of the species are uncertain (Boegle et al. 2010).

**Assumed to respond as *Chara globularis* due to very similar morphology and corresponding habitat requirements (Schubert and Blindow 2003). *Chara virgata* has frequently been considered to be a variant of *C. globularis*.

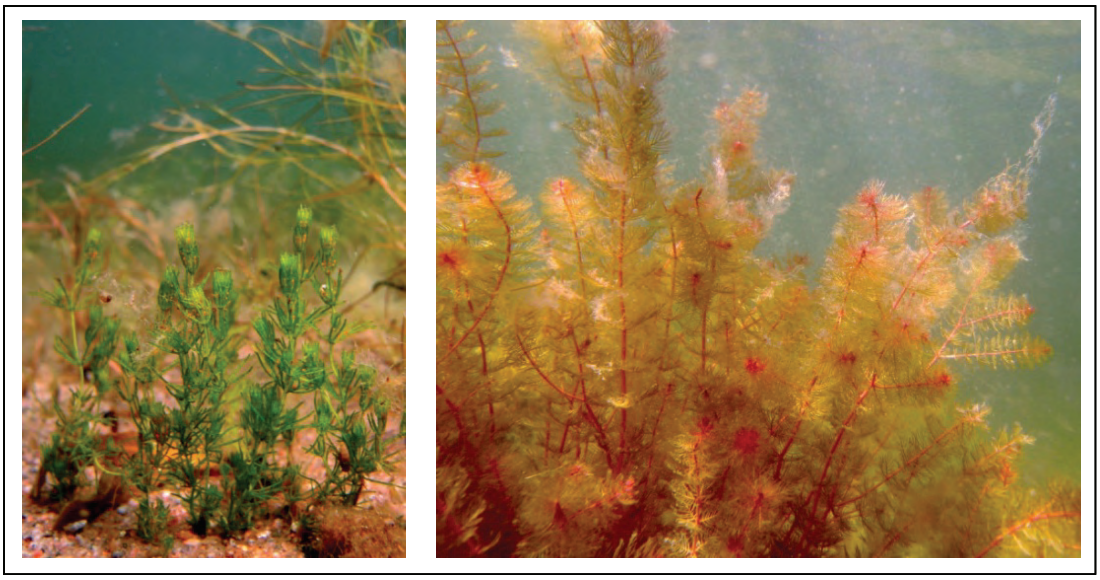


Figure 5. Stoneworts (*Chara* spp., to the left) are sensitive to anthropogenic influences, while water milfoil (*Myriophyllum spicatum*, to the right) is more tolerant. A ratio based on sensitive and tolerant species was used to construct an index for the purpose of assessing the effects of human activities.

2.2 Environmental data

Concurrent with the vegetation surveys, environmental variables were recorded for several inlets. The environmental variables recorded were salinity, turbidity, substrate, and total phosphorus and nitrogen concentrations. However, many inlets had no such records. Sixty-seven per cent (67%) of the inlets had records of salinity. Data were mainly absent from the southern Swedish coast. Records of the other environmental variables were scarcer. Data on nutrient concentrations were only available for 20% of the inlets, mainly from Finland. There was very little detailed information about substrates. These inlets have predominantly soft-sediment bottoms, but hard substrates also occur. Systematic records of environmental pressures due to human activities were not available for most inlets. Thus, I made a remote survey of human pressures and natural environmental variables using satellite images and digital cartographic information (Table 2).

The survey included residential buildings in the (approximate) watershed, number of berth places in inlets, signs of dredging, whether an inlet was officially recognised as a nature harbour, and also distances to wastewater treatment plants, aquaculture, industries, ferry traffic, and navigation routes (Fig. 2F). An ordinal scale with three levels was used to classify each inlet according to anthropogenic pollution and pressure from boating activity (Table 3).

Ferry traffic included large freight, cargo and passenger ferries to the major harbours in the study area, road ferries, and archipelago passenger traffic by medium sized ferries. For archipelago and tourist traffic, only those with two or more routes per week (during summer) were included. The routes identified were compared with data produced by the automatic information system (AIS) for marine vessels published by the Swedish Environmental Protection Agency (Törnqvist and Engdahl 2010) and by the Helsinki Commission (HELCOM) map and data service (2011). The routes identified corresponded with a high intensity of the AIS traffic. Inlets were considered protected from boat-mediated waves if no straight unbroken line could be drawn to the ferry or navigation route (due to protection from islands and capes). Boat-mediated currents were not taken into consideration.

Table 2. Sources of information used in remote survey to classify the 350 inlets according to selected features.

Feature	Source of information
Residential buildings in watersheds	Satellite images in Google Earth (version 6.0.3.2197) and the land-use and property map published by the Swedish mapping, cadastral, and land registration authority (Lantmäteriet, fastighetskartan) or the topographic map published by the Finnish authority (Lantmäteriverket, terrängkartan).
Wastewater treatment plants	The Swedish Meteorological and Hydrological Institute's (SMHI) web portal Home Water (2011) and the Helsinki Commission (HELCOM) map and data service at HELCOM's web portal (2011).
Aquaculture	Swedish aquaculture register (Vattenbruksregistret, file supplemented with Törnqvist and Engdahl 2010) and HELCOM map and data service at HELCOM's web portal (2011).
Industries	Satellite images in Google Earth and information from companies published on the internet (only industries with potential discharge to surrounding waters were included).
Berth places and jetties	Satellite images in Google Earth and files supplemented with Törnqvist and Engdahl (2010). Harmonised with field observations when available.
Ferry traffic	Timetables and maps from organisations and companies operating the traffic routes, or maps from harbour authorities.
Navigation routes	Garmin BlueChart® g2, The Nordics (HXEU800X; version 12.00).
Dredging	Notes from field observations and satellite images in Google Earth.
Nature harbours	Améen and Hansson 2001, Ajanko 2004a, 2004b, Karlsson 2004, 2010, Leek 2007, Granath et al. 2009, 2010, and files supplemented with Törnqvist and Engdahl 2010.
Inlet type	Flad-types were identified using definitions of Munsterhjelm (1997). EU Natura 2000 habitats were identified using definitions in Anon 2003b, 2009 and Johansson and Persson 2010.
Freshwater outflows	Land use, property, and topographical maps, as well as satellite images in Google Earth.

Table 3. Levels of the ordinal scale used in the remote survey of human pressure on the 350 inlets included in the study.

Levels	**Anthropogenic pollution index** (mainly nutrient enrichment)	Boating activity pressure index
1. Very low	> 5 000 m from wastewater treatment plants, > 2 000 m from aquaculture, ≤ 2 residential buildings in watershed, no arable land in watershed, and > 5 000 m from industries.	< 2 berth places/inlet ha, no nature harbour, no signs of dredging, and > 2 000 m from boating route or ferry traffic.
2. Low	> 1 000 but ≤ 5 000 m from wastewater treatment plants, and/or < 10 but > 2 residential buildings in watershed, and/or > 500 but ≤ 2 000 m from aquaculture, and/or arable land is < 50% but > 0% of watershed, and/or > 1 000 but ≤ 5 000 m from industries.	< 5 but ≥ 2 berth places/inlet ha, and/or nature harbours, and/or clear signs of dredging, and/or > 700 but ≤ 2 000 m from ferry traffic, and/or ≤ 2 000 m from boating route.
3. High	≤ 1 000 m from wastewater treatment plants, and/or ≤ 500 m from aquaculture, and/or ≥ 10 residential buildings in watershed, and/or ≥ 50% of watershed is arable land, and/or ≤ 1 000 m from industries.	≥ 5 berth places/inlet ha (marinas, often with clear signs of dredging), and/or ≤ 700 m from ferry traffic.

Potentially high levels of pressure from ferry traffic on inlets (Table 2) were set at a distance of ≤ 700 m between the opening of the inlet and the centre of the traffic route. This number is based on previous studies on the effects of ferry traffic on shore erosion and aquatic vegetation in shallow inlets in the Stockholm archipelago, identifying effects within 500 m (Eriksson et al. 2004; Lindfors 2010, A. Sandström pers. comm.). Since I measured distance to a central traffic line and the route tracks can be hundreds of meters wide, a 700-m limit was used.

In addition to the survey of human activities, inlet type was identified (i.e. level of bay isolation), and wave exposure was estimated using a wave model (described below). Inlet type was identified by studying digital maps, satellite images, and data on depth of the inlets. The inlet types were categorised as either: 1) gloes and glo-flads, 2) flads and juvenile flads, or 3) open inlets (Munsterhjelm 1997; Anon 2009; Johansson and Persson 2010). Freshwater outflows (rivers, streams, and ditches) were also recorded, but were not included in the analysis as the record did not show any relationship with the available salinity measurements. None of the inlets were located in close proximity to major river outflows.

For a selection of Swedish inlets, a more detailed survey was conducted. All inlets surveyed during three years with a high survey intensity (2001, 2007 and 2008) were selected (139 inlets, Fig. 2B), hereafter referred to as 'dataset A'. For these inlets, topographic openness was calculated and a model was used to estimate total phosphorus concentration (described later).

2.2.1 Wave exposure

Wave exposure was estimated using a simplified wave model (SWM; Isæus 2004; Isæus and Rygg 2005; Wennberg and Lindblad 2006), which calculates the wave impact from fetch and wind data in 25 × 25-m grids using digital nautical charts and GIS methods (Fig. 2C). Fetch is an estimate of the distance over which waves can potentially collect wind energy before reaching a site. The wind speeds used in the model were the mean wind speeds measured at local meteorological stations in the Baltic Sea. Values representing the wave exposure at the inlet opening(s) were calculated as the mean exposure of a 50 × 50-m grid to avoid large influence of extreme values at the smaller grid size. For inlets with an opening of < 50 m, values were obtained just outside the opening, and for inlets with several openings the highest values of wave exposure were chosen. Wave exposure inside inlets was not used, as the bathymetric information is of much lower quality at such a scale and results in poor estimates. The SWM has been shown to provide useful wave-exposure estimates in several studies (e.g. Eriksson et al. 2004; Sandström et al. 2005; Snickars et al. 2009), and apart from the hydrological movements and forces created by waves, it functions as a proxy for factors such as water temperature, particle sedimentation, and to some degree also for salinity (Fig. 6).

2.2.2 Topographic openness

Topographic openness (E_a) of the inlets (i.e. degree of isolation from the sea) was calculated as:

$$E_a = 100 \times \frac{A_t}{a} \qquad (Eq.3)$$

where A_t is the smallest cross-sectional area of an inlet opening, and a is the water surface area of the inlet (Persson et al. 1994; Håkansson 2008). The cross-sectional area, A_t, was calculated from depth and distance measurements in the field, or from satellite images and navigational charts in cases where field observations of inlet openings were lacking. Water surface area, a, was identified using the Swedish land-use and property map in ArcGIS 9 (ESRI, Redlands, CA). The shoreline was adjusted for dense reed and grass areas observed on satellite images in Google Earth. The opening mouth(s) of inlets were drawn at the opening transect(s), or if this information was missing, the mouth opening was placed where the smallest cross-sectional area could be identified by satellite images in Google Earth. The topographic openness functions as a predictor of surface-water retention time (Håkansson 2008), which affects factors such as water temperature and particle sedimentation. Mean salinity in the inlets also correlates with the topographic openness, apart from latitude (Fig. 6), although variation in salinity seems to increase with reduced topographic openness due to a larger influence of precipitation and evaporation (Hansen et al. 2008b; Hansen et al. 2012).

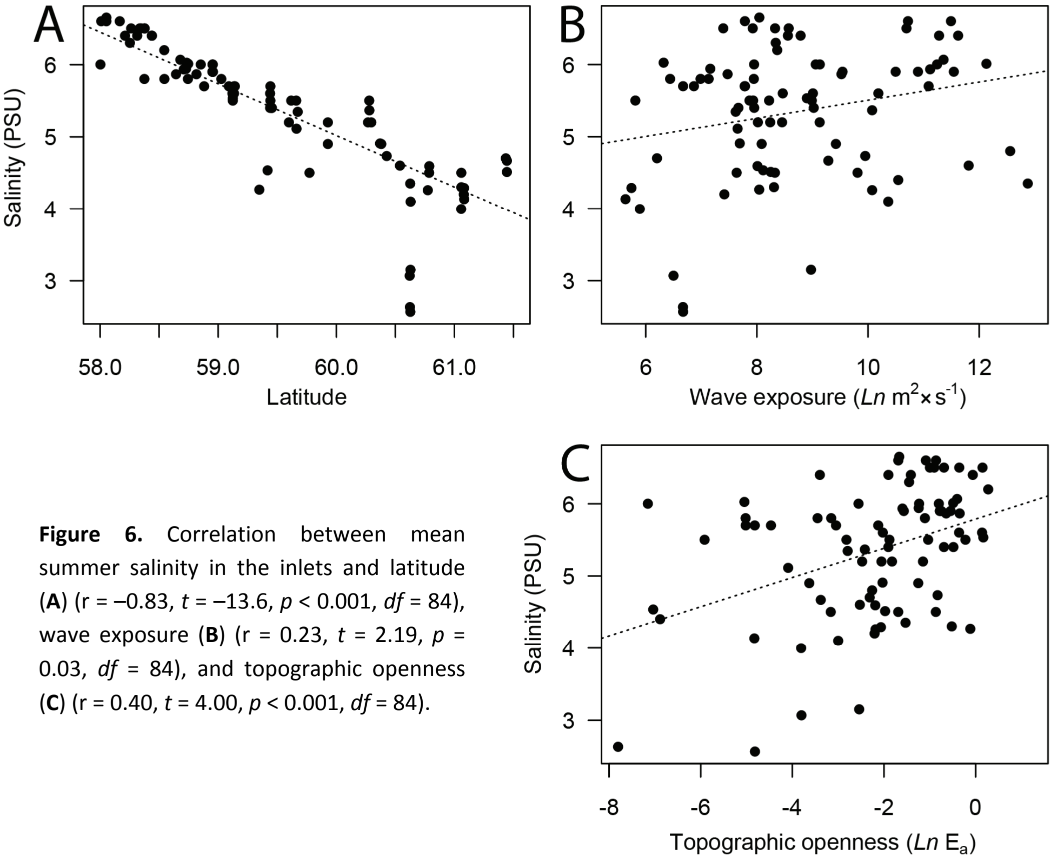


Figure 6. Correlation between mean summer salinity in the inlets and latitude (**A**) (r = –0.83, *t* = –13.6, *p* < 0.001, *df* = 84), wave exposure (**B**) (r = 0.23, *t* = 2.19, *p* = 0.03, *df* = 84), and topographic openness (**C**) (r = 0.40, *t* = 4.00, *p* < 0.001, *df* = 84).

2.2.3 Nutrient model

To calculate the approximate total phosphorus concentration (TP) for inlets in 'dataset A', a nutrient model was used (Smaaland 2004; Isæus et al. 2005). The model uses topographic parameters of the inlets (mean depth, area, and topographic openness), precipitation, estimated annual total phosphorus load, and TP of the adjacent water outside the inlets, to calculate the annual mean TP. The total phosphorus load estimates were based on land use, households' wastewater treatment, keeping of livestock in the watershed, and mean annual precipitation, following relationships presented in Wennerblom and Kvarnäs (1996), with modifications for households' wastewater according to Ek et al. (2011). Households connected to municipal wastewater treatment facilities were not included in the analysis since all of the selected inlets were located more than 1 km from wastewater treatment plants.

Watershed of inlets was identified by using topographic 5-m altitude vectors (Fig. 2D). In cases where such identification was difficult, watersheds were identified by applying the function 'Hydrology' in Spatial Analysist (Arc GIS 9), after altitude vectors had been converted to points and interpolated to a 5-m grid. The watersheds were compared with larger watershed areas published by the Swedish Meteorological and Hydrological Institute (SMHI) to assure accurate identification. Mean annual precipitation was achieved from records of 1 016 weather stations in the region studied, distributed via internet by SMHI (2011a). These data were used to interpolate precipitation for the whole study area at an approximate 2-km grid to obtain values for location of the inlets (Fig. 2B).

Total phosphorus concentration in adjacent waters outside the inlets was obtained from a model provided by SMHI—'Home Water' (2011b). The model has been developed for water quality estimates in lakes, watercourses, and coastal waters in Sweden. It produces data on a water-area level for the WFD (Marmefelt et al. 1999; Marmefelt et al. 2000; Marmefelt et al. 2007;

Sahlberg et al. 2008). The model has been validated against available field measures for most of the Swedish coastal areas, and shows a good correlation (Marmefelt et al. 2007). The model does not, however, produce values at the individual inlet level.

Areas of different land use in the watersheds were obtained from a land-use and property map published by the Swedish mapping, cadastral, and land registration authority (Lantmäteriet). The land-use categories used in the model were forest, arable land, other open land, and water. Data on residential buildings, whether there were permanent or occasional residents, and also the form of wastewater treatment (municipal, private, or none) were obtained from the Swedish property register (Fastighetsregistret 2011), held by the same authority (Lantmäteriet). Records of keeping of livestock were obtained from the Swedish registers on cattle and agricultural facilities held by the Swedish Board of Agriculture (Jordbruksverket, Nötkreatursregistret and Anläggningsregistret 2011). These registers hold records on dairy and beef cattle, calves, hogs, sheep, lamb, and poultry. Unfortunately, there is no national record of horses available. Data on livestock in the watersheds were obtained with 100-m tolerance, as the locations of the livestock units were approximate.

The estimated TP obtained by the nutrient model correlated well with the few available field measurements for the inlets selected (Fig. 7).

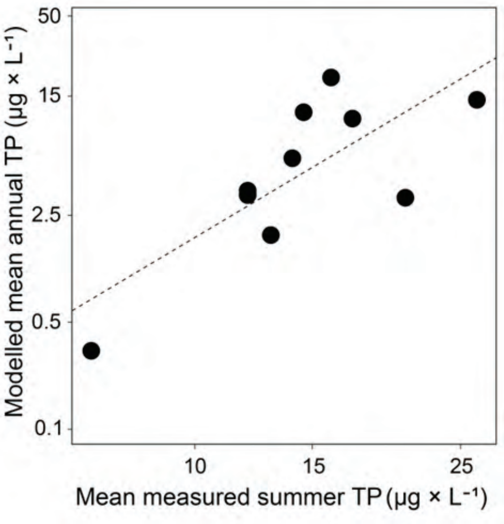


Figure 7. Correlation between modelled annual total phosphorus concentration (TP) and the few available measurements of total phosphorus concentration for the selected inlets (mean values during summer; $r = 0.77$, $t = 3.37$, $p < 0.01$, $df = 8$). Note the logarithmic scale on both axes.

2.3 Statistics

Data for Sweden and Finland were analysed separately (Table 4). The reason for this was twofold. Firstly, the methods for vegetation surveys differed between the two countries. Secondly, the Swedish data were used for model building, and the Finnish data were used to confirm results of analysis of the Swedish data.

The Swedish data were further analysed as two separate datasets. The first, 'dataset A' (Table 4), consisted of 139 inlets with detailed data on topographic openness and modelled TP (as described earlier). This dataset was used to analyse response of the macrophyte community to a gradient in TP. Of the 139 inlets, 26 lacked data on abundance of epiphytes, and were excluded from the analyses. In addition, one inlet was excluded because of an outlying high TP, resulting in 112 inlets being analysed. The second dataset consisted of all inlets in the western Baltic Sea Proper (Fig. 2A), and was used to test for effects of both anthropogenic pollution and boating activity (167 inlets), which is hereafter referred to as 'dataset B' (Table 4). The effect of boating activities was only tested in this region (i.e. the western Baltic Sea Proper) since the number of inlets with high boating activity was low in the other regions, especially for more topographically isolated inlets.

Inter-annual variation was examined in 41 inlets that had been sampled for three years or more (2 of 43 inlets were omitted; see Table 4). For these analyses, data from both countries were merged, since a standardisation method was applied (as described later).

All statistical tests were performed with the software R, version 2.14.1 (R Development Core Team 2011). Only true aquatic macrophytes were used for the analyses. Helophytes (i.e. emergent aquatic plants) such as *Phragmites australis*, *Typha angustifolia*, and *Juncus gerardii* were excluded as the survey method was not designed to adequately sample these species. *Eleocharis* spp. (mainly *E. parvula*) and *Hippuris vulgaris* were, however, included in the data, as these species have mainly been observed as submerged plants in the surveyed inlets (pers. obs. and pers. comm. with field workers).

2.3.1 Swedish data

Structural equation models (SEMs) (Wright 1934; Mitchell 1992; Fox 2006; Grace 2006; ‘sem’ package, Fox and Byrnes 2011) and path analyses were used to investigate the hierarchical relationship between latitude, wave exposure, topographic openness, TP, abundance of epiphytic algae, and the univariate measures of the macrophyte community in ‘dataset A’ (Table 4). In SEMs, as opposed to multiple regressions, variables can be both responses and predictors in the same model. By applying SEM instead of multiple regression, I could examine the effects of several possibly hierarchically ordered environmental variables, and differentiate the direct effects of TP on the macrophyte community from possible indirect effects caused by changed abundance of epiphytes. The full model was based on a conceptual framework, but included only those variables that were available for this dataset (Fig. 8A).

Table 4. Details of the datasets analysed. Swedish and Finnish data were analysed separately. The Swedish data were further analysed as two separate datasets. Inter-annual variation was examined on a different dataset with inlets that had been surveyed for three years or more (from both Sweden and Finland). Numbers in parentheses refer to number of inlets in the final analyses. See text for more details. Abbreviations: SWBSP, southwestern Baltic Sea Proper; WBSP, western Baltic Sea Proper; BS, Bothnian Sea; AS, Archipelago Sea; GF, Gulf of Finland; SEM, structural equation model; CCA, canonical correspondence analysis.

Dataset	**Region**	**Number of inlets**	**Macrophyte response variables** (*transformation*)	**Predictor variables** (*transformation*)	**Statistical test**
Swedish data					
Dataset A	SWBSP WBSP BS	139 (112)	**Univariate:** Cover of all species Number of species (*sqrt*) Macrophyte index based on abundance, $\mathrm{MI_a}$ Macrophyte index based on counts, $\mathrm{MI_c}$	Latitude Wave exposure (*ln*) Topographic openness (*ln*) Total phosphorus concentration (*ln*) Epiphyte abundance (*ln*)	SEM
			Multivariate: Cover of species (*sqrt*)	Latitude Wave exposure (*ln*) Topographic openness (*ln*) Total phosphorus concentration (*ln*)	CCA
Dataset B	WBSP	167	**Univariate:** Cover of all species Number of species (*sqrt*) Macrophyte index based on abundance, $\mathrm{MI_a}$ Macrophyte index based on counts, $\mathrm{MI_c}$	Wave exposure (*ln*) Inlet type Anthropogenic pollution index Boating activity pressure index	SEM
			Multivariate: Cover of species (*sqrt*)	Wave exposure (*ln*) Inlet type Anthropogenic pollution index Boating activity pressure index	CCA
Finnish data	AS GF	50	**Univariate:** Cover of all species Number of species (*sqrt*) Macrophyte index based on abundance, $\mathrm{MI_a}$ Macrophyte index based on counts, $\mathrm{MI_c}$	Topographic openness (*ln*) Total phosphorus concentration (*ln*)	Multiple linear regression
Inter-annual data	WBSP BS AS GF	43 (41)	**Coefficients of variation for:** Cover of all species (*sqrt*) Epiphyte abundance (*sqrt*) Number of species (*sqrt*) Macrophyte index based on abundance, $\mathrm{MI_a}$ Macrophyte index based on counts, $\mathrm{MI_c}$ Species composition (*ln*)	Latitude Wave exposure (*ln*) Topographic openness (*ln*)	Multiple linear regression

The full model was simplified by removing dependencies that did not improve the minimal model, comparing models with maximum likelihood and Chi-square probabilities. Four separate SEMs were performed: for a) mean cover of all species combined, b) number of species, and the macrophyte index based on c) abundance (i.e., cover, MI_a) and d) counts (i.e., presence/absence, MI_c). Predictor variables were *ln*-transformed, and the number of species (response) was transformed by square root to fulfil criteria for parametric tests.

SEMs were also used to examine the effects of both anthropogenic pollution and boating activities on the univariate measures of the macrophyte community in 'dataset B' (Table 4). The factors included in the models were wave exposure, inlet type, anthropogenic pollution index, boating activity index, and the univariate measures of the macrophyte community (Fig. 8B). All factors, except wave exposure, were ordinal with three levels according to Table 3 for anthropogenic pollution index and boating activity index. Boating activity index was assumed to be related to inlet type and wave exposure, since berth places (and marinas) are often located in open inlets that are not exposed to high wave action. Epiphyte abundance was excluded in these analyses, as the previous tests indicated a relationship with only one of the macrophyte response variables, and data on epiphyte abundance were not available for all inlets. Exclusion of epiphytes therefore resulted in a larger sample size. Since the environmental variables (except wave exposure) were ordinal, the 'polycor' package and 'hetcor' function were used in the analyses (Fox 2006). 'Hetcor' computes heterogeneous correlation matrices among ordinal and numeric variables. The path coefficients obtained by 'sem' were compared with bootstrapped results to evaluate their accuracy ('boot' package, see Fox 2006 for details).

Effects of the natural environmental and anthropogenic factors on the species composition of macrophytes were analysed by means of canonical correspondence analysis (CCA) and partial CCAs ('vegan' package, Oksanen et al. 2011). Two separate analyses were conducted, one on 'dataset A' and one on 'dataset B' (Table 4). The environmental variables included were the same as in the SEMs, i.e. numeric in the first analysis and both numeric and ordinal in the second. Before analysis, macrophyte cover was square root-transformed to reduce undue effects of species with very high cover. In addition, species occurring in ≤ 2 inlets were omitted in the analyses to reduce the influence of rare species (7 species). Species in the genera *Eleocharis* and *Ruppia* were grouped together, as they had not always been identified to species level. Significance of the models, and all the factors included, was tested with permutation tests using 999 permutations. Ordinations were inspected for possible arch effects.

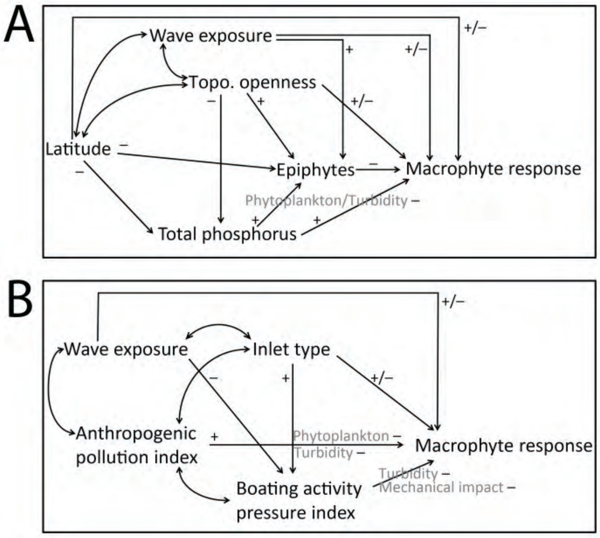


Figure 8. Initial structural models used as starting points in the two analyses (**A** and **B**), which are explained in the text. Direct paths are indicated by single-headed straight arrows showing direction, while correlations are shown with double-headed curved arrows. Plus (+) or minus (–) signs denote hypothesised positive or negative relationships. Direct relationships with the macrophyte response have both signs (+/–) as the relationship can differ depending on the response studied (cover, number of species, or macrophyte indices). Texts in grey font are variables in a conceptual model. These were not included in the analyses due to lack of data.

2.3.2 Finnish data

The Finnish data (concerning 50 inlets) was used to confirm the results of analysis of the Swedish data regarding effects of TP on the univariate macrophyte response variables (Table 4). Here, linear regressions were used to test for effects of topographic openness and mean TP on the macrophyte responses. Wave exposure and epiphyte abundance were not included in the analyses for two reasons. Firstly, the lower number of inlets resulted in lower power for analyses of a complex model similar to the previously computed SEMs on the Swedish data. Secondly, analysis of the Swedish data (‘dataset A’) did not indicate any significant or strong effects of wave exposure and epiphyte abundance on the macrophyte response variables. Interaction between the two predictors (topographic openness and TP) was tested, but it was removed from the models as it was not significant.

2.3.3 Inter-annual variation

Inter-annual variations were examined by calculation of coefficients of variation (standard deviation divided by the mean) for the univariate measures of the macrophyte community in inlets that had been surveyed for three or more years (Table 4). Variation in species composition was analysed by calculating the mean Euclidean distance between site scores in an ordination of the two first axes in a non-metric multi-dimensional scaling (MDS) of the multivariate data, based on Bray-Curtis dissimilarities (‘vegan’ package). Relationships between coefficients of variation for the vegetation, and the predictors latitude, wave exposure, and topographic openness were analysed by means of multiple regression. The models were simplified by a stepwise deletion of non-significant terms. The full models included all second-order interactions. The coefficients of variation were transformed when needed to fulfil criteria for parametric tests.

3 Results

3.1 Swedish data

The path diagrams resulting from the SEMs are shown in Fig. 9. The non-significant Chi-square probabilities indicate that the models had overall good fit. The unexplained variations in the path analyses were, however, large (71–95%). Nevertheless, the results give new information about the study system. For example, epiphyte abundance was negatively related to increasing TP, and did not have a negative effect on the macrophyte response variables (Fig. 9A). Macrophyte species richness was found to increase with increasing TP (Fig. 8A, II). As the number of species recorded during a survey can increase with sampling effort (Gotelli and Colwell 2001), I also tested a model with rarefied number of species (rarefied to the same sampling effort, i.e. number of survey squares, Hurlbert 1971; Oksanen et al. 2011) instead of raw number of species. The response of the rarefied number of species to increasing TP was similar to that of raw number of species (not shown). Both macrophyte indices (MI_a and MI_c) were negatively related to increasing TP (Fig. 8A, III). The analyses also indicated a positive effect of topographic openness on the macrophyte indices, and a negative trend on macrophyte richness. The unexplained variation was large, with an R^2 value of 0.18 and 0.19 for MI_a and MI_c, respectively. Epiphyte abundance increased with increasing wave exposure. Latitude had no direct effect on any of the response variables tested, and was therefore omitted in Fig. 9.

The second set of SEMs indicated that there was a negative effect of boating activity on both macrophyte cover (Fig. 9B, I) and the macrophyte indices (Fig. 9B, III). The R^2 values were higher for the macrophyte indices (0.29) than for macrophyte cover (0.12). There was a correlation between boating activity and the anthropogenic pollution index. Boating activity was, as assumed, negatively related to wave exposure, but positively related to increased openness of inlets. The anthropogenic pollution index had no direct effect on the macrophyte response variables. The results are further illustrated in Fig. 10.

The CCAs indicated that there were significant effects of all the included variables on the species composition of macrophytes (Table 5). The variables included could, however, only explain 17–19% of the variation in community composition in the two datasets. The natural environmental variables explained most of the constrained variation, while the anthropogenic-influenced variables explained less. Further examination of how species were distributed along the TP gradient, or in relation to the anthropogenic pressure indices, was not performed as the level of explained variation for these factors was low.

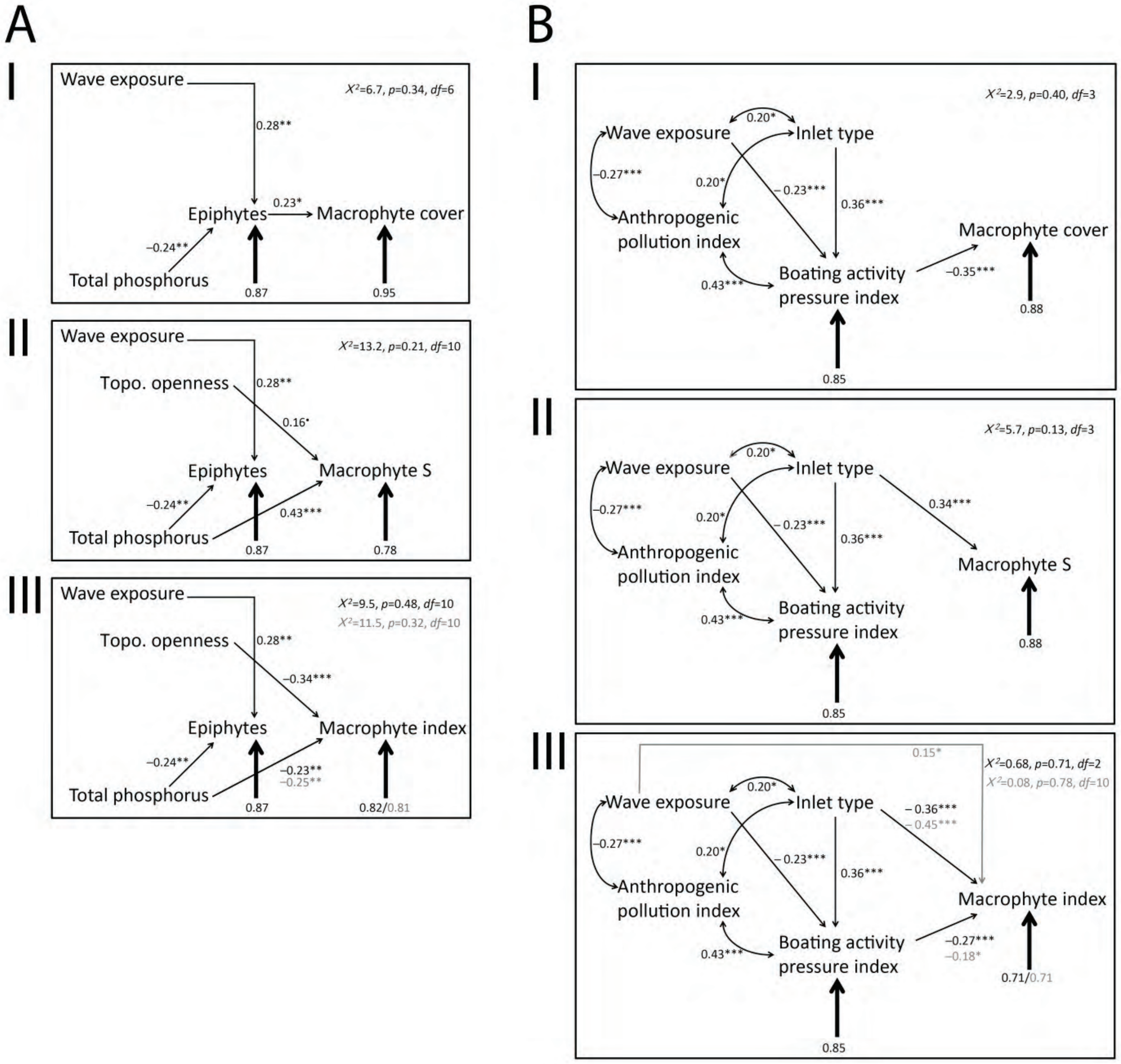


Figure 9. Path diagrams for structural equation models testing the effects of environmental variables on epiphytes and the macrophyte response variables (I) cover, (II) number of species (S), and (III) macrophyte indices based on abundance (black) or counts (grey). Direct paths are indicated by single-headed straight arrows showing direction, while correlations are shown with double-headed curved arrows. Thick arrows from below are error terms (i.e. $1 – R^2$). Models in panel **A** were based on 112 inlets along the Swedish Baltic Sea coast from the southern Baltic Sea Proper to the southern Bothnian Sea ('dataset A') with numeric environmental data. Models in panel **B** were based on 167 inlets from the western Baltic Sea Proper ('dataset B') with ordinal environmental data (except for wave exposure). Arrows and numbers show individual standardised path coefficients with superscripts indicating significance ($^{\bullet}p = 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$). Statistics for the models are given in the upper right-hand corner. (Models should be rejected if the maximum likelihood tests give $p < 0.05$).

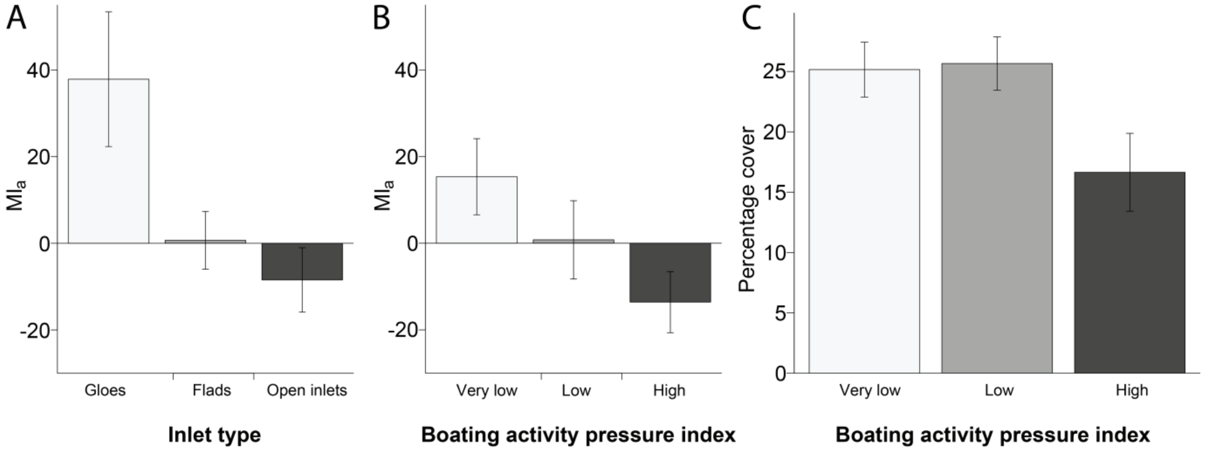


Figure 10. Relationship between inlet type (**A**), or boating activity pressure index (**B**), and the macrophyte index based on abundance (MI_a). Also, relationship between boating activity pressure index and mean macrophyte cover (**C**). Bars denote mean ± CI_{95}. Further details are given in Fig. 9B.

Table 5. Significance of CCAs testing for effects of environmental variables on species composition of macrophytes. Models in **a** were based on 112 inlets along the Swedish Baltic Sea coast from the southern Baltic Sea Proper to the southern Bothnian Sea ('dataset A') with numeric environmental data. Models in **b** were based on 167 inlets from the western Baltic Sea Proper ('dataset B') with ordinal environmental data (except for wave exposure). Total and constrained inertia for the models were 2.70 and 0.51 (**a**), and 2.71 and 0.47 (**b**); explaining 19% and 17% of the variation in species composition, respectively. Explained variation in the last column refers to the fraction explained by the different environmental variables alone computed from partial CCAs. The shared explanation of the variables was 7% and 15% for **a** and **b**, respectively.

Factors	***Df***	X^2	**Pseudo-*F***	***p*-value**	**Explained variation**
a)					
Latitude	1	0.16	7.94	0.001	32%
Topographic openness	1	0.17	8.43	0.001	34%
Wave exposure	1	0.09	4.31	0.001	17%
Total phosphorous concentration	1	0.04	2.14	0.004	9%
Residuals	107	2.20			
b)					
Wave exposure	1	0.08	5.65	0.001	17%
Inlet type	2	0.20	7.14	0.001	42%
Anthropogenic pollution index	2	0.07	2.58	0.001	15%
Boating activity pressure index	2	0.05	1.81	0.004	11%
Residuals	160	2.24			

3.2 Finnish data

Both topographic openness and TP had significant negative effects on the two macrophyte indices (Table 6), similar to what was found for the Swedish data ('dataset A'). However, in contrast to the Swedish results, no significant effect was found on macrophyte species richness ($p = 0.13$); nor was there a significant effect of the two predictor variables on macrophyte cover ($p = 0.21$). Both macrophyte indices showed a steeper decrease with increasing TP of the inlets compared to the Swedish data (Fig. 9A, III). The unexplained variation in the data was also lower than in models of the Swedish data. The relationships between MI_a and TP for both the Finnish and the Swedish datasets are presented in Fig. 11.

Table 6. Results of multiple regression testing the effects of topographic openness and total phosphorus concentration on macrophyte indices, based on **a)** abundance (MI_a), or **b)** counts (MI_c). The analyses were based on 50 inlets in the Archipelago Sea and the western Gulf of Finland.

	Estimate	Std. Error	*t*-value	*p*-value
a MI_a Adj. $R^2 = 0.31$, $F_{2,47} = 12.2$, $p < 0.001$				
Intercept	125	35.7	3.51	0.001
Topographic openness	–8.95	2.95	–3.03	0.004
Total phosphorus concentration	–44.0	10.6	–4.14	< 0.001
b MI_c Adj. $R^2 = 0.36$, $F_{2,47} = 14.6$, $p < 0.001$				
Intercept	110	24.2	4.53	< 0.001
Topographic openness	–4.78	2.00	–2.39	0.021
Total phosphorus concentration	–36.2	7.20	–5.04	< 0.001

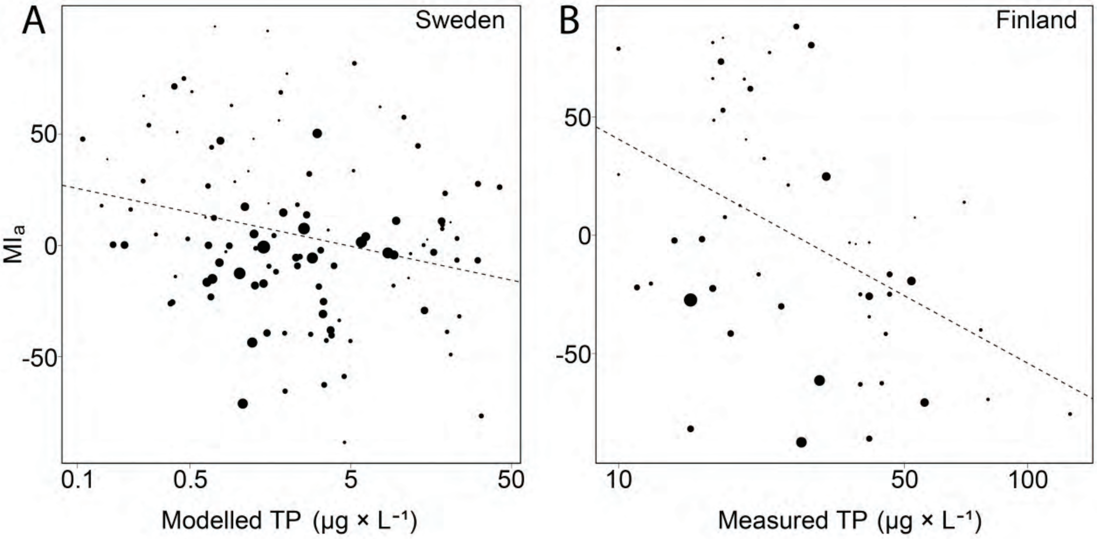


Figure 11. Relationship between the macrophyte index based on abundance (MI_a) and total phosphorus concentration (TP) for inlets along the Baltic Sea coast of Sweden (**A**) and Finland (**B**). Details for panel **A** can be found in Fig. 9A and those for panel **B** can be found in Table 6. As the topographic openness of inlets also had a negative effect on the macrophyte index, points are scaled according to this factor; large points represent a high degree of openness and small points represent a low degree of openness. Note the logarithmic scale of the x-axis.

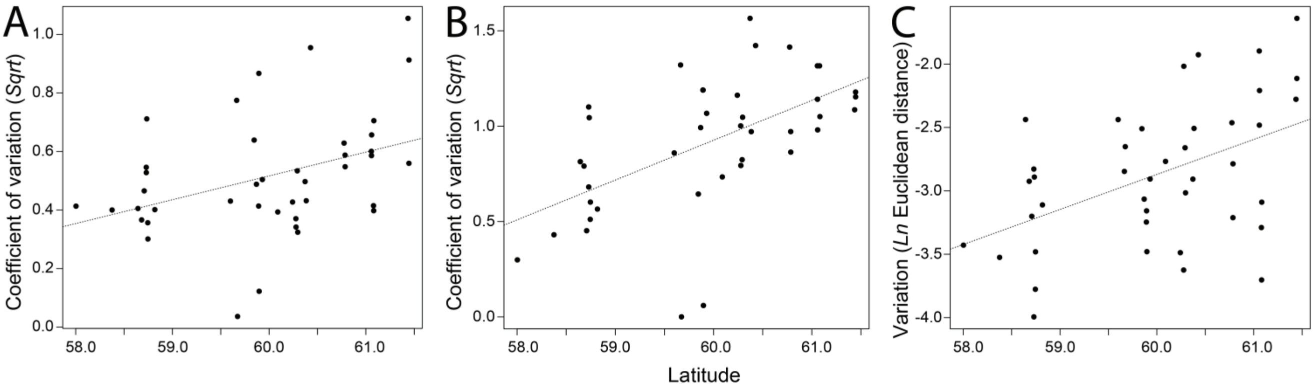


Figure 12. Relationship between inter-annual variation in (**A**) macrophyte cover and latitude (slope = 0.08, adj. R^2 = 0.13, $F_{1,39}$ = 6.8, p = 0.013), (**B**) epiphyte abundance and latitude (slope = 0.21, adj. R^2 = 0.30, $F_{1,38}$ = 17.7, p < 0.001), and (**C**) macrophyte composition and latitude (slope = 0.28, adj. R^2 = 0.21, $F_{1,39}$ = 11.5, p = 0.002). Analyses were based on 41 inlets in the western Baltic Sea Proper, the Archipelago Sea, and the western Gulf of Finland. See text for details of calculations of the inter-annual variation.

3.3 Inter-annual variation

The mean coefficient of variation (CV) of vegetation cover in the inlets was 0.30, with a maximum variation of 1.11. The variation in number of species was lower, with a mean of 0.17 and a maximum of 0.82. The mean CV in MI_a and MI_c was 1.29 and 1.76, respectively. A few inlets showed very high variation, up to a CV of 17. Removal of such outliers resulted in a mean CV of 0.65 and 0.93 for MI_a and MI_c, respectively.

The CV in macrophyte cover and abundance of epiphytes in the inlets increased significantly with increasing latitude (Fig. 12A and B). Variation in macrophyte cover and epiphyte abundance was large at latitudes of about 60° (Fig. 12A and B), corresponding to the geographic region where three longitudinally separated regions were sampled (i.e. the western Baltic Sea Proper, the Archipelago Sea, and the Gulf of Finland; Fig. 5A). Initial tests with these regions as a factor indicated that there was no significant difference, and the factor was therefore omitted from the analyses.

The variation in species composition also increased with increasing latitude (Fig. 12C). The variation in species composition was measured as the mean Euclidean distance in an MDS ordination of sites. Testing of the maximum Euclidean distance gave a similar result. The CV in number of species decreased significantly with increasing wave exposure (adj. R^2 = 0.12, $F_{1,39}$ = 6.35, p = 0.016; not shown). There was no significant relationship between CV of the macrophyte indices (MI_c and MI_a) and the environmental variables tested (p > 0.1).

4 A method for assessment of ecological status

Based on the results of the present study, and on criteria set for assessment of ecological status in the WFD (Table 7), I developed a method for assessment of shallow inlets in the Baltic Sea. Following the geographic divisions and typology in the WFD, these inlets are from the ecoregion *Baltic Sea* and are of the types *shallow* and *meso* to *oligohaline*. They are protected from high wave action, they mainly have soft-sediment bottoms of gyttja, and they have surface-water retention times of approximately one month to less than a day for the most open inlets. Two factors were chosen for construction of the assessment method, macrophyte cover and MI_a. Both factors were found to respond to anthropogenic pressures in the previous analyses. MI_a was chosen over MI_c as the response to boating activity (Fig. 9B, III), and TP (Table 6) was stronger for the first factor. In construction of the method, a division into geographic sub-regions was omitted since no significant difference was found in MI_a and cover with latitude or between longitudinally

Table 7. Definitions of ecological status for coastal waters based on the quality element *macroalgae and angiosperms* (Directive 2000/60/EC).

Status	Description
High	All disturbance-sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are present. The levels of macroalgal cover and angiosperm abundance are consistent with undisturbed conditions.
Good	Most disturbance-sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are present. The level of macroalgal cover and angiosperm abundance show slight signs of disturbance.
Moderate	A moderate number of the disturbance-sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are absent. 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.
Poor	Major alterations in macroalgal and angiosperm taxa associated with undisturbed conditions. The macroalgal and angiosperm community deviate substantially from those normally associated under undisturbed conditions.
Bad	Severe alterations in macroalgal and angiosperm taxa associated with undisturbed conditions. Large proportions of the macroalgal and angiosperm community normally associated under undisturbed conditions are absent.

separated regions. Topographic openness of inlets was, however, included as it was found to have a significant effect on MI_a. To make the method simple, two levels were used to account for differences in topographic openness between the inlets. The argument for using only two levels is that the largest difference in MI_a was found between glo-type inlets (i.e. glo-flads and gloes) and other more open inlets (i.e. juvenile flads, flads, or open inlets; Fig. 10A). The division is supported by Hansen's (2010) similar finding of largest differences in macrophyte biomass and species richness between glo-type inlets and more open flads. Another argument for using the two levels is that they can be identified using satellite images, and are sub-habitats used in the Habitats Directive in Sweden (e.g. Johansson and Persson 2010).

To construct the assessment method and set relevant ecological status classes, macrophyte cover and MI_a were calculated for all 350 surveyed inlets. Mean and variances of the two factors were studied at different degrees of anthropogenic pressure. To achieve a relevant number of levels, without too much unbalance in the number of inlets between levels, the two indices of anthropogenic pollution and boating activity were combined into five levels (Table 8). For glo-type inlets, only three levels could be used as the number of such inlets with class IV and V was low (resulting in class I, II–III, and IV–IV). Analysis of variance (ANOVA) was used to test differences of the two responses (MI_a and cover) between inlets categorised according to level of human influence. Inlet type was included as a factor in the analysis with MI_a as response. Since glo-type inlets could only be divided into three levels of anthropogenic pressure, differences in MI_a were only analysed statistically between these three levels (i.e. class I, II–III, and IV–IV; Table 8). Country was initially included as a factor in the analysis with macrophyte cover as response (as the difference in survey method between the two counties could result in a difference in mean cover), but it was removed since no significant effect was detected ($p = 0.93$). In cases in which a significant difference was found in MI_a or macrophyte cover between the anthropogenic-pressure levels, pairwise comparisons were computed by Tukey contrasts using the 'multcomp' package (Hothorn et al. 2008). This post hoc test is a robust method of comparing multiple means in unbalanced designs (Herberich et al. 2010).

Table 8. Levels of anthropogenic pressure used in construction of the assessment method were based on a combination of both anthropogenic pollution and boating activity indices in Table 3.

Anthropogenic pressure	Anthropogenic pollution index	Boating activity pressure index
I	Very low	Very low
II	Very low	Low
	Low	Very low
III	Low	Low
IV	Very low or low	High
	High	Very low or low
V	High	High

Threshold levels for ecological status classes were set according to standard variance measures. Good ecological status was set between the upper quartile and the lower 95% confidence interval of the lowest level of anthropogenic pressure for $\mathrm{MI_a}$ (Fig. 13). $\mathrm{MI_a}$ for this level of anthropogenic pressure differed significantly from the $\mathrm{MI_a}$ of the two highest anthropogenic pressure levels (Fig. 13). High ecological status was set above the upper quartile of the lowest level of anthropogenic pressure for $\mathrm{MI_a}$. Poor ecological status was set below the lower quartile of macrophyte cover for the lowest level of anthropogenic pressure, and bad ecological status was set below the lower quartile of the highest level of anthropogenic pressure. The reason for setting the criteria at such a low level was that the data included in the present study did not include many severely affected inlets with almost no vegetation cover, which is the definition set for bad status in the WFD (Table 7). Previous studies have, however, reported negative effects on fish reproduction when cover of large macrophytes falls below a level similar to the lower quartile of level V (Sandström et al. 2005). The suggested level for bad status can thus be justified by the results of Sandström et al. (2005). Since the definitions of good ecological status in the WFD allow “slight signs of disturbance”, an alternative—less strict—level was set for good status at the lower quartile of the lowest level of anthropogenic pressure. The thresholds will be discussed further later and should be evaluated in independent studies.

According to the WFD, quality elements should be expressed as quality ratios. Two ecological quality ratios (EQRs) were used for the assessment method:

$$\mathrm{EQR_1} = \frac{(Observed\ \mathrm{MI_a} - Min\ \mathrm{MI_a})}{(Reference\ \mathrm{MI_a} - Min\ \mathrm{MI_a})} \qquad (Eq.4)$$

where the minimum macrophyte index (*Min* $\mathrm{MI_a}$) is the minimum theoretical value (–100) and the reference macrophyte index is the maximum observed under reference conditions (100).

$$\mathrm{EQR_2} = \frac{Observed\ \bar{x}\ macrophyte\ cover}{Reference\ \bar{x}\ macrophyte\ cover} \qquad (Eq.5)$$

where the reference mean ($\bar{x}$) macrophyte cover is the maximum observed under reference conditions (100).

The suggested threshold values for the classification of ecological status are given in Table 9. Threshold values for $\mathrm{EQR_1}$ should be used to classify ‘high’, ‘good’, and ‘moderate’ status, and $\mathrm{EQR_2}$ to identify ‘poor’ and ‘bad’ status. Threshold values for $\mathrm{EQR_1}$ differ depending on inlet type, which is set according to the level of topographic openness. $\mathrm{EQR_2}$ is superior to $\mathrm{EQR_1}$, meaning that inlets should be classified as having poor or bad status when $\mathrm{EQR_2}$ indicates this, regardless of the indication by $\mathrm{EQR_1}$.

Of the 350 inlets included in the present study, 18% would be classified as having high status according to the suggested threshold values. Twenty-five per cent (25%) and 32% would be classified as having good and moderate status, and 19% and 5% as having poor and bad status, respectively.

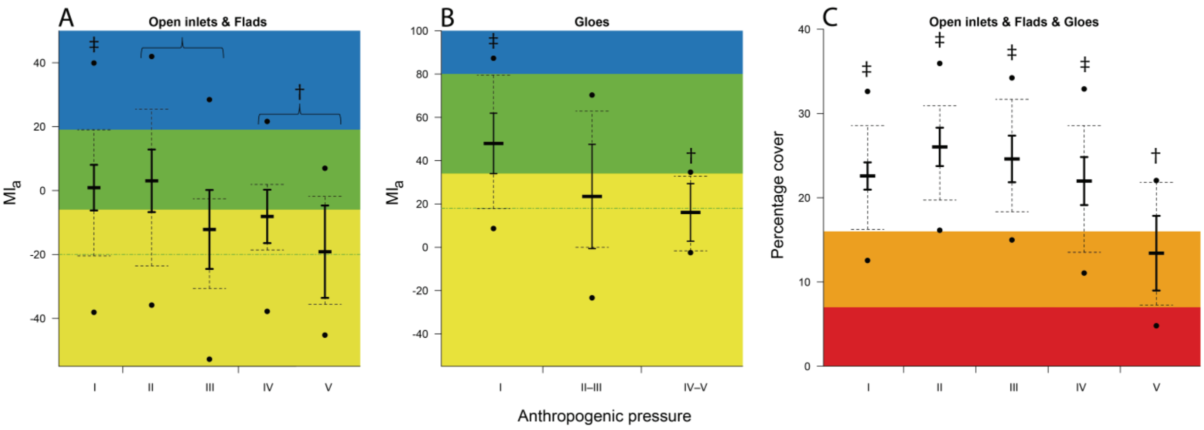


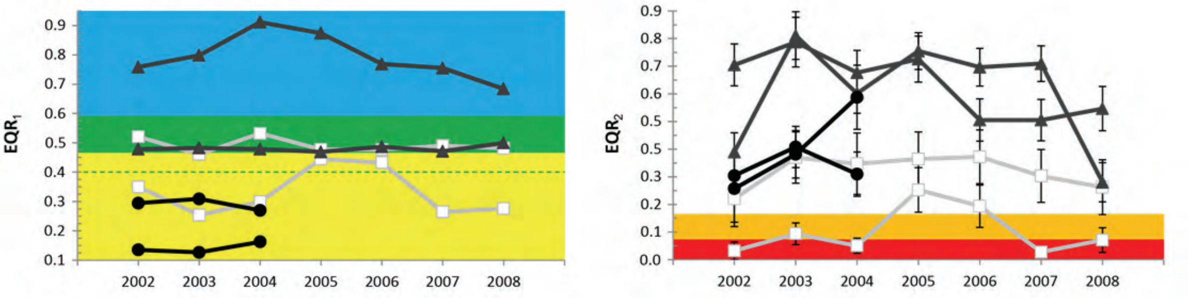
Figure. 13. Mean ± CI_{95} (solid lines), lower and upper quartiles (broken lines), and SD (dots) for macrophyte index based on abundance (MI_a) in open inlets, juvenile flads and flads (**A**) and in gloes and glo-flads (**B**). Mean macrophyte cover in all types of inlets is shown in panel **C**. Categories on the x-axes are level of anthropogenic pressure, from very low (I) to high (V) (Table 8). Categories in panel **B** were merged, as the number of inlets in category IV and V was low. Background colours depict limits for the suggested ecological status classes: blue = high, green = good, yellow = moderate, orange = poor, and red = bad status. Broken vertical green lines indicate alternative limits for good ecological status. MI_a differed significantly between inlet types (**A** and **B**) ($F_{1,346} = 52.7$, $p < 0.001$) and between anthropogenic pressure levels I and IV–V ($F_{2,346} = 4.15$, $p = 0.017$, post hoc $p = 0.015$). Macrophyte cover was significantly lower at the highest anthropogenic pressure level (V) than at all other levels ($F_{4,345} = 6.10$, $p < 0.001$, post hoc $p < 0.02$). Different superscript symbols indicate significant difference.

Table 9. Threshold values for classification of ecological status in shallow Baltic Sea inlets based on macrophyte EQR_1 and EQR_2 for **a**) open inlets, juvenile flads and flads (Natura 2000-types 1150, 1152, 1153 and 1160), and **b**) glo-flads and gloes (Natura 2000-type 1154). Threshold values for EQR_1 differ depending on inlet type, which is set according to the level of topographic openness. Threshold values for EQR_1 should be used to classify 'high', 'good', and 'moderate' status, and EQR_2 to identify 'poor' and 'bad' status. EQR_2 is superior to EQR_1. The same threshold values are applicable to all regions investigated. An alternative, less strict threshold for good status is given in parentheses.

Ecological status	**EQR_1**		**EQR_2**
	Inlet type a	**Inlet type b**	**Inlet types a and b**
High	$0.60 > EQR_1 \leq 1.00$	$0.90 > EQR_1 \leq 1.00$	
Good	$0.47 > EQR_1 \leq 0.60$ $(0.40 > EQR_1 \leq 0.60)$	$0.67 > EQR_1 \leq 0.90$ $(0.59 > EQR_1 \leq 0.90)$	
Moderate	$0.00 \geq EQR_1 \leq 0.47$ $(0.00 \geq EQR_1 \leq 0.40)$	$0.00 \geq EQR_1 \leq 0.67$ $(0.00 \geq EQR_1 \leq 0.59)$	
Poor			$0.07 > EQR_2 \leq 0.16$
Bad			$0.00 \geq EQR_2 \leq 0.07$

To study the performance of the assessment method, year-to-year variation in macrophyte cover and MI_a was examined for a selection of inlets that had been studied over the longest time periods (Fig. 14). The open inlets did not vary much between years. The largest inter-annual variation was recorded for macrophyte cover. Inlets with high anthropogenic pressure had lowest MI_a, corresponding to moderate ecological status, as could be expected from the design of the assessment method. One of the reference inlets did, however, have an almost equally low MI_a, as well as low cover, corresponding to poor or bad status depending on year. Also, this result could be expected considering the large variation in reference inlets shown in Fig. 13. This means that the method will not always give good or high status to inlets with low anthropogenic pressure.

The variation in MI_a was a somewhat larger for the two glo-type inlets with high anthropogenic pressure. Due to inter-annual variation, one of these inlets was classified as having good status in the first year, but poor status thereafter. Figure 14 also shows that the limits set for good ecological status are narrow, and result in alterations between status classes for the inlets, despite quite low year-to-year variation. A larger window, using the suggested lower limit for good status, partly reduces these alterations between status classes.


A. Open inlets & Flads

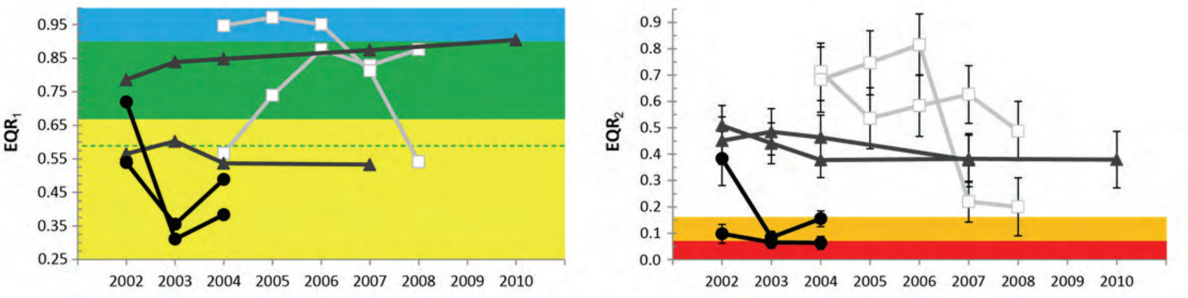

B. Gloes

Figure 14. Inter-annual variation in EQR_1 and EQR_2 for open inlets, flads and juvenile flads (**A**), and gloes and glo-flads (**B**). Bars for EQR_2 denote ± CI_{95}. Inlets are coloured according to anthropogenic pressure (Table 7); white solid rectangles = very low pressure (I), grey solid triangles = low pressure (II), and black solid circles = high pressure (IV). Background colours depict limits for the suggested ecological status classes; blue = high, green = good, yellow = moderate, orange = poor, and red = bad status. Broken vertical green lines indicate alternative limit for good ecological status.

Until now, the focus has been on assessment of individual inlets. One aim of this study was, however, to develop an assessment method that could also be used on a larger WFD water-area level. Examination of the EQR of water areas with at least five inlets revealed that some areas showed variation within status classes, while several had a variation over status classes (Fig. 15). Furthermore, I compared the EQR values of inlets with the present ecological status of the inlets (Fig. 16). The present ecological status of the inlets was extracted from the ecological status of the WFD areas in which the inlets were located. Since inlets were grouped within water areas, mixed-effects models were used for the analyses ('nlme' package, Crawley 2007; Pinheiro et al. 2011), with water area as a random blocking factor. Only EQR of open inlets (and not glo-type inlets) was analysed. I found a significant difference in EQR_1 between poor status and good or high status (Fig. 16A). The large variation in EQR_1 of water areas with moderate ecological status was a result of imprecise classification with the present classification system. Water areas that lacked one of the three measures of biological quality had often been classified as moderate due to uncertainty. Thus, water areas with moderate status were omitted from the analyses. There was no significant difference in EQR_2 between the present ecological status classes (Fig. 16B).

The ecological status obtained by the proposed new method for the shallow inlets was compared with the present ecological status for water areas in the WFD. To calculate the new ecological status with the method presented here (Table 9), a mean EQR value was computed from all inlets in a water area. Only water areas with five or more inlets were examined. The status classes obtained using the proposed method corresponded in part to the status classes obtained using the present classification method (Fig. 17). It is, however, important to note that the present classification system is associated with a high degree of uncertainty and is still under development.

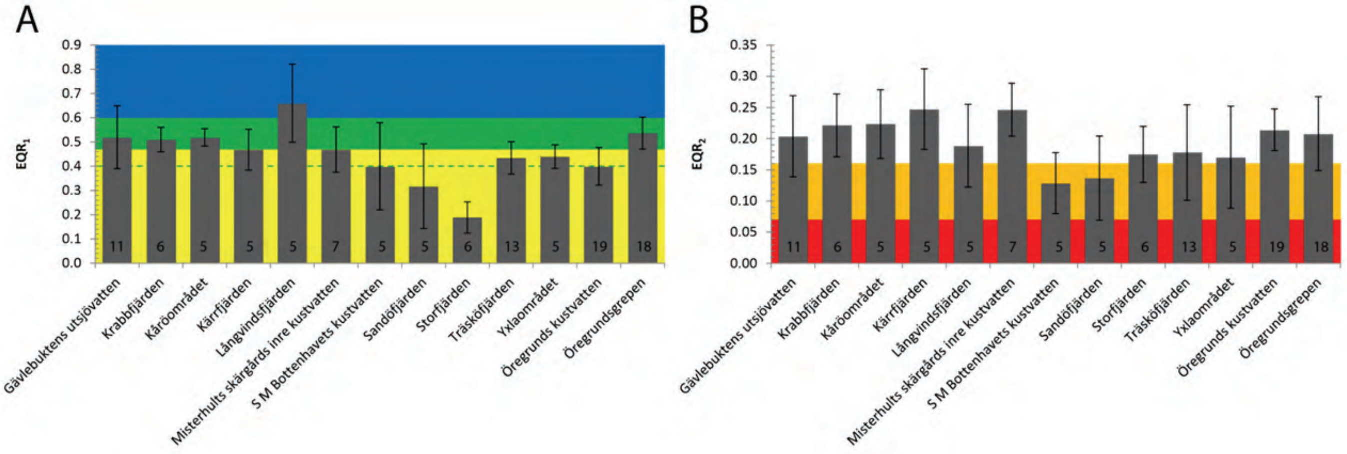


Figure 15. Mean ± CI_{95} EQR_1 (**A**) and EQR_2 (**B**) for open inlets and flads grouped in larger water areas according to the divisions in the WFD. Numbers in bars denote number of inlets in the water areas. Background colours depict limits for the suggested ecological status classes: blue = high, green = good, yellow = moderate, orange = poor, and red = bad status. The broken vertical green line indicates alternative limit for good ecological status.

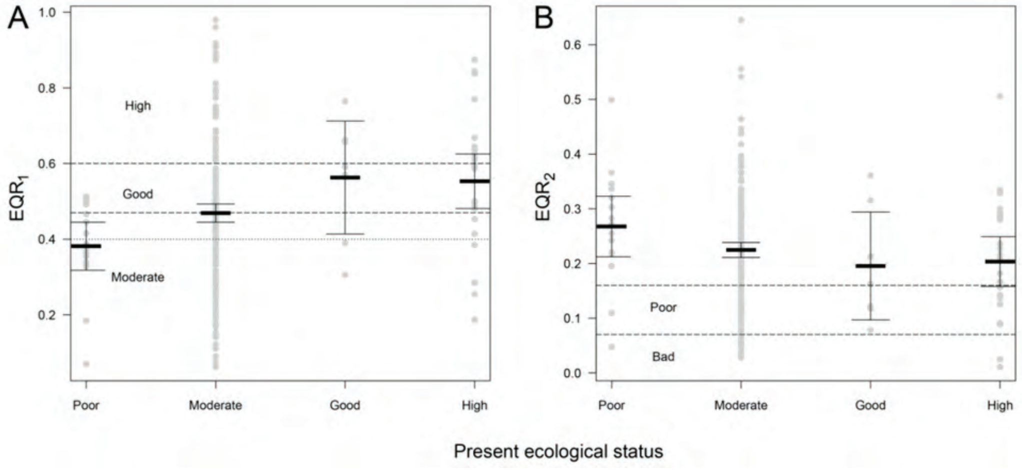


Figure 16. Relationship between the suggested EQRs for open inlets and flads in water areas according to divisions in the WFD, and the present ecological status of the water areas. Mean ± CI_{95} (solid lines) and raw data (grey) for EQR_1 (**A**) and EQR_2 (**B**). Only water areas in which ecological status had been classified according to one or more biological quality elements were included. Broken lines depict borders between the suggested ecological status classes according to EQR_1 and EQR_2. Dotted line indicates alternative limit for good ecological status. EQR_1 differed significantly between water areas with poor status and those with good and high status ($F_{2,15} = 6.57$, $p = 0.009$, $n = 48$ inlets, post hoc $p < 0.05$; mixed-effects model with water area as random blocking factor (18 areas); moderate status was not included in the analysis). There was no significant difference in EQR_2 between status classes ($F_{2,15} = 2.01$, $p = 0.17$).

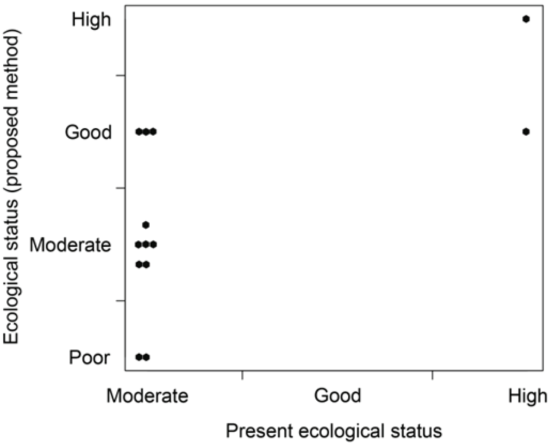


Figure 17. Relationship between the new proposed ecological status (based on open inlets and flads) and the present ecological status of the water areas. Only water areas in which ecological status had been classified according to one or more biological quality elements were included. Water areas with less than five inlets were excluded.

5 Discussion

Elevated total phosphorus concentration and boating activities were found to have an impact on the macrovegetation in the shallow Baltic Sea inlets studied. According to assumptions, the proportion of species documented as sensitive to anthropogenic pressures decreased—while the proportion of tolerant species increased—with increasing TP and level of boating activity. In addition, macrophyte cover was lower in inlets with high, as opposed to low, boating pressure. No effect of elevated TP was found on macrophyte cover.

In contrast to the latter finding, Dahlgren and Kautsky (2004) recorded lower macrophyte cover in inlets with high TP. Their finding was mainly based on one inlet with very low macrophyte cover and extremely high external TP load. Such high TPs were not recorded in the present study, which can explain the difference in results between the studies. The Swedish inlets investigated generally had low TP, while the Finnish inlets had slightly higher TP than the Swedish inlets (up to just over 100 µg L^{-1}). This difference was reflected in a clearer response of reduced proportion of sensitive species with increasing TP for the Finnish inlets as compared to the Swedish inlets. In comparison to eutrophic European lakes (e.g. Penning et al. 2008a), inlets in both countries had comparably low TP, possibly explaining the rather weak relationship between the macrophyte data and TP. The weak response of the macrophyte community to TP agrees with the studies by Kovtun et al. (2009) and Rinne et al. (2011) on macrophytes in the eastern Baltic Sea. Both of these studies found that natural environmental factors had a more significant effect on species composition than had nutrient loading.

The recorded negative effect on macrophyte cover of high boating activity is probably caused by higher turbidity in these inlets. Here, traffic by small pleasure boats inside inlets, or ferry traffic just outside inlets, leads to backwashes, currents, and increased water circulation—resulting in constant suspension of sediments and reduced water transparency. High turbidity is known to negatively affect macrophyte cover and depth distribution in both lakes (e.g., Blindow 1992; Scheffer 2004; Sand-Jensen et al. 2008) and coastal areas (e.g. Kautsky et al. 1986; Duarte 1991; Krause-Jensen et al. 2011) due to reduced light penetration and thereby reduced photosynthetic activity of the macrophytes. Particle sedimentation on macrophytes, due to suspension of bottom sediments, is also known to have a negative effect on macrophytes (Henricson et al. 2006).

Based on the results of previous studies (e.g. Blindow 1992; Sand-Jensen et al. 2008), it is likely that turbidity (i.e. phytoplankton abundance and low light attenuation) is also one of the key factors that drove the change in species composition with increasing TP in the present study—i.e. to an increased proportion of shade-tolerant macrophyte species. The response of the macrophyte index to an increase in TP is in line with results obtained for the macrophyte index applied to European lakes in Penning et al. (2008a). Their index showed the strongest response to TP for Nordic countries and this result was suggested to be a consequence of a clearer relationship between turbidity and TP load in northern Europe than in central Europe.

From the analyses including both anthropogenic pollution and boating activity, it can be concluded that the latter human pressure had a clearer and more direct effect on macrophyte cover and the macrophyte indices in the region investigated. The reduced cover and change in species composition of macrophytes recorded in inlets with high boating activity is in line with the findings of Eriksson et al. (2004), who partly used the same data as used in the present study. However, in contrast to the present results, Eriksson et al. (2004) found a decrease in species richness with increased boating activity. In their study, the macrophyte data were divided into depth intervals, and the largest difference in number of species was found at depths of 1–2.5 m. The results of Eriksson et al. (2004) could not be confirmed with the data in the present study, even when analysis was conducted only on samples deeper than one metre. This suggests that there is no significant difference in species number between inlets with different degrees of boating activity. The new finding can be explained by a larger variation in the number of recorded species in reference inlets, resulting from a higher number of inlets included in the present study.

Figure 18. Inlets with high boating activity were found to have lower macrophyte cover than inlets with low boating pressure.

For Swedish lakes, a different macrophyte index is used to classify ecological status (Anon 2007a; Ecke 2007; Anon 2008). This index, the trophic macrophyte index (TMI), uses specific indicator values for individual species. For management, it would be beneficial to apply the same index to the shallow Baltic Sea inlets. Thus, the TMI index was tested on data in the present study, using the same indicator values for species as in the original method (not shown). The index performed very poorly as an indicator of ecological status for the shallow inlets because it increased (i.e. gave 'better' values) with increasing TP and boating activity, as well as with increasing latitude. This result indicates that the macrophyte species included in the index have a different ecology in the brackish Baltic Sea than in freshwater environments.

The macrophyte index used in the present study could be improved by developing specific indicator values for individual species along anthropogenic pressure gradients, as in the TMI or other macrophyte indices used for European freshwaters (e.g. Schneider and Melzer 2003). However, the low explanation for species occurrences along the TP gradient, and in relation to the anthropogenic pressure indices (CCA, Table 5), did not allow a reliable base for such indicator values. Future research should be aimed at more thoroughly examining the response of individual species to the multiple human-induced pressures and at trying to develop such indices for the species in this diverse macrophyte community.

Number of species has sometimes been suggested as a measure of anthropogenic impact for use in classification systems (e.g. review in Solimini et al. 2006). In the present study, the number of species was found to increase with increasing TP (for the Swedish inlets). This pattern is consistent with results for European lakes presented in Penning et al. (2008a), where species richness followed a unimodal response to increasing TP (cf. Grime 1979). This means that the number of species increases with increasing TP to a certain level, after which it levels off and decreases. Results by Penning et al. (2008a) suggest a peak in species number at around 10–50 µg L^{-1} for European lakes, corresponding to the highest TP of the Swedish inlets studied. Decreasing number of species will thus only function as an index of anthropogenic pressure at the upper half of the response curve, and will not function if the TP gradient is in the lower half of such a relationship. Based on the present results, I conclude that the value of macrophyte species richness for assessment in the WFD is limited, as was also suggested by Penning et al. (2008a).

The abundance of ephemeral, mainly epiphytic filamentous, algae has been used for status classification of inlets in some cases (e.g. Isæus et al. 2005). The results in this study, however, show that abundance of epiphytes cannot be used in assessment of ecological status of the shallow Baltic Sea inlets. The abundance of these algae was not positively related to an increase in TP, but on the contrary displayed a negative response. This relationship may be due to competition for light as a result of increased phytoplankton productivity, but the relationship should be investigated further. The positive influence of epiphytes on macrophyte cover has no clear explanation. However, the residual variation was large and the relationship was weak.

The epiphyte abundance was positively related to increasing wave exposure. This relationship can be explained by an increased amount of drifting algae entering inlets with high wave exposure at their openings. Drifting mats of ephemeral algae occur quite frequently in the Baltic Sea. The phenomenon has probably increased with the large-scale eutrophication process since the second half of the twentieth century (e.g. Bonsdorff 1992). The drifting mats usually consist of ephemeral algae that have become detached from their substratum due to wave action. The mats often drift into shallow inlets (Boström and Bonsdorff 2000; Berglund et al. 2003; Hansen et al. 2010). Once inside inlets, under wave-protected conditions, the algae settle and become entangled in the benthic vegetation.

It is also possible to explain high abundance of ephemeral algae by a decrease in grazing pressure in the outer, more wave-exposed archipelago as a consequence of a trophic cascade (Eriksson et al. 2009; Eriksson et al. 2011). Declines in top-predatory fish in the Baltic Sea have resulted in increased population sizes of invertebrate-feeding fish, and thus potentially reduced grazing on algae by invertebrates. Decreases in recruitment of the piscivorous fish pike (*Esox lucius*) and perch (*Perca fluviatilis*) have been reported mainly for inlets in more wave-exposed archipelago areas in the Baltic Sea (Ljunggren et al. 2005). This pattern coincides with the increase in abundance of ephemeral algae with increasing wave exposure.

According to the WFD, the ecological status of surface waters should be set in comparison to a reference condition (Table 7). This reference condition is defined as the status an ecosystem would have without any anthropogenic influence, i.e. the historic or pristine state. Such historic data are often difficult to find. For the shallow inlets along the Swedish and Finnish Baltic Sea coasts, only a few studies have been published before the second half of the twentieth century. Apart from herbarium collections of some selected species, most of the early investigations of vegetation in shallow soft-bottom inlets were from southwest Finland (e.g. Häyrén 1902; Häyrén 1944; Häyrén 1945; Luther 1947; Luther 1949; Luther 1951a; Luther 1951b). Comparisons between old and new records have been conducted by Blindow (2000), Schubert and Blindow (2003), and Munsterhjelm (2005). Although some general patterns can be revealed by these comparisons, the old records do not give enough data on community composition to set reference criteria for the whole study area.

Instead, I used the lowest level of anthropogenic pressure to define a reference condition. Inlets classified as having the lowest level of anthropogenic pressure had only one or two households in the watersheds, were located far from ferry or boat traffic and point sources of water-discharged nutrients or pollutants. High ecological status, corresponding to reference conditions, was set at the upper quartile of such inlets. This is the closest one can get to a reference condition when sufficient historic data are lacking. Despite the very low local anthropogenic pressure, the macrophyte community in the inlets can, of course, still be influenced by nutrient-enriched seawater due to widespread eutrophication of the Baltic Sea.

The definition of good ecological status in the WFD states that most sensitive macrophytes associated with undisturbed conditions should be present, but that their abundance can show slight signs of disturbance. The question of how this statement should be translated into numbers is challenging. I suggest two alternative levels for good ecological status: one level below CI_{95} of MI_a for inlets with the lowest level of anthropogenic pressure and another at the lower quartile of MI_a for the same inlets. The first suggestion also means that the threshold for good ecological status is outside the significantly lower MI_a identified for inlets with high anthropogenic pressure (i.e. above the CI_{95} of MI_a for such inlets). The second suggestion is less strict, and the threshold is set to include MI_a values of about half of the inlets with high anthropogenic pressure. Many of these inlets (with high anthropogenic pressure) fulfil the criteria that most sensitive macrophytes are present and that the abundance show only a slight sign of decrease. An advantage of applying a larger window for good status is that it reduces alterations between status classes over years. However, an argument against the low threshold is that it will increase the chance of attributing good status to an inlet that shows only slight negative deviation from reference conditions. Necessary management measures may thereby be delayed if the start of a negative trend is not detected in time. This is especially problematic when the monitoring frequency is low.

In the present study, macrophyte responses were studied in relation to a gradient in TP, just as is the case for most studies of shallow lakes. The reason for focusing on phosphorus and not nitrogen is that phosphorus is often the limiting element for autotrophs in these environments (e.g. Scheffer 2004). Shallow water often leads to oxygenated bottoms, at least when the water is not stagnant. Under such conditions, phosphorus is bound to iron in the sediments and largely unavailable for the autotrophs. Phosphorus trapped in the sediments, in combination with water run-off from lowland catchment areas and atmospheric nitrogen fixation by cyanobacteria, provides more access to nitrogen than to phosphorus. However, nutrient dynamics are complex and nitrogen cannot be excluded as a growth-limiting element for autotrophs in the shallow inlets, at least temporarily. Where data on total nitrogen concentration were available for the inlets investigated, these correlated well with the measured TP (r = 0.82 for the Swedish data [10 inlets] and r = 0.65 for the Finnish data [50 inlets]).

The ecological status classification in the WFD is aimed at identification of water areas that deviate significantly from a reference condition due to anthropogenic impact. A question that arises is how this status is related to ecological functions and other national or international objectives, e.g. red-listing of species or the Habitats Directive. In the shallow Baltic Sea inlets, perennial high macrophytes, such as *Potamogeton pectinatus*, *Myriophyllum spicatum*, and *Chara tomentosa*, are important spawning substrates for perch (*Perca fluviatilis*, Snickars et al. 2010). The first two of these species are tolerant to the eutrophication process and the macrophyte index under examination may therefore not function as a good indication of high value for fish reproduction. The threshold values in macrophyte cover for poor and bad status were, however, set to possibly indicate loss of function as reproduction habitat for fish. The threshold values were set in accordance with the finding by Sandström et al. (2005), who found negative effects on recruitment of vegetation-associated fish at low macrophyte cover. A more thorough examination of ecological functions in relation to the macrophyte index and the ecological status classes is, however, needed.

Ecke et al. (2010) observed that high ecological status for lakes in northern Europe did not mean higher number of red-listed species. This is not the case for the shallow inlets examined here. Instead, the proportion of inlets harbouring the only red-listed species in the data (*Chara horrida*, Fig. 19) increased with an increase in ecological status of the inlets (in accordance with the design of the macrophyte index). The proportion of inlets harbouring this species increased from bad status (0%) to poor (6%), moderate (8%), and good status (15%), but there was no further increase in the step to high status.

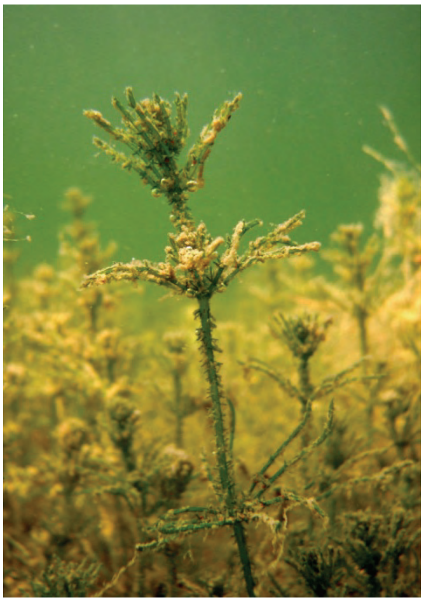


Figure 19. The proportion of inlets harbouring the red-listed species *Chara horrida* increased with increase in ecological status of the inlets. (For details of the latest taxonomy of *C. horrida*, see Boegle et al. 2010).

The assessment method suggested requires replication over a number of years to produce a measure of variation for EQR_1, since it is based on a proportion of mean values per inlet (MI_a, Eq.2). An alternative approach using mean and variances calculated from ratios per survey square was tested, but did not work.

The year-to-year variation in macrophyte cover and species composition were found to increase with latitude, but they were not found to change with topographic openness of the inlets. The latter finding disagrees with previous suggestions by Hansen (2008) and Rosqvist (2010) of increased (Hansen et al. 2008) or decreased (Rosqvist 2010) temporal variation with decreasing topographic openness. The present study included a higher number of inlets from a larger geographic area than in the previous studies, and the previous conclusions should therefore be disregarded at this larger scale. The result of increased variation with higher latitude can partly be attributed to elevated stress and disturbance on the macrophyte community due to a shorter growing season and the ice conditions during winter and spring. For example, a thicker layer of ice in the north results in more severe and deeper ice scour and removal of plant biomass. The result indicates that replication of inlets over several years is of higher importance at higher latitudes to achieve an adequate classification.

At a WFD water-area scale, EQR_1 and EQR_2 showed a large degree of variation. This means that the inlets studied deviate from each other in macrophyte composition and produce quite different EQRs within water areas. Despite this variation, the average EQR values for the water areas gave a status that is consistent with the ecological status classified using existing methods where such classification was available. This result indicates that the method suggested for shallow coastal areas could be a promising complement to the existing methods that are used for deeper areas.

The new method does, however, need to be developed further. The thresholds set to define ecological status classes should be evaluated in independent studies and the method should be developed and tested to also include more exposed soft or sandy bottoms. In addition, the characteristics of the substrate, its chemical properties, and the internal nutrient load to the inlet, should be taken into account to refine and possibly improve the analyses. In addition, possible feedback mechanisms should be examined, such as potentially elevated turbidity as a result of reduced vegetation cover. The rooted vegetation normally promotes resuspension by stabilising the soft-sediment bottoms. The method should be tested further for other regions, such as the Bothnian Bay and southern Scania. The latter region has a different coastal morphology and no clear stages of inlets following a gradient in topographic openness because of a lack of isostatic land uplift. For this region, a different approach will probably be necessary.

6 Conclusion

The aim of this study was to examine the effects of human activities on macrophytes in shallow Baltic Sea inlets, and to develop a method for assessment of ecological status for these shallow waters. Most of these coastal areas are too shallow, or have a species composition that does not allow a classification according to the current methods.

I recorded a shift in the proportion of tolerant to sensitive species with increasing TP and boating activity. The proportion of species previously documented as being sensitive to anthropogenic pressures decreased, while tolerant species increased, with increasing TP and level of boating activity. In addition, macrophyte cover was lower in inlets with high, as compared to low, boating pressure.

Natural environmental factors, such as topographic openness of the inlets, were found to be very important for explaining variation in the macrophyte community. However, a large part of the variation in the macrophyte community was unexplained in the models tested, and should be examined further.

Based on the results, an assessment method for classification of ecological status was developed. The method uses a macrophyte index based on a cover proportion of sensitive to tolerant species, as well as the mean cover of all species combined. The two macrophyte responses are expressed as ecological quality ratios relative to a reference condition, with specific threshold values to classify the ecological status. The status classes obtained using the proposed method corresponded in part to the status classes obtained using established methods. The suggested method can be a complement to the existing methods that are used for deeper areas. It does, however, require further development and independent testing before application.

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Appendix 1: List of all inlets included in the study, with data on location, Water Framework Directive (WFD) area, number of years surveyed, area, depth, type, and ecological status. Inlets are listed according to region and latitude.

Inlet name	Latitude (WGS 84)	Longitude (WGS 84)	Region	WFD surface water area	Years surveyed	Area (km^2)	Mean depth (m)	Max depth (m)	Natura 2000 habitat	Natura 2000 sub habitat	Flad-type	Ecological status
Salen 1	62.2153	17.6122	Bothnian Sea	N M Bottenhavets kustvatten	1	0.174	1.0	2.6	1150	1153	Flad	High
Salen 2 (södra delen)	62.2134	17.6028	Bothnian Sea	N M Bottenhavets kustvatten	1	0.185	1.6	2.5	1150	1154	Glo-flad	Moderate
Lill-Salen	62.2121	17.6164	Bothnian Sea	N M Bottenhavets kustvatten*	1	0.040	0.8	1.5	1150	1154	Glo	Bad
Tjockholmsviken	62.2015	17.6076	Bothnian Sea	N M Bottenhavets kustvatten	1	0.044	0.7	2.4	1150	1153	Flad	Good
Siviksfjärden område A	61.5764	17.0476	Bothnian Sea	Siviksfjärden	1	0.403	1.9	9.5	1160		Open inlet	Good
Siviksfjärden område C	61.5705	17.0693	Bothnian Sea	Siviksfjärden	1	0.072	2.3	5.8	1150	1152	Open inlet	Good
Norbergsfjärden	61.5640	17.0972	Bothnian Sea	Hålsängesfjärden	1	0.421	1.7	3.6	1150	1153	Flad	Good
Fågelviken	61.4455	17.1444	Bothnian Sea	Långvindsfjärden	5	0.016	1.3	2.4	1150	1153	Flad	Moderate
Utskärsviken	61.4454	17.2020	Bothnian Sea	S M Bottenhavets kustvatten	1	0.011	1.5	3.0	1150	1153	Flad	Poor
Yttra Storhamn	61.4449	17.1936	Bothnian Sea	Långvindsfjärden	5	0.041	1.8	2.6	1150	1153	Flad	High
Norra Norrfjärden	61.4429	17.1589	Bothnian Sea	Långvindsfjärden	1	0.422	4.3	9.8	1160		Open inlet	Poor
Mellersta Storhamn	61.4429	17.1983	Bothnian Sea	Långvindsfjärden	1	0.011	1.7	2.5	1150	1153	Flad	High
Mjölkviken	61.4359	17.1884	Bothnian Sea	Långvindsfjärden	5	0.027	1.0	2.0	1150	1153	Flad	High
Snäckenviken	61.4200	17.1786	Bothnian Sea	S M Bottenhavets kustvatten	1	0.015	0.7	1.6	1150	1153	Flad	High
Viken SV Kilsboholmen	61.3163	17.1381	Bothnian Sea	Midsommarfjärden	1	0.139	1.1	2.3			Open inlet	High
Inre Fransoshamnen	61.0849	17.1962	Bothnian Sea	Kusöfjärden	1	0.016	0.4	0.7	1150	1153	Flad	Poor
Viken S Gammelbo	61.0837	17.1808	Bothnian Sea	Kusöfjärden*	3	0.011	0.6	1.1	1150	1154	Glo-flad	Good
Viken på SO Bollön	61.0817	17.1793	Bothnian Sea	Kusöfjärden	3	0.005	0.9	1.5	1150	1153	Flad	High
Viken mellan Bollön och Alderharen	61.0800	17.1796	Bothnian Sea	Kusöfjärden	3	0.025	1.4	2.7	1150	1153	Flad	Poor
Västerhamn	61.0595	17.2664	Bothnian Sea	Kusöfjärden	3	0.024	1.3	2.5	1150	1153	Juv. flad	Poor
Viken N Österhamn	61.0589	17.2740	Bothnian Sea	S M Bottenhavets kustvatten	3	0.016	1.4	3.2	1150	1153	Flad	Poor
Viken O Västerhamn	61.0581	17.2710	Bothnian Sea	S M Bottenhavets kustvatten	3	0.017	0.9	2.6	1150	1154	Glo-flad	Moderate
Holmhamnen	61.0085	17.2519	Bothnian Sea	S M Bottenhavets kustvatten	1	0.028	1.2	3.0	1150	1153	Juv. flad	Good
Sörsundet	60.8921	17.2292	Bothnian Sea	S M Bottenhavets kustvatten	1	0.098	1.8	3.9	1150	1153	Flad	Bad
Näsviken	60.7877	17.3008	Bothnian Sea	Gävlebuktens utsjövatten	5	0.021	0.8	1.8	1150	1153	Flad	High
Halvfärdsrännan	60.7876	17.2914	Bothnian Sea	Gävlebuktens utsjövatten	2	0.009	0.7	1.8	1150	1153	Flad	Good
Viken S S:t Olofsstenen	60.7865	17.2958	Bothnian Sea	Gävlebuktens utsjövatten	5	0.014	0.8	2.3	1150	1153	Flad	High
Viken vid Storsand	60.7859	17.3031	Bothnian Sea	Gävlebuktens utsjövatten	1	0.011	0.6	1.5	1150	1153	Flad	High
Sundet S Halvfärdsrännan	60.7834	17.2909	Bothnian Sea	Gävlebuktens utsjövatten	1	0.007	0.6	0.8	1150	1153	Juv. flad	High
Viken mellan Jutter- och Alderharen	60.7832	17.2983	Bothnian Sea	Gävlebuktens utsjövatten	1	0.004	1.2	1.9	1150	1153	Juv. flad	Bad
Viken mellan Råhällsholmen och Gubbuddarna	60.7805	17.2918	Bothnian Sea	Gävlebuktens utsjövatten	1	0.004	1.0	1.9	1150	1153	Juv. flad	Poor
Valviken	60.7749	17.2910	Bothnian Sea	Gävlebuktens utsjövatten	4	0.008	0.5	1.1	1150	1153	Flad	High
Badviken	60.7173	17.3437	Bothnian Sea	Skutskärsfjärden	1	0.041	1.7	3.8	1150	1153	Juv. flad	Poor
Leken, O Gräsharen	60.6817	17.3087	Bothnian Sea	Yttre Fjärden	1	0.017	0.4	0.8	1150	1153	Flad	Poor
Rönnharsviken	60.6764	17.3286	Bothnian Sea	Skutskärsfjärden	1	0.025	0.5	1.2	1150	1153	Flad	Good
Viken mellan Yttre Arsmellan och Haren	60.6302	17.6357	Bothnian Sea	Gävlebuktens utsjövatten	2	0.153	1.9	3.4	1150	1153	Juv. flad	Poor
Viken vid Nätsten	60.6286	17.6316	Bothnian Sea	Gävlebuktens utsjövatten	2	0.051	1.4	2.6	1150	1153	Flad	Moderate
Glofladan V Österörarna	60.6284	17.6571	Bothnian Sea	Gävlebuktens utsjövatten	1	0.004	0.8	1.3	1150	1154	Glo	Poor
Glofladan mellan Inre och Yttre Vågholmen	60.6278	17.6253	Bothnian Sea	Gävlebuktens utsjövatten	1	0.031	0.7	1.3	1150	1154	Glo-flad	High
Glofladan SO Nätsten	60.6270	17.6325	Bothnian Sea	Gävlebuktens utsjövatten	1	0.006	0.8	2.1	1150	1154	Glo-flad	Poor
Viken S Österörarna	60.6266	17.6590	Bothnian Sea	Gävlebuktens utsjövatten	2	0.031	1.5	3.0	1150	1153	Flad	Bad
Glo N Murarholmen	60.6257	17.6341	Bothnian Sea	Gävlebuktens utsjövatten*	1	0.004	0.5	0.6	1150	1154	Glo	Good
Glofladan N Gubbsundet	60.6248	17.6313	Bothnian Sea	Gävlebuktens utsjövatten	1	0.024	0.9	1.5	1150	1154	Glo-flad	Poor
Glo O Murarholmen	60.6247	17.6368	Bothnian Sea	Gävlebuktens utsjövatten*	1	0.004	0.3	0.4	1150	1154	Glo	Good
Glo N Utterberget	60.6234	17.6432	Bothnian Sea	Gävlebuktens utsjövatten*	1	0.010	0.6	1.0	1150	1154	Glo	Poor
Glofladan mellan Tallharen och Fårhällen	60.6225	17.6469	Bothnian Sea	Lövstabukten*	1	0.008	0.6	1.4	1150	1154	Glo-flad	High
Glofladan N Kalvharen	60.6219	17.6591	Bothnian Sea	Lövstabukten	1	0.016	0.5	0.6	1150	1154	Glo-flad	Good
Viken V Kalvharen	60.6206	17.6561	Bothnian Sea	Lövstabukten	1	0.042	0.8	1.8	1150	1153	Flad	Moderate
Källhamnen	60.6195	17.9648	Bothnian Sea	Öregrundsgrepen	1	0.004	0.5	1.1	1150	1153	Flad	Good
Viken NO Långörarna	60.6190	17.6520	Bothnian Sea	Lövstabukten	1	0.102	1.2	2.4	1150	1153	Juv. flad	Poor
Björn	60.6127	17.9579	Bothnian Sea	Öregrundsgrepen	1	0.257	1.0	2.1	1160		Open inlet	High
Rackgropen	60.6017	17.9757	Bothnian Sea	Öregrundsgrepen	1	0.007	0.7	1.7	1150	1153	Flad	Bad
Del av sundet S Måsörarna	60.5925	18.0008	Bothnian Sea	Öregrundsgrepen	1	0.014	1.1	1.6	1150	1153	Flad	Poor
Viken V Djupsundsörarna	60.5866	18.0012	Bothnian Sea	Öregrundsgrepen	1	0.021	0.5	0.8	1150	1153	Flad	Good
Fjärden innanför Järnören/Gammelglamen	60.5840	18.0079	Bothnian Sea	Öregrundsgrepen	1	0.267	1.2	2.2	1160		Open inlet	Good
Viken V Norrstuggu	60.5800	18.0065	Bothnian Sea	Öregrundsgrepen	1	0.023	0.5	0.8	1150	1154	Glo-flad	Moderate
Draget	60.5400	18.0112	Bothnian Sea	Öregrundsgrepen	1	0.348	1.3	2.4	1150	1153	Juv. flad	Poor
Dragets inre lagun	60.5359	18.0030	Bothnian Sea	Öregrundsgrepen	1	0.018	0.5	0.8	1150	1154	Glo-flad	Good
Norrafjärdens SO del	60.5352	17.6974	Bothnian Sea	Karlholmsfjärden	1	0.108	1.7	2.6	1150	1153	Flad	Moderate
Viken S Svartharen	60.5337	17.7064	Bothnian Sea	Karlholmsfjärden	1	0.041	0.6	1.3	1150	1153	Flad	Good
Viken V Långgryndan	60.5303	18.0241	Bothnian Sea	Öregrundsgrepen	1	0.010	0.5	1.0	1150	1153	Flad	High
Viken N Torkeln	60.5265	17.6810	Bothnian Sea	Karlholmsfjärden	1	0.046	0.8	1.3	1150	1153	Flad	Bad
Svartglo	60.5223	18.4080	Bothnian Sea	Öregrunds kustvatten	1	0.021	1.2	2.6	1150	1153	Flad	Poor
Alarängsviken	60.5175	18.4082	Bothnian Sea	Öregrunds kustvatten	1	0.013	0.7	1.3	1150	1153	Flad	Moderate
Viken på N Högbådan	60.4804	18.4643	Bothnian Sea	Öregrunds kustvatten*	1	0.006	0.6	1.9	1150	1153	Flad	Moderate
Glofladan på N Högbådan	60.4804	18.4631	Bothnian Sea	Öregrunds kustvatten*	1	0.004	0.5	1.1	1150	1154	Glo-flad	Moderate
Östra Fluttudalen	60.4738	18.5567	Bothnian Sea	Öregrunds kustvatten	1	0.053	1.1	2.1	1150	1153	Juv. flad	High
Västra Fluttudalen	60.4731	18.5534	Bothnian Sea	Öregrunds kustvatten	1	0.043	1.5	3.8	1150	1153	Juv. flad	Good
Mjölnasundet	60.4705	18.0938	Bothnian Sea	Öregrundsgrepen	1	0.027	1.0	2.1	1150	1153	Juv. flad	Poor
Fladan SV Brännören	60.4678	18.0997	Bothnian Sea	Öregrundsgrepen	1	0.010	1.0	1.4	1150	1153	Flad	High
Viken V Storgranen	60.4662	18.0941	Bothnian Sea	Öregrundsgrepen	1	0.015	0.5	1.0	1150	1154	Glo-flad	Good
Högörsgropen	60.4611	18.1109	Bothnian Sea	Öregrundsgrepen	1	0.018	1.2	2.1	1150	1153	Flad	Bad
Viken innanför Stor-Mattingsören	60.4608	18.4521	Bothnian Sea	Öregrunds kustvatten	1	0.048	1.5	2.4	1150	1153	Juv. flad	Moderate
Högörssundet–Gräsörssundet–Djupsundet	60.4504	18.1060	Bothnian Sea	Öregrundsgrepen	1	0.394	2.0	4.5	1160		Open inlet	Poor
Glåbodarna	60.4497	18.0996	Bothnian Sea	Öregrundsgrepen	1	0.040	1.3	2.0	1150	1153	Flad	Good
Viken mellan Gumsskärsbådan och Tallskäret	60.4437	18.4798	Bothnian Sea	Öregrunds kustvatten	1	0.064	1.2	2.4	1150	1153	Flad	Good
Viken S Digelskäret (östra delen)	60.4424	18.4962	Bothnian Sea	Öregrunds kustvatten	1	0.053	1.1	1.7	1150	1153	Juv. flad	Moderate
Viken V Norrbådan	60.4355	18.6209	Bothnian Sea	Öregrunds kustvatten	1	0.012	0.9	2.0	1150	1153	Juv. flad	Poor
Bryggebåddalen	60.4322	18.5847	Bothnian Sea	Öregrunds kustvatten	1	0.030	1.1	2.0	1150	1153	Flad	Moderate
Glon V Rångkullen	60.4276	18.1330	Bothnian Sea	Öregrundsgrepen	1	0.010	0.2	0.6	1150	1154	Glo	High
Stångskärsviken	60.4271	18.1407	Bothnian Sea	Öregrundsgrepen	7	0.029	1.6	3.6	1150	1153	Juv. flad	Poor
Viken O Stångskäret	60.4236	18.1466	Bothnian Sea	Öregrundsgrepen	1	0.026	1.0	2.7	1150	1153	Juv. flad	Poor
Viken O Kullaskäret	60.4135	18.5535	Bothnian Sea	Öregrunds kustvatten	1	0.107	1.2	2.7	1150	1153	Juv. flad	Moderate
Viken O Jungfrufjärden	60.3911	18.2282	Bothnian Sea	Öregrundsgrepen	1	0.024	0.7	1.7	1150	1153	Flad	High
Hatten	60.3820	18.2487	Bothnian Sea	Öregrundsgrepen	7	0.098	1.9	3.0	1150	1153	Flad	Good
Kasfjärden	60.3783	18.2791	Bothnian Sea	Öregrundsgrepen	1	0.030	0.8	1.8	1150	1153	Flad	Good
Långörsviken	60.3717	18.2769	Bothnian Sea	Kallriga Fjärden	7	0.143	1.0	2.5	1150	1153	Flad	High
Långörsviken–Lövörssundet	60.3680	18.2762	Bothnian Sea	Kallriga Fjärden	1	0.313	1.7	3.2	1160		Open inlet	Moderate
Yttervarpet	60.3675	18.5572	Bothnian Sea	Gällfjärden	1	0.009	0.9	1.7	1150	1153	Flad	Moderate
Viken V Lill-Måssten	60.3639	18.5635	Bothnian Sea	Öregrunds kustvatten	1	0.009	0.9	1.6	1150	1153	Flad	High
Viken mellan Harudden och Hållet	60.3524	18.2495	Bothnian Sea	Kallriga Fjärden	1	0.157	0.8	1.6	1150	1153	Flad	High
Viken N Djäknevarp	60.3516	18.5583	Bothnian Sea	Öregrunds kustvatten	1	0.023	1.8	2.4	1150	1153	Flad	Poor
Viken mellan Lilla Risten och Måsören	60.3340	18.5883	Bothnian Sea	Öregrunds kustvatten	1	0.013	1.3	2.5	1150	1153	Juv. flad	Poor
Viken mellan Rönnören och Måshällorna	60.2975	18.6570	Bothnian Sea	Öregrunds kustvatten	1	0.036	1.1	2.3	1150	1153	Juv. flad	Moderate
Viken mellan Högastören och Äspörarna	60.2975	18.5994	Bothnian Sea	Öregrunds kustvatten	1	0.024	1.2	1.7	1150	1153	Flad	Moderate
Viken mellan Hundören och Långören	60.2965	18.6471	Bothnian Sea	Öregrunds kustvatten	1	0.009	0.9	1.7	1150	1153	Juv. flad	Good
Viken V Högskäret	60.2946	18.5283	Bothnian Sea	Ängsfjärden	1	0.012	1.7	2.5	1150	1153	Juv. flad	Poor
Kastviken	60.2915	18.6463	Bothnian Sea	Öregrunds kustvatten	1	0.013	1.1	1.9	1150	1153	Juv. flad	Poor
Viken S om Sältingsörarna	60.2809	18.6998	Bothnian Sea	Öregrunds kustvatten	1	0.005	0.7	1.4	1150	1153	Flad	Good
Bodskärets gloflada	60.2803	18.7018	Bothnian Sea	Öregrunds kustvatten	1	0.011	0.8	2.0	1150	1154	Glo-flad	Moderate
Söderfjärdens gloflada	60.2728	18.6218	Bothnian Sea	Kasfjärden	1	0.045	1.6	2.2	1150	1154	Glo-flad	Moderate
Söderfjärden	60.2696	18.6283	Bothnian Sea	Kasfjärden	1	0.201	2.3	3.9	1160		Open inlet	Poor

Inlet name	Latitude (WGS 84)	Longitude (WGS 84)	Region	WFD surface water area	Years surveyed	Area (km^2)	Mean depth (m)	Max depth (m)	Natura 2000 habitat	Natura 2000 sub habitat	Flad-type	Ecological status
Söderhäll	60.2059	18.4655	Bothnian Sea	Hargsviken	1	0.057	1.2	2.9	1150	1153	Flad	Moderate
Viken vid Kyrkbåtörarna	60.2016	18.5774	Bothnian Sea	Galtfjärden	1	0.014	1.1	1.7	1150	1153	Flad	Moderate
Slätöviken	60.1935	18.6364	Bothnian Sea	Raggaröfjärden	1	0.037	2.3	3.5	1150	1153	Juv. flad	Moderate
Nordanvadet	60.1874	18.5287	Bothnian Sea	Galtfjärden	1	0.021	1.9	2.5	1150	1152	Open inlet	Moderate
Viken V Kalvskär	60.1768	18.5070	Bothnian Sea	Hargsviken	1	0.075	1.0	1.7	1150	1153	Flad	Moderate
Askholmsviken	60.1580	18.4996	Bothnian Sea	Hargsviken	1	0.072	0.4	1.0	1150	1152	Open inlet	High
Skabergsviken	59.9298	18.9047	Bothnian Sea	Östhammars kustvatten	1	0.011	0.5	1.0	1150	1154	Glo-flad	Good
Urfjärden	59.9291	18.9313	Bothnian Sea	Östhammars kustvatten	1	0.172	2.0	3.8	1150	1153	Flad	Poor
Skötviken	60.4362	20.0544	Archipelago Sea	Koxnan	1	0.030	2.3	4.8	1150	1153	Flad	Moderate
Västervik	60.4323	20.0463	Archipelago Sea	Saggöfjärden	1	0.018	2.0	3.2	1150	1153	Juv. flad	Moderate
Nordanmellan	60.3988	19.9536	Archipelago Sea	Koxnan	1	0.032	0.8	1.3	1150	1154	Glo-flad	Moderate
Rövarp	60.3833	19.9594	Archipelago Sea	Engrundsfärden	1	0.012	0.6	1.0	1150	1153	Juv. flad	High
Algrunden	60.3819	19.9568	Archipelago Sea	Engrundsfärden	1	0.017	0.7	1.3	1150	1152	Open inlet	High
Lisström	60.3752	19.9327	Archipelago Sea	Engrundsfärden	1	0.122	1.8	2.9	1150	1153	Flad	High
Långö	60.3727	20.0426	Archipelago Sea	Flatöfjärden	1	0.017	0.5	1.4			Open inlet	High
Mellanvik	60.3723	20.0389	Archipelago Sea	Flatöfjärden	1	0.010	0.7	1.3			Open inlet	High
Fladan	60.3431	20.4161	Archipelago Sea	Simskälafjärden	1	0.035	0.9	2.1	1150	1153	Flad	Poor
Korsholmsfladan	60.3278	20.4310	Archipelago Sea	Södra Delet	1	0.031	0.9	1.3	1150	1153	Flad	High
Hemviken (Åland)	60.3273	19.7122	Archipelago Sea	Andersöfjärden	1	0.022	0.7	1.1	1150	1153	Flad	High
Mjärdvik	60.2960	19.7711	Archipelago Sea	Sandviksfjärden	4	0.040	2.0	3.6	1150	1154	Glo-flad	Moderate
Hamnfladan	60.2915	20.3292	Archipelago Sea	Simskälafjärden	4	0.026	1.2	2.6	1150	1153	Juv. flad	Moderate
Andholmssund	60.2786	20.3537	Archipelago Sea	Simskälafjärden	5	0.034	1.1	2.5	1150	1153	Flad	High
Gloet (Åland)	60.2767	19.8231	Archipelago Sea	Ivarskärsfjärden	5	0.059	2.0	3.6	1150	1154	Glo-flad	Good
Gölen	60.2632	20.3970	Archipelago Sea	Södra Delet*	1	0.094	0.5	0.7	1150	1153	Flad	Poor
Bågskärsören	60.2579	20.3137	Archipelago Sea	Vargatafjärden	1	0.024	1.0	1.6	1150	1153	Flad	Poor
Svanvik	60.2521	19.8177	Archipelago Sea	Ivarskärsfjärden	1	0.011	0.7	1.1	1150	1153	Flad	High
Notgrundsgloet	60.2426	19.8284	Archipelago Sea	Röjsbölefjärden	4	0.091	1.1	2.4	1150	1153	Flad	High
Listersbyviken	60.2240	20.3724	Archipelago Sea	Bussöfjärden	1	0.114	0.9	1.9			Open inlet	Good
Inre Kapellviken	60.1210	20.2577	Archipelago Sea	Lumparn	1	0.182	1.2	2.2	1150	1153	Flad	Moderate
Rönnäsfladan	60.1082	20.5330	Archipelago Sea	Mosshaga-Algersö	2	0.046	0.8	1.5	1150	1153	Flad	Moderate
Båthusgrunden	60.1047	20.2732	Archipelago Sea	Österfjärden	1	0.146	0.5	0.8	1150	1153	Flad	Poor
Svinöviken	60.0934	20.2644	Archipelago Sea	Österfjärden	1	0.130	0.4	1.4	1150	1154	Glo-flad	Poor
Norrfladan	60.0894	20.2983	Archipelago Sea	Österfjärden	4	0.042	1.9	4.0	1150	1153	Flad	Moderate
Delsvik	60.0773	20.2215	Archipelago Sea	Föglöfjärden	1	0.024	0.4	1.4	1150	1153	Flad	Good
Gäddviken	60.0533	20.5200	Archipelago Sea	Embarsund	1	0.015	0.4	0.7	1150	1153	Juv. flad	Moderate
Sälgskärsfladan	60.0468	20.6051	Archipelago Sea	Mosshaga-Algersö	1	0.034	0.9	1.5	1150	1153	Flad	Moderate
Hästskrässundet	60.0328	20.4997	Archipelago Sea	Södra Föglö innerskärgård	1	0.040	0.4	1.0	1150	1152	Open inlet	Moderate
Skogbodaviken	60.0172	20.5043	Archipelago Sea	Södra Föglö innerskärgård	1	0.049	0.4	1.4	1150	1154	Glo-flad	Good
Mörboholm	60.0081	20.5418	Archipelago Sea	Södra Föglö innerskärgård	1	0.033	1.4	2.5	1150	1154	Glo-flad	Moderate
Ramsholmsfladan	60.0075	20.5125	Archipelago Sea	Södra Föglö innerskärgård	2	0.014	1.1	2.2	1150	1153	Flad	Moderate
Sunnanvik	60.0494	23.4631	Gulf of Finland	Pohjanpitäjänlahti	1	0.013	2.5	3.5			Open inlet	Moderate
Huluvik	60.0121	23.4540	Gulf of Finland	Pohjanpitäjänlahti	1	0.015	2.0	4.5	1150	1153	Juv. flad	Good
Lillvik	59.9976	23.4790	Gulf of Finland	Pohjanpitäjänlahti	1	0.059	1.3	1.8			Open inlet	Moderate
Gårdsvik	59.9476	23.4266	Gulf of Finland	Dragsvik	1	0.087	1.6	3.1	1150	1153	Flad	Moderate
Strömsö	59.9301	23.7546	Gulf of Finland	Barösund	3	0.116	0.7	1.6	1150	1154	Glo-flad	Bad
Backfladan	59.9145	23.4784	Gulf of Finland	Box	1	0.037	0.8	1.9	1150	1153	Flad	Moderate
Gyltvik	59.9091	23.4113	Gulf of Finland	Box	1	0.081	1.8	2.6	1150	1153	Juv. flad	Poor
Ytteröfladan	59.9072	23.6133	Gulf of Finland	Sandöfjärden	1	0.082	1.1	2.6	1150	1153	Flad	Poor
Solbacksfladan	59.9003	23.3555	Gulf of Finland	Storfjärden	1	0.136	1.0	1.8	1150	1154	Glo-flad	High
Danskog	59.8971	23.3883	Gulf of Finland	Box	3	0.151	1.4	2.9	1150	1153	Flad	Moderate
Simmet	59.8970	23.5073	Gulf of Finland	Sandöfjärden	1	0.086	0.7	1.4	1150	1154	Glo-flad	Poor
Åkernäsfladan	59.8939	23.4746	Gulf of Finland	Sandöfjärden	3	0.182	1.0	3.5	1150	1154	Glo-flad	Poor
Mörnäs	59.8917	23.3596	Gulf of Finland	Storfjärden	3	0.031	1.2	2.1	1150	1153	Juv. flad	Moderate
Nothamn	59.8818	23.6924	Gulf of Finland	Porkkala-Jussarö	1	0.026	2.0	2.5	1150	1153	Juv. flad	Moderate
Älgöfladan	59.8765	23.3769	Gulf of Finland	Storfjärden	1	0.023	2.1	3.7	1150	1153	Juv. flad	Poor
Verkholmsfladan	59.8691	23.4124	Gulf of Finland	Sandöfjärden	3	0.059	1.0	2.0	1150	1153	Flad	Moderate
Krokgloet	59.8663	23.5679	Gulf of Finland	Sandöfjärden	1	0.010	1.0	3.5	1150	1153	Flad	Moderate
Mejholmsfladan	59.8657	23.4017	Gulf of Finland	Sandöfjärden	2	0.065	1.8	3.0	1150	1153	Flad	Poor
Potten	59.8641	23.3706	Gulf of Finland	Storfjärden	1	0.014	2.0	3.5	1150	1152	Open inlet	Moderate
Bönholmsviken	59.8474	23.2400	Gulf of Finland	Storfjärden	2	0.023	1.5	3.0			Open inlet	Poor
Krogarvik	59.8455	23.2468	Gulf of Finland	Storfjärden	3	0.022	1.3	2.3	1150	1152	Open inlet	Moderate
Kallvass	59.8408	23.2335	Gulf of Finland	Storfjärden	2	0.061	2.1	4.0	1150	1152	Open inlet	Moderate
Vindskärsviken	59.8275	23.2091	Gulf of Finland	Hankoniemi	2	0.010	1.6	2.6	1150	1152	Open inlet	Moderate
Jussarö	59.8221	23.5600	Gulf of Finland	Hankoniemi	1	0.009	1.5	2.6	1150	1153	Juv. flad	Moderate
Gisslingöfladen	59.7741	19.1665	W Baltic Sea Proper	Söderarms skärgård	2	0.092	0.9	2.2	1150	1153	Flad	High
Harkranksviken	59.7677	19.1834	W Baltic Sea Proper	Söderarms skärgård	1	0.033	0.9	2.1	1150	1153	Juv. flad	High
Östra Lermaren	59.6737	18.8838	W Baltic Sea Proper	Ålandsfjärden	7	0.110	1.8	3.6	1150	1153	Flad	Good
Räknöviken	59.6644	18.7830	W Baltic Sea Proper	Yxlaområdet	1	0.009	0.6	1.5	1150	1153	Juv. flad	Good
Söderfladen	59.6641	18.8690	W Baltic Sea Proper	Yxlaområdet	8	0.072	1.3	2.7	1150	1154	Glo-flad	Moderate
Bärsöfladen	59.6617	18.7145	W Baltic Sea Proper	Yxlaområdet	1	0.177	1.2	1.9	1150	1153	Flad	Moderate
Norrängsfladen	59.6568	18.8334	W Baltic Sea Proper	Yxlaområdet	1	0.012	1.0	1.5	1150	1154	Glo-flad	Moderate
Norrviken (Hemmarö)	59.6505	18.7847	W Baltic Sea Proper	Yxlaområdet	1	0.043	2.7	5.8			Open inlet	Bad
Hemviken (Ängsö)	59.6192	18.7637	W Baltic Sea Proper	Yxlaområdet	1	0.012	0.8	1.3	1150	1153	Flad	Poor
Stor-Andöviken	59.5997	18.7471	W Baltic Sea Proper	Yxlaområdet	7	0.029	1.6	3.2	1150	1153	Flad	Good
Klintsundet	59.5366	18.7484	W Baltic Sea Proper	Gälnan	1	0.044	1.9	3.2	1150	1152	Open inlet	Bad
V Lagnö	59.5345	18.7237	W Baltic Sea Proper	Gälnan	1	0.047	2.1	2.8	1150	1153	Flad	Poor
Åsättrafladen	59.5040	18.6392	W Baltic Sea Proper	Gälnan	1	0.080	1.2	2.2	1150	1152	Open inlet	Poor
Sund vid Särsö	59.4940	18.8518	W Baltic Sea Proper	Svartlögafjärden	1	0.006	1.5	2.8			Open inlet	Poor
Lundöfladen	59.4896	18.7868	W Baltic Sea Proper	Träsköfjärden	1	0.027	1.9	2.8	1150	1154	Glo-flad	Moderate
S Idholmen & N Finnhamn	59.4809	18.8161	W Baltic Sea Proper	Svartlögafjärden	1	0.027	1.1	2.5			Open inlet	Poor
Finnhamn	59.4756	18.8209	W Baltic Sea Proper	Träsköfjärden	1	0.030	2.1	4.2	1150	1153	Juv. flad	Poor
Hummelmora	59.4575	18.5971	W Baltic Sea Proper	Träsköfjärden	1	0.033	1.3	2.5			Open inlet	Poor
Blötviken	59.4574	18.7346	W Baltic Sea Proper	Träsköfjärden	1	0.044	1.7	3.0	1150	1153	Juv. flad	Bad
Brunskär–Huvudholmen N	59.4557	18.8113	W Baltic Sea Proper	Träsköfjärden	1	0.019	2.2	5.2	1150	1153	Flad	Moderate
St. Kalholmen	59.4538	18.8231	W Baltic Sea Proper	Träsköfjärden*	2	0.012	2.2	5.3	1150	1153	Juv. flad	Poor
St. Huvudholmen–Träskö–Storö	59.4529	18.8058	W Baltic Sea Proper	Träsköfjärden	1	0.025	1.9	2.8	1150	1153	Juv. flad	Moderate
Brunskär–Huvudholmen S	59.4527	18.8129	W Baltic Sea Proper	Träsköfjärden	1	0.012	1.0	1.5	1150	1153	Flad	High
Koholmarna	59.4491	18.7388	W Baltic Sea Proper	Träsköfjärden	1	0.020	1.4	2.6	1150	1153	Flad	Bad
Modermagen	59.4429	19.2172	W Baltic Sea Proper	Gillögafjärden	1	0.006	0.7	1.0	1150	1154	Glo-flad	Good
Sundet mellan Bäckskäret och Gubben	59.4426	19.2136	W Baltic Sea Proper	Ormskärsfjärden	1	0.024	2.0	3.8	1150	1152	Open inlet	Poor
Gumfladen	59.4406	19.2173	W Baltic Sea Proper	Gillögafjärden	1	0.046	2.0	4.3	1150	1153	Juv. flad	Good
Flakholmen	59.4403	18.7792	W Baltic Sea Proper	Träsköfjärden	1	0.009	1.4	2.0	1150	1153	Flad	Moderate
NÖ Idholmen	59.4282	18.6363	W Baltic Sea Proper	Träsköfjärden	1	0.006	0.7	1.5	1150	1152	Juv. flad	Poor
N Björkholmen–Krokholmarna	59.4210	18.6556	W Baltic Sea Proper	Träsköfjärden	1	0.009	2.1	5.2			Open inlet	Poor
Roskärsfladen inre	59.4190	19.0199	W Baltic Sea Proper	Björkskärsfjärden	2	0.034	0.8	1.6	1150	1154	Glo-flad	High
Saffransskäret	59.4186	18.9386	W Baltic Sea Proper	Kallskärsfjärden	1	0.026	2.0	5.6			Open inlet	Good
Roskärsfladen yttre	59.4177	19.0143	W Baltic Sea Proper	Björkskärsfjärden	1	0.018	1.3	2.2	1150	1153	Juv. flad	Good
Ö Lillön	59.4091	18.6121	W Baltic Sea Proper	Träsköfjärden	1	0.030	2.1	4.7			Open inlet	Bad
V Västerholmen	59.3979	18.7375	W Baltic Sea Proper	Skagsfjärden	1	0.013	1.5	2.5			Open inlet	Good
Ö Västerholmen	59.3883	18.6066	W Baltic Sea Proper	Träsköfjärden	1	0.017	1.6	3.0			Open inlet	Good
Bolviken	59.3825	18.5301	W Baltic Sea Proper	Sandöfjärden	1	0.029	2.9	5.0	1150	1152	Open inlet	Bad
Kalvsviksviken	59.3534	18.6253	W Baltic Sea Proper	Älgöfjärden	1	0.014	1.1	2.0	1150	1153	Juv. flad	High
Bäckmansfladen	59.3500	18.6635	W Baltic Sea Proper	Älgöfjärden	1	0.015	1.2	2.0			Open inlet	Good
Norrviken (Vindö)	59.3489	18.7378	W Baltic Sea Proper	Sollenkrokafjärden	2	0.011	1.5	3.0			Open inlet	Poor
Maren (Vindö)	59.3362	18.7017	W Baltic Sea Proper	Älgöfjärden*	1	0.034	1.2	1.8	1150	1154	Glo-flad	Moderate
Källmoviken	59.3298	18.7404	W Baltic Sea Proper	Sollenkrokafjärden*	2	0.019	1.6	2.6	1150	1153	Flad	High
Älvsalaviken	59.2994	18.6339	W Baltic Sea Proper	Breviken	1	0.049	1.7	2.5	1150	1153	Flad	Moderate

Inlet name	Latitude (WGS 84)	Longitude (WGS 84)	Region	WFD surface water area	Years surveyed	Area (km^2)	Mean depth (m)	Max depth (m)	Natura 2000 habitat	Natura 2000 sub habitat	Flad-type	Ecological status
S Näsudden	59.2987	18.7870	W Baltic Sea Proper	Brandfjärden	1	0.014	1.3	2.5	1150	1152	Open inlet	Bad
Fårviken	59.2831	18.6311	W Baltic Sea Proper	Breviken	1	0.024	2.1	3.2	1150	1152	Open inlet	Poor
Västerviken	59.2812	18.6907	W Baltic Sea Proper	Nämdöfjärden	1	0.039	1.4	2.5	1150	1153	Flad	Poor
Norrviken (Fågelbrolandet)	59.2799	18.5584	W Baltic Sea Proper	Tranaröfjärden	1	0.103	0.9	2.0	1150	1154	Glo-flad	Moderate
Västergården	59.2760	18.5384	W Baltic Sea Proper	Tranaröfjärden	1	0.037	1.6	2.5			Open inlet	Bad
Hanskroka	59.2622	18.5511	W Baltic Sea Proper	Tranaröfjärden	1	0.013	1.3	2.0	1150	1153	Flad	Bad
Slängen	59.2319	18.5498	W Baltic Sea Proper	Björnöfjärden	1	0.050	1.8	2.8	1150	1154	Glo-flad	Bad
Norra fladen	59.1425	18.6838	W Baltic Sea Proper	Norrfjärden	1	0.126	1.1	2.4	1150	1153	Flad	High
Mellanfladen	59.1361	18.6795	W Baltic Sea Proper	Norrfjärden	1	0.007	0.3	0.5	1150	1154	Glo-flad	Moderate
Södra fladen	59.1345	18.6726	W Baltic Sea Proper	Norrfjärden	1	0.122	2.2	5.3	1150	1153	Flad	Good
Killingen–Trädgårdsgrund	59.1246	18.3638	W Baltic Sea Proper	Sandemars fjärd	1	0.137	1.5	4.0	1160		Open inlet	Good
Svärdsnäsviken	59.1245	18.3419	W Baltic Sea Proper	Sandemars fjärd	1	0.330	2.0	4.3	1160		Open inlet	Moderate
Höggarn–Killingen	59.1213	18.3536	W Baltic Sea Proper	Sandemars fjärd	1	0.076	1.6	4.9			Open inlet	Good
Gunnarsholmen	59.1199	18.3713	W Baltic Sea Proper	Sandemars fjärd	1	0.003	1.2	1.9			Open inlet	Moderate
NÖ Kymmendö	59.1169	18.5222	W Baltic Sea Proper	Hanstensfjärden	1	0.012	1.0	2.0	1150	1153	Flad	Poor
Torviken	59.1134	18.4788	W Baltic Sea Proper	Hanstensfjärden*	1	0.021	1.4	2.0	1150	1154	Glo-flad	Poor
Tistronskäret	59.1079	18.6697	W Baltic Sea Proper	Biskopsfjärden	1	0.025	1.7	2.4	1150	1152	Open inlet	Moderate
Östra Fladen Boskapsön	59.0917	18.6245	W Baltic Sea Proper	Biskopsfjärden	1	0.290	1.4	4.2	1150	1152	Open inlet	Good
Fiversättra	59.0836	18.4813	W Baltic Sea Proper	Hanstensfjärden	1	0.012	0.7	1.3	1150	1152	Open inlet	High
Ramsholmen	59.0480	18.1880	W Baltic Sea Proper	Mysingen	1	0.071	1.4	2.0	1150	1153	Juv. flad	Poor
Hansviken	59.0279	18.0230	W Baltic Sea Proper	Horsfjärden	1	0.035	1.0	2.4	1150	1152	Open inlet	Good
SV Ängsön	59.0199	18.5529	W Baltic Sea Proper	Norstensfjärden	1	0.018	1.2	2.5	1150	1153	Juv. flad	Poor
Brantvarpet	58.9560	18.3309	W Baltic Sea Proper	Stockholms skärgårds s kustvatten	1	0.014	1.2	1.9	1150	1153	Juv. flad	Good
Häggnäsviken	58.9557	17.5921	W Baltic Sea Proper	Gälöfjärden	1	0.748	1.6	5.2	1160		Open inlet	Moderate
Viken mellan Skängeludden och Brantvarpet	58.9548	18.3294	W Baltic Sea Proper	Stockholms skärgårds s kustvatten	1	0.030	1.2	2.5	1150	1153	Juv. flad	Good
Löjskärsfladen	58.9546	18.3341	W Baltic Sea Proper	Stockholms skärgårds s kustvatten	1	0.122	2.2	4.3	1150	1153	Juv. flad	Good
Rävsalaviken	58.9528	17.6051	W Baltic Sea Proper	Gälöfjärden	1	0.177	1.6	3.9			Open inlet	Moderate
Vänsviken	58.9514	18.3196	W Baltic Sea Proper	Stockholms skärgårds s kustvatten	1	0.082	1.9	3.6	1150	1153	Juv. flad	Good
Byviken	58.9333	18.2287	W Baltic Sea Proper	Mysingen	1	0.124	1.3	3.5	1150	1153	Flad	Good
Gravamaren	58.8815	17.8758	W Baltic Sea Proper	Dragfjärden	1	0.108	2.3	4.0	1150	1153	Flad	Moderate
Hundsviken	58.8785	17.4859	W Baltic Sea Proper	Hållsviken	1	0.025	0.6	1.5	1150	1152	Open inlet	Moderate
Hemviken (Rassa vikar)	58.8700	17.8770	W Baltic Sea Proper	Dragfjärden	1	0.030	2.2	3.8	1150	1153	Juv. flad	Moderate
Ekulsvikmaren	58.8652	17.8598	W Baltic Sea Proper	Dragfjärden	1	0.017	0.6	1.1	1150	1154	Glo-flad	High
Storvarpet	58.8568	17.5947	W Baltic Sea Proper	Fågelöfjärden	1	0.016	1.3	2.4			Open inlet	Good
Maren (Nynäshamn)	58.8531	17.8740	W Baltic Sea Proper	Dragfjärden	1	0.116	3.8	6.2	1150	1153	Flad	Poor
Koholmsflan	58.8354	17.6143	W Baltic Sea Proper	Asköfjärden	1	0.007	1.2	2.5	1150	1152	Open inlet	High
Skitviken	58.8240	17.6326	W Baltic Sea Proper	Krabbfjärden	1	0.008	0.8	1.6	1150	1153	Flad	Moderate
Svarthålet	58.8171	17.4659	W Baltic Sea Proper	Gunnarbofjärden	5	0.021	0.9	1.9	1150	1152	Open inlet	Moderate
Södra Flan	58.8093	17.6534	W Baltic Sea Proper	Krabbfjärden	1	0.054	1.7	3.1	1150	1152	Open inlet	Good
Skutviken	58.8052	17.6761	W Baltic Sea Proper	Krabbfjärden	2	0.035	1.2	2.5	1150	1152	Open inlet	Good
Viken SV Lacka	58.7505	17.5641	W Baltic Sea Proper	Krabbfjärden	1	0.006	1.1	3.5	1150	1152	Open inlet	Poor
Hamnhamn	58.7468	17.5720	W Baltic Sea Proper	Krabbfjärden	4	0.014	1.2	4.9	1150	1153	Juv. flad	Good
Långa uddsviken	58.7451	17.3816	W Baltic Sea Proper	Dragviksfjärden	1	0.010	1.7	3.1	1150	1152	Open inlet	Moderate
Sanda holme	58.7448	17.3353	W Baltic Sea Proper	Kråkfjärden	1	0.035	0.9	1.3	1150	1153	Flad	Moderate
Lermaren	58.7443	17.4654	W Baltic Sea Proper	Tvären	5	0.025	1.0	2.0	1150	1154	Glo-flad	Good
Stenmarsfladen	58.7349	17.5106	W Baltic Sea Proper	Krabbfjärden	5	0.037	0.8	1.3	1150	1154	Glo-flad	Good
Viken S Björkskär	58.7309	17.5125	W Baltic Sea Proper	Krabbfjärden	1	0.016	1.1	2.4	1150	1153	Flad	Good
Långa Klubben	58.7304	17.4177	W Baltic Sea Proper	Kränkfjärden	3	0.014	1.2	2.5	1150	1153	Juv. flad	Moderate
Östra viken	58.7294	17.1901	W Baltic Sea Proper	Risöområdet	1	0.028	1.0	1.8	1150	1153	Juv. flad	Moderate
Kuggviken	58.7284	17.4436	W Baltic Sea Proper	Ringsöfjärden	5	0.050	1.1	2.5	1150	1153	Flad	Poor
Östra Kittelö	58.7092	17.3049	W Baltic Sea Proper	Risöområdet	4	0.023	1.2	2.2	1150	1153	Flad	Moderate
Gräshålet	58.6807	17.4758	W Baltic Sea Proper	Kränkfjärden	5	0.018	1.1	3.2	1150	1153	Juv. flad	Good
Slängaviken	58.6784	16.9557	W Baltic Sea Proper	Marsviken	1	0.043	0.6	0.8	1150	1152	Open inlet	Good
Beten	58.6450	17.1545	W Baltic Sea Proper	Furöområdet	4a	0.038	1.2	3.3	1150	1153	Flad	Moderate
Mörkviken	58.6145	16.9189	W Baltic Sea Proper	Bråvikens kustvatten	1	0.026	1.0	1.9	1150	1152	Open inlet	Moderate
Flada på Myrholmarna	58.5892	16.8772	W Baltic Sea Proper	Bosöfjärden	1	0.016	0.9	3.2	1150	1153	Flad	Moderate
Glo på Myrholmarna	58.5886	16.8758	W Baltic Sea Proper	Bosöfjärden*	1	0.004	1.1	1.6	1150	1154	Glo	Good
Grunda sjön	58.5606	16.7835	W Baltic Sea Proper	Bosöfjärden	1	0.019	0.6	1.7	1150	1153	Flad	Poor
Viken på S St. Stångskär	58.5541	16.9943	W Baltic Sea Proper	Bråvikens kustvatten	1	0.004	0.5	0.8	1150	1153	Flad	High
Ramnöfjärden	58.5450	16.8245	W Baltic Sea Proper	Bosöfjärden	1	0.140	0.6	0.9	1150	1152	Open inlet	Moderate
Viken på V Kallhamn	58.5443	16.9737	W Baltic Sea Proper	Bråvikens kustvatten	1	0.012	1.5	2.5	1150	1152	Open inlet	Moderate
Utsättersfjärden	58.5429	16.8133	W Baltic Sea Proper	Bosöfjärden	1	0.109	0.5	1.1	1150	1154	Glo-flad	Moderate
Sundet mellan Korsö och Utterskär	58.5245	16.9732	W Baltic Sea Proper	Bråvikens kustvatten	1	0.016	1.1	1.9	1150	1152	Open inlet	Moderate
Norra sundet mellan Västra och Östra Tyxholm	58.4403	16.9997	W Baltic Sea Proper	St Anna skärgårds kustvatten	1	0.010	1.2	2.0	1150	1153	Juv. flad	Good
Sundet mellan Krokiga träden, Västra Tyxholm och Flötskär	58.4396	16.9960	W Baltic Sea Proper	St Anna skärgårds kustvatten	1	0.012	1.5	2.6	1150	1152	Open inlet	Moderate
Norrflagen	58.3785	16.9180	W Baltic Sea Proper	Kärrfjärden	1	0.044	0.9	2.5	1150	1152	Open inlet	Moderate
Häradsskärsflagen	58.3769	16.9554	W Baltic Sea Proper	Kärrfjärden	1	0.107	2.2	4.6	1150	1153	Juv. flad	Good
Sörflagen	58.3763	16.9166	W Baltic Sea Proper	Kärrfjärden	3	0.019	0.7	1.1	1150	1154	Glo-flad	Good
Flada på Måsklabbarna	58.3600	17.0065	W Baltic Sea Proper	Kärrfjärden	1	0.003	0.3	0.7	1150	1153	Flad	Good
Gloflada på Måsklabbarna	58.3591	17.0055	W Baltic Sea Proper	Kärrfjärden	1	0.001	0.4	0.6	1150	1154	Glo-flad	Moderate
Sundet mellan Brottskären	58.3471	16.9400	W Baltic Sea Proper	Kärrfjärden	1	0.029	1.6	2.8	1150	1152	Open inlet	Good
Äspskärsflagen	58.3368	16.9732	W Baltic Sea Proper	Kärrfjärden	1	0.026	1.6	3.6	1150	1153	Flad	Good
Viken på S Hamna	58.3151	17.0088	W Baltic Sea Proper	Kullskärsdjupet	1	0.029	0.9	2.2	1150	1153	Juv. flad	Good
Tjärnsvik	58.2684	16.8830	W Baltic Sea Proper	Finnfjärden	1	0.051	1.6	2.9	1150	1153	Flad	Moderate
Sundet mellan Torrön, Gröskär och St. Tallskär	58.2644	16.9814	W Baltic Sea Proper	Turmulefjärden	1	0.070	1.9	3.7	1150	1153	Juv. flad	Good
Viken NV Källholmshällen	58.2541	16.9642	W Baltic Sea Proper	Turmulefjärden	1	0.008	0.8	1.6	1150	1152	Open inlet	Poor
Sörsundsviken	58.2520	16.8803	W Baltic Sea Proper	Orren	1	0.033	1.4	2.9	1150	1152	Open inlet	Moderate
Fladan på Sandskären	58.2120	16.9895	W Baltic Sea Proper	Ytteröområdet	1	0.009	0.7	1.1	1150	1153	Flad	Moderate
Gloflada på Gubbön	58.1966	16.9578	W Baltic Sea Proper	Ytteröområdet*	1	0.015	1.3	2.6	1150	1154	Glo-flad	High
Viken innanför Skräckskärsklabben	58.1673	16.9789	W Baltic Sea Proper	Ytteröområdet	1	0.008	1.4	3.4	1150	1153	Flad	Good
Mörtviken	58.0742	16.7650	W Baltic Sea Proper	Licknevarpefjärden*	1	0.031	0.2	0.6	1150	1154	Glo-flad	Moderate
Härsfjärden	58.0741	16.7763	W Baltic Sea Proper	Yttre Valdemarsviken*	1	0.165	1.0	2.6	1150	1154	Glo-flad	High
Gloflada vid Båtsa på Kvädö	58.0573	16.7924	W Baltic Sea Proper	Kvädöfjärden	1	0.018	0.4	0.6	1150	1154	Glo-flad	Moderate
Långfjärdsviken	58.0547	16.7438	W Baltic Sea Proper	Licknevarpefjärden	1	0.212	1.3	2.8	1150	1153	Flad	High
Båtsviken	58.0539	16.7968	W Baltic Sea Proper	Kvädöfjärden	1	0.061	1.5	2.3	1150	1153	Juv. flad	Moderate
Fjärden	58.0195	16.7650	W Baltic Sea Proper	Kvädöfjärden	1	0.071	0.8	2.0	1150	1153	Flad	High
Sundet mellan Kolmosö, Äleskär och Torrö	58.0109	16.7772	W Baltic Sea Proper	Kvädöfjärden	1	0.179	1.5	2.7	1150	1153	Juv. flad	High
Kungshamnen	58.0060	16.8050	W Baltic Sea Proper	Kvädöfjärden	1	0.007	0.6	1.2	1150	1154	Glo-flad	Good
Bredkroken	58.0042	16.8019	W Baltic Sea Proper	Kvädöfjärden	3	0.025	0.7	1.5	1150	1154	Glo-flad	Good
Hummeldalen	57.9442	16.7937	W Baltic Sea Proper	Kåröområdet	1	0.019	1.5	2.4	1150	1153	Flad	Poor
Viggskär	57.8877	16.8185	W Baltic Sea Proper	Kåröområdet	1	0.028	1.2	2.5	1150	1153	Juv. flad	Good
Kalvö	57.8723	16.7232	W Baltic Sea Proper	Rågödjupet	1	0.013	1.7	4.0			Open inlet	Good
Gamla Städsholmen	57.8721	16.7985	W Baltic Sea Proper	Kåröområdet	1	0.011	0.5	1.1	1150	1153	Flad	Good
Storskärskroken	57.8649	16.8132	W Baltic Sea Proper	Kåröområdet	1	0.021	1.5	4.3	1150	1152	Open inlet	Good
Maren (Rågö)	57.8616	16.7405	W Baltic Sea Proper	Rågödjupet*	1	0.006	0.6	1.0	1150	1153	Flad	High
Mellanviken	57.8518	16.6715	W Baltic Sea Proper	Smågöfjärden	1	0.027	1.7	2.9	1150	1153	Juv. flad	Poor
Slongsviken	57.8448	16.6783	W Baltic Sea Proper	Smågöfjärden	1	0.014	1.1	2.2	1150	1152	Open inlet	Moderate
Storkläppen	57.8428	16.8459	W Baltic Sea Proper	Västerviks kustvatten*	1	0.004	1.3	3.0	1150	1153	Flad	Good
Jutskär	57.8395	16.7975	W Baltic Sea Proper	Kåröområdet	1	0.026	1.7	3.5	1150	1152	Open inlet	Good
Rotsö	57.8174	16.7218	W Baltic Sea Proper	Torröfjärden	1	0.010	1.5	2.4	1150	1153	Juv. flad	Good
Maren	57.8004	16.7152	W Baltic Sea Proper	Torröfjärden	1	0.056	1.7	4.5	1150	1153	Juv. flad	Moderate
Skaftholmen	57.7804	16.7155	W Baltic Sea Proper	Asken	1	0.029	1.8	3.9	1150	1153	Juv. flad	Good
Stora Berkskär Västra	57.5991	16.7657	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.007	1.2	3.2	1150	1153	Juv. flad	Good
Stora Berkskär Sundet	57.5983	16.7713	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.002	0.8	1.7	1150	1153	Juv. flad	Good
Örö	57.5713	16.7733	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.013	1.2	3.4	1150	1153	Flad	Good
Svinskär Glo	57.5591	16.7402	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.014	1.4	2.6	1150	1154	Glo-flad	Moderate
St. Själholmen	57.5443	16.7449	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.033	1.0	2.9	1150	1153	Flad	Moderate

Inlet name	Latitude (WGS 84)	Longitude (WGS 84)	Region	WFD surface water area	Years surveyed	Area (km^2)	Mean depth (m)	Max depth (m)	Natura 2000 habitat	Natura 2000 sub habitat	Flad-type	Ecological status
Vimmerbytorget	57.5429	16.6781	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.020	1.2	2.3	1150	1153	Juv. flad	Good
Sävarp	57.5327	16.7382	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.015	0.6	1.7	1150	1153	Flad	Moderate
Älö-Husholmen	57.5318	16.6930	W Baltic Sea Proper	Misterhults skärgårds inre kustvatten	1	0.006	1.1	2.4	1150	1152	Open inlet	High
Marsö Västre Flage	57.4603	16.6985	W Baltic Sea Proper	Ärnöområdet	1	0.030	1.9	3.5	1150	1153	Juv. flad	High
Bålstaviken	57.4560	16.6736	W Baltic Sea Proper	Ärnöområdet	2	0.125	1.5	4.1	1150	1153	Juv. flad	High
Store Vass	57.4538	16.6927	W Baltic Sea Proper	Ärnöområdet	1	0.038	1.6	4.3	1150	1153	Juv. flad	High
Norra Ekö hamn	57.3285	16.5762	W Baltic Sea Proper	Figeholmsområdets kustvatten	1	0.020	1.5	2.9	1150	1153	Juv. flad	Good
Furö glo	57.2813	16.6188	W Baltic Sea Proper	Oskarshamnsområdet*	1	0.019	0.6	1.0	1150	1154	Glo-flad	Moderate
Smältevik	57.2003	16.4557	W Baltic Sea Proper	Påskallavikområdet	1	0.323	0.9	1.8	1150	1153	Flad	Moderate
Gåslefjärden	57.1937	16.4895	W Baltic Sea Proper	Oskarshamnsområdet	1	0.028	1.2	2.2	1150	1153	Flad	Poor
Versvarp	57.1897	16.4823	W Baltic Sea Proper	Påskallavikområdet	1	0.029	1.0	2.5	1150	1152	Open inlet	Good
Bjärköfjärden	57.1156	16.5846	W Baltic Sea Proper	Emområdet	1	0.065	0.8	1.5	1150	1153	Flad	Moderate
Massenate	57.0379	16.5265	W Baltic Sea Proper	Mönsteråsområdet	2	0.231	0.7	1.5	1160		Open inlet	High
Grenlevik	56.9663	16.4798	W Baltic Sea Proper	Lövöområdet	1	0.011	1.4	2.5	1150	1152	Open inlet	Moderate
Lilla Böneskär	56.9656	16.4848	W Baltic Sea Proper	Lövöområdet	1	0.013	0.8	1.6	1150	1153	Juv. flad	Moderate
Salthamn	56.9026	16.4524	W Baltic Sea Proper	Pataholmsviken	1	0.016	1.0	2.1	1150	1153	Juv. flad	High
Bäcken	56.8031	16.7937	W Baltic Sea Proper	S Ölands kustvatten	1	0.025	0.4	0.7	1150	1152	Open inlet	High
Sörö ström	56.7264	16.3707	W Baltic Sea Proper	S n Kalmarsund	1	0.096	0.7	1.7	1150	1153	Flad	Moderate
Hästholmarna	56.4814	16.1563	SW Baltic Sea Proper	N v s Kalmarsunds kustvatten	1	0.018	0.6	1.0	1150	1153	Flad	Moderate
Revskär	56.4503	16.1321	SW Baltic Sea Proper	M v s Kalmarsunds kustvatten	2	0.036	0.4	0.7	1150	1153	Juv. flad	High
Baggaholmarna	56.4488	16.1282	SW Baltic Sea Proper	M v s Kalmarsunds kustvatten	2	0.077	0.7	1.2	1160		Open inlet	Moderate
Stackaskär	56.4462	16.1287	SW Baltic Sea Proper	M v s Kalmarsunds kustvatten	2	0.013	0.5	1.4	1150	1153	Juv. flad	Moderate
Trolleboda	56.3009	16.0524	SW Baltic Sea Proper	M v s Kalmarsunds kustvatten	1	0.008	0.5	0.9	1150	1154	Glo-flad	Moderate
Pajen	56.2495	16.0318	SW Baltic Sea Proper	S v s Kalmarsunds kustvatten	2	0.160	0.6	1.1	1150	1153	Flad	Good
Tromtösundaviken	56.1712	15.4873	SW Baltic Sea Proper	Västra fjärden	1	0.145	0.7	1.0	1160		Open inlet	High
Väster om Tromtö	56.1624	15.4627	SW Baltic Sea Proper	Västra fjärden	1	0.412	1.5	3.0	1160		Open inlet	High
Brunnsviken	56.1578	15.3208	SW Baltic Sea Proper	Ronnebyfjärden	4	0.048	0.8	2.3	1150	1154	Glo-flad	Moderate
Vångsösund	56.1513	15.1157	SW Baltic Sea Proper	Vierydfjorden	2	0.050	1.0	2.7	1150	1153	Flad	Poor
Flagen	56.1425	15.8168	SW Baltic Sea Proper	Hallarumsviken	1	0.071	0.5	0.8	1150	1152	Open inlet	High
Bredasund	56.1412	15.3280	SW Baltic Sea Proper	Blekinge skärgårds kustvatten*	1	0.698	0.8	1.3	1150	1154	Glo-flad	Moderate
Södra Maren	56.1023	15.6119	SW Baltic Sea Proper	Blekinge skärgårds kustvatten	3	0.032	1.2	3.0	1150	1153	Flad	Good
Sörviken	56.0896	15.8497	SW Baltic Sea Proper	S v s Kalmarsunds kustvatten	1	0.011	0.4	0.6	1150	1154	Glo	Good
Edenryd	56.0371	14.5117	SW Baltic Sea Proper	Valjeviken	1	0.023	0.4	0.6	1150	1152	Open inlet	High
Krogstorp	56.0332	14.4951	SW Baltic Sea Proper	Tostebergabukten	2	0.025	0.2	0.5	1150	1152	Open inlet	Good

a Only part of inlet was surveyed during several years. Ecological status for inlet is based on survey of whole inlet.

* Inlet is located adjecent to, by not in, the WFD-area

Appendix 2: List of submerged macrophyte taxa recorded in the 350 inlets included in the present study. Frequencies of occurrence are given in the second and third columns. Taxa were recorded visually by free divers along survey transect lines, both in 0.5 × 0.5-m survey squares and between the squares. (Between-square data were not available for all inlets). See text for details.

Taxa	**Presense in no. of inlets (squares)**	**Presense in no. of inlets (between squares)**
Furcellaria lumbricalis	7	15
Vaucheria spp. (cf. *dichotoma*)	35	26
Chorda filum	104	102
Fucus vesiculosus	191	144
Leathesia difformis	0	2
Chaetomorpha linum	6	8
Monostroma balticum	21	22
Chara spp.	8	11
Chara aspera	170	140
Chara baltica	113	119
Chara canescens	74	73
Chara connivens	6	3
Chara globularis/virgata	35	54
Chara horrida	29	33
Chara tomentosa	165	144
Tolypella nidifica	45	51
Bryophyta spp.	4	0
Drepanocladus aduncus	4	5
Fontinalis antipyretica	3	4
Callitriche hermaphroditica	82	73
Ceratophyllum demersum	159	138
Eleocharis spp.	5	3
Eleocharis parvula	2	1
Elodea canadensis	2	2
Hippuris vulgaris	24	25
Lemna trisulca	21	16
Myriophyllum alterniflorum	19	27
Myriophyllum sibiricum	106	75
Myriophyllum spicatum	197	181
Myriophyllum verticillatum	1	4
Najas marina	198	178
Nuphar lutea	2	0
Nymphaea alba	5	1
Potamogeton berchtoldii	1	2
Potamogeton crispus	0	3
Potamogeton filiformis	51	43
Potamogeton gramineus × *perfoliatus*	0	1
Potamogeton obtusifolius	5	1
Potamogeton pectinatus	349	273
Potamogeton perfoliatus	206	169
Potamogeton pusillus	29	32
Potamogeton vaginatus	1	2
Ranunculus circinatus	105	84
Ranunculus peltatus (incl. ssp. *baudotii*)	55	85
Ruppia spp.	14	17
Ruppia cirrhosa	50	62
Ruppia maritima	76	70
Subularia aquatica	1	3
Zannichellia palustris	194	182
Zostera marina	10	10