BACTERIOPLANKTON GROWTH

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Key Message

Bacterioplankton growth rate is an indicator of the decomposition of organic matter and thereby trophic status of the Sea. The metabolism of bacterioplankton accounts for about half of the mineralization of organic matter and thereby pelagic oxygen consumption.

The bacterioplankton growth rate in deep waters indicates good trophic status in the off-shore Bothnian Bay and Bothnian Sea. Deep water growth rates were 67 % higher than at corresponding depths in the Atlantic Ocean, lacking excess enrichment. The decline that has earlier been reported has now ceased. During the last few years, the tendency is increased growth rates in both basins, but there is no significant long-term trends in either of them.

Results and Assessment

Relevance of the indicator for describing developments of the environment

Bacterioplankton growth rate is an indicator of the trophic status in aquatic environments. The growth requires a consumption and oxidation of organic carbon, which is a large part of the biochemical oxygen demand in situ. Bacterioplankton growth rate thereby indicates the rate of oxygen consumption that may lead to oxygen deficiency in the water column, when exceeding oxygen supply. The bacterial growth rate indicator is applicable in all aquatic environments.

Bacterioplankton growth rate is a relatively unambiguous indicator of the flux of organic matter in the pelagic ecosystem (Billen, et al. 1990). Even if the relationship between the factors specific growth rate and abundance may vary, their product representing biomass production reflects the substrate requirement of the bacterial community. Density limitation (i.e. competition) or temperature does therefore not directly appear to control the bacterial community biomass production. This agrees with empirical observations that bacterial growth rate over larger scales correlate with the trophic status of an ecosystem (Cole, et al. 1988, Billen, et al. 1990) , and at smaller scales the trophic status of water layers and seasons (Wikner and Hagström 1999).

Results

The bacterial growth in the Bothnian Bay and Bothnian Sea deep water (40-100m) show no significant trends for the period 1994-2018 (Table 1).

The bacterioplankton growth was on average 74 nmol C dm^{-3} day^{-1} in the Bothnian Bay, while being 12 % higher in the Bothnian Sea (ANOVA, total df=1056, p=0.010). The higher value in the Bothnian Sea was in accordance with the higher trophic status of this basin. This difference was still low considering that the level of phytoplankton production is two times higher in the Bothnian Sea. The relatively high bacterial growth in the Bothnian Bay is explained by the higher load per volume of organic matter from rivers (Sandberg et al. 2004).

The ability of bacterial community growth to measure changes in trophic status was shown by the seasonally recurrent variation in the deep water by a factor of 3 (data not shown). Highest values occurred during the summer months when also the highest sedimentation is expected.

The bacterioplankton growth in the Bothnian Sea corresponded to a bacterial oxygen consumption of 2.1 µmol O_2 dm^{-3} day^{-1}, assuming a bacterial growth efficiency relationship according to del Giorgio and Cole (del Giorgio and Cole 1998). The oxygen consumption can be presented relative the average oxygen concentrations of 379 and 237 µmol dm^{-3}, respectively, for the Bothnian Bay and Bothnian Sea (mean values in deep water 2014-2018). Assuming bacterioplankton to account for half of the total respiration (Robinson and le B Williams 2005), average daily oxygen consumption would then correspond to 1.0 and 1.8 % day^{-1}, respectively.

Assessment

The bacterioplankton growth rate in the deep water of the Bothnian Bay and Bothnian Sea was at a level assessed as representing good conditions. This indicates that the export of organic matter by sedimentation to the deep water occur within allowable limits. This quality factor does therefore not support that these basins are disturbed by eutrophication.

The status classification is based on that the level of bacterioplankton growth found is comparable to rates at similar depth of oceanic water (Dufour and Torreton 1996). Another way to compare this is by absolute rates of total oxygen consumption calculated from the bacterial growth (assuming 50 % due to bacterial growth). The level in the Gulf of Bothnia was 67 % higher than the mean oxygen consumption measured at the same depth interval in the ocean (Robinson and le B Williams 2005). Higher productivity, and thereby oxygen consumption, is expected in coastal waters compared to oceanic, so it´s not obvious that the higher rates in the Gulf of Bothnia are above allowable limits.

