Sakrapport

Övervakning av metaller och organiska miljögifter i limnisk biota, 2013

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1 Introduction

This report summarises the monitoring activities within the National Swedish Contaminant Monitoring Programme for freshwater biota. It is the result of joint efforts from the Department of Applied Environmental Science at Stockholm University (analyses of organochlorines, flame retardants, perfluorinated compounds and trace metals); the Department of Chemistry at Umeå University (analyses of PCDD/PCDF); and the Department of Environmental Research and Monitoring at the Swedish Museum of Natural History (co-ordination, sample collection, administration and preparation, recording of biological variables, freeze-storage of biological tissues in the Environmental Specimen Bank (ESB) for retrospective studies, data preparation and statistical analyses). The monitoring programme is financed by the Environmental Protection Agency (EPA), Sweden.

The data in this report represents the bioavailable portion of the investigated contaminants i.e. the portion that has passed through biological membranes and may cause toxic effects. The objectives of the freshwater monitoring programme can be summarised as follows:

• to estimate the levels and normal variation of various contaminants in freshwater biota from representative sites throughout the country, uninfluenced by local sources;

• to describe the general contaminant load and to supply reference values for regional and local monitoring programmes;

• to monitor long term time trends and to estimate the rate of changes found; quantified objective: to detect an annual change of 10% within a time period of 10 years with a power of 80% at a significance level of 5%.

• to estimate the response in biota to actions taken to reduce the discharge of various contaminants; quantified objective: to detect a 50% decrease within a time period of 10 years with a power of 80% at a significance level of 5%.

• to detect incidents of regional influence or widespread incidents of ‘Chernobyl’- character and to act as watchdog monitoring to detect renewed usage of banned contaminants; quantified objective: to detect an increase of 200% a single year with a power of 80% at a significance level of 5%.

• to indicate large scale spatial differences; quantified objective: to detect differences of a factor 2 between sites with a power of 80% at a significance level of 5%.

• to explore the developmental and regional differences in the composition and pattern of e.g., PCBs, HCHs, DDTs, PCDD/F, PBDE/HBCD, PAHs and PFASs, as well as the ratio between various contaminants;

• the measured concentrations are relevant for human consumption as the species sampled are important for recreational fishing and are commonly consumed;

• all analysed, and a large number of additional specimens, of the annually systematically collected material are stored frozen in the Environmental Specimen Bank (ESB). This material
enables future retrospective studies of contaminants unknown or impossible to analyse today, as well as control analyses for suspected analytical errors;

- although the programme is focused on contaminant concentration in biota, the development of biological variables e.g., length, age and fat content, are monitored at all sites.

- some of the monitored lakes are chosen because of additional investigations of water chemistry and fish population carried out by the Swedish University of Agricultural Sciences (SLU) and the Swedish Board of Fisheries respectively. These lakes still fulfil the original selection criteria (see chapter 6).

- experience from the national programme with time series of >30 years can be used in the design of regional and local monitoring programmes;

- the unique material of high quality and long time series is further used to explore relationships between biological variables and contaminant concentrations in various tissues; the effects of changes in sampling strategy, the estimates of variance components and the influence on the concept of power etc.;

- the accessibility of high quality data collected and analysed in a consistent manner is an indispensable prerequisite to evaluate the validity of hypotheses and models concerning the fate and distribution of various contaminants. It could furthermore be used as input of ‘real’ data in model building activities concerning freshwater ecosystems;

- by using target levels criteria, the results from the investigations can be used as a tool to prioritize pollutants and to find localities where there is a risk for effects on biota.

The current report displays the time series of analysed contaminants in biota, and summarises the results from the statistical treatment. It does not in general give background or explanations to significant changes found in the time series. Increasing concentrations thus require intensified studies. Short comments are given for temporal trends and spatial variation. However, it should be stressed that geographical differences may not reflect anthropogenic influence, but may be due to factors such as productivity, temperature, pH etc.

One of the 16 national goals for the Swedish environment is an environment free of pollutants. The definition of this goal can be translated roughly as follows:

The environment shall be free from substances and metals that have been created or extracted by society and that can threaten human health or biological diversity.

The national monitoring programmes are a part of this aim and the results are important in the follow up work.
Acknowledgement

The National Swedish Contaminant Monitoring Programme for freshwater biota is financed by the Swedish Environmental Protection Agency. Henrik Dahlgren, Jill Staveley Öhlund and Eva Kylberg at the Swedish museum of Natural History are thanked for sample coordination and sample pre-preparation.
2 Summary

The environmental contaminants examined in this report can be classified into four groups – trace metals, chlorinated compounds, brominated flame retardants and perfluoroalkyl substances. Each of these contaminants has been examined in pike, perch and Arctic char from 32 lakes geographically spread from the north to the south of Sweden. The following summary examines overall trends, spatial and temporal, for the four groups.

Fat Content, Age and Length
Pike and perch displayed a decreasing trend in fat content at 50 % of the sites examined. An increasing trend in fat content could be seen for Arctic char from Lake Tjulträsk. The age of the perch sampled within the programme was somewhat lower in the most southern and south eastern parts of Sweden, whereas the length of the perch was homogenous in all lakes sampled.

Trace Metals
No general temporal trend could be observed for mercury in the freshwater environment. However, in all lakes and species, except Arctic char from Abiskojaure, these concentrations are above the suggested EU-target level of 20 ng/g wet weight.

Lead is generally decreasing over the study period (in time series of sufficient length), supposedly due to the elimination of lead in gasoline. In all lakes, Pb concentration is below the suggested EU-target level of 1.0 ug/g wet weight. This result has to be interpreted carefully as the recalculation between levels of lead in whole-body and liver is based on only one study.

Cadmium concentrations show no consistent trends over the monitored period. It is worth noting that despite several measures taken to reduce discharges of cadmium, the most recent concentrations in Arctic char and pike are similar to concentrations measured 30 years ago in the longer time series. In a majority of the lakes, Cd concentration in perch is above the suggested EU target level of 0.16 ug/g wet weight. This result has to be interpreted carefully as the recalculation between levels of cadmium in whole-body and liver is based on only one study.

Nickel concentrations showed a general increasing trend in perch. Chromium concentrations showed a general decreasing trend in all matrices during the monitoring period, but this decrease is most probably caused by the change of method for chromium analysis in 2004.

The concentrations of Zinc in perch liver are consistent in all lakes monitored. The concentrations are decreasing significantly at a majority of the perch sampling sites and in pike from Lake Storvindeln.

No general temporal trend were observed for copper, arsenic, silver, aluminium, tin, and bismuth concentrations in fish liver during the monitoring period.
**Chlorinated Compounds**

Generally, a decreasing trend was observed for all compounds (DDT’s, PCB’s, HCH’s, HCB and PCDD/PCDF) in all species examined (with a few exceptions).

The chlorinated compounds generally show a somewhat higher concentration in the southern parts of Sweden than in the north.

CB-153 concentration is below the suggested target level of 1.6 ug/g lipid weight in all species and areas, while the target level for CB-118 of 0.024 ug/g lipid weight is exceeded in perch from Lake Fysingen and Lake Krankesjön. For DDE the concentration is below the suggested target level of 0.005 ug/g wet weight for all species and areas. sHCH is below the suggested target level of 0.026 ug/g wet weight for all species and areas. HCB is below the suggested target level of 0.010 ug/g wet weight for all species and areas. TCDD-equivalents is below the suggested target level of 3.5 pg WHO05-TEQ/g wet weight for all species and areas.

**Brominated Flame Retardants**

No general linear trend is observed during the whole monitoring period for the BDEs. However the concentrations of BDEs in Lake Bolmen increased from the start of the monitoring period until the late 80s to the mid 90s and appear to have decreased since then. The lower brominated flame retardants (BDE-47, BDE-99 and BDE-100) peaked earlier than the higher (BDE-153 and BDE-154).

In all areas, BDE-47 is above the suggested target level of 0.0085 ng/g wet weight for all species.

The concentration of HBCDD is under LOQ in a majority of the freshwater samples.

**PFA(s)**

PFNA, PFDA, and PFUnDA all show significantly increasing concentrations in Arctic char liver from Lake Abiskojaure. PFDA, PFUnDA, PFDoDA, and PFTrDA show increasing trends in perch liver from Lake Skärgölen. A decreasing trend in PFOS is also indicated for perch in Lake Skärgölen for the last ten years.

In about 40 % of the perch lakes, PFOS concentrations in liver are above the suggested target level for PFOS in whole fish (9.1 ng/g wet weight). This result has to be interpreted with caution since no recalculation for the results from the liver analysis has been made, especially since liver in most cases contains higher concentrations of PFA(s) than muscle tissue.

**Priority Substances 2007 and 2010**

For four of the five priority substances - DEHP, HCBD, pentachlorobenzene, and organotin compounds – all or most values were below LOQ in the years examined. The chloroalkane SCCP did have values above LOQ, however, no consistent spatial variation was seen. The highest concentrations of SCCP (approximately 30 ng/g wet weight) were found in Lake Stor-Backsjön in Jämtland County and in Lake Fiolen in Kronobergs County. No statistical difference in concentration of SCCP between year 2007 and 2010 was found.

Information about the lakes sampled within the programme can be seen in Appendix 1.
3 Sampling

3.1 Collected specimens
In general, older specimens show a greater within-year variation compared to younger specimens. To increase the comparability between years, relatively young specimens are collected.

For many species, adults are more mobile than sub-adults. However, the specimens collected need to be of a certain size to allow individual chemical analysis, and thus the size and age of the specimens varies between species and sites (see chapter 4).

To be able to make a selection of individuals of equal size and weight for analysis, about 50 individuals are collected at each site. Only healthy looking specimens with undamaged skin are selected. The collected specimens are placed individually in polyethene plastic bags, deep frozen as soon as possible, and transported to the sample preparation laboratory.

Collected specimens not used in the annual contaminant monitoring programme are stored in the ESB (see Odsjö 1993 for further information). These specimens are registered - biological information, notes about available tissue amounts, together with a precise location in the cold-store are accessible from a database. These specimens are thus available for retrospective analyses or for control purposes.

Sampling of perch is carried out in the autumn (August-October) outside the spawning season. Char is sampled in the autumn (August-November), which is usually during spawning. Pike is collected in spring (April-May), during or soon after spawning.

Earlier in the programme’s existence, roach were collected from a number of lakes. This was either prior to or during the same time as the collection of perch. Since 2007, collection of roach has ceased. The lakes are shown in Figure 5.1 and 5.2.

3.2 Number of samples and sampling frequency
Previously, 10 specimens were analysed annually from each lake, either individually or as a pooled sample, but from 2011 and onward 12 samples are analysed (individually or as a pool). Historically, individual samples were common, but this has changed. Nowadays, the pooling of samples is done more or less exclusively for organic pollutants. This is mostly due to greater cost-effectiveness, which in turn allows analyses of additional locations and substances (Bignert et al. 2014).

Sampling is carried out annually in all time series. The sampling recommendation prescribes a range for age and/or weight of individuals. In a few cases it has not been possible to achieve the required number of individuals within that range. A lower frequency would result in a considerable decrease of statistical and interpretational power. During a period of reduced analytical capacity (2001-2005), several of the collected samples were not analysed but instead stored in the ESB. This situation has now changed, and since 2007 most material is analysed for most substances.

3.3 Sample preparation and registered variables
For each specimen total body weight, total length, body length, sex, age, gonad weight, state of nutrition, liver weight and sample weight are registered (see chapter 4 for descriptions of various age determination methods, depending on species).
The epidermis and subcutaneous fatty tissue are carefully removed. Muscle samples are taken from the middle dorsal muscle layer. The liver is completely removed and weighed. See TemaNord (1995) for further details about sample preparation.

Fish muscle tissue is analysed for organochlorines (DDTs, PCBs, HCHs, HCB and dioxins), PBDE (Poly Brominated Diphenyl Ethers), HBCD, and PAH (Polycyclic Aromatic Hydrocarbons). Fish liver is analysed for PFASs (Perfluoroalkyl substances).

In addition to the above analyses, muscle samples are analysed for mercury, and liver samples for lead, cadmium, nickel, chromium, copper, zinc, silver, aluminium, bismuth, tin and arsenic.

### 3.4 Age determination

Age determination in pike is made by reading the age of the cleithrum. In char and perch, the otoliths are used for age determination. After determination, the material is stored at room temperature, and filed using the relevant specimen number. This allows redetermination or a second opinion if there are uncertainties.

### 3.5 Data registration

Data are stored in a flat ASCII file in a hierarchical fashion where each individual specimen represents one level. Each measured value is coded; the codes are defined in a code list. The primary data files are processed through a quality control program. Suspect values are checked and corrected if necessary. Data are retrieved from the primary file into a table format suitable for further import to database or statistical programs.
4 Sample matrices

Of the three species collected, pike has been collected for the longest period. Perch is the most numerous in terms of both the number of collected individuals and the number of lakes.

Table 4.1. Number of individual specimens of various species sampled for analysis of contaminants within the base programme.

<table>
<thead>
<tr>
<th>Species</th>
<th>N of individual specimen</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pike</td>
<td>1284</td>
<td>23</td>
</tr>
<tr>
<td>Char</td>
<td>685</td>
<td>12</td>
</tr>
<tr>
<td>Perch</td>
<td>3721</td>
<td>65</td>
</tr>
<tr>
<td>Total</td>
<td>5690</td>
<td>100</td>
</tr>
</tbody>
</table>

4.1 Pike (Esox lucius)

Male pike become sexually mature between 1-3 years of age; females become sexually mature between 2-5 years of age. Spawning takes place during March - May. Adult pike feed on fish, snakes, frogs and young birds. Pike is a lean fish with an average muscle fat content of 0.56% (geometric mean of all samples).

Pike are collected from two sites: Lake Bolmen (Småland) since 1967, and Lake Storvindeln (Västerbotten) since 1968 (table 4.2). These two time series are probably the longest series of frozen stored fish in the world. They have been used for retrospective studies of contaminant concentrations for several pollutants.

The specimens from Lake Bolmen are collected during March - May. Specimens from Lake Storvindeln are collected mid-May with few exceptions.

Table 4.2. Number of samples, number of years collected and the arithmetic mean for weight, age and length with 95% confidence intervals for pike analysed at Lake Bolmen and Lake Storvindeln.

<table>
<thead>
<tr>
<th></th>
<th>Lake Bolmen (95% c.i)</th>
<th>Lake Storvindeln (95% c.i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n samples</td>
<td>581</td>
<td>703</td>
</tr>
<tr>
<td>n years</td>
<td>45</td>
<td>44</td>
</tr>
<tr>
<td>Age (years)</td>
<td>5.2 (5.0-5.4)</td>
<td>5.7 (5.5-5.9)</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>54.3 (53.4-55.2)</td>
<td>60.3 (59.4-61.2)</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>1158 (1087-1230)</td>
<td>1383 (1325-1442)</td>
</tr>
</tbody>
</table>

4.2 Arctic char (Salvelinus alpinus)

Arctic char become sexually mature between 3-5 years of age. Spawning takes place during August - October. Arctic char muscle tissue is the fattiest of the three species sampled, with an average fat content of about 1.5% (geometric mean of all samples).
Arctic char is collected in autumn from three sites: Lake Abiskojaure (Norrbotten) since 1981, Lake Tjulträsk (Västerbotten) since 1982, and Lake Stor-Björsjön since 2007 (table 4.3).

Table 4.3. Number of samples, number of years collected and arithmetic mean for weight, age and length with 95% confidence intervals for char analysed at Lakes Abiskojaure, Tjulträsk and Stor-Björsjön.

<table>
<thead>
<tr>
<th></th>
<th>Lake Abiskojaure (95% c.i.)</th>
<th>Lake Tjulträsk (95% c.i.)</th>
<th>Lake Stor-Björsjön (95% c.i.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n samples</td>
<td>372</td>
<td>186</td>
<td>69</td>
</tr>
<tr>
<td>n of years</td>
<td>32</td>
<td>31</td>
<td>6</td>
</tr>
<tr>
<td>Age (years)</td>
<td>5.2 (5.0-5.3)</td>
<td>5.2 (5.1-5.3)</td>
<td>5.6 (5.1-5.9)</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>27.4 (27.0-27.9)</td>
<td>26.6 (25.9-27.3)</td>
<td>27.0 (26.1-27.9)</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>226 (212-240)</td>
<td>197 (178-215)</td>
<td>177 (159-196)</td>
</tr>
</tbody>
</table>

4.3 Perch (*Perca fluviatilis*)

Perch is an omnivorous, opportunistic predatory fish. Male perch become sexually mature between 2-4 years of age; females become sexually mature between 3-6 years of age. Spawning takes place during April - June when water temperature is around 7-8°C. Perch muscle tissue is lean and contains approximately 0.4% fat (geometric mean of all samples). Perch is collected from 27 lakes (table 4.4). Sample collection occurs between August – October.
Table 4.4. Number of samples, number of years collected and arithmetic mean for age, length and weight with 95% confidence intervals for perch analysed within the monitoring programme.

