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Implementation of European marine policy: New water quality targets for German Baltic waters

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ABSTRACT

A full re-calculation of Water Framework Directive reference and target concentrations for German coastal waters and the western Baltic Sea is presented, which includes a harmonization with HELCOM Baltic Sea Action Plan (BSAP) targets. Further, maximum allowable nutrient inputs (MAI) and target concentrations in rivers for the German Baltic catchments are suggested. For this purpose a spatially coupled, large scale and integrative modeling approach is used, which links the river basin flux model MONERIS to ERGOM-MOM, a three-dimensional ecosystem model of the Baltic Sea. The years around 1880 are considered as reference conditions reflecting a high ecological status and are reconstructed and simulated with the model system. Alternative approaches are briefly described, as well. For every WFD water body and the open sea, target concentrations for nitrogen and phosphorus compounds as well as chlorophyll a are provided by adding 50% to the reference concentrations. In general, the targets are less strict for coastal waters and slightly stricter for the sea (e.g. 1.2 mg/m³ chl.a summer average for the Bay of Mecklenburg), compared to current values. By taking into account the specifics of every water body, this approach overcomes the inconsistencies of earlier approaches. Our targets are well in agreement with the BSAP targets, but provide spatially refined and extended results. The full data are presented in Appendix A1 and A2.

To reach the targets, German nitrogen inputs have to be reduced by 34%. Likely average maximum allowable concentrations in German Baltic rivers are between 2.6 and 3.1 mg N/l. However, the concrete value depends on the scenario and uncertainties with respect to atmospheric deposition. To our results, MAI according to the BSAP may be sufficient for the open sea, but are not sufficient to reach a good WFD status in German coastal waters.

1. Introduction

The European Marine Strategy Framework Directive (MSFD, 2008/56/EC) aims to achieve and/or maintain Good Environmental Status (GES) of EU marine waters by 2020. The Directive defines GES as: "The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive" (MSFD Article 3). GES is described by a comprehensive set of 11 qualitative descriptors. Descriptor 5 relates specifically to eutrophication and states that the human-induced eutrophication should be minimized. One of the first steps that had to be finished until July 2012 was the initial assessment of Member States' marine waters (Art. 8 MSFD), the

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determination of GES (Art. 9 MSFD) and the establishment of environmental targets and associated indicators to achieve GES (Art. 10 MSFD). The German initial assessment for the Baltic Sea waters concluded that these waters currently fail to achieve good environmental status and that the enrichment with nutrients and organic material is still too high, resulting in considerable impacts on the marine ecosystems. As a consequence, the qualitative environmental target "seas without significant impacts by anthropogenic eutrophication" was set and it was acknowledged that further reductions in nutrient inputs are necessary to achieve GES.

The EU Water Framework Directive's (WFD, 2000/60/EC) objectives are similar to the MSFD. The WFD aims to establish and/or maintain "good ecological status" and "good chemical status" for all surface waters by 2015 and spatially overlaps with the MSFD in coastal waters up to the baseline plus 1 nautical mile (12 nautical miles for the chemical status). The adoption of the WFD in 2000 can be regarded as a major landmark since the management of rivers, lakes, coastal waters, and ground waters was no longer based on national or political boundaries but on river basins. For all WFD river basins comprehensive River Basin Management Plans linking coastal water objectives to measures in respective catchments had to be established by 2009 and need to be reviewed by 2015. "Good ecological status" according to the WFD is defined based on reference conditions that describe a "high status with no, or very minor disturbance from human activities" [18]. Subsequently reference conditions have been developed for different biological elements [2,9,33] and hydro-chemical parameter [11] as well as different surface waters [5,38,39,58] all over Europe. Similar activities took place in the Baltic [12,13,26,41] and in German waters [4,7,8,10,42]. Of the 44 German Baltic coastal water bodies assessed under the WFD in 2009 all but one failed to achieve "good ecological status" mainly due to eutrophication effects.

Recognizing that most problems in the marine environment are transboundary in nature the MSFD establishes European marine regions and sub-regions on the basis of geographical and environmental criteria and demands that GES is achieved at this spatial scale. The Baltic Sea is one out of four European marine regions and subject to an existing Regional Sea Convention, the Helsinki Convention, signed in 1974. In 1992 coastal waters became part of the convention area. The governing body is the Helsinki Commission (HELCOM). In 2007, the HELCOM Baltic Sea Action Plan (BSAP), a comprehensive program to restore good ecological status of the Baltic marine environment by 2021, was adopted. The BSAP can be regarded as a regional contribution to achieving GES according to the MSFD for those HELCOM Contracting Parties being also EU Member States. In the BSAP 2007 HELCOM Contracting Parties agreed on maximum allowable inputs of nutrients (MAI) in order to reach GES of the Baltic Sea and committed to country-wise provisional nutrient reduction requirements (CART) [14]. These MAI and CART have been revised during 2011–2013 ([22].) based on an improved modeling approach and revised harmonized eutrophication status targets resulting in a renewed commitment of HELCOM Contracting Parties at the HELCOM Ministerial Meeting in October 2013.

Starting point of this study was an evaluation of the existing reference and target concentrations for nutrients and chlorophyll for German rivers, coastal waters and the Baltic Sea, according to WFD and BSAP. It turned out that the scientific basis for deriving reference concentrations for nutrients in coastal waters needs a revision, in particular the associated target thresholds were far too ambitious to be reached even with an optimal river basin management [45,34]. Existing water quality targets for the Szczecin lagoon, for example are 0.016 mg/l total phosphorus (TP) and 0.11 mg/l total nitrogen (TN) [10]. Schernewski et al. [46] in comparison suggest re-calculated, model-based thresholds of 0.1 mg/l TP and 0.7 mg/l TN. The existing target (threshold) concentrations for nutrients did not match the target for chlorophyll a although these two water quality objectives correlate. Further, target concentrations in rivers need to be developed for the German Baltic Sea catchment. Problems and inconsistencies largely resulted from the fact that several consultants and researchers worked independently on certain WFD biological elements and hydro-chemical parameters using different methodologies. Furthermore, target values were derived largely independently for the open sea, coastal waters, rivers and lakes without considering interconnections of these surfaces waters and recognizing marine waters as the ultimate sink of nutrients (Fig. 1).

Without reliable target for water quality neither the WFD nor the MSFD or the BSAP can be successfully implemented since management objectives guiding measures cannot be derived. In recognition of this challenge, a full re-calculation of all reference and target concentrations was carried out, using a spatially coupled, large scale and integrative modeling approach. For this purpose, the river basin flux model MONERIS was linked to ERGOM-MOM, a three-dimensional ecosystem model of the Baltic Sea. This process was carried out by permanent involvement of a stakeholder group consisting of national and federal state authorities as well as scientists.

The time period around 1880 was selected as a historical reference because it represents a period before industrialization and agricultural intensification. Little influence of anthropogenic activities can be assumed because strong evidence exists that water transparency and macrophyte coverage even in inner coastal waters were still high (e.g. [1,26,49]). Reconstructed historical loads were then used as a basis to simulate the resulting nutrient and chlorophyll concentrations in Baltic coastal and open waters.

The methodology is presented to derive reference concentrations (situation around 1880) from model simulations, further the discussion process in the stakeholder group and the approach to achieve harmonized, spatially differentiated target values for inner and outer coastal waters and the German Baltic Sea, as well as maximum allowable annual German Baltic riverine and atmospheric nutrient inputs.

2. Materials and methods

The ecosystem model ERGOM-MOM is an integrated biogeochemical model linked to a 3D circulation model covering the entire Baltic Sea. A horizontal resolution of 1 nautical mile (nm) is applied in the western Baltic Sea and in inner and outer coastal waters. The vertical water column is sub-divided into layers with a thickness of 2 m. The biogeochemical model consists of nine state variables. This model is coupled with the circulation model via advection diffusion equations for the state variables. The nutrient variables are dissolved ammonium, nitrate and phosphate. Primary production is represented by three functional phytoplankton groups: large cells, small cells and nitrogen fixers. A dynamically developing bulk zooplankton variable provides grazing pressure on the phytoplankton. Accumulated dead particles are represented in a detritus state variable. During the process of sedimentation a portion of the detritus is mineralized into dissolved ammonium and phosphate. Another portion reaches the sea bottom where it accumulates as sedimentary detritus and is subsequently buried, mineralized or resuspended in the water column. Under oxic conditions parts of phosphate are bound to iron oxides in the sediment, but can be mobilized under anoxic conditions. Oxygen concentrations are calculated from biogeochemical processes via stoichiometric ratios and control processes such as denitrification and nitrification. Neumann [35], Neumann et al. [36] and Neumann and Schernewski [37] provide detailed model descriptions and validations. Recent comparative studies [19,30,20] proved that the biogeochemical model ERGOM is sufficiently reliable in the western Baltic Sea and suitable for scenario simulations. Weather data for the present time were taken from the Rossby Center Atmosphere model RCA3.0 on the basis of ERA-40 [28]. For the historical simulations the weather reconstruction of Schenk and Zorita [43] was used.

Riverine nutrient input for 1970–2000 was provided by the Baltic Nest Institute (BNI) including 80 catchment areas around the Baltic Sea. After 2000 the official HELCOM Pollution Load Compilation (PLC-5) data [23] for riverine nutrient input was used. Since PLC provides only aggregated country-wise data for the nine Baltic Sea basins, the country loads were allocated according to the share of each river in BNI data. The historic nutrient loads of 16 main Baltic rivers, outside Germany, were reconstructed by following the approach of Gustafsson et al. [21] and all loads attributed to these rivers. The atmospheric nutrient input was computed by distributing the loads taken from Ruoho-Airola et al. [40] for every sub-region including a decline towards the open sea. The German riverine input was allocated to altogether 78 emission areas (Fig. 2), using the proportion calculated by MONERIS, which was vice versa used to estimate the historical river loads.

MONERIS allows simulation and tracking of nutrients from the emission source through the environment to the river mouth. It is based on a geographical information system (GIS), which includes various digital maps and extensive statistical information. MONERIS is applied to calculate riverine nutrient emissions from the German Baltic river basin, considering also nutrient retention in the river and providing monthly loads at the river mouth. Behrendt and Dannowski [3] and Venohr et al. [53] present details about the model. A comparison between observed and model simulated N and P loads for the period 1983–2005 is documented in Venohr et al. [52]. MONERIS model simulations for the years around 1880 were based on historical statistic data sets and compiled literature data. The German Baltic river basins cover an area of 28,600 km^2 or about 2% of the Baltic Sea catchment [23]. In 1880, arable land covered 55%, forests 18% and grassland 15% of the catchment. Agriculture already covered an area comparable to the present situation, but was still not intensified with only limited application of manure. The nitrogen surplus (difference between fertilizer application and removal with harvest) was still close to zero. Tile drainage and sewer systems were already in place. The total human population in the catchment was 1.4 million, roughly 50% less than today. Details about approach and results are described in [27].

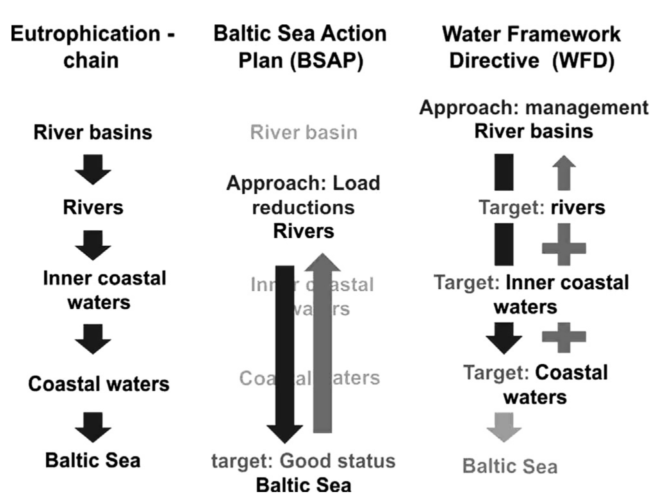

Fig. 1. The Eutrophication chain and the approaches in the Baltic Sea Action Plan (BSAP) and the Water Framework Directive (WFD). The BSAP defines a target status for the sea and calculates maximum allowable nutrient loads for the sub-regions of the Baltic Sea, taking atmospheric deposition into account. The WFD follows a spatially integrated approach, as well, based on the catchment of river basins. However, in practice targets for different categories of surface water are defined largely independently. In the Germany Baltic Sea transitional water bodies are not defined. Enclosed coastal waters are called inner coastal waters.

Two ERGOM-MOM model simulations were carried out. The first covered the present situation between 1970 and 2008. The average annual German Baltic riverine loads, for example, for the years 2000 until 2008 were about 21,100 t total nitrogen (TN) and 474 t total phosphorous (TP) with an N to P relationship of 39. The second simulation covered the historical situation, using the loads provided by MONERIS for the years around 1880. The historic annual German Baltic riverine loads were 5127 t TN and 227 t TP (molar N/P=44). The historic run covered the years 1875 until 1885. In subsequent calculations, the simulation results were averaged over the period 2000 until 2008 resp. 1881 until 1885 to reduce the effects of interannual variability and the model dependency on initial starting conditions.

To calculate maximum allowable German nutrient inputs and subsequent target concentrations for German rivers, a simplified, spatially integrated approach was used, that allows a direct comparison to existing MAI and the BSAP. The annual DIN and DIP loads and average chl.a concentrations were extracted from model simulations for an area, which is known to influence water quality in the German Baltic Sea (9.5°–14.8°east, 53.6°–55.35°north). To extend the data set, earlier ERGOM-MOM simulations [20,31] were additionally considered. Chl.a sub-surface data was spatially integrated over this area, averaged for the month Mai until September and related to the annual nutrient load of the previous year. The use of geographical names follows HELCOM monitoring and assessment documents.

