Cyanobacterial blooms in the Baltic Sea

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Key Message

Cyanobacterial blooms in the Baltic Sea show large inter-annual variability both in intensity and coverage. Nutrient conditions were similar in 2004 and 2005, with extremely high phosphate levels in the surface layer. Weather conditions during summer 2004 were not favourable for cyanobacteria (cold and windy), which resulted in a weak bloom.

Warm, calm and sunny weather during early July 2005, in combination with the available phosphate, resulted in a widespread and intense bloom. Vast areas, from Åland to the Gulf of Gdansk, were covered with surface accumulations of cyanobacteria. The coast and archipelago of east Sweden were severely affected. Thick cyanobacteria aggregations were deposited onto the coast. These prevented swimming and their decay released unpleasant odours, which attracted attention from both the public and media.

High concentrations of phosphorus (normal winter values, 0.5-0.6 µmol/l) were also available in the Arkona and the Bornholm Deep during the summer but no bloom was detected. This has been confirmed by measurements in the area. Why no cyanobacterial bloom appeared in this area is unclear.

Results and Assessment

Relevance of the indicator for describing developments in the environment

Analysis of sediment cores has indicated that cyanobacterial blooms are as old as the brackish phase of the Baltic Sea, starting 7000 years B.P. (Bianchi 2000). It has also been suggested that cyanobacteria pigments in sediment cores have increased in concentration since the 1960s (Poutanen et al 2001). In recent years there has been a debate on whether there has been an increase of the intensity and extent of the cyanobacterial blooms due to eutrophication (Karhu 1994, Finni 2001, Bianchi 2000). Monitoring of extent and intensity of surface blooms may give clues about possible human impacts and natural variability.

For several years since the end of the 1980s, concentrations of phosphorus and nitrogen have decreased in the surface water of the Baltic Proper, which has been interpreted as a result of measures taken against eutrophication. However, in February/March 2004 phosphate concentrations, especially in the northern and central parts, were found to be about double normal values. Since the load to the Baltic has not increased, this excess phosphate must have come from the deep water and is most likely due to the entrainment of phosphate rich deep water caused by the 2002/2003 inflows. (Larsson & Andersson, 2005)

The excess phosphate could have led to a strong bloom of cyanobacteria during the following summer. However, summer 2004 was both cold and windy. When the warmth came in August some minor blooms were detected, but not to the same extent as during recent summers, i.e. 2002, 2003 or 2005. (See Figure 6)

The phosphate concentrations during winter and early spring 2005 remained elevated (about double normal values) and were available to contribute to the intense and widespread bloom during July 2005.

High concentrations of phosphorus (normal winter values, 0.5-0.6 µmol/l) were also available in the Arkona and the Bornholm Deep, during the whole summer but no bloom was detected. This was confirmed by measurements in the area. Why only minor cyanobacterial bloom appeared in this area is unclear. (SMHI, R/V Argos cruise report, 2005)

Assessment

2004

The first cyanobacterial bloom was detected on the 1st of July in the area of the Landsort Deep and east of Gotland. The accumulations were mainly *Nodularia spumigena*. The weather during July was changeable with frequent cloud cover, thus satellite detection of blooms was difficult. Measurements at Landsort Deep indicated that the bloom was three weeks delayed compared to normal.

During late July, strong blooms were visible along the Estonian Coast in the Gulf of Finland, where the weather was more favourable than in the remainder of the Baltic Sea.

Cyanobacteria blooms were detected across much of the Baltic Proper, but the full extent of the bloom was difficult to document due to cloud cover. The bloom reached its maximum extent during 6th of August (~120 000 km^2). Observations of the bloom continued onto the 25th August, while it became increasingly patchy.