<table>
<thead>
<tr>
<th>LAKE</th>
<th>N SAMPLES</th>
<th>N OF YEARS</th>
<th>AGE (YEARS)</th>
<th>LENGTH (CM) 95% C.I.</th>
<th>WEIGHT (G) 95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allgjuttern</td>
<td>99</td>
<td>10</td>
<td>4.5 (4.3-4.7)</td>
<td>18.3 (17.9-18.7)</td>
<td>60.0 (55.7-64.2)</td>
</tr>
<tr>
<td>Brännträsket</td>
<td>80</td>
<td>9</td>
<td>7.5 (7.1-8.0)</td>
<td>18.9 (18.5-19.2)</td>
<td>69.3 (64.3-74.3)</td>
</tr>
<tr>
<td>Bysjön</td>
<td>139</td>
<td>13</td>
<td>5.4 (5.2-5.7)</td>
<td>17.3 (17.1-17.5)</td>
<td>56.2 (54.0-58.3)</td>
</tr>
<tr>
<td>Bästetträsk</td>
<td>78</td>
<td>9</td>
<td>4.0 (3.8-4.2)</td>
<td>17.8 (17.4-18.1)</td>
<td>57.0 (53.4-60.5)</td>
</tr>
<tr>
<td>Degervattnet</td>
<td>140</td>
<td>13</td>
<td>5.9 (5.6-6.2)</td>
<td>17.9 (17.6-18.1)</td>
<td>63.1 (60.1-66.1)</td>
</tr>
<tr>
<td>Fiolen</td>
<td>130</td>
<td>13</td>
<td>5.0 (4.7-5.3)</td>
<td>18.2 (17.2-18.6)</td>
<td>69.1 (63.2-75.1)</td>
</tr>
<tr>
<td>Fräcksjön</td>
<td>80</td>
<td>8</td>
<td>5.2 (4.9-5.5)</td>
<td>16.6 (16.4-16.9)</td>
<td>46.8 (44.5-49.2)</td>
</tr>
<tr>
<td>Fysingen</td>
<td>70</td>
<td>8</td>
<td>4.5 (4.2-4.8)</td>
<td>16.9 (16.6-17.2)</td>
<td>49.9 (46.4-53.3)</td>
</tr>
<tr>
<td>Gipsjön</td>
<td>79</td>
<td>9</td>
<td>6.2 (5.9-6.4)</td>
<td>17.6 (17.3-17.9)</td>
<td>58.9 (55.5-62.2)</td>
</tr>
<tr>
<td>Hjärtsjön</td>
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<td>13</td>
<td>4.2 (3.9-4.4)</td>
<td>18.5 (18.2-18.8)</td>
<td>69.8 (65.4-74.3)</td>
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<tr>
<td>Horsan</td>
<td>105</td>
<td>8</td>
<td>5.4 (5.1-5.7)</td>
<td>18.2 (17.8-18.5)</td>
<td>60.5 (56.9-64.1)</td>
</tr>
<tr>
<td>Krageholmsjön</td>
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<td>17.0 (16.7-17.4)</td>
<td>63.0 (57.9-68.2)</td>
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<tr>
<td>Krankesjön</td>
<td>94</td>
<td>7</td>
<td>3.0 (2.8-3.1)</td>
<td>17.2 (16.9-17.6)</td>
<td>59.9 (55.8-64.0)</td>
</tr>
<tr>
<td>Lilla Öresjön</td>
<td>70</td>
<td>9</td>
<td>5.6 (5.3-5.9)</td>
<td>18.5 (18.0-19.0)</td>
<td>65.2 (59.3-71.0)</td>
</tr>
<tr>
<td>Limmingsjön</td>
<td>80</td>
<td>8</td>
<td>5.0 (4.8-5.2)</td>
<td>17.5 (17.2-17.8)</td>
<td>55.2 (52.8-57.6)</td>
</tr>
<tr>
<td>Remmarnsjön</td>
<td>140</td>
<td>13</td>
<td>6.7 (6.4-6.9)</td>
<td>19.3 (18.8-19.9)</td>
<td>84.0 (76.0-92.0)</td>
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<tr>
<td>Skärgölen</td>
<td>449</td>
<td>32</td>
<td>4.6 (4.5-4.7)</td>
<td>15.1 (15.0-15.3)</td>
<td>39.2 (37.6-40.8)</td>
</tr>
<tr>
<td>Spjutsjön</td>
<td>68</td>
<td>6</td>
<td>3.6 (3.4-3.8)</td>
<td>18.1 (17.8-18.4)</td>
<td>61.2 (57.5-64.9)</td>
</tr>
<tr>
<td>Stora Envättern</td>
<td>139</td>
<td>13</td>
<td>5.9 (5.7-6.2)</td>
<td>17.1 (16.8-17.3)</td>
<td>52.8 (50.1-55.5)</td>
</tr>
<tr>
<td>Stensjön</td>
<td>195</td>
<td>16</td>
<td>7.0 (6.7-7.2)</td>
<td>18.2 (18.0-18.4)</td>
<td>60.7 (58.7-62.6)</td>
</tr>
<tr>
<td>Stora Skärsjön</td>
<td>100</td>
<td>12</td>
<td>6.4 (6.1-6.6)</td>
<td>16.8 (16.5-17.1)</td>
<td>52.3 (48.9-55.7)</td>
</tr>
<tr>
<td>Stor-Backsjön</td>
<td>80</td>
<td>9</td>
<td>6.1 (5.9-6.4)</td>
<td>18.0 (17.8-18.3)</td>
<td>59.8 (57.2-62.4)</td>
</tr>
<tr>
<td>Svartsjön</td>
<td>82</td>
<td>7</td>
<td>6.0 (5.4-6.6)</td>
<td>15.6 (14.6-16.6)</td>
<td>43.9 (32.0-55.9)</td>
</tr>
<tr>
<td>Sänne</td>
<td>80</td>
<td>9</td>
<td>5.5 (5.2-5.8)</td>
<td>17.0 (16.7-17.3)</td>
<td>47.7 (43.8-51.6)</td>
</tr>
<tr>
<td>Tärnan</td>
<td>100</td>
<td>13</td>
<td>6.1 (5.7-6.5)</td>
<td>17.4 (17.0-17.8)</td>
<td>55.3 (50.8-59.9)</td>
</tr>
<tr>
<td>Älgsjön</td>
<td>90</td>
<td>8</td>
<td>5.8 (5.4-6.2)</td>
<td>17.0 (16.7-17.3)</td>
<td>50.5 (47.7-53.3)</td>
</tr>
<tr>
<td>Övre Skärsjön</td>
<td>120</td>
<td>13</td>
<td>6.9 (6.5-7.3)</td>
<td>17.9 (17.6-18.1)</td>
<td>58.9 (56.4-61.4)</td>
</tr>
</tbody>
</table>
5 Sampling sites

Location and names of the sample sites are shown in figure 5.1. The sampling sites are selected following the below criteria:

- lakes must not be influenced by local contamination;
- land use in the areas surrounding the lake should be well investigated and intensive rural areas avoided;
- lakes should preferably be placed high in the drainage system;
- the influence of liming activities should be avoided;
- lakes should have some protection against future exploitation;
- oligotrophic lakes are preferred;
- To facilitate regional comparisons, the selected lakes should preferably be as similar as possible concerning factors that could influence the concentration of various contaminants in the analysed biological tissues.

Generally, fish from eutrophic lakes show a slower response to changes in the amount of discharge in the lake compared to oligotrophic lakes, thus explaining the preference for oligotrophic lakes for these monitoring activities.

Sample collection occurs in 32 lakes distributed from north to south of Sweden (Fig. 5.1). Lakes where samples were collected earlier, but are no longer sampled, are shown in figure 5.2. The discontinued collection is mostly due to intentional changes e.g., liming. Samples from these locations are, however, still available in the ESB and could be used for comparisons and retrospective analyses. More information about the lakes currently sampled in the programme can be found in Annex 1.
Figure 5.1. Map showing lake location, including species and year, within the Swedish National Monitoring Programme.

* Roach has been collected before and/or at the same time as perch.
**Figure 5.2.** Location of lakes where sampling has been discontinued, including species sampled and years. In Lake Ämten, perch, roach and pike were collected during the stated years.

<table>
<thead>
<tr>
<th>NR</th>
<th>Sampling site</th>
<th>Species</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stormytjärn</td>
<td>Perch</td>
<td>1999-1999</td>
</tr>
<tr>
<td>2</td>
<td>Bysjön, Ockelbo</td>
<td>Perch</td>
<td>2005-2006</td>
</tr>
<tr>
<td>3</td>
<td>Ämten</td>
<td>P.R.P</td>
<td>1982-2000</td>
</tr>
<tr>
<td>4</td>
<td>Bylsjön</td>
<td>Perch</td>
<td>1982-96, 2006</td>
</tr>
<tr>
<td>5</td>
<td>Norra Yngem</td>
<td>Perch</td>
<td>2005-2006</td>
</tr>
<tr>
<td>6</td>
<td>Rutehogstjärn</td>
<td>Perch</td>
<td>1997-99</td>
</tr>
<tr>
<td>7</td>
<td>Kvarnsjön</td>
<td>Perch</td>
<td>1981-96</td>
</tr>
<tr>
<td>8</td>
<td>Stora Edsjoen</td>
<td>Perch</td>
<td>1984-96</td>
</tr>
<tr>
<td>9</td>
<td>Stora Pipsjön</td>
<td>Perch</td>
<td>1987-96</td>
</tr>
<tr>
<td>10</td>
<td>Pålgrasan</td>
<td>Perch</td>
<td>2005-2006</td>
</tr>
</tbody>
</table>
6 Analytical methods

6.1 Organochlorines and brominated flame retardants
The analyses of organochlorines and brominated flame retardants are carried out at the Institute of Applied Environmental Science (ITM) at Stockholm University. Specific analytical methods applied are described in the respective chapters where applicable. Before 1988, organochlorines were analysed by a packed column gas chromatography (GC). During 1988, analysis on a capillary column was introduced, allowing analysis of individual congeners (Eriksson et al. 1994). The extraction method originates from the method described by Jensen et al. (1983) where wet tissues are extracted with a mixture of polar and non-polar solvents. The organochlorines are analysed on a gas chromatograph (GC) equipped with a μ-electron capture detector (Eriksson et al. 1994). The BFRs are analysed by a GC connected to a mass spectrometer operating in electron capture negative ionization mode (NICI) (Sellström et al. 1998).

6.1.1 Quality assurance
Quality control for organochlorines has continuously improved over the last 20 years, resulting in accreditation in 1999. Assessment is performed once a year by the accreditation body SWEDAC. The laboratory is fulfilling the obligations in SS-EN ICO/IEC 17025:2005. The accreditation is valid for CB28, 52, 101, 118, 153, 138, 180, HCB, p,p'-DDE, p,p'-DDD, p,p'-DDE and α, β- and γ-HCH in biological tissues. So far the BFRs are not accredited but the analysis of BDE-47, 99,100, 153, 154 and HBCD are in many ways performed with the same quality aspects as the organochlorines.

The Quality Assurance program is based on the Quality Manual, standard operation procedures (SOPs) and supplements. The annual audit includes a review of the SOPs, reference materials, proficiency testing, filing system, qualifications of the staff, up-to-date record of the training of the staff (to be able to perform their assigned tasks), accredited methods and audit of the quality program.

6.1.2 Standards
The original of all standards are well documented with known purity and certified concentration with uncertainty for the solutions.

6.1.3 Selectivity
To have the possibility to control impurities in solvents, equipments and glassware, one blank sample is extracted together with each batch of environmental samples.

Coelution of PCB congeners and pesticides in GC analysis is dependent upon instrumental conditions such as column type, length, internal diameter, film thickness and oven temperature. To minimize possible coelutions, two 60 m columns are used in parallel, the commonly used 5 % phenyl-methyldisilicone phase and the more polar 14 % cyanopropylphenyl-methyldisilicone phase. The only remaining known coelution is for CB-138, which coelutes with CB-163 (Larsen et al. 1990). Therefore CB-138 is reported as CB138+163. PBDE and HBCD are analysed on a 30 m DB-5 MS column, monitoring m/z 79 and 81.

When introducing a new matrix one of the samples is re-extracted with a mixture of more polar solvents for control of no remaining contaminants in the matrix residual.
Samples from new matrixes and samples from already established matrixes from new sampling locations are also examined for suitable internal standards.

### 6.1.4 Reference Material

Two laboratory reference materials (LRM) are used as extraction controls, chosen with respect to their lipid content and level of contaminants. The controls consist of herring respectively salmon muscle, homogenised in a household mixer and stored in aliquots in airtight bags of aluminium laminate at -80°C. At every extraction event one extraction control is extracted as well.

The certified reference material CRM 718 (herring muscle) is analysed for PCB once a year.

### 6.1.5 Proficiency testing

Concerning PCBs and pesticides, the laboratory has participated in the periodic QUASIMEME proficiency testing since 1993, with two rounds every year, each one containing two samples. Around 95% of all reported values have been satisfactory according to QUASIMEME, meaning they have been within +/- 2 standard deviations of the assigned value. In 2000, the laboratory participated in the first interlaboratory study ever performed for PBDEs and HBCD, contaminants that since 2001 are incorporated in the QUASIMEME proficiency testing scheme. Around 80% of the values the laboratory has produced during the years have been satisfactory according to QUASIMEME.

### 6.1.6 Quantification limits and uncertainty in the measurements

Calculation of the uncertainty in the measurement is based on the Nordtest Report TR 537 “Handbook for calculation of measurement uncertainty in environmental laboratories”, where the within-laboratory reproducibility is combined with estimate of the method and laboratory bias. The within-laboratory reproducibility is calculated from LRM from more than 8000 PCB- and pesticide values during a period of nearly 20 years and around 2000 BDE- and HBCD values during nearly 15 years. The bias is estimated from proficiency testing of more than 8 samples during at least 4 years. The bias for PBDE is used also for HBCD since no reliable proficiency testing (or certified reference material) exists today. Finally, the expanded uncertainty is calculated, using a coverage factor of 2 to reach approximately 95% confidence level (table 6.3). The reproducibility for the PCBs and pesticides follows the theory stated by Horwitz where the relative standard deviation increase when the concentration level decrease (Horwitz and Albert, 2006). The reproducibility for the PBDEs and HBCD follows a function where the relative standard deviations increase first at the very lowest concentration.

#### Table 6.3. Expanded uncertainty (%) at different concentrations

<table>
<thead>
<tr>
<th></th>
<th>CB28,101,118,153,138,180,HCB</th>
<th>CB52</th>
<th>HCH α, β, γ</th>
<th>ppDDE</th>
<th>ppDDT</th>
<th>ng/g lw</th>
<th>PBDEs</th>
<th>HBCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-50</td>
<td>36</td>
<td>49</td>
<td>40</td>
<td>43</td>
<td></td>
<td>0.2-1</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>4-50</td>
<td>29</td>
<td>30</td>
<td>34</td>
<td>31</td>
<td>52</td>
<td>&gt; 2</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>&gt; 50</td>
<td>29</td>
<td>30</td>
<td>34</td>
<td>31</td>
<td>38</td>
<td>2-25</td>
<td>103</td>
<td></td>
</tr>
</tbody>
</table>

The quantification limit is estimated to approximately 2 ng/g fat weight for all analysed PCBs, α, β, γ–HCH, HCB, pp-DDE and pp-DDD and 4 ng/g fat weight for pp-DDT. For all
analysed PBDEs the quantification limit is estimated to approximately 0.2 ng/g fat weight and for HBCDD 2 ng/g.

6.2 Dioxins, dibenzofurans and dioxin-like PCBs
The analyses of dioxins and dioxin-like PCBs are carried out at the Department of Chemistry, Umeå University. The extraction method is described by Wiberg et al. (1998), the clean-up method by Danielsson et al. (2005), and the instrumental analysis (GC-HRMS) by Liljelind et al. (2003). The laboratory participates in the annual FOOD intercalibration rounds, including laboratory reference material (salmon tissue) with each set of samples.

6.3 Perfluoroalkyl substances
The analyses of perfluoroalkyl substances are carried out at the Department of Applied Environmental Science (ITM), Stockholm University.

6.3.1 Sample preparation and instrumental analysis
A sample aliquot of approximately 1.0 g homogenized tissue in a polypropylene (PP)-centrifuge tube was spiked with 10 ng each of a suite of mass-labelled internal standards (18O- or 13C-labelled perfluoroalkyl sulfonates and carboxylic acids). The samples were extracted twice with 5 mL of acetonitrile in an ultrasonic bath. Following centrifugation, the supernatant extract was removed and the combined acetonitrile phases were concentrated to 1 mL under a stream of nitrogen. The concentrated extract underwent dispersive clean-up on graphitized carbon and acetic acid. A volume of 0.5 mL of the cleaned-up extract was added to 0.5 mL of aqueous ammonium acetate. Precipitation occurred and the extract was centrifuged before the clear supernatant was transferred to an autoinjector vial for instrumental analysis and the volume standards M8PFOA and M8PFOS were added. Aliquots of the final extracts were injected automatically on an ultra performance liquid chromatography (UPLC) system (Acquity, Waters) coupled to a tandem mass spectrometer (MS-MS; Xevo TQS, Waters). Compound separation was achieved on a BEH C18 UPLC column (1.7 µm particles, 50 × 2.1 mm, Waters) with a binary gradient of ammonium acetate buffered methanol and water. The mass spectrometer was operated in negative electrospray ionisation mode. Quantification was performed in selected reaction monitoring chromatograms using the internal standard method.

6.3.2 Quality control
The extraction method employed in the present study (with the exception of the concentration step) has previously been validated for biological matrices and showed excellent analyte recoveries ranging between 90 and 110% for PFCAs from C6 to C14 (Powley & Buck 2005). Including extract concentrations, we determined recoveries between 70 and 90% for C6- to C10-PFCAs and 65 – 70% for C11-C15 PFCAs. Extraction efficiencies for perfluorosulfonates (PFSAs), including perfluorooctane sulfonamide (FOSA), were determined to 70 – 95%. Method quantification limits (MQLs) for all analytes were determined on the basis of blank extraction experiments and ranged between 0.05 and 0.5 ng/g wet weight for the different compounds. A fish tissue sample used in an international inter-laboratory comparison (ILC) study in 2007 (van Leeuwen et al. 2009) was analysed as control sample along with all sample batches. The obtained concentrations were in good
agreement with the mean concentrations from the ILC study for all seven compounds quantified in the ILC.

6.4 Trace metals

The analyses of trace metals are carried out at the Analytical Environmental Chemistry Unit at the Department of Applied Environmental Science (ITM), University of Stockholm.

6.4.1 Sample preparation and instrumental analysis

Analytical methods for metals in liver are performed according to the Swedish standards SS-EN 13805 (Foodstuffs – Determination of trace elements – Pressure digestion) and SS-EN ISO 17294-2 (Water quality – Application of inductively coupled plasma mass spectrometry (ICP-MS) – Part 2: Determination of 62 elements), and for mercury according to the US EPA Method 7473 (mercury in solids and solutions by thermal decomposition, amalgamation and atomic absorption spectrophotometry).

6.4.2 Quality control

The laboratory participates in the periodic QUASIMEME intercalibration rounds.

6.4.3 Reference Material

CRMs (certified reference material) used for mercury are:
DORM-2 and DORM-3 (dogfish muscle)
For all other metals, CRMs used are:
DOLT-3 (dogfish liver)
NIST 1566 (oyster tissue)
TORT-2 (lobster hepatopancreas)
7 Statistical treatment and graphical presentation

7.1 Trend detection
One of the main objectives of the monitoring programme is to detect trends. Trend detection is carried out in three steps.

7.1.1 Log-linear regression analyses
Log-linear regression analyses are performed for the entire investigated time period and also for the most recent ten years for longer time series.

The slope of the line describes the yearly percentage change. A slope of 5% implies that the concentration is halved in 14 years, whereas 10% corresponds to a similar reduction in 7 years, and 2% in 35 years (table 7.1).

