REPORT OCEANOGRAPHY No. 51, 2015

Coastal eutrophication status assessment using HEAT 1.0 (WFD methodology) versus HEAT 3.0 (MSFD methodology)

and

Development of an oxygen consumption indicator

Front image:
The Baltic Sea. Photo: Karin Wesslander

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Summary

This report contains two parts which are self standing reports and a contribution to the HELCOM project EUTRO-OPER. The work has been funded and commissioned by SwAM (Swedish agency for marine and water management) 2014-2015.

- Coastal eutrophication status assessment using HEAT 1.0 (WFD methodology) versus HEAT 3.0 (MSFD methodology)

Eutrophication status is assessed nationally in coastal waters within the Water Framework Directive (WFD) and in open sea areas within the Marine Strategy Framework Directive (MSFD). Both WFD and MSFD consider eutrophication but with different approaches and it is therefore a need for harmonisation in the assessment process.

The Excel based tool HEAT (HELCOM Eutrophication Assessment Tool) has been used in previous assessments in the HELCOM region. There are two versions of the tool; HEAT 1.0 and HEAT 3.0, the first is based on the WFD methodology and the second is based on the MSFD methodology. The main difference between HEAT 1.0 and HEAT 3.0 is how the indicators are grouped. Here we assess the eutrophication status in coastal waters by applying HEAT and compare the results with the national WFD assessments. The present test includes data on 33 selected coastal water bodies in five countries: Estonia, Finland, Latvia, Poland and Sweden. Data on reference condition, acceptable deviation, status and class boundaries of all indicators used in WFD for reporting ecological status (biological and physical-chemical) have been provided for each tested water body. The data has been inserted in the HEAT 1.0 and HEAT 3.0 tools and been compared with the national WFD assessments.

Both HEAT versions gave lower status in more than 50 % of the cases. For some tests the status changed to sub-GES from GES when HEAT is applied. The good/moderate boundary is the same in both HEAT and the WFD while the lower class boundaries in general are stricter in HEAT, which explains the lower status. In national WFD assessments expert judgment is used when there is little, no or very uncertain in situ data. The status in HEAT is given by the one-out-all-out principle but it is still possible to include expert judgment through the weighting factors.

- Development of an oxygen consumption indicator

It was investigated if the oxygen consumption can be used as an oxygen indicator for the Baltic Sea. The method is based on the idea of calculating the oxygen consumption in a stabile layer below the productive zone during summer and relating this to nutrient concentrations. With more nutrients available there is an increased biological production. By estimating how much oxygen is needed to mineralise the biological material it may be possible to link the oxygen consumption to eutrophication.

The oxygen consumption was calculated for the BY15-Gotland Deep in the Eastern Gotland Basin. We identified a stabile layer between 30 and 50 m and a large change in both oxygen and nutrients from June to August. However, the oxygen consumption had a very high inter-annual variation and there were no significant correlation with the winter mean of nutrient concentrations. It was not possible to calculate the diffusion between the layers because of too sparse measurements at the stratification which limits the method. The calculation of the diffusion is however possible to improve with a model. Further on, the depth of the stabile layer is varying between areas and also between years.

We realised that the method has too many restrictions to be a functional indicator. A functional indicator shall not be dependent on heavy modelling or demand too much on expert judgement.

We also investigated if a possible candidate to use as a more simple oxygen consumption indicator could be the use of oxygen saturation at a specific depth. If we assume that the temperature has not changed much since the establishment of stratification we may expect that changes in oxygen saturation observed in August at this depth would be caused by the biological oxygen consumption occurring during late spring and summer. The correlation with winter mean nutrients slightly improved in this case.

Sammanfattning

Den här rapporten innehåller två delar vilka båda är fristående rapporter och ett bidrag till HELCOM-projektet EUTRO-OPER. Uppdraget har finansierats och beställts av Havs- och Vattenmyndigheten (HaV), 2014-2015.

- Bedömning av övergödning i kustvatten med HEAT 1.0 (Vattendirektivets metodik) versus HEAT 3.0 (Havsmiljödirektivets metodik)

Status för övergödning bedöms nationellt i kustnära områden in Vattendirektivet (VD) och i öppet hav inom Havsmiljödirektivet (HMD). Båda direktiven tar hänsyn till övergödning men med olika tillvägagångssätt och det finns därför ett behov av harmonisering i bedömningsprocessen.

Det Excelbaserade verktyget HEAT (HELCOM Eutrophication Assessment Tool) har använts i tidigare bedömningar i HELCOM-regionen. Det finns två versioner; HEAT 1.0 och HEAT 3.0, den första är baserat på VD metodik och den andra är baserad på HMD metodik. Den största skillnaden mellan HEAT 1.0 och HEAT 3.0 är hur indikatorerna är grupperade. Här bedömer vi status för övergödning i kustvatten med HEAT och jämför resultaten med den nationella bedömningen inom VD. Detta test inkluderar data för 33 vattenförekomster i fem länder; Estland, Finland, Lettland, Polen och Sverige. Information om referensvärden, acceptabel avvikelse, status och klassgränser för alla indikatorer som används inom VD för att rapportera ekologisk status (biologisk och fysisk-kemisk) har tillhandahållits för varje testområde. Informationen har lagts in i HEAT 1.0 och HEAT 3.0 och jämförts med den nationella bedömningen inom VD.

Båda HEAT-verktygen genererade lägre status i mer än 50 % av fallen. För en del fall ändrades status till sub-GES från GES när HEAT användes. Klassgränsen för god/måttlig status är densamma i HEAT och VD medan de lägre klassgränserna generellt är striktare i HEAT vilket förklarar den lägre statusen. I nationella bedömningar inom VD används expertbedömning i de fall där in situ data är bristfällig, saknas eller har hög osäkerhet. Statusen i HEAT ges av en-ut-alla-ut principen men det är ändå möjligt att inkludera expertbedömning genom viktningsprocessen.

- Utveckling av en syreindikator

Det undersöktes om syrekonsumption kan användas som en syreindikator för Östersjön. Metoden är baserad på idén att beräkna syrekonsumptionen i ett stabilt lager under den produktiva zonen sommartid och relatera den till närsaltskoncentrationer. Med mer närsalter tillgängliga ökar den biologiska produktionen. Genom att uppskatta hur mycket syre som behövs för att bryta ned det biologiska materialet borde det vara möjligt att koppla syrekonsumption till övergödning.

Syrekonsumptionen beräknades för BY15-Gotlandsdjupet i östra Gotlandsbassängen. Vi identifierade ett stabilt lager mellan 30 och 50 meter och en stor förändring i syre och närsalter från juni till augusti. Syrekonsumptionen hade stora variationer mellan år och det fanns ingen signifikant korrelation till vintermedel av närsalter. Det var inte möjligt att beräkna diffusionen på grund av för glesa mätningar kring skiktningen, detta begränsar metoden. Det är däremot möjligt att förbättra uppskattningen av diffusionen med en modell. Djupet av det stabila lagret varierar mellan områden och även mellan år vilket kräver en del handpåläggning för metoden.

Vi insåg att metoden har för många begränsningar för att vara en funktionell indikator. En funktionell indikator ska inte vara beroende av krävande modellering eller för mycket handpåläggning.

Vi undersökte också om en möjlig kandidat till en lite enklare syrekonsumptionindikator skulle kunna vara att beräkna syremättnaden på en specifik nivå. Om vi antar att temperaturen inte har ändrats så mycket sedan skiktningen etablerades kan vi förvänta oss att förändringen i syremättnad i augusti beror på biologisk syrekonsumption under sen vår och sommar. Korrelationen med vinternärsalter förbättrades något i detta fall.

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Coastal eutrophication status assessment using HEAT 1.0 (WFD methodology) versus HEAT 3.0 (MSFD methodology)

1 Background

Eutrophication status is assessed nationally in coastal waters within the Water Framework Directive (WFD; 2000/60/EC) and in open sea areas within the Marine Strategy Framework Directive (MSFD; 2008/56/EC). Both WFD and MSFD consider eutrophication but with different approaches and it is therefore a need for harmonisation in the assessment process. The eutrophication status in the HELCOM region has previously been assessed regionally using the HELCOM Eutrophication Assessment Tool (HEAT). There are two versions of the tool that have been used; HEAT 1.0 and HEAT 3.0. The HEAT 1.0 is based on the WFD and was used in the HELCOM Initial Holistic Assessment (HELCOM 2010a and HELCOM 2010b) where both coastal and open sea areas were assessed. HEAT 3.0 is based on the MSFD and was used in the last thematic assessment of the open sea areas of the Baltic Sea that was made for the period 2007-2011 (HELCOM 2014), the coastal region was not included in this assessment. For future assessments, better understanding of the differences between the tools and methodologies to harmonize the coastal and open sea area assessments is needed.

We here present results on how the eutrophication assessment on a selection of coastal water types in the Baltic Sea varies with the use of different assessment tools such as HEAT 1.0, HEAT 3.0 and nationally WFD-assessments. There is also a need to harmonize between the Baltic Sea and the North Sea region. For that reason, one Swedish coastal water type in Kattegat was assessed using the “Common Procedure for the Identification of the Eutrophication Status of the OSPAR Maritime Area”, (OSPAR 2013-08), hereafter referred to as COMP in this test. Kattegat is included in two sea conventions, HELCOM and OSPAR, and is thus assessed by the region’s different methods.

This work is part of the HELCOM EUTRO-OPER project “Making the HELCOM eutrophication assessment operational”.

2 Aim

The aim of the report is to identify problems and differences between the assessment tools HEAT 1.0 and HEAT 3.0 when used on coastal waters.

3 Methodology

3.1 WFD versus MSFD

One of the main differences between the WFD and the MSFD is how the indicators related to eutrophication are grouped. In the WFD, indicators related to eutrophication are grouped as biological and physical-chemical quality elements (Table 1). The biological elements, QE1-QE3, are the most important group in the status classification and include phytoplankton, macro vegetation and invertebrate fauna. Physical-chemical elements, QE4, are mainly supportive and include nutrients, water transparency and dissolved oxygen. In the MSFD, the indicators related to eutrophication for descriptor 5 are grouped in a different way; as criteria C1) Nutrient levels, C2) Direct effects and C3) Indirect effects of nutrient enrichment. Direct effects include phytoplankton, water transparency and abundance of opportunistic macro vegetation. Indirect effects include abundance of perennial seaweed and sea grass and dissolved oxygen.

Another main difference between WFD and MSFD is how the water body finally gets its status class. An assessment in the WFD results in one of five status classes for **ecological status**; high, good, moderate, poor or bad. An assessment in the MSFD on the other hand results in one of two status classes for **environmental status**; GES (good environmental status) or subGES. Good ecological and good environmental status is not equally comparable since classification methods are different.

To assess the **ecological status** an ecological quality ratio (EQR) is calculated for each indicator which gives the status for that specific indicator. Indicators with a numerical positive (+) relationship to nutrient input are calculated differently from indicators with negative (-) relationship:

$EQR = RefCon/AcStat$ (+)

$EQR = AcStat/RefCon$ (-)

$0 \leq EQR \leq 1$

where RefCon is the reference condition and AcStat is the actual status of the parameter for the assessed time period. An EQR close to 1 indicate high status and close to 0 indicate bad status. The class boundary for the good/moderate boundary of biological parameters shall be determined through intercalibration processes and the other boundaries are set nationally. When data are not available for the water body to be assessed expert judgement may be used. According to the directive, the supporting parameters need to be assessed only if the biological elements show good or high status. The final ecological status is given by the one out-all out principle meaning that the element having the worst status determines the final status.

The **environmental** status is on the other hand given by a holistic assessment procedure using the ecosystem approach where GES is determined for 11 descriptors. How status for indicators and descriptors shall be weighted for the final status classification is still to be determined for the second MSFD-round.

3.2 Assessment tools

This section gives a description of the main methodologies of HEAT 1.0, HEAT 3.0 and OSPAR COMP.

3.2.1 HEAT 1.0 methodology

The grouping of indicators in HEAT 1.0 is based on the WFD and the four subgroups named QE1-QE4, see Table 1. To do an assessment in HEAT 1.0, Ref Con and AcStat are used to calculate the EQR for each indicator and this step is similar to WFD. If a sub-group contains more than one indicator there is an option to give each indicator individual weights and the sub-group gets by this a weighted averaged EQR. Each indicator is also given an acceptable deviation (AcDev) from the RefCon. The mean acceptable deviation within a sub-group is then used to determine the class boundaries for each sub-group and a status class can be assigned (Table 2). The final eutrophication status is given by the one out-all out principle meaning that the sub-group with the lowest status determines the result. Just as for the WFD, five classes are used. In HEAT 1.0, there is an upper limit for AcDev that are 110% for indicators which are positively related to eutrophication and 52.5% for indicators which are negatively related. The methodology of HEAT 1.0 is described in more detailed in Andersen et al 2011. An example of an HEAT 1.0 template is shown in Figure 1.