The lack of significant decrease of oxygen levels in the Bothnian Bay since the beginning of the 1970´s, corroborate that oxygen supply to the deep water has been and remained sufficient to account for total respiration. This supports that the deep water bacterial growth is within allowable limits. Decline in oxygen concentration has, however, been observed in the Bothnian Sea during the past 40 years, making the classification for this basin more difficult. It seems unlikely that the only 12% higher bacterial growth rate in the Bothnian Sea than Bay alone could explain the observed oxygen decline. Instead, temperature increase and import of oxygen deficient water from the Baltic Proper explain the decline in oxygen concentration in the Bothnian Sea (Ahlgren et al 2017).

A management consequence of the low rates observed is that it will be extraordinarily difficult to reduce them further by nutrient reductions. This would also require a questionable aim to achieve an oxygen consumption level similar to those found in the Atlantic Ocean at corresponding depth.

Metadata

Data description

Values

The bacterioplankton growth estimates are based on uptake of the nucleotide thymidine into the DNA (i.e. chromosome) of the bacteria. The original method is published in international scientific journals and has been used in many marine research studies since the beginning of the 1980´s. The method has been part of the Helsinki commission guidelines for a longer period of time (Helcom COMBINE manual part C, Annex C-11).

Values were averaged for the depths sampled within the water layer chosen (median n=4). Typically, values are based on 8-20 samplings distributed over the year. Data is collected by the Swedish national marine monitoring program, funded by the Swedish Agency for Marine and Water Management and the Swedish Environmental Protection Agency. Figure 1 show sampled stations.

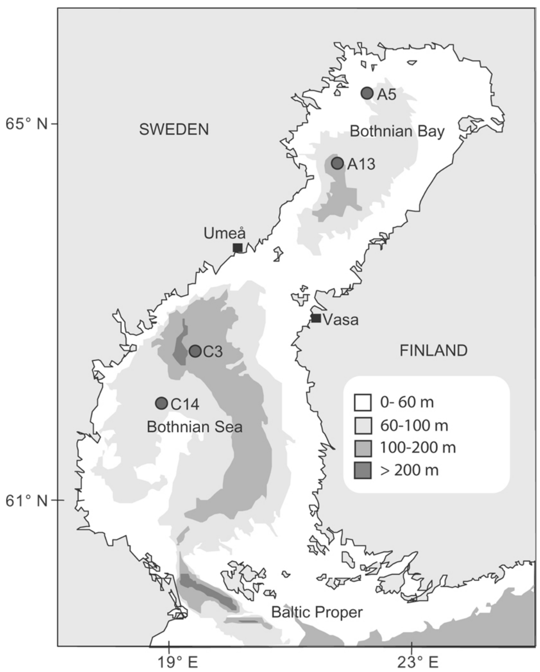

Figure 1. Sampling stations for pelagic indicators in the Gulf of Bothnia.

Statistics

Linear interpolation replaced missing values and data was averaged to yield monthly time series, as required for the seasonal decomposition. About 20% of the values in the analyzed time series were interpolated. The average seasonal variation was removed from the time series by a multiplicative model and endpoints weighted by 0.5 in the software SPSS® v.25.

The seasonally decomposed time series were typically serially autocorrelated by one lag and therefore analyzed for trends by first order autoregression (SPSS®). It uses a least-square technique where errors follow a first order autoregression.

A non-parametric test for analysis for trends were also performed using Multitest (Department of Computer and Information Science, Linköping University), an Excel-based software for Mann Kendall tests for monotonic trends (Helsel, 2005). No significant time trends were found (data not shown).

To show the general trends in the time series a negative exponential smoother was applied. This is a local smoothing technique using polynomial regression and weighted values computed from the Gaussian density function (SigmaPlot v. 25®).

The statistical power of the time series was estimated from the standard deviation of the autoregression (Root Mean Square Error), the non-centrality parameter and the non-central t-distribution. As a guidance to assess significant changes, a difference of 25 % in 2 years can be detected with 80 % probability.

The difference between the Bothnian Bay and Bothnian Sea was determined from marginal means in an ANOVA on bacterial growth data, where area and year were fixed factors, and month a co-variate.

