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Application of the Danish EPA's Marine Model Complex and Development of a Method Applicable for the River Basin Management Plans 2021-2027

Scenario Summary

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Eelgrass in Kertinge Nor
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Preface

This report is commissioned and funded by the Danish Environmental Protection Agency (EPA). The data, methods and results included in the report are intended to be an integrated part of the material behind the Danish River Basin Management Plans (RBMP) 2021-2027.

The work reported was managed and performed by DHI and AU/DCE. During the project, a steering committee followed the development, and was involved through dialogue and follow-up on progress, etc. The steering committee consisted of members from the Danish Ministry of Environment and Food (MFVM), the Danish EPA (MST), DHI and AU.

In addition, a follow-up group consisting of members from The Danish Agriculture & Food Council, SEGES, Sustainable Agriculture (BL), the Danish Society for Nature Conservation, the Danish Sports Fishing Association, Danish Fishermen PO (DFPO), the Danish Ports, and KL/municipalities was affiliated with the project. The follow-up group has been continuously informed about the progress of the project at meetings convened by the MFVM.

Choice of methods, data processing, description and presentation of results have been solely AU's and DHI's decision and responsibility.

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1 Introduction

When preparing the Danish River Basin Management Plans 2015-2021 (RMBP 2015-2021), DHI and Aarhus University (AU) developed a number of mechanistic (DHI) and statistical (AU) models that were used for calculating chlorophyll-a target values defining the threshold (GM) between ‘Good Ecological Status’ (GES) and ‘Moderate Ecological Status’. The models were also used for calculating Maximum Allowable Inputs (MAIs) of total nitrogen (N) from Danish catchments based on the GM threshold value and a proxy for eelgrass depth limit. Hence, the development aimed at both the model development and the development of a method for calculating the MAIs.

As part of the political, regulatory package ‘The Food and Agriculture Agreement from 2015’ an international evaluation of the procedures used in the RBMP 2015-2021 was conducted. The evaluation was finalised autumn 2017 with a report (Herman *et al.* 2017) including a number of recommendations for improving the scientific background behind the RBMP 2021-2027.

To follow up on the international evaluation, the Danish EPA facilitated a range of research and development projects (R&D) projects with the overall aim of developing methods to calculate robust, transparent and differentiated chlorophyll-a reference values (and corresponding GM values) and MAIs in as many water bodies as possible for incorporation into the RBMP 2021-2027.

Two central R&D projects relate to the continued model development in the assessment of reference chlorophyll-a values (and corresponding target values) and final MAI calculations. Other projects support different aspects of the final MAI calculations, but here we focus on the following two central R&D projects:

- ‘Recommendations for the continued development of models and methods for use in the River Basin Management Plan 2021-2027. Follow-up on the international evaluation of marine models behind the River Basin Management Plan 2015-2021’ (Erichsen & Timmermann 2018)
- ‘Application of the Danish EPA’s Marine Model Complex and Development of a Method Applicable for the River Basin Management Plans 2021-2027’.

The outcome of the above research projects is a set of MAIs based on a range of scenarios reflecting different assumptions regarding future developments in nutrient loading from neighbouring countries and the atmosphere as described in Erichsen *et al.* 2020a. The different management scenarios and the corresponding results for each water body are presented in detail in Erichsen et al 2020b-l. In the present technical note, we provide an overview of the different management scenarios, pinpoint some of the assumptions and related implications, as well as provide an overview of the results on national scale.

2 Preconditions for MAI Calculations

The Danish MAIs will, among other things, also depend on future loadings from neighbouring countries and atmospheric N-depositions as described in more detail in Erichsen *et al.* 2020. In addition, some water bodies may also respond to Danish land-based P loadings, which is why one set of Danish land-based N-MAIs corresponds to a set of Danish land-based P-MAIs.

In order to calculate a set of Danish land-based N-MAIs with the developed models, we need to make assumptions on future loadings and management strategies from neighbouring countries (management scenarios), and Danish land-based P loadings.

With respect to reductions in neighbouring countries, the Danish EPA has defined a set of preconditions to be used for constructing management scenarios defining potential developments in future non-Danish land-based loadings and atmospheric deposition. For each scenario, Danish land-based N-MAIs are calculated based on 0%, 10%, 20%, 30% and 50% Danish land-based P reductions, respectively.

In this technical note, we have not assessed the feasibility of the scenarios defined by the Danish, but solely provided N-MAIs that will ensure that the targets are reached given that the preconditions related to nutrient loading from other countries, atmospheric N deposition and P loading from Danish catchments are fulfilled.

Danish MAI's corresponding to 11 different scenarios has been calculated and presented in separate reports. In the following an overview of the main results from the different scenarios is provided. How the different scenarios are implemented in the models and the details behind nutrient loadings and scenario reductions are described in more details in Erichsen *et al.* 2020b-l.

2.1 Management Scenario Definitions

As described above, the Danish EPA has defined a set of assumptions regarding nutrient inputs from other countries and the atmosphere to be used as preconditions for the Danish land-based N-MAI calculations. The preconditions are grouped into three management scenarios and one scenario related to the interpretation of the Water Framework Directive (WFD-scenario).

2.1.1 Management Scenario 1 – Regional Treaties and RBMP 2015-2021

Management scenario 1 assumes that all national and international adopted treaties related to nutrient management, including RBMP 2015-2021, have been implemented. This corresponds to:

- Full implementation of the BSAP (HELCOM) and similar reduction targets in the North Sea (OSPAR)
- Implementation of RBMP 2015-2021 in all relevant EU countries
- Full implementation of the NEC-directive with respect to atmospheric N-deposition.

2.1.2 Management Scenario 2 - Land-based Nutrient Scenarios

The second group of scenarios encompasses assumptions for the land-based loadings from neighbouring countries that are not based on adopted treaties. The assumptions include:

a. Neighbouring countries are assumed to have had the same percentage of nutrient reduction as Denmark when Danish land-based N-MAIs are reached. The reduction percentage is relative to the basis period 1997-2001

b. Neighbouring countries are assumed to have the same area-specific anthropogenic loadings (kg/ha) as Denmark when Danish N-MAIs are reached

c. Loadings from neighbouring countries are unchanged compared to the present-day loadings (2014-2018)

d. Danish land-based N-MAIs assuming updated BSAP targets. A new set of targets is being developed in HELCOM and will be adopted by the end of 2021.

e. Additional Wadden Sea P-reductions

For the above five sub-scenarios (a-e), the atmospheric deposition will be kept as described in management scenario 1, i.e. full implementation of the NEC-directive concerning atmospheric N-deposition.

2.1.3 Management Scenario 3 - Atmospheric N Scenarios

The third group of scenarios encompasses assumptions for the atmospheric N-depositions originating from emissions in Denmark and surrounding countries. These assumptions are:

a. Danish land-based N-MAIs correspond to 2027 NEC-prognosis. Both Danish and international N-depositions are based on the prognosis of the NEC-implementation instead of the full implementation.

b. Danish land-based N-MAIs assuming synergy impacts from climate actions. As Denmark and other countries work to minimise climate changes, some synergies are expected to impact N-depositions as well.

For the above two sub-scenarios, the land-based nutrient loadings will be kept as described in management scenario 1, i.e. adopted treaties (BSAP and RBMP 2015-2021) have been implemented (see Erichsen *et al.* (2020a) for details).

2.1.4 WFD-Scenarios

The method for estimating land-based MAIs applicable for RBMP 2021-2027 (Erichsen *et al.* 2020a) include averaging between indicators and model-results (statistical and mechanistic model results, respectively). The method estimates an individual N-MAI for each indicator that would bring the indicator from the present status to the boundary between “good” and “moderate” status and includes a system contribution in the calculation of Danish land-based N-MAIs. This system contribution covers delays or lag-time in response to nutrient reductions, feedback mechanisms, climate changes and uncertainties (see Erichsen *et al.* 2020 for details).

In the WFD-scenarios the implications of the different aspects of the method for calculating MAI are addressed by making scenarios based on:

a. Increasing the likelihood of achieving GES by changing the indicator target values from the good-moderate boundary to a target value between good and high status (see Figure 2-1).

b. One-out-all-out principles. This approach will use average model results per indicator but include the lowest MAI between the two indicators.

c. MAI calculations are performed without taking the system contribution into account.