<table>
<thead>
<tr>
<th>Increase</th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
<th>7%</th>
<th>10%</th>
<th>12%</th>
<th>15%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70</td>
<td>35</td>
<td>24</td>
<td>18</td>
<td>14</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Decrease</td>
<td>69</td>
<td>35</td>
<td>23</td>
<td>17</td>
<td>14</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

7.1.2 Non-parametric trend test
The regression analysis presumes, among other things, that the regression line gives a good description of the trend. The leverage affect of points at the end of the line is a well-known fact. An exaggerated slope, caused ‘by chance’ by a single or a few points at the end of the line increases the risk of a false significant result when no real trend exist. A non-parametric alternative to the regression analysis is the Mann-Kendall trend test (Gilbert 1987; Helsel and Hirsch 1995; Swertz 1995). This test generally has lower power than the regression analysis, and does not take into account differences in magnitude of the concentrations - it only counts the number of consecutive years where the concentration increases or decreases compared with the year before. If the regression analysis yields a significant result but the Mann-Kendall test does not, the explanation could be either that the latter test has lower power, or that the influence of endpoints in the time series has become unaccountably large on the slope. Hence, the eighth line reports Kendall's 'τ', and the corresponding p-value. The Kendall's 'τ' ranges from 0 to 1 like the traditional correlation coefficient ‘r’ but will generally be lower. ‘Strong’ linear correlations of 0.9 or above, corresponds to τ-values of about 0.7 or above (Helsel and Hirsch 1995, p. 212). This test was recommended by the Swedish EPA for use in water quality monitoring programmes using annual samples in an evaluation comparing several other trend tests (Loftis et al. 1989).

7.1.3 Non-linear trend components
An alternative to the regression line used to describe development over time is a type of smoothed line. The smoother applied here is a simple 3-point running mean smoother fitted to the annual geometric mean values. In cases where the regression line is a poor fit, the smoothed line may be more appropriate. The significance of this line is tested using an
ANOVA, where the variance explained by the smoother and the regression line is compared with the total variance. This procedure is used in assessments at ICES and is described by Nicholson et al. (1995).

7.2 Outliers and values below the detection limit

Observations further from the regression line than what is expected from the residual variance around the line are subject to special concern. These deviations may be caused by an atypical occurrence of something in the physical environment, a changed pollution load, or errors in the sampling or analytical procedure. The procedure to detect suspected outliers in this context is described by Hoaglin and Welsch (1978). It makes use of the leverage coefficients and the standardised residuals. The standardised residuals are tested against a $t_{0.05}$ distribution with $n-2$ degrees of freedom. When calculating the $i$th standardised residual, the current observation is left out, implying that the $i$th observation does not influence the slope or the variance around the regression line. The suspected outliers are merely indicated in the figures and are included in the statistical calculations, except in a very few cases, which are pointed out in the figures.

Values reported that are below the quantification limit are substituted using the reported LOQ (or in the case that this information is missing the minimum value for the current year) divided by the square root of 2.

7.3 Plot Legends

Analytical results from each of the investigated elements are displayed graphically. A selection of sites and species are presented as figures; no time series is shorter than four years.

Each figure displays the geometric mean concentration of each year (circles) together with the individual analyses (small dots) and the 95% confidence intervals of the geometric means. The overall geometric mean value for the time series is depicted as a thin horizontal line.

The trend for the whole time period is presented by a regression line (plotted if $p < 0.10$, two-sided regression analysis); $p < 0.05$ is presented by a red line and $0.05 < p < 0.10$ is presented by a dashed blue line. The trend for the last ten years is plotted if $p < 0.2$ and $p < 0.05$ is presented by a red line and $0.05 < p < 0.2$ is presented by a dashed light blue line. Ten years is often a too short period to statistically detect a trend unless it is of considerable magnitude. Nevertheless, the ten year regression line will indicate a possible change in the direction of a trend. Furthermore, the residual variance around the line compared to the residual variance for the entire period will indicate if the sensitivity has increased as a result of e.g., improved sampling technique or that problems in the chemical analysis have disappeared.

A smoother is applied to test for non-linear trend components (see section 7.1.3). The smoothed line is plotted if $p < 0.10$ and $p < 0.05$ is presented by a red line and $0.05 < p < 0.10$ is presented by a dashed blue line. A broken line segment indicates a gap in the time series with a missing year.

The log-linear regression lines fitted through the geometric mean concentrations follow smooth exponential functions.
A cross inside a circle indicates a suspected outlier (see section 7.3). Suspected outliers are indicated in the figures and are included in the statistical analyses except in a few cases, as pointed out in the figures.

Each figure has a header with species name and sampling locality. Below the header, the results from several statistical analyses are reported:

Tv=…, lp% or dp%=… T is the target level (see Chapter 10) calculated on a lipid weight base (lp%) or on dry weight base (dp%), original target value was given on a wet weight basis.

n(tot)= first line reports the total number of analyses included together with the number of years ( n(yrs)= );

m= overall geometric mean value together with its 95% confidence interval is reported on the second line of the plot (N.B. d.f. = number of years -1);

slope= reports the slope, expressed as the yearly percentage change together with its 95% confidence interval;

CV = reports the coefficient of variation around the regression line, as a measure of between-year variation, together with the lowest detectable change in the current time series with a power of 80%, one-sided test, α=0.05. The last figure on this line is the estimated number of years required to detect an annual change of 10% with a power of 80%, one-sided test, α=0.05.

power= reports the power to detect a log-linear trend in the time series (Nicholson and Fryer 1991). The first number represents the power to detect an annual change of 5% with the number of years in the current time series. The second number is the power estimated as if the slope were 5% per year and the number of years were ten. The third number is the lowest detectable change (given in percent per year) for a ten year period with the current between year variation at a power of 80%. The results of the power analyses from the various time series are summarised in chapter 8;

r²= reports the coefficient of determination (r²) together with a p-value for a two-sided test (H₀: slope = 0) i.e. a significant value is interpreted as a true change, provided that the assumptions of the regression analysis are fulfilled;

y(11)= reports the concentration estimated from the regression line for the last year together with a 95% confidence interval e.g., y(06)=2.55(2.17, 3.01) is the estimated concentration of year 2006 where the residual variance around the regression line is used to calculate the confidence interval. Provided that the regression line is relevant to describe the trend, the residual variance might be more appropriate than the within-year variance in this respect;

tao= reports Kendall's 'τ', and the corresponding p-value;

sd(sm)= reports the coefficient of variation around the smoothed line. The significance of this line can be tested by means of an ANOVA (see section 7.1.3). The p-value is reported for this test. A significant result will indicate a non-linear trend component. After the p-value, the minimum trend (percentage per year) likely to be detected at a power of 80% during a period of 10 years, should a log-linear trend occur, is shown. This estimate is compensated for the loss of degrees of freedom, considering the smoother.

Below these nine lines are additional lines with information concerning the regression of the last ten years.
In a few cases where an extreme outlying observation may compromise the confidence in the regression line, the ordinary regression line is replaced by the ‘Kendall-Theil Robust line’ (Helsel and Hirsch 1995, page 266). In these cases only the ‘Theil’-slope and Kendall’s ‘τ’ are reported.

7.4 Legend for the three dimensional maps

The height of the bars represents the arithmetic mean for the last three years, or less if results are not available. The bars are split into three sections of equal size (that each represents the same concentration).

Three dimensional maps with target levels are only presented if the target level lies within the concentration range. The green section of the bars denotes arithmetic mean concentrations below the suggested target level and the red sections denote arithmetic mean concentrations above the suggested target level.
8 The power of the programme

Before starting to interpret the results from the statistical analyses of the time series, it is essential to know with what power temporal changes can be detected (i.e., the chance to reveal true trends with the investigated matrices). It is crucial to know whether a negative result of a trend test indicates a stable situation, or if the monitoring programme is too poor to detect even serious changes in the contaminant load in the environment. One approach to this problem is to estimate the power of the time series based on the ‘random’ between-year variation. Alternatively, the lowest detectable trend could be estimated at a fixed power to represent the sensitiveness of the time series.

The first task would thus be to estimate the ‘random’ between-year variation. In the results presented below, this variation is calculated using the residual distance from a log-linear regression line. In many cases the log-linear line, fitted to the current observations, seems to be an acceptable ‘neutral’ representation of the true development of the time series. In cases where a significant ‘non-linear’ trend has been detected (see chapter 7) the regression line may not serve this purpose; hence the sensitiveness- or power-results based on such time series are marked with an asterix in the following tables. These results are also excluded from estimations of median performances.

Another problem is that a single outlier could ruin the estimation of the between-year variation. In the present results suspected outliers are included, which means that the power and sensitiveness might be underestimated.

Results from the longest timeseries for most of the contaminants, Lake Abiskojaure (Arctic char), Lake Bolmen and Lake Storvindeln (pike) and Lake Skärgölen (perch), are presented in Table 8.1, 8.2, 8.3 and 8.4.

Table 8.1 shows the number of years that various contaminants have been analysed and detected from the monitored sites.
Table 8.1. Number of years that various contaminants have been analysed and detected.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Lake Abiskojaure</th>
<th>Lake Storvindeln</th>
<th>Lake Bolmen</th>
<th>Lake Skärgölen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>31</td>
<td>40</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>Pb</td>
<td>31</td>
<td>41</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Cd</td>
<td>31</td>
<td>41</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Ni</td>
<td>31</td>
<td>41</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Cr</td>
<td>31</td>
<td>41</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Cu</td>
<td>31</td>
<td>41</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>Zn</td>
<td>31</td>
<td>41</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>As</td>
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<tr>
<td>Ag</td>
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<td>9</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Al</td>
<td>13</td>
<td>12</td>
<td>10</td>
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<tr>
<td>Bi</td>
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<td>Sn</td>
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<td>CB-153</td>
<td>23</td>
<td>22</td>
<td>21</td>
<td>7</td>
</tr>
<tr>
<td>DDE</td>
<td>27</td>
<td>41</td>
<td>42</td>
<td>13</td>
</tr>
<tr>
<td>γ-HCH</td>
<td>23</td>
<td>15</td>
<td>21</td>
<td>7</td>
</tr>
<tr>
<td>HCB</td>
<td>23</td>
<td>22</td>
<td>21</td>
<td>7</td>
</tr>
<tr>
<td>TCDD-eqv (PCDD/PCDF)</td>
<td>-</td>
<td>12</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>PFOS</td>
<td>19</td>
<td>-</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>BDE-47</td>
<td>22</td>
<td>-</td>
<td>37</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 8.2 shows the number of years required to detect an annual change of 10% with a power of 80%. The power is to a great extent dependent of the length of the time series. The possibility to statistically verify an annual change of 10% at a power of 80% generally requires 10-20 years for organic substances.

Table 8.2. The number of years required to detect an annual change of 10% with a power of 80%.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Lake Abiskojaure</th>
<th>Lake Storvindeln</th>
<th>Lake Bolmen</th>
<th>Lake Skärgölen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Pb</td>
<td>14</td>
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<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Cd</td>
<td>16</td>
<td>11</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Ni</td>
<td>14</td>
<td>12</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Cr</td>
<td>16</td>
<td>17</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Cu</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>9</td>
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<tr>
<td>Zn</td>
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<tr>
<td>As</td>
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<tr>
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<tr>
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<td>Sn</td>
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<td>CB-153</td>
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<td>9</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>DDE</td>
<td>13</td>
<td>11</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>γ-HCH</td>
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<td>12</td>
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<td>7</td>
</tr>
<tr>
<td>HCB</td>
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<td>11</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>TCDD-eqv (PCDD/PCDF)</td>
<td>-</td>
<td>13</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>PFOS</td>
<td>14</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>BDE-47</td>
<td>25</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
</tbody>
</table>
The lowest trend that is possible to detect within a 10 year period with a power of 80% is presented both for the entire time series (table 8.3).

Table 8.3. The lowest trend possible to detect (in %) within a 10 year period with a power of 80% for the entire time series.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Lake Abiskojaure</th>
<th>Lake Storvindeln</th>
<th>Lake Bolmen</th>
<th>Lake Skärgölen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>7.4</td>
<td>9.5</td>
<td>6.9</td>
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</tr>
<tr>
<td>Pb</td>
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<td>Cd</td>
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<td>Ni</td>
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</tr>
<tr>
<td>Cr</td>
<td>22</td>
<td>24</td>
<td>32</td>
<td>44</td>
</tr>
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<td>Cu</td>
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<td>9.1</td>
<td>9.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Zn</td>
<td>7.2</td>
<td>7.1</td>
<td>16</td>
<td>3.4</td>
</tr>
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<tr>
<td>Ag</td>
<td>18</td>
<td>4.2</td>
<td>13</td>
<td>8.7</td>
</tr>
<tr>
<td>Al</td>
<td>16</td>
<td>18</td>
<td>9.3</td>
<td>13</td>
</tr>
<tr>
<td>Bi</td>
<td>4.0</td>
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<tr>
<td>Sn</td>
<td>16</td>
<td>21</td>
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<td>14</td>
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<td>11</td>
<td>6.9</td>
<td>12</td>
<td>5.4</td>
</tr>
<tr>
<td>DDE</td>
<td>14</td>
<td>10</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>γ-HCH</td>
<td>25</td>
<td>13</td>
<td>8.7</td>
<td>4.2</td>
</tr>
<tr>
<td>HCB</td>
<td>8.3</td>
<td>10</td>
<td>13</td>
<td>0.65</td>
</tr>
<tr>
<td>TCDD-eqv (PCDD/PCDF)</td>
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<tr>
<td>PFOS</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>BDE-47</td>
<td>49</td>
<td>-</td>
<td>18</td>
<td>-</td>
</tr>
</tbody>
</table>

The power to detect an annual change of 10% for the monitoring period i.e., the length of the timeseries, varies depending on site and investigated contaminant (table 8.4). For the longest time series, the estimated power is close to 100% in most cases.
Table 8.4. Power to detect an annual change of 10% for the entire monitoring period. The length of the time series varies depending on site and investigated contaminant. In cases where considerable increased power has been achieved during the most recent ten years period, this value has been used.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Lake Abiskojaure</th>
<th>Lake Storvindeln</th>
<th>Lake Bolmen</th>
<th>Lake Skärgölen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Pb</td>
<td>1.0</td>
<td>1.0</td>
<td>0.87</td>
<td>0.99</td>
</tr>
<tr>
<td>Cd</td>
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<td>1.0</td>
<td>0.89</td>
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</tr>
<tr>
<td>Ni</td>
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<td>1.0</td>
<td>0.83</td>
<td>0.63</td>
</tr>
<tr>
<td>Cr</td>
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<td>1.0</td>
<td>0.44</td>
<td>0.16</td>
</tr>
<tr>
<td>Cu</td>
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<td>1.0</td>
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<td>1.0</td>
</tr>
<tr>
<td>Zn</td>
<td>1.0</td>
<td>1.0</td>
<td>0.95</td>
<td>1.0</td>
</tr>
<tr>
<td>As</td>
<td>0.96</td>
<td>0.75</td>
<td>1.0</td>
<td>0.25</td>
</tr>
<tr>
<td>Ag</td>
<td>0.37</td>
<td>1.0</td>
<td>0.46</td>
<td>0.97</td>
</tr>
<tr>
<td>Al</td>
<td>0.81</td>
<td>0.60</td>
<td>0.85</td>
<td>0.72</td>
</tr>
<tr>
<td>Bi</td>
<td>0.95</td>
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<td>0.26</td>
<td>0.36</td>
</tr>
<tr>
<td>Sn</td>
<td>0.31</td>
<td>0.15</td>
<td>0.37</td>
<td>0.46</td>
</tr>
<tr>
<td>CB-153</td>
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<td>0.77</td>
</tr>
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<td>1.0</td>
<td>0.58</td>
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<td>γ-HCH</td>
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<td>0.93</td>
</tr>
<tr>
<td>HCB</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>TCDD-&lt;sub&gt;eqv&lt;/sub&gt; (PCDD/PCDF)</td>
<td>-</td>
<td>0.77</td>
<td>0.85</td>
<td>1.0</td>
</tr>
<tr>
<td>PFOS</td>
<td>0.98</td>
<td>-</td>
<td>-</td>
<td>0.99</td>
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<td>BDE-47</td>
<td>0.66</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
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</tbody>
</table>
9 Pollutant regulation: conventions and legislation

9.1 The Stockholm Convention on Persistent Organic Pollutants
The Stockholm Convention on Persistent Organic Pollutants (POPs) is an international agreement requiring measures for reducing or preventing release of dangerous substances into the environment. The Stockholm Convention was adopted in 2001 and entered into force in 2004. The convention deals with organic compounds that are persistent and remain in the environment for a long time, have a potential for long-range transport, bioaccumulate in fatty tissues of organisms, and have adverse effects on human health or the environment. Initially, 12 chemicals were included in the treaty in 2001 (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene, PCB, hexachlorobenzene, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans). In May 2009, an amendment was adopted into the convention, and nine additional chemicals were listed as POPs (hexabromodiphenylether, tetra-/pentabromodiphenylether, chlordecone, hexabromobiphenyl, lindane, α- and β–hexachlorocyclohexane, pentachlorobenzenen and PFOS). In May 2011 an amendment was adopted into the convention and technical endosulfan and its related isomers were added to the list with a specific exemption. Five more substances have been nominated to be included on the list, and are currently under review by the Persistent Organic Pollutants Review Committee (short-chained chlorinated paraffins, hexabromocyclododecane, chlorinated naphtalenes, hexachlorobutadiene, and pentachlorophenol) (www.pops.int).

9.2 The Convention on Long-Range Trans boundary Air Pollution
The Convention on Long Range Trans boundary Air Pollution (CLRTAP) was initiated in 1972 at a United Nations Conference on the Human Environment in Stockholm. After the scientific findings that acidification in Swedish lakes was caused by sulphur emission from continental Europe, the necessity for international measures to reduce emissions to air that had environmental effects far from its source, was addressed. In 1979, the convention was signed in Geneva, and entered into force in 1983. Initially, the convention focused on sulphuric compounds causing acidification, but later eight protocols were added for other groups of substances e.g., nitrogen oxides, volatile organic compounds (VOCs) and persistent organic pollutants (POPs) (http://www.unece.org/env/lrtap/lrtap_h1.htm).