3.2.2 HEAT 3.0 methodology

The grouping of indicators in HEAT 3.0 is in line with the MSFD and the subgroups are C1-C3 accordingly (Table 1). In this version of HEAT there is an option to either use RefCon and AcDev to produce a target, EUT_target = RefCon ± AcDev, or to use a pre-defined EUT_target. From the relation between the AcStat and EUT_target a eutrophication ratio (EUT_Ratio) is determined. The EUT_Ratio is defined between 0 and 2 where 1.0 is the Good/Moderate boundary and also GES/subGES boundary. Each group (criteria) is then given a eutrophication sum (EUT_sum) which is a weighted average of the EUT_Ratios included in that criteria. From this EUT_sum the criteria status class is determined. In contrast to HEAT 1.0, the class boundary limits in HEAT 3.0 are linear and fixed and hence not dependent on AcDev (Table 3).

The final status class is then determined by the one out-all out principle, the criteria with the lowest status sets the final status. An example of an HEAT 3.0 template is shown in Figure 2.

Table 1. Grouping of indicators in WFD vs MSFD.

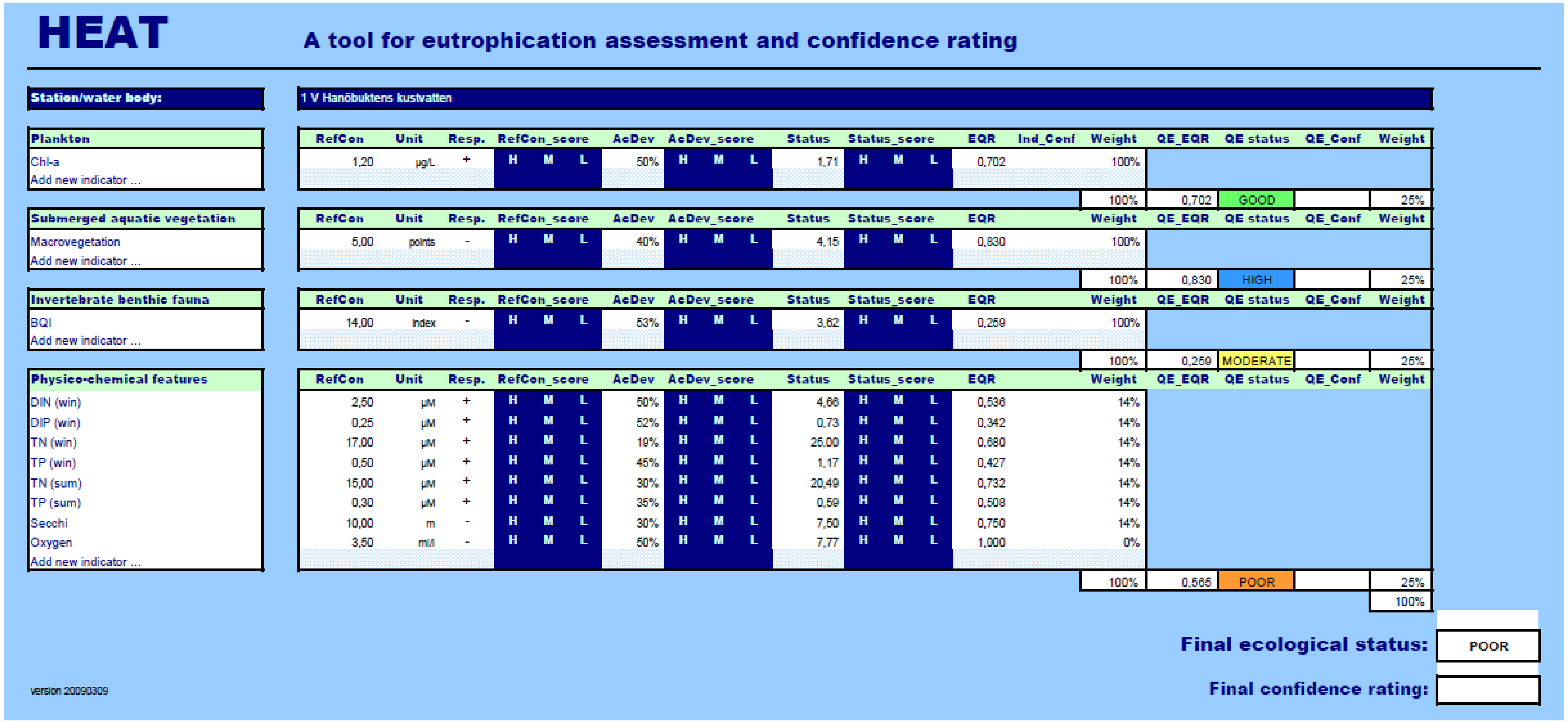
	WFD Quality element		MSFD Criteria element		
Indicator	Biological elements (QE1-QE3)	Physical-chemical elements (QE4)	Nutrient levels (C1)	Direct effects (C2)	Indirect effects (C3)
Chl-a	QE1			C2	
Biovolume	QE1			C2	
Macrovegetation	QE2			C2	C3
Invertebrate fauna	QE3				
DIN (win)		QE4	C1		
DIP (win)		QE4	C1		
TN (win)		QE4	C1		
TP (win)		QE4	C1		
TN (sum)		QE4	C1		
TP (sum)		QE4	C1		
Secchi depth (sum)		QE4		C2	
Oxygen concentration		QE4			C3

Table 2. How class boundary values between status classes are defined in HEAT 1.0.An example with acceptable deviation (AcDev) =50% is given.

	Indicators with a numerical **positive** relationship to nutrient input		Indicators with a numerical **negative** relationship to nutrient input	
Class boundary	Boundary value	EQR with AcDev = 50%	Boundary value	EQR with AcDev = 50%
$EQR_{RefCon/High}$	0.95	0.95	0.95	0.95
$EQR_{High/Good}$	$0.5EQR_{RefCon/High}$ $+ 0.5EQR_{Good/Moderate}$	0.81	$0.5EQR_{RefCon/High}$ $+ 0.5EQR_{Good/Moderate}$	0.73
$EQR_{Good/Moderate}$	1/(1+ AcDev)	0.67	(1- AcDev)	0.5
$EQR_{Moderate/Poor}$	$0.5EQR_{Good/Moderate}$ $+ 0.5EQR_{Poor/Bad}$	0.53	$0.5EQR_{Good/Moderate}$ $+ 0.5EQR_{Poor/Bad}$	0.28
$EQR_{Poor/Bad}$	$2EQR_{Good/Moderate} – EQR_{RefCon/High}$	0.38	$2EQR_{Good/Moderate} – EQR_{RefCon/High}$	0.05

Table 3. Status class boundary limits in HEAT 3.0.

Status class	Range
High	$0.00 \leq$ EUT_Ratio ≤ 0.50
Good	$0.50 \leq$ EUT_Ratio ≤ 1.00
Moderate	$1.00 \leq$ EUT_Ratio ≤ 1.50
Poor	$1.50 \leq$ EUT_Ratio ≤ 2.00
Bad	EUT_Ratio > 2.00



Station/water body: 1 V Hanöbuktens kustvatten

Plankton	RefCon	Unit	Resp.	RefCon_score			AcDev	AcDev_score			Status	Status_score			EQR	Ind_Conf	Weight	QE_EQR	QE status	QE_Conf	Weight
Chl-a	1,20	µg/L	+	H	M	L	50%	H	M	L	1,71	H	M	L	0,702		100%				
Add new indicator ...																					
																	100%	0,702	GOOD		25%

Submerged aquatic vegetation	RefCon	Unit	Resp.	RefCon_score			AcDev	AcDev_score			Status	Status_score			EQR		Weight	QE_EQR	QE status	QE_Conf	Weight
Macrovegetation	5,00	points	-	H	M	L	40%	H	M	L	4,15	H	M	L	0,830		100%				
Add new indicator ...																					
																	100%	0,830	HIGH		25%

Invertebrate benthic fauna	RefCon	Unit	Resp.	RefCon_score			AcDev	AcDev_score			Status	Status_score			EQR		Weight	QE_EQR	QE status	QE_Conf	Weight
BQI	14,00	index	-	H	M	L	53%	H	M	L	3,62	H	M	L	0,259		100%				
Add new indicator ...																					
																	100%	0,259	MODERATE		25%

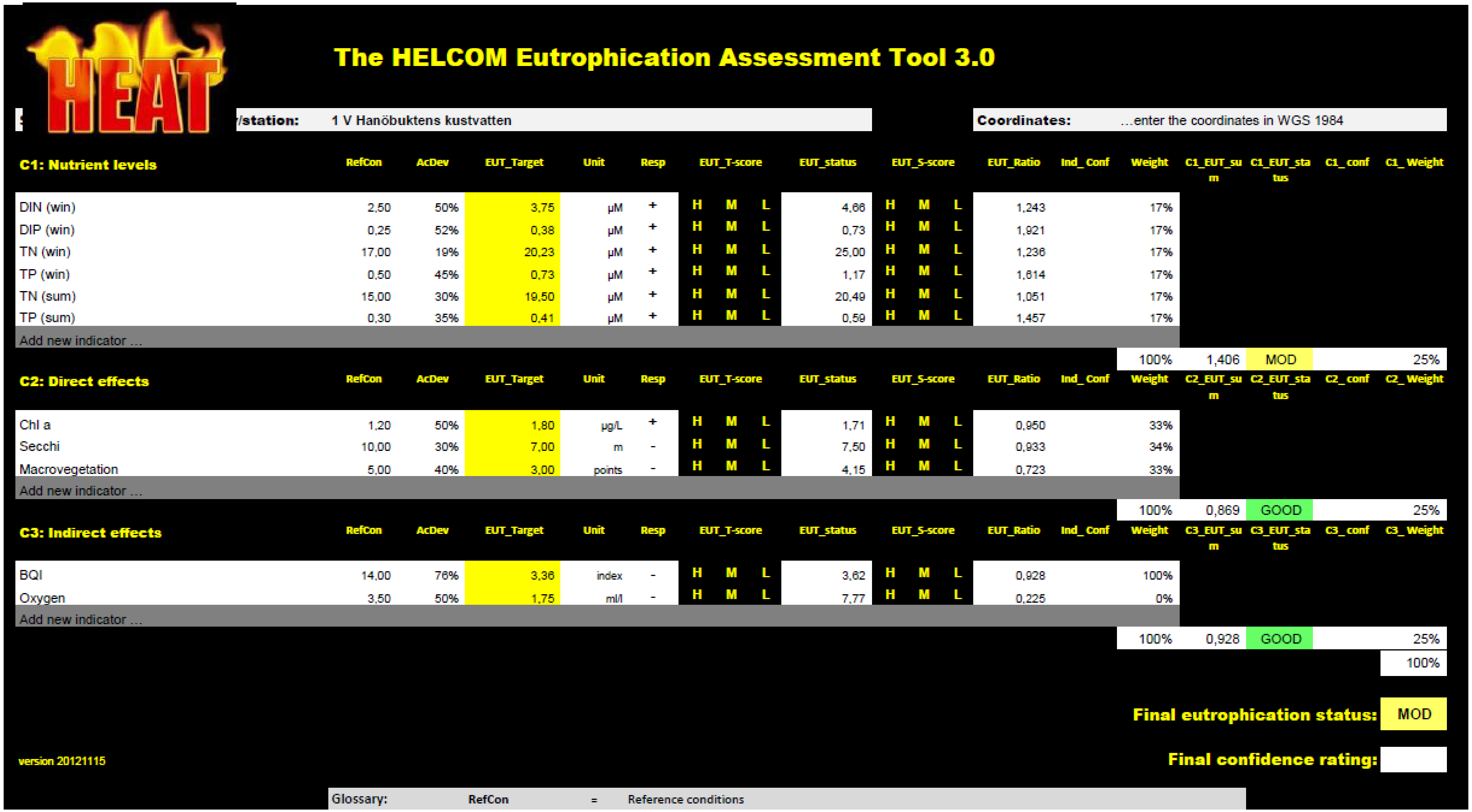
Physico-chemical features	RefCon	Unit	Resp.	RefCon_score			AcDev	AcDev_score			Status	Status_score			EQR		Weight	QE_EQR	QE status	QE_Conf	Weight
DIN (win)	2,50	µM	+	H	M	L	50%	H	M	L	4,66	H	M	L	0,536		14%				
DIP (win)	0,25	µM	+	H	M	L	52%	H	M	L	0,73	H	M	L	0,342		14%				
TN (win)	17,00	µM	+	H	M	L	19%	H	M	L	25,00	H	M	L	0,680		14%				
TP (win)	0,50	µM	+	H	M	L	45%	H	M	L	1,17	H	M	L	0,427		14%				
TN (sum)	15,00	µM	+	H	M	L	30%	H	M	L	20,49	H	M	L	0,732		14%				
TP (sum)	0,30	µM	+	H	M	L	35%	H	M	L	0,59	H	M	L	0,508		14%				
Secchi	10,00	m	-	H	M	L	30%	H	M	L	7,50	H	M	L	0,750		14%				
Oxygen	3,50	ml/l	-	H	M	L	50%	H	M	L	7,77	H	M	L	1,000		0%				
Add new indicator ...																					
																	100%	0,565	POOR		25%
																					100%

Final ecological status: POOR

Final confidence rating:

version 20090309

Figure 1. Example of an HEAT 1.0 template.



