Name of indicator	## 3.6 Spring bloom intensity index
Type of Indicator	State indicator
Author(s)	Jenni Attila, Sofia Junttila, Saku Anttila and Vivi Fleming-Lehtinen
Description of the indicator	The indicator estimates the annual total biomass of the phytoplankton spring bloom. Spring is a period of extensive and rapid phytoplankton growth, during which the main part of the annual phytoplankton production occurs. Quantifying the spring bloom intensity, or the total biomass developed during a spring bloom, is not possible using monitoring station measurements, which do not produce data at a sufficiently high spatial or temporal frequency. This spring bloom intensity index -indicator is developed based on the method developed for Alg@line FerryBox data in Fleming and Kaitala (2006) and also for remote sensing data by Platt and Sathyendranath (2008) and Platt *et al.* (2008). The spring bloom intensity is estimated by combining remote sensing and ship-of-opportunity data in order to obtain maximum spatial and temporal coverage. The indicator is demonstrated for the MARMONI 3FIN, 4FIN-ESTand 1EST-LAT areas shown in Figure 1. In principle, the method is applicable to all Baltic Sea sub-basins. Nevertheless, it is recommended that the method is first validated against adequate *in situ* chlorophyll *a* measurements when the method is applied to a new sub-basin or water body.
Relationship of the indicator to marine biodiversity	The phytoplankton spring bloom provides a source of energy to the zooplankton community during its growth phase (Lignell *et al*. 1993). The annual peak of zooplankton biomass follows the peak of the spring bloom (Lignell *et al*. 1993), which thus indirectly affects the early development of communities at higher trophic levels as well (Platt *et al*. 2003). Despite grazing by zooplankton, most of the spring algal biomass eventually settles to the bottom (Lignell *et al*. 1993), thus potentially increasing oxygen depletion in stratified areas. However, since the spring bloom forms the major carbon flux to the bottom, it also provides the main annual input of food to the benthic communities (Kuparinen *et al.* 1984, Tallberg & Heiskanen 1998).
Relevance of the indicator to different policy instruments	Marine Strategy Framework Directive (MSFD) descriptors 1, 4, 5. HELCOM Baltic Sea Action Plan (BSAP)
Relevance to commission decision criteria and indicator	1.6. Habitat condition 1.6.2. Relative abundance and/or biomass, as appropriate
Method(s) for obtaining indicator values	The spring bloom intensity index of Fleming and Kaitala (2006) was further developed using both ship-of-opportunity and remote sensing chlorophyll *a* data in order to produce an estimate of the total areal algal biomass produced during the spring bloom. From this data, we first defined parameters such as the initiation, amplitude, timing and duration of the spring bloom (Figure 2), based on frequent and spatially comprehensive remote sensing chlorophyll *a* measurements. This information was used to derive the spring bloom index. The remote sensing, or Earth Observation (EO), instrument used in the development of the indicator was MERIS (MEdium Resolution Imaging Spectrometer). For the method development, we used MERIS data archives consisting of years 2003-2011. The dataset was processed and is archived at the Finnish Environment Institute (SYKE). Chlorophyll *a* concentrations are derived from MERIS observations, i.e. from the measured reflectances, using a neural network-based bio-optical processor (FUB) developed at the Free University of Berlin (Schroeder *et al*. 2007a-b). The FUB processor performs atmospheric correction and solves chlorophyll *a* concentrations from the MERIS measurements. The pre-processing of the data consisted of rectification and cloud masking of the individual images. For the method development, the daily images were further combined to weekly composites. Figure 3 shows two examples of weekly composites for the assessment area 4FIN-EST in the Gulf of Finland. Each year, the dataset covered the period April-October (typically weeks between 13 and 44). In principle, spring bloom indicator does not require data after the summer minimum is reached, but data is available in time series (Figure 3) for other purposes, such as detecting cyanobacteria period during July-August. The developed indicator is directly applicable using other instruments, such as the forthcoming OLCI (Ocean and Land Colour Instrument), which after its launch in 2015 onboard the Sentinel 3A satellite will be the most prominent satellite instrument for detecting Baltic Sea water quality. While Sentinel 3 is not yet on mission, the gap-filling years between the optimal instruments MERIS and OLCI can be substituted with MODIS and VIIRS data. These instruments provide a chlorophyll *a* estimate with a more modest ground resolution. The method was developed using nine years of MERIS data. The available data showed that

