ABSTRACT

In this report the results from the Swedish environmental monitoring of offshore sediments are investigated. The *Swedish status and trend monitoring programme* (SSTMP) started in 2003 and includes sampling and analysis of organic pollutants and elements in surface sediment at 16 stations located in accumulation areas in the sea basins around Sweden (Fig. 1, Table 1). So far, sampling and analyses have been conducted at three occasions (2003, 2008 and 2014). This report summarizes the results and compares the levels in the different sea basins. Possible time trends are investigated although the time series so far is too short for a robust analysis.

Metals

Metals occur naturally in the environment and the levels in sediments in lakes and seas have a natural geographical variation. However, the levels of many metals have increased in the environment since the industrial revolution. Metal levels can also be affected by the presence or lack of oxygen in the surface sediments, that is, the redox conditions, as some metals are redox-sensitive and can react with other sediment components. Because of these factors – local or regional geological variation, anthropogenic influence, and redox conditions combined with sediment properties – the levels of metals in surface sediments vary between the sea basins.

The sediments of the Gulf of Bothnia are characterized by high levels of arsenic and cobalt, where at least arsenic levels are likely to be affected by high levels in the bedrock in the catchment area and a metal smelter point source. In the Baltic Proper, higher levels of cadmium, copper and zinc occur. The levels of cadmium exceed the ecotoxicologically based environmental quality standard for sediment at several of the monitoring stations in this part of the Baltic Sea. Cadmium, copper and zinc form insoluble sulfides under reducing conditions in the sediment, which may be one explanation for the high levels of these metals in surface sediment in the Baltic Proper, where anoxic conditions prevail. In addition to high levels in the Baltic Proper, cadmium levels are elevated in the Bothnian Bay and the far north of the Bothnian Sea. The copper and zinc levels are elevated at station SE-1 in the southern Bothnian Bay, which may be related to proximity to a point source. On the other hand, the chromium levels are noticeably lower in the Baltic Proper than in other sea areas. This could possibly also be related to the redox conditions in the sediment.

Mercury and lead levels are of similar magnitude for most stations but elevated at a few specific stations: in the southern Bothnian Bay (station SE-1) and in the Arkona basin in the southern Baltic Sea (station SE-12 and for lead also station SE-11). In the southern Bothnian Bay, there may be an impact from a point source, but the reason for the high levels in the southern Baltic is unclear. Compared with the stations in the Baltic Sea, the metal levels in sediment in the Kattegat and Skagerrak, on the Swedish west coast, are low.

Mercury, cadmium and lead are the metals of most environmental concern in the management of the Water and Marine Strategy Framework Directives within the EU. All three metals contribute to the Baltic Sea not achieving good environmental status in terms of pollution levels. Mercury is the substance that exceeds its environmental quality standards most frequently, mainly in biota, and more measures are needed to reduce levels further. Mercury can be transported long-range in the atmosphere and a large part of the mercury supplied to the Baltic Sea derive from atmospheric deposition. This means that global efforts to reduce the levels of this element are important. The observation of elevated levels of Hg in the sediment at specific stations also points to the importance of addressing point sources to reduce levels in the environment, for instance to remediate contaminated areas.

Organic pollutants

Organic pollutants are predominantly of anthropogenic origin, although a few, such as dioxins and PAHs, can also be formed in smaller amounts in natural processes such as forest fires.

Almost all the analysed organic pollutants occur at their highest levels in the Baltic Proper and the southern Baltic. This is the case for, e.g., DDE and DDD which are degradation products of DDT, HCHs, chlordanes, PCBs, dioxins, chlorinated aliphatics, PAHs, TBT, cybutryne, chlorinated paraffins (SCCP), octyl- and nonylphenols, phthalates, and BTEX (i.e., the sum of benzene, toluene, ethyl benzene and xylene). The sediments at the stations located in Kattegat and Skagerrak generally contain the lowest levels of pollutants although the concentrations of some substances are elevated here compared to the Gulf of Bothnia, such as PAHs.

The Baltic Proper is also the area with the highest sediment levels of total organic carbon (TOC). Because organic pollutants tend to partition to organic carbon, it is difficult to determine to what extent the higher pollutant levels in sediment in the Baltic Proper are related to higher TOC levels or to a higher pollutant load to this sea area. For some substances, e.g. DDT and its degradation products, HCHs, chlordanes and PCBs, the levels are elevated relative to the TOC levels in the southern Baltic Sea, especially at station SE-12. On the other hand, the pollutant levels are generally lower in the Gulf of Bothnia than what the correlation to TOC predicts, for example for SCCP, PAHs and the degradation products of DDT. The sorption to TOC is influenced by different factors such as salinity, pH and quality of the organic carbon, and the sorption can thus not be expected to be of the same magnitude in the entire Baltic Sea and the sea basins on the west coast of Sweden. Furthermore, the TOC levels in the sediment are affected by the redox conditions, with a slower degradation rate in the reducing conditions that prevail in the sediment in the Baltic Proper. Therefore, the relation between levels of pollutants and TOC in the water column is not necessarily reflected in the sediment.

One of the most problematic substances groups within the marine and water management are the **PBDEs**, which often exceeds the environmental quality standard (EQS) in biota. For sediment, no quality standard is available. In this study, PBDE levels in sediment tend to be highest in the Baltic Proper but they are generally in the same magnitude for the different sea areas, indicating that atmospheric deposition is an important transport route for PBDEs. However, station SE-16 in Skagerrak had relatively high levels both in 2008 and 2014. Since the levels increase as well as decrease at the different stations, no time trend can be established between 2008 and 2014.

Another problematic group of substances, often hindering water bodies to reach good environmental status within the water management due to exceeding threshold values in biota, are the **dioxins**. The dioxins have so far only been measured during the sampling in 2014, and the levels were then relatively similar in the various sea areas. However, the toxic equivalent (TEQ) levels are elevated in the southern Baltic Sea (station SE-12) and two stations in the Baltic Proper.

The **perfluorinated** substances, which were included in the monitoring survey in 2014, showed surprisingly high levels in the Gulf of Bothnia. The measured levels in this area are unreasonably elevated compared to the other sea basins considering that water and biota studies point to the opposite relationship, i.e. lower concentrations in the northern parts of the Baltic Sea than in the southern parts (Nguyen et al. 2017, Kirchgeorg et al. 2010, Faxneld et al. 2016). The elevated levels may be related to contamination of samples, but it cannot be ruled out that differences in sampling time may have affected the results (July–August in the Gulf of Bothnia compared to May–June for other areas).

For some substances, there are ecotoxicologically based EQS for sediment within the EU Water Framework Directive, and exceedances of the EQS mean that there can be a risk of negative effects on sediment-living organisms. For other substances, there are instead indicative values for sediments recently published by the Swedish Agency for Marine and Water Management. These indicative values are often based on ecotoxicological studies on aquatic organisms and then

recalculated to sediment organisms. They are thus more uncertain than the EQS. An exceedance of the values implies that more investigations should be carried out to determine if there may be risks of not achieving good status in the water body.

For **PAHs**, there are EQS for anthracene and fluoranthene in sediment. In this study, fluoranthene never exceeds its EQS while anthracene exceeds its EQS at the three stations on the west coast in 2003 but not at any station in 2008 and 2014. Of the four PAHs with indicative values (naphthalene, benzo(b)fluoranthene, benzo(a)pyrene and benzo(k)fluoranthene), naphthalene never exceeds its indicative value whereas the other three substances exceed theirs at several stations. In 2014, benzo(b)fluoranthene was the substance that most frequently exceeded its indicative value, but also benzo(a)pyrene and benzo(k)fluoranthene exceeded their indicative values in the southern Baltic and on the west coast of Sweden. These sea areas are generally the most problematic in terms of elevated and potentially toxic PAH levels in sediment, and this issue needs to be further investigated.

The indicative values for **nonyl-** and **octylphenol** were exceeded at some stations in 2003, mainly for octylphenol. In 2014, however, the indicative values were not exceeded at any of the stations. Likewise, the indicative value for **HCHs** was exceeded at two stations in 2008 but not at any station in 2014. The levels of **HCB**, **pentachlorobenzene**, **SCCP**, **trichloromethane**, **HBCDD** and **DEHP** never exceeded their respective indicative value.

Substances that have been banned or phased out are expected to display decreasing trends in the environment over time. In the case of **HCB**, however, the levels in sediment have increased between 2008 and 2014, especially at stations in the northern part of the Baltic Proper with a high sediment accumulation rate, where the surface sediment thus quickly responds to changes in pollutant levels in the water column. The trend for some stations shows gradually increasing levels of HCB from 2003 onwards. This trend has been analysed in more detail in a report by Josefsson (2018), and similar trends over time have also been seen in other matrices. However, the reasons why the levels of HCB are increasing are unclear.

The levels of **TBT** seem to decrease over time and are in 2014 below the reporting limit at all stations in the Gulf of Bothnia and on the west coast of Sweden. The levels have also decreased in the Baltic Proper and the southern parts of the Baltic Sea but are still exceeding the EQS at all stations in these areas. The levels have decreased mainly at stations in the northern Baltic Proper, whereas the trend over time is less clear for the southern stations. This can partly be connected to differences in sediment accumulation rate and thus to the age of the sampled sediment at the different stations. **Cybutryne** levels are above the reporting limit at the stations in the Baltic Proper in 2014 and exceeds its indicative value at four of the stations. The levels are higher in 2014 than 2008 at all six stations in the Baltic Proper except one. Since cybutryne has only been measured during two out of three survey years, it is not possible to determine whether the levels increase over time or not, but since the levels are highest at the stations with the highest sediment accumulation rates and thus the youngest surface sediment, it is likely that the trend in the marine environment is increasing. The use of cybutryne as a biocide was banned within EU in 2018 and the levels are therefore expected to decrease during future surveys. The use of TBT has also been prohibited and since 2003 it is not allowed in anti-fouling paint within the EU. However, TBT should continue to be monitored and actions should be taken to, for example, decrease the dispersal of the substances from old paint layers or from heavily polluted coastal sediments.

To conclude, the Baltic Proper sediments around Gotland and in the southern parts of the Baltic Sea have the highest load of environmental pollutants in this survey. For many substances, the highest levels occur in these basins, although the geographical pattern differs between individual substances. The levels of cadmium and TBT in these sea areas are high enough to pose a risk for sediment-living organisms. At the stations in the Baltic Proper, no signs of life have been observed as these bottoms and bottom waters are anoxic, but high pollutant levels in off-shore sediment can, for most substances, indicate that levels are elevated also in coastal sediments. The contaminants

may pose a greater risk there, as oxygen conditions are generally more favourable for benthic organisms. The levels of HCB do not exceed the indicative value for this substance in sediment, but levels seem to increase rather than decrease in the sediments despite global bans on intentional use and actions to decrease unintentional releases. The levels of dioxins and perfluorinated substances in the off-shore sediments have so far only been investigated during one survey and need to be monitored also during future surveys.