3. Calculations and stakeholder process

In 2012, all responsible authorities involved in the implementation of the WFD in the German Baltic Sea, representatives of the federal state environmental ministries of Schleswig-Holstein and Mecklenburg-Vorpommern, of the Federal Environmental Agency as well as scientists met to discuss the existing water quality objectives in German inner and outer coastal waters and the Baltic Sea itself. It became obvious that the threshold concentrations defining the boundary between good and moderate status were partly unrealistic and thresholds for different parameters did not match each other. These problems hamper a successful and harmonized implementation of WFD and BSAP. Therefore, the decision was to carry out a full re-calculation of all reference and target concentrations, using a spatially coupled, large scale and integrative modeling approach and to propose for maximum allowable river loads/concentrations.

Concrete task was to provide reference and target concentrations for nitrogen (N) and phosphorus (P) as average winter concentrations (December to February) of near surface dissolved inorganic N and P compounds (DIN, DIP), annual average near surface concentrations for total N and total P as well as average near surface summer concentrations (May to September) of chlorophyll a (chl.a) in German coastal and open Baltic sea waters.

Premises and framework conditions were that the target thresholds for N, P and chl.a should (a) take into account the specific spatial conditions (surface water type, distance to river outlets and other emission sources); (b) be calculated for all official German Baltic monitoring stations and WFD water bodies as well as relevant HELCOM regional seas; (c) be harmonized with the targets according to the new BSAP (d) focus on chl.a and fit to the inter-calibrated chl.a threshold for WFD-outer coastal waters (called B3, see Fig. 6);

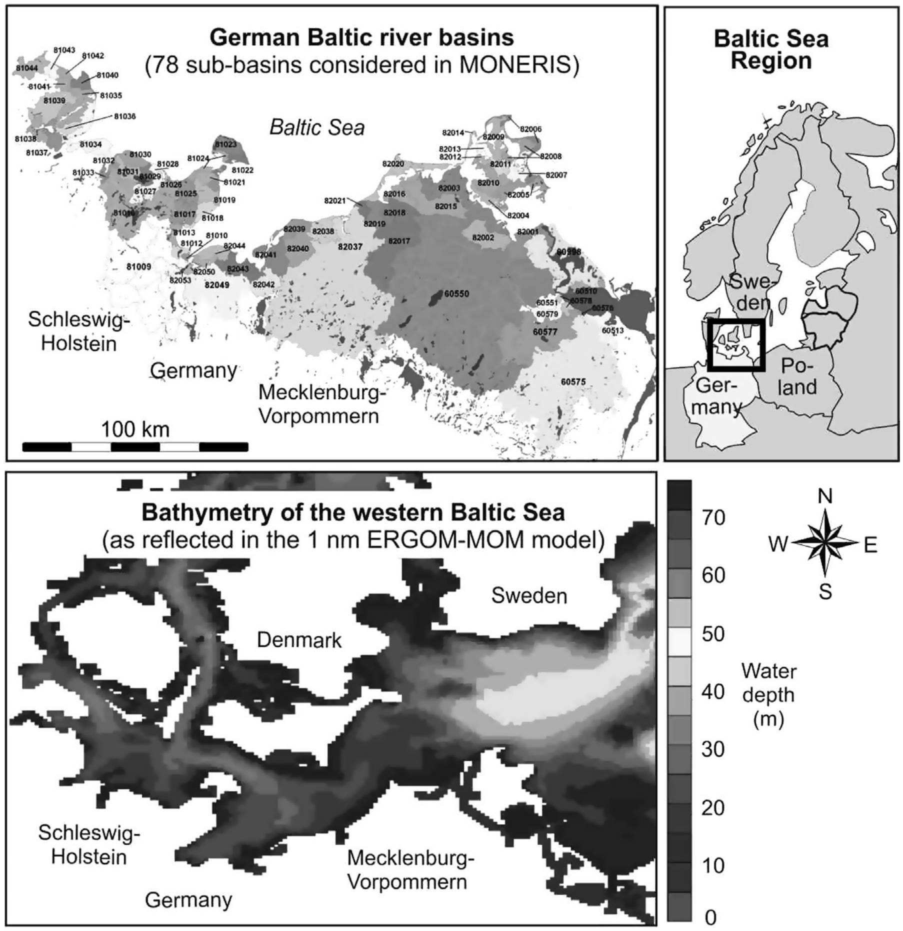

Fig. 2. The German Baltic catchment with the 78 nutrient emission areas (sub-catchments) assumed in the nutrient flux model MONERIS and the bathymetry of the western Baltic Sea as reflected and the Baltic Sea model ERGOM-MOM.

(e) suggest target concentrations and resulting loads in German rivers draining to the Baltic Sea; (f) be calculated with one scientifically justified und uniform methodology; (g) show highest possible reliability and (h) be provided in time for the revision of WFD river basin management plans.

To guide the process and to serve as a discussion forum, an officially acknowledged, national working group on water quality objectives including all representatives of environmental authorities was established. The group met five times until Feb. 2013 and the approach was presented to a broader end-user audience, twice.

During the first meeting possible approaches to define water quality objectives were discussed: (1) The first approach assumed that the data of the early 1960s still represent a good environmental quality and that this period can directly be used to define targets. The model would be used to extrapolate the scarce data to all water bodies. This method would avoid the previous definition of reference conditions and is not fully in agreement with the WFD. (2) The second approach considered up-dated calculations based on pristine conditions (several 1000 years ago). The lack of knowledge and data for this situation as well as high uncertainties with respect to the model application prohibited this method. (3) The third approach assumed a realistic historic reference situation and calculated targets based on that. (4) The fourth approach considered a transfer of historic reference conditions to the presence. The models would have calculated potential reference conditions based on recent basic data (e.g. land-use cover, population density). In a second step the effects of future climate change would have taken into account. This was the most innovative and scientifically challenging approach, but included assumptions which by some authorities were considered as too subjective. Therefore, the national working group favoured approach 3.

During the second meeting possible reference conditions were discussed. The WFD common implementation strategy (CIS) provides additional explanations (REFCOND, 2003): 'Reference conditions do not equate necessarily to totally undisturbed, pristine conditions.' They '…shall be established for each water body type.' CIS-COAST [17] further states: '…it is unrealistic to base reference conditions upon historic landscapes that no longer exist in modern Europe.' 'The description of the biological reference conditions must permit the comparison of monitoring results with the reference conditions…'. 'A hierarchical approach for defining reference conditions is suggested using the various methods in the following order: An existing undisturbed site or a site with only very minor disturbance; or historical data and information; or models…'.

Existing literature shows the complexity of finding and defining a high ecological status for WFD biological elements (benthic invertebrates, macroalgae and angiosperms, phytoplankton) especially for German lagoons, fjords and bays. However, compiled historic data, maps and evaluations indicate that at least water transparency and macrophyte coverage in the sea and in all coastal waters were high before the year 1900 [6,32,49,51,57]. Danish and Swedish data support the need to define a very early 'pre-industrial' state, like 1880, as reference condition [1,26,41]. However, other authors refer to the minor changes that took place between 1880 and the 1950s, indicate a high ecological status still for the 1950s and early 1960s and suggest this period as a possible reference state [13,50]. Phytoplankton biomass in Kiel Bight, for example, did not increase during the first half of the 20th century but may have doubled during the 1960s [54]. These results are supported by model applications [44].

The Working Group concluded that the years around 1880 can be assumed to characterize high ecological status with minor disturbance from human activities as required by the WFD and that this period should be chosen as a reference state for the German Baltic. For these years sufficient data and agricultural statistics existed and allowed the application of the river basin model MONERIS to calculate spatially resolved historic riverine loads for N and P to the German Baltic Sea [27]. Sufficient historic weather and nutrient load data for the entire Baltic allowed simulations with the Baltic Sea model ERGOM.

The process to define water quality targets target and MAI was as follows:

1. MONERIS load data served as input for the Baltic Sea model ERGOM-MOM to calculate historic reference conditions in coastal waters and the Baltic Sea. Parallel, an ERGOM-MOM run was carried out for the present situation (1970–2008, using the years 2000–2008 in the calculations).
2. To reduce uncertainties resulting from input data and the model as well as to increase the reliability of reference concentrations, the relative difference between the ERGOM-MOM simulations of 2000–2008 and the historic situation was calculated. The historic concentrations were divided by the present concentrations for every model grid point and every parameter. The results were variable factors for every spot and parameter (chl.a, N, P) in the western Baltic Sea. The smaller the factor, the lower is the historic concentration compared to the situation today.
3. To closely link historic reference and target concentrations with present monitoring data, the median over the yearly mean (TN, TP) or the seasonal mean (DIN, DIP, chl.a) of the years 2001–2012 was calculated for every monitoring station. The availability of most recent monitoring data allows taking a 4 years longer period (compared to the model simulation) into account. This concentration was multiplied with the factor obtained under point 2. With this approach real monitoring data were projected into the past and served for the definition of reference conditions.
4. Target values defining the boundaries between a good and a moderate status were calculated by adding 50% to the reference concentration of step 3, following WFD guidance [17].
5. ERGOM-MOM model bathymetry does not resolve all German inner coastal waters and small lagoons. Here, a direct calculation of reduction factors, as described in 2 is not possible. Factors for water bodies that are not covered by the model grid were obtained by a transfer of averaged factors from water bodies of the same type that were spatially covered by the model grid.
6. For the use of authorities, the calculated target concentrations for monitoring stations were averaged to receive targets on water body level, which are the relevant managing and evaluation units in the WFD. Additionally the data was averaged for each surface water type, including the span. The suggestion is that a good status for a parameter (chl.a., TN, TP, DIN, DIP) is reached, when the median concentration over a 5 year observation period (based annually aggregated data) remains below the target concentration (threshold between good and moderate status).
7. For several coastal water types, the calculated thresholds for average winter concentrations of dissolved inorganic N and P did not meet the required accuracy, when compared to present data. This was a result of weak winter data availability and model short-comings. Because of an explicitly expressed demand of the authorities, a correction took place. It was based on the existing correlation between winter concentrations and total annual concentrations of N and P in the long-term monitoring data (see chapter 4.3).
8. Maximum allowable nutrient loads and resulting average target concentrations for TN in German Baltic rivers were calculated based on the dependency between chl.a, DIN loads and DIN/DIP load relationships.

4. Results and discussion

4.1. Historic model simulations to define reference conditions

Two model simulations with ERGOM-MOM for the western Baltic Sea were carried out, one for the present situation and another reflecting the historical situation around the years 1880, using the historic nutrient loads provided by MONERIS. Fig. 3 shows a comparison between model simulations and data for averaged surface chl.a concentration in the Mecklenburg Bight (station a in Fig. 6). The model is well able to describe the annual course of chl.a concentrations and the agreement between data and model is, taking into account all uncertainties, acceptable.

Systematic differences between model and data became obvious for DIN and DIP concentrations during winter. The model results did not fully meet the quality requirements for different reasons (quality of input data, bio-availability of nutrients, simplified process description etc.). This was unfortunate because the demand with respect to quality and reliability is high as all values might finally enter laws.

Against this background the historic model simulation results were not used to define historic reference conditions directly. Instead, the relative difference between the ERGOM-MOM simulations of the present situation and the historic one was calculated (factor = historic model data divided through present model data) and later multiplied with recent monitoring data. This approach is commonly used in modeling and calculation of future climate change effects. The obtained factors for chl.a, TN and TP for the entire western Baltic Sea are shown in Fig. 4. The maps indicate a general increase of factors from inner coastal waters towards the Baltic Sea. It means that the reduced nutrient loads in the historic run had a strong effect on concentrations in inner coastal waters, while they had less effect on the open Baltic Sea. Factors close to

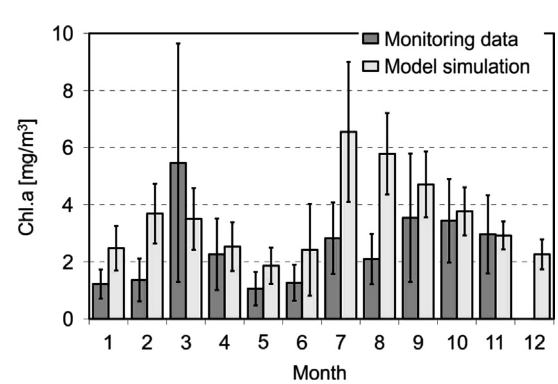

Fig. 3. Near surface monthly averaged chlorophyll a concentration for the years 1973 to 2008 in the Mecklenburger Bucht (Bay of Mecklenburg). Monitoring data is compared to ERGOM-MOM simulation results and the spans indicate the standard deviation.

