Document title	Progress in developing Cyanobacterial bloom indicator
Code	5-7
Category	CMNT
Agenda Item	5 – Further development of HELCOM eutrophication assessment methodology
Submission date	6.2.2015
Submitted by	Finland
Reference	EUTRO-OPER 4-2015

Background

One of the tasks of EUTRO-OPER was to complement the core set of indicators through developing new indicators. EUTRO-OPER 1-2015 agreed to develop an indicator on cyanobacterial bloom accumulations. The first version of the indicator was developed in MARMONI-project. Work done under EUTRO-OPER will examine the applicability of the indicator to HELCOM assessment areas.

Action required

The Meeting is invited to note the development of the indicator and discuss the work.

FRONT PAGE

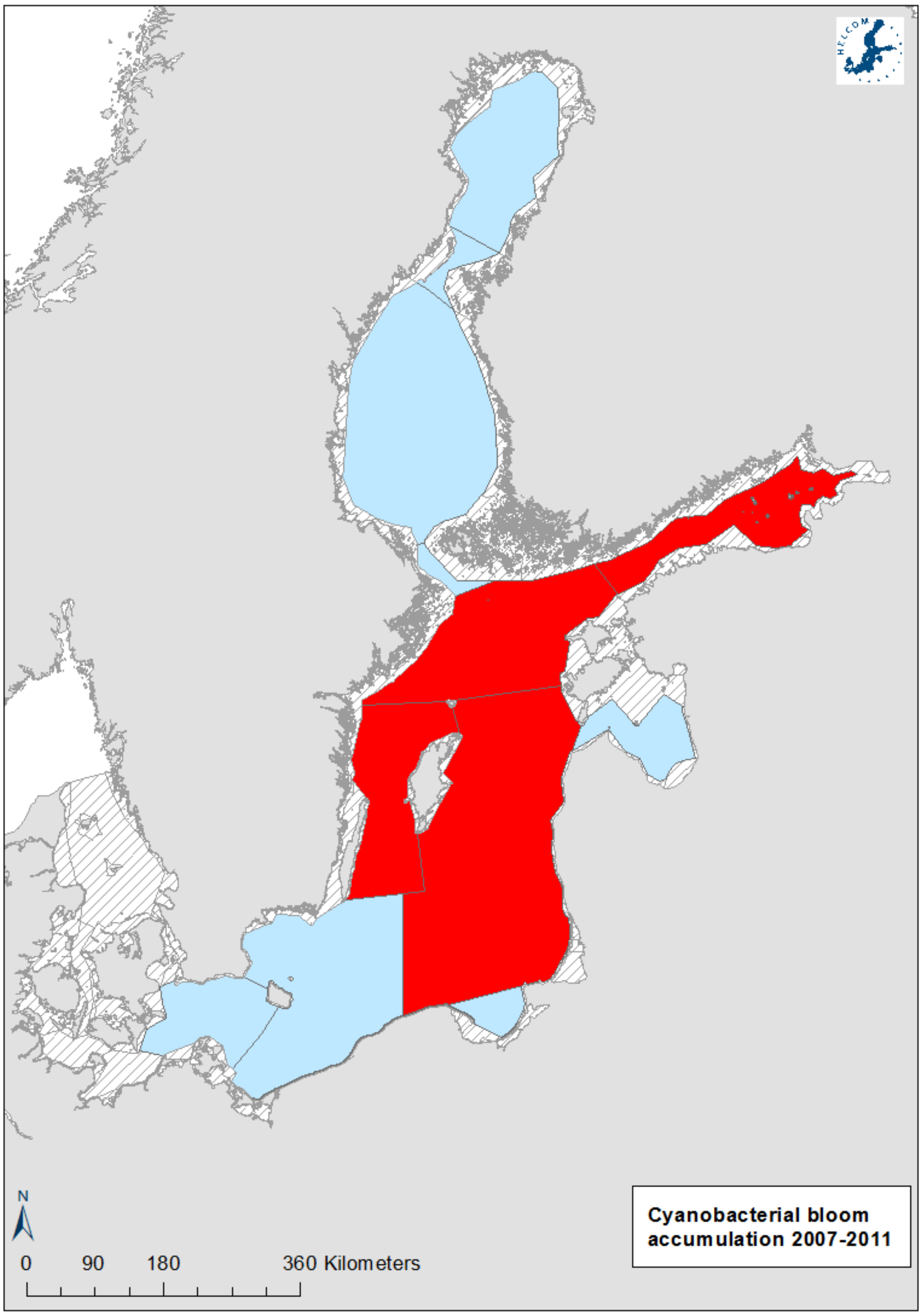


Figure: *Status of cyanobacterial bloom accumulation during 2007-2011. Blue = area in good environmental status, red = area not in good environmental status, light blue = indicator applicable (under progress) and striped = indicator not applicable.*