	although satellite information is spatially and temporally very representative, clouds may hamper the accurate detection of the initiation of the spring bloom, as it this period tends to be cloudy. Thus, complementing data is often necessity for determining the start week of the spring bloom. For this purpose, Alg@line FerryBox data was applied. The Alg@line FerryBox system collects water quality data with automated equipment onboard eight merchant ships traversing the Baltic Sea. Water quality data, among them chlorophyll *a*, are recorded with a spatial resolution of 200 m. The system includes a sequence water sampler collecting up to 24 water samples along the ship route. Time series of weekly mean chlorophyll *a* concentrations were calculated from MERIS and Alg@line data (Figure 4 and Figure 5). The spring bloom intensity index calculated from MERIS and Alg@line data were combined to form one time series for each assessment area (see assessment areas in Figure 1). The limit for the spring bloom period chlorophyll *a* concentrations was set at 5 µg/l (Figure 4A) (Fleming and Kaitala 2006). The intensity index was calculated by a time-intensity integral for the weeks where weekly average exceeded the limit value. Figure 6 presents the intensity index for the assessment area 4FIN-EST using Alg@line data for the years 1992-2008 and MERIS data for the period 2003-2011. The trend line for the same assessment area is presented in Figure 6. The other characteristics (amplitude, initiation, duration, and timing of maximum) were also determined from time series of weekly mean chlorophyll *a* concentrations. Table 1 gives examples of these statistics calculated for each assessment area.
Documentation of relationship between indicator and pressure	The indicator reacts primarily to pressures such as changes in nutrient composition, hydrography and climate change. The start of the phytoplankton bloom is initiated by increase in light availability in the euphotic zone and the development of vertical stratification after the winter (Svedrup 1952). The course of the bloom is determined by nutrient availability in the upper water column (Lignell *et al*. 1992, Fleming & Kaitala 2006). Loading of nitrogen, phosphorus and silicate are thus identified as the main pressures of the indicator. Spring bloom intensity responds positively to pressures.
Geographical relevance of indicator	2. Regional
How Reference Conditions (target values/thresholds) for the indicator were obtained?	The target is trend-based, assuming that the spring bloom intensity index shows neither a decrease nor an increase from the level defined from Alga@line measurements during 1992-2008. The target level was derived using the time series of the spring bloom intensity index (Fleming and Kaitala 2006). Figure 6 presents the spring bloom intensity index and the trend line derived using Alg@line measurements for years 1992-2008 and using MERIS data for years 2003-2011 for the assessment area 4FIN-EST. The trend line implies changes in spring bloom intensity level that can be utilized to define the amount of biomass. If the trend is increasing, it means that the intensity of spring bloom (i.e. biomass) increases. If the trend is decreasing, the spring bloom intensity decreases.
Method for determining GES	GES is determined quantitatively using the target approach. The indicator is applicable for all areas where the spring bloom occurs in such intensity that it has importance for annual phytoplankton succession, zooplankton community and where it forms relevant carbon flux to the bottom. The method can be applied both in local and regional scale as well as on national waters, i.e. for example for each coastal water body (relevant for WFD reporting for example). At present, it has been tested for northern parts of the Baltic Sea.
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Illustrative material for indicator documentation