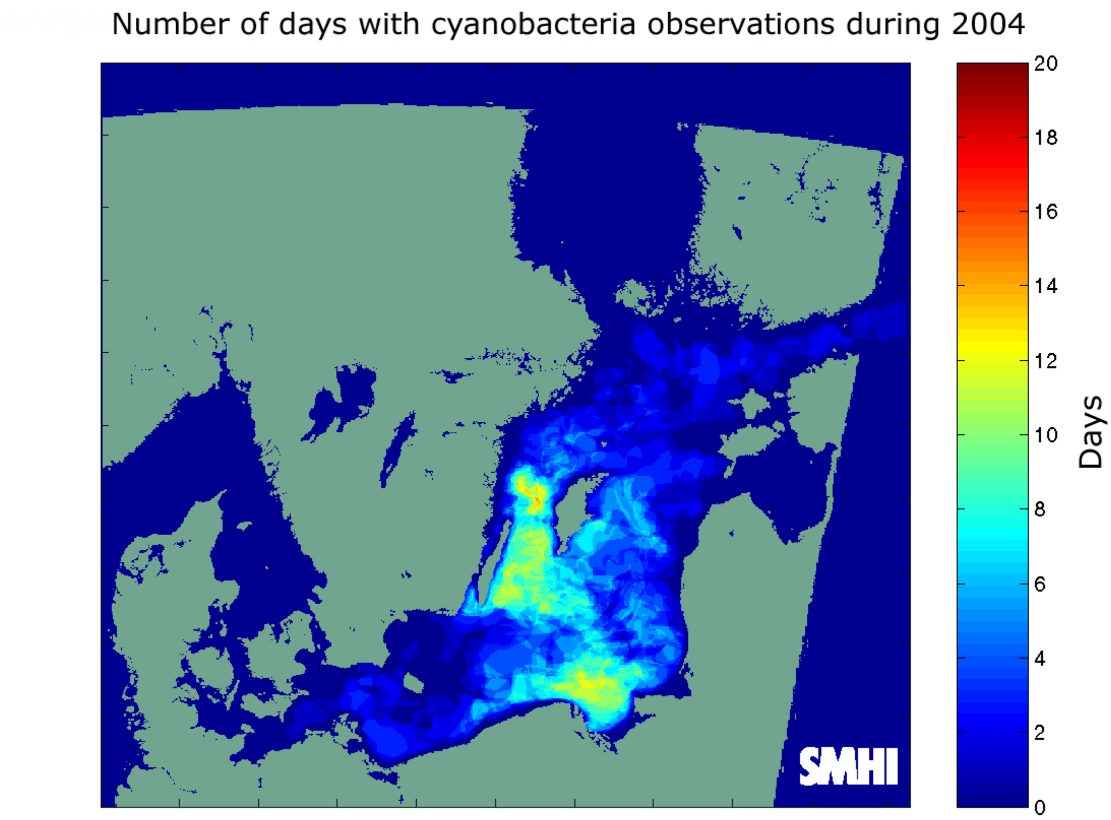

Figure 1. Number of days during 2004 with surface accumulations of cyanobacteria observed in each pixel. (based on NOAA-AVHRR satellite imagery)

