

## Hydrography and oxygen in the deep basins

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### Key Message

The Baltic Sea is a sensitive sea area. The region is characterised by its natural formation as an enclosed estuary with high freshwater input and restricted access to oceanic high saline water. The stratification and fjord-like conditions, in combination with eutrophication and other factors, form the basis for a problematic oxygen situation in the deep water.

Anoxic conditions are characterised by the total absence of oxygen. When all oxygen is consumed by microbial processes hydrogen sulphide (H<sub>2</sub>S) is formed, which is toxic for all higher marine life. Anoxic conditions lead to release of phosphate and silicate from the sediments to the water column, which, through vertical mixing, can reach the surface layer and the photic zone. A surplus of phosphate in relation to nitrate favour cyanobacteria growth in the Baltic Sea during summer.

This fact sheet gives an overview of the development of salinity since 1990 to 2017 and oxygen from 1960 to 2017 and describes recent changes in these variables. The most notable changes since the major Baltic inflow in 2014 are:

- Deep water salinity has increased in the Baltic Proper, which hampers vertical mixing.
- The area of the central Baltic affected by oxygen deficiency (hypoxia, O<sub>2</sub> < 2 ml/l) and absence of oxygen (anoxic or sulphidic conditions) remains high.
- The hydrogen sulphide concentrations are lower than before the inflow 2014.

### Results and Assessment

#### Relevance of the BSEFS for describing developments in the environment

Salinity, temperature and oxygen are physical background parameters, constraining biodiversity, fish recruitment and water quality in a semi-enclosed water body as the Baltic Sea.

Surface waters in the Baltic are strongly influenced by land run-off of freshwater. Changes in run-off alter the surface salinity while inflows through the Sound and the Belt Sea control the salinity of the deeper waters. Stratification between the upper and lower layers inhibits surface and deep waters mixing together, and thus preventing the oxygenated surface water penetrating to deep water. The strength of the stratification is indicated by the salinity difference between the surface and deep water.

Oxygen depletion is widely used as an indicator of the indirect effects of nutrient enrichment due to increased oxygen consumption. Lowest oxygen levels are experienced at the end of summer, between August and October, when detritus from biological activity in the surface waters has sank, and is decomposed by bacteria. This process consumes the oxygen. When oxygen is depleted bacteria start to use anaerobic processes for degradation of organic matter, producing toxic hydrogen sulphide. Oxygen levels above 4.6 mg/l (3.2 ml/l) are considered to cause no problems for most macroscopic animals and this limit could be considered as a precautionary limit to avoid catastrophic mortality events (Vaquer-Sunyer and Duarte (2008)).