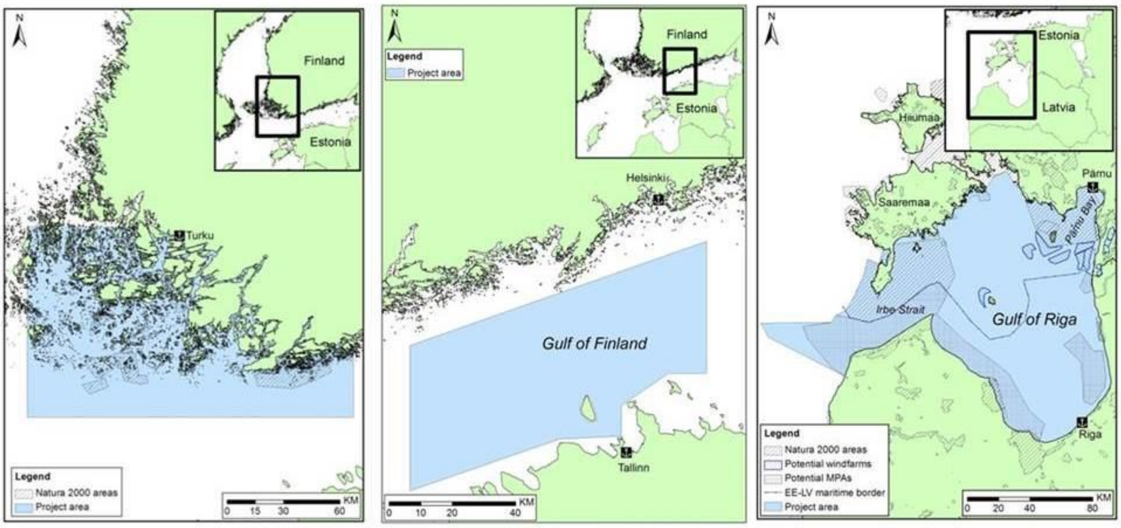


Figure 1. MARMONI areas for method development: 3FIN Coastal area of SW Finland (left), 4FIN-EST Gulf of Finland (middle) and 1EST-LAT Gulf of Riga (right).

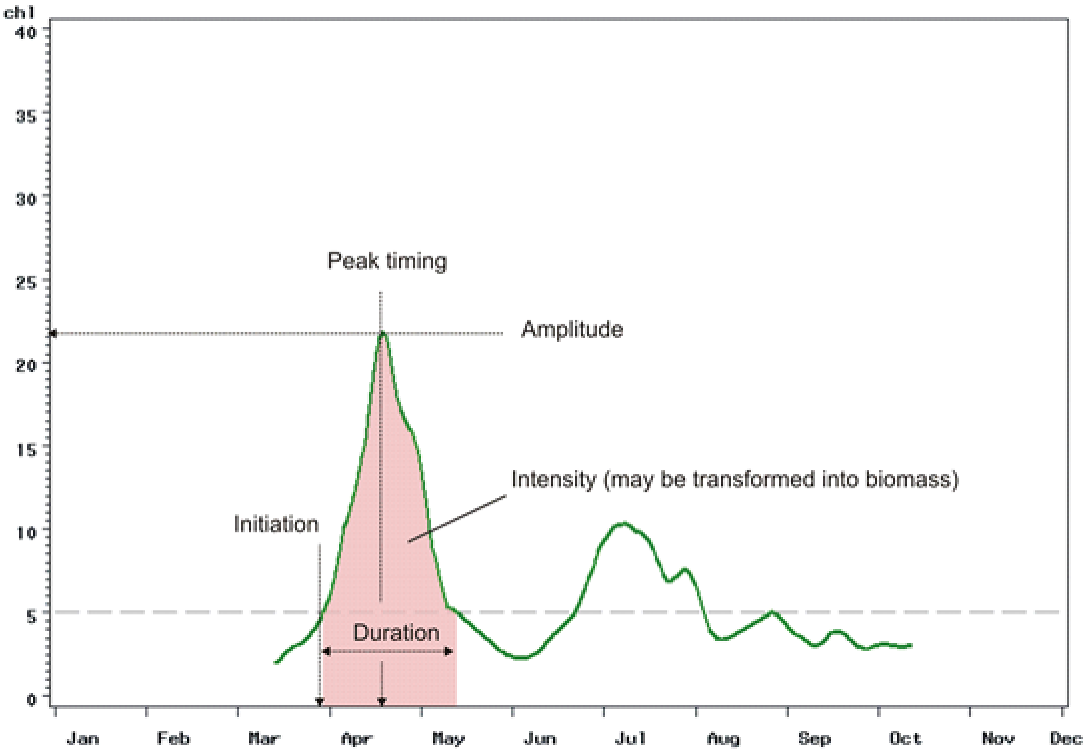


Figure 2. The properties of the spring phytoplankton bloom in the western Gulf of Finland in 2009, characterized from a time series of chlorophyll concentration. The characteristics that can be determined are amplitude, initiation, timing of maximum and duration.