Key message

GES was not reached in any of the sub-basins used in the indicator development, namely in the Gulf of Finland, Northern Baltic Proper, Eastern Gotland Basin and Western Gotland Basin. The sub-basins causing greatest concern regarding status of 2007-2011 were the Gulf of Finland status while the status on the Northern Baltic Proper, Eastern Gotland Basin and Western Gotland Basin were 10-14% below GES. The data sets used in the status estimation starts from year 2002, thus trends for the indicator cannot be assessed reliably for the time period of 2007-2011.

The confidence of the status estimate was high for all sub-basins covered (ES score 100). The target confidence was moderate (ET-Score 50). Thus, the final confidence ratio (FCR) for the indicator was 75 (high).

Relevance of indicator

The indicator describes the symptoms of eutrophication in the sea areas caused by nutrient enrichment. Especially phosphorus load in a dominantly nitrogen-limited environment is considered the main anthropogenic pressure affecting the indicator. Human populations as well as anthropogenic activities such as agriculture and industry contribute the majority of nutrient input to the Baltic Sea. Eutrophication is driven by a surplus of the nutrients nitrogen and phosphorus in the sea. Nutrient over-enrichment causes elevated levels of algal and plant growth, increased turbidity, oxygen depletion, changes in species composition and nuisance blooms of algae (HELCOM, 2013). The indicator reflects also changes in the phytoplankton community. These are related to the changes in nutrient composition and climate, and have direct impact on sea-use and ecosystem service. Extensive cyanobacterial blooms have a potentially negative impact on the biodiversity of marine ecosystems as well as on its socio-economic value.

Policy relevance of the core indicator

	Primary importance	Secondary importance
BSAP segment and objective	Eutrophication: natural level of algal blooms	Biodiversity: thriving and balanced communities of plants and animals
MSFD descriptor and criteria	5.2	1.6

Authors

Saku Anttila[*,1], Vivi Fleming-Lehtinen[2], Jenni Attila[1], Sofia Junttila[1] and Heidi Hällfors[1]

1) Finnish Environment Institute (SYKE), P O Box 140, FI-00251, Helsinki, Finland.

2) Baltic Marine Environment Protection Commission

*Corresponding author, email address saku.anttila@ymparisto.fi

Refer to this indicator

[to be filled later]

INDICATOR CONCEPT

Policy relevance

Eutrophication is one of the four thematic segments of the HELCOM Baltic Sea Action Plan (BSAP) with the strategic goal of having a Baltic Sea unaffected by eutrophication (HELCOM 2007). Eutrophication is defined in the BSAP as a condition in an aquatic ecosystem where high nutrient concentrations stimulate the growth of algae which leads to imbalanced functioning of the system. The goal for eutrophication is broken down into five ecological objectives, of which one is "natural levels of algal blooms".

The EU Marine Strategy Framework Directive (Anonymous 2008) requires that "human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters" (Descriptor 5).

Role of indicator in the ecosystem

Surface blooms of nitrogen-fixing cyanobacteria, though considered to be a natural phenomenon (Bianchi et al. 2000), have become extensive and frequent in many parts of the Baltic Sea since the 1990's (Finni et al. 2001). The blooms consist partly of the toxic species Nodularia spumigena, which has been reported to have negative effects on grazing zooplankton (Engström et al. 2000, Sellner et al. 1994, Sopanen et al. 2009). Cyanobacteria have been shown to have allelopathic effects on other phytoplankton groups and increasing effects on bacteria (Suikkanen et al. 2004, 2005). Since a major part of the cyanobacteria biomass generated during the bloom events eventually is settled on the bottom, it potentially increases oxygen depletion in stratified areas (Vahtera et al. 2007a). Thus extensive cyanobacterial blooms potentially have a negative impact on the biodiversity of both the pelagic and the benthic communities.

Good environmental status

The target values for the assessment areas were derived by using independent satellite based time series on algae accumulations from the Baltic Sea by Kahru and Elmgren (2014). This data set covers years 1979-2014. The periods with highest status in the target value data set were identified and transformed to CSA values by using a linear model defined between these two. GES is reached, when the current status is higher than the identified target. Results presented here include Gulf of Finland (GoF), Northern Baltic Proper (NBP), Eastern Gotland Basin (EGB) and Western Gotland Basin (WGB), but its geographical relevance is Baltic Sea wide. The indicator may be extended to cover all the Baltic open sea and outer coastal assessment units; its GES boundaries are set region-specifically.