9.3 EU chemical legislation

9.3.1 REACH
REACH is the EU chemicals policy that entered into force on the 1st of June 2007 (EC 1907/2006). REACH stands for Registration, Evaluation, Authorization and Restriction of Chemical Substances. The policy places more responsibility on industry, and importers and users have to gather information about their chemicals, which they then report to the European Chemicals Agency (ECHA) based in Helsinki. ECHA manages REACH by gathering information and keeping databases of chemicals used in the EU. (http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm).
9.3.2 RoHS directive

The Directive on the Restriction of Hazardous Substances (RoHS) was adopted in February 2003. The RoHS directive reduces the use of six chemical substances in electrical or electronic products that were released on the market after July 2006. These substances are mercury, cadmium, lead, chromium VI, polybrominated biphenyls and polybrominated diphenyl ethers. The maximum allowed amount of these substances (based on weight) is 0.01% for cadmium, and 0.1% for the other substances. (http://www.kemi.se/templates/Page___3794.aspx).

9.3.3 Water Framework Directive

The Water Framework Directive (WFD) aims to achieve good ecological and chemical status of all surface waters and ground water bodies in the EU by 2015. The WFD was adopted in October 2000, and deals with fresh water, coastal-zone and estuary waters. Within the WFD, a list of 33 prioritized substances has been established, and eight additional substances were later added. To evaluate if “good chemical status” has been achieved, threshold values, or Environmental Quality Standards (EQS), have been established for the listed substances (see chapter 10). It is the responsibility of each member state to assess and report if the goal has been fulfilled. (http://ec.europa.eu/environment/water/water-framework/index_en.html).

9.3.4 Marine Strategy Framework Directive

The Marine Strategy Framework Directive (MSFD) was adopted in 2008 with the aim of achieving good environmental status in all European marine waters by 2020. Two of eleven descriptors that have been identified for good environmental status deal with contaminants. These are “contaminants and pollution effects” and “contaminants in fish and other sea food”. The implementation for Swedish waters will be based on the regional international conventions of OSPAR and HELCOM. (http://ec.europa.eu/environment/water/index_en.htm).

9.4 Swedish chemical legislation

One of the 16 Swedish environmental quality objectives is “A non-toxic environment”, which means that concentrations of non-naturally occurring substances should be close to zero, and naturally occurring substances should be close to background concentrations. Their impact on human health and ecosystems should be negligible (http://www.miljomal.se/4-Giftfri-miljo/Definition/). The agency responsible for coordinating this work is the Swedish Chemicals Agency (KEMI). The Swedish chemical legislation follows EU legislation. Much of the national legislations that existed before June 2007 were replaced by REACH. (http://www.kemi.se/templates/Page____3064.aspx).
10 Target levels for chemical status assessment

Good Environmental Status (GES), in accordance with the Marine Strategy Framework Directive 2008/56/EC (MSFD), is defined as “concentrations of contaminants at levels not giving rise to pollution effects”. GES is determined from quality assessments based on target levels representing a threshold that should not be exceeded. Established to protect sensitive organisms from the harmful effects of hazardous substances, target levels have been developed within several groups or conventions; Environmental Quality Standards (EQS) developed within the EC to evaluate GES, and the Environmental Assessment Criteria (EAC), developed within OSPAR. In addition to EQSs and EACs, chemical status can also be assessed from the point of human consumption. Maximum levels for contaminants in food are set in Commission Regulation (EC, No 1881/2006).

The Environmental Quality Standards Directive (2013/39/EU) lays Environmental Quality Standards (EQSs) for priority substances and certain other pollutants, as provided for in Article 16 of the WFD, with the aim of achieving good surface water chemical status. The objective is to protect pelagic and benthic freshwater and marine ecosystems, as well as human beings from adverse impacts of chemical contaminants. The annual average concentration (AA-EQS) refers to the annual arithmetic mean concentration providing protection against chronic exposure and cover short-term chemical effects in biota. The methodological framework used in deriving these EQSs is described in CIS (2011). Substance EQS Data Sheets (SDS) contains background information regarding the development of EQS (available at the CIRCABC webpage). Here, data from ecotoxicological studies are compiled to Specific Quality Standards (QS), derived for water, sediment, biota (QS_{biota}), which is set to protect for secondary poisoning in predators, and human health (QS_{hh}). To date, EQS_{biota} is available for 11 out of 45 substances.

Within the OSPAR convention, Environmental Assessment Criteria (EAC) has been developed for interpretation of chemical monitoring data in sediments and biota (OSPAR CEMP 2009). Concentrations below the EACs are considered to present no significant risk to the environment and may be considered as related to the EQSs.

In this report, primarily internationally agreed target levels such as EQS, EAC or EC recommendations for foodstuffs are used. If reliable target levels have been produced with specific regard to Swedish environmental conditions, these are considered (e.g. HCH and BDEs). Only one type of target level is applied within each substance group (e.g. we do not mix EQS and EACs depending on availability of different PCB or PAH congeners).

Concentration of substances lacking internationally agreed target levels are presented without evaluation against target levels (e.g Cr, Cu, Zn, As, Ag, Al, Sn, Bi).
Table 10.1. Target levels for various environmental pollutants.

<table>
<thead>
<tr>
<th>Group of substance</th>
<th>Target levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fish (µg/kg ww)</td>
</tr>
<tr>
<td>Metals</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>160</td>
</tr>
<tr>
<td>Lead</td>
<td>1000</td>
</tr>
<tr>
<td>Mercury</td>
<td>20</td>
</tr>
<tr>
<td>Nickel</td>
<td>730</td>
</tr>
<tr>
<td>Pesticides</td>
<td></td>
</tr>
<tr>
<td>DDE (p,p’)</td>
<td>5</td>
</tr>
<tr>
<td>HCH (incl. lindane)</td>
<td>2.6/26</td>
</tr>
<tr>
<td>PCBs</td>
<td></td>
</tr>
<tr>
<td>CB-28</td>
<td>64 lw</td>
</tr>
<tr>
<td>CB-52</td>
<td>108 lw</td>
</tr>
<tr>
<td>CB-101</td>
<td>120 lw</td>
</tr>
<tr>
<td>CB-105</td>
<td></td>
</tr>
<tr>
<td>CB-118</td>
<td>24 lw</td>
</tr>
<tr>
<td>CB-138</td>
<td>316 lw</td>
</tr>
<tr>
<td>CB-153</td>
<td>1600 lw</td>
</tr>
<tr>
<td>CB-156</td>
<td></td>
</tr>
<tr>
<td>CB-180</td>
<td>480 lw</td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>BDEs (congeners 28, 47, 99, 100, 153, and 154)</td>
<td>0.0085</td>
</tr>
<tr>
<td>ΣPCDDs+PCDFs</td>
<td>0.0035</td>
</tr>
<tr>
<td>HCB</td>
<td>10</td>
</tr>
<tr>
<td>PFOS</td>
<td>9.1</td>
</tr>
</tbody>
</table>

10.1 Metals

10.1.1 Cadmium

There is no EQS or EAC developed for cadmium. The QS<sub>biota</sub> is set at 0.16 mg/kg prey tissue wet weight and evaluates whole fish concentrations in a freshwater system. The QS<sub>hh</sub> is set at 0.1 – 1.0 mg/kg in edible parts of fish. The EC foodstuff regulation sets a maximum level for muscle meat at 0.05 mg/kg wet weight. The directive states that where fish are intended to be eaten whole, the maximum level shall apply to the whole fish.

Selected target level: QS<sub>biota</sub>

10.1.2 Lead

There is no EQS or EAC developed for lead. The QS<sub>biota</sub> is set at 1000 µg/kg prey tissue wet weight and evaluates whole fish concentrations. The QS<sub>hh</sub> is set at limit values of 200 – 1000 µg/kg fishery product wet weight. The EC foodstuff regulation sets a maximum level for lead in muscle meat of fish at 0.3 mg/kg wet weight. The directive states that where fish are intended to be eaten whole, the maximum level shall apply to the whole fish.

Selected target level: QS<sub>biota</sub>
10.1.3 Mercury
The EQSbiota for mercury is set at 20 µg/kg (methyl-Hg) prey tissue wet weight to protect against secondary poisoning. There is no EAC developed for mercury. The EC foodstuff regulation sets a maximum level for mercury at 0.5 mg/kg wet weight. The directive states that where fish are intended to be eaten whole, the maximum level shall apply to the whole fish.
Selected target level: EQSbiota

10.1.4 Nickel
There is no EQS or EAC developed for nickel. The QSbiota is set at 0.73 mg/kg prey tissue wet weight. The QSah is set at 0.67 mg/kg fishery product wet weight. There is no EC foodstuff regulation developed for nickel.
Selected target level: QSbiota

10.2 Pesticides
10.2.1 DDTs, (DDT, DDE and DDD)
There are no EQS or EC foodstuff regulation developed for any of the DDTs. The EAC developed for DDE is set at 0.005 mg/kg wet weight.
Selected target level: EAC

10.2.2 HCH
There are no EQS or EC foodstuff regulation developed for HCHs. The EACs developed for γHCH in fish liver is set at 11 µg/kg lipid weight. With regard to Swedish levels of organic carbon in the sediments and factors for bioconcentration (BCF) and biomagnification (BMF), the Swedish Environmental Research Institute (IVL) have performed translations between EQS for surface water to biota (Lilja et al. 2010). The IVL target level is set for the sum of HCH (including lindane) at 26 µg/kg wet weight in a limnic environment and 2.6 µg/kg wet weight in a marine environment.
Selected target level: IVL

10.3 PCBs
The draft EQS for concentrations of CBs is based on biota and is set at 0.003 µg/kg wet weight. The EQS is based on effects in organisms exposed to Aroclor 1254 which contains the PCBs CB-28, CB-52, CB-101, CB-118, CB-138, CB-153, and CB-180 in a proportion superior to 90%. The EAC developed for PCBs is expressed as µg/kg lipid weight: CB-28: 64, CB-52: 108, CB-101: 120, CB-118:24, CB-138: 316, CB-153: 1600, CB-180: 480. The EC foodstuff regulation developed for concentrations of PCBs in muscle meat of fish is set for the sum of CB-28, CB-52, CB-101, CB-138, CB-153, CB-180 (ICES - 6) at 75 ng/g wet weight.
Selected target level: EAC

10.4 Brominated flame retardants
10.4.1 BDEs
The EQSbiota for concentrations of sumBDEs is set at 0.0085 µg/kg wet weight. There are no EAC or EC foodstuff regulation developed for BDEs. The EQSbiota is based on QS set for human health.
Selected target level: proposed EQSbiota
10.4.2 HBCDD
The EQSbiota for concentrations of HBCDD is based on secondary poisoning of predators and set at 167 µg/kg fresh weight. There are no EAC or EC foodstuff regulation developed for HBCDD.
Selected target level: proposed EQSbiota

10.5 Other

10.5.1 Dioxins, furans and dioxin-like PCBs.
The EQSbiota for concentrations of dioxins is based on human health and set at $\Sigma$ PCDD/Fs: 0.0035 µg WHO05-TEQ/kg ww. The QS set for human health was identified as the critical EQS because of the consensus regarding the value used in existing food legislation and because there is a greater uncertainty regarding the values calculated for QS sec. pois.
Selected target level: proposed EQSbiota

10.5.2 HCB
The EQSbiota for HCB is based on human health and set at 10 µg/kg fishery product wet weight. There is no EC foodstuff regulation developed for HCB.
Selected target level: EQSbiota

10.5.3 PFOS
The EQSbiota for concentrations of PFOS is based on human health and set at 0.0091 mg/kg wet weight. There are no EAC or EC foodstuff regulation developed for PFOS.
Selected target level: proposed EQSbiota
11 Biological variables

11.1 Results

11.1.1 Spatial Variation

Figure 11.1. Spatial variation in mean fat percentage in perch muscle.

Figure 11.2. Spatial variation in mean age (year) in perch.
Fat content in perch muscle is relatively consistent in all lakes sampled within the programme, however, it seemed to be somewhat lower in the southern part of Sweden (around 0.5%). The highest fat percentage was found in perch muscle from Lake Svartsjön (0.71%) in Västra Götaland County and the lowest (0.35%) in Lake Sännen in Blekinge County and in Lake Stora Envättern in Stockholm County (Fig. 11.1).

The fat content in pike muscle from Lake Bolmen and Lake Storvindeln are of similar magnitude (with a mean value of approximately 0.6 % fat over the monitored time period). The fat content in Arctic char muscle is higher than for pike and perch with a mean fat content of approximately 1.5 % in char from both of the lakes (Fig. 11.5).

The age of the perch sampled within the programme is lower in the most southern and south eastern parts of Sweden (Fig. 11.2).
The total length of the perch sampled is very homogenous, which is a result of the perch sent for analyses are selected within a certain length span (Fig.11.3).

Some variation is seen for the total weight but no clear spatial pattern is observed (Fig. 11.4).

### 11.1.2 Temporal variation

Fat content in pike from Lake Bolmen shows significant decreasing trends during the time period 1967/68 – 2012 (Fig. 11.5), while no trend was detected for pike in Lake Storvindeln. The annual decrease was 0.93%. On the other hand, the fat content in Arctic char from Lake Tjulträsk shows a significant increasing trend (with 2% per year) during the whole monitoring period (1982-2012) but no trend could be detected in Arctic char from Lake Abiskojaure.

The fat content in perch from Lake Skärgölen (Fig.11.6) shows a significant decreasing trend of 0.73% per year during the time period 1980-2012. But no trend is seen in perch from Lake Stensjön.

The number of years required to detect an annual change of 10% for fat content varies between 6-13 years for the pike, char and perch time series.

Figure 11.5. Fat content in Arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln).
11.2 Summary

The fat content in pike from Lake Bolmen and in perch from Lake Skärgölen, show significant decreasing trends during the monitoring period. The fat content in Arctic char from lake Tjulträsk is increasing during the monitoring period.

The age of the perch sampled within the programme is somewhat lower in the most southern and south eastern parts of Sweden. Since the length of the fish is within the same length interval at all sampling sites, this indicates a faster growth rate in these areas with younger fish.
12 Mercury - Hg

12.1 Introduction

12.1.1 Usage, Production and Sources

Mercury exists naturally in the environment in a number of chemical and physical forms. The main inorganic forms include $\text{Hg}^0$ (metallic), $\text{Hg}_2^{++}$ (mercurous), $\text{Hg}^{++}$ (mercuric). Organic forms include $\text{CH}_3\text{HgCH}_3$ (dimethylmercury) and $\text{CH}_3\text{Hg}^+$ (monomethylmercury) (Suzuki et al. 1991).

Some of the more well-known uses of mercury include thermometers, barometers, sphygmomanometers (blood pressure cuffs), float valves (e.g., ball cock in flushing system of toilets), some electrical switches, amalgam for dental restoration, batteries, fluorescent lamps, anti-lock braking systems (ABS) in some 4WD vehicles and airbag sensors in some vehicle models. It can also be found in beauty products, such as mascara, as thiomersal. For a comprehensive list of mercury usage in everyday life, see Huber (1998). Highly toxic and bioaccumulatory methylmercury compounds were previously used as fungicides or were unwanted byproducts of the chemical industry (Clarkson 1992).

Natural sources of mercury include volcanoes, forest fires, fossil fuels, petroleum and cinnabar ore, which is mined primarily in Spain and Italy, although shortages of this rare metal have encouraged mining in other countries (Calvert 2007). There are numerous atmospheric anthropogenic sources of mercury such as fossil fuel combustion, mining, smelting and solid waste combustion; and soil and water anthropogenic sources such as agricultural application of fertilisers, industrial wastewater disposal, landfills, the manufacture of cement and metals, and through other industrial processes. In Sweden, a south to north gradient exists in atmospheric mercury concentration, due to the south being closer to source points in Europe (Wängberg and Munthe 2001). However, mercury use has almost ceased in Sweden (AMAP/UNEP 2008).

In Swedish top layer soils (mor), the highest mercury concentrations are seen in the south, decreasing towards the north, with considerable local variation. Mercury concentrations vary regionally, with means from 0.2 mg/kg to 0.5 mg/kg seen. Natural background levels in mor/top layer soils are estimated to be 0.07 mg/kg, based on concentrations seen from the least affected northern areas. Natural background mercury concentrations in pike are estimated to be 0.2 mg/kg (European Communities 2002).

12.1.2 Environmental Fate

Mercury concentration in fish is highly correlated with water pH, with acidic conditions favouring mercury methylation; increased water temperature is known to increase methylation rates (Doetzel 2007). Sulphate reducing bacteria has been shown to be a controlling factor of mercury methylation in estuarine sediments (Choi and Bartha 1994). Fish biology also influences mercury levels, with age, size and diet affecting bioaccumulation rates (Doetzel 2007).
12.1.3 Toxic Effects
Mercury is a bioaccumulator (Clarkson 1992). Methylmercury is the form of mercury of most concern to human health and ecosystem processes. Methylmercury combines with the amino acid cysteine to form a structure similar to another amino acid, methionine, which penetrates all mammalian cells and easily crosses the blood-brain barrier, from whence the central nervous system can be affected (Suzuki et al. 1991, Huber 1998). High exposure can affect brain development, with young children and infants most at risk (Doetzel 2007), as methylmercury disturbs cell division and therefore development (Huber 1998).

The severity of symptoms after mercury exposure depends upon exposure level. Symptoms related to severe exposure are well documented after two major disasters of methylmercury contamination in Iraq in 1972, and Japan in 1957 (for a brief overview see Huber 1998; Amin-Zaki et al. 1974, Rustam and Hadmi 1974, Clarkson 1992). Symptoms are related to type of exposure, for example, inhalation of elemental mercury vapours results in respiratory problems, followed by neurological disturbance and general systemic effects. However, one of the most common routes of mercury exposure is via ingestion of methylmercury (Ratcliffe et al. 1996), often through consumption of contaminated fish (Huber 1998), the risk of which can be greater for in utero children in pregnant women (Koren and Bend 2010). Exposure becomes problematic if contaminated fish (or other contaminated substances) are eaten often, and neurological effects in both adults and children in utero can be seen (Ratcliffe et al. 1996).

Wildlife in all environments is affected by mercury accumulation; however animals in aquatic systems appear to show more intense bioaccumulation/biomagnification effects than terrestrial species (Huber 1998). Bioaccumulation usually occurs through diet (Huber 1998). A biomagnification effect is seen in fish at higher trophic levels (i.e., piscivorous fish) compared to those at lower trophic levels (da Silva et al. 2005). In the 1960s, the usage of methylmercury compounds as fungicides on seed grains led to the realisation that this compound was an ecological poison, because large bird species that preyed on smaller birds that in turn had eaten these grains, suffered from severe population declines (Clarkson 1992). While methylmercury accumulates in fish muscle, highest concentrations are generally seen in the blood, spleen, kidney and liver; in mammals and birds, highest concentrations are typically seen in the feathers and fur (Huber 1998). Embryos and very young animals tend to be the most affected by mercury damage due to its ability to interfere with cell division processes (Huber 1998).