The HELCOM Eutrophication Assessment Tool 3.0

/station: 1 V Hanöbuktens kustvatten

Coordinates: …enter the coordinates in WGS 1984

C1: Nutrient levels	RefCon	AcDev	EUT_Target	Unit	Resp	EUT_T-score	EUT_status	EUT_S-score	EUT_Ratio	Ind_Conf	Weight	C1_EUT_sum	C1_EUT_status	C1_conf	C1_Weight
DIN (win)	2,50	50%	3,75	µM	+	H M L	4,66	H M L	1,243		17%				
DIP (win)	0,25	52%	0,38	µM	+	H M L	0,73	H M L	1,921		17%				
TN (win)	17,00	19%	20,23	µM	+	H M L	25,00	H M L	1,236		17%				
TP (win)	0,50	45%	0,73	µM	+	H M L	1,17	H M L	1,614		17%				
TN (sum)	15,00	30%	19,50	µM	+	H M L	20,49	H M L	1,051		17%				
TP (sum)	0,30	35%	0,41	µM	+	H M L	0,59	H M L	1,457		17%				
Add new indicator …															
											100%	1,406	MOD		25%

C2: Direct effects	RefCon	AcDev	EUT_Target	Unit	Resp	EUT_T-score	EUT_status	EUT_S-score	EUT_Ratio	Ind_Conf	Weight	C2_EUT_sum	C2_EUT_status	C2_conf	C2_Weight
Chl a	1,20	50%	1,80	µg/L	+	H M L	1,71	H M L	0,950		33%				
Secchi	10,00	30%	7,00	m	-	H M L	7,50	H M L	0,933		34%				
Macrovegetation	5,00	40%	3,00	points	-	H M L	4,15	H M L	0,723		33%				
Add new indicator …															
											100%	0,869	GOOD		25%

C3: Indirect effects	RefCon	AcDev	EUT_Target	Unit	Resp	EUT_T-score	EUT_status	EUT_S-score	EUT_Ratio	Ind_Conf	Weight	C3_EUT_sum	C3_EUT_status	C3_conf	C3_Weight
BQI	14,00	76%	3,36	index	-	H M L	3,62	H M L	0,928		100%				
Oxygen	3,50	50%	1,75	ml/l	-	H M L	7,77	H M L	0,225		0%				
Add new indicator …															
											100%	0,928	GOOD		25%
															100%

Final eutrophication status: MOD

Final confidence rating:

version 20121115

Glossary: RefCon = Reference conditions

Figure 2. Example of an HEAT 3.0 template.

3.2.3 COMP methodology

In the OSPAR region eutrophication status is assessed by using the OSPAR Comprehensive Procedure (COMP). Assessed parameters are grouped in four categories;

- Category 1) The degree of nutrient enrichment (riverine inputs, direct charges, nutrient concentrations, N/P ratio)
- Category 2) Direct effects of nutrient enrichment (chlorophyll-a, phytoplankton, macrophytes)
- Category 3) Indirect effects of nutrient enrichment (oxygen deficiency, zoobenthos, fish, organic carbon)
- Category 4) Other possible effects such as algal toxins.

If status of the assessed parameter is above the assessment level, the parameter is scored as (+) meaning elevated level, else the score is (-). The assessment level is defined as the background level + 50%. First an initial classification is made, see table 4.

Table 4. Procedure of initial assessment in COMP.

5.4 The initial classification shall be as follows:

a. areas showing an increased degree of nutrient enrichment accompanied by direct and/or indirect/ other possible effects are regarded as **‘problem areas’**;

b. areas may show direct effects and/or indirect or other possible effects, when there is no evident increased nutrient enrichment, for example, as a result of transboundary transport of (toxic) algae and/or organic matter arising from adjacent/remote areas. These areas could be classified as **‘problem areas’**;

c. areas with an increased degree of nutrient enrichment where:

(i) either there is firm, scientifically based evidence of the absence of (direct, indirect, or other possible) eutrophication effects – these are classified initially as ‘**non-problem areas’**, although the increased degree of nutrient enrichment in these areas may contribute to eutrophication problems elsewhere;

(ii) or there is not enough data to perform an assessment or where the data available is not fit for the purpose – these are classified initially as **‘potential problem areas’**;

d. areas without nutrient enrichment and related (in)direct/ other possible effects are considered to be **‘non-problem areas’**.

Finally an overall classification of the area is made where it is possible to include other information in the judgement (Table 5).

Table 5. Template for the overall COMP assessment.

Key to the table

NI	Riverine inputs and direct discharges of total N and total P
DI	Winter DIN and/or DIP concentrations
NP	Increased winter N/P ratio
Ca	Maximum and mean chlorophyll *a* concentration
Ps	Area-specific phytoplankton indicator species
Mp	Macrophytes including macroalgae
O_2	Oxygen deficiency
Ck	Changes/kills in zoobenthos and fish kills
Oc	Organic carbon/organic matter
At	Algal toxins (DSP/PSP mussel infection events)

\+ = Increased trends, elevated levels, shifts or changes in the respective assessment parameters

\- = Neither increased trends nor elevated levels nor shifts nor changes in the respective assessment parameters

? = Not enough data to perform an assessment or the data available is not fit for the purpose

Note: Categories I, II and/or III/IV are scored ‘+’ in cases where one or more of its respective assessment parameters is showing an increased trend, elevated levels, shifts or changes.

Area	**Category I** Degree of nutrient enrichment		**Category II** Direct effects		**Category III and IV** Indirect effects/other possible effects				Initial classification	Appraisal of all relevant information (concerning the harmonised assessment parameters, their respective assessment levels and the supporting environmental factors)	Final classification	Assessment period
	NI		Ca		O_2		At					
	DI		Ps		Ck							
	NP		Mp		Oc							
	NI		Ca		O_2		At					
	DI		Ps		Ck							
	NP		Mp		Oc							
	NI		Ca		O_2		At					
	DI		Ps		Ck							
	NP		Mp		Oc							

3.3 Testing procedure

The present test includes data on 33 selected coastal water bodies from five countries: Estonia, Finland, Latvia, Poland and Sweden.

Estonia; one water body in Gulf of Finland, Finland; three coastal water types were tested, number of water bodies in brackets; Outer coastal waters of the Bothnian Bay (5), the Quark (1) and The Archipelago & western Gulf of Finland (4), Latvia; one water type were assessed, LAT 001, Poland; one coastal type was tested for Polish waters, the Gdansk Basin (SEA 009) with three water bodies, Sweden; three coastal water types were tested, number of tested water bodies in brackets: 7-Arkona-Hanö Bukt (9), 23-Outer Bothnian Bay (7) and 4-Kattegat (2). Location map and classification schemes for the Swedish test sites are presented in Annex B.

Data on RefCon, AcStat, AcDev and class boundaries of all indicators used in WFD for reporting ecological status (biological and physical-chemical) have been provided from participating countries from the latest WFD classification (2013). The information has been inserted in HEAT 1.0 and HEAT 3.0 tools and assigned status results have been compared with the national WFD assessment. In the test, all indicators in a sub-group have been equally weighted. The confidence rating has not been considered.

4 Result and Discussion

The detailed result of the testing procedure for each water body is shown as an Annex A, where also comments are made per country.

According to the WFD, biological indicators, QE1-QE3, should be assessed in the first place. If the status is moderate or lower there is no need to assess the supporting parameters, QE4, and the final status is moderate or lower. If the biological quality elements are classified to good or high status the physical-chemical parameters shall also be assessed. However, for some of the tested water bodies the final status is good even if the biological parameters have been assessed to moderate or lower. In these cases expert judgment has been included in the assessment procedure. This can be due to high uncertainty in the biological parameters and because of little or no in situ data. This makes it difficult to compare results with HEAT that do not have this expert judgment.

The HEAT assessments are mostly stricter than the national WFD-classification. To summarize, in more than 50% of the tests both HEAT-versions generate lower status (Table 6) than the national WFD. The change is mostly only one status class and never no more than two status classes. For some cases the status is changed to sub-GES from GES when HEAT is applied.

The main difference between national WFD and HEAT 1.0 assessments is probably due to differences in class boundary setting since the grouping of indicators is same. The other difference is of course because of the expert judgment is included in the WFD. The HEAT tool is stricter because of its one out-all out approach. It is more difficult to compare the class boundaries for HEAT 3.0 since these are calculated completely different. The grouping in HEAT 3.0 also differs from WFD and HEAT 1.0 which is another major reason for the differences. However, the good/moderate boundary is the same for all three assessments apart from HEAT 1.0 that sometimes differ because of its limitation in acceptable deviation. When comparing the WFD class boundaries with the one in HEAT the major difference is found at the lower classes.

One benefit of using a tool like HEAT is that it simplifies the process of comparing results between countries since the same method is used. However, there are still rooms for individual tuning of the assessment with the use of AcDev and the weighting procedure.

The term AcDev has different meaning in HEAT 1.0, where it sets the classification boundaries, and in HEAT 3.0, where it is used to produce a target together with RefCon. HEAT 3.0 has fixed class boundaries.

A challenge is how to make an assessment of one coastal water type that includes several coastal water bodies that are each one assessed independently. One way of doing can be to give each water body a percentage number that relates to how much of the water type it represents, and then do the same for the status. The status class that is most representative for the water type also sets the overall status. A dummy-example can be the following: water type A has three water bodies (1, 2and 3). Water body 1 has good, 2 has poor and 3 has bad status. Water body 1 represents 60 %, 2 represents 30 % and 3 represents 10 % of the water type area. The final status for A is thus good since this is the most representative for the type.

Table 6. Change in assessments made with HEAT 1.0 and HEAT 3.0 compared with national WFD assessments. A number of 33 coastal water bodies have been tested. The change in status (higher, none, lower) is presented as number and percentages. Below is how many test units have changed one status class vs. two status classes. No assessment unit changed its status class more than two classes.

	HEAT 1.0	HEAT 3.0
Higher status than WFD One - /two status classes	3 (10%) 1/2	6 (20%) 6/0
No change in status	10 (30%)	8 (27%)
Lower status than WFD One - /two status classes	17 (57%) 11/6	16 (53%) 11/5

For the Swedish coastal water type Kattegat, the test also included assessment using OSPAR COMP (Table 7). There are only data from two water bodies in the water type; the other bodies are assessed with expert judgment. In COMP, the assessment level is calculated as a 50% deviation from the background level. In Table 7, the national assessment level is also included where they differ.

All assessed parameters are below assessment levels and hence Kattegat coastal water is classified as a non-problem area using COMP. Kattegat is assessed with moderate status in the WFD and high vs. good status in HEAT 1.0 and HEAT 3.0 respectively.

Table 7. Assessment of Swedish water type 4-Kattegat using OSPAR COMP.

Parameter	Background level	Assessment level	Status level 2007-2012		Score	
	Water type 4 Kattegat S =20	Water bodies	Water bodies		Water bodies	
		Onsala kv and N m Hallands kv	Onsala kv	N m Hallands kv	Onsala kv	N m Hallands kv
DIN (winter)	4.5	6.75	6.71	5.63	(-)	(-)
DIP (winter)	0.4	0.6	0.53	0.53	(-)	(-)
TN (winter)	17	22[a] /25.5[b]	17.9	17.83	(-)	(-)
TP (winter)	0.7	0.9[a]/1.05[b]	0.84	0.86	(-)	(-)
TN (summer)	12	16[a] / 18[b]	14	14.39	(-)	(-)
TP (summer)	0.4	0.56[a] /0.6[b]	0.42	0.42	(-)	(-)
Chlorophyll	1.0	1.5	1.21	0.97	(-)	(-)
Biovolume	0.5	1.1[a] 0.75[b]	Not assessed	No data		
Macrovegetation	5	3	Not assessed	4.5		(-)
Oxygen	3.5	2.1	4.45	4.70	(-)	(-)
Overall assessment	(-)					

[a] G/M class boundary in WFD

[b] OSPAR Assessment level: Background level+50%

5 Acknowledgement

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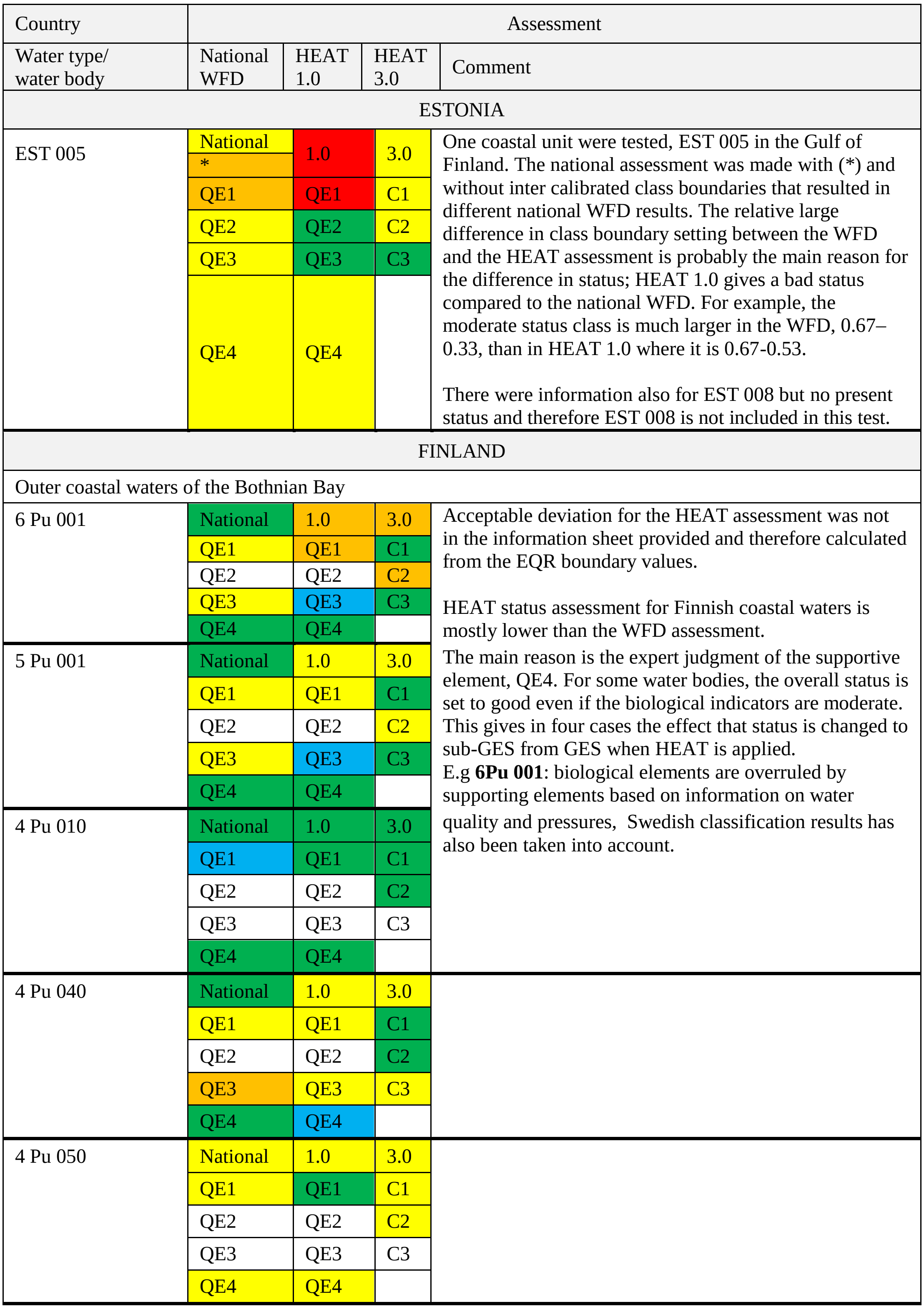
WFD; DIRECTIVE 2000/60/EC

Results from testing HEAT

High	Good	Moderate	Poor	Bad

Table A1. Assessment results from national WFD compared with HEAT 1.0 and HEAT 3.0. QE1-QE4 refers to the WFD quality elements; QE1-Plankton, QE2-Makrophytes, QE3-Bottomfauna and QE4-Physical-Chemical parameters. C1-C3 refers to the MSFD criteria; C1-Nutrient levels, C2-Direct effects and C3-Indirect effects. Status is presented as color according to the top color bar for each indicator sub group and per water body. Right column includes comments about data, result etc.



Country	Assessment			
Water type/ water body	National WFD	HEAT 1.0	HEAT 3.0	Comment
ESTONIA				
EST 005	National *	1.0	3.0	One coastal unit were tested, EST 005 in the Gulf of Finland. The national assessment was made with (*) and without inter calibrated class boundaries that resulted in different national WFD results. The relative large difference in class boundary setting between the WFD and the HEAT assessment is probably the main reason for the difference in status; HEAT 1.0 gives a bad status compared to the national WFD. For example, the moderate status class is much larger in the WFD, 0.67–0.33, than in HEAT 1.0 where it is 0.67-0.53. There were information also for EST 008 but no present status and therefore EST 008 is not included in this test.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
FINLAND				
Outer coastal waters of the Bothnian Bay				
6 Pu 001	National	1.0	3.0	Acceptable deviation for the HEAT assessment was not in the information sheet provided and therefore calculated from the EQR boundary values. HEAT status assessment for Finnish coastal waters is mostly lower than the WFD assessment. The main reason is the expert judgment of the supportive element, QE4. For some water bodies, the overall status is set to good even if the biological indicators are moderate. This gives in four cases the effect that status is changed to sub-GES from GES when HEAT is applied. E.g **6Pu 001**: biological elements are overruled by supporting elements based on information on water quality and pressures, Swedish classification results has also been taken into account.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
5 Pu 001	National	1.0	3.0	
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
4 Pu 010	National	1.0	3.0	
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
4 Pu 040	National	1.0	3.0	
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
4 Pu 050	National	1.0	3.0	
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		

Quark					
3 Mu 110	🟩 National	🟨 1.0	🟨 3.0		
	🟨 QE1	🟨 QE1	🟩 C1		
	QE2	🟦 QE2	🟨 C2		
	🟨 QE3	🟦 QE3	🟩 C3		
	🟩 QE4	🟩 QE4			
Archipelago & western GoF					
3 Lu 030	🟨 National	🟥 1.0	🟥 3.0		
	🟨 QE1	🟥 QE1	🟨 C1		
	🟧 QE2	🟥 QE2	🟥 C2		
	🟩 QE3	🟦 QE3	🟩 C3		
	🟨 QE4	🟨 QE4			
3 Lu 050	🟨 National	🟥 1.0	🟥 3.0		
	🟧 QE1	🟥 QE1	🟨 C1		
	🟧 QE2	🟥 QE2	🟥 C2		
	🟩 QE3	🟦 QE3	🟦 C3		
	🟨 QE4	🟨 QE4			
3 Lu 070	🟩 National	🟩 1.0	🟩 3.0		
	🟩 QE1	🟩 QE1	🟩 C1		
	QE2	QE2	🟩 C2		
	QE3	QE3	C3		
	🟩 QE4	🟩 QE4			
2 Lu 020	🟨 National	🟥 1.0	🟥 3.0		National vs HEAT 1.0: Large difference because of difference in EQR for parameters. National EQR ≠ Ref/status, which is how it is calculated in HEAT 1.0.
	🟧 QE1	🟥 QE1	🟨 C1		
	🟨 QE2	🟥 QE2	🟥 C2		
	🟨 QE3	🟦 QE3	🟩 C3		
	🟨 QE4	🟨 QE4			
LATVIA					
LAT001	National	🟥 1.0	🟥 3.0		No overall or sub-group specified status classification for the WFD was in the information sheet provided, and therefore the test only included the comparison between the HEAT tools that showed equal results. Each parameter is assessed as; Chl-bad, biovolume-moderate, DIN-bad, DIP-moderate and Secchi-moderate.
	QE1	🟥 QE1	🟥 C1		
	QE2	QE2	🟧 C2		
	QE3	QE3	C3		
	QE4	🟧 QE4			
POLAND					
Gdańsk Basin (SEA - 009)					
1. Vistula Lagoon (PL TW I WB 1)	National	🟨 1.0	🟧 3.0*	🟨 3.0**	The national overall WFD assessment was not given and the test therefore only includes the comparison between HEAT tools. The test in HEAT 3.0 included assessment with target* vs. assessment with RefCon and AcDev**. From the classification schemes provided: chl: M, Secchi:M.
	🟨 QE1	🟨 QE1	🟩 C1	🟩 C1	
	QE2	QE2	🟧 C2	🟨 C2	
	QE3	QE3	C3	C3	
	🟨 QE4	🟩 QE4			
2.Puck Lagoon (PL TW II WB 2)	National	🟥 1.0	🟥 3.0*	🟥 3.0**	For the HEAT 1.0 test max Acdev = 53% (76% reported) for Secchi. WFD; From the classification schemes provided: chl: B, Secchi:B.
	🟥 QE1	🟥 QE1	🟥 C1	🟥 C1	
	QE2	QE2	🟥 C2	🟧 C2	
	QE3	QE3	C3	C3	
	🟥 QE4	🟨 QE4			
3.internal Gulf of Gdańsk (PL TW IV WB 4)	National	🟧 1.0	🟧 3.0*	🟨 3.0**	WFD; From the classification schemes provided: chl: M, Secchi:G, DIN:H, DIP:H. Of the three water bodies two got one class
	🟨 QE1	🟨 QE1	🟦 C1	🟦 C1	
	QE2	QE2	🟧 C2	🟨 C2	

	QE3	QE3	C3	C3	lower when target was used and two were the same. There were no major different between HEAT 1.0 and HEAT 3.0 in this test.
	🟩 QE4	🟦 QE4			

SWEDEN				
A) Water type 7: Arkona - Hanö Bukt				
1 V.Hanöbuktens kustvatten	🟧 National	🟧 1.0	🟨 3.0	National poor status based on expert judgment such as reports from fishermen. BQI have a national AcDev=71% but this is changed to 53% in HEAT 1.0 because of the tool's limitations.
	🟩 QE1	🟩 QE1	🟨 C1	
	🟦 QE2	🟦 QE2	🟩 C2	
	🟨 QE3	🟨 QE3	🟨 C3	
	🟨 QE4	🟧 QE4		
3 Valjeviken	🟧 National	🟥 1.0	🟥 3.0	Expert judgment due to high uncertainties in satellite data for chlorophyll.
	🟥 QE1	🟥 QE1	C1	
	🟨 QE2	🟨 QE2	🟥 C2	
	🟨 QE3	🟨 QE3	🟧 C3	
	🟧 QE4	🟥 QE4		
4 Tostebergabukt.	🟧 National	🟨 1.0	🟨 3.0	National poor status based on expert judgment such as reports from fishermen.
	🟨 QE1	🟨 QE1	🟨 C1	
	🟩 QE2	🟩 QE2	🟨 C2	
	QE3	QE3	C3	
	🟨 QE4	🟧 QE4		
5 Landöbukten	🟧 National	🟨 1.0	🟨 3.0	National poor status based on expert judgment such as reports from fishermen.
	🟨 QE1	🟨 QE1	🟨 C1	
	🟩 QE2	🟨 QE2	🟨 C2	
	QE3	QE3	C3	
	🟨 QE4	🟧 QE4		
6 Sandhammaren-Simrishamn	🟨 National	🟧 1.0	🟨 3.0	
	🟩 QE1	🟩 QE1	🟨 C1	
	🟦 QE2	🟦 QE2	🟩 C2	
	🟨 QE3	QE3	C3	
	🟨 QE4	🟧 QE4		
7 Östra Sydkustens kustvatten	🟨 National	🟧 1.0	🟧 3.0	
	🟦 QE1	🟦 QE1	🟧 C1	
	🟨 QE2	QE2	🟩 C2	
	QE3	QE3	C3	
	🟨 QE4	🟧 QE4		
8 Västra sydkustens kustvatten	🟨 National	🟨 1.0	🟨 3.0	WFD status is moderate even if biological QE has status high. This is based on nutrients that have moderate status.
	🟦 QE1	🟩 QE1	🟩 C1	
	QE2	QE2	🟩 C2	
	QE3	QE3	C3	
	🟨 QE4	🟨 QE4		
9 Södra Öresunds kustvatten	🟨 National	🟧 1.0	🟨 3.0	WFD status is moderate even if biological QE has status good. This is based on nutrients that have moderate status since the biological QE are assessed from expert judgment.
	🟦 QE1	🟦 QE1	🟨 C1	
	🟩 QE2	🟩 QE2	🟩 C2	
	🟩 QE3	🟨 QE3	🟩 C3	
	🟨 QE4	🟧 QE4		
10 Höllviken	🟨 National	🟥 1.0	🟥 3.0	WFD status is moderate even if biological QE has status good. This is based on nutrients that have moderate status since the biological QE are assessed from very little data.
	QE1	QE1	C1	
	🟩 QE2	QE2	🟥 C2	
	🟩 QE3	🟨 QE3	🟩 C3	

	QE4	QE4		
B) Water type 23: Outer Bothnian Bay				
1 Knivskärsfj.	National	1.0	3.0	2013. EQR but no status value are found and therefore is status calculated from EQR (to use in HEAT). AcDev for Secchi set to 53% in HEAT 1.0 (56%). Biological QE are overruled by the supporting factors. This is because of few in situ data. Satellite and model data are used instead.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
2 Hamnskärsfj.	National	1.0	3.0	2013. EQR but no status value are found and therefore is status calculated from EQR (to use in HEAT). AcDev for Secchi set to 53% in HEAT 1.0 (56%). Expert judgment because of few in situ data. Satellite and model data are used instead.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
3 Enskärsfj.	National	1.0	3.0	2013. EQR but no status value are found and therefore is status calculated from EQR (to use in HEAT). AcDev for Secchi set to 53% in HEAT 1.0 (56%). Biological QE are overruled by the supporting factors. This is because of few in situ data. Satellite and model data are used instead.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
4 S Seskaröfj.	National	1.0	3.0	2013. EQR but no status value are found and therefore is status calculated from EQR (to use in HEAT). AcDev for Secchi set to 53% in HEAT 1.0 (56%). Biological QE are overruled by the supporting factors. This is because of few in situ data. Satellite and model data are used instead.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
5 Norrbotten	National	1.0	3.0	2013. . EQR but no status value are found and therefore is status calculated from EQR (to use in HEAT). AcDev for Secchi set to 53% in HEAT 1.0 (56%). Chlorophyll is based on satellite data and has high uncertainty.
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
6 M Bottenviken	National	1.0	3.0	2013. AcDev for Secchi set to 53% in HEAT 1.0 (56%). AcDev for biovolume set to 110% in HEAT 1.0 (163%).
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
8 S Bottenviken	National	1.0	3.0	2013. Status in HEAT is calculated from EQR. AcDev for Secchi depth set to 53% in HEAT 1.0 (56%).
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
C) Water type 4: Kattegat				
4 Onsala kustvatten	National	1.0	3.0	2013. Good status in HEAT 1 if not oxygen is included
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		
5 N m Hallands kustvatten	National	1.0	3.0	2013. Good status in HEAT 1 if not oxygen is included
	QE1	QE1	C1	
	QE2	QE2	C2	
	QE3	QE3	C3	
	QE4	QE4		

ANNEX B

Test sites from Sweden and information of class boundaries. National data used in the test is from VISS (http://www.viss.lansstyrelsen.se/) and SMHI.

Water Type 7

Skånes kustvatten

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Skala 1:647625

Table B1. Water type 7: Skånes kustvatten Arkona - Hanö Bukt. Class boundaries: EQR (WFD, HEAT1.0), EUT_ratios (HEAT3.0) with parameter values.
Nutrients have a salinity relationship and here is an example of salinity > 7 presented.

WFD Cat.	MSFD Crit.	Indicator	AcDev % Resp. +/-	National WFD					HEAT 1.0				HEAT 3.0			
				R	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
1	2	Chl-a (VI-VIII)	50 (+)	1	0,8	0,67	0,35	0,15	0,8	0,67	0,53	0,38	0,5	1,0	1,5	>2,0
		µgL^{-1}		1,2	1,5	1,8	3,4	8,0	1.5	1.8	2.26	3.15	0,9	1,8	2,7	>3,6
1	2	Biovolume (VI-VIII)	79 (+)	1	0,72	0,56	0,24	0,08	0,75	0,56	0,36	0,17	0,5	1,0	1,5	>2,0
		mm^{3}L^{-1}		0,18	0,25	0,32	0,74	2,26	0.24	0.32	0.5	1.05	0,16	0,32	0,48	>0,64
2	2	Macroveg.	40 (-)	1	0,80	0,60	0,40	0,21	0,78	0,6	0,43	0,25	0,5	1,0	1,5	>2,0
		index		5	4	3	2	1	3,9	3	2,15	1,25	6	3	2	<1,5
3	3	BQI	71 (-) *	1	0,76	0,29	0,19	0,10	0,71	0,47	0,23	0,01	0,5	1,0	1,5	>2,0
		index		14	10,7	4,06	2,7	1,3	9,94	6,58	3.22	0.14	8,12	4,06	2,71	<2,03
4	1	DIN (XII,I,II)	50 (+)	1	0,80	0,67	0,45	0,29	0,81	0,67	0,53	0,38	0,5	1,0	1,5	>2,0
		µmolL^{-1}		2,5	3,1	3,8	5,6	8,8	3,1	3,8	4,7	6,58	1,9	3,8	5,7	>7,6
4	1	DIP (XII,I,II)	52 (+)	1	0,81	0,66	0,45	0,29	0,80	0,66	0,51	0,37	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,25	0,31	0,38	0,56	0,88	0,31	0,38	0,49	0,68	0,19	0,38	0,57	>0,76
4	1	TN (XII,I,II)	19 (+)	1	0,91	0,84	0,67	0,50	0,90	0,84	0,79	0,73	0,5	1,0	1,5	>2,0
		µmolL^{-1}		17	19	20	26	34	19	20	21,52	23,29	8,5	20	25,5	>34
4	1	TP (XII,I,II)	45 (+)	1	0,82	0,69	0,47	0,31	0,82	0,69	0,56	0,43	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,5	0,61	0,72	1,05	1,6	0,61	0,72	0,89	1,16	0,36	0,72	1,08	>1,44
4	1	TN (VI-VIII)	30 (+)	1	0,86	0,77	0,55	0,38	0,86	0,77	0,68	0,59	0,5	1,0	1,5	>2,0
		µmolL^{-1}		15	17	19	27	39	17	19	22	25	7,5	19	22,5	>30
4	1	TP (VI-VIII)	35 (+)	1	0,85	0,74	0,53	0,36	0,85	0,74	0,64	0,53	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,3	0,35	0,41	0,56	0,83	0,35	0,41	0,47	0,56	0,21	0,41	0,62	>0,82
4	2	Secchi (VI-VIII)	30 (-)	1	0,83	0,70	0,40	0,20	0,83	0,7	0,58	0,45	0,5	1,0	1,5	>2,0
		m		10	8,3	7,0	4,0	2,0	8,3	7,0	5,8	4,5	14	7	4,7	<3,5
4	3	Oxygen		-	-	-	-	-	-	-	-	-	-	-	-	-
		mlL^{-1}		-	-	-	-	-	-	-	-	-	-	-	-	-

*Max AcDev in HEAT 1.0 for indicators with positive response is 110% and for negative response 53%.

Water Type 23

Outer Bothnian Bay

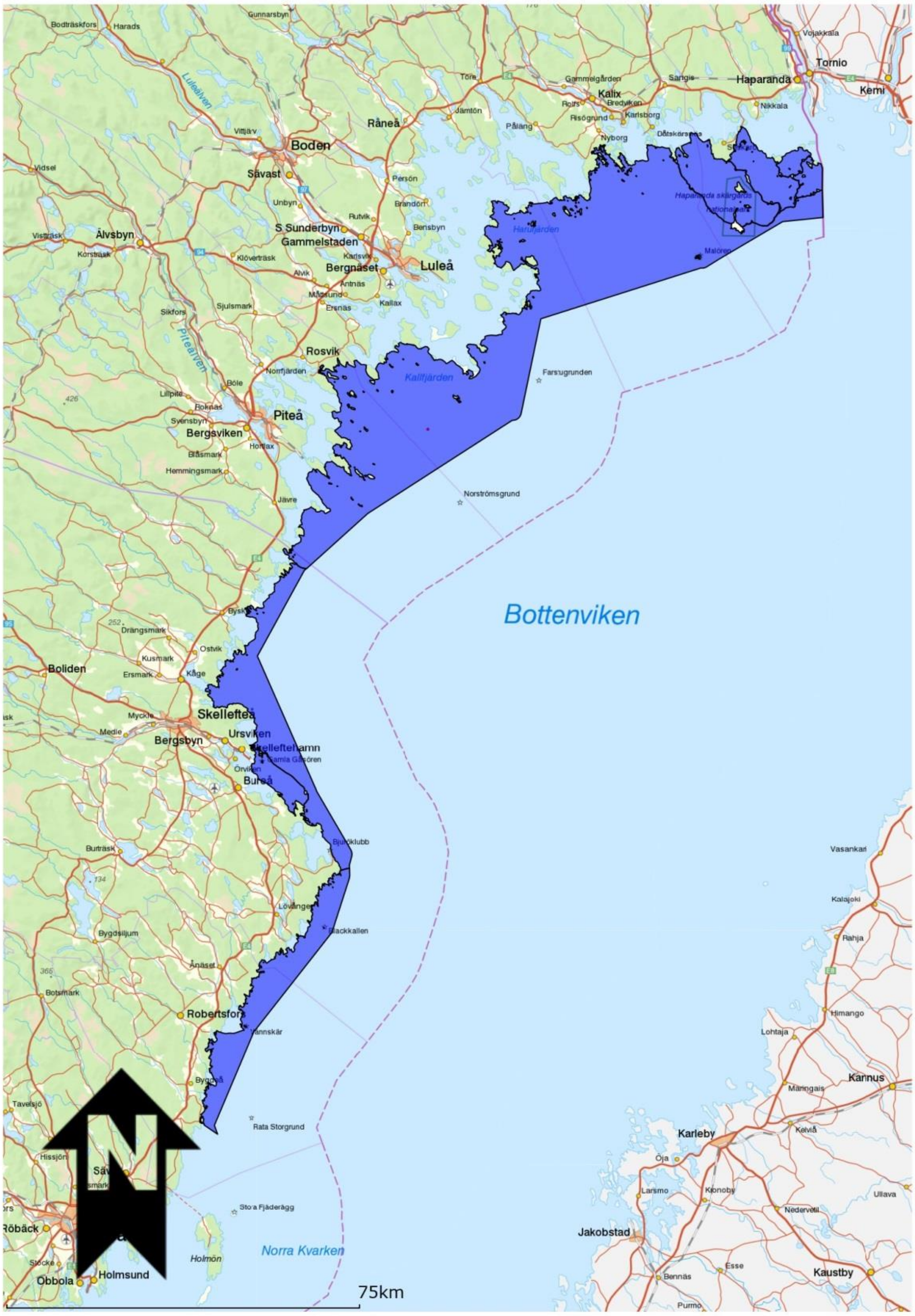

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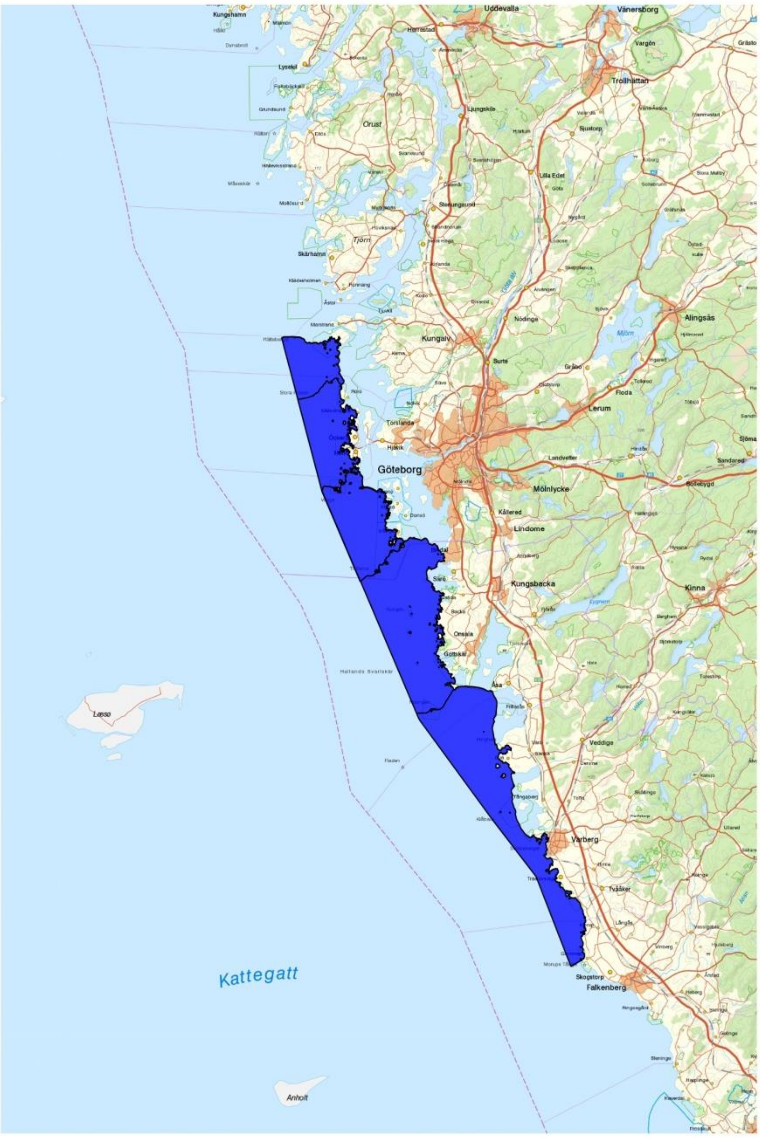
Table B2. Water type 23: Bothnian outer bay. Class boundaries: EQR (WFD, HEAT1.0), EUT_ratios (HEAT3.0) with parameter values. Nutrients have a salinity relationship and here is an example of salinity > 3 presented.

WFD Cat.	MSFD Crit.	Indicator	AcDev % Resp. +/-	National WFD					HEAT 1.0				HEAT 3.0			
				R	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
1	2	Chl-a (VI-VIII)	82 (+)	1	0,73	0,55	0,30	0,13	0,75	0,55	0,35	0,15	0,5	1,0	1,5	>2,0
		µgL^{-1}		1,1	1,5	2,0	3,7	8,7	1.5	2,0	3,14	7,33	1	2,0	3	>4
1	2	Biovolume (VI-VIII)	163 (+)*	1	0,56	0,38	0,2	0,07	0,71	0,48	0,24	0,01	0,5	1,0	1,5	>2,0
		mm^{3}L^{-1}		0,15	0,27	0,4	0,74	2,26	0.21	0.32	0.63	15	0,2	0,4	0,6	>0,8
2	2	Macroveg.	40 (-)	1	0,80	0,60	0,40	0,21	0,78	0,6	0,43	0,25	0,5	1,0	1,5	>2,0
		index		5	4	3	2	1	3,9	3	2,15	1,25	6	3	2	<1,5
3	3	BQI	86 (-) *	1	0,57	0,14	0,09	0,05	0,71	0,47	0,23	0,01	0,5	1,0	1,5	>2,0
		index		11	6,3	1,5	1,0	0,5	7,81	5,17	2,53	0.11	3	1,5	1	<0,75
4	1	DIN (XII,I,II)	50 (+)	1	0,8	0,67	0,44	0,29	0,81	0,67	0,53	0,38	0,5	1,0	1,5	>2,0
		µmolL^{-1}		5	6,3	7,5	11,3	17,5	6,2	7,5	9,4	13,2	3,75	7,5	11,25	>15
4	1	DIP (XII,I,II)	50 (+)	1	0,8	0,67	0,44	0,29	0,81	0,67	0,53	0,38	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,10	0,13	0,15	0,23	0,35	0,12	0,15	0,19	0,27	0,08	0,15	0,225	>0,3
4	1	TN (XII,I,II)	18 (+)	1	0,93	0,85	0,68	0,51	0,90	0,85	0,80	0,74	0,5	1,0	1,5	>2,0
		µmolL^{-1}		18	20	22	27	36	20	22	22,5	24,32	11	22	33	>44
4	1	TP (XII,I,II)	56 (+)	1	0,78	0,64	0,42	0,26	0,80	0,64	0,49	0,33	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,2	0,26	0,31	0,48	0,76	0,25	0,31	0,41	0,61	0,16	0,31	0,46	>0,62
4	1	TN (VI-VIII)	32 (+)	1	0,83	0,69	0,47	0,31	0,85	0,76	0,66	0,57	0,5	1,0	1,5	>2,0
		µmolL^{-1}		17	20	22	31	44	20	22,4	25,8	29,8	11,2	22,4	33,6	>44,8
4	1	TP (VI-VIII)	45 (+)	1	0,85	0,74	0,53	0,36	0,82	0,69	0,56	0,43	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,15	0,18	0,22	0,32	0,49	0,18	0,22	0,27	0,35	0,11	0,22	0,33	>0,44
4	2	Secchi (VI-VIII)	56 (-)*	1	0,67	0,44	0,29	0,20	0,71	0,47	0,23	0,01	0,5	1,0	1,5	>2,0
		m		7,5	5,0	3,3	2,2	1,5	5,3	3,5	1,72	0,075	6,6	3,3	2,2	<1,65
4	3	Oxygen		-	-	-	-	-	-	-	-	-	-	-	-	-
		mlL^{-1}		-	-	-	-	-	-	-	-	-	-	-	-	-

*Max AcDev in HEAT 1.0 for indicators with positive response is 110% and for negative response 53%. Maximum used in HEAT calculation

water type 4

kattegat



, RAÄ, SGU, Sjöfartsverket, SMHI, SVO, SCB, SJV, FM, Bergsstaten, SLU, DIRNAT Skala 1:1074174

Table B3. Water type 4: Kattegat. Class boundaries: EQR (WFD, HEAT1.0), EUT_ratios (HEAT3.0) with parameter values. Nutrients have a salinity relationship and here is an example of salinity > 20 presented.

WFD Cat.	MSFD Crit.	Indicator	AcDev % Resp. +/-	National WFD					HEAT 1.0				HEAT 3.0			
				R	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
1	2	Chl-a (VI-VIII)	50 (+)	1	0,83	0,67	0,33	0,17	0,81	0,67	0,53	0,38	0,5	1,0	1,5	>2,0
		µgL^{-1}		1	1,2	1,5	3,0	6,0	1,23	1,5	1,9	2,63	0,5	1,5	2,25	>3
1	2	Biovolume (VI-VIII)	122 (+)*	1	0,67	0,45	0,22	0,08	0,71	0,48	0,24	0,01	0,5	1,0	1,5	>2,0
		mm^{3}L^{-1}		0,5	0,75	1,1	2,25	6,1	0,7	1,04	2,08		0,55	1,1	1,65	>2,2
2	2	Macroveg.	40 (-)	1	0,80	0,60	0,40	0,21	0,78	0,6	0,43	0,25	0,5	1,0	1,5	>2,0
		index		5	4	3	2	1	3,9	3	2,15	1,25	6	3	2	<1,5
3	3	BQI	34 (-)	1	0,89	0,66	0,44	0,22	0,81	0,66	0,52	0,37	0,5	1,0	1,5	>2,0
		index		15,7	13,9	10,3	6,9	3,4	12,7	10,3	8,16	5,8	20,6	10,3	6,9	<5,2
4	1	DIN (XII,I,II)	50 (+)	1	0,8	0,67	0,44	0,29	0,81	0,67	0,53	0,38	0,5	1,0	1,5	>2,0
		µmolL^{-1}		4,5	5,6	6,8	10,1	15,8	5,6	6,8	8,5	11,8	3,4	6,8	10,3	>13,6
4	1	DIP (XII,I,II)	47 (+)	1	0,81	0,68	0,45	0,29	0,82	0,68	0,55	0,41	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,4	0,5	0,6	0,9	1,4	0,49	0,6	0,73	0,98	0,3	0,6	0,9	>1,2
4	1	TN (XII,I,II)	27 (+)	1	0,88	0,79	0,60	0,43	0,87	0,79	0,71	0,62	0,5	1,0	1,5	>2,0
		µmolL^{-1}		17	19	22	28	40	19,5	22	23,9	27,4	11	22	33	>44
4	1	TP (XII,I,II)	28 (+)	1	0,87	0,78	0,58	0,41	0,87	0,78	0,70	0,61	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,7	0,8	0,9	1,21	1,72	0,8	0,9	1	1,14	0,5	0,9	1,4	>1,8
4	1	TN (VI-VIII)	30 (+)	1	0,87	0,77	0,57	0,40	0,86	0,77	0,68	0,59	0,5	1,0	1,5	>2,0
		µmolL^{-1}		12	14	16	21	30	14	16	17,6	20,33	8	16	24	>32
4	1	TP (VI-VIII)	41 (+)	1	0,83	0,71	0,50	0,33	0,83	0,71	0,59	0,47	0,5	1,0	1,5	>2,0
		µmolL^{-1}		0,4	0,48	0,56	0,8	1,2	0,48	0,56	0,68	0,85	0,28	0,56	0,84	>1,12
4	2	Secchi (VI-VIII)	24 (-)	1	0,90	0,76	0,48	0,33	0,86	0,76	0,67	0,57	0,5	1,0	1,5	>2,0
		m		10,5	9,5	8,0	5,0	3,5	9	8	7	6,0	16	8	5,33	<4
4	3	Oxygen		-	-	-	-	-	-	-	-	-	-	-	-	-
		mlL^{-1}		-	-	-	-	-	-	-	-	-	-	-	-	-

*Max AcDev in HEAT 1.0 for indicators with positive response is 110% and for negative response 53%. Maximum used in HEAT calculation

Development of an oxygen consumption indicator

Karin Wesslander, Kari Eilola, Iréne Wåhlström

SMHI, Göteborg 2014-12-11

7 Background

This assignment is an attempt to develop an oxygen indicator for the HELCOM region, within the HELCOM project EUTRO-OPER. The indicator should be applicable in the HELCOM-region, there should be a link to eutrophication and it should be straight-forward to update annually. The previously, within the TARGREV-project, developed indicator for oxygen, the "Oxygen Debt-indicator", has some limitations in its application (HELCOM 2013). It is restricted to deep basins and an update of the indicator demand special resources such as specific programming and statistical skills.

The basic idea in this study is to estimate the oxygen consumption in the stagnant layer below the productive surface layer during summer (Fig. 1) and see if and how this can be linked to eutrophication.

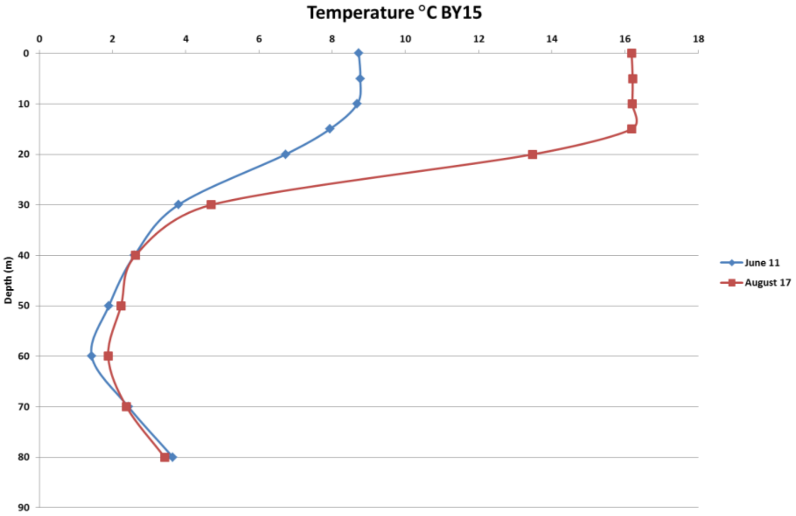


Fig. 1. Temperature in June and August (1986) in the central Baltic Proper at station By15.

7.1 Method

Oxygen budget for the summer season for horizontal water layer below the euphotic zone is calculated in accordance with Eilola (1998). The amount of organic matter broken down in the layer is directly related to the oxygen consumption (*CONS*) described as:

$$CONS_{(u,d)} = DEPL_{(u,d)} + DIFF_{(u,d)} + ADV_{(u,d)}$$

Here *DEPL* is the oxygen depletion in the horizontal water layer between the upper (u) and deeper (d) boundary. *DIFF* is the vertical diffusion and *ADV* is the advection of oxygen. Due to small temporal differences in salinity and temperature within the layer, advection is neglected in this attempt. Fig. 2 is an illustration of the different processes.

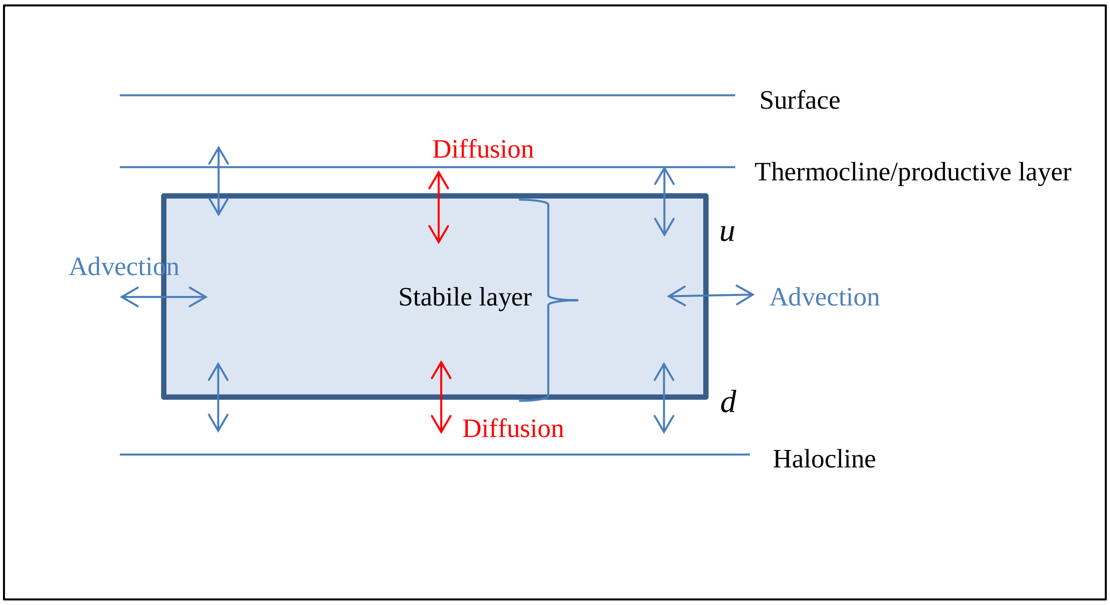


Fig. 2. Conceptual sketch of the different processes.

The oxygen depletion and diffusion are computed from observations as:

$$DEPL_{(u,d)} = -\int_{u}^{d} A(z)\frac{\partial O_2(z)}{\partial t}dz$$

$$DIFF_{(u,d)} = -A(u)\left(\kappa(u)\frac{\partial O_2(u)}{\partial z} - \frac{A(d)}{A(u)}\kappa(d)\frac{\partial O_2(d)}{\partial z}\right)$$

A(z) is the horizontal area at depth z and $\frac{\partial O_2(z)}{\partial t}$ is the rate of oxygen change with time. The term $\frac{\partial O_2(z)}{\partial z}$ is the vertical gradient of oxygen concentration and κ(z) is the vertical diffusivity coefficient at depth z calculated as:

$$\kappa_{(u,d)} = \frac{\alpha_{(u,d)}}{N_{(u,d)}}$$

where α is an empirical intensity factor accounting for the mean mixing activity of turbulence. N is the Brunt-Väisälä frequency defined as:

$$N^2_{(u,d)} = \frac{g}{\rho_0}\frac{\partial\rho(u,d)}{\partial z}$$

g is the acceleration of gravity and ρ_0 the reference density.

Calculations were performed in the free available R, a software programming language. Data used was observations reported to the HELCOM COMBINE database**.** The station Gotland deep (BY15) was selected for the calculations due to large amount of in-situ measurements.

7.2 Result and discussion

To calculate the oxygen consumption for the summer season, a stabile depth interval as well as the months with the largest decrease in the oxygen concentration were identified (Fig. 3). The stabile layer below the thermocline, but above the halocline was determined from comparing temperature and salinity from different depth interval and was established as the depth between 30-50 m. One may note the quite small changes in mean salinity (Fig. 3a) and temperature (Fig. 3b) in this depth interval. The temperature in the surface layer may, however, change by several degrees between June, July and August (e.g. Fig. 1) indicating that vertical transports are indeed very small below the thermocline. The relatively large spread between individual years, shown by the whiskers and boxes (Fig. 3a and 3b), indicates that there may also be years when the layer seem less stagnant. In Fig. 3c and 3d, the largest oxygen reduction as well as an increase in phosphate concentration indicates that the largest decomposition of organic matter would occur between June and July.

In Fig. 4, the results of the yearly mean oxygen consumption, depletion and diffusion between July and June is shown (left y-axis), together with the upper 10 m January-February mean of phosphate concentration in the station BY15 (right y-axis, grey dots). The ranges in the annual calculations have large variations for the consumption, depletion and diffusion, which imply that there are uncertainties in calculations performed from in-situ measurements. One reservation is that we have used the monthly mean when several observations exist and by this has the actual number of days between measurements not been taken into account in the calculation, which may influence the results.

An attempt to calculate the empirical intensity factor α of the vertical diffusion from in-situ measurements of salinity and temperature was performed. The computed values for the α-parameter were scattered with unrealistic numbers found in several years. This can be due to missing observations on the particular depths but also due to advective processes, which we have neglected, that affects the water mass and are difficult to estimate. Thus, a constant value for this parameter was chosen in the calculations (α=1.5 x 10^{-7} m^2 s^{-2}), which is a constant used in modern circulation models for the Baltic Proper (Meier, 2001; Gustafsson, 2003; Omstedt, 2011; Stigebrandt and Kalen, 2013).

However, despite the uncertainties a comparison of the oxygen consumption (*CONS*) with the upper 10 m mean phosphate winter concentration was made to investigate a possible link between increasing nutrient concentrations in wintertime with increasing oxygen consumption during summer. This test gave a small negative correlation coefficient (r~ -0.2) which would imply no significant link. The result is similar if the 10 m mean phosphate concentration is compared with oxygen consumption, depletion and diffusion for the whole Eastern Gotland Basin.

If we go a bit deeper in the analyses and divide the data set into two periods, 1990-1999 and 2000-2009, and calculate oxygen depletion between June and August we get different results. In Fig. 5 we see the two periods differ from each other. The mean oxygen depletion is larger in the second period that also has a positive mean phosphate production. The winter concentration of nutrients is also larger in this second period, though, none of the changes observed in Fig. 5 are statistically significant at the 95 % confidence level. This is of course a smoothed result since we are dealing with averages based on several years of data, but it still implies that it has to be more clear how to aggregate the data from observations.

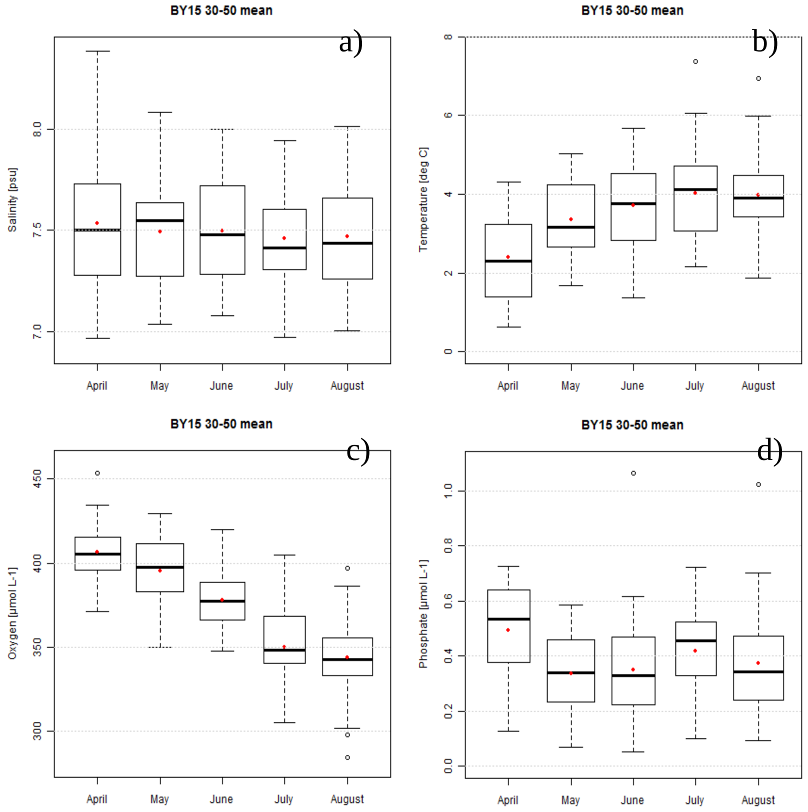


Fig. 3. Boxplots of a) salinity, b) temperature, c) oxygen concentration and d) phosphate concentration for 30-50 m at the Gotland deep for April-August. The box's lower and upper limits are the first and third quartiles respectively, the thick horizontal line is the median, the red dot is the mean, black open circle outliers and the whiskers represent min and max without outliers.

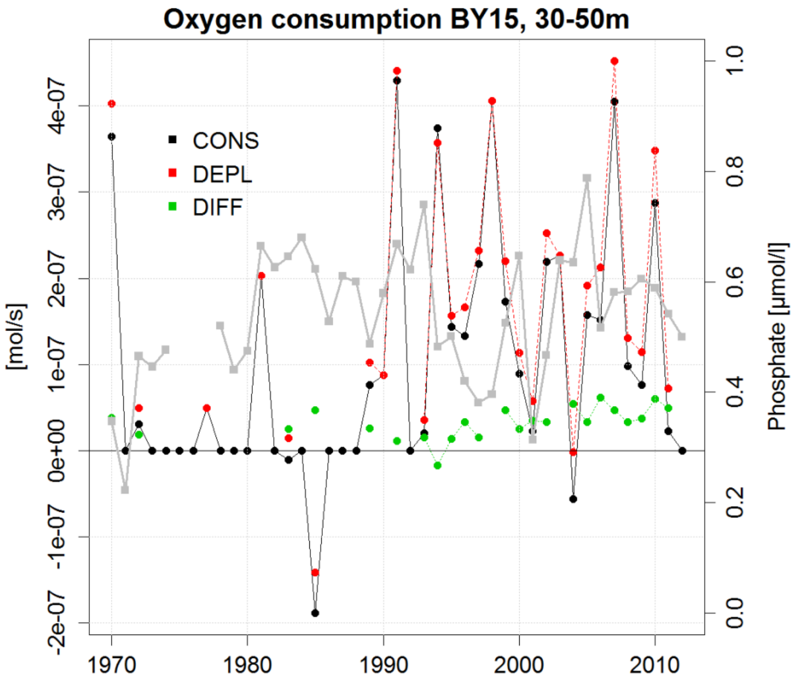


Fig. 4. The June-July consumption (black dots), depletion (red dots) and diffusion (green dots) for oxygen in BY15 between 30-50 m depth. The right y-axis is the upper 10 m mean phosphate concentration (grey dots) in BY15 during winter (January-February).

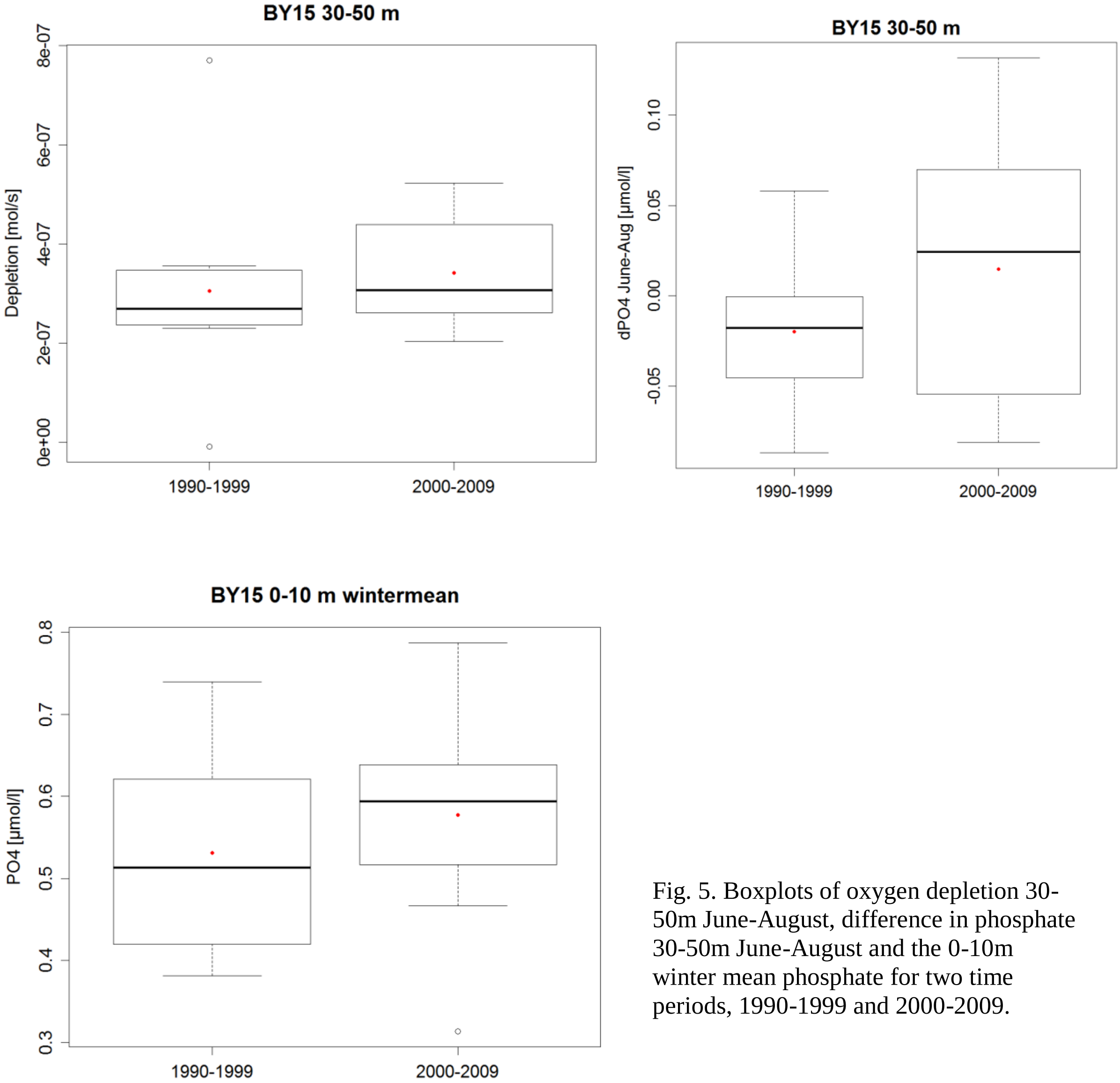


Fig. 5. Boxplots of oxygen depletion 30-50m June-August, difference in phosphate 30-50m June-August and the 0-10m winter mean phosphate for two time periods, 1990-1999 and 2000-2009.

When the oxygen depletion between June and August is compared with winter values of phosphate concentration, the correlation is positive even though the correlation is still small (Fig. 5 and 6). To understand fully the result that certain congeniality arises with winter phosphate if oxygen consumption between June-August is used instead of June-July, i.e. a longer time period is adopted during summer, require further investigations that are out of reach for the present study. This might indicate that the temporal development of the oxygen consumption diverges between years and one explanation arises from different conditions for algal blooms. The June-August distribution of calculated oxygen change is still large (R^2=0.21) but that is also the case for the phosphate winter values (R^2=0.28). Notice a negative value for the oxygen depletion (< -100%) implying an oxygen production. A probable explanation for this negative value is an effect from adjacent water masses that has influenced the oxygen concentration through the transport and mixing of the water masses. One may also mention that the first available observations in June and in August, respectively, were used for the compilation in Fig. 6. The number of days for which oxygen depletion was computed varied fairly randomly between 48 and 81 days between the years (there was no trend in the number of days during the period).

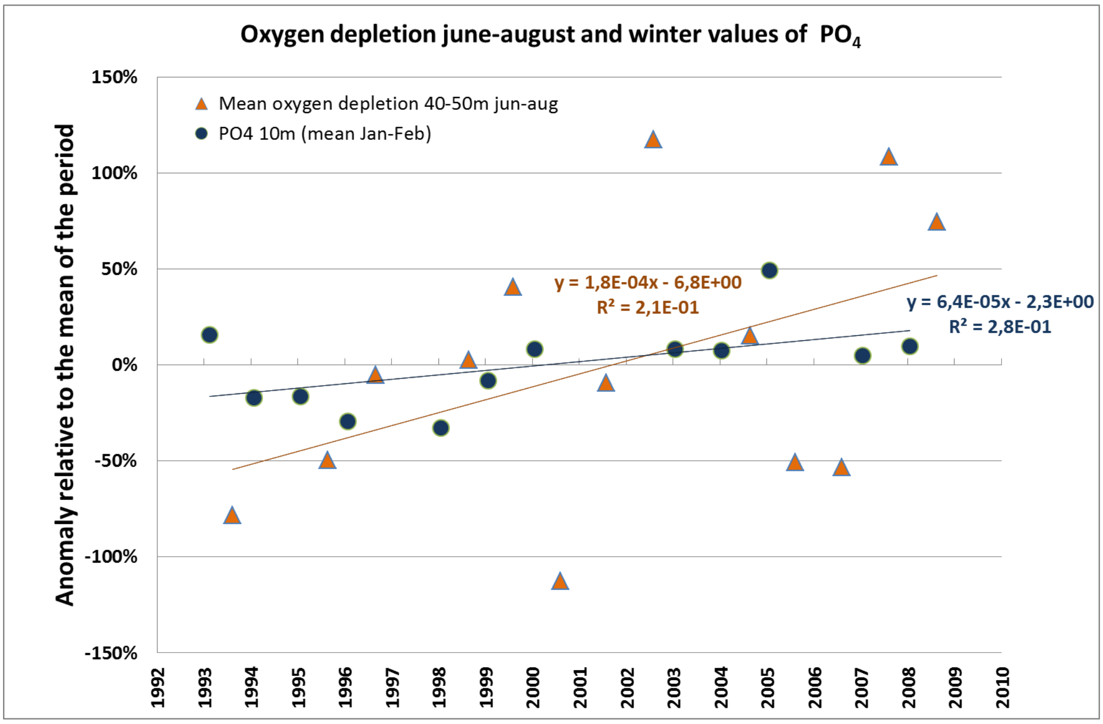


Fig. 6. Calculated anomalies in percent (%) relative the periods mean of oxygen change between observations in June and August (triangle) for years with data at 40 to 50 m depth during 1993-2009. The values are integrated over a 20 m depth interval and areas of 1m^2.The calculations here also consider the number of days between measurements. Note, positive depletion corresponds to a decrease in oxygen consumption from June to August. Circles show the mean winter phosphate concentration (January-February) at 10 m depth. Linear regression lines for the two datasets and its equations and regression coefficient (R^2) are drawn in the same color next to the line. Data is from the SHARK-database at SMHI.

To finalize the study we also investigated if a possible candidate to use as a more simple oxygen depletion indicator could be the use of oxygen saturation at 50 meter depth at BY 15. If we assume that the temperature has not changed much since the establishment of stratification (see Fig.1) we may expect that changes in oxygen saturation observed in August at this depth would be caused by the biological oxygen consumption occurring during late spring and summer. In Fig. 7 we show the mean 50 meter depth oxygen saturation at BY15 in August and the winter concentration of PO4 in the preceding winter. The results are fairly similar to Fig. 6 but the correlations coefficient of oxygen depletion (i.e. the R^2 of oxygen saturation) is slightly improved in this case.

To get a rough estimate of the correlation between the mean changes of winter phosphate and oxygen depletion we calculate some numbers for comparison. The increase in mean PO_4 between the periods was 0.17 mmol PO_4 m^{-3} which would cause a potential increase of export production of 3.43 mmol m^{-2} (=20m x0.17 mmol P m^{-3}) if we assume that the production takes place in the upper 20 m. The export of this matter would require increased oxygen consumption below 20 m depth of about 3.43x138=473 mmolO_2 m^{-2} if we assume complete oxidation of typical Redfield plankton with O_2:P ratio of 138.

The corresponding change in mean oxygen saturation between the two periods was -2.527% which corresponds to about -10.15 mmol O_2 m^{-3} when we use the initial concentration of 401 mmol O_2 m^{-3}. Hence, if we assume that the change in oxygen consumption is similar in the layer 20m-60m, the increased oxygen consumption between 20m and 60m depth becomes 406 mmol O_2 m^{-2} (=40m x 10.15 mmol O_2 m^{-3}) which would indicate that a large fraction of the increased production (473 mmolO_2 m^{-2}) may cause an increased organic matter decomposition above the halocline during summer. There is of course an uncertainty in this estimate because of the assumptions of the amount of exported matter, the Redfield ratio and other factors caused by the large variability in observations. The results indicate, however, that there may be some correlation between the increased winter DIP and oxygen consumption at 50 m depth.

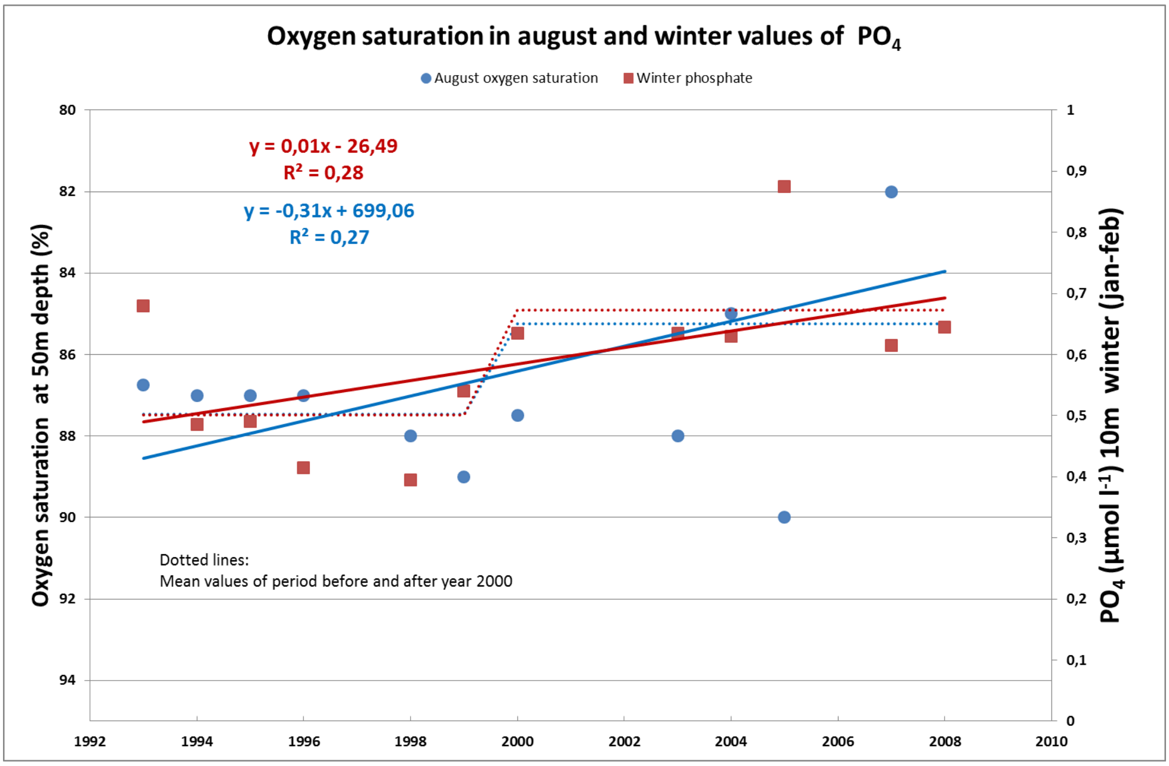


Fig. 7. Mean 50 m depth oxygen saturation (%) at BY15 in August (left axes), and the winter (Jan-Feb) mean phosphate concentration at 10 m depth (right axes) from years with simultaneous measurements. The dashed lines show mean values for the years before 2000 and the years from 2000 and forward. The average oxygen concentration at 50 meter depth in April was 9 ml O_2 l^{-1} (= 401 mmol O_2 m^{-3}) and the mean oxygen saturation was 100% (SHARK data). Linear regression lines for the two datasets and its equations and regression coefficient (R^2) are drawn in the same color next to the line. Data is from the SHARK-database at SMHI.

7.3 Conclusions

A possible continuation of this study of the oxygen consumption as an indicator for eutrophication is to calculate different time periods as well as include a model to identify and quantify the effect of diffusion and advection and by that try to understand the annual spreading of the calculations. Another necessity is to identify representative stagnant layers in other parts of the Baltic Sea in addition the Gotland Deep. The layers are plausibly different due to stratification conditions as well as if the region is affected of, for instance, inflows and/or other water mass transports with different properties. The model can also be used to try to investigate which link to envisage between, for example, winter dissolved inorganic phosphorus and oxygen consumption below the thermocline. The correlations among these two indicators might not be 100 % due to biological effects, such as different onset of the spring bloom, the sinking rates and decomposition capacity, which influence the inter annual magnitude of oxygen consumption.

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8 SMHI Publications

SMHI publish seven report series. Three of these, the R-series, are intended for international readers and are in most cases written in English. For the others the Swedish language is used.

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