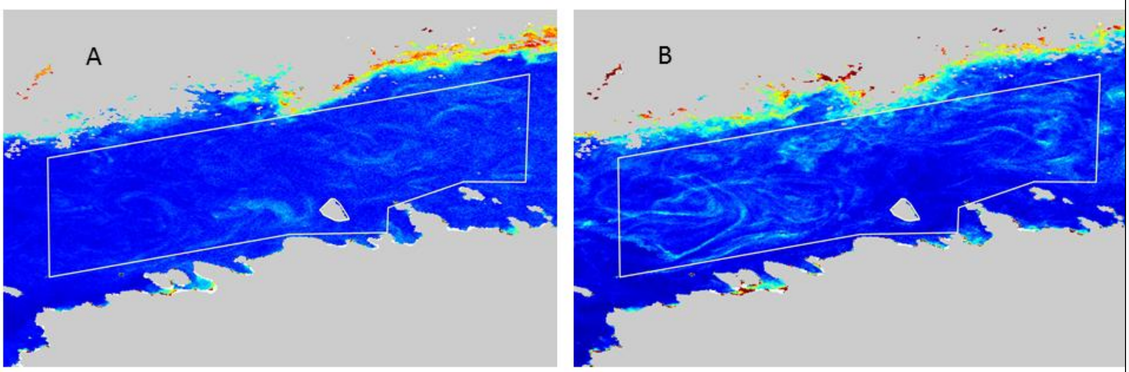


Figure 3. Two examples of EO interpretation of weekly chlorophyll *a* mean concentration [µg/l] during spring bloom 2005 in the MARMONI project area 4FIN-EST Gulf of Finland, A) week 17 (25.4.-1.5.) and B) week 18 (2.-8.5.).

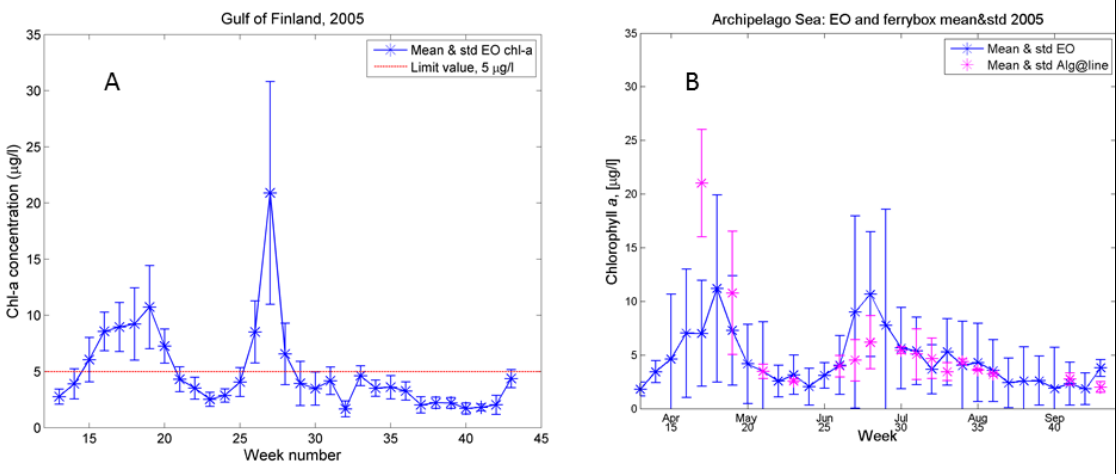
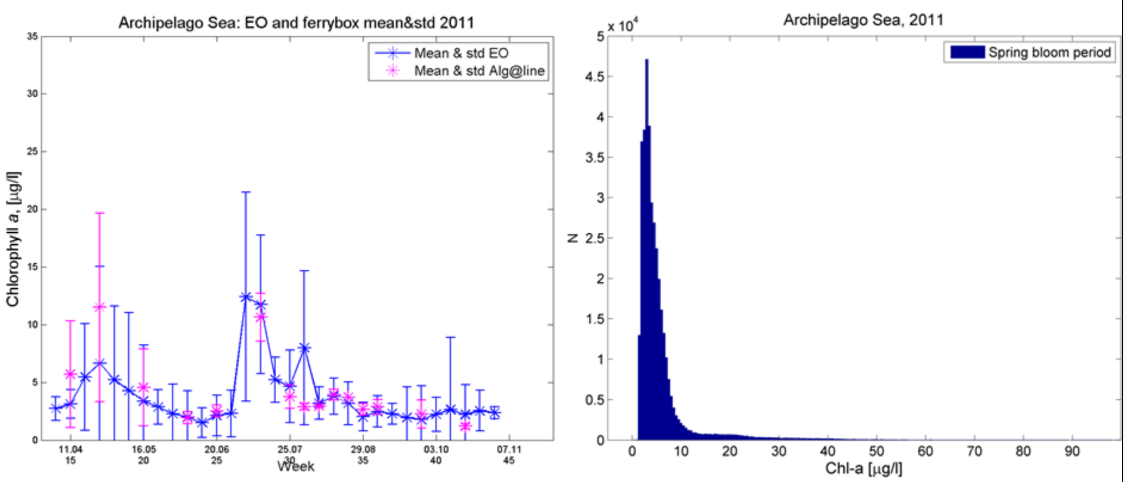