12.1.4 Conventions, aims and restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction of the discharge of mercury to air and water by 50% by 1995, with 1987 as the base year.

The use of mercury in paper pulp industries has been banned in Sweden since 1966.

According to a governmental proposition (1993/94:163), the aim was that all mercury usage in Sweden should have ceased by 2000.

12.1.5 Target Levels
The target level (TL) used for Hg in the time series for fish is 20 µg/kg wet weigh. The original target level is set for concentrations of mercury in whole-fish and the data presented in this report is measured in muscle and therefore the target level is recalculated in the time series for perch where information about the whole fish:muscle ratio is available. The
recalculation of the TL for whole-fish is based on a study that compared concentrations of Hg in the muscle and whole-fish of perch (Boalt et al., 2011). The whole-fish:muscle ratio was 0.72 for perch (Boalt et al., 2011). For further information on TL and selection of target level see chapter 10.

12.2 Results

12.2.1 Spatial Variation

![Figure 12.1. Spatial variation in concentration (ng/g wet weight) of Hg in perch muscle.]

The highest concentration of Hg was found in perch from Lilla Öresjön (397 ng/g wet weight) close to Gothenburg, in Lake Brännträsket (369 ng/g wet weight) in Norrbotten County, and Lake Stora Envättern (365 ng/g wet weight) in Stockholm County in 2010-2012. The lowest concentration of Hg (44 ng/g wet weight) in perch muscle was from Lake Krageholmssjön in the county of Skåne (Fig. 12.1).

The concentration of Hg in pike from Lake Bolmen (mean 360 ng/g wet weight) and Lake Storvindeln (mean 300 ng/g wet weight) is more than ten times higher than in Arctic char from Lake Abiskojaure (Fig.12.2).

12.2.2 Temporal variation

The time series for Arctic char from Lake Abiskojaure show a significant decreasing trend for Hg of 1.2% per year for the whole time period (Fig. 12.2). No significant trend is detected for Hg in pike from Lake Bolmen and Lake Storvindeln and in the majority of the perch time series (Fig. 12.2-12.5). However, during the last ten years significant decreasing trends of about 6% per year are seen for pike in Lake Storvindeln and perch in Lake Skärgölen. In addition, about half of the slopes in the perch time series are negative and that might indicate decreasing concentrations over time.
The number of years required to detect an annual change of 10% for Hg varies between 8-16 years for the pike, char and perch time series.

**Figure 12.2.** Mercury concentrations (ng/g fresh weight) in Arctic char muscle (Lake Abiskojaure) and in pike muscle (Lake Bolmen and Lake Storvindeln). The green area denotes the levels below the suggested target value for mercury in fish.

**Figure 12.3.** Mercury concentrations (ng/g fresh weight) in perch muscle from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen. The green area denotes the levels below the suggested target value for mercury in fish.
Figure 12.4. Mercury concentrations (ng/g fresh weight) in perch muscle from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön. The green area denotes the levels below the suggested target value for mercury in fish.

Figure 12.5. Mercury concentrations (ng/g fresh weight) in perch muscle from Lake Remmarsjön, Lake Degervatnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for mercury in fish.

12.2.3 Comparison to thresholds

The suggested target level for Hg based on ECs EQS$_{biota}$ (Environmental Quality Standard) of 20 ng/g wet weight was exceeded in all species and lakes sampled within the programme, except in Arctic char from Lake Abiskojaure where the mean value 2012 was below the target level (Fig. 12.2-12.6).
Figure 12.6. Spatial variation in concentration (ng/wet weight) of Hg in perch muscle. The green sections of the bars are representing concentrations under the threshold level (20 ng/g wet weight) and the red sections concentrations above.

12.3 Summary

The highest concentration of Hg in perch (2010-2012) was found in Lake Lilla Öresjön, close to Gothenburg, in Lake Brännträsket in Norrbotten County, and in Lake Stora Envättern in Stockholm County.

Hg concentrations vary between species and sites. Seen over time, the Hg concentration has decreased in Arctic char from Lake Abiskojaure since the end of the 1970s and for perch from Lake Skärgölen during the last 10 years. For the other lakes and species, no clear trends are observed.

In all areas and species (except in Arctic char from Lake Abiskojaure), Hg concentration is above the suggested target level.
13 Lead - Pb

13.1 Introduction

13.1.1 Usage, Production and Sources
Lead occurs in many isotopes, but only three are stable. There are four natural isotopes, \(^{204}\text{Pb}, \^{206}\text{Pb}, \^{207}\text{Pb}\) and \(^{208}\text{Pb}\). \(^{204}\text{Pb}\) is slightly radioactive, and has a half life of 22.2 years. In nature, lead is usually found in ore with zinc, silver or copper. Atmospheric sources of lead in Sweden show a south to north gradient, due to northward atmospheric transport from sources located elsewhere in Europe (Renberg et al. 2000). The main sources of lead pollution in Sweden come from ammunition, lead petrol emissions and associated contamination in roadside soils (although leaded gasoline was eliminated in 1994 in Sweden (Faiz et al. 1996)), lead pigments, cables and batteries. There are also point sources (e.g. metal works) that have resulted in high local pollution (Bergbäck et al. 1992), e.g. a secondary lead smelter in Landskrona where lead from car batteries is recycled (Farago et al. 1999).

The primary use for lead is in car batteries. There are numerous other uses including, but not limited to, lead in the ballast keel of sailboats, scuba diving weight belts, fishing sinkers, firearms (bullets and shot), colouring elements in paints and ceramic glazes, PVC plastics, lead sheeting used for sound proofing, lining chemical treatment baths, storage vessels, weathering, roofing, cladding, organ pipes, soldering, electrodes, high voltage power cables, tennis racquets, statues, sculptures, anti-knocking additive in aviation fuel, leaded gasoline, solar energy cells and infrared detectors and coffins. Houses built prior to 1980 are at a higher risk of having been painted with lead-based paints. Many cities did (and some still do) use lead water and sewage pipes. Lead can leach out of the water pipes into drinking water. Lead arsenate was the most commonly used insecticide in deciduous fruit tree orchards prior to the introduction of DDT in 1947. High lead levels are still found in some top soils in the USA (Peryea and Creger 1993, Peryea and Kammereck 1995).

13.1.2 Environmental Fate
Increased acidity levels appear to contribute to increased lead bioavailability in soils (Jin et al. 2005). In lakes, the level of lead in fish body tissues is often greater in low-alkalinity water compared to lakes with a higher pH (Spry and Wiener 1991). These results indicate that pH may influence lead bioavailability in water systems and sediments.

13.1.3 Toxic Effects
Lead is a non-essential element (Tewari et al. 1987) and a known neurotoxin, damaging the nervous system and causing brain and blood disorders. The toxic effects of lead involve several organ systems and biochemical activities. The risk is highest for children and those \textit{in utero}, partly because of high permeability of the blood-brain barrier and placenta (Klaassen and Rozman, 1991). Some neurophysiological development affects can be seen in children even at low levels of lead exposure (Gidlow 2004).

Lead is known to bioaccumulate in soft tissue, but to a much greater extent in the bone matrix. Approximately 90% of the total amount of lead in humans is found in the skeleton (Klaassen and Rozman, 1991). Between 90% to 95% of lead that is found in blood is isolated in the red blood cells where haemoglobin synthesis can be inhibited, and subsequently
symptoms such as anaemia are seen (Gidlow 2004). In females, lead is a known abortifacient, but problems in male reproduction are equivocal (Gidlow 2004).

In animals, absorbed lead enters the blood and soft tissues, but is eventually redistributed to the bones. In birds, lead shot is a common cause for lead poisoning (Cook and Trainer 1966, Pattee et al. 1981), and there have been reports of fishing sinkers causing bird deaths (Locke et al. 1981). In Sweden, bird death from lead poisoning is more common in swans, geese and ducks, but has also been reported in woodpeckers (Mörner and Petersson 1999). Lead levels were found to be highest in woodpecker liver and kidney (Mörner and Petersson 1999).

13.1.4 Conventions, Aims and Restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction of the discharges of lead to air and water by 50% by 1995, with 1987 as the base year.

The recommended limit for children’s food is set by the Swedish National Food Administration (SNFA) at 50 ng/g fresh weight (SLVFS, 1993). Within the European Community, the limit in fish muscle is set at 0.2 ug/g, and in mussels at 1.5 ug/g. (EG, 2002).

13.1.5 Target Levels
The target level (TL) used for Pb in the time series for perch is 1000 µg/kg wet weight in whole-fish. For further information on TL and selection of target level see chapter 10. The original TL has been recalculated to dry weight in liver for each time series to fit the presented data. The recalculation of the TL for whole-fish is based on a study that compared concentrations of Pb in the liver and whole-fish of perch from the Baltic (Boalt et al., 2011). The whole-fish:liver ratio was 12.18 for perch. (Boalt et al., 2011) and the recalculation to dry weight is based on the dry weight in each time series. The recalculated target level (Tv) together with the dry percentage (dp) is shown above the statistical information in each time series.

13.1 Results

13.1.1 Spatial Variation
Figure 13.1. Spatial variation in concentration (ug/g dry weight) of Pb in perch liver.

The highest concentration of Pb (0.38 ug/g dry weight) was found in perch liver from Lake Hjärtsjön in the county of Småland (2010-2012). The lowest concentration of Pb (0.008 ug/g dry weight) was found in perch liver from Lake Fysingen close to Stockholm (Fig. 13.1).

The concentration of Pb is of a similar magnitude in pike from Lake Storvindeln and Lake Bolmen and in Arctic char from Lake Abiskojaure (with concentrations around 0.01 ug/g dry weight in 2012) (Fig. 13.2).

13.1.2 Temporal variation

The pike and char time series show significant decreasing trends for Pb of about 4-13% per year in all monitored lakes (Fig. 13.2) from 1969/1980/1998-2012. A significant decreasing trend is also observed in perch from Lake Stensjön (1997-2012) (Fig. 13.5). The general trend in the other perch time series are also decreasing concentrations of Pb over time. The monitored period is probably too short to give statistical significant results for these rates of decrease.

The decreasing trends for Pb are consistent with other time series reported for Pb in marine biota (Bignert et al. 2010), and are most probably a result of the ban of lead in gasoline in 1994.

The number of years required to detect an annual change of 10% for Pb varies between 10 - 17 years for the pike, char and perch time series.
Figure 13.2. Lead concentrations (µg/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 13.3. Lead concentrations (µg/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen. The green area denotes the levels below the suggested target value for lead in fish.
Figure 13.4. Lead concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön. The green area denotes the levels below the suggested target value for lead in fish.

Figure 13.5. Lead concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervatnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for lead in fish.

13.1.3 Comparison to thresholds

In all areas, Pb concentration in perch is below the suggested target level based on the QS_{biota} of 1 ug/g wet weight. This result has to be interpreted carefully as the recalculation between levels of lead in whole-body and liver is based on only one study.
13.2 Summary

The highest concentration of Pb in perch liver was found in Lake Hjärtsjön in the county of Småland in 2010-2012.

Lead concentrations varied between species and sites; however temporally, Pb concentration has decreased by approximately 4-13% per year in the freshwater environment since the end of the 1960s.

In all areas, Pb concentration in perch is below the suggested target level.
14 Cadmium - Cd

14.1 Introduction

14.1.1 Usage, Production and Sources
Cadmium is an important metal in many industrial applications. It was used extensively until the end of the 1970s in electroplating or galvanising because of its noncorrosive properties. It has also been used (and to some extent is still used) as a cathode material for nickel-cadmium batteries, and as a colour pigment for paints and plastics. However, its industrial use has decreased considerably during recent years. In 1982, Sweden was the first country in the world to introduce a principal ban for certain industrial applications. Cadmium can also enter the environment as a by-product of zinc and lead mining and smelting, and as an undesired element in fertilisers.

Natural cadmium occurs in ores with zinc, copper and lead, and volcanic activity can increase atmospheric cadmium concentrations (Godt et al. 2006). In Sweden, cadmium discharge into the environment has been estimated to have decreased by approximately 45% between 1985 – 1990, while the airborne cadmium load during the same period is estimated to have decreased by approximately 15% (SNV, Rapport 4135).

14.1.2 Environmental Fate
a) Decreased contaminant load may cause a corresponding decrease in the amount of bioavailable cadmium.

b) Increased mobility of Cd-ions due to acidification may cause increased cadmium concentration in run off (e.g. Borg et al. 1988).

c) Cadmium can be bound to metallothionein (MT) (da Silva and Williams, 1994). It is known that various compounds can induce (and possibly also inhibit) the formation of MT in fish liver (Bouquegneau et al. 1975). A change in the amount of MT, due to induction, inhibition or ceased induction or inhibition, might thus change the metal concentration in the analysed liver tissue.

14.1.3 Toxic Effects
The most common source of cadmium for humans is via cigarette smoke (Godt et al. 2006). There is also a low risk of being exposed to cadmium via oral and dermal pathways (Godt et al. 2006). Cadmium is generally found in the liver or kidneys - 30% of the cadmium body burden is found in kidneys - with kidneys being the main organ for long term cadmium accumulation in humans, leading to renal tube dysfunction (Godt et al. 2006). Bone tissues are affected secondarily (after kidneys). At very high exposure rates, affects on the respiratory system (e.g. emphysema) are known, while the nervous system in developing animals appears to be sensitive (Godt et al. 2006). There have been some effects on reproduction, and some proof of carcinogenic effects (Godt et al 2006). Cadmium transported in blood plasma becomes bound to albumin and is then preferentially taken up by the liver, where metallothionein is synthesised (Godt et al. 2006). The placenta is only a partial barrier to foetal exposure. Cadmium is excreted in faeces and urine (Godt et al. 2006).
14.1.4 Conventions, Aims and Restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction in discharges of cadmium to air and water by 50% by 1995, with 1987 as the base year.

The Swedish Parliament has agreed on a general reduction of cadmium discharge, aiming at a reduction of 70% between 1985 and 1995, and further, that all use of cadmium that implies a risk of discharge to the environment, in a longer term perspective, will cease (prop 1990/91:90, JoU 30, rskr.343).

In 1982, the use of cadmium in electroplating and as a thermal stabiliser was banned in Sweden.

In 1987, a fee on batteries containing cadmium was introduced in Sweden. This fee was raised considerably in 1991.

In 1993, the content of cadmium in fertilisers was restricted to 100g/ton of phosphorus in Sweden.

Since 2009, Sweden has followed the cadmium restrictions in fertilizers within REACH.

14.1.5 Target Levels
The target level (TL) used for Cd in the time series for perch is 160 ug/kg wet weight in whole-fish. For further information on TL and selection of target level see chapter 10. Since most data presented here are ug Cd per g dry weight liver, the original TL has been recalculated for comparison. The recalculation of the TL for whole-fish is based on a study that compared concentrations of Cd in the liver and whole-fish of perch (Boalt et al., 2011). The whole-fish:liver ratio was 0.16 for perch (Boalt et al., 2011) and the recalculation to dry weight is based on the dry weight in each time series. The recalculated target level (Tv) together with the dry weight percentage (dp) is shown above the statistical information in each time series.

14.2 Results
14.2.1 Spatial Variation
Figure 14.1. Spatial variation in concentration (ug/g dry weight) of Cd in perch liver.

The highest concentration of Cd (24 ug/g dry weight) was found in perch liver from Lake Fiolen in the county of Småland (2010-2012). The lowest concentrations of Cd in perch liver were seen in Lake Krageholmssjön (0.26 ug/g dry weight) and Lake Krankesjön (0.25 ug/g dry weight) in the county of Skåne (Fig. 14.1). The levels of cadmium in perch liver are generally somewhat higher in the south of Sweden than in the north.

The concentration of Cd varies between species and sites (Fig. 14.1.-14.5). In Arctic char the concentration of Cd is more than four times higher (1.1 ug/g dry weight, mean over the whole time period) compared to pike from Lake Storvindeln and Lake Bolmen (0.05 and 0.28 ug/g dry weight respectively, mean over the whole time period) (Fig. 14.2).

14.2.2 Temporal variation
Significant decreasing trends were observed in perch liver from Lake Skärgölen (Fig. 14.3) and Lake Stensjön (Fig. 14.5) from 2000-2012. The decrease varied between about 6-7% per year. For the last ten years decreasing trends were observed for perch at Lake Stensjön (Fig. 14.5) and Lake Degervattnet (Fig. 14.5) and for pike at Lake Storvindeln (Fig. 14.2). The decrease varied between 0.5-7% per year. On the other hand, increasing trends were observed for perch from Lake Remmarsjön and Lake Hjärtsjön with 4-7% per year, also increasing trends for the last ten years was observed in Arctic char from Abiskojaure (Fig. 14.2). The number of years required to detect an annual change of 10% for Cd varies between 7-16 years for the pike, char and perch time series.
**Figure 14.2.** Cadmium concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

**Figure 14.3.** Cadmium concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen. The green area denotes the levels below the suggested target value for cadmium in fish.
14.2.3 Comparison to thresholds

In the majority of the lakes, Cd concentration in perch is above the suggested target level based on the QS\textsubscript{biota} of 0.16 ug/g wet weight. This result has to be interpreted carefully since the recalculation between levels of cadmium in whole body and liver is based on only one study.
14.3 Summary

The highest concentration of Cd in perch liver was found in Lake Fiolen in the county of Småland in 2010-2012.

Cadmium concentrations varied between species and sites and the trends were inconclusive.

In the majority of the lakes, Cd concentration in perch is above the suggested target level.
15 Nickel - Ni

15.1 Introduction

15.1.1 Usage, Production and Sources

The most common ores of nickel include pentlandite, pyrrhotite, and garnierite. In addition, nickel also occurs as an impurity in ores of iron, copper, cobalt, and other metals. Natural nickel is a mixture of five isotopes, i.e. $^{58}\text{Ni}$, $^{60}\text{Ni}$, $^{61}\text{Ni}$, $^{62}\text{Ni}$, and $^{64}\text{Ni}$. Seven radioactive isotopes of nickel are also known; however, only $^{63}\text{Ni}$ of the radioactive isotopes is used in industry for the detection of explosives, and in certain kinds of electronic devices, such as surge protectors.