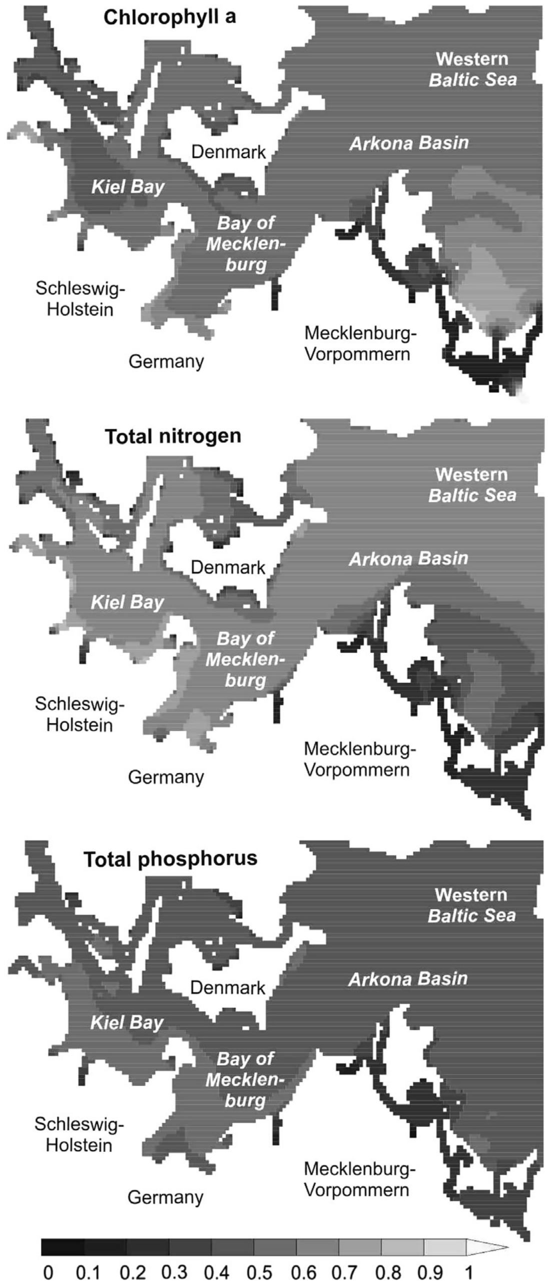

Fig. 4. Model simulations with ERGOM-MOM provide data about the historic (1880) and the present situation of the western Baltic Sea. The figures show the relative difference between historical and present state (historic model data divided through present model data) for the parameters chlorophyll a (May–September averages), total nitrogen (TN, annual averages) and total phosphorus (TP, annual averages), with small factors indicating large differences. The resulting, shown factors are the basis for the calculation of reference conditions according to the Water Framework Directive (WFD).

1 in the Pomeranian Bay off the island of Usedom, which indicate no differences between 1880 and today, are model artefacts and have been neglected. In inner coastal waters, the model suggests nearly a linear relationship between riverine load reduction and concentrations in all inner coastal waters. These waters benefit especially from nitrogen load reductions in German river catchments, which reduce phytoplankton (indicated by chl.a) concentrations in coastal waters. The important role of the Odra river as major nutrient source in the western Baltic is very well visible. It controls water quality in the entire Pomeranian Bay, along the Polish coast and at coastal waters round the island of Rügen. About 95% of the Odra river basin is on Polish and Czech territory and beyond control of German river basin management approaches. This underlines that a close cooperation of neighboring countries both within HELCOM and on WFD River Basin District level is extremely important.

In the open western Baltic Sea our approach suggests factors of about 0.6 for TN and 0.5 for TP. The historic river loads were about 25% (TN) resp. 50% (TP) of the present nutrient loads, but caused TN and TP nutrient concentrations in the open sea of 60%, resp. 50% compared to today. The results clearly indicate that the outer German coastal waters (B3 and B4 types according to the WFD, see Fig. 6) and the open western Baltic Sea are not sensitive to load reductions in Germany and can hardly be controlled via German river basin management measures. Here, long-distance import of nutrients from other parts of the Baltic Sea and the Odra river largely determine water quality and are of high importance for the definition of water quality thresholds. This is especially true for all eastern German outer coastal waters. Input from the North Sea is of minor importance. Germany is largely not in control over the state of its outer coastal waters and the German Baltic Sea, but nutrient loads from German river basins determine the quality in inner coastal waters (B1 and B2 types according to the WFD, see Fig. 6).

4.2. New water quality targets

The factors were multiplied with recent monitoring data. Therefore, quality and reliability of water quality thresholds depend on quality of monitoring data. Figs. 7 and 8 give an impression of the strong interannual variability of data and of long-term trends. To receive reference concentrations for chl.a, for example, average annual summer data of every station were multiplied with the site specific factor (See Appendix A1 and A2). To receive stable and reliable reference concentrations for a station, the resulting (reference) data for every year were averaged. Fig. 5 shows site (monitoring station) specific chl.a reference concentrations, where a site specific factor was multiplied with different types of data (averages and medians over 6 resp. 11 years) of these sites. It gives an insight to what extent the interannual variability of monitoring data (which is shown in Fig. 3) is reflected in long-term medians and averages and how these differences effects our calculated reference and target thresholds. The difference between chl.a reference concentrations calculated based on long-term averages and medians in some cases, like the Unterwarnow, exceeds 40%. For the Unterwarnow it means that, depending on using average or median, the reference concentration for chl.a can be either 3.5 or 5.2 mg/m^3 chl.a. The target threshold is calculated by adding 50% to the reference concentration. The target concentration for the Unterwarnow can be either 5.3 or 7.8 mg/m^3 chl.a.

Altogether, the long-term median (2001–2012) turned out to be most reliable to reflect the present data and was used in the calculation of reference and target values for all stations and parameters. Fig. 5 compares our proposed new reference concentrations with the current type specific reference conditions according to Sagert et al. [42]. The current values for these selected inner coastal waters seem in most cases unrealistic low. One single chl.a reference value for all B2a (5–10 psu) and B2b (10–18 psu) water body types is not appropriate, because it does not reflect the specific situations in all individual water bodies within one type sufficiently. These results question the suitability of the German typology as a basis for reference and target value definitions. The necessity of our spatially differentiated approach is obvious, because it allows going beyond the typology and allows specific tailor-made targets for every single water body. This seems to be reasonable because the water body is the management unit of the WFD.

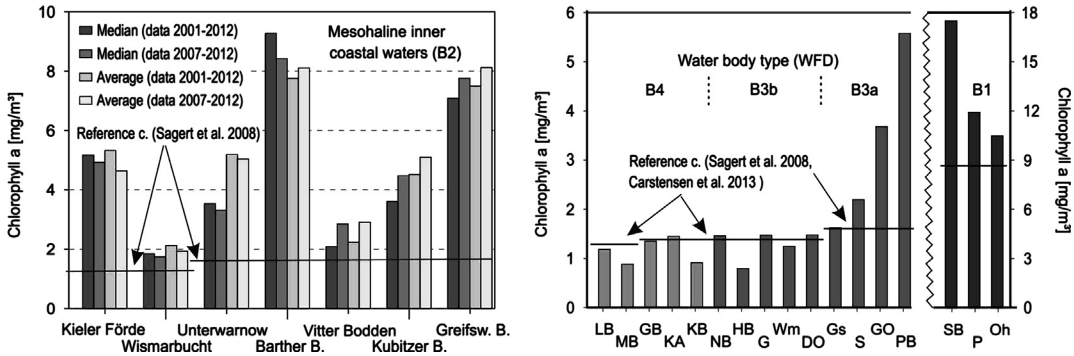

Fig. 5. Chlorophyll a (near-surface summer) reference concentrations for selected German meso-haline inner coastal waters (WFD-type B2) (top). Shown are reference conditions resulting from our approach using medians and averages over 6 resp. 11 years. Results for other water body types based on the median of the period 2001–2012 (bottom) are shown for Lübecker Bucht (LB), Mecklenburger Bucht (MB), Geltinger Bucht (GB), Kieler Außenförde (KA), Kieler Bucht (KB), Neustädter Bucht (NB), Hohwachter Bucht (HB), Grömitz (G), Warnemünde (Wm), Darsser Ort (DO), Gellenstrom (Gs), Sassnitz (S), Greifswalder Oie (GO), Pommersche Bucht (PB), Saaler Bodden (SB), Peenestrom (P), Oderhaff (Oh). Additionally current reference conditions of Sagert et al. [42] (for sub-types B2a and B2b) and Carstensen et al. [14] are indicated (black lines). Details about the stations are in Appendix A1 and A2.

Figs. 7 and 8 give a detailed insight into data variability and the approach to define new reference and target concentrations for selected monitoring stations. The figures show examples for all German WFD coastal water types, as well as Baltic Sea stations. The German typology and the locations of selected monitoring stations are indicated in Fig. 6. In nearly all inner coastal waters (B1 and B2 types), our chl.a target concentrations are much higher compared to Sagert et al. [42]. For the outer coastal waters (B3 and B4 types) both approaches are, in general, well in agreement. Sagert et al. [42] suggests values of 1.9 (B3b) and 2.3 mg/m³ chl.a (B3a). Further, the values are well in agreement with internationally inter-calibrated chl.a values and the HELCOM suggestions of 1.9 mg/m³ chl.a as a summer average for the total Danish straits sea area [14]. Differences are mainly a result of the more detailed site specific approach. For stations with a large distance to pollution source and/or frequent up-welling processes significantly lower target values our suggested, e.g. for Hohwachter Bucht (1.1 mg/m³ chl.a), Mecklenburger Bucht (1.2 mg/m³ chl.a) or Kieler Bucht (1.3 mg/m³ chl.a). Vice versa for monitoring stations in outer coastal waters (B3-types) that are strongly influenced by pollution sources like the Odra, much higher values are suggested, e.g. Zinnovitz (7.8 mg/m³ chl.a), Greifswalder Oie (5.1 mg/m³ chl.a) or Sassnitz (3.1 mg/m³ chl.a).

Historical chl.a data to support our target concentrations does not exist. However, early chl.a concentrations can be calculated from historical phytoplankton data, which are available from Kiel Fjord for 1905 and 1906 [54]. Using a conversion factor of 50, as applied by Hoppe et al. [29], the average phytoplankton carbon biomass of 55 mg/m^3 corresponds to a chl.a concentration of 1.1 mg/m^3. This concentration meets the suggested target of 1.3 mg/m³ chl.a very well.

TN and TP reference and target concentrations (annual near surface averages) for all German Baltic water bodies are documented in Appendix A1 and A2 and some results are summarized in Table 1. The existing target values for TN and TP for inner coastal waters (types B1 and B2) of Brockmann et al. [10] are in most cases and of Sagert et al. [42] for several water bodies unrealistic low because they do not take into account the individual situation of each water body. Both approaches suffer from several weaknesses. (a) the riverine loads in Brockmann et al. [10] calculated with MONERIS did not reflect a real historic situation but assume artificial background concentrations and loads; (b) the natural gradients of nutrient concentration between river and open sea and especially the role of inner coastal waters as retention and transformation units for nutrients calculated by Brockmann et al. [10] are neglected; (c) hydrodynamic processes and spatial transport in the Baltic sea as well as the exposition of water bodies towards pollution sources are neglected and finally, (d) explicit assumptions concerning the nutrient loads from neighboring states and other Baltic regions are lacking.

For Bornholm Basin, Arkona Basin and Danish Straits, Carstensen et al. [14] suggest chl.a target concentrations of 2.44; 1.89 and 1.44 mg/m³ chl.a. Spatially integrating our results over the surface area of these Baltic Sea basins, we receive similar concentrations of 1.97 (Bornholm Basin), 1.79 (Arkona Basin) and 1.56 mg/m³ chl.a (Danish straits). Therefore, the proposed target values for the western Baltic Sea by Carstensen et al. [14] are largely confirmed (Table 1, Fig. 7). The small difference can be largely explained by the different approaches and differences in the considered period for the analysis.

4.3. An alternative approach for winter nutrient target concentrations

Not for all water body types the calculation of DIN and DIP winter reference and target concentrations the methodology described above (multiplication of a factor with present data) provided convincing results, when compared to data (Fig. 9). This is especially true for inner coastal waters (types B1 and B2). As an alternative, DIN and DIP winter target concentrations were calculated based on average annual TN resp. TP concentrations. For every water body sub-type a separate linear regression between winter DIN (DIP) and average annual TN (TP) was established with the following coefficients of determination (R^2) for the sub-water body types: B1 0.28; B2a 0.35; B2b 0.74; B3a 0.39; B3b 0.73; B4 0.59. In outer coastal waters and the open sea both methods show comparable results. In inner coastal waters the differences between both methods are significant, differ between monitoring stations and the relation between target and data varies (Fig. 9). It is questionable if dissolved inorganic nutrient concentrations in inner coastal waters are at all a suitable quality indicator. Data availability and the reliability of annual averages of data are poor. Changes of the N/P relationship in nutrient loads can cause shifts in the nutrient limitation of primary production and this can cause strong changes in N and P concentrations. Dissolved organic matter plays an important role as nutrient source (e.g. [48]) and fast mineralization processes as well as the interaction between sediment and water body in these shallow systems have a strong influence on concentrations. However, the targets calculated with