Figure 4. A) Time series of mean chlorophyll *a* concentrations and standard deviations derived from remote sensing data (EO, blue lines and bars). The red line indicates the spring bloom limit value, 5µg/l. This example is from the MARMONI project area 4FIN-EST Gulf of Finland in 2005. B) Similar time series using remote sensing data (blue lines and bars) and Alg@line FerryBox data (purple stars and bars). This example is from the MARMONI project area 3FIN Coastal area of SW Finland in 2005.



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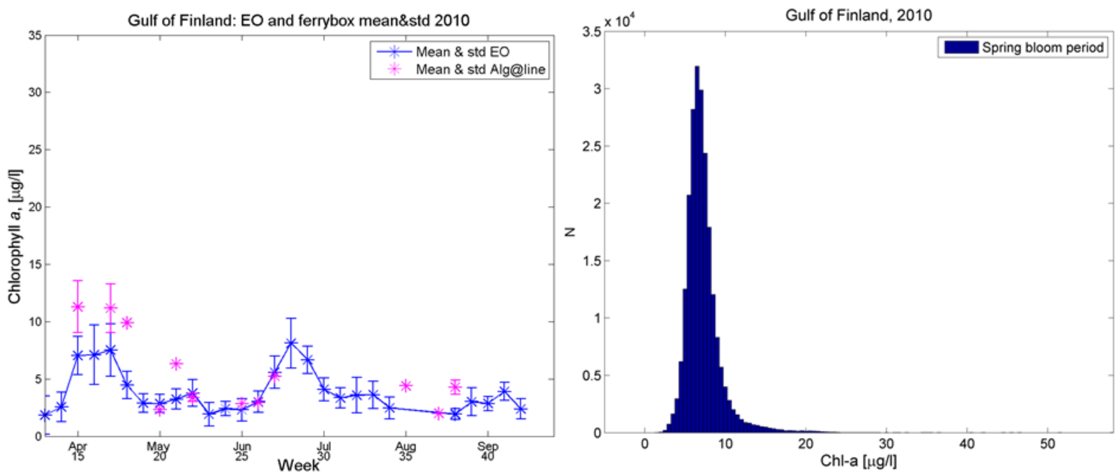

B

Figure 5. A) Left: Time series using remote sensing data (EO, blue lines and bars) and Alg@line FerryBox data (purple stars and bars) from the MARMONI project area 3FIN Coastal area of SW Finland in 2011. Right: Histogram describing the distribution of chlorophyll *a* concentrations during the spring bloom period. B) Left: Time series using remote sensing data (blue lines and bars) and Alg@line FerryBox data (purple stars and bars) from the MARMONI project area 4FIN-EST Gulf of Finland in 2010. Right: Histogram describing the distribution of chlorophyll *a* concentrations during the spring bloom period.