HELCOM_ID	**Basin**	**Target (μg l–1)**
SEA-001	Kattegat	No suitable data currently available/gathered
SEA-002	Great Belt	No suitable data currently available/gathered
SEA-003	The Sound	No suitable data currently available/gathered
SEA-004	Kiel Bay	No suitable data currently available/gathered
SEA-005	Bay of Mecklenburg	No suitable data currently available/gathered
SEA-006	Arkona Sea	Under progress
SEA-007	Bornholm Sea	Under progress
SEA-008	Eastern Gotland Basin	0.87

SEA-009	Gdansk Basin	Under progress
SEA-010	Western Gotland Basin	0.84
SEA-011	Gulf of Riga	Under progress
SEA-012	Northern Baltic Proper	0.77
SEA-013	Gulf of Finland	0.96
SEA-014	Åland Sea	Under progress
SEA-015	Bothnian Sea	Under progress
SEA-016	The Quark	Under progress
SEA-017	Bothnian Bay	Under progress

Anthropogenic pressures linked to the indicator

The increase cyanobacteria surface accumulations is dependent on nutrient concentrations, and thus linked strongly to anthropogenic nutrient loads from land and air.

Assessment protocol

- Algae barometer value for each assessment area was used to describe the daily surface algae situation observed with satellite data. The algae barometer value is a weighted sum of the proportion of algae observations in different classes in an assessment area (Rapala et al. 2012).

- The indicator combines the annual information from the bloom characteristics, namely the duration, intensity and severity of algal accumulations, into a Cyanobacterial Surface Accumulation –index (CSA-index). Bloom characteristics are estimated by using Empirical Cumulative Distribution Functions (ECDF) derived from seasonal time series of algae barometer values

- Area specific targets were first identified from the Fraction of Cyanobacteria Accumulations –data (FCA) by Kahru & Elmgren (2014) and then transformed into CSA-index by using a linear model between these two data sets. A break point detection method by in Rodionov (2004) and Rodionov & Overland (2005) were used to detect periods in time series with the highest FCA-values.

- For the status, CSAs of years 2007-2011 were calculated. GES is reached when the status exceeds the target.

The assessments of the open sea areas were based on an integration of state data from core set indicators. The indicators were grouped under the following three "criteria" as described in the Commission Decision (2010/477/EU): 1. Nutrient levels, 2. Direct Effects, 3. Indirect Effects.

The cyanobacterial surface accumulations -indicator is listed under Criteria 2 (direct effects), along with summer chlorophyll-*a* concentration, summer water transparency and spring bloom intensity.

RESULTS

GES was not reached in any of the sub-basins covered. The sub-basins causing greatest concern regarding status of 2007-2011 were the Gulf of Finland status while the status on the Northern Baltic Proper, Eastern Gotland Basin and Western Gotland Basin were 10-14% below GES.