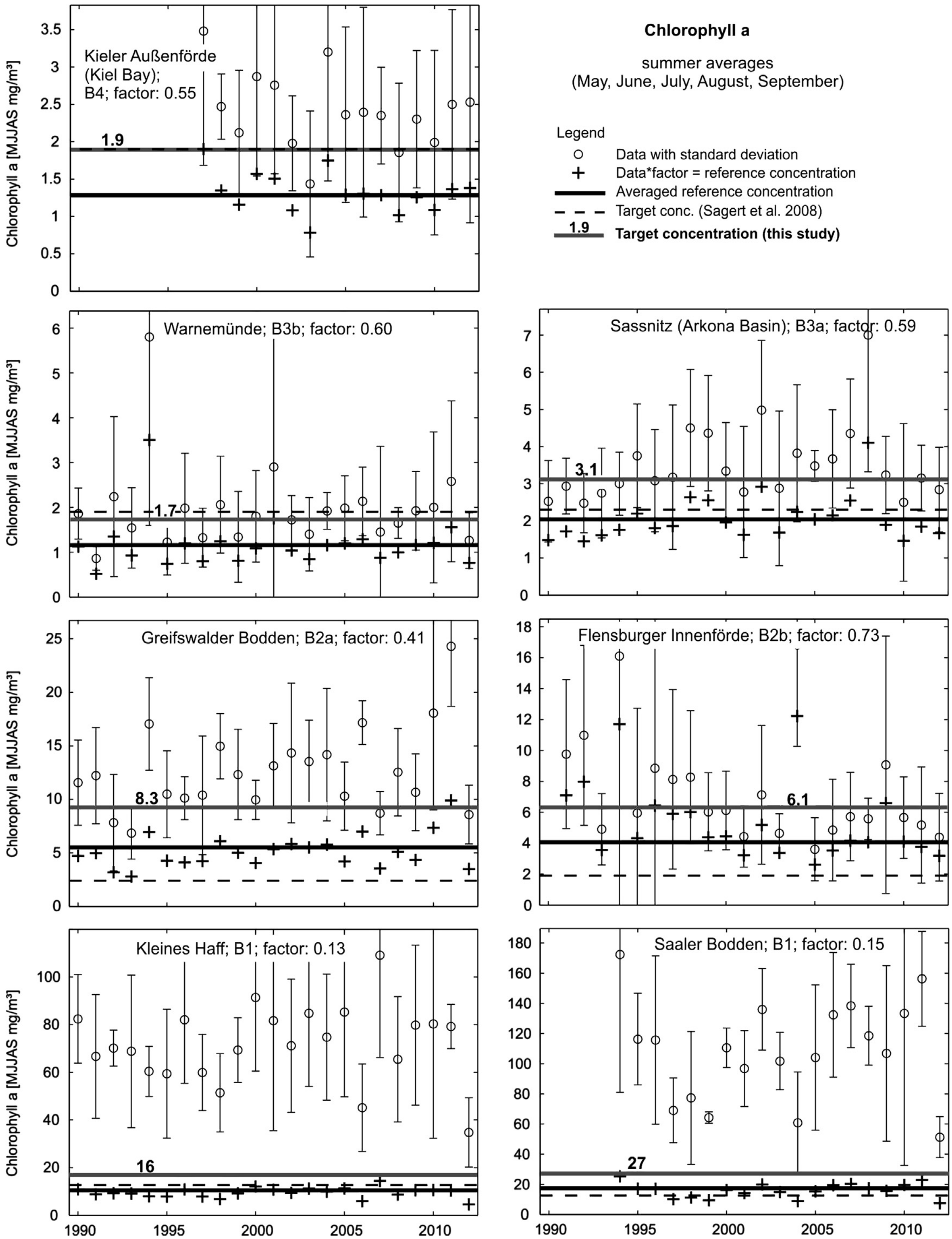

Fig. 6. The German Baltic typology according to the Water Framework Directive and selected monitoring locations. Water body types are further sub-divided according to salinity (B1a: 0.5–3 psu; B1b: 3–5 psu; B2a: 5–10 psu; B2b: 10–18 psu; B3a: 5–10 psu; B3b: 10–18 psu). Similar sub-types in different regions are called water bodies, the smallest unit in the WFD. Exact positions of the monitoring stations are provided in Appendix A1 and A2.

the regression approach are suggested as new target concentrations for winter DIN and DIP.

4.4. Maximum allowable nutrient inputs (MAI)

According to our results, chl.a is the most reliable quality indicator across the continuum from inner coastal waters to the open sea and most suitable with respect to WFD and BSAP. Therefore, chl.a target concentrations were used to calculate MAI and subsequent target concentrations for German rivers. Fig. 10 illustrates that the seasonally averaged, spatially integrated chl.a concentrations not only depend on DIN loads of the previous year. The DIN/DIP relationship in loads controls the N or P limitation of primary production and has to be taken into account, as well. The function based on this data combines both dependencies (Fig. 10).

The comparison between calculated chl.a concentrations using this function and expected data shows a very good fit (Fig. 11) and proves that the function in Fig. 10 is suitable to calculate the MAI.

Table 1
Compilation and comparison of water quality targets (reference+50%) for total nitrogen (TN) and total phosphorus (TP). The values are near surface annual averages.) Concentration averages by Sagert et al. [42] refer to May–September. Danish Straits include the HELCOM sub-basins Bay of Mecklenburg and Kiel Bay.

WFD-type	Salinity [psu]	**Targets for total nitrogen/*phosphorus*** [μmol/l]			
		Brockmann et al. [10]	Sagert et al. [42]	Carstensen et al. [14]	This study
B1	1.8–3.5	15/*0.5–0.8*	51/–	–	31–76/*1.3–2.8*
B2	5–18	12–20/*0.5–0.9*	16.1–18.5/–	–	11–73/*0.4–1.7*
B3	6.5–15	14-18/*0.6–0.9*	16.1–18.0/–	–	14–45/*0.4–1.3*
B4	10.5–20	15/*0.8–0.9*	16.1/–	–	18–19/*0.4–0.6*
Danish Straits	8–22	–	–	21.8/*0.97*	19.3/*0.47*
Arkona Basin	7–9	15/*0.7*	–	17.4/*0.66*	19.3/*0.52*
Bornholm Basin	5–8	–	–	16.3/*0.57*	16.7/*0.46*

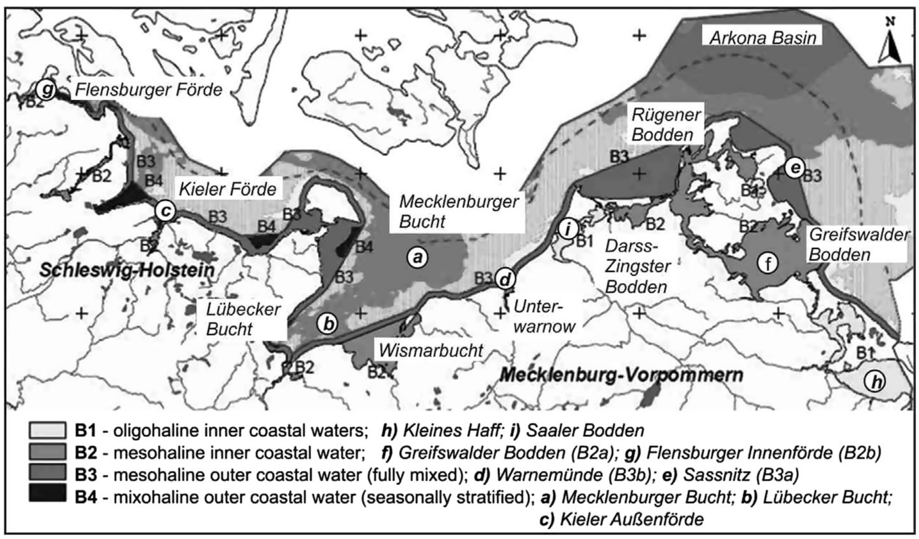

Fig. 7. Long-term (1990–2012) chlorophyll a (near-surface, summer) concentrations for 7 selected monitoring stations representing all German WFD coastal water types B1–B4. Shown are monitoring data including standard-deviation (annually averaged for May to September; the data multiplied with the factor that resulted from model runs (historic model data divided through present model data, see Fig. 4) to receive historic (1880) reference data; the calculated median reference conditions for the years 2001–2012; the current target concentration (reference+50%, threshold between good and moderate state) according to Sagert et al. [42] and our proposed, new target concentration. Full data and geographical coordinates of the stations are provided in Appendix A1 and A2.

A similar linear relationship exists between the TN-loads and observed summer chl.a. In the calculations it is assumed that all countries reduce nutrient loads similar to Germany. TP loads are kept constant. To reduce the spatially integrated, near surface summer chl. a concentration from 4.5 mg/m³ to the target of 3.6 mg/m³ (a reduction of 20%), the total nitrogen load has to be reduced from 32,700 t/a to 21,500 t/a (a reduction of 34%). There are two options to reduce nutrient loads, either via reduced waterborne or via reduced atmospheric loads. If the chl.a target concentration should be reached with waterborne nitrogen load reductions alone, the average TN concentration in rivers would have to be reduced from 4.7 mg/l TN to 2.0 mg/l TN. Alternative options involving atmospheric load reductions are given in Table 2. To reach the 1880 reference conditions, where chl.a concentrations are 46% lower, would require a 64% load reduction. This underlines that load reductions do not result in proportionally lower chl.a concentrations.

Our simplified, seasonally averaged, spatially integrated approach allows a direct comparison to existing MAI in the BSAP. The MAI according to the updated BSAP [25] suggest total load reduction of 7670 t TN/a as well as 175 t TP/a for Germany during the next 15 years.

Estimates based on HELCOM [25] show that only about 3050 t of the N reductions would directly affect and improve German Baltic water quality. According to the calculations, a BSAP implementation would not meet the suggested new water quality objective for German Baltic waters and would not ensure a good status according to the WFD. The BSAP target objectives for the open sea are largely similar to ours, but different to the BSAP our results indicate that the suggested load reductions are not sufficient. This apparent contradiction is a result of different spatial units. While the BSAP focusses on the open sea only, we use a spatially integrated approach including all coastal waters. The suggested N load reductions in the BSAP might be sufficient for reaching the targets in the open sea, but they are not at all sufficient to reach the targets in German inner and outer coastal waters. However, it has to be admitted that serious uncertainties exist about the exact amount of atmospheric deposition and its spatial and temporal distribution. Additionally, the spatial aggregated approach and the neglect of the effect of TP load reduction limit the reliability of the results.

5. Conclusion

The spatially resolved model approach is a refinement and complement of the Baltic Nest box model approach, used for MAI calculations within the BSAP. It allows the harmonization of water quality objective between WFD and BSAP, considers the

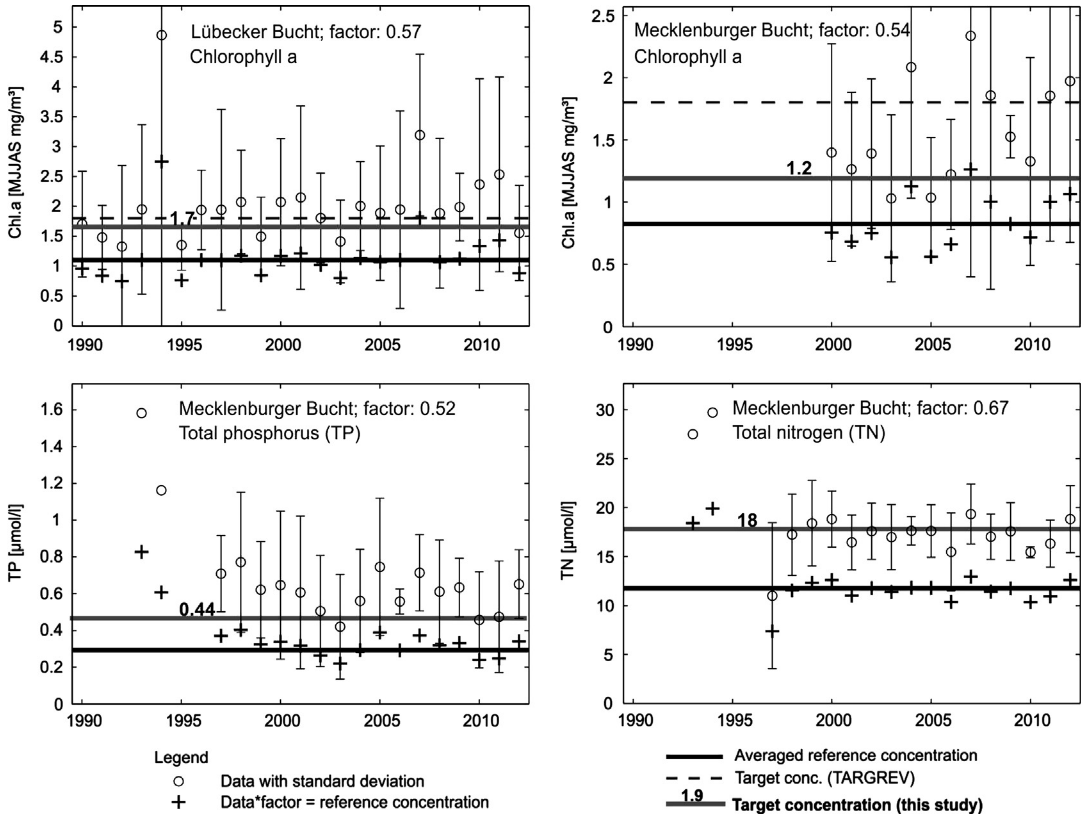

Fig. 8. Long-term (1990–2012) chlorophyll a (near-surface, summer) concentrations for the Lübecker Bucht and the central station of the Mecklenburger Bucht as well as total nitrogen and total phosphorus concentrations for the Mecklenburger Bucht (HELCOM station Bay of Mecklenburg). TN and TP data for the Lübecker Bucht is very similar and therefore not presented. Shown are monitoring data including standard-deviation; the data multiplied with the factor that resulted from model runs (historic model data divided through present model data) to receive historic (1880) reference data; the averaged calculated reference conditions; the former target concentration (reference + 50%, threshold between good and moderate state) according to Sagert et al. [42] and our proposed, new target concentration. Full data and geographical coordinates of the stations are provided in Appendix A1 and A2.