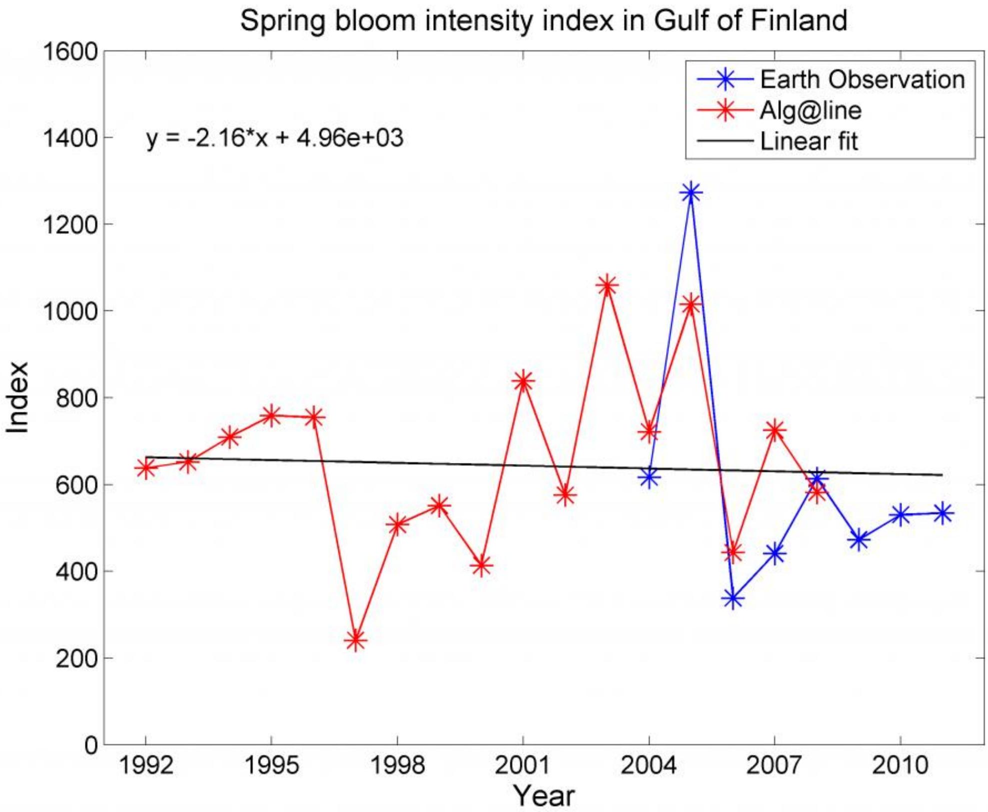

Figure 6. Time series of spring bloom intensity index in the project area 4FIN-EST Gulf of Finland. Blue stars and lines represent remote sensing data and red stars and lines Alg@line Ferry Box data. Black line is the linear fit for the data.

Table 1. The statistics describing the spring bloom: the mean chlorophyll *a* concentration during the spring bloom, maximum concentration (peak maximum in table, amplitude), length of the spring bloom in days and weeks (duration), the start (initiation) and end week for all the studied areas 3FIN Coastal area of SW Finland (Archipelago Sea), 4FIN-EST Gulf of Finland and 1EST-LAT Gulf of Riga for the years 2009-2011.

Sea area	Year	Intensity index	Mean(ug/l)	Peak (ug/l)	Peak wk	Peak's maximum (ug/l)	Length (days)	Length (wk)	Start (wk)	End (wk)
Archipelago Sea	2009	82,41	5,89	6,02	17	92,99	14	2	16	17
	2010	168,90	6,03	6,56	16	99,70	28	4	15	18
	2011	121,29	5,78	6,64	17	99,90	21	3	16	18
Gulf of Finland	2009	135,09	6,43	7,55	16	82,65	21	3	16	18
	2010	151,54	7,22	7,52	17	58,16	21	3	15	17
	2011	152,60	7,27	7,74	16	88,76	21	3	16	18
Gulf of Riga	2009	607,73	10,85	15,20	16	61,28	56	8	15	22
	2010	576,02	10,29	19,37	17	65,02	56	8	15	22
	2011	783,24	13,99	20,76	17	99,48	56	8	14	22