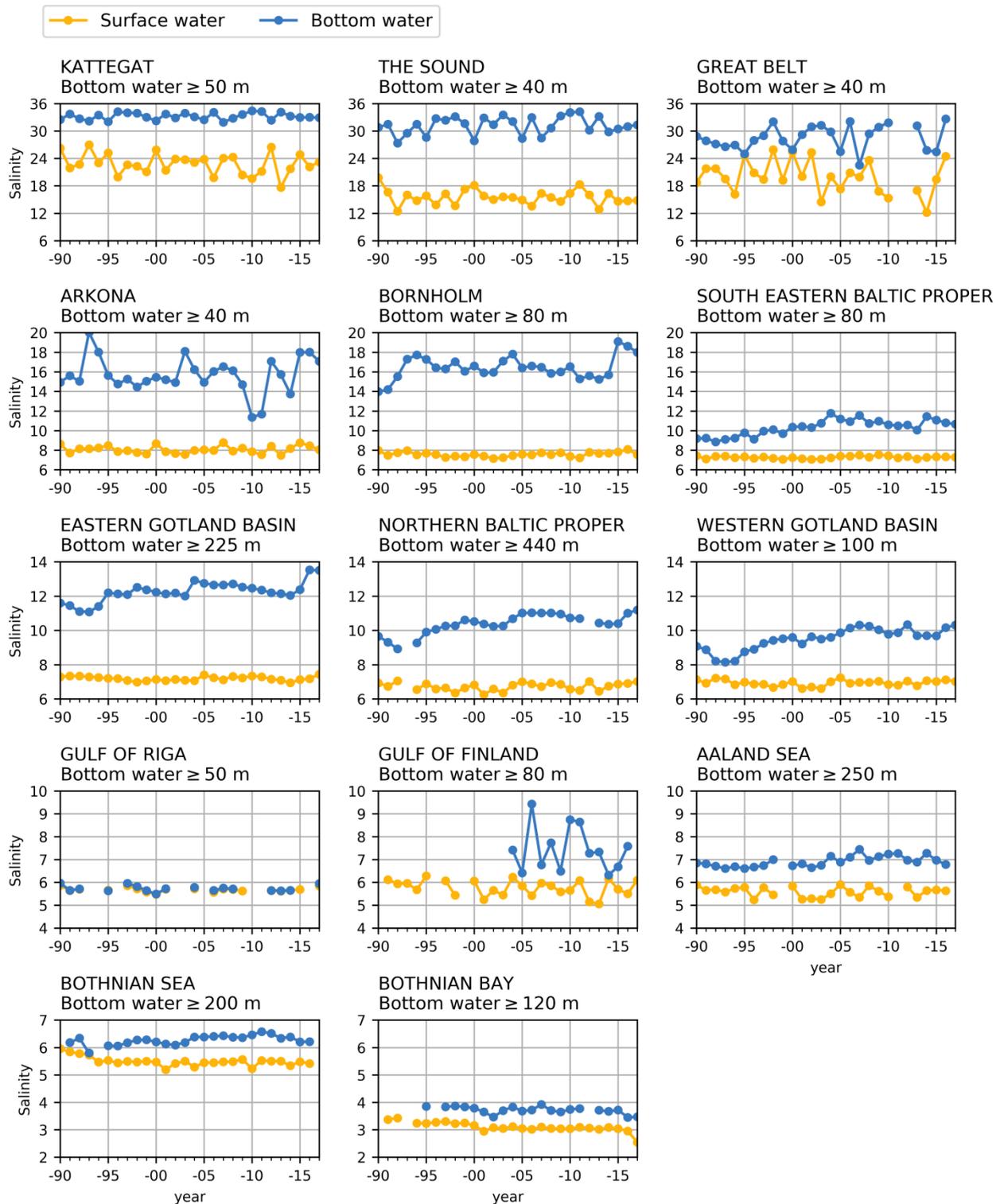
#### Policy relevance and policy references

Oxygen levels are used as an indicator of eutrophication by both HELCOM and OSPAR. It is listed as a core variable of the HELCOM COMBINE programme. Oxygen is delivered to the deep waters of the Baltic in the saline inflows that come through the Sound and Belt Sea. Hydrographic measurements (temperature and salinity) allow us to trace these inflows, and other water movements within the Baltic.