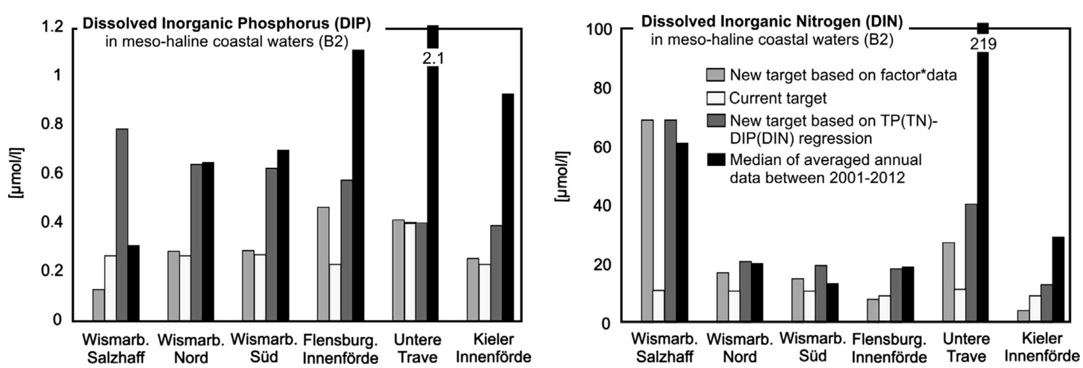

Fig. 9. Monitoring data for DIP and DIN (2001–2012) in meso-haline coastal waters (B2) compared to current target values, new targets based on the methodology in Figs. 7 and 8 and based average a regression to annual average TN resp. TP concentrations.

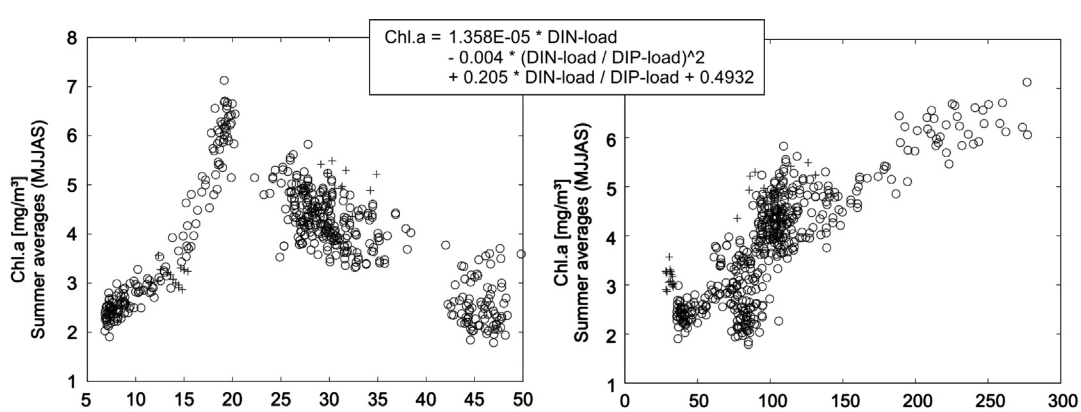

Fig. 10. Relationships between summer (May–Sept.) near surface chlorophyll a concentrations (averages over the western Baltic Sea) and bio-available dissolved inorganic nitrogen loads (DIN) of the previous year as well as the DIN/DIP relationship in loads. The equation combines both relationships. All data is based on model simulations with ERGOM-MOM. Different symbols indicate different model runs.

dependencies between nutrient concentrations and biological indicators, like chl.a, and reflects the gradients from inner coastal waters and lagoons towards the open sea. The definition of the years around 1880 as reference conditions, with a high ecological status, and the deviation of target concentration by adding 50% turned out to be scientifically reasonable and pragmatic. Compared to current targets, the suggested values are in general slightly stricter for the open sea and less strict in inner coastal waters. Despite that a good ecological status in inner coastal water is still very hard to reach.

The newly suggested water quality targets show that lagoons, bays and estuaries are individuals, determined by the hydrodynamic and morphometric conditions as well as the distance to nutrient sources (Fig. 12). They form single water bodies within one WFD water body type and require very different target values. Even within one water body strong gradients are observed. Therefore, the spatial differentiation of reference and targets value is necessary and a major step towards a successful WFD implementation. WFD CIS asks to take into account the interannual variability of reference conditions and to express it in form of ranges. Our results show that spatial variability is of similar importance, but usually neglected. Because of spatial (and temporal) variability and resulting wide ranges, reference and target values aggregated on water body type level have only a very limited meaning and suitability for practical management. Most reliable and useful are targets for every single monitoring station or at least every water body.

Chl.a turned out to be a suitable indicator across the gradient from land to sea. In several coastal waters winter dissolved inorganic nutrient concentrations have only a low value as quality indicator.

The used model revealed several weaknesses that require attention and improvement. However, it became obvious that the higher the spatial and temporal resolution, the more important becomes quality as well as spatial and temporal resolution of input data, namely discharge and nutrient concentrations. Further the bio-availability of compounds and the N/P ratio in loads requires attention. It seems that in some coastal waters similar chl.a targets can be reached with alternative management approaches either focussing on N or on P load reductions. Additionally, the role of extreme events on the state of ecosystems requires more attention.

The MAI for Germany and the updated nutrient reduction targets of the Baltic Sea Action Plan HELCOM [25] are, according to our results, not sufficient to reach a good ecological status in German Baltic coastal waters. The BSAP has a focus on the open sea. The suggested low N load reductions into the western Baltic Sea in general, and the focus on a reduction of atmospheric deposition, allows much too high N loads into German coastal waters to meet the WFD targets. Future updates of the Baltic Sea Action Plan should take coastal waters and their specific demands and conditions into account. At present, transport pattern and spatial distribution as well as amount and bio-availability of

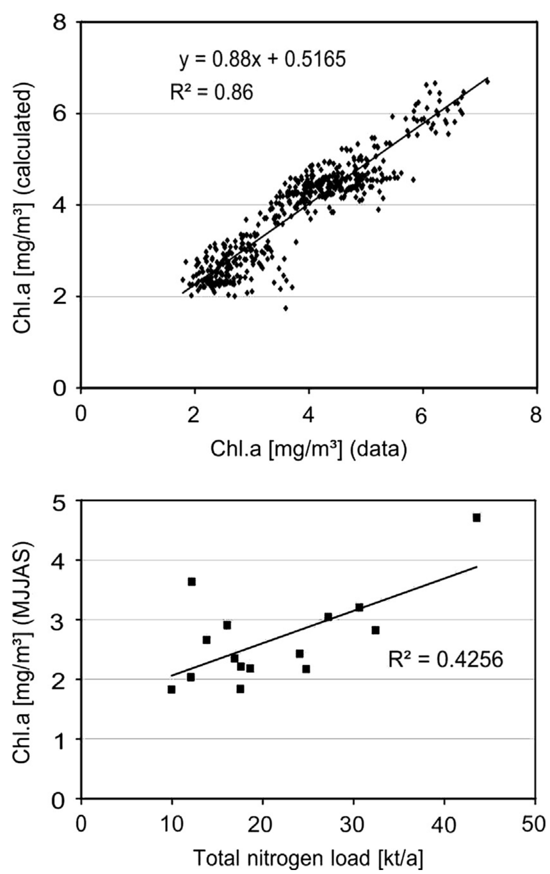

Fig. 11. Top: Relationship between calculated chlorophyll a concentrations and measured monitoring data. All data are near surface summer (May–Sept.) averages, integrated over the western Baltic Sea. For calculated concentrations the function shown in Fig. 10, based on ERGOM-MOM model simulations, was used. Bottom: relationship between chlorophyll a concentration data and total nitrogen loads (averaged over the western Baltic Sea, taken from PLC-5).

Table 2
The nutrient load situation between 1997 and 2003 (following [24,25]), around 1880 (reference situation) and four options to reach the maximum allowable (nitrogen) input (MAI) related to the German Baltic catchment. The chl.a concentrations are average, spatially aggregated, near surface values for summer (May–Sept.). Concentrations in rivers assume a total discharge of 121.8 m³/s. The atmospheric deposition load is calculated for the area of 9.5–14.8° east and 53.6–55.3° north based on German Federal Agency data (pers. com.). This area is assumed to be relevant for water quality in German coastal and marine waters. 'MAI-rivers only': load reductions to reach the MAI take place in rivers exclusively. 'MAI-Göteborg-Protokoll' assumes a 20% reduction of atmospheric N loads, the remaining reduction requirement is covered by waterborne sources. 'MAI-proportional' assumes 34% reductions of both atmospheric and waterborne sources. 'MAI-atmospheric' is based on a 50% reduction of atmospheric deposition. 'Baltic Sea Action Plan 2013' numbers correspond to MAI stated in the BSAP of 2013 [25] adjusted to the selected area.

	Total load TN [t/a]	Waterborne TN [t/a]	Atmospheric TN [t/a]	Conc. in rivers TN [mg/l]	Total load TP [t/a]	Average chl.a [mg/m³]
Today (1997–2003)	32,697	19,690	13,007	**4.7**	526	4.5
MAI-rivers only	21,478	8471	13,007	**2.0**	526	3.6
MAI-Göteborg-Protokoll 20%	21,478	11,072	10,406	**2.6**	526	3.6
MAI-proportional 34%	21,478	12,934	8544	**3.1**	526	3.6
MAI-atmosph. Deposition 50%	21,478	14974	6504	**3.6**	526	3.6
Baltic Sea Action Plan (2013)	29,640	17,740	11,900	**4.3**	356	4.2
Refence conditions (1880)	9027	5127	3900	**1.46**	227	2.4

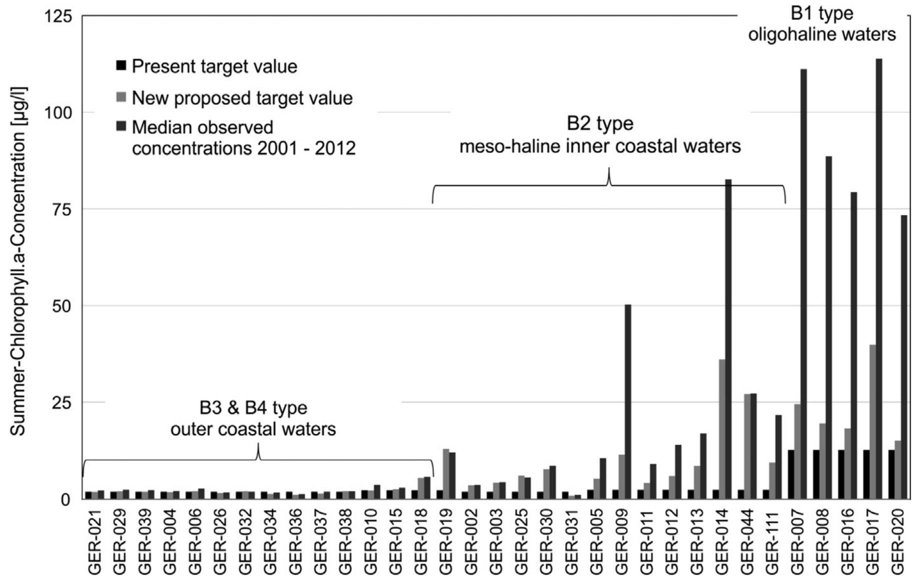

Fig. 12. New water quality targets for German Baltic waters (WFD water bodies and single stations) for chl.a (averaged over summer) compared with present targets and median of observed values. The current target concentrations are according to Sagert et al. [42] and Carstensen et al. [14].

atmospheric N and P deposition to the Baltic Sea are not well known, generate uncertainty in the results and require further attention and additional research.

Acknowledgments

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Appendix A

See Table A1.

New water quality targets for German Baltic waters (WFD water bodies and single stations) for chlorophyll (near-surface summer averages between May and September), total nitrogen (TN, annual averages) and total phosphorus (TP, annual averages). Beside data (median concentrations between 2001–2012), the current target concentrations according to Sagert et al. [42], Carstensen et al. [14] and Brockmann et al. [10] are shown. Our suggested, new target concentrations result from reference concentration + 50%. Factors result from model runs (historic model data divided through present model data) and are used to calculate reference concentrations (factor multiplied with median data). More about the HELCOM monitoring and assessment strategy including stations under www.helcom.fi.

See Table A2.

New water quality targets for German Baltic waters (WFD water bodies and single stations) for dissolved inorganic nitrogen and dissolved inorganic phosphorus (near surface winter averages December–February). Beside data (median concentrations between 2001 and 2012), the current target concentrations according to Carstensen et al. [14] and Brockmann et al. [10] are shown. Model target concentrations result from reference concentration + 50%. Factors result from model runs (historic model data divided through present model data) and are used to calculate reference concentrations (factor multiplied with median data). New target concentrations are based on regression analysis (see chapter 4.3 for details). More about the HELCOM monitoring and assessment strategy including stations under www.helcom.fi.

Table A1
New water quality targets for German Baltic waters (WFD water bodies and single stations) for chlorophyll (near-surface summer averages between May and September), total nitrogen (TN, annual averages) and total phosphorus (TP, annual averages). Beside data (median concentrations between 2001-2012), the current target concentrations according to Sagert et al. (2008), Carstensen et al. (2013) and Brockmann et al. (2005) are shown. Our suggested, new target concentrations result from reference concentration +50%. Factors result from model runs (historic model data divided through present model data) and are used to calculate reference concentrations (factor multiplied with median data). More about the HELCOM monitoring and assessment strategy including stations under www.helcom.fi.