The most important use of nickel is in manufacturing of a variety of alloys including stainless steel (Cempel and Nikel, 2006). Moreover, nickel is also very popular in the battery industry. Nickel-cadmium and nickel-metal hydride batteries are the main line products. Nickel are used in a great variety of appliances, including hand-held power tools, compact disc players, pocket recorders, camcorders, cordless and cellular telephones, scanner radios, and laptop computers. Nickel is also used in electroplating.

15.1.2 Environmental Fate

Nickel can be released to the environment both by natural sources and anthropogenic activities. Weathering of rocks and soils, volcanic emissions, forest fires are the main natural sources of atmospheric nickel. Anthropogenic activities producing nickel include combustion of fossil fuel, incineration of waste, using stainless steel utensils, smoking tobacco (Cempel and Nikel, 2006). Domestic wastewater effluents and non-ferrous metal smelter are responsible for the nickel contamination in aquatic ecosystems (Cempel and Nikel, 2006). In water, nickel can deposit to sediments or uptake by biota. Nickel typically accumulates in the surface soils once deposit from industrial and agricultural activities (Scott-Fordsmand, 1997).

15.1.3 Toxic Effects

Nickel is one of the essential metals for the function of several animals, organisms, and plants. Toxicity can occur either when the amount of Ni in the body is abundant or deficient. Nickel has not been recognized as a nutritional element for human. Therefore, exposure to nickel compounds can have adverse effects on human health. Human exposure to Ni is primarily through ingestion of contaminated drinking water or food and inhalation (Cempel and Nikel, 2006).

Allergic skin reactions by nickel has been reported as one of the most common causes of allergic contact dermatitis (Andrea, 2005). Erythema, eczema and lichenification can be produced once skin is in contact with nickel. Nickel compounds have been exhibited as carcinogenic in some animals and modes of human exposure (Kasprzak et al., 2003; WHO, 1991). The ability to enter cells determines its carcinogenic properties. High water-soluble nickel compounds have less carcinogenic potency than some certain water-soluble nickel compounds (Cempel and Nikel, 2006). Recent studies have reported the ability of nickel to
enhance lipid peroxidation in the liver, kidney, lung, bone marrow and serum (Cempel and Nikel, 2006; Denkhaus and Salnikow, 2002).

15.1.4 Target Levels
The target level (TL) for nickel is 730 µg/kg wet weight for whole-fish. For further information on TL and selection of target level see chapter 10. The concentrations of Ni presented in this report are in liver and there are no conversion factors available for recalculation to whole-fish at present, therefore the TL is not presented in the timeseries for Ni.

15.2 Results

15.2.1 Spatial Variation

Figure 15.1. Spatial variation in concentration (ug/g dry weight) of Ni in perch liver.

No general spatial pattern was observed for Ni in perch liver. The highest concentration of Ni (0.15 ug/g dry weight) was found in perch liver from Lake Fysingen close to Stockholm in 2010-2012. The lowest concentration of Ni (0.044 ug/g dry weight) in perch liver came from Lake Krankesjön in the county of Skåne (Fig. 15.1).

The concentration of Ni in Arctic char from Lake Abiskojaure with a mean concentration of 0.17 ug/g dry weight is three to four times as high as in pike from Lake Bolmen and Lake Storvindeln (Fig. 15.2). The Ni concentration in Arctic char is also higher compared to perch.

15.2.2 Temporal variation
The concentration of nickel in perch liver increased significantly, by about 7-11% per year, in Lake Bysjön, Lake Stora Envättern, Lake Skärgölen and Lake Krageholmssjön (Fig. 15.2-15.3) from 2000-2012. Moreover, a decreasing trend for the last ten years was observed for perch at Lake Degervattnet (Fig. 15.5). No significant trends were observed for the other
matrices and sites within the programme (Fig. 15.2-15.5) for Ni. However, the general trend (though not significant) in the perch time series is increasing concentrations over time.

The number of years required to detect an annual change of 10% for Cd varies between 10 - 15 years for the pike, char and perch time series.

Figure 15.2. Nickel concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 15.3. Nickel concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.
15.3 Summary

The highest concentration of Ni in perch liver was found in Lake Fysingen close to Stockholm in 2010-2012.

Nickel concentrations varied between species and sites and showed a general increasing trend in perch during the monitored period.
16 Chromium - Cr

16.1 Introduction

The method for chromium analysis was changed in 2004. The new method gives in general lower concentrations. The level of quantification is also lower with the new method.

16.1.1 Usage, Production and Sources

The abundance of chromium in the Earth's crust is about 100 to 300 ppm in rock (Domy, 2001). Chromium does not occur as a free element. Rocks or sediments present a wide range of chromium concentration whereas natural water contain quite small amounts (Richard and Bourg, 1991). Most chromium is produced from chromite, or chrome iron ore (FeCr2O4). Chromium is used in the manufacturing of stainless steels, electroplating, leather tanning, pigments for inks and paints.

There are four naturally occurring isotopes of chromium: $^{50}\text{Cr}$, $^{52}\text{Cr}$, $^{53}\text{Cr}$, $^{54}\text{Cr}$ and seven known radioactive isotope (Eisler, 1986). Oxidation states of chromium can vary from Cr (0) to Cr (VI), in which Cr (III) and Cr (VI) are the most stable and important species for natural aquatic systems (Richard and Bourg, 1991). Aqueous chromium presents as Cr$^{3+}$ state under reducing environments and pH lower than 3.6, while Cr (VI) is only presented in oxidizing condition (Richard and Bourg, 1991).

16.1.2 Environmental Fate

Chromium can be transported between various environmental media and once present in the environment, it can be taken up by human and other biota. Chromium is introduced to the environment mainly through anthropogenic activities than through weathering processes (Eisler, 1986). Chromium alloy, metal producing, coal combustion, municipal incinerators, cement production, and cooling towers are responsible for major atmospheric emissions of Cr (Towill et al., 1978). The transformation and transport of chromium in the atmosphere are in association with aerosols. Chromium is removed from the atmosphere by both wet and dry deposition and reintroduced via resuspension of chromium-containing soil particles. In the aquatic environment, the major sources of chromium are atmospheric deposition, industrial activities (i.e. electroplating, metal finishing industries and waste water treatment plant), and weathering of natural rocks (Kimbrough et al., 1999). Chromium leaks to soil and sediment mainly from human activities, i.e. using chromium in phosphate fertilizers, chromium plating bath, ferrochromium slag (de Lopez Camelo et al., 1997).

16.1.3 Toxic Effects

The toxicity of chromium is regulated by its oxidation state, irrespective of its total concentration. Chromium (III) appears to be a nutrient for some plants and animals, including humans; however, Cr (VI) has been reported to be toxic to bacteria, plants, and animals (Richard and Bourg, 1991). Environmental properties, i.e. hardness, temperature, pH, and salinity of water, in combination with biological factors, i.e. species, life stage, sensitivities of local population, determines the toxicity of chromium to aquatic biota (de Lopez Camelo et al., 1997). In addition, interaction effects of chromium with other contaminants, duration of exposure, and chemical form of Cr are also important factors. In general, Cr (III) is less toxic
than Cr (VI) due to its high oxidizing potential and its easier membrane permeability (Eisler, 1986; Richard and Bourg, 1991). For sensitive aquatic biota, LC50 of Cr(III) were from 2000 to 3200 ppb while Cr(VI) ranged from 445 to 2000 ppb (Eisler, 1986). Chromium is a trace element that has significant biological effects to the human body. Small amounts of chromium are necessary for plants and animals to metabolize glucose and synthesize amino acid and nucleic acid (Richard and Bourg, 1991). Chromium deficiency leads to diabetes-like symptoms in humans (Towill et al., 1978). At high level, chromium can cause nausea, skin ulcerations or lung cancer depending on exposure pathway and amounts of uptake.

16.1.4 Conventions, Aim, and restriction
The maximum chromium concentration in drinking water, recommended by the Commission of European Communities, the World Health Organization or the U.S. Environmental Protection Agency, is 50 µg/l (Richard and Bourg, 1991).

16.1.5 Target levels
No national target level for biota is agreed upon for Cr.
16.2 Results

16.2.1 Spatial Variation

Figure 16.1. Spatial variation in concentration (ug/g dry weight) of Cr in perch liver.

No general spatial pattern was observed for Cr in perch liver. The highest concentrations of Cr were found in perch liver from Lake Svartsjön (0.12 ug/g dry weight) in Västra Götaland County and Lake Sännén (0.11 ug/g dry weight) in the county of Blekinge in 2010-2012. The lowest concentration of Cr found in perch liver came from Lake Krankesjön (0.046 ug/g dry weight) in Skåne County and Lake Övre Skärsjön (0.047 ug/g dry weight) close to Stockholm (Fig. 16.1).

The concentration of Cr in pike from Lake Storvindeln is almost twice as high as in pike from Lake Bolmen (Fig. 16.2).

16.2.2 Temporal variation

The time series for chromium show significantly decreasing concentrations in most species and sites monitored within the programme (Fig. 16.2-16.5), but this significant decrease is most probably caused by the change in method for chromium analysis in 2004. The true development of Cr concentrations over time in these investigated freshwater systems are unclear.

The number of years required to detect an annual change of 10% for Cr varies between 16-24 years for the pike, char and perch time series.
Figure 16.2. Chromium concentrations (µg/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 16.3. Chromium concentrations (µg/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärgölen.
Figure 16.4. Chromium concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön, and Lake Krageholmsjön.

Figure 16.5. Chromium concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervatnet, Lake Stensjön, and Lake Övre Skärsjön.

16.3 Summary

The highest concentration of Cr in perch liver was found in Lake Sännen in Blekinge County and Lake Svartsjön in Västra Götaland County in 2010-2012.

Chromium concentrations showed a general decreasing trend in all matrices during the monitoring period, but this decrease is most probably caused by the change of method for chromium analysis in 2004.
17 Copper - Cu

17.1 Introduction

17.1.1 Usage, Production and Sources
Copper is a nutritionally essential metal, and concentration is regulated by homeostatic mechanisms. Free copper is effectively controlled by metallothionein synthesis (da Silva and Williams 1994) induced by copper itself or by other substances. Although copper is not believed to accumulate with continued exposure, changes found in biological tissues may still reflect changes in concentration of the ambient water.

Copper occurs naturally in rocks, soil, water, sediment and at low levels in air. In its natural (metallic) form, copper can be found in electrical wiring and some water pipes, for example, plumbing, building wire, telecommunications, automotive electrical wiring and air conditioning systems (Dorsey et al. 2004). Copper compounds can be found in alloys such as brass and bronze. Other anthropogenic sources include road run off (Rice et al. 2002) and mining of copper ore. Copper compounds are commonly used in agriculture as fungicides, in wood, leather and fabric preservative, or for water treatment (Dorsey et al. 2004).

17.1.2 Conventions, Aims and Restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction in the discharge of copper to air and water by 50% by 1995, with 1987 as the base year.

17.1.3 Target Levels
No national target level for biota concerning copper is agreed upon.

Average copper concentration in the earth’s crust is 50 ppm (Dorsey et al. 2004). The ‘background concentration at diffuse loading’ in blue mussels for copper is <10 μg/g dry weight, proposed by Knutzen and Skie (1992).

17.2 Results

17.2.1 Spatial Variation
No general spatial pattern was observed for Cu in perch liver. The highest concentration of Cu (63 ug/g dry weight) was found in perch liver from Lake Övre Skärsjön in Västmanland County in 2010-2012. The lowest concentration of Cu (7.3 ug/g dry weight) was found in perch liver from Lake Fysingen close to Stockholm (Fig. 17.1).

The concentration of Cu in pike from Lake Bolmen is almost twice as high as in pike from Lake Storvindeln (Fig. 17.2).

17.2.2 Temporal variation

Decreasing trends of between 3.5-6.1% are observed for copper in perch liver from Lake Bysjön and Lake Skärgölen during 2000-2012 (Fig. 17.4). Also, significant decreasing trends for the last ten years are seen for perch at Lake Stensjön, with an annual decrease of 4.3% (Fig. 17.5) and for pike at Lake Storvindeln, with an annual decrease of 4.6% (Fig. 17.2). No trend is detected for the other matrices and sites monitored within the programme (Fig. 17.3-17.5) for Cu.

The number of years required to detect an annual change of 10% for Cu varies between 6 - 14 years for the pike, char and perch time series.
Figure 17.2. Copper concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 17.3. Copper concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärgölen.
Figure 17.4. Copper concentrations (µg/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön, and Lake Krageholmssjön.

Figure 17.5. Copper concentrations (µg/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervatnet, Lake Stensjön, and Lake Övre Skärsjön.

17.3 Summary

The highest concentration of Cu in perch liver was found in Lake Övre Skärsjön in Västmanland County in 2010-2012.

No general trend is observed for copper during the monitored period.
18 Zinc - Zn

18.1 Introduction

18.1.1 Usage, Production and Sources
Zinc is a nutritionally essential metal naturally present in some foods. It is a biological requirement for many animals and plants (Zinc factsheet 2011). Zinc concentration is regulated by homeostatic mechanisms. Hence, it is not believed to accumulate with continued exposure, but changes found in biological tissues may still reflect changes in concentration of the ambient water. Zinc occurs naturally in the environment, but most zinc comes from human activities such as mining, steel production and coal burning. In its pure form, anthropogenic sources of zinc can include use in galvanising steel and iron to prevent rust and corrosion; it is mixed with other metals to form alloys such as brass and bronze; and it is used to make dry cell batteries (Draggan 2008). Zinc compounds are used in industry for things such as making white paints and ceramics, producing rubber, preserving wood and dyeing fabrics (Draggan 2008). Tyre tread material contains approximately 1% weight of zinc. Wear of tyres on road surfaces can contribute a small amount of zinc to the environment (Councell et al. 2004). Some sunscreens use zinc oxide nanoparticles (Osmond and McCall 2010); other zinc compounds can be found in, for example, deodorants, nappy rash cream and anti-dandruff shampoo (Draggan 2008).

18.1.2 Environmental Fate
Zinc is present in water, air and soil. In air, zinc is present mostly as small particles that fall to the earth and drain into waterways with precipitation. Most of this zinc ends up settling in sediment at the bottom of water bodies; however some zinc can remain bound to the soil. Dissolved zinc in water can increase acidity levels (Draggan 2008).

18.1.3 Conventions, Aims and Restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction in the discharge of zinc to air and water by 50% by 1995, with 1987 as the base year.

18.1.4 Target levels
No national target level for biota is agreed upon for Zn.

18.2 Results

18.2.1 Spatial Variation
No general spatial pattern was observed for Zn in perch liver. The highest concentration of Zn (132 ug/g dry weight) was found in perch liver from Lake Hjärtsjön in Småland County in 2010-2012. The lowest concentration of Zn (93 ug/g dry weight) came from perch liver from Lake Gipsjön in Dalarna County (Fig. 18.1).

Pike in Lake Bolmen had almost twice as high concentration (197 ug/g dry weight) in 2012 compared to pike in Lake Storvindeln, Arctic char in Lake Abiskojaure and perch from the lakes in the monitoring programme (Fig. 18.2-18.5).

18.2.2 Temporal variation
Significant decreasing trends were observed for zinc in pike liver from Lake Storvindeln (annual change of 1.3%) and in perch liver from a majority of the sampling sites (annual changes of about 1-3%) (Fig. 18.2-18.5).

The number of years required to detect an annual change of 10% for Zn varies between 5 - 14 years for the pike, char and perch time series.
Figure 18.2. Zinc concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 18.3. Zinc concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärgölen.
**Figure 18.4.** Zinc concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön, and Lake Krageholmssjön.

**Figure 18.5.** Zinc concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervatnet, Lake Stensjön, and Lake Övre Skärsjön.

### 18.3 Summary

The highest concentration of Zn in perch liver was found in Lake Hjärtsjön in Småländ County in 2010-2012. However, the results of the Zn concentrations are very homogenous among the lakes investigated within the monitoring programme.

Zinc is decreasing significantly at a majority of the perch sampling sites and in pike from Lake Storvindeln.
19 Arsenic - As

19.1 Introduction

19.1.1 Uses, Production and Sources
Arsenic is a natural component of the earth’s crust, and is found in all environmental media (WHO 2001). Major anthropogenic sources of environmental arsenic contamination are via industrial smelters, coal-fired power plants and production and use of arsenic pesticides and herbicides (Eisler 1994). An estimation of world arsenic production showed that copper chrome arsenate (CCA) used in timber treatment accounts for most arsenic use; however this source has recently decreased due to new arsenic compound regulations, which has seen the industry sector turn to arsenic-free preparations (KEMI).

Elemental arsenic is produced by reduction of arsenic trioxide (As$_2$O$_3$) with charcoal, which in turn is produced as a by-product of metal smelting operations, especially in copper smelting (WHO 2001) (Eisler 2007). Sweden was the world’s leading producer of arsenic trioxide, with ore from the Boliden area containing the highest levels of arsenic (Eisler 2007) (SGU).

19.1.2 Toxicological Effects
Acute, subacute and chronic arsenic effects can involve a number of organ systems including the respiratory, gastrointestinal, cardiovascular, nervous, and haematopoietic systems and disturbance of liver function, which has been observed in both humans and animals after chronic exposure. There is evidence that arsenic affects the heart in humans (WHO 1981).

In general, inorganic arsenic is more toxic than organic arsenic to aquatic biota, with trivalent species being more toxic than pentavalent. The toxic effects are modified by numerous biological factors such as water temperature, pH, organic content, phosphate concentration, suspended solids and the presence of other substances and toxicants (Eisler 1994). Arsenic from water bioaccumulates in aquatic organisms, but there has been no evidence of biomagnification in the food web (Eisler 1994) (SGU 2005).

19.1.3 Conventions, Aims and Restrictions
Restrictions on the use of arsenic as a wood preservative are described in Annex XVII of the EU Regulation (EC) 1907/2006 on the Registration, Evaluation and Authorisation of Chemicals (REACH).

COMMISSION DIRECTIVE 2006/139/EC (20th December 2006) amending Council Directive 76/769/EEC in regards to restrictions on the marketing and use of arsenic compounds for the purpose of adapting Annex I to technical progress, states that arsenic compounds may not be used in the EU as substances and constituents of preparations intended for, amongst other things, the preservation of wood. Wood treated with arsenic compounds may not be placed on the EU market.