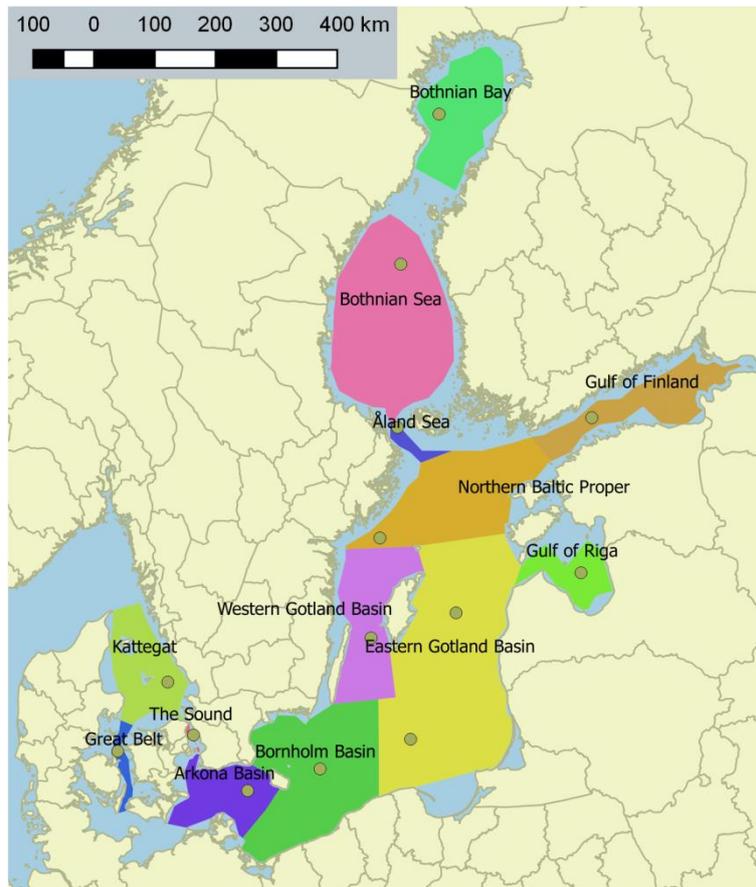
#### Assessment

##### *Changes in salinity*

Time series of winter surface salinity between 1990 and 2017 (Figure 1) show stable winter average (Dec-Feb) salinities in the surface waters (0-10 m) of the Baltic Proper. Surface winter salinity (Figure 1) has remained fairly constant in the southern Baltic Proper since 1990, around 8 psu in the Arkona and Bornholm basins to around 7 psu in Eastern, Northern and Western Gotland basins of the Baltic Proper. In the Eastern Gotland Basin the surface salinity decreased between 2011 and 2014, but has risen again during the past three years and is currently close to 8 psu. In the Bothnian Sea salinity in the surface water has decreased by about 0.5 psu since 1990. Deep water salinity has increased in the Eastern, Northern and Western Gotland basins of the Baltic Proper reaching new peaks after every inflow since 1990. At present it is close to 14 psu in the bottom water of the Eastern Gotland Basin. The effect of the winter 2002-2003 inflow is visible in the deep water salinity data from Arkona and Bornholm that same winter. But it was not seen in the winter-averaged data from the Eastern Gotland Deep until the following winter, 2003-2004. Smaller salinity increases after this inflow can also be tracked in the Northern and Western Baltic Proper but are not very clear in the winter averaged data. After the inflow in the winter 2002-2003 the deep water salinity in the Baltic Proper slowly decreases until the next large inflow in the winter 2014-2015. This inflow is one of the largest inflows recorded and is well described in Naumann et al. (2018), as well as a series of smaller inflows 2014-2016. The 2014 inflow is seen in as a small increase in winter mean salinity already in the winter 2014-2015 but it is not until the following winter (2015-2016) the increase in salinity is clear. The difference between surface and deep water salinity, in the main part of the Baltic Proper, is much greater than at the start of the 1990s, and this will hinder vertical mixing.