HELCOM ID	WFD water body name	Station ID	Station description	WFD type	Median data (2001–12)	Factor	**New target**	Target (current)	Median data (2001–12)	Factor	**New target**	Target (current)	Median data (2001–12)	Factor	**New target**	Target (current)
					Chlorophyll a (μg/l)				**Total Nitrogen (μmol/l)**				**Total Phosphorus (μmol/l)**			
GER-002	Wismarbucht, Nordteil	Mean		B2b	3.67	0.650	**3.6**	1.9	24.26	0.641	**23.0**	13.3	1.07	0.494	**0.80**	0.55
		LUNG_WB3	Wismarbucht n. Walfisch	B2b	4.54	0.641	**4.4**	1.9	26.74	0.561	**22.5**	13.3	1.17	0.476	**0.84**	0.55
		LUNG_WB5	Wismarbucht w. Innenreede	B2b	2.80	0.658	**2.8**	1.9	21.77	0.721	**23.6**	13.3	0.97	0.512	**0.75**	0.55
GER-003	Wismarbucht, Salzhaff	LUNG_SH2	Salzhaff nw. Tessmannsdorf	B2b	4.38	0.650	**4.3**	1.9	58.40	0.693	**60.7**	13.3	1.40	0.529	**1.11**	0.55
GER-004	suedl Mecklenburger Bucht/ Travemuende-Warnemuende	Mean		B3b	2.07	0.585	**1.8**	1.9	19.78	0.697	**20.7**	14.3	0.93	0.540	**0.76**	0.61
		LUNG_O3	n. Poel	B3b	2.00	0.557	**1.7**	1.9	19.10	0.692	**19.8**	14.3	0.90	0.539	**0.74**	0.61
		LUNG_O4	Bok	B3b	1.88	0.565	**1.6**	1.9	19.33	0.684	**19.8**	14.3	0.95	0.534	**0.77**	0.61
		LUNG_O5	Warnemuende	B3b	1.92	0.603	**1.7**	1.9	19.36	0.687	**20.0**	14.3	0.92	0.552	**0.77**	0.61
		LUNG_WB6	Wismarbucht o. Krakentief	B3b	2.48	0.613	**2.3**	1.9	21.34	0.726	**23.2**	14.3	0.95	0.536	**0.77**	0.61
GER-005	Unterwarnow	LUNG_UW4	Unterwarnow (Warnowwerft)	B2a	10.55	0.335	**5.3**	2.4	59.55	0.255	**22.8**	17.1	1.68	0.330	**0.83**	0.77
GER-006	sued Mecklenburger Bucht/ Warnemuende bis Darss	Mean		B3b	2.77	0.520	**2.1**	1.9	23.96	0.551	**18.3**	14.3	1.00	0.477	**0.71**	0.61
		LUNG_O6	nw. Fischland	B3b	2.01	0.574	**1.7**	1.9	18.66	0.669	**18.7**	14.3	0.94	0.513	**0.72**	0.61
		LUNG_O7	n Darsser Ort	B3b	2.38	0.577	**2.1**	1.9	19.68	0.635	**18.8**	14.3	0.96	0.499	**0.72**	0.61
		LUNG_UW5	Mole Warnemuende	B3b	3.92	0.410	**2.4**	1.9	33.54	0.349	**17.6**	14.3	1.10	0.419	**0.69**	0.61
GER-007	Ribnitzer See / Saaler Bodden		Mean	B1	111.17	0.147	**24.5**	12.7	219.78	0.217	**71.5**	15	4.33	0.281	**1.82**	0.8
		LUNG_DB16	Saaler Bodden	B1	118.58	0.147	**26.1**	12.7	204.56	0.217	**66.6**	15	4.31	0.281	**1.82**	0.8
		LUNG_DB19	Ribnitzer See	B1	103.76	0.147	**22.9**	12.7	235.00	0.217	**76.5**	15	4.35	0.281	**1.83**	0.8
GER-008	Koppelstrom / Bodstedter Bo.	LUNG_DB10	Bodstedt	B1	88.60	0.147	**19.5**	12.7	171.83	0.217	**55.9**	15	3.39	0.281	**1.43**	0.8
GER-009	Barther Bodden, Grabow	Mean		B2a	50.29	0.153	**11.5**	2.4	105.48	0.150	**23.5**	17.1	2.68	0.179	**0.71**	0.77
		LUNG_DB2	Grabow	B2a	38.32	0.156	**9.0**	2.4	91.54	0.156	**21.5**	17.1	2.29	0.187	**0.65**	0.77
		LUNG_DB6	Barther Bodden	B2a	62.26	0.149	**13.9**	2.4	119.41	0.143	**25.6**	17.1	3.06	0.170	**0.78**	0.77
GER-010	Prerowb./Darsser Ort-Dornb.	LUNG_GS	Gellenstrom	B3a	3.69	0.410	**2.3**	2.3	21.45	0.348	**11.2**	18	0.96	0.336	**0.48**	0.9
GER-011	Westruegensche Bodden	Mean		B2a	9.09	0.305	**4.2**	2.4	36.74	0.268	**14.8**	17.1	1.25	0.268	**0.50**	0.77
		LUNG_RB1	Schaproder Bodden	B2a	8.02	0.335	**4.0**	2.4	33.63	0.299	**15.1**	17.1	1.19	0.287	**0.51**	0.77
		LUNG_RB2	Vitter Bodden	B2a	8.30	0.251	**3.1**	2.4	34.24	0.217	**11.1**	17.1	1.22	0.235	**0.44**	0.77
		LUNG_KB90	Kubitzer Bodden	B2a	10.94	0.330	**5.4**	2.4	42.36	0.288	**18.3**	17.1	1.33	0.282	**0.56**	0.77
GER-012	Strelasund	LUNG_S66	Strelasund	B2a	13.98	0.284	**6.0**	2.4	41.08	0.269	**16.6**	17.1	1.64	0.250	**0.62**	0.77
GER-013	Greifswalder Bodden	Mean		B2a	16.93	0.357	**8.6**	2.4	39.12	0.294	**16.9**	17.1	1.67	0.260	**0.64**	0.77
		LUNG_GB10	s. Ruden	B2a	25.12	0.282	**10.6**	2.4	47.37	0.241	**17.1**	17.1	2.13	0.241	**0.77**	0.77
		LUNG_GB19	Zentralbereich	B2a	13.54	0.407	**8.3**	2.4	33.92	0.330	**16.8**	17.1	1.50	0.281	**0.63**	0.77
		LUNG_GB2	s. Vilm	B2a	12.14	0.381	**6.9**	2.4	36.08	0.312	**16.9**	17.1	1.38	0.257	**0.53**	0.77
GER-014	Kleiner Jasmunder Bodden	LUNG_RB15	Buschvitz	B2a	82.62	0.291	**36.1**	2.4	154.61	0.251	**58.2**	17.1	4.54	0.252	**1.71**	0.77
GER-015	Nord- & Ostruegensche Gew.	Mean		B3a	2.94	0.578	**2.5**	2.3	20.82	0.540	**16.7**	18	0.91	0.425	**0.57**	0.9
		LUNG_O10	no. Kap Arkona	B3a	2.36	0.559	**2.0**	2.3	20.30	0.615	**18.7**	18	0.87	0.451	**0.59**	0.9
		LUNG_O11	Sassnitz	B3a	3.48	0.586	**3.1**	2.3	20.97	0.494	**15.5**	18	0.86	0.418	**0.54**	0.9
		LUNG_O9	nw. Hiddensee	B3a	2.30	0.594	**2.1**	2.3	18.83	0.638	**18.0**	18	0.88	0.454	**0.60**	0.9
		LUNG_OMU	Prorer Wiek	B3a	3.62	0.571	**3.1**	2.3	23.18	0.413	**14.4**	18	1.02	0.376	**0.57**	0.9
GER-016	Peenestrom	Mean		B1	79.35	0.153	**18.2**	12.7	117.81	0.193	**33.9**	15	3.95	0.252	**1.48**	0.8
		LUNG_P20	s. Peenemuende	B1	78.36	0.147	**17.3**	12.7	109.43	0.217	**35.6**	15	3.18	0.281	**1.34**	0.8
		LUNG_P42	s. Wolgast	B1	81.04	0.160	**19.5**	12.7	112.09	0.186	**31.2**	15	3.61	0.233	**1.26**	0.8

Table A1 (*continued*)

HELCOM ID	WFD water body name	Station ID	Station description	WFD type	Median data (2001–12)	Factor	**New target**	Target (current)	Median data (2001–12)	Factor	**New target**	Target (current)	Median data (2001–12)	Factor	**New target**	Target (current)
					Chlorophyll a (μg/l)				**Total Nitrogen (μmol/l)**				**Total Phosphorus (μmol/l)**			
		LUNG_P48	Lassan	B1	78.66	0.151	**17.8**	12.7	131.91	0.175	**34.7**	15	5.07	0.242	**1.85**	0.8
GER-017	Achterwasser	LUNG_AW1	Trockenort	B1	115.52	0.230	**39.9**	12.7	122.53	0.200	**36.7**	15	3.73	0.230	**1.29**	0.8
GER-018	Pommersche Bucht, Nordteil	Mean		B3a	5.77	0.640	**5.5**	2.3	29.62	0.470	**20.8**	18	1.13	0.420	**0.70**	0.9
		LUNG_O133	Greifswalder Oie	B3a	6.24	0.548	**5.1**	2.3	30.01	0.380	**17.1**	18	1.16	0.350	**0.60**	0.9
		LUNG_O14	Zinnowitz	B3a	5.30	0.732	**5.8**	2.3	29.23	0.560	**24.5**	18	1.09	0.490	**0.80**	0.9
GER-019	Pommersche Bucht, Suedteil	Mean		B3a	12.03	0.723	**12.9**	2.3	48.41	0.517	**37.6**	18	1.60	0.476	**1.15**	0.9
		LUNG_OB1	n. Ahlbeck	B3a	12.88	0.752	**14.5**	2.3	50.01	0.545	**40.9**	18	1.78	0.496	**1.32**	0.9
		LUNG_OB2	n. Ahlbeck	B3a	16.22	0.678	**16.5**	2.3	59.73	0.501	**44.9**	18	1.71	0.467	**1.20**	0.9
		LUNG_OB4	n. Ahlbeck	B3a	7.00	0.740	**7.8**	2.3	35.48	0.506	**26.9**	18	1.30	0.466	**0.92**	0.9
GER-020	Kleines Haff	Mean		B1	73.39	0.138	**15.1**	12.7	113.70	0.253	**43.1**	15	5.37	0.324	**2.60**	0.8
		LUNG_KHJ	Zentralbereich	B1	67.57	0.143	**14.5**	12.7	119.13	0.255	**45.5**	15	5.55	0.332	**2.76**	0.8
		LUNG_KHM	Mitte Staatsgrenze	B1	79.20	0.132	**15.7**	12.7	108.26	0.250	**40.6**	15	5.19	0.315	**2.45**	0.8
GER-021	Flensburger Aussenfoerde	LLUR_225003	Flensburger Aussenfoerde	B4	2.27	0.553	**1.9**	1.9	16.75	0.704	**17.7**	15	0.64	0.585	**0.57**	0.84
GER-025	Flensburg Innenfoerde	LLUR_225019	Flensburger Innenfoerde	B2b	5.58	0.727	**6.1**	1.9	23.66	0.593	**21.0**	13.3	0.95	0.477	**0.68**	0.55
GER-026	Fehmarn Belt	LLUR_225081	Fehmarn-Ost	B3b	1.75	0.604	**1.6**	1.9	17.23	0.744	**19.2**	14.3	0.66	0.557	**0.56**	0.61
GER-029	Eckernfoerder Bucht, Tiefe	LLUR_225007	Bookniseck	B4	2.42	0.556	**2.0**	1.9	16.26	0.791	**19.3**	15	0.60	0.605	**0.56**	0.84
GER-030	Kieler Innenfoerde	LLUR_225103	Kieler Innenfoerde	B2b	8.63	0.599	**7.8**	1.9	27.10	0.344	**14.0**	13.3	0.87	0.338	**0.44**	0.55
GER-031	Orther Bucht	LLUR_225278	Orther Bucht	B2b	1.09	0.549	**0.9**	1.9	17.18	0.363	**9.4**	12	0.51	0.414	**0.32**	0.44
GER-032	Neustaedter Bucht	LLUR_225054	Neustaedter Bucht	B3b	1.92	0.707	**2.0**	1.9	18.27	0.722	**19.8**	14.3	0.63	0.538	**0.51**	0.61
GER-034	Probstei	LLUR_225090	Kolberger Heide-Ost	B3b	1.72	0.529	**1.4**	1.9	15.74	0.712	**16.8**	14.3	0.54	0.568	**0.45**	0.61
GER-036	Fehmarn Sund	LLUR_225049	NO Hohwachter Bucht	B3b	1.34	0.549	**1.1**	1.9	16.83	0.733	**18.5**	14.3	0.63	0.552	**0.53**	0.61
GER-037	Eckernfoerder Bucht, Rand	LLUR_225028	Schwedeneck	B3b	1.92	0.505	**1.5**	1.9	16.43	0.743	**18.3**	14.3	0.54	0.577	**0.47**	0.61
GER-038	Groemitz	LLUR_225082	Luebecker Bucht vor Groemitz	B3b	2.04	0.672	**2.1**	1.9	16.26	0.770	**18.8**	14.3	0.60	0.559	**0.50**	0.61
GER-039	Kieler Aussenfoerde	LLUR_225059	Kieler Aussenfoerde	B4	2.35	0.546	**1.9**	1.9	17.23	0.741	**19.2**	15	0.66	0.571	**0.57**	0.84
GER-044	untere Trave	LLUR_225025	Trave bei Schlutup	B2a	27.24	0.663	**27.1**	2.4	125.69	0.389	**73.3**	19	2.85	0.408	**1.74**	0.91
GER-111	Nordruegensche Bodden	Mean		B2a	21.63	0.291	**9.4**	2.4	47.61	0.251	**17.9**	17.1	1.75	0.252	**0.66**	0.77
		LUNG_RB10	Lietzow	B2a	33.27	0.291	**14.5**	2.4	57.80	0.251	**21.8**	17.1	1.92	0.252	**0.72**	0.77
		LUNG_RB3	Bugspitze	B2a	7.95	0.291	**3.5**	2.4	32.06	0.251	**12.1**	17.1	1.29	0.252	**0.50**	0.77
		LUNG_RB6	Wittower Faehre	B2a	16.45	0.291	**7.2**	2.4	43.42	0.251	**16.4**	17.1	1.61	0.252	**0.62**	0.77
		LUNG_RB9	Glowe	B2a	28.86	0.291	**12.6**	2.4	57.14	0.251	**21.5**	17.1	2.17	0.252	**0.83**	0.77
SEA-004	Kiel Bay	LLUR_225006	Central station Kiel Bay	sea	1.78	0.477	**1.3**	2	16.43	0.666	**16.4**		0.60	0.533	**0.48**	
SEA-005	Bay of Mecklenburg	Mean		sea	1.74	0.553	**1.4**	1.8	17.64	0.689	**18.2**		0.62	0.520	**0.48**	
		LLUR_225057	Central station Bay of Luebeck	sea	1.95	0.565	**1.7**	1.8	17.73	0.708	**18.8**		0.68	0.518	**0.53**	
		LLUR_225058	Cent. stat. Bay of Mecklenburg	sea	1.52	0.540	**1.2**	1.8	17.55	0.670	**17.6**		0.56	0.522	**0.44**	

Table A2
New water quality targets for German Baltic waters (WFD water bodies and single stations) for dissolved inorganic nitrogen and dissolved inorganic phosphorus (near surface winter averages December-February). Beside data (median concentrations between 2001-2012), the current target concentrations according to Carstensen et al. (2013) and Brockmann et al. (2005) are shown. Model target concentrations result from reference concentration +50%. Factors result from model runs (historic model data divided through present model data) and are used to calculate reference concentrations (factor multiplied with median data). New target concentrations are based on regression analysis (see chapter 4.3 for details). More about the HELCOM monitoring and assessment strategy including stations under www.helcom.fi.