Figures

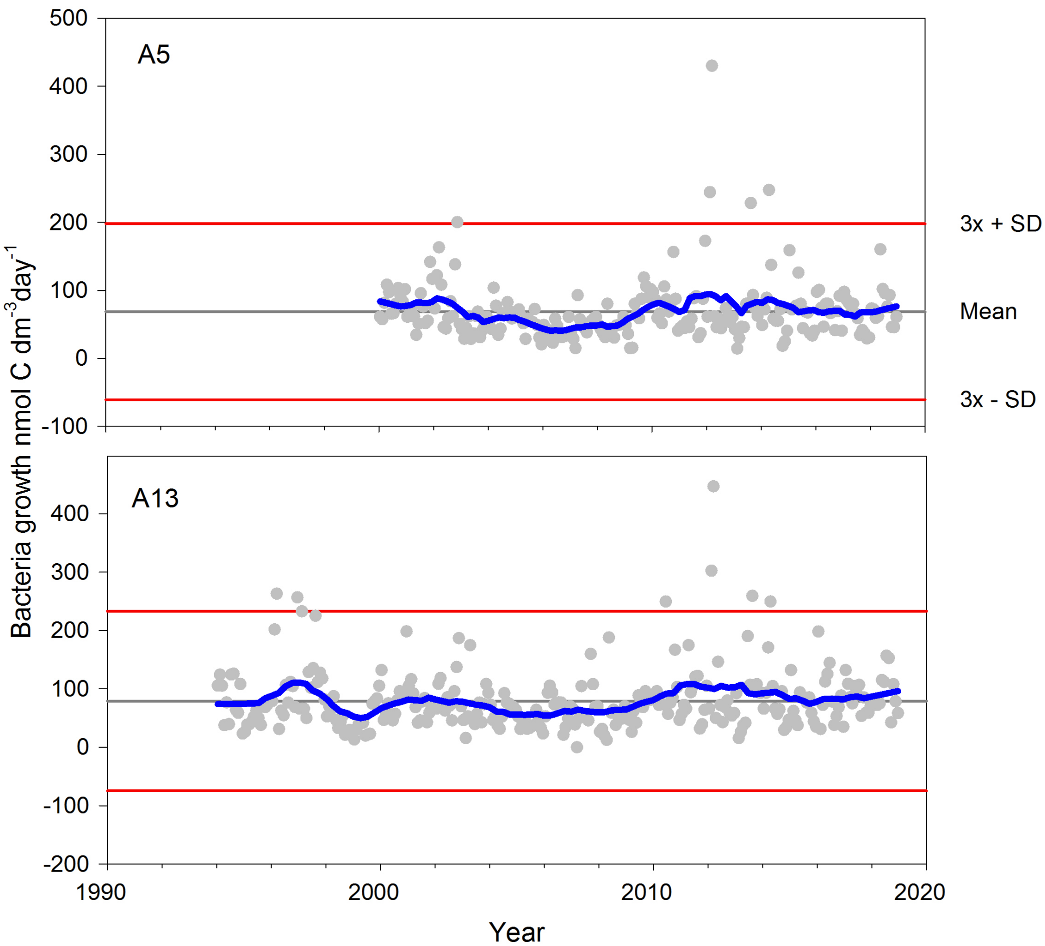

Figure 2. The bacterioplankton growth rate at stations A5 and A13 below the stratified layer (40-100m) in the Bothnian Bay show no significant trend since 1994. A negative exponential smoother is shown (in blue) together with seasonally adjusted data (in grey). The 3 x SD lines represent the upper and lower 99% confidence limits of the smoothed time series, suggested as action limits for the quality factor. Year ticks are located at the 1st of January each year.