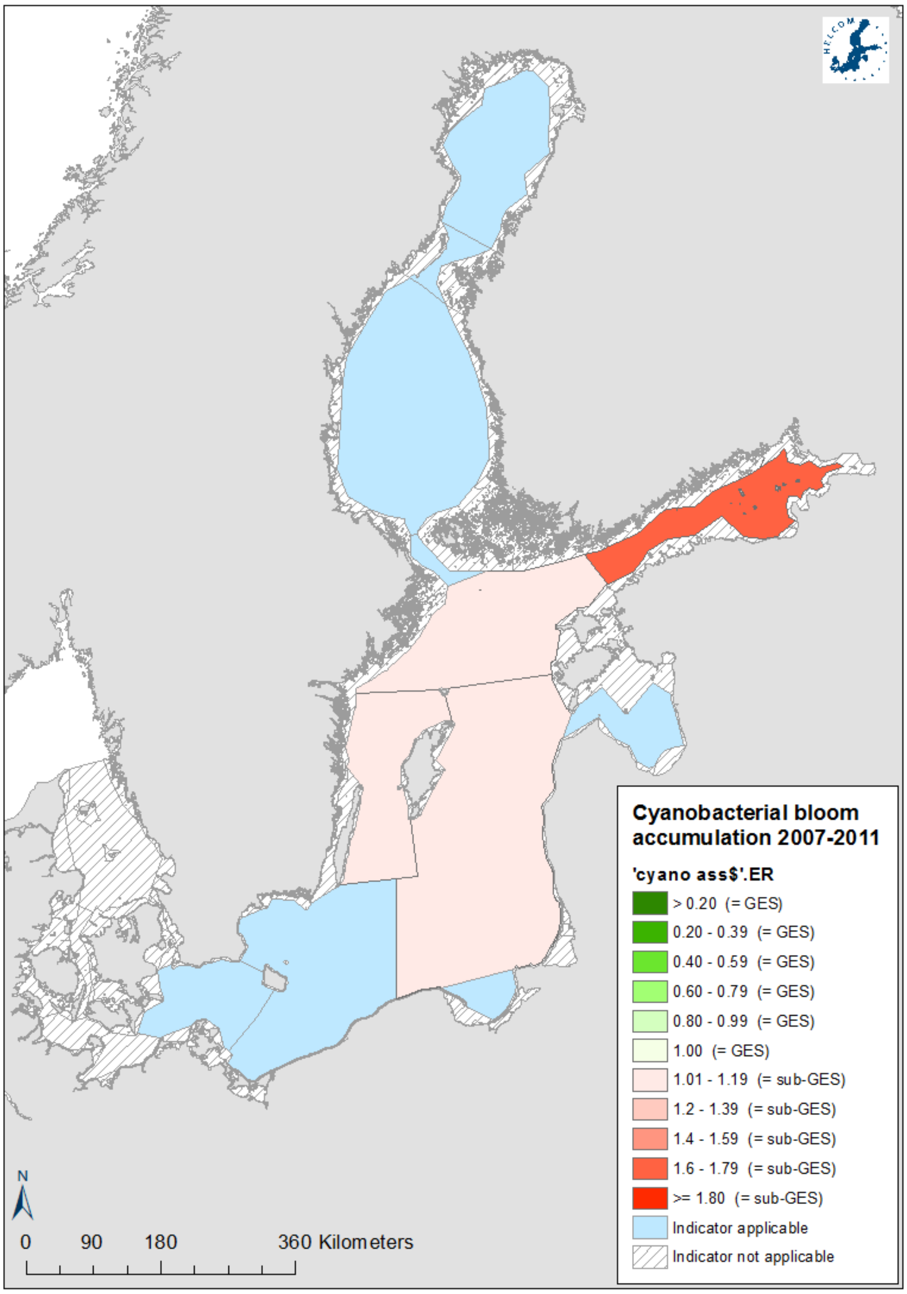


Figure: *Status of the CSA -indicator, presented as eutrophication ratio (ER). ER shows the present concentration in relation to the GES boundary, increasing along with increasing eutrophication. The GES-boundary has been reached when ER ≤ 1.00.*