HELCOM ID	WFD water body name	Station ID	Station description	WFD type	Median data (2001–12)	Factor	Target (model)	**New target (based on TN)**	Target (current)	Median data (2001–12)	Factor	Target (model)	**New target (based on TP)**	Target (current)
					Dissolved Inorganic Nitrogen (μmol/l)					**Dissolved Inorganic Phosphorus (μmol/l)**				
GER-002	Wismarbucht, Nordteil	Mean		B2b	16.60	0.654	16.27	**15.15**	11	0.68	0.283	0.29	**0.63**	0.27
		LUNG_WB3	Wismarbucht n. Walfisch	B2b	20.02	0.560	16.82	**17.20**	11	0.65	0.292	0.28	**0.63**	0.27
		LUNG_WB5	Wismarbucht w. Innenreede	B2b	13.18	0.747	14.77	**13.11**	11	0.70	0.274	0.29	**0.64**	0.27
GER-003	Wismarbucht, Salzhaff	LUNG_SH2	Salzhaff nw. Tessmannsdorf	B2b	60.82	0.753	68.70	**76.33**	11	0.31	0.278	0.13	**0.74**	0.27
GER-004	suedl- Mecklenburger Bucht/ Travemuende-Warnemuende	Mean		B3b	8.34	0.721	9.01	**9.49**	10.5	0.64	0.314	0.30	**0.60**	0.29
		LUNG_O3	n. Poel	B3b	7.95	0.784	9.35	**8.17**	10.5	0.63	0.321	0.30	**0.59**	0.29
		LUNG_O4	Bok	B3b	6.40	0.737	7.08	**8.48**	10.5	0.61	0.329	0.30	**0.60**	0.29
		LUNG_O5	Warnemuende	B3b	5.89	0.628	5.55	**8.57**	10.5	0.61	0.318	0.29	**0.61**	0.29
		LUNG_WB6	Wismarbucht o. Krakentief	B3b	13.11	0.734	14.43	**12.74**	10.5	0.70	0.287	0.30	**0.60**	0.29
GER-005	Unterwarnow	LUNG_UW4	Unterwarnow (Warnowwerft)	B2a	94.72	0.065	9.24	**12.29**	12	0.95	0.187	0.27	**0.28**	0.39
GER-006	suedliche Mecklenburger Bucht/ Warnemuende bis Darss	Mean		B3b	9.23	0.451	6.25	**10.88**	10.5	0.63	0.302	0.29	**0.54**	0.29
		LUNG_O6	nw. Fischland	B3b	5.28	0.622	4.93	**7.14**	10.5	0.62	0.320	0.30	**0.57**	0.29
		LUNG_O7	n Darsser Ort	B3b	5.47	0.561	4.60	**8.44**	10.5	0.59	0.315	0.28	**0.56**	0.29
		LUNG_UW5	Mole Warnemuende	B3b	16.95	0.170	4.32	**17.04**	10.5	0.68	0.271	0.28	**0.50**	0.29
GER-007	Ribnitzer See / Saaler Bodden	Mean		B1	100.25	0.141	21.20	**57.10**	11	0.18	0.117	0.03	**0.39**	0.33
		LUNG_DB16	Saaler Bodden	B1	80.05	0.141	16.93	**52.27**	11	0.16	0.117	0.03	**0.39**	0.33
		LUNG_DB19	Ribnitzer See	B1	120.45	0.141	25.48	**61.92**	11	0.20	0.117	0.04	**0.40**	0.33
GER-008	Koppelstrom/Bodstedter Bo.	LUNG_DB10	Bodstedt	B1	69.21	0.141	14.64	**41.90**	11	0.29	0.117	0.05	**0.24**	0.33
GER-009	Barther Bodden, Grabow	Mean		B2a	44.04	0.030	1.98	**13.95**	12	0.20	0.023	0.01	**0.18**	0.39
		LUNG_DB2	Grabow	B2a	40.24	0.021	1.27	**12.49**	12	0.21	0.032	0.01	**0.18**	0.39
		LUNG_DB6	Barther Bodden	B2a	47.83	0.039	2.80	**15.42**	12	0.18	0.013	0.00	**0.18**	0.39
GER-010	Prerowb./Darsser Ort-Dornb.	LUNG_GS	Gellenstrom	B3a	6.33	0.311	2.95	**3.24**	11	0.67	0.241	0.24	**0.36**	0.38
GER-011	Westruegensche Bodden	Mean		B2a	7.92	0.129	1.53	**5.84**	12	0.28	0.167	0.07	**0.20**	0.39
		LUNG_RB1	Schaproder Bodden	B2a	9.25	0.224	3.11	**6.69**	12	0.30	0.236	0.11	**0.22**	0.39
		LUNG_RB2	Vitter Bodden	B2a	6.58	0.033	0.33	**4.99**	12	0.26	0.098	0.04	**0.18**	0.39
GER-012	Strelasund	LUNG_S66	Strelasund	B2a	16.76	0.127	3.19	**8.02**	12	0.52	0.171	0.13	**0.21**	0.39
GER-013	Greifswalder Bodden	Mean		B2a	12.07	0.083	1.51	**7.97**	12	0.77	0.126	0.15	**0.22**	0.39
		LUNG_GB10	s. Ruden	B2a	12.64	0.067	1.27	**8.69**	12	0.77	0.104	0.12	**0.22**	0.39
		LUNG_GB19	Zentralbereich	B2a	12.64	0.086	1.63	**7.48**	12	0.74	0.136	0.15	**0.23**	0.39
		LUNG_GB2	s. Vilm	B2a	10.94	0.097	1.59	**7.74**	12	0.80	0.139	0.17	**0.21**	0.39
GER-013	Westruegensche Bodden	LUNG_KB90	Kubitzer Bodden	B2a	15.74	0.174	4.11	**8.95**	12	0.41	0.208	0.13	**0.22**	0.39
GER-014	Kleiner Jasmunder Bodden	LUNG_RB15	Buschvitz	B2a	33.40	0.093	4.66	**35.87**	12	0.09	0.132	0.02	**0.34**	0.39
GER-015	Nord- & Ostruegensche Gew.	Mean		B3a	5.76	0.559	4.82	**4.49**	11	0.61	0.359	0.33	**0.43**	0.38
		LUNG_O10	no. Kap Arkona	B3a	4.68	0.690	4.84	**4.92**	11	0.61	0.370	0.34	**0.45**	0.38
		LUNG_O11	Sassnitz	B3a	4.87	0.442	3.23	**4.33**	11	0.60	0.319	0.29	**0.42**	0.38
		LUNG_O9	nw. Hiddensee	B3a	5.10	0.818	6.26	**4.04**	11	0.60	0.446	0.40	**0.46**	0.38
		LUNG_OMU	Prorer Wiek	B3a	8.37	0.285	3.58	**4.66**	11	0.64	0.299	0.29	**0.41**	0.38
GER-016	Peenestrom	Mean		B1	57.49	0.089	7.70	**21.80**	11	0.74	0.091	0.10	**0.29**	0.33
		LUNG_P20	s. Peenemuende	B1	41.45	0.141	8.77	**22.13**	11	0.68	0.117	0.12	**0.21**	0.33
		LUNG_P42	s. Wolgast	B1	46.70	0.062	4.34	**19.69**	11	0.42	0.078	0.05	**0.23**	0.33
		LUNG_P48	Lassan	B1	84.32	0.065	8.22	**23.59**	11	1.13	0.079	0.13	**0.44**	0.33

Table A2 (*continued*)

HELCOM ID	WFD water body name	Station ID	Station description	WFD type	Median data (2001–12)	Factor	Target (model)	**New target** (based on TN)	Target (current)	Median data (2001–12)	Factor	Target (model)	**New target** (based on TP)	Target (current)
					Dissolved Inorganic Nitrogen (μmol/l)					**Dissolved Inorganic Phosphorus (μmol/l)**				
GER-018	Pommersche Bucht, Nordteil	Mean		B3a	7.57	0.265	3.01	**8.72**	11	0.72	0.240	0.26	**0.48**	0.38
		LUNG_O133	Greifswalder Oie	B3a	4.87	0.152	1.11	**7.25**	11	0.72	0.197	0.21	**0.41**	0.38
		LUNG_O14	Zinnowitz	B3a	10.27	0.378	5.82	**10.19**	11	0.71	0.282	0.30	**0.56**	0.38
GER-019	Pommersche Bucht, Suedteil	Mean		B3a	18.54	0.300	8.33	**20.74**	11	0.90	0.214	0.29	**0.69**	0.38
		LUNG_OB1	n. Ahlbeck	B3a	21.41	0.290	9.31	**22.85**	11	0.98	0.216	0.32	**0.77**	0.38
		LUNG_OB2	n. Ahlbeck	B3a	20.58	0.274	8.46	**26.56**	11	0.89	0.207	0.28	**0.70**	0.38
		LUNG_OB4	n. Ahlbeck	B3a	13.63	0.335	6.85	**12.82**	11	0.83	0.219	0.27	**0.59**	0.38
GER-020	Kleines Haff	Mean		B1	82.64	0.219	27.09	**27.34**	11	2.01	0.156	0.47	**0.64**	0.33
		LUNG_KHJ	Zentralbereich	B1	95.89	0.239	34.38	**29.61**	11	2.06	0.181	0.56	**0.69**	0.33
		LUNG_KHM	Mitte Staatsgrenze	B1	69.39	0.198	20.61	**25.06**	11	1.96	0.131	0.39	**0.59**	0.33
GER-021	Flensburger Aussenfoerde	LLUR_225003	Geltinger Bucht	B4	6.86	0.634	6.52	**7.33**	10.5	0.66	0.378	0.37	**0.67**	0.32
GER-025	Flensburg Innenfoerde	LLUR_225019	Flensburger Innenfoerde	B2b	18.97	0.277	7.88	**13.60**	9	1.11	0.280	0.47	**0.59**	0.23
GER-026	Fehmarn Belt	LLUR_225081	Fehmarn-Ost	B3b	7.36	0.667	7.36	**5.22**	10.5	0.81	0.319	0.39	**0.55**	0.26
GER-029	Eckernfoerder Bucht, Tiefe	LLUR_225007	Bookniseck	B4	5.84	0.867	7.59	**7.64**	10.5	0.64	0.417	0.40	**0.67**	0.32
GER-030	Kieler Innenfoerde	LLUR_225103	Kieler Innenfoerde	B2b	28.88	0.093	4.03	**10.86**	9	0.93	0.183	0.26	**0.41**	0.23
GER-032	Neustaedter Bucht	LLUR_225054	Neustaedter Bucht	B3b	5.47	0.433	3.55	**6.99**	10.5	0.78	0.249	0.29	**0.52**	0.26
GER-034	Probstei	LLUR_225090	Kolberger Heide-Ost	B3b	11.02	0.706	11.67	**2.27**	10.5	0.73	0.371	0.41	**0.53**	0.26
GER-036	Fehmarn Sund	LLUR_225049	NO Hohwachter Bucht	B3b	7.12	0.864	9.23	**4.39**	10.5	0.72	0.375	0.41	**0.54**	0.26
GER-037	Eckernfoerder Bucht, Rand	LLUR_225028	Schwedeneck	B3b	5.47	0.838	6.88	**3.69**	10.5	0.66	0.395	0.39	**0.54**	0.26
GER-038	Groemitz	LLUR_225082	Luebecker Bucht vor Groemitz	B3b	9.47	0.528	7.50	**3.48**	10.5	0.81	0.272	0.33	**0.54**	0.26
GER-039	Kieler Aussenfoerde	LLUR_225059	Kieler Aussenfoerde	B4	6.70	0.781	7.85	**8.27**	10.5	0.69	0.381	0.39	**0.66**	0.32
GER-044	untere Trave	LLUR_225025	Trave bei Schlutup	B2a	219.37	0.185	60.88	**108.57**	12	2.12	0.232	0.74	**0.77**	0.4
GER-111	Nordruegensche Bodden	Mean		B2a	13.48	0.093	1.88	**9.11**	12	0.19	0.132	0.04	**0.22**	0.39
		LUNG_RB10	Lietzow	B2a	16.34	0.093	2.28	**11.66**	12	0.02	0.132	0.00	**0.23**	0.39
		LUNG_RB3	Bugspitze	B2a	12.07	0.093	1.68	**5.22**	12	0.36	0.132	0.07	**0.20**	0.39
		LUNG_RB6	Wittower Faehre	B2a	13.13	0.093	1.83	**8.06**	12	0.24	0.132	0.05	**0.21**	0.39
		LUNG_RB9	Glowe	B2a	12.36	0.093	1.72	**11.49**	12	0.15	0.132	0.03	**0.24**	0.39
SEA-004	Kiel Bay	LLUR_225006	Central station Kiel Bay	sea	5.28	0.717	5.68	**6.79**	5.5	0.71	0.369	0.39	**0.52**	0.57
SEA-005	Bay of Mecklenburg	Mean		sea	6.44	0.745	7.19	**7.41**	4.3	0.61	0.318	0.29	**0.52**	0.49
		LLUR_225057	Central station Bay of Luebeck	sea	7.06	0.770	8.15	**7.65**	4.3	0.47	0.307	0.22	**0.54**	0.49
		LLUR_225058	Cent. stat. Bay of Mecklenburg	sea	5.82	0.719	6.28	**7.18**	4.3	0.74	0.328	0.36	**0.50**	0.49

References

[1] Aarup T. Transparency of the North Sea and Baltic Sea—a Secchi depth data mining study. Oceanologia 2002;44:323–37.

[2] Basset A, Barbone E, Borja A, Elliott M, Jona-Lasinio G, Marques JC, et al. Natural variability and reference conditions: setting type-specific classification boundaries for lagoon macroinvertebrates in the Mediterranean and Black Seas. Hydrobiologia 2013;704:325–45.

[3] Nutrients and heavy metals in the Odra river system. In: Behrendt H, Dannowski R, editors. Berlin: Weißensee Verlag; 2005.

[4] Behrendt H, Opitz D, Kolanek A, Korol R, Stronska M. Changes of the nutrient loads of the Odra River during the second half of last century – their causes and consequences. J Water Land Dev 2008;12:127–44.

[5] Bennion H, Fluin J, Simpson GL. Assessing eutrophication and reference conditions for Scottish freshwater lochs using subfossil diatoms. J Appl Ecol 2004;41:124–38.

[6] Blümel C, Domin A, Krause JC, Schubert M, Schiewer U, Schubert H. Der historische Makrophytenbewuchs der inneren Gewässer der deutschen Ostseeküste. Rostocker Meeresbiologische Beiträge 2002;10:5–111.

[7] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (ed). Festlegung von Umweltzielen für die deutsche Ostsee nach Artikel 10 Meeres-strategie-Rahmenrichtlinie. Bonn, ⟨http://www.meeresschutz.info/index.php/berichte.html⟩; 2012.

[8] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (ed). Beschreibung eines guten Umweltzustands für die deutsche Ostsee nach Artikel 9 Meeresstrategie-Rahmenrichtlinie. Bonn, ⟨http://www.meeresschutz.info/index.php/berichte.html⟩; 2012.

[9] Borja Á, Dauer DM, Grémare A. The importance of setting targets and reference conditions in assessing marine ecosystem quality. Ecol Indic 2012;12(1):1–7.

[10] Brockmann U, Topcu D, Schütt M. Referenz- und Schwellenwerte für die Küsten- und Übergangsgewässer an der deutschen Nord- und Ostseeküste. Bericht, BLM-AG; 2005. 19p.

[11] Cardoso AC, Solimini A, Premazzi G, Carvalho L, Lyche Solheim A, Rekolainen S. Phosphorus reference concentrations in European lakes. Hydrobiologia 2007;584:3–12.

[12] Carstensen J, Heiskanen A-S, Kauppila P, Neumann T, Schernewski G, Gromisz S. Developing reference conditions for phytoplankton in the Baltic coastal waters; Part II: examples of reference conditions developed for the Baltic Sea. EUR 21582/EN/2 European Communities; 2005. 74 p.

[13] Carstensen J, Henriksen P. Phytoplankton biomass response to nitrogen inputs: a method for WFD boundary setting applied to Danish coastal waters. Hydrobiologia 2009;633:137–49.

[14] Carstensen J, Andersen JH, Dromph K, Fleming-Lehtinen V, Simis S, Gustafsson B., et al. Approaches and methods for eutrophication target setting in the Baltic Sea region. HELCOM, Baltic Sea Environment Proceedings; 2013, vol. 133. 134p, ⟨http://helcom.fi/helcom-at-work/publications/⟩.

[17] CIS-COAST. Transitional and Coastal Waters Typology, Reference Conditions and Classification Systems, Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Guidance document no. 5, European Communities; 2003. ISBN 92-894-5125-4.

[18] CIS-REFCOND. Rivers and Lakes – Typology, Reference Conditions and Classification Systems, Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Guidance Document no. 10, European Communities; 2003. ISBN 92-894-5614-0.

[19] Eilola K, Gustafsson B, Kuznetsov I, Meier H, Neumann T, Savchuk O. Evaluation of biogeochemical cycles in an ensemble of three state-of-the-art numerical models of the Baltic Sea. J Mar. Syst 2011;88:267–84.

[20] Friedland R, Neumann T, Schernewski G. Climate change and the Baltic Sea Action Plan: model simulations on the future of the western Baltic Sea. J Mar Syst 2012;105–108:175–86.

[21] Gustafsson BG, Schenk F, Blenckner T, Eilola K, Meier HEM, Müller-Karulis B, et al. Reconstructing the development of Baltic Sea eutrophication 1850–2006. AMBIO 2012;41(6):534–48.

[22] Gustafsson BG., Mörth CM. Revision of the maximum allowable inputs and country allocation scheme of the Baltic Sea Action Plan [in preparation].

[23] HELCOM. Fifth Baltic Sea Pollution Load Compilation (PLC-5). Baltic Sea environment proceedings; 2011, 128. 218p. ⟨www.helcom.fi/stc/files/Publications/Proceedings/BSEP128.pdf⟩.

[24] HELCOM. Review of the fifth Baltic Sea Pollution Load Compilation for the 2013 HELCOM Ministerial Meeting. Helsinki Commission, Baltic Sea environment proceedings, no. 141; 2013. 1–54.

[25] HELCOM. Summary report on the development of revised Maximum Allowable Inputs (MAI) and updated Country Allocated Reduction Targets (CART) of the Baltic Sea Action Plan. Helsinki Commission, ⟨http://www.helcom.fi/Documents/Ministerial2013/Associated%20docu-ments/Supporting/Summary%20report%20on%20MAI-CART.pdf⟩; 2013.

[26] Henriksen P. Reference conditions for phytoplankton at Danish Water Framework Directive intercalibration sites. Dev Hydrobiol 2009;207:255–62.

[27] Hirt U, Mahnkopf J, Gadegast M, Czudowski L, Mischke U, Heidecke C. et al. Reference conditions for rivers of the German Baltic Sea catchment – Reconstructing nutrient regimes using the model MONERIS. Regional Environmental Change, 14. p. 1123–38, doi: 10.1007/s10113-013-0559-7.

[28] Höglund A, Meier HEM, Broman B, Kriezi E. Validation and correction of regionalised ERA-40 wind fields over the Baltic Sea using the Rossby Center Atmosphere model RCA3.0, Rapport Oceanografi; 2009. 97, SMHI, Norrköping, Sweden.

[29] Hoppe HG, Giesenhagen HC, Koppe R, Hansen H-P, Gocke K. Impact of change in climate and policy from 1988 to 2007 on environmental and microbial variables at the time series station Boknis Eck, Baltic Sea. Biogeosci Discuss 2012;9:18655–706.

[30] Maar M, Moller EF, Larsen J, Madsen KS, Wan Z, She J, et al. Ecosystem modeling across a salinity gradient from the North Sea to the Baltic. Sea Ecol Model 2011;222:1696–711.

[31] Meier HEM, Andersson HC, Arheimer B, Blenckner T, Chubarenko B, Donnelly C, et al. Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem—first results from multi-model ensemble simulations. Environ Res Lett 2012;7:034005. http://dx.doi.org/10.1088/1748-9326/7/3/034005.

[32] Mertens M, Selig U. Vergleich von historischen und rezenten Makrophytenbeständen in den inneren Küstengewässern Schleswig- Holsteins. Rostocker Meeresbiologische Beiträge 2007;17:55–66.

[33] Muxika I, Borja A, Bald J. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. Mar Pollut Bull 2007;55(1–6):16–29.

[34] Nausch G, Bachor A, Petenati T, Voss J, WEBER Mv. Nährstoffe in den deutschen Küstengewässern der Ostsee und angrenzenden Gebieten. – Meeresumwelt Aktuell Nord- und Ostsee; 2011, 1, ISSN 1867-8874. 1–16.

[35] Neumann T. Towards a 3D-ecosystem model of the Baltic Sea. J Mar Syst 2000;25(34):405–19.

[36] Neumann T, Fennel W, Kremp C. Experimental simulations with an ecosystem model of the Baltic Sea: a nutrient load reduction experiment. Glob Biogeochem Cycles 2002;16(3):1033–54.

[37] Neumann T, Schernewski G. Eutrophication in the Baltic Sea and shifts in nitrogen fixation analyzed with a 3D ecosystem model. J Mar Syst 2008;74:592–602.

[38] Poikane S, Alves MH, Argillier C, Van Den Berg M, Buzzi, Hoehn E, et al. Defining chlorophyll-a reference conditions in European lakes. Environ Manag 2010;45:1286–98.

[39] Rekolainen S. Site-specific chlorophyll reference conditions for lakes in Northern and Western Europe. Hydrobiologia 2009;633(1):59–66.

[40] Ruoho-Airola T, Eilola K, Savchuk OP, Parviainen M, Tarvainen V. Atmospheric nutrient input to the Baltic Sea from 1850–2006: a reconstruction from modeling results and historical data. AMBIO 2012;41(6):549–57.

[41] Savchuk OP, Wulff F, Hille S, Humborg C, Pollehne F. The Baltic Sea a century ago – a reconstruction from model simulations, verified by observations. J Mar Syst 2008;74:485–94.

[42] Sagert S, Selig U, Schubert H. Phytoplankton indicators for ecological classification of coastal waters along the German Baltic coast. Rostock Meeresbiolog Beitr 2008;20:45–69.

[43] Schenk F, Zorita E. Reconstruction of high resolution atmospheric fields for Northern Europe using analog-upscaling. Clim Past 2012;8:819–68.

[44] Schernewski G, Neumann T. The trophic state of the Baltic Sea a century ago? A model simulation study J Mar Syst 2005;53:109–24.

[45] Schernewski G, Behrendt H, Neumann T. An integrated river basin-coast-sea modeling scenario for nitrogen management in coastal waters. J Coast Conserv 2008;12:53–66.

[46] Schernewski G, Stybel N, Neumann T. Managing eutrophication: cost-effectiveness of zebra mussel farming in the oder (Szczecin) lagoon. Ecol Soc 2012;17(2):4. http://dx.doi.org/10.5751/ES-04644-170204.

[48] Schlungbaum G. Sedimentchemische Untersuchungen in Küstengewässern der DDR. – Teil 11: Phosphatsorpptionsgleichgewichte zwischen Sediment und Wasser in flachen eutrophen Küstengewässern. Acta Hydrochim Hydrobiol 1982;10(2):136–52.

[49] Schories D, Selig U. Die Bedeutung eingeschleppter Arten (alien species) für die Europäische Wasserrahmenrichtlinie am Beispiel der Ostsee. Rostocker Meeresbiologische Beiträge 2006;15:147–58.

[50] Schories D, Pehlke C, Selig U. Depth distributions of Fucus vesiculosus L. and Zostera marina L. as classification parameters for implementing the European Water Framework Directive on the German Baltic coast. Ecol Indic 2009;9(4):670–80.

[51] Selig U, Eggert A, Schories D, Schubert M, Blümel C, Schubert H. Ecological classification of macroalgae and angiosperm communities of inner coastal waters in the southern Baltic Sea. Ecol Indic 2007;7(3):665–78.

[52] Venohr V, Hürdler J, Opitz D. Potential von Maßnahmen zur Reduktion der Nährstoffflüsse im Einzugsgebiet der Oder. Coastline Rep 2010;15:151–66.

[53] Venohr M, Hirt U, Hofmann J, Opitz D, Gericke A, Wetzig A, et al. Modeling of nutrient emissions in river systems – MONERIS – methods and background. Int Rev Hydrobiol 2011;96(5):435–83.

[54] Wasmund N, Göbel J, v Bodungen B. 100-years-changes in the phytoplankton community of Kiel Bight (Baltic Sea). J Mar Syst 2008;73:300–22.

[57] Winkler HM, Debus L. Auffällige Bestandsveränderungen bei wichtigen Fischarten der Darß-Zingster Boddenkette und mögliche Ursachen. Rostocker Meeresbiologische Beiträge 2006;16:61–70.

[58] Wolfram G, Argillier C, De Bortoli J, Buzzi G, Dokulil MT, Hoehn E, et al. Reference conditions and WFD compliant class boundaries for phytoplankton biomass and chlorophyll-a in Alpine lakes. Hydrobiologia 2009;633:45–58.