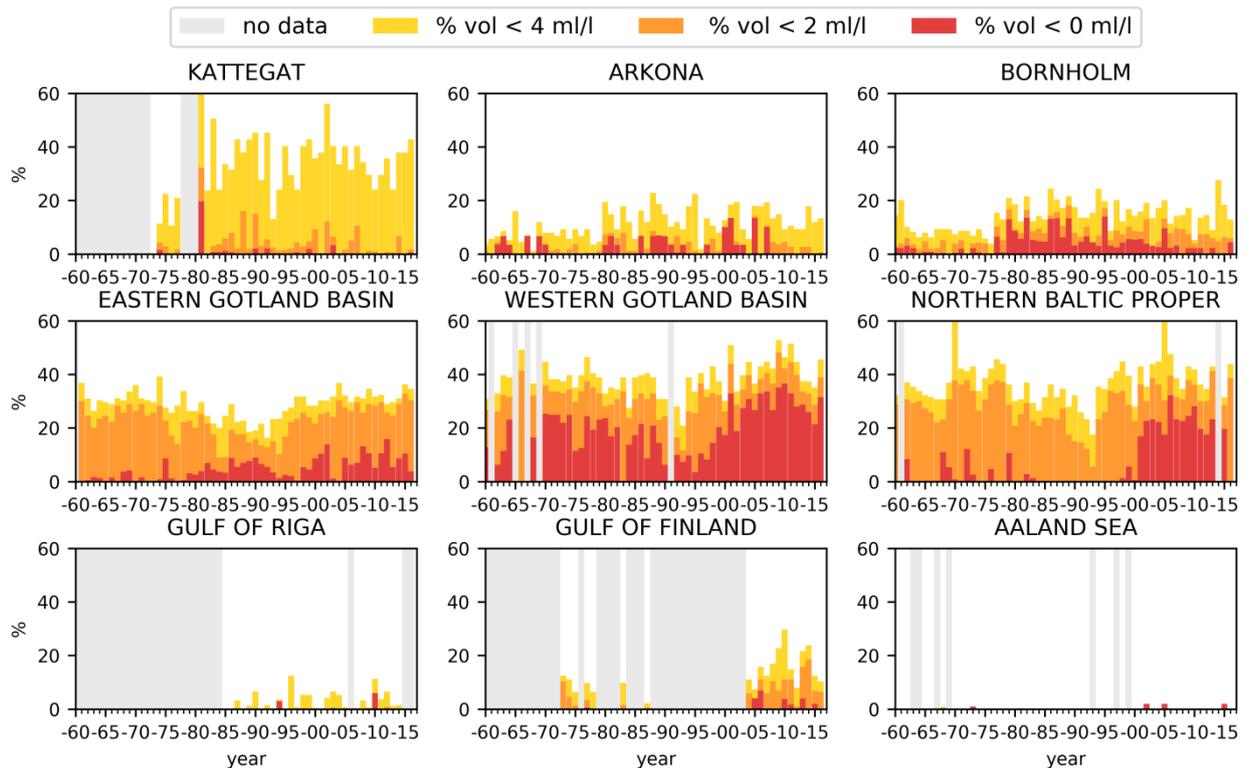
**Figure 1.** Surface (orange) and deep water (blue) salinity from 1990 to 2017 at selected monitoring stations in the HELCOM marine area. Depth for surface water is 0-10 m at all stations, deep water values are calculated from a mean of all values at and below the depths specified in the title of each plot.



**Figure 2.** Map showing the HELCOM marine area and the basins and stations in them that are used in this fact sheet. In Figure 1 the southernmost station (BSC-III-10) in the Eastern Gotland Basin is presented as South-Eastern Baltic Proper while the northernmost station (BY15 Gotland deep) is representing the Eastern Gotland Basin.