19.1.4 Target Levels
No national target level for biota concerning arsenic is agreed upon.
Concentrations in water are usually $< 10 \mu g/l$ (WHO 2001).

19.2 Results

19.2.1 Spatial Variation

No general spatial pattern was observed for As in perch liver. The highest concentration of As ($1.68 \mu g/g$ dry weight) was found in perch liver from Lake Krageholmssjön in Skåne County in 2010-2012. The lowest concentration of As ($0.20 \mu g/g$ dry weight) came from perch liver from Lake Gipsjön in Dalarna County (Fig. 19.1).

Arctic char from Lake Abiskojaure and pike from Lake Bolmen and Lake Storvindeln had similar concentrations of As in 2012 (around $0.2 \mu g/g$ dry weight) (Fig. 19.2).

19.2.2 Temporal variation

Significant increasing trends were observed for arsenic in pike liver from Lake Storvindeln (about 8%), pike liver from Lake Bolmen (about 3%), and in Arctic char from Abiskojaure (about 6%) (Fig. 19.2). Also, increasing trends during the last ten years were observed for perch from Lake Skärgölen (20% per year) and Lake Degervattnet (9% per year) (Fig. 19.3, 19.5) A significant decreasing trend in perch liver from Lake Övre Skärsjön (6%) (Fig. 19.5) was found whereas no significant trends were seen for the other perch sites within the monitoring programme (Fig. 19.3-19.5).

The number of years required to detect an annual change of 10% for As varies between 8-18 years for the pike, char and perch time series.
Figure 19.2. Arsenic concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 19.3. Arsenic concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärölen.
Figure 19.4. Arsenic concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön, and Lake Krageholmssjön.

Figure 19.5. Arsenic concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön, and Lake Övre Skärösjön.

19.3 Summary

The highest concentration of As in perch liver was found in Lake Krageholmssjön in Skåne County in 2010-2012.

No general temporal trend was observed for arsenic concentrations in fish liver.
20 Silver - Ag

20.1 Introduction

20.1.1 Uses, Production and Sources
Silver is a noble metal (resistant to corrosion and oxidation) that occurs naturally, especially in sulfide-rich ores and in combination with other noble metals and copper, lead and zinc (Eisler 1996) (IVL 2007). The main source of silver today is as a by-product in copper and lead smelting. In Sweden, silver is extracted in a copper mine near Gällivare, a lead mine at Arjeplog, and mines close to Skelefteå (IVL 2007).

Anthropogenic sources of silver are mainly smelting operations, the manufacture and disposal of certain photographic and electrical supplies, coal combustion and cloud seeding (WHO 2002). Silver is used for jewellery, ornaments, tableware, utensils and currency (Eisler 1996) (IVL 2007) (WHO 2004). Electronics, batteries and solders containing silver may appear as solid waste either deposited in landfills or burnt in waste incinerators. Dispersal of residues in the environment may occur via leakage or emissions to the air (IVL 2007).

Medicinally, silver is used for its bactericidal properties. Soluble silver compounds are used as antiseptic and bacteriostatic agents, as disinfectants (WHO 2004); and as antiseptic and antiodour agents in products such as in washing machines, refrigerators, socks and shoes (IVL 2007). Metallic silver is used in amalgam dental fillings alloyed with mercury and small amounts of other metals (IVL 2007).

Silver concentration in biota has been found to be higher near sewage outfalls, electroplating plants, mine waste and silver-iodide-seeded areas, than from more distant sites (Eisler 1996).

20.1.2 Toxicological Effects
Silver has no known biological function in living organisms (IVL 2007). It occurs naturally in several oxidation states. The most common states are elemental silver Ag° and the monovalent ion Ag+. Soluble silver salts are generally more toxic than insoluble salts. Silver as ionic Ag⁺ is one of the most toxic metals known to aquatic organisms in laboratory studies (Eisler 1996) (IVL) Silver has an affinity for suspended particles (Gill et al. 1994). In fish, silver has been found to induce the metal-binding protein metallothionein (IVL 2007).

20.1.3 Conventions, Aims and Restrictions
Silver and all of the chemical compounds that emit silver or silver ions, should be regarded as a biocide product if its purpose is to prevent growth of bacteria. Silver used as a biocide product is restricted by the European directive 98/8/EC concerning the placing of biocidal products on the market.

20.1.4 Target Levels
No national target level for biota concerning silver is agreed upon.

The tolerable daily intake of silver for humans has been set at 5 µg/kg body weight (IRIS 1991). WHO recommendations for the protection of groundwater, reports a critical concentration of 50 µg/l (WHO 2004).
Silver is comparably rare in the earth’s crust. The crustal abundance is estimated at 0.07 mg/kg, predominantly concentrated in basalt (Eisler 1996). Average concentration of silver in natural waters is 0.2 – 0.3 µg/l (WHO 2004).

In Sweden, the analyses of background concentrations of silver have shown concentrations of 0.07 mg/kg in the fine particulate fraction of moraine, and 0.2 mg/kg in the fine fraction of sediment soils (SGU 2005). In analysed lake sediments, measured concentrations were 0.16 – 0.66 mg/kg dry weight (Grahn et al. 2006), and 5 – 22 mg/kg dry weight (IVL 2007). Background concentrations of silver in fish muscle from lakes have been measured as <0.21 µg/kg fresh weight (IVL 2007).

20.2 Results

20.2.1 Spatial Variation

![Figure 20.1. Spatial variation in concentration (µg/g dry weight) of Ag in perch liver.](image)

Figure 20.1. Spatial variation in concentration (µg/g dry weight) of Ag in perch liver.
No general spatial pattern was observed for Ag in perch liver. However, a few lakes had higher concentrations compared to the rest of the lakes. The highest concentration of Ag (0.34 μg/g dry weight) was found in perch liver from Lake Hjärtsjön in Småland County in 2010-2012. The lowest concentration of Ag (0.04 μg/g dry weight) came from perch liver from Lake Fysingen close to Stockholm and Lake Kranksjön in Skåne County (Fig. 20.1).

Pike from Lake Storvindeln and Lake Bolmen had similar concentrations of Ag (0.1 μg/g dry weight) and Arctic char from Lake Abiskojaure had almost twice as high concentration in 2012.

### 20.2.2 Temporal variation

Significant decreasing trends were observed for silver in perch liver from Lake Skärgölen (4.6%) between 2000 and 2012 and in perch liver at Lake Degervattnet (14%), Lake Stensjön (6.7%) and pike liver at Lake Storvindeln (4.3%) for the last ten years whereas no significant trends were seen for the other matrices and sites within the monitoring programme (Fig. 20.2-20.5).

The number of years required to detect an annual change of 10% for Ag varies between 6-22 years for the pike, char and perch time series.

![Figure 20.2. Silver concentrations (μg/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).](image-url)
Figure 20.3. Silver concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärgölen.

Figure 20.4. Silver concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön, and Lake Krageholmssjön.
Figure 20.5. Silver concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervatnet, Lake Stensjön, and Lake Övre Skärsjön.

20.3 Summary

The highest concentration of Ag in perch liver was found in Lake Hjärtsjön in Småland County in 2010-2012.

No general temporal trend was observed for silver concentrations in fish liver.
21 Aluminium - Al

21.1 Introduction

21.1.1 Uses, Production and Sources

Aluminium (Al) is the most abundant metal in the Earth’s crust and is released from both natural and anthropogenic sources (Poléo, 1995). It has a silvery white to dull gray colour and the oxidation state is 3+. Aluminium is always combined with other elements in the nature, and form substances such as aluminosilicates, oxides, and hydroxides in rocks and minerals. Metallic aluminium is refined from bauxite ore which is known as the primary commercial source of aluminium. Aluminium is never found in the elemental state because of its strong affinity to oxygen. Oxides and silicates are two common forms of aluminium. Mass numbers of known isotopes of aluminium range from 21 to 42; however, only $^{27}$Al occurs naturally. As a metal, aluminium is a good thermal and electrical conductor. In addition, aluminium is widely used in aerospace industry, transportation, packaging, construction, household due to its low density, durability and corrosion resist ability. Aluminium is also used as an emulsifying agent and an adjuvant in certain vaccines (Mitkus et al., 2011). Therefore, humans are exposed to Al via incidental ingestion of food and water containing aluminium or through vaccination. Aluminium can be used to form alloy with other metals (copper, magnesium, silicon).

21.1.2 Environmental Fate

Atmospheric aluminium is derived from the weathering of aluminosilicate rocks and soils, coal combustion, cement manufacture, metal smelting and waste incineration (Jones and Bennett, 1986). In water, aluminium can form several complex ions depending on pH and the amount of dissolved organic matter (Priest, 2005). Dissolved aluminium which may be toxic to aquatic biota can only be found in water with pH < 5 (Jones and Bennett, 1986). Aluminium is present at a high abundance in soil and its chemical forms depend on the type and depth of the soil. Soluble and exchangeable aluminium occurs in acidic soils, while insoluble forms may accumulate in the B horizon of podzolic soils (Jones and Bennett, 1986). Several plants can absorb aluminium from soils and accumulate very high concentration of aluminium.

21.1.3 Toxicological Effects

The health effects of aluminium are of interest especially because of its widespread occurrence in the environment and in commerce. Aluminium competes with calcium for absorption and bone mineralization. Therefore, increasing amounts of dietary aluminium may cause calcium deficiency and adverse effects on skeletal mineralization (Zafar et al., 2004). Aluminium is known as a neurotoxin though its role as an agent causing toxicity remains unclear (Banks and Kastin, 1989). In very high doses, aluminium can cause neurotoxicity, altering function of blood-brain barrier in rat (Banks and Kastin, 1989; Miu et al., 2003). Aluminium neurotoxicity may occur in humans since high concentration of aluminium was detected in elderly people with syndromes concerning impaired coordination and memory (Bowdler et al., 1979). Aluminium in some forms is known as acute toxic to fish and other aquatic organism even though its level is remarkably low in fresh water (Poléo, 1995). At pH
from 5.0 to 6.0, Al-hydroxites bind and polymerize on the surface of fish gills, causing respiratory and ion regulatory dysfunctions.

21.1.4 Conventions, Aims and Restrictions
The World Health Organization on esthetic grounds specifies that aluminium concentrations in tap water should not exceed 200 µg/l (Priest, 2005).

21.1.5 Target Levels
No national target level for biota concerning aluminium is agreed upon.

21.2 Results

21.2.1 Spatial Variation

Figure 21.1. Spatial variation in concentration (ug/g dry weight) of Al in perch liver.

No general spatial trend for aluminium in perch liver is observed. The highest concentration of Al (53 ug/g dry weight) was found in perch liver from Lake Skärgölen in Kalmar County in 2010-2012. The lowest concentration of Al (2.3 ug/g dry weight) came from perch liver from Lake Krankesjön in Skåne County (Fig. 21.1).

The concentration of Al in pike is similar at the two lakes (about 1.9 ug/g dry weight) in 2012, while the concentration in Arctic char is more than twice as high (4.5 ug/g dry weight) (Fig. 21.2).
21.2.2 Temporal variation

A significant increasing trend of 5% per year was seen for perch liver at Lake Krageholmssjön, while a decreasing trend for the last ten years was seen at Lake Degervattnet (7.8%) and in pike liver at Lake Storvindeln (9.4%). No significant trends were seen for aluminium for the other matrices and sites within the monitoring programme (Fig. 21.2-21.5).

The number of years required to detect an annual change of 10% for Al varies between 9-14 years for the pike, char and perch time series.

Figure 21.2. Aluminium concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 21.3. Aluminium concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärpgölen.
21.3 Summary

The highest concentration of Al in perch liver was found in Lake Skärgölen in Kalmar County in 2010-2012.

No general temporal trend was observed for aluminium concentrations in fish liver.
22 Bismuth - Bi

22.1 Introduction

22.1.1 Uses, Production and Sources
Bismuth is a relatively rare element since its abundance in the Earth's crust is estimated to be about 0.2 parts per million (Jayasinghe et al., 2004; Das et al., 2006). Bismuth is seldom found in its elemental state (as a pure metal) in the earth. Its compounds are generally found along with ores of other metals, such as lead, silver, gold, and cobalt. The most important mineral of bismuth are bismuthinite, also known as bismuth glance (Bi$_2$S$_3$) and bismite (Bi$_2$O$_3$) (Hammond, 2004; Jayasinghe et al., 2004). Bismuth is mainly produced as a by-product from lead and copper smelting. There is only one naturally occurring isotope of bismuth, $^{209}\text{Bi}$. Bismuth is used in semiconductors, cosmetic products, alloys, catalysts in the chemistry industry, metallurgical additives, and preparation and recycling of uranium in nuclear fuels (Das et al., 2006). Alloy of bismuth can be made into pellets and used as an alternative for lead shotshells (Jayasinghe et al., 2004). In medicine, it is used in the treatment of gastrointestinal tract disturbance, e.g. gastritis and peptic ulcer (Gorbach, 1990).

22.1.2 Toxicological Effects
The Food and Agricultural Organization and the World Health Organization do not classify bismuth as an essential element for the body (Das et al., 2006). Bismuth compounds will be excreted through urine in case it is absorbed. Therefore, it is considered to be of low toxicity. However, a number of toxic effects have been found in humans and other animals at certain concentrations. The use of bismuth-containing medication was declined as a result of reports concerning severe neurological symptoms, liver and kidney damages associated with intake of bismuth salts (Ross et al., 1996; Burguera et al., 1999). Bismuth can enter the nervous system of mice and affect motor neuron (Das et al., 2006). There is limited information on the effects and environmental fate of bismuth, but in general, bismuth is considered to have a small environmental impact and is less toxic than its other neighbours in the periodic table (lead, antimony, polonium).

22.1.3 Target Levels
No national target level for biota concerning bismuth is agreed upon.

22.2 Results

22.2.1 Spatial Variation
Figure 22.1. Spatial variation in concentration (ug/g dry weight) of Bi in perch liver.

No general spatial trend for bismuth in perch liver is observed. The highest concentration of Bi (0.03 ug/g dry weight) was found in perch liver from Lake Sännen in Blekinge County in 2010-2012. The lowest concentration of Bi (0.002 ug/g dry weight) in perch liver is reported for Lake Krankesjön in Skåne County and Lake Algjuttern in Kalmar County (Fig. 22.1).

Pike from Lake Storvindeln and Lake Bolmen had the same magnitude of concentration of Bi (0.002 ug/g dry weight) and the concentration of Bi in Arctic char from Lake Abiskojaure was half of the amount, 0.001 ug/g dry weight (Fig. 22.2).

22.2.2 Temporal variation

A significant decreasing trend was observed for bismuth in perch liver from Lake Fiolen of 5.4%. No significant trends were seen for Bi for the other matrices and sites within the monitoring programme (Fig.22.2-22.5).

The number of years required to detect an annual change of 10% for Bi varies between 6-14 years for the pike, char and perch time series.
Figure 22.2. Bismuth concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Figure 22.3. Bismuth concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärgölen.
22.3 Summary

The highest concentration of Bi in perch liver was found in Lake Sännen in Blekinge County.

No general temporal trend was observed for bismuth concentrations in fish liver.
23 Tin – Sn

23.1 Introduction

23.1.1 Uses, Production and Sources

Tin is a chemical element with the symbol Sn. Tin has chemical similarities to both lead and germanium. It has two oxidation states, stannous Sn\(^{+2}\) and stannic Sn\(^{+4}\), which is slightly more stable (Goyer and Clarkson 2001). Tin is mainly obtained from the mineral cassiterite. Tin has the greatest number of stable isotopes, 10, \(^{120}\)Sn, \(^{118}\)Sn, \(^{116}\)Sn, \(^{119}\)Sn, \(^{117}\)Sn, \(^{124}\)Sn, \(^{122}\)Sn, \(^{112}\)Sn, \(^{114}\)Sn, \(^{115}\)Sn, and where three of them are potentially radioactive. There are also 29 additional unstable isotopes.

The most commercially significant inorganic tin compounds include tin (II) chloride, tin (IV) chloride, tin (IV) oxide, potassium and sodium stannates, tin (II) fluoride, tin (II) difluoroborate, and tin (II) pyrophosphate (WHO, 2005). Of these, tin (II) chloride is the most important compound, and it is predominantly used as a reducing agent in organic and inorganic synthesis and in manufacture of metallized glazing, glass, and pigments. Moreover, tin (IV) chloride is also an important compound and it is used in organic synthesis, in plastics, as an intermediate in organotin compound manufacture, and in the production of tin (IV) oxide films on glass (WHO, 2005).

Tin does not oxidize easily in air, and therefore it is used for coating other metals in order to prevent corrosion. Tin is thus used in many alloys, particularly in soft solders, which accounts for about 34% of all tin produced. It is also largely used as corrosion-resistant tin-plating of steel. Another 25-30% of the produced tin is used as a protective coating for other metals, especially food containers, because of its low toxicity. Organic tin compounds have been used in fungicides, bactericides, and slimicides, and it has also been used as stabilizer in plastics (Goyer and Clarkson, 2001).

23.1.2 Environmental Fate

Tin can be released to the environment both by natural and anthropogenic sources. Tin occurs naturally in the Earth’s crust. Both organic and inorganic forms of tin compounds are found in various environmental media. Tin is a component in many soils, and inorganic tin compounds may be released in dusts from wind storms, roads, and agricultural activities (WHO, 2005). Tin can be released from production, use, disposal, and recovery of tin and tin compounds (WHO, 2005). Gases, dusts, and fumes that contain tin may be released from smelting and refining processes, industrial uses of tin, waste incineration, and burning of fossil fuels (WHO, 2005). Tin may also be released to soil from landfilling of tin-containing wastes, including used cans. Moreover, the degradation of organotin can result in the formation of inorganic tin (WHO, 2005).

23.1.3 Toxicological Effects

Inorganic tin salts have low toxicity. They are poorly absorbed and rapidly excreted (Winship, 1988). Instead, some organic tin compounds are highly toxic. The two most toxic ones are trimethyltin and triethyltin (Winship, 1988, Goyer and Clarkson, 2001).
Inorganic tin compounds have low toxicity in both aquatic and terrestrial organisms. This is mainly due to their low solubility, poor absorption, low accumulation in tissues, and rapid excretion.

Toxicity tests on fish shows that tin (II) chloride is more toxic than tin (IV) chloride. 96h LC$_{50}$ test for fish ranges from 35 mg of tin (II) per litre to > 1000 mg tin (IV) per litre. 7- and 28-day LC$_{50}$ embryo-larval test for fish ranged from 0.4 to 2.1 mg/litre for tin (II) (WHO, 2005).