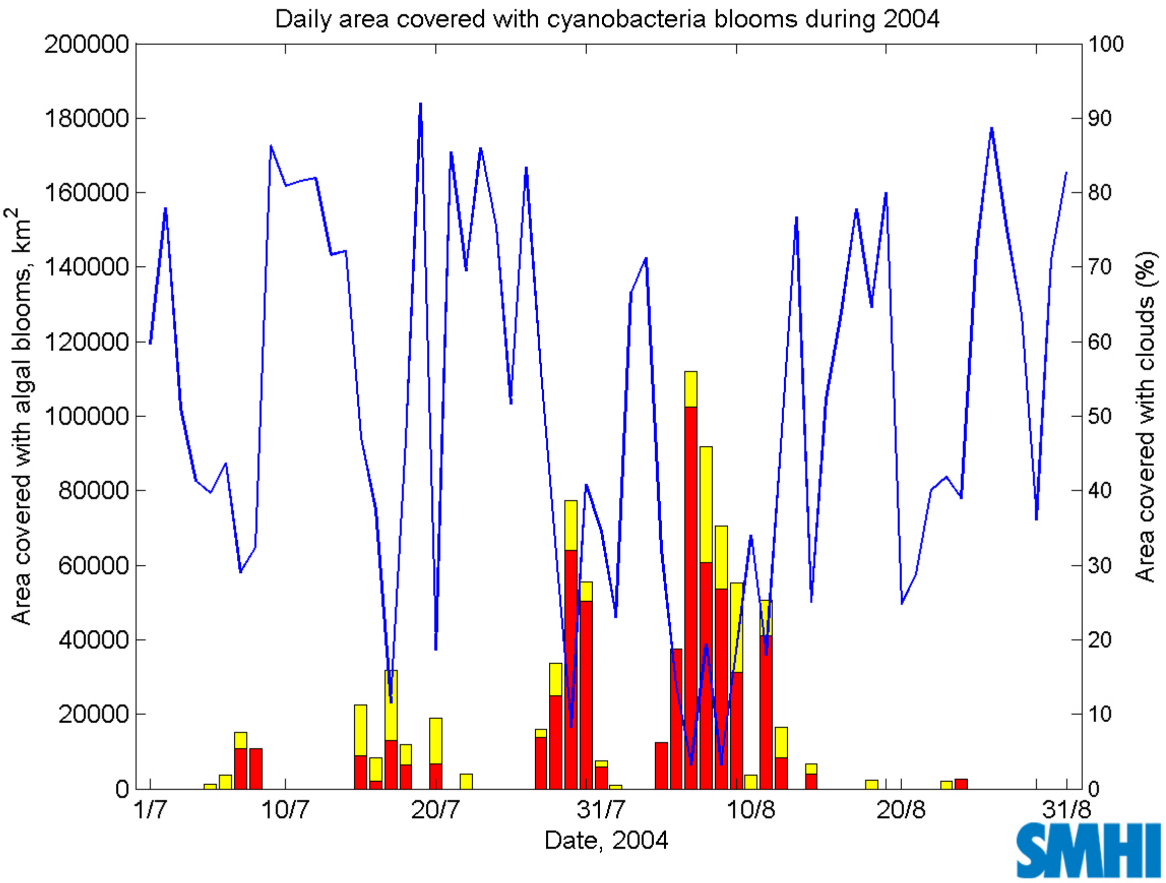

Figure 2. Daily extent of surface accumulations of cyanobacteria in the Baltic Sea during 2004, observed by NOAA-AVHRR satellite imagery. Red bars correspond to definite bloom observations and yellow bars indicate uncertain bloom observations. The blue line represents the integrated cloud cover (in percent of the total area) over the whole Baltic Sea, excluding the Kattegat, Skagerrak and Bothnian Bay.

2005

The first observation of surface accumulations of cyanobacteria was made on the 1st of July. Calm, sunny and warm weather conditions, and extremely high winter and early spring phosphorus concentrations (~1 µmol/l at BY4, BY5, BY15, BY38, BY10, BSCIII-10) of were favourable for a massive bloom and within days intense blooms affected vast areas of the Baltic Proper. Maximum extent (~130 000 km^2) was observed on the 11th July. Most observations were concentrated to the north Baltic Proper and around Öland and Gotland.

The bloom in the open Baltic Proper was restricted to July and only a few small surface accumulations were observed during early August.

Cloud conditions during early July were suitable for detection of cyanobacteria blooms. From mid July cloudy weather prevailed. The area covered by cyanobacterial blooms during this time is likely to be underestimated. The closing phase of the bloom in early August could be seen both in satellite imagery and in offshore water samples. Measurements and observations between 9th and 12th August confirm that no visual surface accumulations were present and only dead or dying cyanobacteria cells were found in the water samples. (SMHI, R/V Argos Cruise report, 2005)

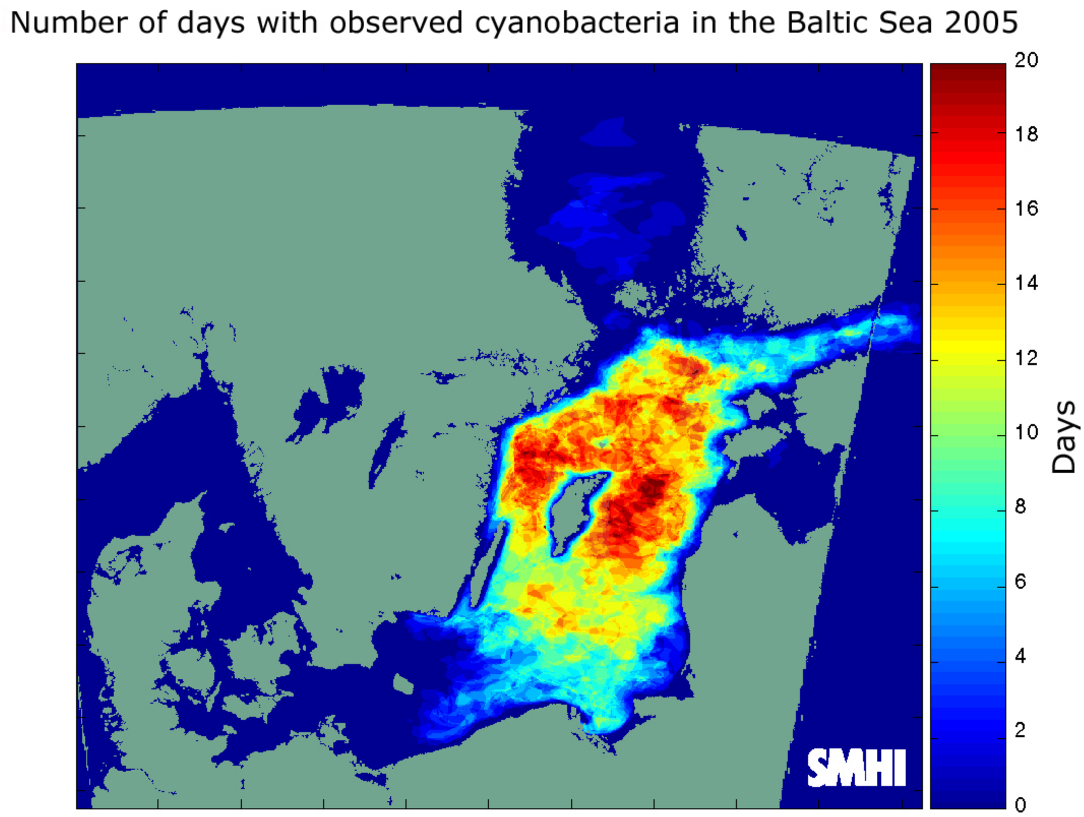

Figure 3. Number of days during 2005 with surface accumulations of cyanobacteria observed in each pixel. (based on NOAA-AVHRR satellite imagery)