### *Oxygen*

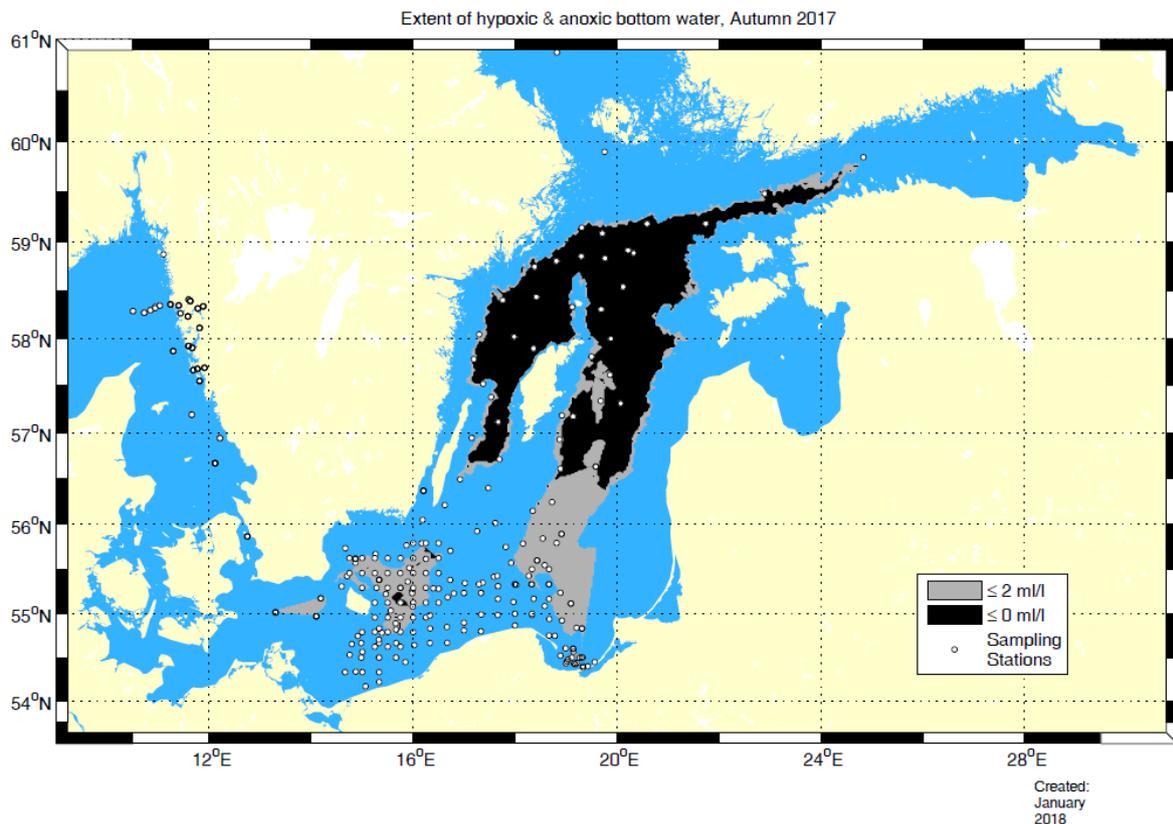
For each of the basin in Figure 2 oxygen profiles from 1960 – 2016 were examined using data from the autumn months (August, September and October). The profiles were interpolated to 1 m depth resolution and the depths at which the oxygen concentration fell below 4 ml/l, 2 ml/l (hypoxia) and 0 ml/l (anoxia) were selected. The volume of each depth was calculated using data from the Baltic Sea Bathymetry Data Base (Baltic Sea Hydrographic Commission, 2013) and an estimate of the volume of water below each oxygen limit could thereby be calculated. This method takes into account oxic waters that remain below layers of anoxic waters after inflow events. The values were interpreted in terms of the proportion of the volume of each basin affected by reduced oxygen levels. Results are presented as time series in Figure 3. The figure for each basin is based on oxygen profiles from the deepest monitoring station in that basin. The positions of the basins are shown on the map in Figure 2.



**Figure 3.** Autumn oxygen conditions as a percentage of the total volume of the basins. Grey areas in the panels mark periods with either no data available or too little data to make a reliable evaluation of the situation. Volume percentages below 0, 2 and 4 ml/l are shown in red, orange and yellow colours respectively.

The Kattegat very rarely experience anoxia but has oxygen concentrations below 4 ml/l in between 30-40% of its volume more or less every year in the autumn which is what is presented here. In the Arkona Basin anoxia is a sparse phenomenon, while in the Bornholm Basin it is a more seasonal feature occurring almost every year. The volume affected by anoxia has decreased to only a few percent after the inflow 2004. The Northern Baltic Proper as well as the Eastern and Western Gotland basins are the basins most affected by anoxia. The Western Gotland basin shows the largest percentages of its volume with anoxia. Here the volume of anoxic waters steadily increased after the inflow 1994 and has been fairly constant around 30% since the beginning of 2000. Despite this the severity of anoxia is in a way lower in the Western Gotland basin than in the Eastern Gotland Basin. Hydrogen sulphide concentrations are lower in the southern part of the Western Gotland basin and oxygen conditions varies over the year, tending to show a seasonal cycle with the highest sulphide concentrations during the autumn and the lowest at the end of the winter season. At some occasions oxygen has been measured in the whole water column even during the 21<sup>st</sup> century. Note that the conditions differ notably between the northern parts of this basin and the southern parts with less variable oxygen conditions in the northern part compared to the southern. The Northern Baltic Proper rarely experienced large volumes of anoxic water until the beginning of the 21<sup>st</sup> century. However oxygen conditions were still severe being well below 2 ml/l in a large part of the basin. After year 2000 the anoxic volume in the Northern Baltic Proper lays around 20% of the basins total volume until the effects of the inflow 2014 are seen in 2016. The offshore Gulf of Bothnia, including the Åland Sea does not suffer from low oxygen levels. The data coverage for the Gulf of Finland is poor in the 1990's in this dataset. The Bothnian Bay and Bothnian Sea are not included in figure 3 since they do not show any oxygen deficiency. However, there are indications that the oxygen conditions in the Bothnian Sea may also be declining (Ahlgren et al., 2017).

A map of the areal extent of hypoxia was produced by using gridded linear interpolation of a larger dataset and shows the area of bottoms affected by anoxia in 2017 in Figure 4. For a more detailed description of the dataset and method see Hansson et al 2018. The map shows that the Western Gotland Basin and the Northern Baltic Proper still suffer from a large areal extent of anoxia. The southern parts of the Eastern Gotland Basin remains oxygenated after the 2014 inflow, although with oxygen concentrations <2ml/l. Hydrogen sulphide was removed in large parts of the Eastern Gotland basin after the inflow 2014 but are now slowly building up again. In the map (Figure 4) this means that the central part of the Eastern Gotland Basin is still coloured black indicating anoxia.



**Figure 4** shows the regional distribution of the bottom areas where oxygen concentrations are below the critical level of 2 ml/l. The spatial change over time follows the changes discussed above.

## References

- Ahlgren J., Grimvall A., Omstedt A., Rolff C. and Wikner J. (2017). Temperature, DOC level and basin interactions explain the declining oxygen concentrations in the Bothnian Sea. *Journal of Marine Systems*. 170. . 10.1016/j.jmarsys.2016.12.010.
- Baltic Sea Hydrographic Commission. (2013). Baltic Sea Bathymetry Database version 0.9.3. Downloaded from <http://data.bshc.pro/>
- Hansson M., Viktorsson L., Andersson L. (2018). Oxygen Survey in the Baltic Sea 2017 - Extent of Anoxia and Hypoxia, 1960-2017. SMHI Report Oceanography no. 63.
- Michael Naumann, Volker Mohrholz and Joanna J. Waniek. (2018). WATER EXCHANGE AND CONDITIONS IN THE DEEP BASINS. HELCOM Baltic Sea Environment Fact Sheets. Online. 8 February 2018, <http://www.helcom.fi/baltic-sea-trends/environment-fact-sheets/>.

Vaquer-Sunyer, R. and Duarte, C. M. (2008). Thresholds of hypoxia for marine biodiversity, P. Natl. Acad. Sci. USA, 105, 15452–15455.

## Data

The surface water layer is defined as the average of 0-10 m and the bottom water is defined so it includes the deepest measurements at each station and the depths used for each basin are given in Figure 2 above. The winter is defined as December, January and February with December data from the year previous to January and February. The winter data is presented as belonging to the year of January and February.

Data for each station was selected by including all profiles within a 0.1 degree radius from the positions given in the map in Figure 2.

This study has made use of the official HELCOM COMBINE-programme dataset. Data is from the HELCOM data archive held at the International Council for the Exploration of the Sea (<http://www.ices.dk>). Data to ICES is normally reported by contracting parties on annual basis and all data for 2016 will therefore not be available until the upcoming year.

The map in Figure 2 and its basins are drawn from the shapefile “HELCOM subbasins with coastal and offshore division 2018” downloaded from the HELCOM map service, <http://maps.helcom.fi/website/mapservice/>. With exception of the Northern Baltic Proper and the Western Gotland Basin where the older version of the basin divisions are used so that the deep station BY31 can be used for the Northern Baltic Proper.

To calculate the volume of anoxic water in each basin, hypsographs were created from the Baltic Sea Bathymetry Database 500 m gridded bathymetry together with the HELCOM shapefile using the offshore basins shown in Figure 2.

## Metadata

### Technical information

### Quality information

Data collected for the HELCOM COMBINE programme is collected and analysed according to agreed methods (COMBINE Manual). Laboratories participate in quality assurance consortia such as QUASIMEME and are almost uniformly ISO accredited for good laboratory practice.