The main human exposure to tin is through food. Those that routinely consume canned fruit, vegetables, and juices from unlacquered cans could ingest 50-60 mg tin daily (WHO, 2005).

**23.1.4 Target Levels**

No national target level for biota concerning tin is agreed upon.
23.2 Results

23.2.1 Spatial variation

Almost all values for Sn in perch liver were in 2010-2012 below LOQ, regardless of lake so therefore a map is not presented. The value for LOQ ranges between 0.04-0.29 ug/g dw.

The concentration of Sn in pike liver from Lake Bolmen and Lake Storvindeln and in Arctic char liver from Lake Abiskojaure ranges between 0.05-0.06 ug/g dry weight (Fig. 23.1).

23.2.2 Temporal variation

Significant increasing trends for perch were observed in Lake Skärgölen and Lake Remmarsjön from 2000/2001-2012 with an annual increase of between 10-17% (Fig. 23.2-23.4). No trends in Sn concentrations were observed for Arctic char or pike within the monitoring programme (Fig. 23.1).

The number of years required to detect an annual change of 10% for Sn varies between 12-22 years for the pike, char and perch time series.

Figure 23.1. Tin concentrations (ug/g dry weight) in Arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).
Figure 23.2. Tin concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern, and Lake Skärölen.

Figure 23.3. Tin concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön, and Lake Krageholmsjön.
23.3 Summary

Almost all values of Sn concentrations were below LOQ in 2010-2012.

Arctic char and pike did not show any trends in Sn concentration, while perch from Lake Skärgölen and Remmarsjön showed significant increasing trends in Sn concentrations.
24 PCBs, Polychlorinated biphenyls

24.1 Introduction

24.1.1 Usage, Production and Sources
Polychlorinated biphenyls (PCBs) consist of two linked benzene rings with chlorine atoms substituted for one or more hydrogen atoms. Of a possible 209 congeners, 20 have non-ortho chlorine substitutions and so can attain a planar structure similar to the highly toxic polychlorinated dibenzo-\(p\)-dioxins and dibenzofurans (McKinney et al. 1985, Serico et al. 1991). PCBs are synthetic chemicals that have been used in a wide variety of manufacturing processes especially as plasticizers and as insulators and fire retardants. It is widely distributed in the environment through inappropriate handling of waste material or e.g., leakage from large condensers and hydraulic systems.

24.1.2 Toxicological Effects
PCBs can influence human health by affecting multiple organ systems (ATSDR 2000, Carpenter 1998, Carpenter 2006) and their toxicological effects on e.g., reproduction in mink, is well documented (Aulerich et al. 1977, Jensen et al. 1977, Bleavins et al. 1980).

24.1.3 Conventions, Aims and Restrictions
In 1992, HELCOM revised the PCBs for which special bans and restrictions on transport, trade, handling, use and disposal were imposed. The Minister Declaration from 1988, within HELCOM, calls for a reduction of stable organic substances by 50% by 1995, with 1987 as the base year.

The Minister Declaration from 1996, within HELCOM, and the declaration in Esbjerg 1995, calls for measures for toxic, persistent, bioaccumulating substances like PCBs to have ceased completely in the year 2020.

PCB is one of the initial 12 Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs, an international agreement requiring measures for reducing or preventing release of dangerous substances into the environment.

In 1973, PCB use was banned in Sweden, except for within sealed systems. In 1978, all new use of PCBs was forbidden.

24.1.4 Target Levels
The target levels used for CB-153 and CB-118 in the time series for fish are 1600 and 24 ug/kg lipid weight respectively. For further information on target levels and selection of target level see chapter 10.
24.2 Results

24.2.1 Spatial Variation

Figure 24.1. Spatial variation in concentration (ug/g lipid weight) of CB-118 in perch muscle.

Figure 24.2. Spatial variation in concentration (ug/g lipid weight) of CB-153 in perch muscle.

In recent years, PCBs have only been analysed in perch from five lakes within the national Swedish monitoring programme for contaminants in freshwater biota. The highest concentration of CB-118 (0.13 ug/g lw) was found in Lake Fysingen close to Stockholm and the highest concentration of CB-153 was found in perch from Lake Krankesjön in Skåne County (0.19 ug/g lw) and Lake Fysingen (0.18 ug/g lw) in 2010-2012. The lowest concentration of CB-118 and CB-153 (0.005 and 0.016 ug/g lw respectively) in perch muscle came from Lake Skärgölen (Fig. 24.1-24.2).
The concentration of CB-153 and CB-118 in pike from Lake Bolmen is about three times higher than in pike from Lake Storvindeln and about ten times higher than in perch and Arctic char from the lakes monitored within the programme (Fig. 24.3-24.6).

24.2.2 Temporal variation

The pike and char time series show significant decreasing trends for CB-118 of about 4-8% per year in all lakes that are monitored (Fig. 24.3). No trend is detected for CB-118 in the perch time series from Lake Skärgölen and Lake Stensjön (Fig. 24.4).

CB-153 shows similar decreasing trends for pike and char as CB-118 (with the exception of pike from Lake Bolmen where no trend is detected), with an annual decrease of about 3-7% (Fig. 24.5). No trend is detected in the perch time series (Fig. 24.6).

The trends for CB-153 and CB-118 are consistent with and of similar magnitude to other time series for PCBs in marine biota (Bignert et al. 2010).

The number of years required to detect an annual change of 10% for CB-118 varies between 9 - 14 years for the pike, char and perch time series.

The number of years required to detect an annual change of 10% for CB-153 varies between 8 - 15 years for the pike, char and perch time series.

Figure 24.3. CB-118 concentrations (ug/g lipid weight) in Arctic char muscle (Lake Abiskojaure and Lake Tjultrask) and in pike muscle (Lake Bolmen and Lake Storvindeln). The green area denotes the levels below the suggested target value for CB-118 in fish.
Figure 24.4. CB-118 concentrations (ug/g lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön). The green area denotes the levels below the suggested target value for CB-118 in fish.

Figure 24.5. CB-153 concentrations (ug/g lipid weight) in Arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln). The green area denotes the levels below the suggested target value for CB-153 in fish.
The green area denotes the levels below the suggested target value for CB-153 in fish.

24.2.3 Comparison to thresholds

In all areas and species, CB-153 concentration is below the suggested target level based on the OSPAR EAC (Environmental Assessment Criteria) of 1.6 ug/g lipid weight.

The suggested target level for CB-118 based on the OSPAR EAC (Environmental Assessment Criteria) of 0.024 ug/g lipid weight was exceeded in perch from Lake Krankesjön and Lake Fysingen (Fig. 24.7) and the levels in pike from Lake Bolmen were close to the threshold.

Figure 24.7. Spatial variation in concentration (ug/g lipid weight) of CB-118 in perch muscle. The green sections of the bars are representing concentrations under the threshold level (0.024 ug/g lipid weight) and the red sections concentrations above.
24.3 Summary

The highest concentration in perch of CB-118 was found in Lake Fysingen close to Stockholm and the highest concentration of CB-153 was found both in Lake Fysingen and Lake Krankesjön in Skåne County in 2010-2012.

CB-118 and CB-153 concentrations varied between species and sites; however temporally, the concentration has decreased by approximately 3-8% per year (with a few exceptions) in the freshwater environment since the end of the 1960/70s.

In all areas and species, CB-153 concentration is below the suggested target level, whereas the target level for CB-118 is exceeded in perch from Lake Krankesjön and Lake Fysingen.
25 DDTs, Dichlorodiphenylethenes

25.1 Introduction

25.1.1 Usage, Production and Sources

DDT is a persistent synthetic pesticide that primarily degrades to DDE and DDD. It is still used in some countries as it is an effective pesticide against mosquitoes and hence malaria. The presence of DDT and its metabolites in the Arctic area indicates long range transport (Welch et al. 1991).

25.1.2 Toxicological Effects

DDT has severe health effects on wildlife. In fish-eating birds, reduced reproductive success is widely documented e.g., reduced productivity in top predator white-tailed sea eagles (Helander et al. 2008). This is due to several factors such as failure to return to nesting sites, egg shell thinning, inability of eggs to hatch, reduced number of reproducing pairs and nestling brood size (Hamlin et al. 2010, Helander et al. 2008). Also, embryo mortality, thyroid malfunction, and immunosupression have been documented (Hamlin et al. 2010).

25.1.3 Conventions, Aims and Restrictions

In 1992, the Helsinki Convention (HELCOM) revised the DDTs for which special bans and restrictions on transport, trade, handling, use and disposal were imposed. The Minister Declaration from 1988, within HELCOM, calls for a reduction of stable organic substances by 50% by 1995, with 1987 as the base year.

DDT is one of the initial 12 Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs, an international agreement requiring measures for reducing or preventing release of dangerous substances into the environment.

The Stockholm Convention was adopted in 2001 and entered into force in 2004.

In Sweden, DDT was partially banned as a pesticide in 1970, and completely banned in 1975 due to its persistence and environmental impact.

In western European countries, the use of DDT ceased around 1990, although heavy use was banned between 1970 and 1975 in most countries bordering the Baltic Sea.

25.1.4 Target Levels

The target level used for DDE in the time series for fish is 5 ug/kg wet weight. For further information on target levels and selection of target level see chapter 10. The original target level has been recalculated for each time series based on the lipid percentage. The recalculated target level (Tv) together with the lipid percentage (lp) is shown above the statistical information in each time series.
25.2 Results

25.2.1 Spatial Variation

**Figure 25.1.** Spatial variation in concentration (ug/g lipid weight) of DDE in perch muscle.

**Figure 25.2.** Spatial variation in concentration (ug/g lipid weight) of DDT in perch muscle.
In recent years DDTs are only analysed in perch from six lakes within the national Swedish monitoring programme for contaminants in freshwater biota. The highest concentration of DDE (0.40 ug/g lw) in perch muscle was found in Lake Krankesjön in Skåne County (Fig. 25.1) in 2010-2012 and the lowest concentration (0.035 ug/g lw) was found in Lake Skärgölen in Kalmar County. The highest concentration of DDT (0.01 ug/g lw) in perch muscle during the same time period was found in Lake Horsan in Gotland (Fig. 25.2) and the lowest concentration (0.006 ug/g lw) was found in Lake Skärgölen and Lake Svartsjön in Västra Götaland County.

The concentration of DDE in pike from Lake Bolmen is about six times higher than in pike from Lake Storvindeln and almost 20 times higher than in Arctic char and between two and six times higher than in perch from the lakes monitored within the programme (Fig. 25.3-25.6).

25.2.2 Temporal variation

Temporal trends of DDE and DDT in char from Lake Abiskojaure and Lake Tjulträsk and in pike from Lake Bolmen and Lake Storvindeln show similar patterns (Fig. 25.3, 25.5). The pesticide has decreased significantly during the period 1967/68/81-2012, with an annual change of between 6.3-20 %.

DDE and DDT show significant decreasing trends in perch from Lake Skärgölen with an annual change of 5.5.0 and 6.9 % respectively (Fig. 25.4, 25.6) during the period 1980-2012. No trend is detected in perch from Lake Stensjön (Fig. 25.4, 25.6), but the lake has only been monitored for ten years, with a gap between 2000 and 2005. This time period is too short to be able to detect a trend of 5-10% annual change with this material.

The concentration of DDT is close to or at the LOQ (level of quantification) for most of the matrices and sights that are monitored during recent years.

The number of years required to detect an annual change of 10% for DDE varies between 11 - 18 years for the pike, char and perch time series.

The number of years required to detect an annual change of 10% for DDT varies between 13 - 22 years for the pike, char and perch time series.
Figure 25.3. DDE concentrations (ug/g lipid weight) in Arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln). The green area denotes the levels below the suggested target value for DDE in fish.

Figure 25.4. DDE concentrations (ug/g lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön). The green area denotes the levels below the suggested target value for DDE in fish.
25.2.3 Comparison to thresholds

In all areas and species, DDE concentration is below the suggested target level based on the OSPAR EAC (Environmental Assessment Criteria) of 0.005 ug/g wet weight.
25.3 Summary

The highest concentration of DDE in perch muscle was found in Lake Krankesjön in Skåne County in 2010-2012, and the highest concentration of DDT in perch muscle during the same time period was from Lake Horsan in Gotland.

DDE and DDT concentrations varied between species and sites; however temporally, the concentration has decreased by approximately 5-20% per year in the freshwater environment since the end of the 1970s.

In all areas and species, DDE concentration is below the suggested target level.
26 HCHs, Hexachlorocyclohexanes

The isomers α-HCH, β-HCH and γ-HCH i.e., lindane, have been analysed in muscle tissue for various fish species since 1980. The concentrations of β -HCH are in many cases close to the quantification limit, which implies analytical problems.

26.1 Introduction

26.1.1 Uses, Production and Sources
Technical HCH contains various isomers: 60 - 75% α-HCH; 15% γ-HCH (lindane); 7 -10% β-HCH; 7% δ-HCH; and 1 - 2% ε-HCH, and came into general use in 1950 (Gaul, 1992). The γ-isomer is the most toxic isomer of the HCHs, being 500 - 1000 times as potent as the α-isomer (White-Stevens 1971).

26.1.2 Conventions, Aims and Restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction of stable organic substances by 50% by 1995, with 1987 as the base year.

HCHs are three of the initial 12 Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs, an international agreement requiring measures for reducing or preventing release of dangerous substances into the environment.

In Sweden, the use of lindane was severely restricted in 1970, and subsequently prohibited for use in agriculture in 1978 because of its suspected carcinogenic properties and persistence. Remaining use was banned in 1988/89.

The use of technical HCH stopped in countries around the Baltic between 1970 - 1980. Since 1980, use of lindane in Europe has been allowed only as an insecticide. It was still used to a great extent in France and Italy as recently as 1990 (Yi-Fan et al. 1996).

26.1.3 Target Levels
The target level used for sHCH in the time series for fish is 26 ug/kg wet weight. For further information on target levels and selection of target level see chapter 10. The original target level has been recalculated for each time series based on the lipid percentage. The recalculated target level (Tv) together with the lipid percentage (lp) is shown above the statistical information in each time series.

26.2 Results

26.2.1 Spatial Variation
In recent years HCHs are only analysed in perch from six lakes within the national Swedish monitoring programme for contaminants in freshwater biota. The concentrations are rather homogenous among the lakes, but the highest concentration of α-HCH, 2010-2012 (0.0050 ug/g lw) was found in perch from Lake Krankesjön in Skåne County. The levels in the other lakes that are analysed for α-HCH are close to or at LOQ (Fig. 26.1). The concentrations of β-HCH and lindane in perch muscle were almost all under LOQ in 2010-2012 and are therefor not presented as maps.

The concentration of lindane is of similar magnitude in pike from Lake Bolmen and Lake Storvindeln, and in perch from Lake Skärgölen and Stensjön, but about three times higher than in Arctic char from Lake Abiskojaure and Lake Tjulträsk (Fig. 26.2-26.3).

26.2.2 Temporal variation
Temporal trends of lindane in char from Lake Abiskojaure and Lake Tjulträsk, and in pike from Lake Bolmen and Lake Storvindeln, show similar patterns (Fig. 26.2-26.3). Lindane has decreased significantly during the period 1980-2012, with an annual change of between 4.4-11%. During the last ten years, levels of lindane are close to or at LOQ.

αHCH has decreased significantly in char from Lake Abiskojaure and in pike from Lake Bolmen with an annual change of 6.3 and 3.9 % respectively (Fig. 26.4). A decrease for the last seven years is seen in pike from Storvindeln of 5.8% per year.

Lindane shows significantly decreasing trends in perch from Lake Stensjön during the whole time period and for the last six years in Lake Skärgölen, with an annual change of 4.1 and 5.5 % respectively (Fig. 26.3) during the period 1980/00-2012.

αHCH is decreasing significantly in perch from Lake Stensjön with an annual change of 2.3% and in Lake Skärgölen for the last six years with an annual decrease of 4.7% (Fig. 26.5).

The number of years required to detect an annual change of 10% for lindane varies between 7-17 years for the pike, char and perch time series.
The number of years required to detect an annual change of 10% for sHCH varies between 6-13 years for the pike, char and perch time series.

Figure 26.2. Lindane concentrations (ug/g lipid weight) in Arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln).

Figure 26.3. Lindane concentrations (ug/g lipid weight) in perch muscle (Lake Skårgölen and Lake Stensjön).
26.2.3 Comparison to thresholds

In all areas and species, sHCH concentration is below the suggested target level based on IVLs (The Swedish Environmental Research Institute) conversion of the EQS for surface water to biota of 0.026 ug/g wet weight (Fig. 26.4-26.5).
26.3 Summary

The highest concentration of α-HCH in perch muscle was found in Lake Krankesjön in Skåne County in 2010-2012.

The lindane concentrations varied between species and sites; however temporally, the concentration has decreased by approximately 1.4-11% per year in the freshwater environment since the end of the 1960/70s.

In all areas and species, sHCH concentration is below the suggested target level.
27 HCB, Hexachlorobenzene

27.1 Introduction

27.1.1 Uses, Production and Sources
The use of the highly persistent HCB as a fungicide is banned in the Baltic countries. Although it may still reach the environment as a by-product of many chlorinating processes, for example pentachlorophenol and vinyl chloride monomer production, we have reason to expect a decrease in biological samples from the Baltic.

27.1.2 Conventions, Aims and Restrictions
The Minister Declaration from 1988, within HELCOM, calls for a reduction of stable organic substances by 50% by 1995, with 1987 as the base year.

HCB is one of the initial 12 Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs, an international agreement requiring measures for reducing or preventing release of dangerous substances to the environment.

In 1980, HCB was withdrawn from the market in Sweden because of its carcinogenic effects on experimental animals and its persistence.

The use of HCB as a fungicide is banned in the Baltic countries.

27.1.3 Target Levels
The target level used for HCB in the time series for fish is 10 ug/kg wet weight. For further information on target levels and selection of target level see chapter 10. The original target level has been recalculated for each time series based on the lipid percentage. The recalculated target level (Tv) together with the lipid percentage (lp) is shown above the statistical information in each time series.

27.2 Results

27.2.1 Spatial Variation
The concentrations of HCB in perch muscle were almost all under the LOQ in 2010-2012 and are therefore not presented in a map.

The concentrations of HCB in pike and Arctic char (Lake Bolmen, