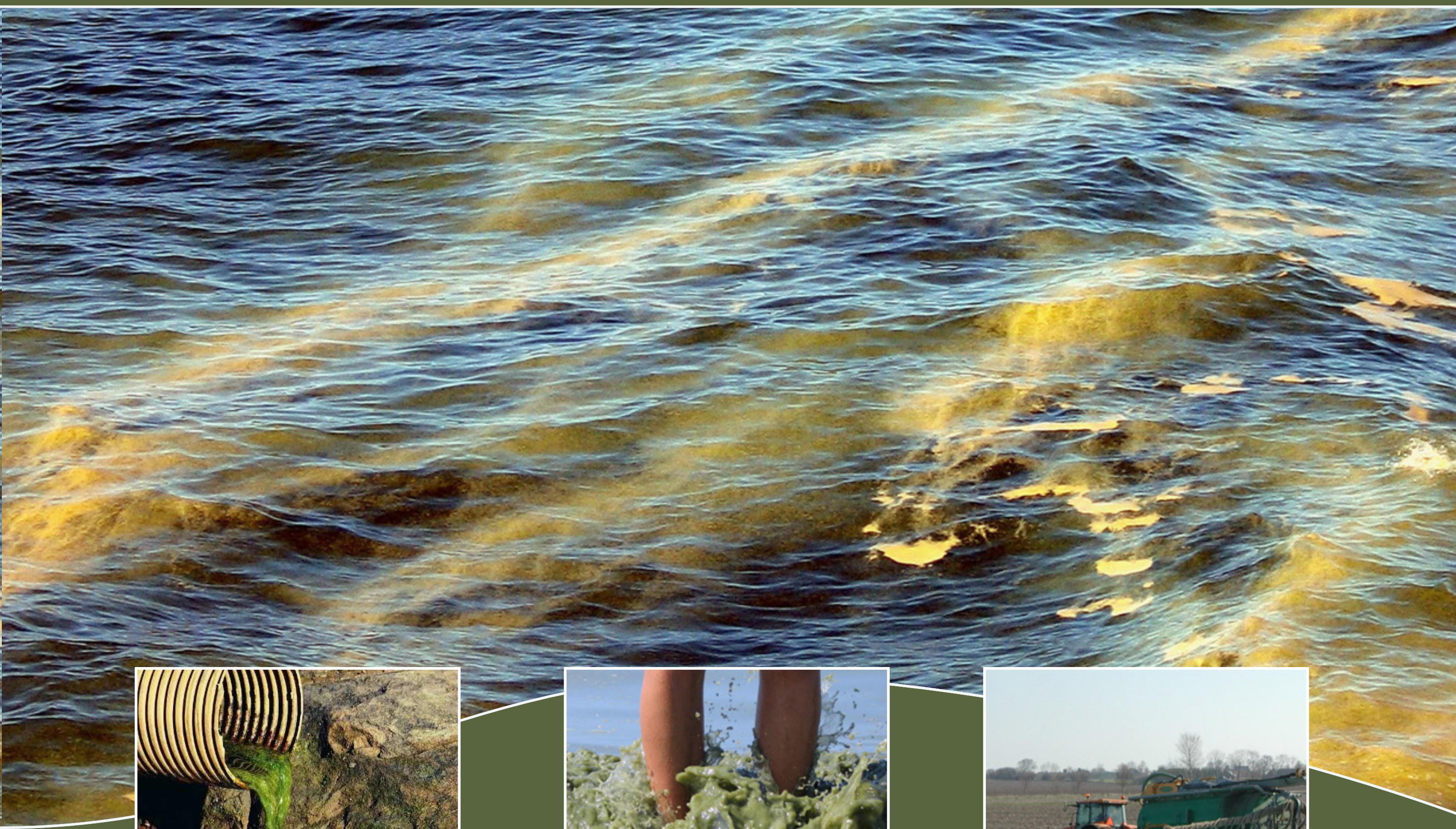
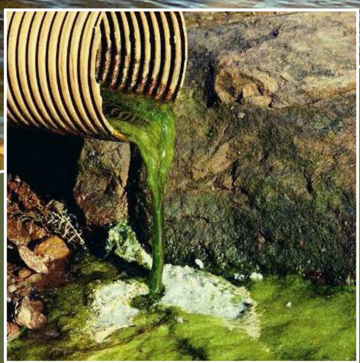
Baltic Sea Environment Proceedings No. 115A

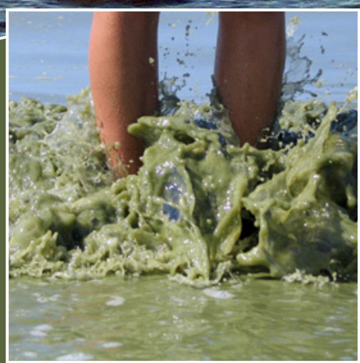
Eutrophication in the Baltic Sea

An integrated thematic assessment of the effects of nutrient enrichment in the Baltic Sea region

Executive Summary







Helsinki Commission

Baltic Marine Environment Protection Commission

Preface

In November 2007, the Ministers of the Environment and high-level representatives of the Contracting Parties of HELCOM adopted the Baltic Sea Action Plan (BSAP), with the target of achieving good ecological status in the Baltic Sea. The Action Plan aims to solve all major environmental problems affecting the Baltic Sea, the most serious of which is eutrophication arising from excessive inputs of nutrients.

To be able to follow the environmental status of the Baltic Sea with respect to meeting the targets agreed for eutrophication, HELCOM Contracting Parties agreed to elaborate an assessment employing a common tool and a harmonized approach across the Baltic Sea. This Executive Summary presents an overview of the first Integrated Thematic Assessment of Eutrophication in the Baltic Sea based on application of the common assessment tool. The full assessment report (HELCOM 2009a) contains the detailed assessment results and information on the methodology used for the assessment is presented in HELCOM (2009b).

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1 Introduction

The Baltic Sea environment is unique and fragile. It is influenced by a variety of human activities that result in effects on species and habitats in the Baltic ecosystem.

The catchment area of the Baltic Sea is more than 1,700,000 km^2, with a population of approximately 85 million inhabitants. The high population density, together with a well-developed agricultural sector and other human activities including fossil fuel combustion from energy production and transport, result in large inputs of nutrients, mainly compounds of nitrogen and phosphorus, entering the Baltic Sea.

The different sub-areas of the Baltic Sea differ considerably in their characteristics from south to north and from east to west in terms of ice cover, temperature, salinity, and residence time of the water. The combination of a large catchment area with associated human activities and a small body of water with limited exchange with the Skagerrak and the North Sea makes the Baltic Sea very sensitive to nutrient enrichment and eutrophication.

What is eutrophication?

Eutrophication arises when excessive amounts of nutrients, mainly nitrogen (N) and phosphorus (P) but also organic matter (represented by carbon (C)), build up in aquatic ecosystems and cause accelerated growth of algae and plants, often resulting in undesirable effects.

Why is the Baltic Sea sensitive to eutrophication?

The Baltic Sea is a nearly enclosed brackish-water area, with seawater renewal occurring through the narrow Danish Straits and Sound areas linking the Baltic to the North Sea. Major inflows of seawater have only occurred rarely in recent decades, leaving the water in the deeper basins without a renewal of oxygen. This slow renewal of water is the main reason for the sensitivity of the Baltic Sea to eutrophication because nutrients once discharged to the sea will remain in the sea for a long time, sometimes for decades.

Vertical stratification of the water masses is another feature that markedly increases the vulnerability of the Baltic Sea. It is mainly a result of the large inflow of freshwater from the vast catchment area surrounding the Baltic, including the many rivers. This salinity stratification hinders or prevents ventilation and oxygenation of the bottom waters and sediments by vertical mixing of the water, which often leads to oxygen depletion. In the absence of oxygen, reduced sediments release significant quantities of phosphorus to the overlying water.

How is eutrophication manifested in the Baltic Sea?

Large inputs of nutrients arising from various human activities lead to nutrient enrichment in the sea. These increased concentrations will generally cause an increase in phytoplankton primary production and the growth of short-lived macroalgae. An increase in phytoplankton biomass will cause turbidity in the water and thus a decrease in light penetration through the water column which can ultimately reduce the colonization depth of macroalgae and seagrasses. In association with these changes, there may be changes in the dominance of various species groups. The increase in phytoplankton biomass will ultimately also increase the sedimentation of organic matter to the seabed. The decomposition of this sedimented organic matter may cause oxygen depletion in the sediments and bottom water, resulting in the loss of benthic animals and fish.