For the above three sub-scenarios, the land-based nutrient loadings and atmospheric N depositions will be kept as described in management scenario 1.

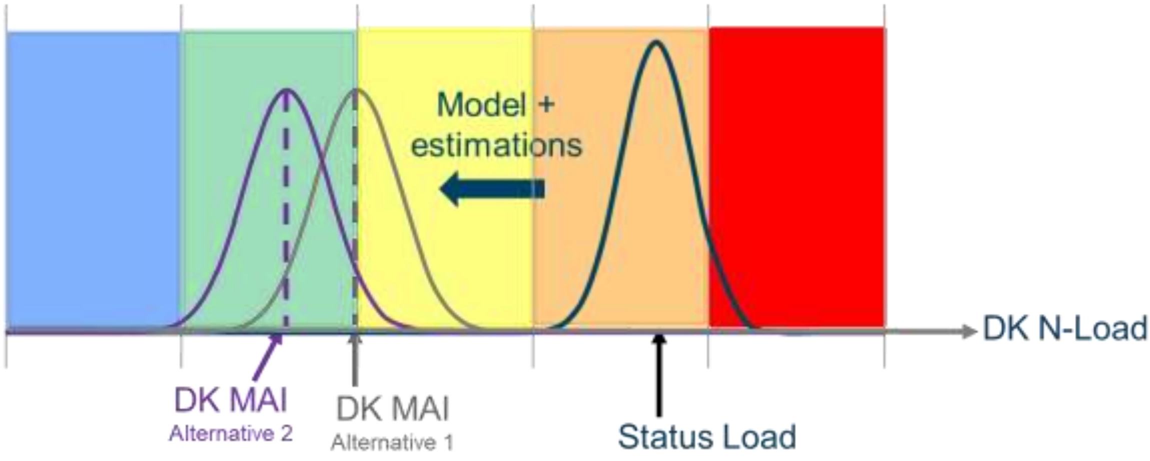

Figure 2-1 Calculation of MAI when the target is defined as the boundary separating "moderate" and "good" status classes (alternative 1) or when the target is in the middle of "good" ecological status class (alternative 2). The present-day loading results in an indicator status value (curve placed in the orange field).
The status value is determined with a certainty represented by the curve (normal distribution). The alternative 1 curve represents the method described in Erichsen *et al.* (2020a) where the resulting MAI equals an indicator values matching the boundary between moderate and good. Given the uncertainty the indicator values might however be moderate (GES is not reached). The alternative 2 curve represents a situation where we aim at a target between high-good and good-moderate, which will increase the likelihood of reaching GES.

2.2 Method for Calculating Danish N-MAI

Based on the assumed future load reductions from neighbouring countries and atmospheric deposition as described in section 2.1, maximum allowable input of nitrogen from Danish catchments (Danish N-MAIs) to each of the 109 water bodies is calculated as described in Erichsen *et al*. (2020a).

Since the Danish water bodies are all more or less connected, the reduction needed for a single water body cannot be assessed in isolation. In addition, it is necessary to consider the load reduction requirement estimated for nearby water bodies. To account for connected water bodies, the following scheme was applied:

1. Catchments are assigned to each water body. Local catchments are assigned to the inner part (sub-catchments) of estuaries (upstream water bodies), whereas two or more local catchments (main catchments) are assigned for downstream water bodies (e.g. the outer part of estuaries) and more open water bodies.

2. Load reductions (in %) for each individual water body are calculated as described in Erichsen *et al.* (2020a) and transformed into a reduction requirement in tons using the load of the assigned catchment.

3. For up-stream water bodies (with local catchments) the calculated reduction is a minimum requirement, which is obtained independently of downstream waterbody requirements.

4. Reduction requirements for downstream water bodies are corrected, considering any minimum reduction handled by up-stream water bodies.

5. Reduction requirements are transformed into MAIs by subtracting load reduction from the status load and aggregated to the corresponding local and/or regional catchment.

2.3 Assumptions and implications

The method described in Erichsen *et al.* 2020a ensures that it is possible to calculate N-MAI values that will obtain GES for every single water body. However, due to the scenario assumptions regarding future nutrient input from neighbouring countries and the atmosphere, some water bodies may not obtain GES in a specific scenario. To obtain GES in these water bodies other countries may need to reduce more than assumed in the scenario (both for land-based and atmosphere load) and/or Danish land-based P-reductions will need to increase.

If an indicator in a specific water body cannot reach GES solely by reducing Danish land-based N-loads, we truncate at reference N-loadings. This implies that Danish N reductions are required to get closer to GES, but the method described in Erichsen *et al.* 2020a does not provide an answer given the preconditions for that specific management or WFD scenario.

If we cannot reach GES by reducing Danish land-based N-loads to reference loadings, the different technical notes (Erichsen *et al.* 2020b-l) include a footnote indicating weather one or two of the indicators are truncated at reference loadings.

Which land-based N-loadings to apply if the specific management scenario or WFD scenario does not provide a solution is an administrative or political decision.

Examples:

- Water body no. 56: Østersøen, Bornholm: None of the management scenarios provide a basis that allows for additional Danish land-based N and/or P reductions to ensure GES. Bornholm relies on reductions in neighbouring countries and is not very sensitive to Danish land-based nutrient loadings.
- Water body no. 238 Halkær Bredning: This water body almost solely relies on Danish land-based nutrient reductions to obtain GES. However, as is shown in Erichsen *et al.* 2020b-l, this water body can only obtain GES if significant P, as well as N, reductions are implemented.

Furthermore, for the different management and WFD scenarios we have investigated which expected reductions other countries than Denmark are expected to implement over the coming plan period. These data are described in Erichsen *et al.* 2020b-l. However, we did not find any evidence of expected P reductions from Germany in the German Bight waters.

The Danish part of the Wadden Sea area is sensitive to P reductions but as we could not find evidence for expected P reductions from neighbouring countries this has not been included in the different data presented in Erichsen *et al.* 2020b-l or in this report. Hence, a number of the Danish Wadden Sea water bodies cannot – or have limited possibility – of reaching GES through Danish land-based N-reductions alone. This is investigated in scenario 2e.

The two examples above and the lack of P-reductions in German Bight show the implications of the method applied in the present report (see Erichsen *et al.* 2020a for details). In many water bodies the method does provide a solution that can be implemented to obtain GES, but the data presented in Table 2-2 cannot alone be adopted as maximum allowable N inputs, as it assumes the preconditions are met.

In Table 2-1 the assumptions for and implications of the different scenarios are highlighted, and in Table 2-2 the results of the method based on the different management scenarios and WFD scenarios are summarized.

Table 2-1 Overview of the different management scenarios and WFD scenarios. The table includes number of water bodies[1] that obtain GES without including a cut-off at reference loadings, and how many water bodies that includes a cut-off at one or two indicators, respectively. The numbers outside brackets relates to 0% reductions in Danish land-based P-loadings and numbers inside brackets relates to a 50% reduction.

Number of water bodies	Management scenario 1	Management scenario 2a	Management scenario 2b	Management scenario 2c	Management scenario 2d	Management scenario 2e (20%)	Management scenario 2e (30%)	Management scenario 3a	Management scenario 3b1	Management scenario 3b3	WFD scenario 1a	WFD scenario 1b	WFD scenario 1c
GES[2] (without any other efforts)	8	8	-	8	8	8	8	8	8	8	8	8	8
GES (assuming management scenarios without Danish land-based reduction)	16 (16)	13	-	7 (8)	16 (16)	16 (16)	16 (17)	14 (14)	17 (17)	23 (23)	6 (8)	16 (16)	10 (10)
GES (assuming management scenarios and Danish land-based reductions)	86 (91)	87	-	75 (79)	86 (91)	87 (92)	88 (92)	88 (93)	86 (90)	80 (84)	84 (87)	57 (75)	72 (79)
One indicator not reaching target	33 (10)	-	-	53 (22)	33 (10)	33 (9)	32 (9)	35 (11)	32 (10)	21 (4)	51 (18)	30 (9)	47 (39)
Two indicators not reaching target	3 (0)	-	-	19 (6)	3(0)	3 (0)	2 (0)	3 (0)	3 (0)	3 (0)	16 (3)	3 (0)	29 (14)

[1] The analysis covers 108 water bodies. Water body no. 205 Kattegat, Nordsjælland >20m, is not included as it has no catchment, but follows water body no. 200, Kattegat, Nordsjælland.

[2] Based on observations from 2014-2018

2.4 Results

The results from each management scenario encompasses N-MAIs for catchments to each of the 109 Danish water bodies, which can be summarized to a national MAI reflecting the maximum allowable nutrient input from all Danish catchments given the scenario preconditions. The national MAIs resulting from the different management scenarios and after summarizing MAIs from each water body catchment is presented in Table 2-1.

Table 2-2 National MAIs for each of the management scenarios reflecting different assumptions regarding future nutrient (N and P) input from neighbouring countries and the atmosphere. For each management scenario, the impact of assumed future Danish phosphorus reductions are shown as well.

		N-MAIs and reduction needs based on the different preconditions (management scenarios and WFD scenarios)				
Average (2014-2018) Danish land-based P-loadings (Ton P/year)	*2,028*	Danish land-based P-reductions				
Average (2014-2018) Danish land-based N-loadings (Ton N/year)	*58,100*	P: 0 %	P: 10 %	P: 20 %	P: 30 %	P: 50 %
Management Scenario 1						
N-MAI	(Tons N/year)	*36,624*	*37,294*	*38,014*	*38,832*	*41,982*
Reduction need	(Tons N/year)	*21,476*	*20,806*	*20,086*	*19,268*	*16,118*
Reduction need	(%)	37	36	35	33	28
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 2a						
N-MAI	(Tons N/year)	*36,173*	-	-	-	-
Reduction need	(Tons N/year)	*21,927*	-	-	-	-
Reduction need	(%)	38	-	-	-	-
P-MAI	(Tons P/year)	2,028	-	-	-	-
Management Scenario 2b						
N-MAI	(Tons N/year)	*27,293*	-	-	-	-
Reduction need	(Tons N/year)	*30,807*	-	-	-	-
Reduction need	(%)	53	-	-	-	-
P-MAI	(Tons P/year)	2,028	-	-	-	-

		N-MAIs and reduction needs based on the different preconditions (management scenarios and WFD scenarios)				
Management Scenario 2c						
N-MAI	(Tons N/year)	*29,553*	*29,820*	*30,125*	*30,433*	*31,127*
Reduction need	(Tons N/year)	*28,547*	*28,280*	*27,975*	*27,667*	*26,973*
Reduction need	(%)	49	49	48	48	46
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 2d						
N-MAI	(Tons N/year)	*36,763*	*37,425*	*38,139*	*38,949*	*42,084*
Reduction need	(Tons N/year)	*21,337*	*20,675*	*19,961*	*19,151*	*16,016*
Reduction need	(%)	37	36	34	33	28
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 2e - 20%						
N-MAI	(Tons N/year)	37,254	38,175	38,914	39,838	42,405
Reduction need	(Tons N/year)	20846	19925	19186	18262	15695
Reduction need	(%)	36	34	33	31	27
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 2e - 30%						
N-MAI	(Tons N/year)	37719	38299	38943	40049	43115
Reduction need	(Tons N/year)	20381	19801	19157	18051	14985
Reduction need	(%)	35	34	33	31	26

		N-MAIs and reduction needs based on the different preconditions (management scenarios and WFD scenarios)				
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 3a						
N-MAI	(Tons N/year)	*35,963*	*36,619*	*37,328*	*38,089*	*41,160*
Reduction need	(Tons N/year)	*22,137*	*21,481*	*20,772*	*20,011*	*16,940*
Reduction need	(%)	38	37	36	34	29
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 3b – 20%						
N-MAI	(Tons N/year)	*36,952*	*37,623*	*38,343*	*39,228*	*42,422*
Reduction need	(Tons N/year)	*21,148*	*20,477*	*19,757*	*18,872*	*15,678*
Reduction need	(%)	36	35	34	32	27
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 3b – 30%						
N-MAI	(Tons N/year)	*37,901*	*38,625*	*39,394*	*40,628*	*43,785*
Reduction need	(Tons N/year)	*20,199*	*19,475*	*18,706*	*17,472*	*14,315*
Reduction need	(%)	35	34	32	30	25
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
Management Scenario 3b – 50%						
N-MAI	(Tons N/year)	*38,624*	*39,348*	*40,117*	*41,648*	*44,594*
Reduction need	(Tons N/year)	*19,476*	*18,752*	*17,983*	*16,452*	*13,506*

		N-MAIs and reduction needs based on the different preconditions (management scenarios and WFD scenarios)				
Reduction need	(%)	34	32	31	28	23
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
WFD-scenario 1a						
N-MAI	(Tons N/year)	*27,555*	*27,863*	*28,157*	*28,493*	*29,245*
Reduction need	(Tons N/year)	*30,545*	*30,237*	*29,943*	*29,607*	*28,855*
Reduction need	(%)	53	52	52	51	50
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
WFD-scenario 1b						
N-MAI	(Tons N/year)	*29,252*	*29,820*	*30,561*	*31,359*	*34,453*
Reduction need	(Tons N/year)	*28,848*	*28,280*	*27,539*	*26,741*	*23,647*
Reduction need	(%)	50	49	47	46	41
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014
WFD-scenario 1c						
N-MAI	(Tons N/year)	*31,090*	*31,231*	*31,387*	*31,660*	*32,734*
Reduction need	(Tons N/year)	*27,010*	*26,869*	*26,713*	*26,440*	*25,366*
Reduction need	(%)	46	46	46	46	44
P-MAI	(Tons P/year)	2,028	1,825	1,622	1,420	1,014

The national MAIs resulting from the different management scenarios varies between 26 Kt N/year to 45 kt/year depending on scenario preconditions and different assumptions concerning reduction in the Danish land-based P load. For each scenario, not all water bodies will obtain good ecological status for both indicators even when N loadings are reduced to reference levels. The reason is that reduction of Danish land-based N loading in some cases are not sufficient to counteract effects of other nutrient sources (Danish P load, N and P load from neighboring countries and/or atmospheric N deposition). It is, however, possible to obtain GES in all Danish water bodies, but it might require larger efforts from neighboring countries, larger reduction in atmospheric N deposition and/or larger reductions in Danish P loadings than reflected in the presented management and WFD scenarios. Within the range of the tested scenarios, 93 of the water bodies obtained GES for both indicators in one or more scenarios, while for the remaining 15 water bodies it was only possible to obtain GES for one of the indicators. These 15 water bodies are mostly open waters influenced by Baltic Sea or North Sea water (e.g. Bornholm, Kattegat and Storebælt) or water bodies directly influenced by German rivers (e.g. Flensborg Fjord and the Wadden Sea).

Scenario 1 contains almost the same preconditions as used for calculating MAI for RBMP 2015-2021 (Erichsen and Timmermann 2017) except for the implementation of additional German land-based N-reductions according to their RBMP 2015-2021 plans. Although the model framework as well as the methods have been revised and updated the end result on national scale is very similar. When accounting for a shift in method for calculating nutrient run off, national MAI for RBMP 2015-2021 and for RBMP 2021-2027 was 39[3] kt N/year and 37 kt N/year, respectively. In this scenario, 77 of the water bodies would reach GES without additional reductions in Danish P loadings, whereas 87 water bodies would reach GES if P reductions of 50% were implemented.

Scenario 2 reflects the impact of land-based N and P loading from neighboring countries on Danish MAIs. If updated BSAP ceilings are used (scenario 2d) national MAI increase only slightly compared to scenario 1 and no additional water bodies obtain GES. When requiring same N reduction from Danish and neighbouring countries relative to 1997-2001 (scenario 2a) Danish MAI decrease slightly compared to scenario 1 as nitrogen loadings from neighboring countries have decreased more since 1997-2001 relative to loadings from Danish catchments. When requiring same anthropogenic footprint from Danish and neighbouring countries (scenario 2b) Danish MAIs decrease considerable compared to scenario 1 as Denmark currently has a higher anthropogenic N load compared to neighbouring countries. In the scenario 2c where neighbouring countries does not reduce land-based N loadings compared to today's loadings, the Danish MAIs are reduced significantly and the number of water bodies reaching GES reduces likewise to 48 (P0) respectively 64 (P50).

Scenario 3 reflects the impact of atmospheric N deposition on Danish MAIs. As expected, Danish MAI will decrease if the NEC directive is not fully implemented (scenario 3a) whereas Danish MAI will increase significantly if further reductions in atmospheric N deposition is implemented e.g. as a side-effect of implementing measures to reduce climate change.

The WFD scenarios reflects changes in the method described in Erichsen *et al.* (2020a). In Erichsen *et al.* (2020a) MAIs are calculated based on an average of individual indicator-MAIs and aiming at the boundary between Good-Moderate conditions introducing a system contribution. In the WFD scenarios we aim at an average threshold value in the middle between High-Good and Good-Moderate boundaries (1a), apply the one-out-all-out principles (1b) and exclude the system contributions (1c). In all the WFD scenarios the Danish N MAIs are reduced significantly.

[3] The MAI presented in Erichsen & Timmerman (2017) as background material for the international panel of experts was estimated to 42 kt N/year. Since then, the method behind the yearly loadings have been revised (REF) why the corresponding MAI loadings today would be 39 kt N/year.

2.5 Closing Remarks

The estimated maximum allowable nitrogen input (N-MAI) to Danish water bodies resulting from the different management scenarios are described in detail in Erichsen *et al.* 2020 b-k. In this report the individual water body N-MAIs have been summarized to a Danish N-MAI for each management scenario reflecting the maximum allowable nutrient input from all Danish catchments given the different scenario preconditions regarding future nutrient input from neighbouring countries and the atmosphere.

We have not assessed whether the preconditions defining the scenarios are realistic or even possible. If the preconditions are fulfilled, and the MAI for Danish water bodies is reached by the end of 2027, all Danish water bodies will most likely not have reached Good Ecological Status (GES) as defined in the WFD. This is because

- With the given preconditions in the different management scenarios, one or both of the indicators (chlorophyll-a and light) may not reach the target value even when N loadings are reduced to background levels. The reason is that reduction of Danish N loading in some cases are not sufficient to counteract effects of other nutrient sources (Danish P load, N and P load from neighbouring countries and/or atmospheric N deposition). It is, however, possible to obtain GES in all Danish water bodies, but it might require larger efforts from neighbouring countries, larger reduction in atmospheric N deposition and/or larger reductions in Danish P loadings than reflected in the presented management scenarios. In these situations, administrative choices must be made, like applying an average reduction from neighbouring water bodies, reductions like down-stream water bodies or a general MAI (kg/ha) for those water bodies. However, the implication is that GES for both indicators cannot be expected in these water bodies, not even if N-MAI is obtained.
- The MAI estimation is based on the depth of light as a proxy for the indicator eelgrass depth limit. Hence, even if light has reached the target value, recovery for eelgrass is expected to take several years (and even decades). In addition, other barriers than light availability, such as sediment suitability, lack of seedlings, etc., may delay or even prevent eelgrass recovery.
- As some ecosystems respond with significant time-lags to changes in loadings, it will take years before the full environmental effects of nutrient reductions can be observed. Hence, reaching MAI will provide the conditions for obtaining GES but the achievement of GES will likely be delayed. The method used for management scenario 1, 2 and 3 is not based on the one-out-all-out principle as required in the WFD, but on an average of two indicators. Hence, it is expected that both indicators will be as close to the target value as possible, but one will, in some cases be above and one below the target value. If the one-out-all-out principle was followed, the estimated MAIs would be significantly lower and the precision in reaching the exact target value would also be lower.
- In management scenario 1, 2 and 3, we are using the boundary between good and moderate status as the target value. Due to uncertainties, there is a 50% chance that the water body will end in good status and a 50% chance that the water body will end in moderate status, once MAI has been reached. Aiming for at higher certainty, that the estimated MAI will result in achievement of at least good ecological status would require lower MAIs as illustrated by WFD scenario 1a.

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