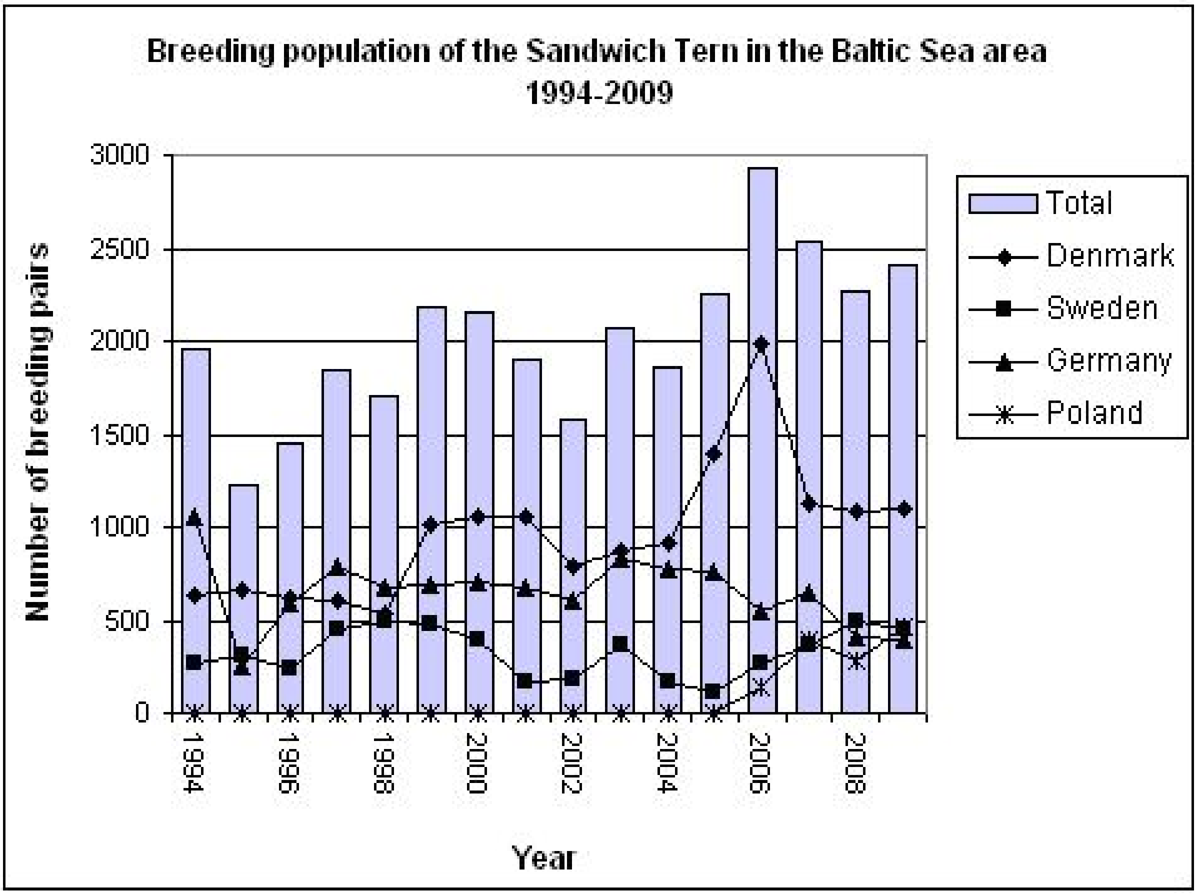

Figure 4. Daily extent of surface accumulations of cyanobacteria in the Baltic Sea during 2005, observed by NOAA-AVHRR satellite imagery. Red bars correspond to definite bloom observations and yellow bars indicate uncertain bloom observations. The blue line represents the integrated cloud cover (in percent of the total area) over the whole Baltic Sea, excluding the Kattegat, Skagerrak and Bothnian Bay.

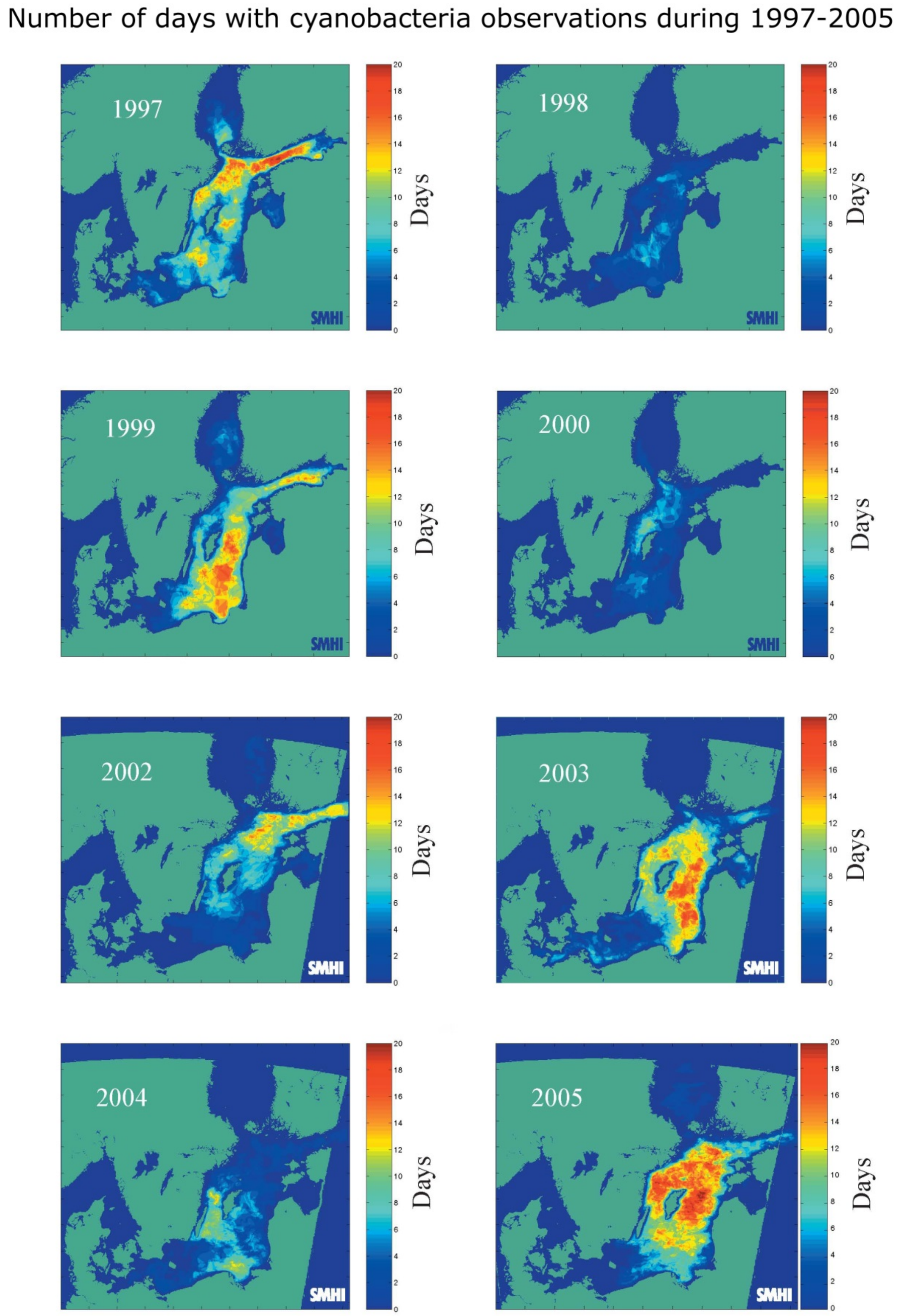

Figure 5. Summary of number of days with cyanobacterial observed in each pixel during the period 1997-2005, based on NOAA-AVHRR satellite imagery. Year 2001 is missing due to antenna malfunction at the receiving station.

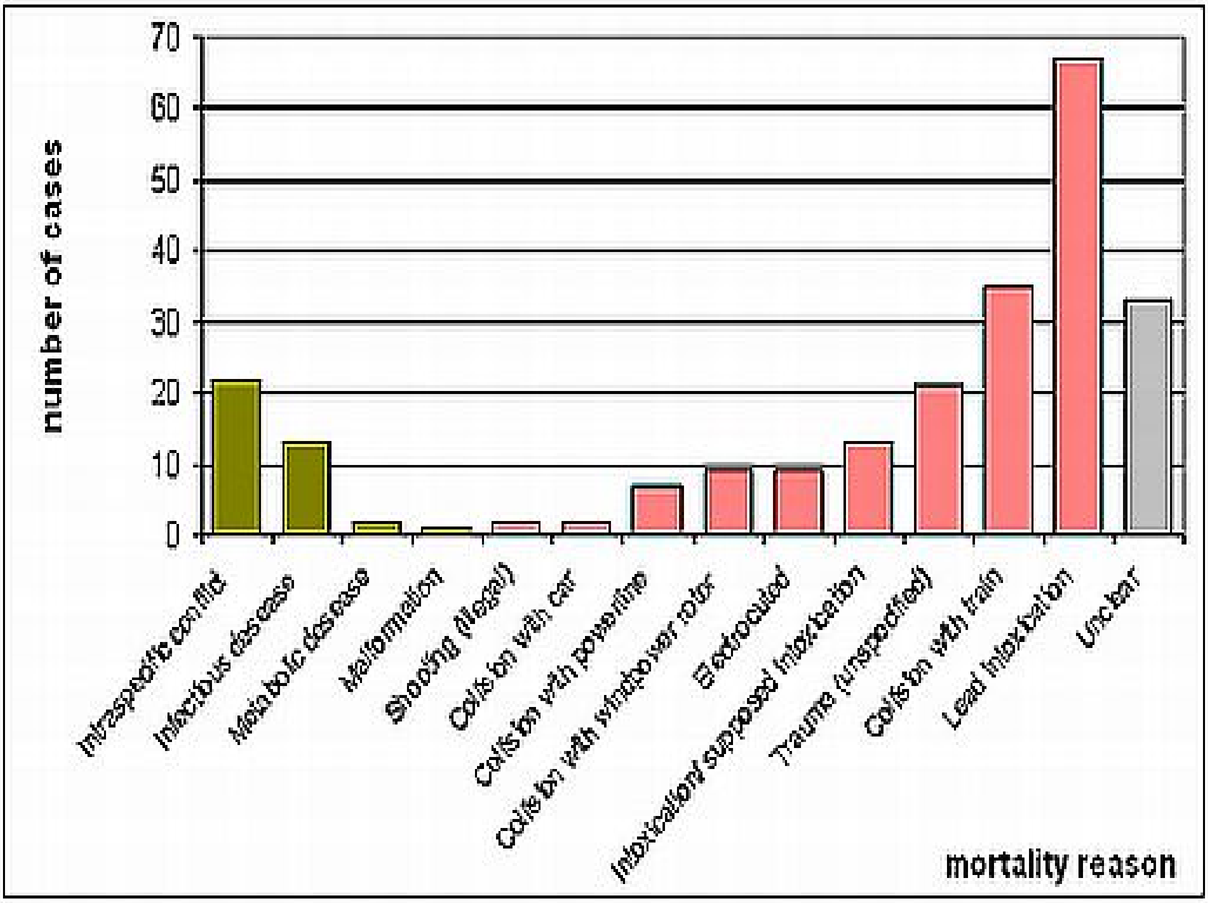

Figure 6. Scatter plot over annual and temporal bloom coverage, 1997-2005. The graph shows the area covered by blooms versus the number of days with observed blooms. Year 2001 is missing due to antenna malfunction at the receiving station.

Reference

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Data

The SMHI satellite receiving station in Norrköping collected the NOAA-AVHRR data.

Metadata

Technical information

1. Data source: The AVHRR-data from NOAA-satellites was received with the antenna at SMHI headquarters, Norrköping.

2. Description of data: The AVHRR-sensor measures radiation in 5 broad wavelength bands ranging from visible to thermal infrared.

3. Geographical coverage: The satellite monitoring of cyanobacteria has many advantages compared to regular vessel based monitoring. The NOAA-AVHRR has a wide swath width (~2600km), hence most areas of the Baltic Sea are covered. An exception is near all land areas such as within archipelagos. These cannot be monitored due to the coarse pixel resolution (~1km). The satellite data format excludes the inner parts of the Gulf of Finland.

4. Temporal coverage: Data from the NOAA-AVHRR sensor have been available since the late 1970s. Karhu et al. (1994;1997) has produced a compiled time series of satellite data for analysis of cyanobacterial blooms in the Baltic Sea from 1982 to 1994. In 2002, SMHI initiated BAWS (Baltic Algal Watch System) that performs daily interpretations of satellite imagery during the summer. AVHRR data have also been analysed between 1997 and 2000 by SMHI in the EU-project HABES (Harmful Algal Blooms Expert System).

5. Methodology and frequency of data collection: Satellite imagery is analysed using both automatic cloud masks and manual interpretations. NOAA satellites have a repeat cycle of ~0.5 days and since there are several NOAA satellites mounted with the AVHRR sensor there can be ~12 overpasses per day. Between 0-6 overpasses are unsuitable for further analysis due to low viewing angles, sun glint, clouds or haze. The best viewing conditions are usually encountered during the morning.

6. Methodology of data manipulation: Data were calibrated to albedo for visible and near infrared channels, and to brightness temperature for the thermal channels. Data were also geographically corrected to the Mercator projection.

Quality information

1. Strength and weakness: Satellite data have high sampling frequency and allow a synoptic view. However, monitoring is limited to open sea areas due to the coarse pixel size, and is also limited by cloud cover.

2. Reliability, accuracy, robustness, and uncertainty: The AVHRR satellite can only be used for monitoring of meso-scale, surface accumulations of cyanobacteria. Algae can be found further down the water column. These are impossible to detect with satellite imagery. Therefore satellite data must be complemented by shipborne measurements, for example by data from Alg@line. Uncertain bloom observations are always noted and reanalysed when more satellite scenes are available.

Satellite data from the high-resolution channels of MODIS (Moderate Resolution Imaging Spectroradiometer) flown on the TERRA and AQUA satellites and MERIS (MEdium Resolution Imaging Spectrometer Instrument) were used when good imagery was available to re-analyse the algal maps derived from the NOAA-AVHRR data. Manual corrections were performed if needed.

3. Further work required: During 2006 SMHI and BAWS will introduce a new area coverage (including the Gulf of Finland) and projection (Albers Equal Area). An algorithm (inspired by Karhu, 1997) has also been developed during 2005 to screen clouds and cyanobacterial blooms. The algorithm should reduce the need for manual interpretations.

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