2 Eutrophication status of the Baltic Sea

The eutrophication status was assessed and classified in 189 'areas' of the Baltic Sea, of which 17 are open areas and 172 are coastal areas (Fig. 1). The open waters in the Bothnian Bay and in the

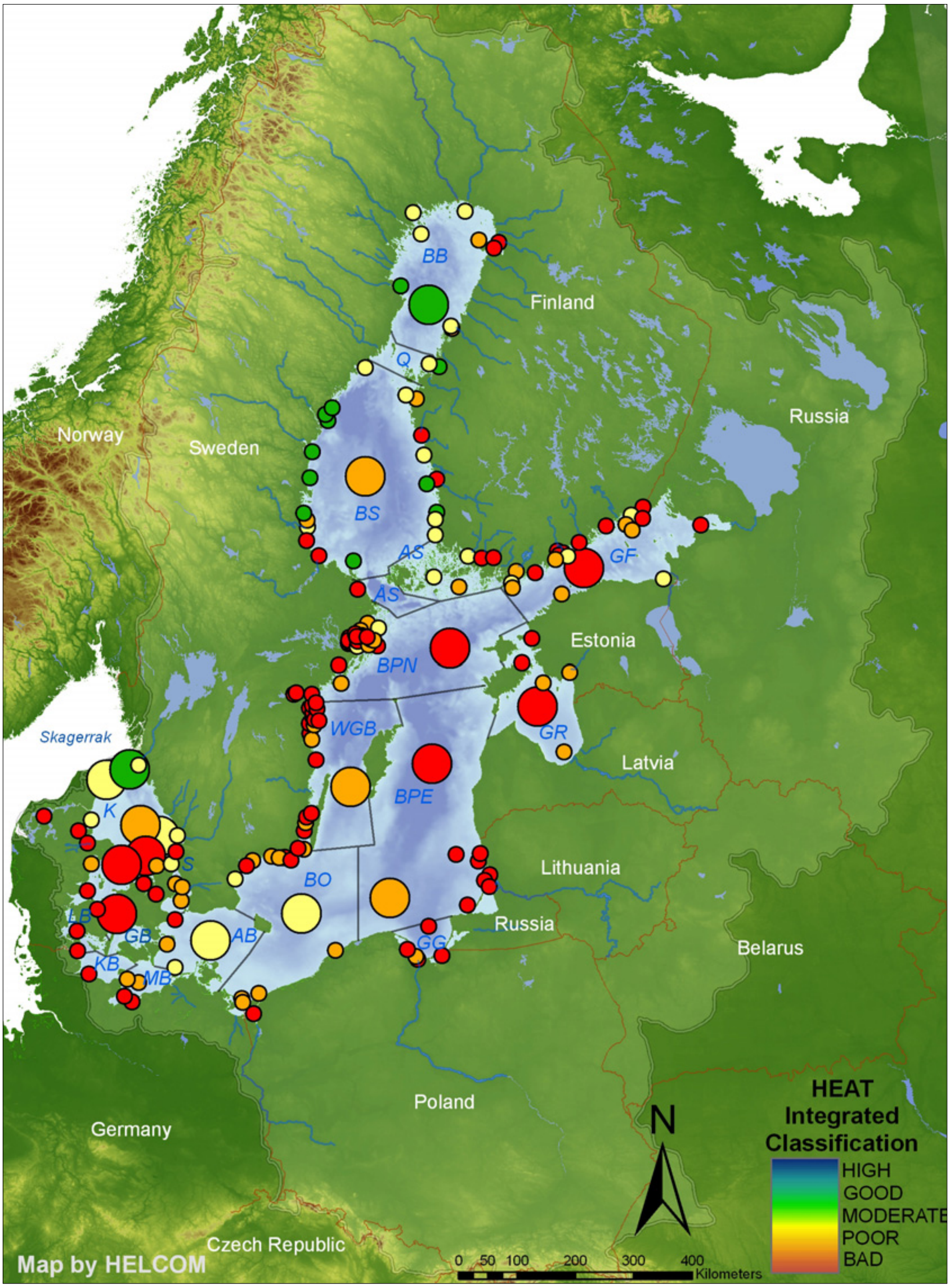


Figure 1. Integrated classification of eutrophication status based on 189 areas. Good status is equivalent to 'areas not affected by eutrophication', while moderate, poor and bad are equivalent to 'areas affected by eutrophication'. Large circles represent open basins, while small circles represent coastal areas or stations. HEAT = HELCOM Eutrophication Assessment Tool (Annex 1). Abbreviations: BB=Bothnian Bay, Q=The Quark, BS=Bothnian Sea, AS=Archipelago Sea, ÅS=Åland Sea, BPN= Northern Baltic Proper, GF=Gulf of Finland, BPE= Baltic Proper, Eastern Gotland Basin, GR=Gulf of Riga, WGB=Western Gotland Basin, GG=Gulf of Gdansk, BO=Bornholm Basin, AB=Arkona Basin, MB=Mecklenburg Bight, KB=Kiel Bight, GB=Great Belt, LB=Little Belt, S=The Sound, K=Kattegat.

Swedish parts of the northeastern Kattegat were classified as 'areas not affected by eutrophication'. It is commonly acknowledged that the open parts of the Bothnian Bay are close to pristine and that the northeastern Kattegat is influenced by Atlantic waters. Open waters of all other basins are classified as 'areas affected by eutrophication'. The fact that the open parts of the Bothnian Sea are classified as an 'area affected by eutrophication' is related to a well-documented increase in chlorophyll-*a* concentrations. For coastal waters, eleven areas have been classified as 'areas not affected by eutrophication' and 161 as 'areas affected by eutrophication'.

Figure 2 shows the distribution of 'eutrophication classes' within fifteen major Baltic Sea basins.

2.1 Nutrients

The external loads of nutrients to the Baltic Sea principally originate from land and from atmospheric deposition (Section 3), but internal fluxes from sediments and the fixation of atmospheric nitrogen by cyanobacteria can also be substantial. The major removal pathways of nutrients are through permanent sediment burial, denitrification (only N), and export to the Skagerrak. Seasonal variations in supply, removal, and transformation processes give rise to distinct seasonal patterns for nutrient concentrations. Distinct spatial gradients are also observed, with elevated nutrient concentrations in estuaries and coastal waters compared to open waters. This gradient is most pronounced in the Danish Straits and Baltic Proper. Nutrient concentrations in coastal areas of the Gulf of Finland are similar to those in the open sea owing to coastal-offshore mixing.

There are distinct spatial gradients for nutrients in the open waters, with nutrient levels increasing towards the Gulf of Finland and the Gulf of Riga, and phosphorus levels decreasing towards the Bothnian Bay (Fig. 3).

Nutrient concentrations increased up to the 1980s, and in all areas except for the Gulf of Finland, phosphorus concentrations have declined during the past two decades. Nitrogen concentrations have declined in the Gulf of Riga, Baltic Proper and Danish Straits. These declines are partly caused by lower nutrient loads from land, particularly in the coastal zone, but changing volumes of hypoxia in the Baltic Proper significantly alter nutrient concentrations in bottom waters and, through subsequently mixing, surface waters. This does not affect the Baltic Proper alone but also connecting basins through advective exchanges. In particular, the Gulf of Finland has been severely affected by

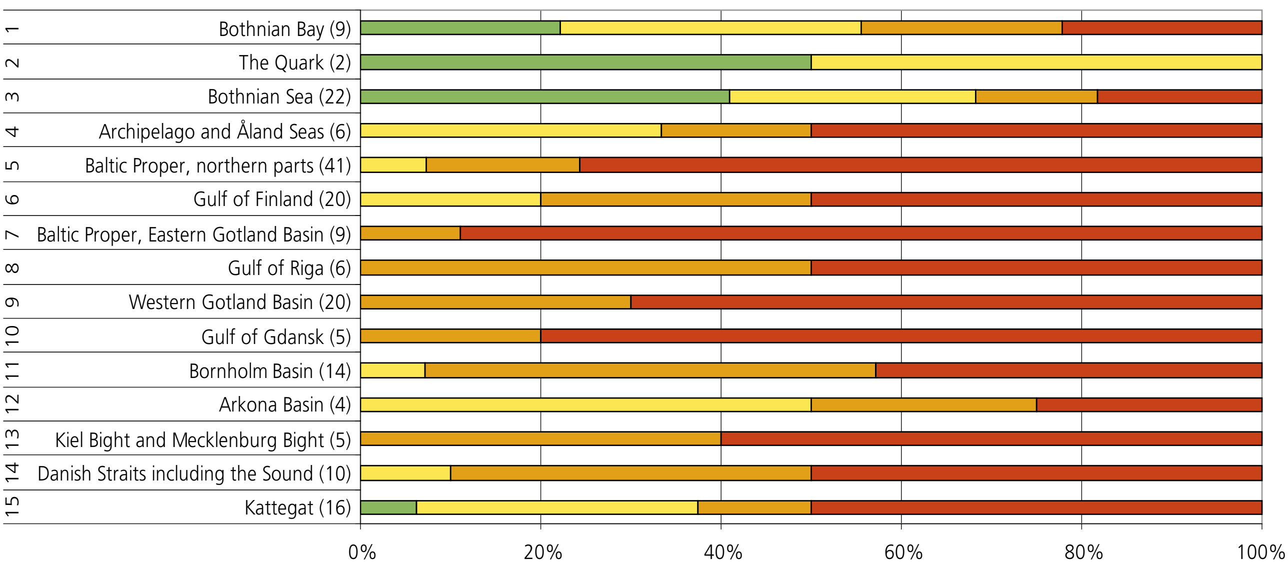


Figure 2. Overview of eutrophication classifications per basin based on the application of the HELCOM Eutrophication Assessment Tool (HEAT) (see HELCOM (2009a, 2009b) for details). The good class (green) equals 'areas not affected by eutrophication', while moderate, poor and bad classes (yellow, orange and red, respectively) equal 'areas affected by eutrophication'.

internal loading of phosphorus from the sediments caused by poor oxygen conditions.

Management actions to reduce nutrient loads from land have shown results in some regions, reducing nutrient concentrations to the level of the 1970s. However, further reduction measures are generally necessary.

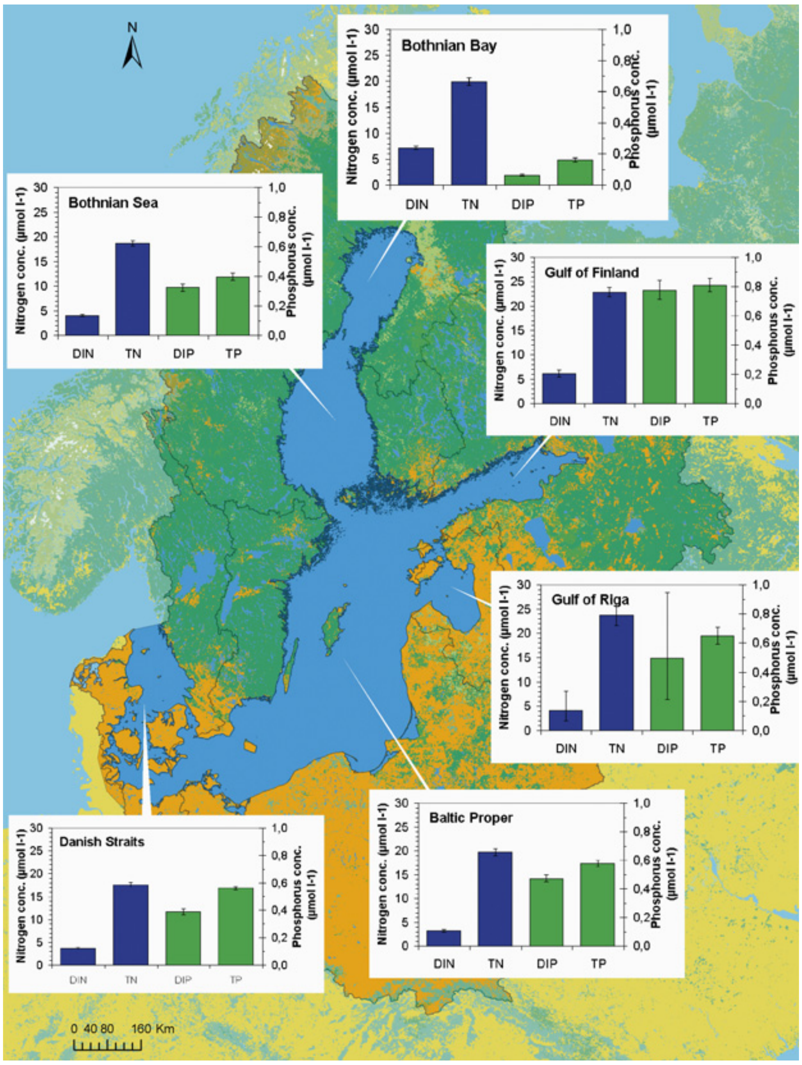


Figure 3. Map of the Baltic Sea area with assessments of four nutrient components in open parts of the six sub-areas: Bothnian Bay, Bothnian Sea, Gulf of Finland, Gulf of Riga, Baltic Proper and the Danish Straits. Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) represent winter means, and total nitrogen (TN) and total phosphorus (TP) mainly represent annual means.

2.2 Phytoplankton and water transparency

In most open and coastal Baltic areas, chlorophyll-*a* concentrations indicated the prevalence of eutrophication. In other words, Ecological Quality Ratio (EQR) values derived for chlorophyll-*a* showed a clear deviation from reference conditions (Fig. 4).

In the open sea, the chlorophyll-*a* derived status was the highest in the Bothnian Bay and the Kattegat and lowest in the Gulf of Finland, the Northern Baltic Proper, and the Gulf of Riga. Typically, chlorophyll-*a* derived EQR values were lower in the inner coastal waters than in the outer coastal waters. During recent decades, chlorophyll-*a* concentrations have been increasing in most of the Baltic Sea sub-regions, although in the 2000s chlorophyll levels in many open sea areas showed signs of a decreasing tend.

Reduced water transparency is an effect of increased nutrient loads and phytoplankton growth. Water transparency status has decreased in all Baltic Sea sub-areas, reflecting visible eutrophication effects in the entire Baltic Sea, both at coastal and open-sea sites (Fig. 5).

Summer chlorophyll-*a* in the open Baltic Sea

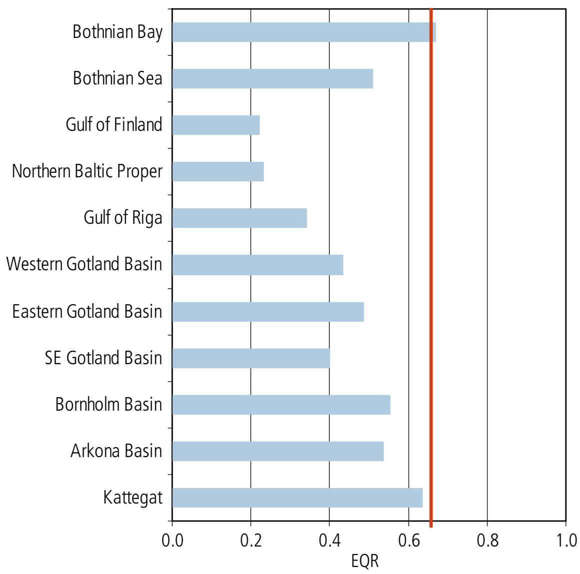


Figure 4. Chlorophyll-*a* status in the Baltic Sea open areas expressed as Ecological Quality Ratio (EQR) values. The EQR values are based on the average summer (June-September) chlorophyll-*a* concentrations for the period 2001-2006 and reference conditions for the respective areas. The red line indicates the target EQR of 0.67.

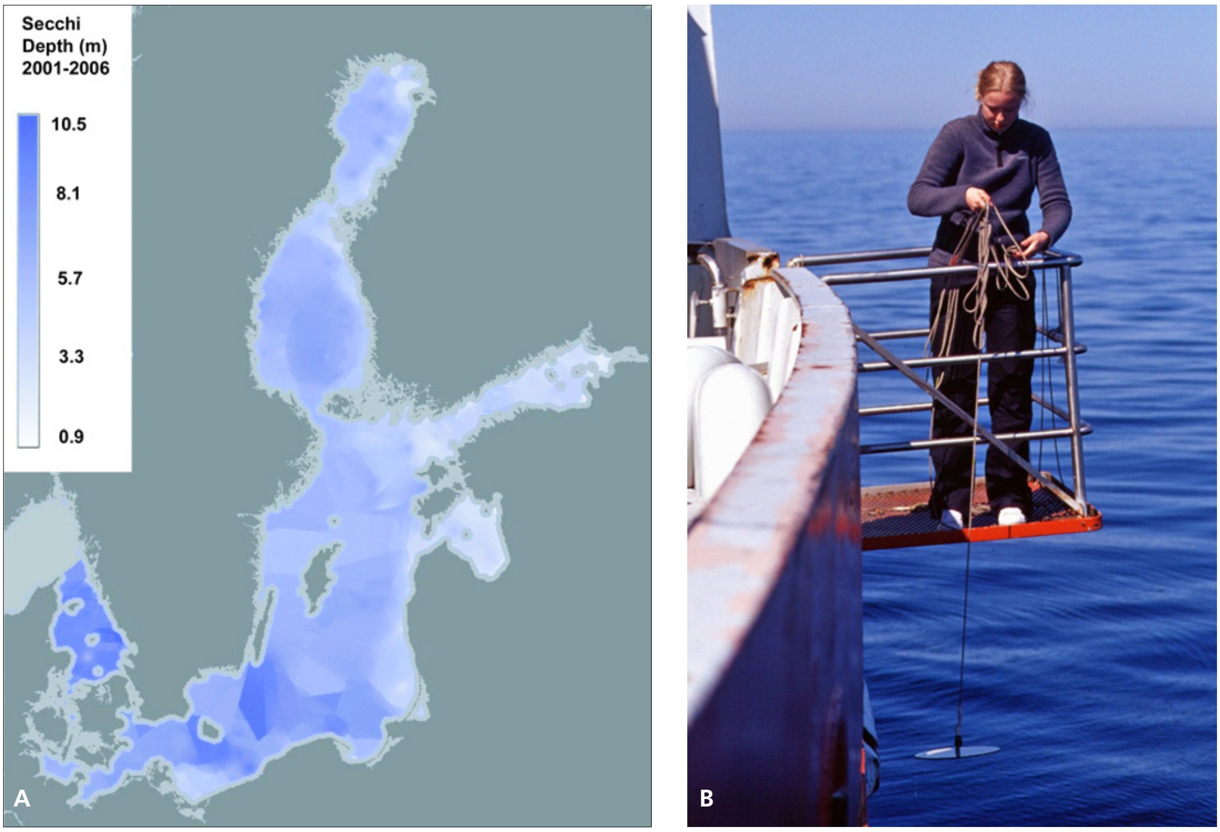


Figure 5. Map showing the water transparency status in 2001-2006 in the Baltic Sea area (A) and Secchi disk used for measurements of water transparency (B).

Water transparency status is generally lower in the inner coastal and transitional waters and increases in the outer archipelagos and open sea. The status varies greatly among the sub-basins of the Baltic Sea, partly reflecting the regional differences in eutrophication status. A decrease in summer water transparency has been observed in the open-sea areas in all Baltic Sea sub-regions over the past one hundred years. In the Kattegat, Arkona Basin, Bornholm Basin and Eastern Gotland Basin, the decreasing trend ceased during the past 15 to 25 years and since then the status has improved. In all other areas, the status is still deteriorating. The recent trend reversal in southern sub-basins gives a positive signal of the possibilities of ecosystem recovery from the current eutrophic status.

2.3 Submerged aquatic vegetation

Extensive seagrass meadows and perennial macroalgal communities harbour the highest biodiversity in coastal, shallow-water ecosystems. Eutrophication has complex effects on submerged aquatic vegetation (SAV) causing limited depth penetration of SAV species, preventing the settlement of new specimens on the seafloor, reducing the amount of suitable substrate to be colonized by perennial species, and favouring opportunistic species with a short life cycle and rapid development over the perennial species, thus causing a shift in community composition.

Generally, the level of eutrophication has caused serious changes in the Baltic Sea SAV communities, although the gaps in historic data do not allow us to identify the exact timing of larger shifts in communities. Present-day monitoring data show that in several areas the degradation of communities is ongoing (Fig. 6).

At the same time, positive signs of a slowing down or reversal of eutrophication effects on SAV parameters could be observed in areas of the Northern Baltic Proper and Gulf of Finland, where the distribution of macrophyte species has recovered.

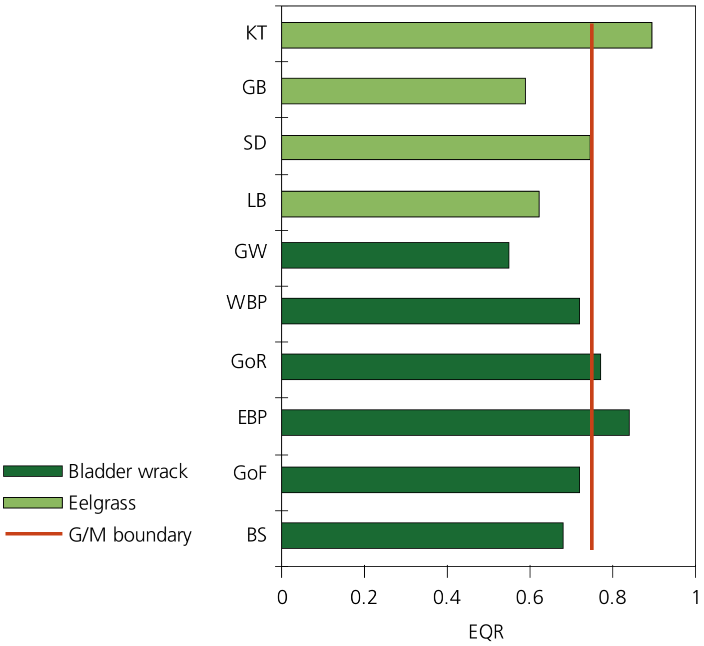


Figure 6. EQR values derived from data on maximum depth penetration of eelgrass and bladderwrack (left), and bladderwrack in good conditions (right, top) and in severely impaired conditions (right, bottom). Abbreviations: KT = Kattegat, GB = Great Belt, SD = Sound, LB = Little Belt, GW = Western Gotland Basin, WBP = Western Baltic Proper, GoR = Gulf of Riga, EBP = Eastern Baltic Proper, GoF = Gulf of Finland, BS = Bothnian Sea; G/M = good/moderate.

2.4 Oxygen conditions

Oxygen depletion is a common effect of eutrophication in the bottom waters of coastal marine ecosystems. It is caused by the consumption of oxygen by the microbial processes responsible for the degradation of organic matter accumulating at the sea floor. Oxygen depletion may result in hypoxia (literally 'low oxygen') or even anoxia (absence of oxygen). These events may be (1) episodic, (2) annually occurring in summer or autumn (most common), or (3) persistent (typical of the deep basins of the Baltic Sea).

Figure 7. Free sulphide at the surface of the water in Odense Fjord, released because of hypoxia.

In terms of the biological response to hypoxia, the level at which low oxygen concentrations become lethal is species dependent. The benthic responses to hypoxia include a shift from communities of large, slow-growing and slowly reproducing species to communities of small, rapidly reproducing organisms. Anoxic conditions result in the formation of hydrogen sulphide (H_2S), which is lethal to higher organisms (Fig. 7).

Oxygen depletion has a clear impact on biogeochemical cycles. Anoxic periods cause the release of phosphorus from sediments. Ammonium is also enriched under hypoxic conditions. The dissolved inorganic phosphorus and ammonium from the bottom waters can be mixed into the upper water column and enhance algal blooms.

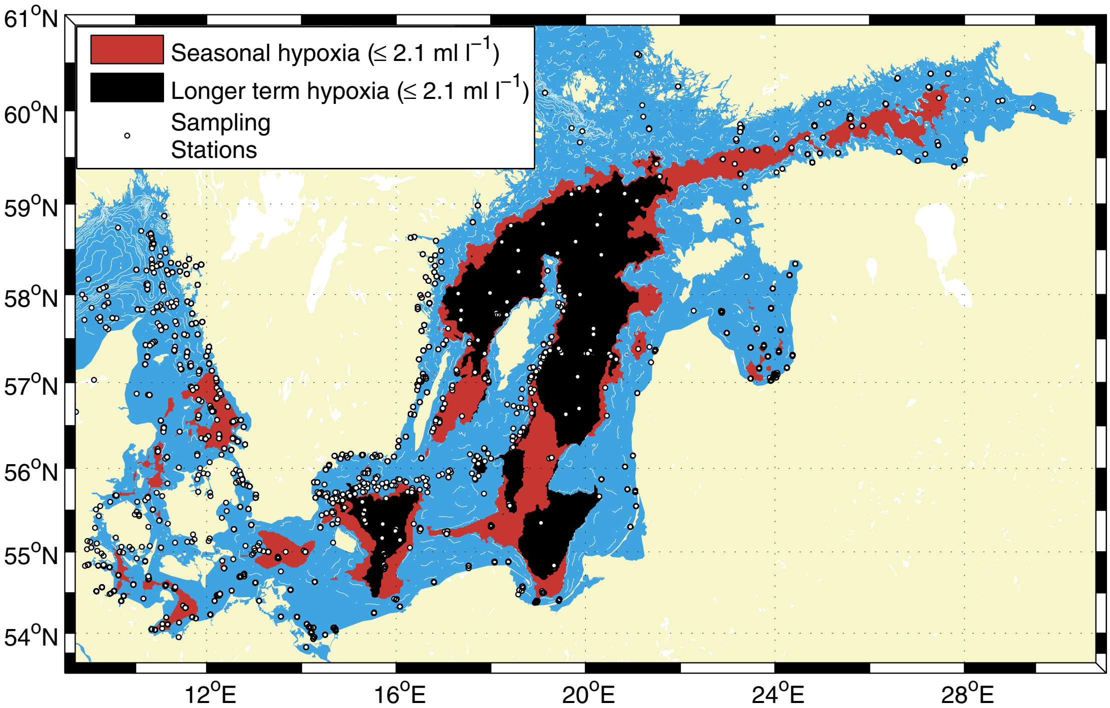


Figure 8. **Extent of seasonal hypoxia (red) and longer-term hypoxia (black) during 2001–2006.**

During the 2001–2006 assessment period, the Gulf of Bothnia appeared to be free of both seasonal and long-term hypoxia, with the exception of some coastal sites. All other basins of the Baltic seem to have suffered from seasonal or permanent hypoxia during this period (Fig. 8).

In 2002, large parts of the Baltic Sea, mainly in the southwestern and western parts, experienced the worst-ever hypoxia. In recent years, the occurrence of moderate hypoxia has increased in some areas. This is an indication of excessive oxygen consumption, most likely caused by eutrophication. Long-term hypoxic effects were observed in the Eastern and Western Gotland Basins, and the Northern Baltic Proper. This resulted from a combination of stagnation (caused by climatic factors) and ongoing eutrophication. The measurements indicate a significant increase in oxygen consumption since the 1960s at some stations in the Northern Baltic Proper, Sound and Kattegat. This is indicative of acute eutrophication.

2.5 Benthic invertebrate communities

The composition of animal communities living on the sea floor of the Baltic Sea reflects the conditions of the environment (Fig. 9). In the eutrophication process, broad-scale changes in the composition of the benthic invertebrate communities – usually involving reduced biodiversity – accompany the increasing organic enrichment of the sediments. At advanced stages of eutrophication, oxygen depletion becomes common.

In many areas of the Baltic, the benthic animals are exposed to widespread oxygen depletion. There are no benthic invertebrates in areas with

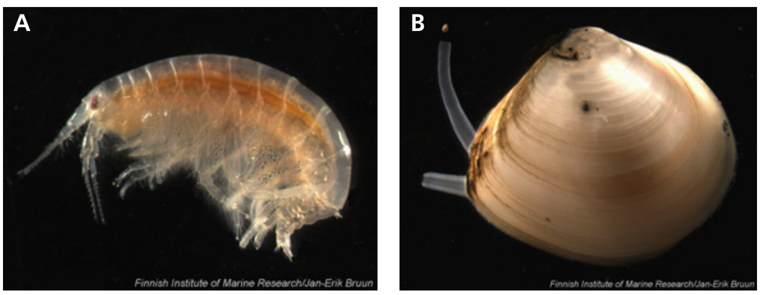


Figure 9. **Under normal conditions, dominant benthic species in the Baltic Sea include *Monoporeia affinis* (Panel A) and *Macoma balthica* (Panel B).**

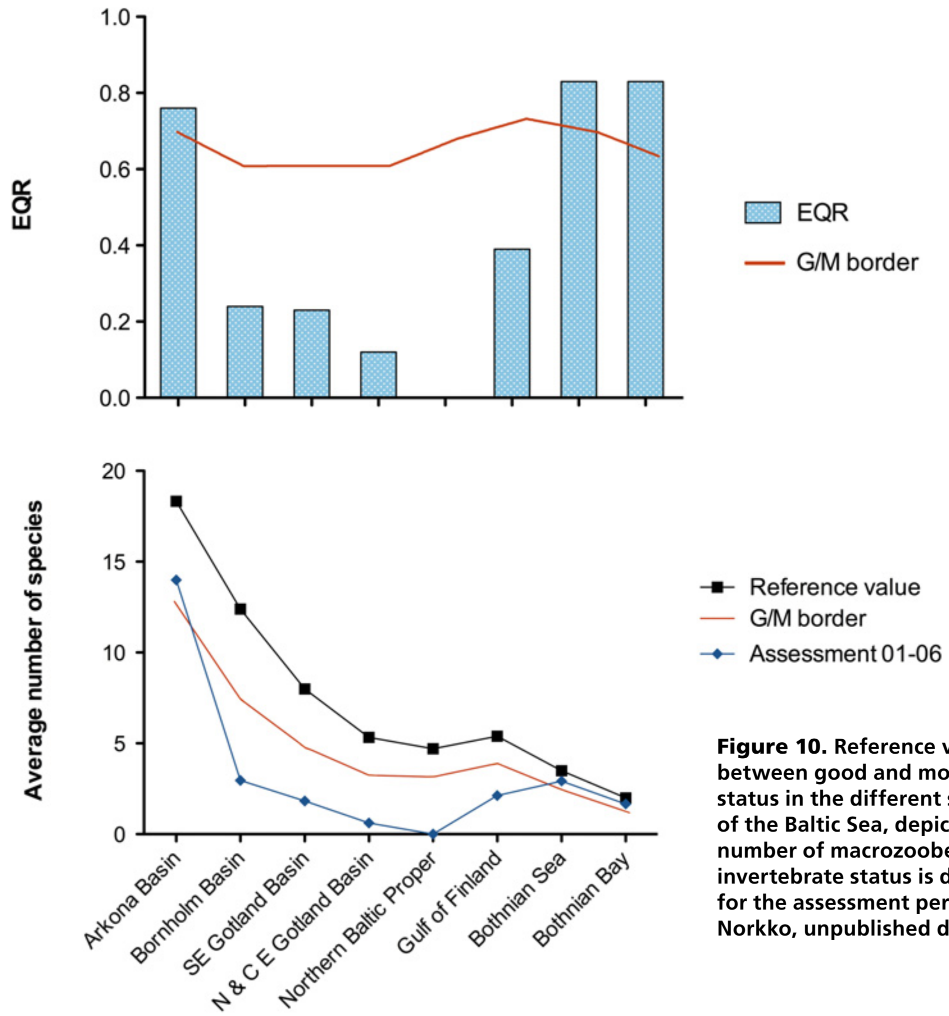


Figure 10. Reference values and the border between good and moderate (G/M) ecological status in the different sub-basins in open-sea areas of the Baltic Sea, depicted as EQR and the average number of macrozoobenthos species. Benthic invertebrate status is described as an average for the assessment period 2001–2006 (Villnäs & Norkko, unpublished data).

permanent oxygen depletion, for example, in the deep parts of the Baltic Proper. In areas with periodic oxygen depletion every late summer and autumn, the number of benthic species is reduced significantly and mature communities cannot develop. In marine areas with temporary oxygen depletion, intermittent recovery will occur whenever conditions improve. Oxygen depletion may be viewed as a temporal and spatial mosaic of disturbance that results in the loss of habitats, reductions in biodiversity, and a loss of functionally important species.

Macrobenthic communities are severely degraded throughout the open-sea areas of the Baltic Proper and the Gulf of Finland, whereas conditions in the Arkona Basin, Danish Straits, open Kattegat and the Gulf of Bothnia, in general, are classified as being good (Fig. 10).

Macrozoobenthic communities in coastal waters are highly variable both between and within different sub-basins. In general, more sheltered and enclosed coastal water bodies are in a worse state than more exposed open coasts. The difficulty in defining historic reference conditions emphasizes the importance of conducting long-term monitoring over large spatial scales to be able to assess changes.

3 The causes of eutrophication: Nutrient inputs to the Baltic Sea

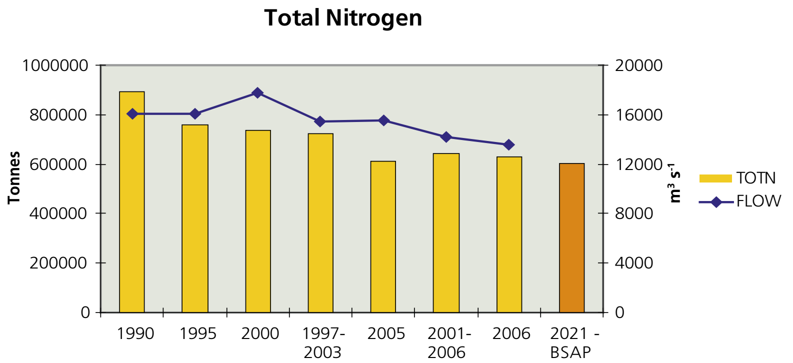
Nutrients originate from a variety of human activities and ultimately arrive in the sea via: (1) emissions to air and subsequent deposition, either directly into the sea or onto the land and waterbodies of the catchment area, (2) discharges from point sources located along the coast or originating in the catchment area and transported via rivers, and (3) losses from diffuse sources, mainly agriculture and scattered dwellings, along the coast or in the catchment. Nutrients from natural background sources also contribute to the load. In addition, internal fluxes from sediments and the fixation of atmospheric nitrogen by cyanobacteria can also be substantial. The major removal pathways of nutrients are through permanent sediment burial, denitrification (only N), and export to the Skagerrak.

In the Baltic Sea catchment area, the major anthropogenic source of waterborne nitrogen is diffuse inputs. They constitute 71% of the total load into surface waters within the catchment area. Agriculture alone contributed about 80% of the reported total diffuse load. The largest loads of phosphorus originated from point sources (56%), with municipalities as the main source, constituting 90% of total point source discharges in 2000.

About 75% of the nitrogen and at least 95% of the phosphorus enter the Baltic Sea via rivers or as direct discharges. The atmospheric deposition of nitrogen to the sea comprises about one quarter of the total nitrogen load to the Baltic Sea; it originates from emissions both inside and outside the Baltic catchment area, with shipping the most important, and continuously increasing, source. Phosphorus enters the Baltic Sea mainly as waterborne input.

In addition to the external anthropogenic loads, internal processes can increase or decrease nutrient levels. For phosphorus, reserves accumulated in the sediments of the seabed are an important extra source when released back to the water column under anoxic conditions. This sediment release affects the balance of phosphorus in the Baltic Sea, especially in the Baltic Proper, the Gulf of Finland, and the Gulf of Riga. Nitrogen fixation accomplished mainly by filamentous cyanobacteria adds to the nitrogen load in the sea. In contrast, bacterial denitrification removes nitrogen from the ecosystem.

Estimated annual average waterborne inputs to the Baltic Sea of nitrogen were approximately 641,000 tonnes and of phosphorus approximately 30,200 tonnes for the period 2001–2006. There appears to be a slightly decreasing trend in the riverine and direct point-source loads of both nitrogen and phosphorus in the Baltic Sea catchment between 1990 and 2006 (Fig. 11). However, the target input



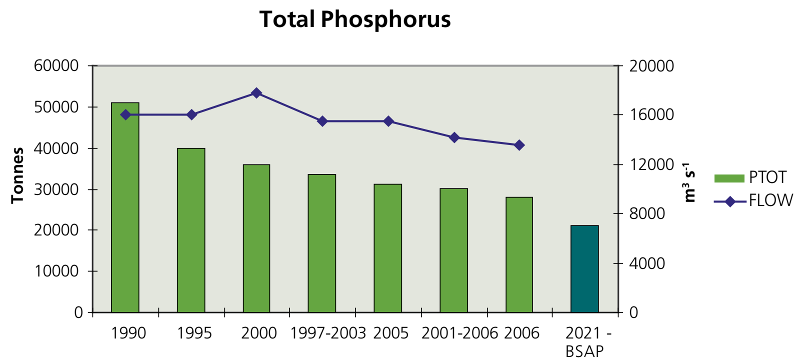


Figure 11. Direct riverine and point-source loads of nitrogen (top) and phosphorus (bottom) to the Baltic Sea with the maximum allowable loads *sensu* the Baltic Sea Action Plan indicated in orange and dark green.

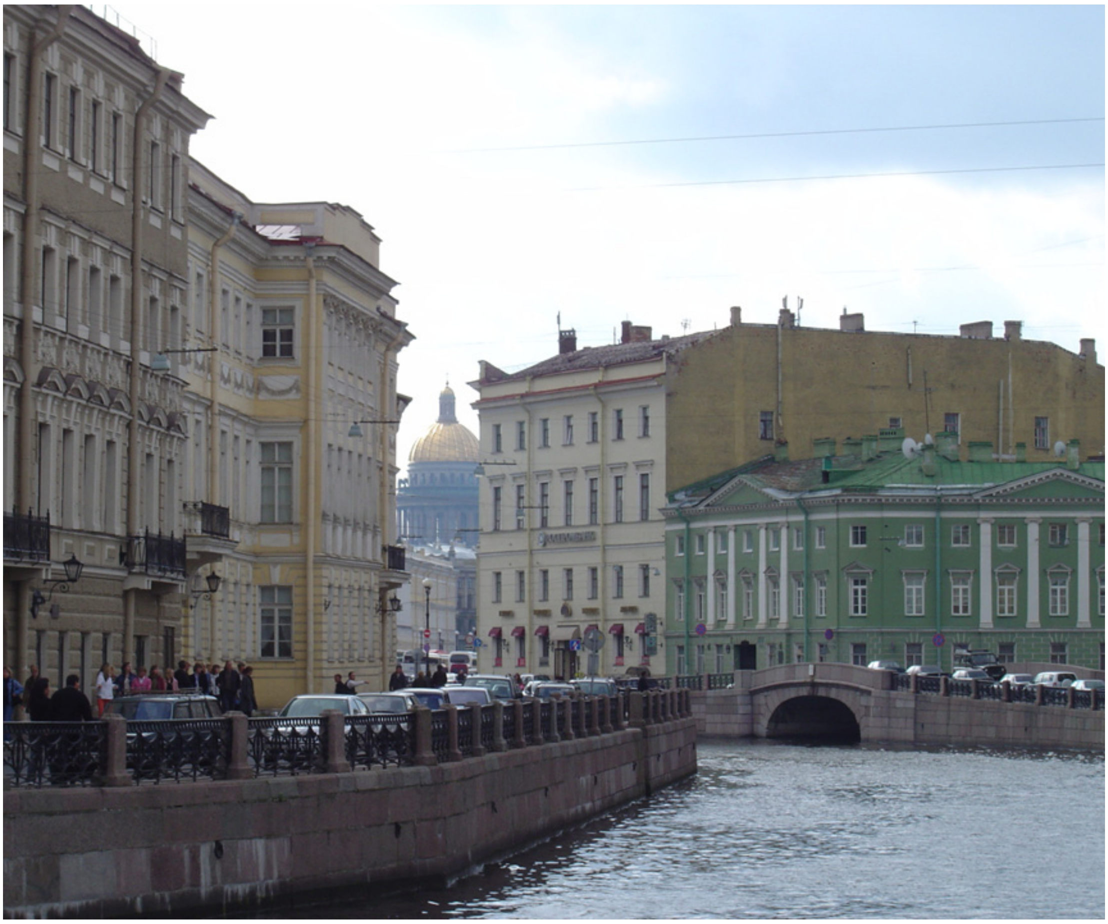
Table 1. Waterborne inputs of nitrogen and phosphorus to the Baltic Sea in 2006.

	Area	TN	TN load/area	TP	TP load/area
		t	t km^{-2}	t	t km^{-2}
1	Gulf of Bothnia	109,069	0.94	4,612	0.04
2	Gulf of Finland	129,671	4.38	5,006	0.17
3	Gulf of Riga	58,417	3.58	2,659	0.16
4	Baltic Proper	227,838	1.03	12,875	0.06
5	Danish Straits	102,395	2.41	2,835	0.07
	Total	**627,390**	–	**27,987**	–

levels indicated in the Baltic Sea Action Plan have not been reached for either of the nutrients. There are large variations in area-specific inputs (cf. Table 1). The only part of the Baltic Sea with low specific loads of both nitrogen and phosphorus is the Gulf of Bothnia.

Although these decreases are not yet reflected in reduced nutrient concentrations in the Baltic Sea, the results confirm the fact that the measures taken to reduce the nutrient inputs are effective. However, there is a time lag before a positive response to these actions can be observed in the receiving environments. Diffuse sources play a dominant role, especially for nitrogen inputs, and with climate change there is a risk that future loads may increase again.

Atmospheric nitrogen deposition is assumed to be at least 25% of the total nitrogen input to the Baltic Sea. The annual nitrogen deposition to the Baltic Sea was estimated at 196,000 tonnes in 2006. Nitrogen deposition to the Baltic Sea decreased by about 33% during the period 1980–2005. In future, it is assumed that nitrogen deposition will increase again owing to increased precipitation and growing contributions from shipping and agriculture.



4 Conclusions and recommendations

4.1 Action-oriented issues

Although reductions in nutrient loadings have been achieved by most Baltic Sea countries and the long-term results are good, the short-term development (2004–2006) is not as encouraging. The reductions have not yet resulted in a Baltic Sea unaffected by eutrophication. Thus, additional reductions are needed and they will be driven by proper implementation of national action plans and HELCOM recommendations, as well as by a number of legally binding international agreements and EU directives, including the Marine Strategy Framework Directive, the Urban Waste Water Treatment Directive, the Nitrates Directive, and the Water Framework Directive (WFD).

Because most of the areas assessed were classified as 'areas affected by eutrophication', current actions and measures also need to be reviewed and strengthened immediately to prevent further degradation on a short-term basis and, in the longer term, to meet the objectives of the HELCOM Baltic Sea Action Plan (BSAP), the WFD, and the Marine Strategy Framework Directive. HELCOM should conduct an annual review of progress in the reduction of nutrient loads to the Baltic Sea by its member countries as part of the BSAP implementation process.

It is further recommended to develop a Baltic Sea-wide nutrient management strategy covering both open and coastal waters that is parallel to the implementation process of the BSAP and relevant EU directives. This would result in the 'convergence' of the implementation of the BSAP with the implementation of other significant international instruments, creating a synergism in this work. A framework for a Baltic Sea-wide nutrient management strategy is shown in Figure 12.

4.2 Technical and scientific issues

The thematic assessment presented in this executive summary represents a progression from a single-indicator based assessment of eutrophication status toward an integrated indicator-based assessment. It applies a HELCOM Eutrophication Assessment Tool (HEAT) for an overall assessment and classification of the eutrophication status (Annex 1). HEAT distinguishes

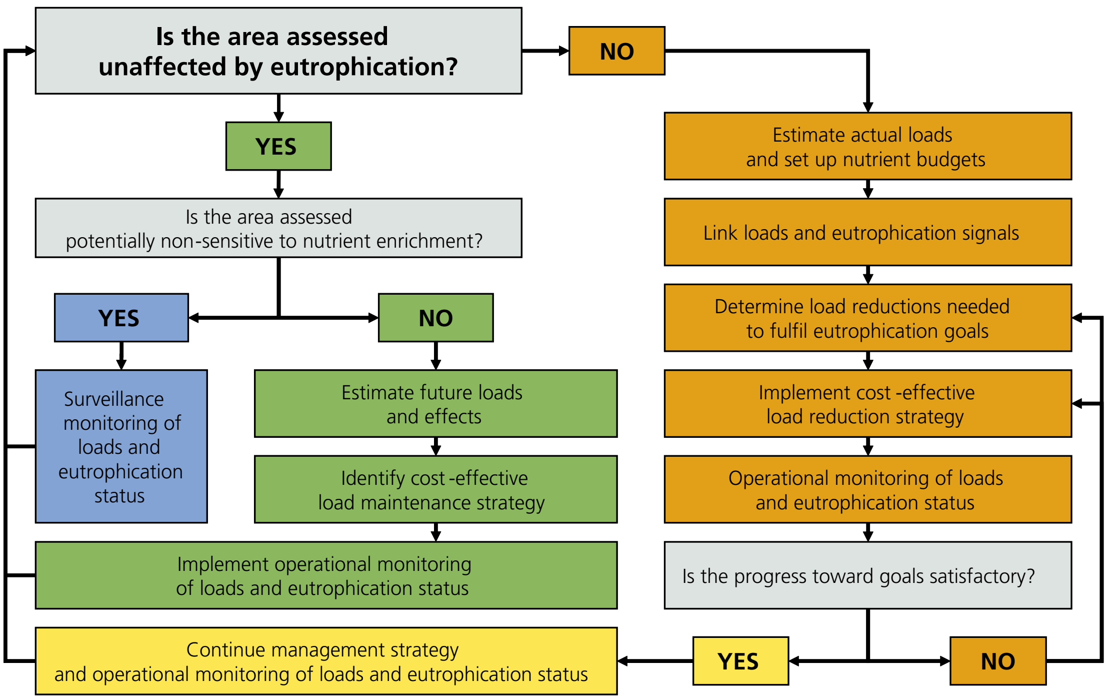


Figure 12. Framework for a Baltic Sea-wide nutrient management strategy. Based on National Research Council (2000) and Backer (2008).

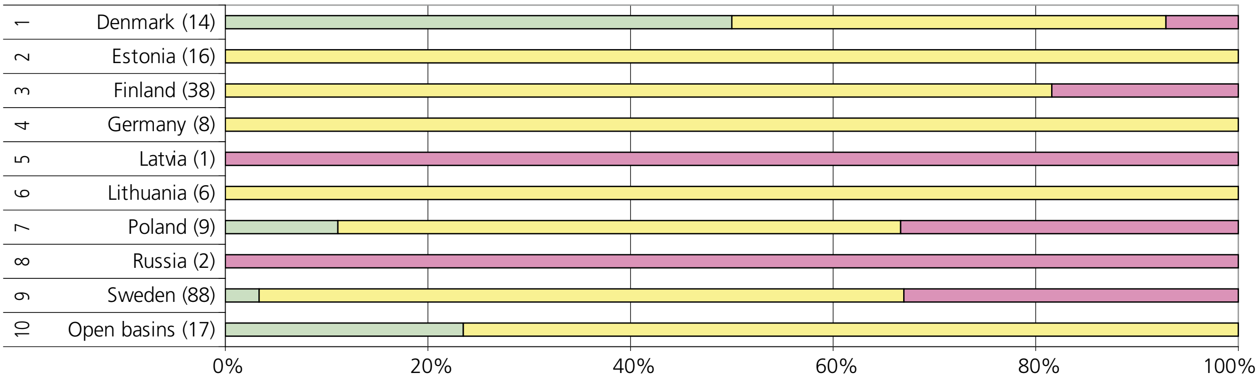


Figure 13. Provisional 'accuracy assessment' of the eutrophication classifications. Coastal eutrophication classifications are presented according to country and for all open basins. Classes I and II (light green and light yellow) indicate a high or acceptable quality; class III (rose) indicates low quality. See HELCOM (2009a, 2009b) for details.

'areas affected by eutrophication' from 'areas not affected by eutrophication' (see HELCOM (2009a, 2009b) for details). In addition, HEAT produces a provisional 'accuracy assessment' of the classification results in order to assess the reliability of the final classification (Fig. 13).

The eutrophication assessment presents the current eutrophication or ecological status as an Ecological Quality Ratio (EQR), which is calculated on the basis of synoptic information on reference conditions and actual status, the latter for the period 2001–2006 (Fig. 1). One of the benefits of this approach is that it enables comparison between different parts of the Baltic Sea in a harmonized way and, hence, it exemplifies basin-, area- or site-specific deviations from unaffected conditions.

The use of the EQR approach, despite its advantages, is sensitive to inaccurate information on reference conditions. Thus, it is crucial to further develop and improve the information base in regard to reference conditions especially by enhancing quality, consistency, and geographical coverage. In general, reference conditions for chlorophyll-*a*, water transparency, submerged aquatic vegetation in coastal waters, and benthic invertebrate communities in open basins seem to be acceptable but with room for improvements. Reference conditions for nutrients, phytoplankton indicators other than chlorophyll-*a*, oxygen concentrations, and benthic invertebrate communities in coastal waters should been seen as a first but significant step towards more accurate information and, consequently, improved assessment on a

Baltic Sea-wide scale. As a first step, a Baltic Sea-wide 'catalogue' of reference conditions for nutrients, phytoplankton, water transparency, oxygen concentrations, benthic macrophytes, and invertebrate communities should be developed.

The acceptable deviations from reference conditions, used for setting boundaries between good environmental status in terms of eutrophication ('areas not affected by eutrophication') and unacceptable status ('areas affected by eutrophication'), can be seen as a first step to establish reasonable boundaries between affected and non-affected areas; however, they may need further refinement.

Regarding the monitoring data, although the HELCOM COMBINE monitoring network is a good, scientifically well-justified source of data, this assessment shows the need for better geographical coverage, for example, in the open parts of the Baltic Proper and the coastal waters of Latvia and Russia. In terms of indicators, there is a need for better data on submerged aquatic vegetation and benthic invertebrate communities in coastal waters.

It is recommended that, based on this assessment, existing monitoring networks should be reviewed and improved with special focus on: (1) implications of a more quantitative definition of eutrophication; (2) better spatial coverage in coastal waters, especially in Latvia and Russia; (3) better temporal coverage in the southern and eastern parts of the Baltic Proper; and (4) benthic communities, for example, benthic invertebrate communities and submerged aquatic vegetation in coastal waters, especially in Finland, Germany, Latvia, Lithuania, Poland, and Russia. Furthermore, the monitoring network should be expanded to include modelling activities and remote sensing, thus providing a better basis for environmental assessments and ultimately management actions.

This thematic assessment should be seen as one step in the conduct of regular thematic and holistic assessments of eutrophication in the Baltic Sea. Updates should be planned immediately, with a first step to include an update of this assessment in the HELCOM Holistic Assessment by extending the assessment period to 2001–2008. The next step could be to determine a time frame for a second HELCOM Thematic

Assessment of Eutrophication in the Baltic Sea, for example, for 2009–2014 or other relevant period that would correspond to reporting for the Baltic Sea Action Plan or the WFD.

Further work should be conducted to develop and improve the existing set of eutrophication indicators. Greater coherence should be sought between the eutrophication indicators used in indicator-based assessments, such as HEAT, and the HELCOM Indicator Fact Sheets, which should also make use of EQR values. This would create a set of eutrophication indicators that can be used both for Fact Sheets, providing relevant background and policy-relevant information, and as part of a suite of indicators used in the assessment tool. New Indicator Fact Sheets should also be prepared on submerged aquatic vegetation, benthic invertebrate communities, and overall eutrophication status.

Baltic Sea-wide integrated indicator-based assessment tools such as HEAT should also be used when preparing the first holistic assessment of the status of and pressures on the marine environment of the Baltic Sea. Such tools should continue to be developed, however, particularly regarding confidence rating and accuracy assessment.

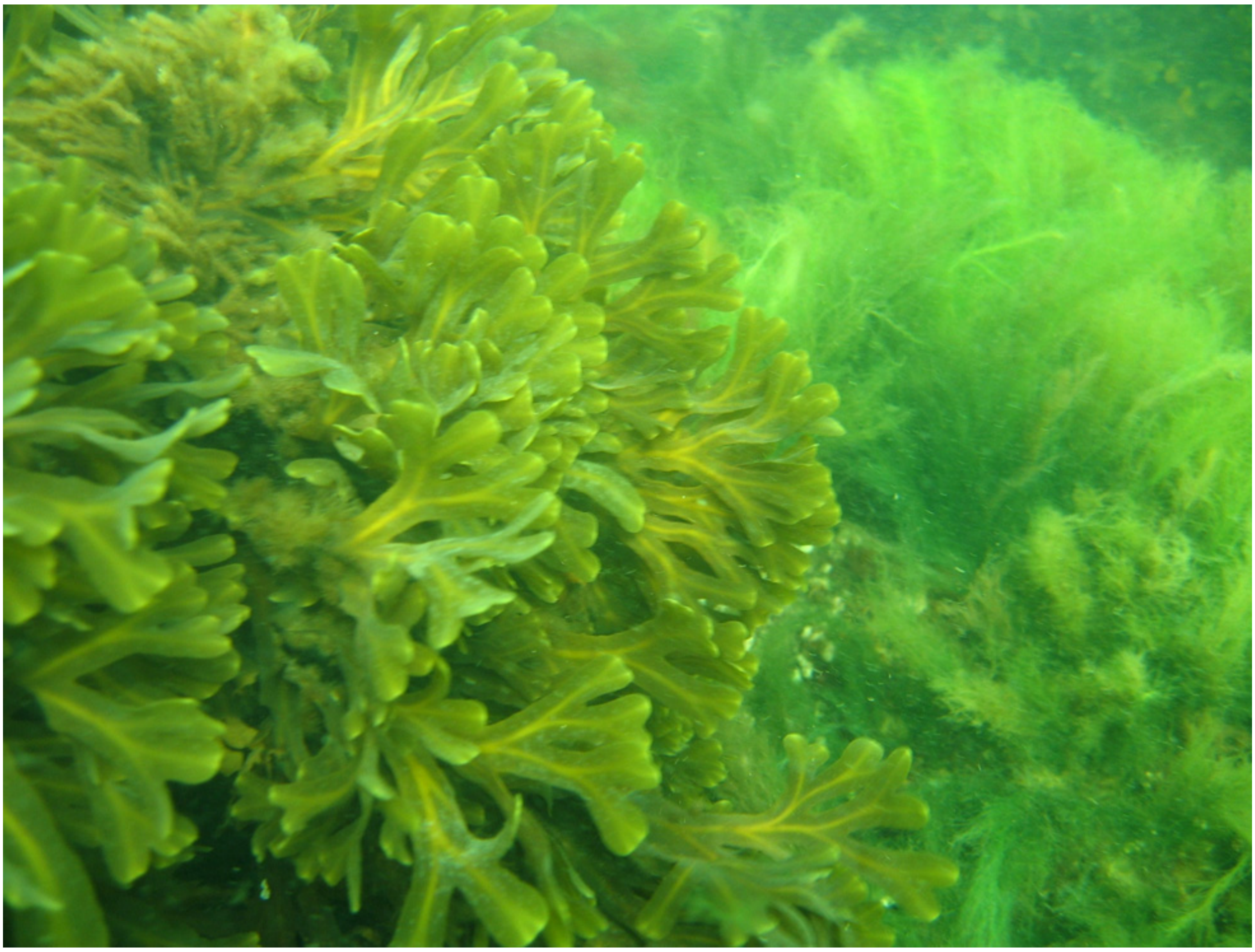
In addition, coherence in the work in relation to future Pollution Load Compilations and future assessments of eutrophication status should be strengthened, both to improve the quality and accuracy of the assessments and to improve the technical and scientific information on which management actions are being based.