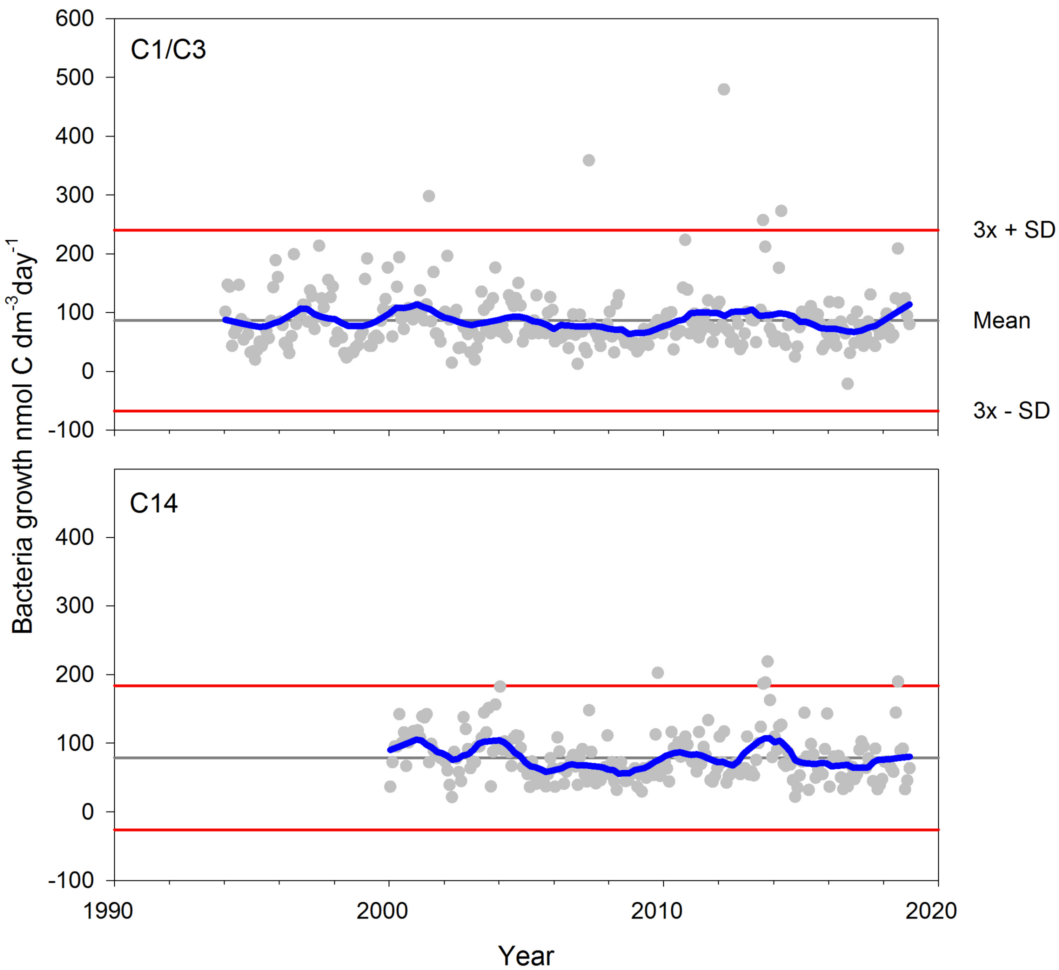

Figure 3. The bacterioplankton growth rate at stations C14 and C1/C3 below the stratified layer (40-100m) in the Bothnian Sea show no significant trend since 1994. Lines defined as in Figure 2.

Tables

Table 1. Bacterial community growth below the pycnocline level show no significant trends in the Bothnian Bay nor the Bothnian Sea for the periods investigated. The 95 % confidence interval (C. I.) of the trend is shown. The significance (α) shows the risk to be wrong if stating that there is a trend, which should be below 0.05 for a statistical significant statement. The series mean of bacterial growth rate is shown.

Sea area	Station	Period	Trend	±95%CI	α	Years	Bacterial growth rate
			(% $year^{-1}$)	(% $year^{-1}$)	(-)		(nmol dm^{-3} day^{-1})
Bothnian Bay	A5	2000-2018	0.6	2.3	0.592	19	69
Bothnian Bay	A13	2000-2018	2.6	3.4	0.138	19	80
Bothnian Sea	C1/C3	2000-2018	-0.9	3.0	0.562	19	87
Bothnian Sea	C14	2000-2018	-1.0	1.7	0.250	19	79
Bothnian Bay	A13	1994-2018	1.2	2.3	0.309	25	79
Bothnian Sea	C1/C3	1994-2018	-0.2	1.2	0.711	25	86

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