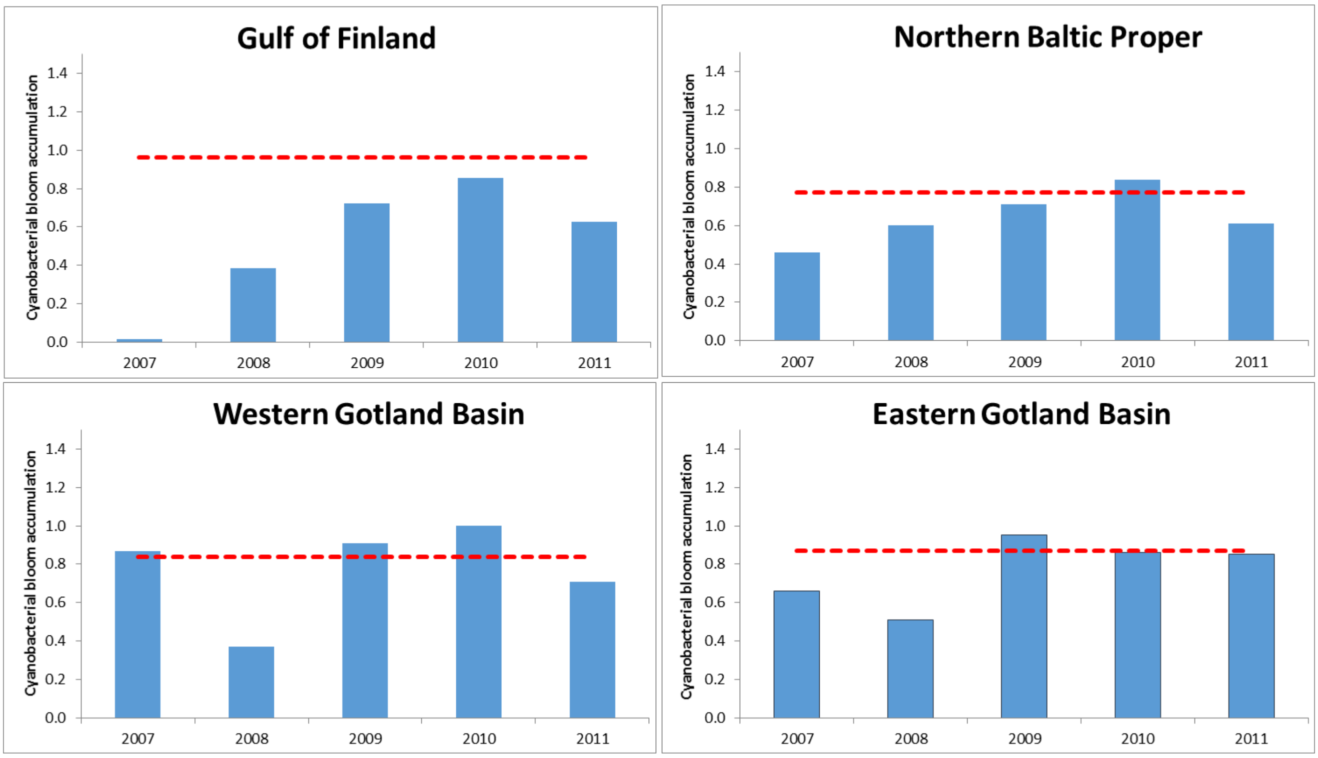


Figure: *Cyanobacterial bloom accumulation within years (blue column) and GES-boundary (or GES-target) as agreed by HELCOM HOD 39/2012 (red broken line).*

Table: *GES targets, present concentration (as average 2007-2011), eutrophication ratio (ER) and status based on the CSA index presented for the four open sea basins covered in the indicator development phase. ER is a quantitative value for the level of eutrophication, calculated as the ratio between the GES target and the present concentration – when ER > 1, GES has not been reached.*

Sub-basin	**Target (µg l^{-1})**	**Average 2007-2011 (µg l^{-1})**	**Eutrophication ratio, ER**	**STATUS**
Kattegat	No suitable data currently available/gathered	-	-	-
Great Belt	No suitable data currently available/gathered	-	-	-
The Sound	No suitable data currently available/gathered	-	-	-
Kiel Bay	No suitable data currently available/gathered	-	-	-
Bay of Mecklenburg	No suitable data currently available/gathered	-	-	-

Arkona Basin	Under progress	Under progress	Under progress	Under progress
Bornholm Basin	Under progress	Under progress	Under progress	Under progress
Eastern Gotland Basin	0.87	0.770	1.13	sub-GES
Gdansk Basin	Under progress	Under progress	Under progress	Under progress
Western Gotland Basin	0.84	0.753	1.12	sub-GES
Northern Baltic Proper	0.77	0.656	1.17	sub-GES
Gulf of Riga	Under progress	Under progress	Under progress	Under progress
Gulf of Finland	0.96	0.558	1.65	sub-GES
Aland Sea	Under progress	Under progress	Under progress	Under progress
Bothnian Sea	Under progress	Under progress	Under progress	Under progress
The Quark	Under progress	Under progress	Under progress	Under progress
Bothnian Bay	Under progress	Under progress	Under progress	Under progress

Long-term development

The longest satellite based time series on algae accumulations from the Baltic Sea is presented by Kahru and Elmgren (2014). For the assessment areas studied, the general trend in sub-basins is decreasing for Northern Baltic Proper and Western Gotland Basin. For the Gulf of Finland and Eastern Gotland basin the recent years show slightly better statuses than during time period of 1998-2010. However, observations before 1996 show in average higher status years following. The mean Fraction of Cyanobacteria Accumulations estimates are presented in the Fig. 12 of Kahru & Elmgren.

MONITORING REQUIREMENTS

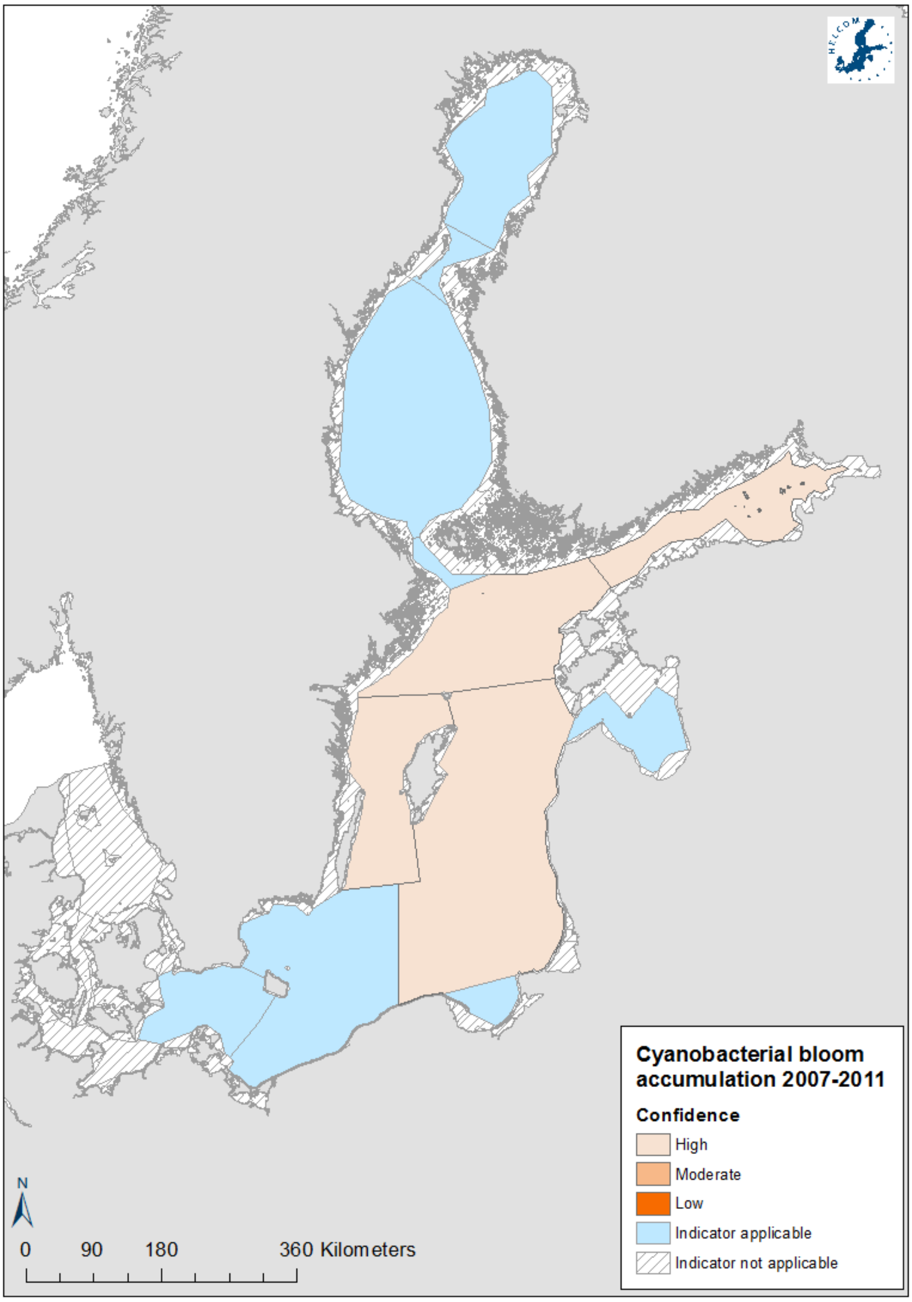
Requirements

The daily algal surface accumulation remote sensing products of the Finnish Environment Institute (SYKE) from years 2003 – 2014 were used as the main data source in the development (http://www.syke.fi/surfacealgalblooms). These are in turn based on the respective chlorophyll a product (www.syke.fi/chl-a). Remote sensing instruments used were MERIS (MEdium Resolution Imaging Spectrometer by ESA) for the years 2003-2011 and MODIS (MODerate Resolution Imaging Spectroradiometer by NASA) for the 2012-2014

Gaps

The temporal and spatial coverage of the satellite remote sensing data used can be considered high in the open sea areas as well as in the outer coastal coastal assessment areas of the Baltic Sea. Further work is required in order to include other data sources such as Ferrybox and citizen observations.

DESCRIPTION OF DATA AND CONFIDENCE



The confidence of the status estimate was high for all sub-basins covered (ES-score 100). CSA -index showed a significant linear correspondence with r2 value of 0.77 (n=44) when compared with best available independent data source (Kahru & Elmgren, 2014). Remote sensing data set gave at least one valid observation in average of 49% of days during the seasons in 2003-2014. This temporal coverage was generally higher for the test areas of GoF and NBP than for the WGB and EGB. Spatial coverage, namely the average cloud-free area in EO images varied between 18-31%. It must be noted that totally cloudy images were also included in these calculations.

The target confidence was moderate (ET-Score 50). The data set used to derive target conditions was started from year 1979. The relative standard deviations of the target periods were 13% in the Gulf of Finland and in the Western Gotland Basin. In the Northern Baltic Proper (24%) and Eastern Gotland Basin (21%) these values were higher.

Thus, the final confidence ratio (FCR) for the indicator was 75 (high). See Andersen et al. 2010 and Fleming-Lehtinen et al. 2015 for further details.

Metadata

Data sources

The data source was the daily EO based surface algae products of the Finnish Environment Institute (SYKE) from the years 2003-2014 (operative version of the product can be found on www.syke.fi/surfacealgalblooms), which are in turn based on the chl-a product (www.syke.fi/chl-a). The remote sensing data used in this study were produced with same methods as the operative version but reprocessed in order to provide as harmonized data set as possible. Remote sensing instruments used in deriving the chl-a information were MERIS for the years 2003-2011 and MODIS for 2012-2013. All available raw data for the areas of interest were downloaded by using EOLI-SA service by ESA (https://earth.esa.int/web/guest/eoli) and from NASA's Ocean color near real time data service (see http://oceancolor.gsfc.nasa.gov/) for the MERIS and MODIS instruments, respectively. Chl-a concentrations were derived for the MERIS observations according to Schroeder et al. (2007a, 2007b) and for the MODIS data according to Maritorena et al. (2002, 2010) and O'Reilly et al. (1998, 2000). In the case of MODIS data, the algorithm showing the best performance when compared against in situ data were used.

The Fraction with Cyanobacterial Accumulations (FCA) data for the years 1979-2013 by Kahru and Elmgren (2014), were used to test the performance of the CSA-index and to derive the indicator target values. FCA is defined as the ratio between the number of turbid (detected surface accumulations) and valid (no surface accumulations detected) pixels during a two month period (July-August) from satellite sensors with daily or multiple overpasses per day. The satellite instruments used in FCA estimation were AVHRR, SeaWiFS, MODIS Aqua, MODIS Terra and VIIRS. The method for retrieving FCA and the data used in the comparison presented here are described in detail in Kahru and Elmgren (2014).

Description of data: [To be filled]

Geographical coverage: Spatial coverage, namely the average cloud-free area in EO images varied between 18-31%. It must be noted that totally cloudy images were included in these calculations. - The indicator can be applied for the open sea and outer coastal assessment areas of the Baltic Sea.

Temporal coverage: Remote sensing data set gave at least one valid observation in average of 49% of days during the seasons in 2003-2014. This temporal coverage was generally higher for the test areas of GoF and NBP than for the WGB and EGB.

Data aggregation: The 2007-2011 values for each sub-basin were estimated as an inter-annual summer (20th of June– 31st of August) averages.

Further work required

Further work is anticipated on the inclusion of other data sources for the indicator as well as on the possibility to use modeling to derive the target conditions. Also information derived from the new remote sensing instruments (e.g. Sentinel 3 satellite instrument by European Space Agency to be launched on late 2015) requires careful harmonization of the derived information on the algae accumulations from other instruments.

Arrangements for up-dating the indicator

Indicator can be updated annually after the cyanobacteria accumulation period.

View data

Indicator data is not yet available in ICES data base.

REFERENCES, PUBLICATIONS AND ARCHIVE

References and relevant publications

Anonymous. 2000. DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive). Official Journal of the European Union, L 327/2, 22.12.2000.

Anonymous. 2008. Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Union, L 164/19, 25.06.2008.

Bianchi TS, Engelhaupt, E, Westman, P, Andrén, T, Rolff, C and Elmgren, R. 2000. Cyanobacterial blooms in the Baltic Sea: Natural or human-induced? Limnology and Oceanography 45:716-726.

Engström, J, Koski, M, Viitasalo, M, Reinikainen, M, Repka, S and Sivonen, K. 2000. Feeding interactions of the copepods Eyrytemora affinis and Acartia bifilosa with the cyanobacteria Nodularia sp.

Finni, T., Kononen, K., Olsonen, R., Wallström, K., 2001. The history of cyanobacterial blooms in the Baltic Sea. Ambio 30, 172-178. Journal of Plankton Research 22:1403-1409.

HELCOM, 2007. Activities 2006 Overview. Baltic Sea Environment Proceedings 112. 74 pp. http://helcom.fi/Lists/Publications/BSEP112.pdf

HELCOM. 2012. HELCOM core indicators, final report of the HELCOM CORESET project. Baltic Sea Environment Proceedings 136. 71 pp. http://helcom.fi/Lists/Publications/BSEP136.pdf

HELCOM. 2013. Eutrophication status of the Baltic Sea 2007-2011 - A concise thematic assessment. Baltic Sea Environment Proceedings 143. 41 pp. Available online at http://helcom.fi/Lists/Publications/BSEP143.pdf

Kahru, M., Elmgren, R. 2014. Satellite detection of multi-decadal time series of cyanobacteria accumulations in the Baltic Sea. Biogeosciences Discussions, 11, 3319-3364.

Maritorena S, Siegel, DA, Peterson, AR, 2002. Optimization of a semianalytical ocean color model for global-scale applications. Applied Optics, 41: 2705-2714.

Maritorena S, Fanton d'Andon, OH, Mangin, A, Siegel, DA, 2010. Merged Satellite Ocean Color Data Products Using a Bio-Optical Model: Characteristics, Benefits and Issues. Remote Sensing of Environment, 114, 8: 1791-1804.

O'Reilly, J. E., Maritorena, S., Mitchell, B. G., Siegel, D. A., Carder, K. L., Garver, S. A., Kahru, M. and McClain, C. 1998. Ocean color chlorophyll algorithms for SeaWiFS. Journal of Geophysical Research: Oceans (1978–2012), 103(C11), 24937-24953.

O'Reilly, JE, Maritorena, S, Siegel, DA, O'Brien, MC, Toole, D, Mitchell, BG, Kahru, M, Chavez, FP, Strutton, P, Cota, GF, Hooker, SB, McClain, CR, Carder, KL, Müller-Karger, F, Harding, L, Magnuson, A, Phinney, D, Moore, GF, Aiken, J, Arrigo, KR, Letelier, R, Culver, M, 2000. Ocean color chlorophyll algorithms for SeaWiFS, OC2, and OC4: Version 4. In S. B. Hooker, & E. R. Firestone (Eds.), SeaWiFS Postlaunch Calibration and Validation Analyses, Part 3, NASA Technical Memorandum, 2000-206892, vol. 11 (pp. 9 – 27). Greenbelt, MD: NASA Goddard Space Center.

Rapala, J, Kilponen, J, Järvinen, M, Lahti, K. 2012. Finland: guidelines for monitoring of cyanobacteria and their toxins. In Chorus, I. (ed.). Current approaches to Cyanotoxin risk assessment, risk management and regulations in different countries. Umweltbundesamt publications, 63: 54-62.

Rodionov, S. N. 2004. A sequential algorithm for testing climate regime shifts. Geophysical Research Letters, 31(9), L09204.

Rodionov, S., & Overland, J. E. 2005. Application of a sequential regime shift detection method to the bering sea ecosystem. ICES Journal of Marine Science, 62(3), 328-332.

Schroeder, TH, Behnert, I, Schaale, M, Fisher, J, Doerffer, R, 2007a. Atmospheric correction for MERIS above Case-2 waters. International Journal of Remote Sensing, 28, pp. 1469–1486.

Schroeder, TH, Schaale, M, Fisher, J, 2007b. Retrieval of atmospheric and oceanic properties from MERIS measurements: A new Case-2 water processor for BEAM. International Journal of Remote Sensing, 28: 5627-5630.

Sellner, KG, Olson, MM and Kononen, K, 1994. Copepod grazing in a summer cyanobacteria bloom in the Gulf of Finland. Hydrobiologia 292/293:249-254.

Sopanen, S, Uronen, P, Kuuppo, P, Svensen, C, Rühl, A, Tamminen, T, Granéli, E and Legrand, C, 2009. Transfer of nodularin to the copepod Eyrytemora affinis through the microbial food web. Aquat. Microb. Ecol. 55:115-130.

Suikkanen, S, Fistarol, GO and Granéli, E, 2004. Allelopathic effects of the Baltic cyanobacteria Nodularia spumigena, Aphanizomenon flos-aquae and Anabaena lemmermannii on algal monocultures. Journal of Experimental Marine Biology and Ecology 308:85-101.

Suikkanen, S, Fistarol, GO and Granéli, E, 2005. Effects of cyanobacterial allelochemicals on a natural plankton community. Marine Ecology Progress Series 287:1-9.

Vahtera E, Conley DJ, Gustafsson BG, Kuosa H, Pitkänen H, Savchuk OP, Tamminen T, Viitasalo M, Voss M, Wasmund N, Wulff F, 2007a. Internal ecosystem feedbacks enhance nitrogen-fixing cyanobacteria blooms and complicate management in the Baltic Sea. Ambio 36:186-194.