Baltic Marine Environment Protection Commission

Making the HELCOM eutrophication assessment operational (EUTRO-OPER)
Gdynia, Poland, 9-11 February 2015

EUTRO-OPER 4-2015

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Code	5-1
Category	CMNT
Agenda Item	5 – Further development of HELCOM eutrophication assessment methodology
Submission date	23.1.2015
Submitted by	Sweden
Reference	EUTRO-OPER 1-2014

Background

EUTRO-OPER 1-2014 agreed that the project will contribute to expanding the existing core set of eutrophication indicators, through developing new indicators on total nutrients (N and P), nutrient ratios, spring bloom intensity (measured through chlorophyll-*a*), cyanobacterial bloom accumulations and oxygen consumption. The time-table for developing these indicators was agreed to be fitted together with the indicator development schedule under CORESET II, in order for them to be considered in the HOLAS II process. In order for this to be possible, the new eutrophication indicators shall be finalized by the end of March 2015 (during work phase 3).

Sweden agreed to take lead of the testing and development of the oxygen consumption indicator.

This document contributes to subtask 3b.i in the EUTRO-OPER road map (document 6-1).

Action required

The Meeting is requested to comment the work presented by Sweden, and agree on the next steps in developing the oxygen consumption indicator.

Development of an oxygen consumption indicator

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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.

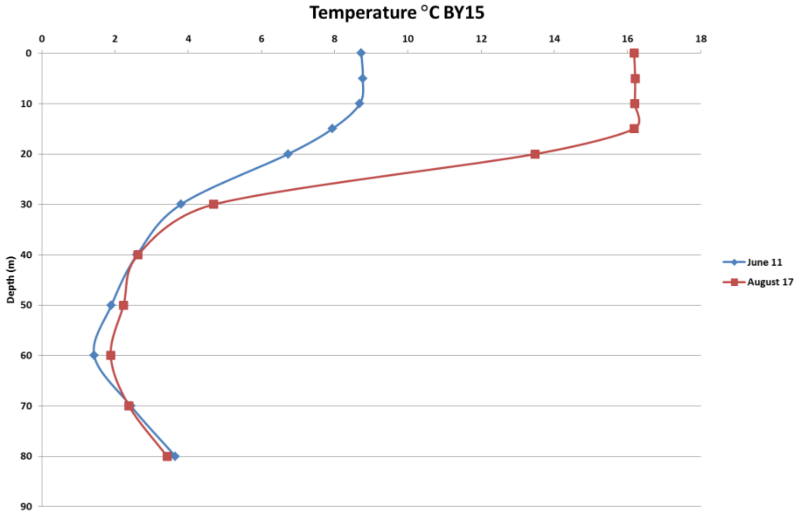

Fig. 1. Temperature in June and August (1986) in the central Baltic Proper at station By15.

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.

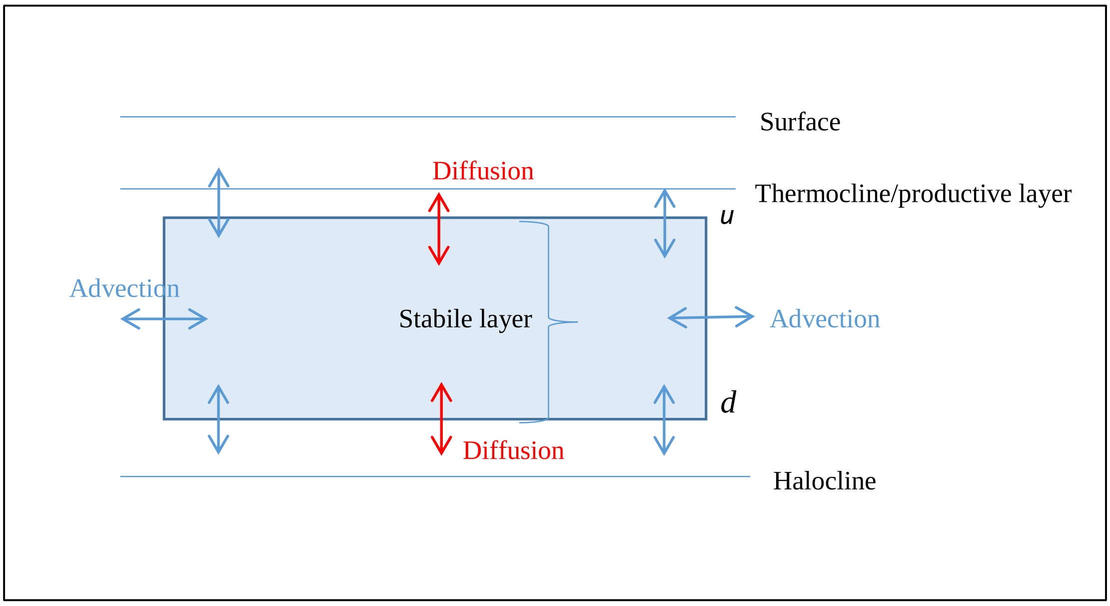

Fig. 2. Conceptual sketch of the different processes.

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:

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

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.

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.

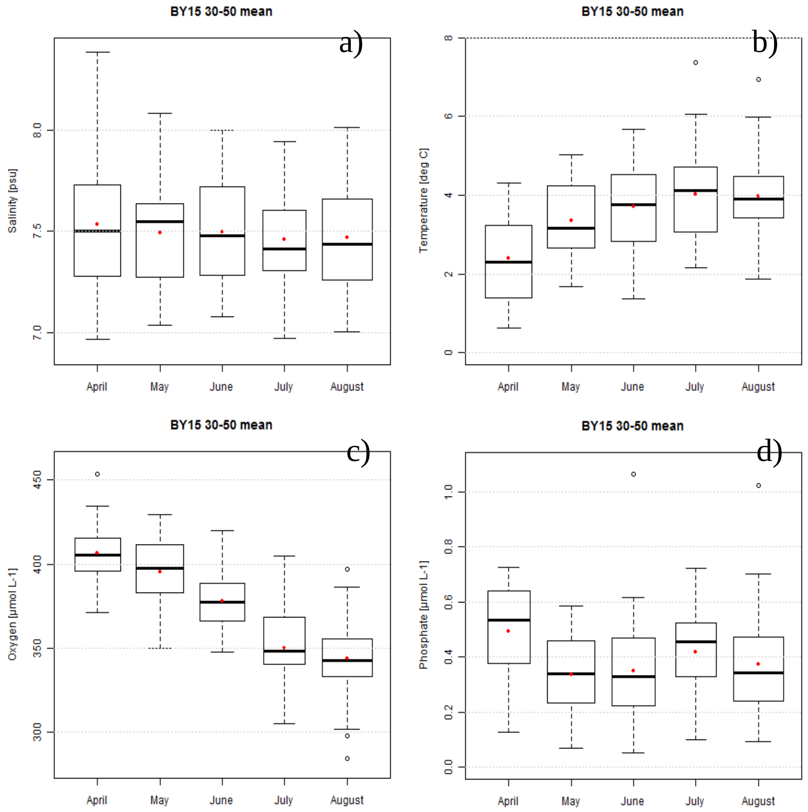

Fig. 3. Boxplots of a) salinity, b) temperature, c) oxygen concentration and d) phosphate concentration for 30-50 m at the Gotland deep for April-August. The box's lower and upper limits are the first and third quartiles respectively, the thick horizontal line is the median, the red dot is the mean,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

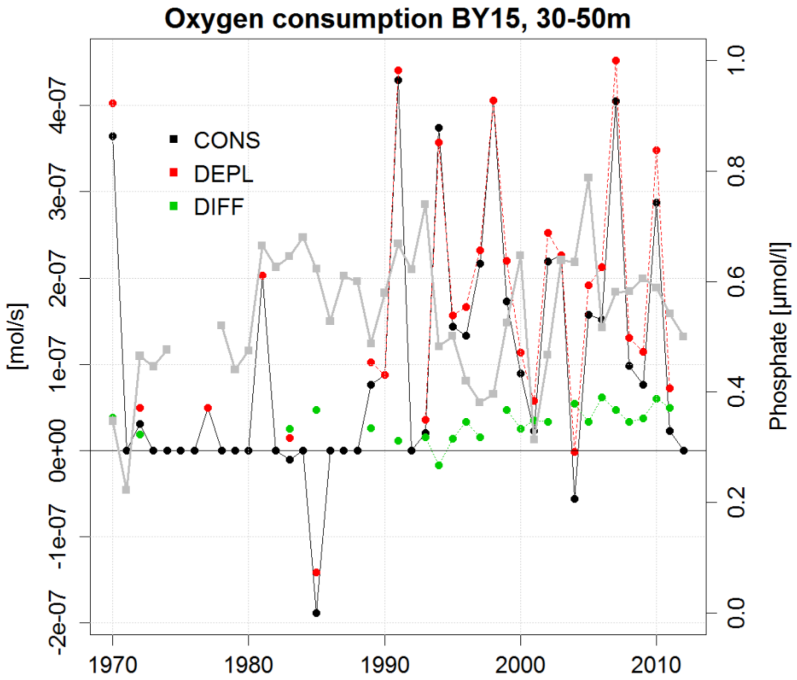

Fig. 4. The June-July consumption (black dots), depletion (red dots) and diffusion (green dots) for oxygen in BY15 between 30-50 m depth. The right y-axis is the upper 10 m mean phosphate concentration (grey dots) in BY15 during winter (January-February).

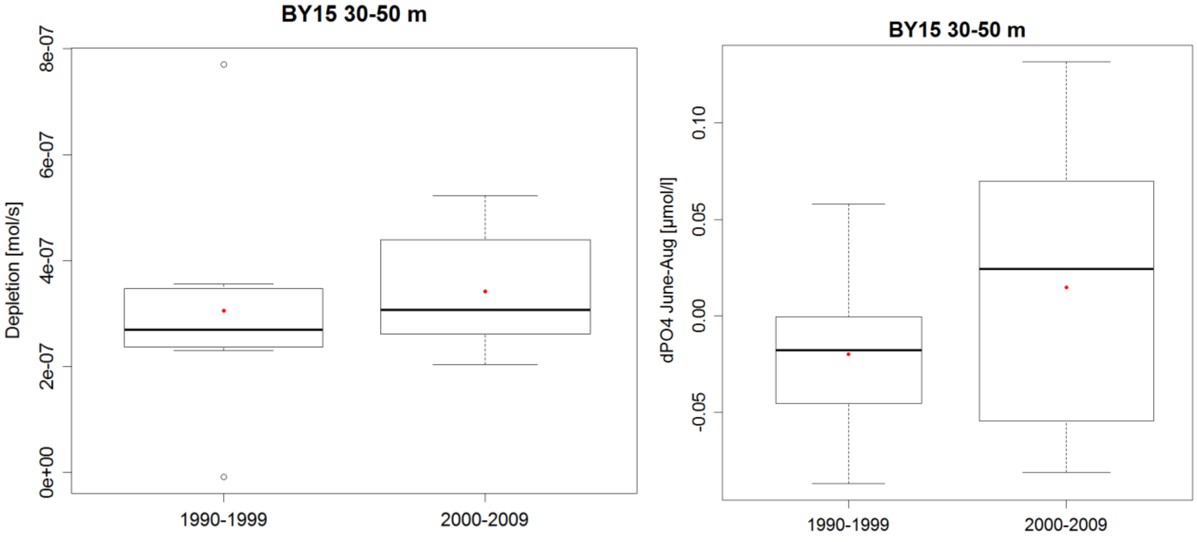

Fig. 5. Boxplots of oxygen depletion 30-50m June-August, difference in phosphate 30-50m June-August and the 0-10m winter mean phosphate for two time periods, 1990-1999 and 2000-2009.

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).

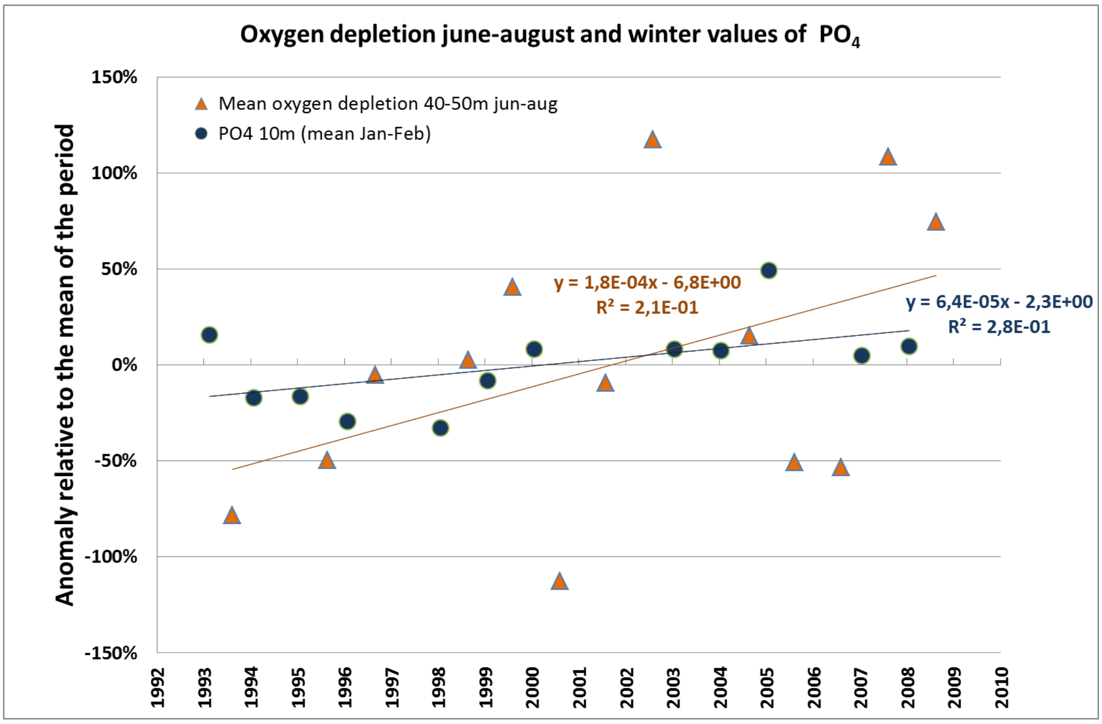

Fig. 6. Calculated anomalies in percent (%) relative the periods mean of oxygen change between observations in June and August (triangle) for years with data at 40 to 50 m depth during 1993-2009. The values are integrated over a 20 m depth interval and areas of 1m^2.The calculations here also consider 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.

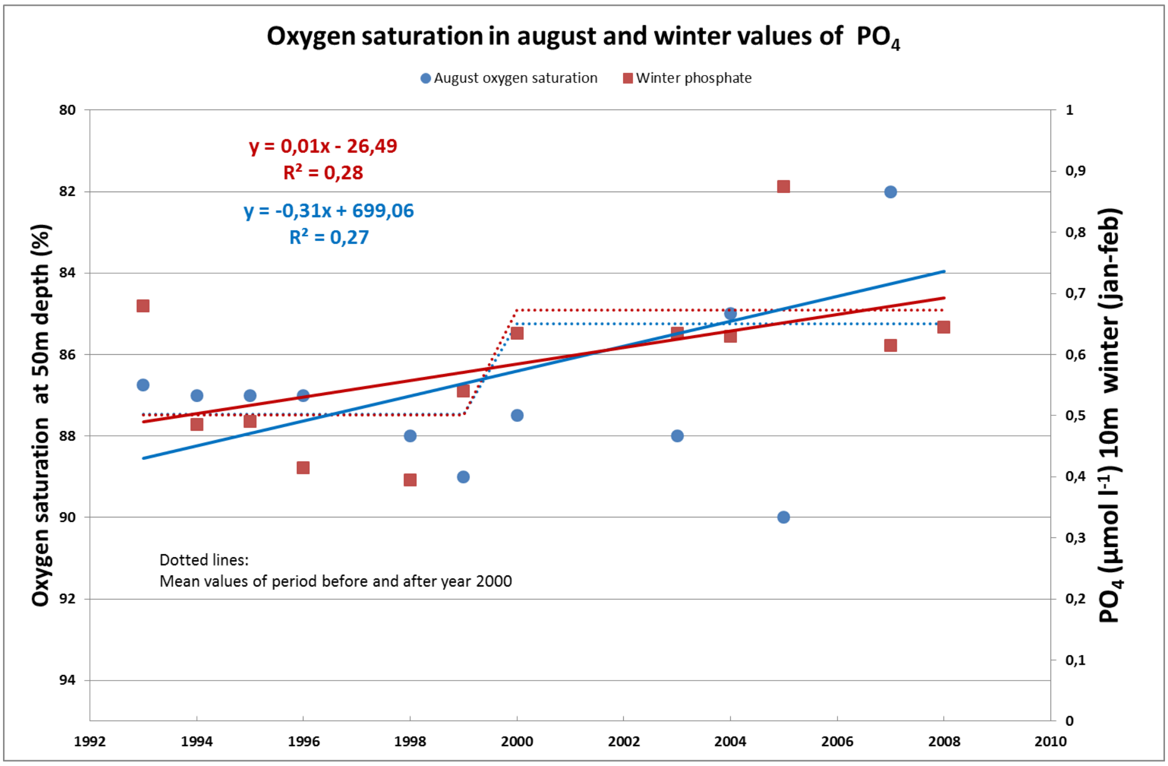

Fig. 7. Mean 50 m depth oxygen saturation (%) at BY15 in August (left axes), and the winter (Jan-Feb) mean phosphate concentration at 10 m depth (right axes) from years with simultaneous measurements. The dashed lines show mean values for the years before 2000 and the years from 2000 and forward. The 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.

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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