5 Perspectives

The eutrophication status will only improve if loads of both nitrogen and phosphorus are significantly further reduced. The key to improvement is the progressive reduction of loads, especially from diffuse sources. Given the strong links between eutrophication abatement and protection of marine biodiversity, improving eutrophication status will also result in significant improvements in habitat quality and conservation status in many parts of the Baltic Sea.

Possible shifting baselines and regime shifts pose a challenge. Management should not permit loads that give rise to irreversible regime shifts. Hence, management should set allowable maximum loads in the HELCOM Baltic Sea Action Plan to levels that permit the system to recover and develop to a status without eutrophication. This would promote greater robustness and resilience in the ecosystem also in relation to other stressors, including climate change.

Climate change creates an extra challenge because precipitation is projected to increase especially in the northern part of the Baltic Sea catchment area, which may, in combination with increasing winter temperatures, lead to increased winter runoff and leaching of nutrients. Furthermore, an increase in water temperatures will make benthic communities more vulnerable to eutrophication and hypoxia. Ultimately, the effects of climate change could make the HELCOM strategic goal on eutrophication 'Baltic Sea unaffected by eutrophication' impossible to attain using currently agreed reduction targets. Further reductions are evidently required in order to reduce eutrophication effects, especially under a changing climate.



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Annex 1

Assessment methodology

In documenting the eutrophication status, the assessment summarized here puts focus on nutrient loads and concentrations, the status of biological quality elements (phytoplankton, submerged aquatic vegetation and benthic invertebrates), and oxygen conditions. For nutrients, biological quality elements, and oxygen conditions, the assessment compares reference conditions with the actual status in the period 2001–2006 and considers temporal trends. In addition, the assessment produces a final and integrated classification of eutrophication status, on the basis of which general conclusions and recommendations have been made.

The final classification of eutrophication status in different parts of the Baltic Sea has been made by application of the HELCOM Eutrophication Assessment Tool (HEAT). HEAT is indicator-based and uses the 'one out – all out principle' similarly to the EU Water Framework Directive (WFD), which means that the overall classification of an assessed area is based on the most sensitive quality element. HEAT also estimates a so-called interim 'confidence' of the final classification results in order to assess the reliability of the final classification.

In some coastal areas, the classification presented in this assessment cannot be directly compared to the results of national assessments and the Baltic Sea intercalibration exercise under the Water Framework Directive owing to differences in spatial and temporal scaling, as well as the use of parameters that are considered supporting in WFD.

This assessment is based on jointly agreed methods and assessment principles. It is scientifically based and the majority of data sets used originate from HELCOM Cooperative Monitoring in the Baltic Marine Environment (COMBINE) programme or the HELCOM Fifth Pollution Load Compilation (PLC-5) as well as research activities. Hence, most data are quality assured and controlled in accordance with HELCOM COMBINE guidelines. The indicators used

in regard to phytoplankton, submerged aquatic vegetation, benthic invertebrate fauna as well as physico-chemical features and loads have been reported in various national, regional or European assessment reports.

Eutrophication signals assessed

The assessment summarized here has been based on an evaluation of a suite of five ecological objectives, or quality elements, that have been chosen as signals of eutrophication in relation to the strategic goal of the Baltic Sea Action Plan for a 'Baltic Sea unaffected by eutrophication'.

Table A1. Ecological objectives and their associated indicator measurements assessed in the Integrated Thematic Assessment of Eutrophication in the Baltic Sea.

Ecological objective	Indicator
'Concentrations of nutrients close to natural levels'	Winter surface concentrations of nutrients
'Clear water'	Secchi depth
'Natural level of algal blooms'	Chlorophyll-*a* concentrations
'Natural distribution and occurrence of plants and animals'	Depth range of submerged aquatic vegetation
'Natural oxygen levels'	Abundance and structure of benthic invertebrate communities

To make these ecological objectives operational, indicators have been agreed with initial target values that, when achieved, are intended to represent good ecological and environmental status of the Baltic marine environment. These ecological objectives and the indicators that have been chosen, out of many potential indicators or parameters, to represent one means of measuring each objective are listed in Table A1.

The thematic assessment focused on three aspects: 1) status of the indicator in the period 2001–2006; 2) status expressed as Ecological Quality Ratio; and 3) temporal trends, over the length of the time series of data available for the specific indicator or eutrophication signal.

The Ecological Quality Ratio (EQR value) has its model in the Water Framework Directive (WFD), which has goals nearly identical to those of the Baltic Sea Action Plan. An EQR represents the relationship between the observed value of an ecological parameter in a water body and the value for that parameter in reference conditions applicable to that water body. The EQR ratio is expressed as a numerical value between one (best) and zero (worst). The relationship between EQRs, WFD classifications, and ecological status is shown in Figure A1.

Under the WFD, EU Member States must divide the ecological quality ratio scale into five classes from high to bad ecological status by assigning a numerical value to each of the boundaries between the classes. In practice, EQR values close to one indicate a status with no, minor or slight deviation from reference conditions, and hence an acceptable status corresponding to 'areas unaffected by eutrophication'. Low EQR values indicate moderate, major or strong deviations from reference conditions and an unacceptable status corresponding to 'areas affected by eutrophication' having a moderate, poor or bad ecological status.

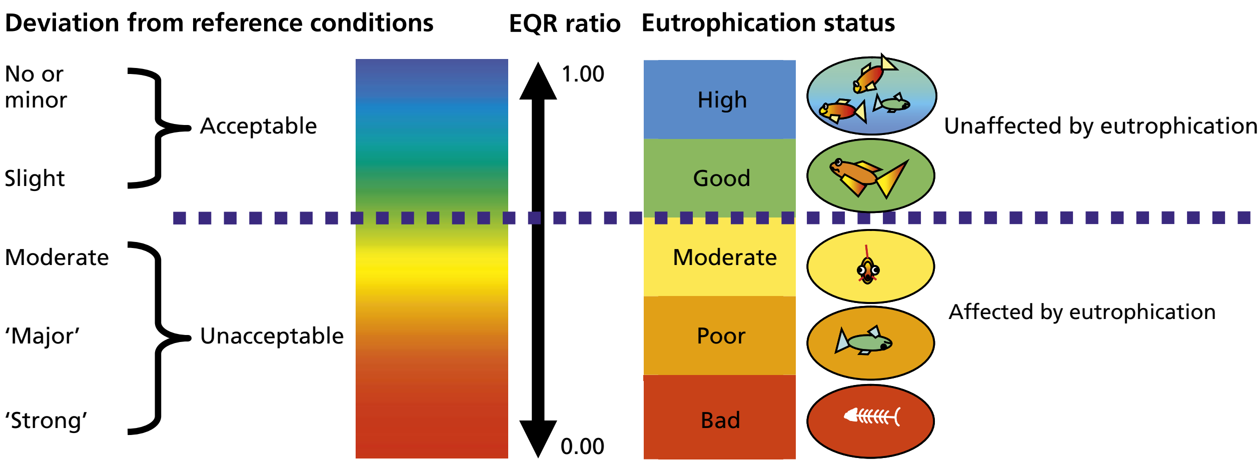

Figure A1. Overview of the EQR concept and its use for classifying water bodies affected by eutrophication. Based on Anon. (2000, 2005). Fish by courtesy of P. Pollard, SEPA.

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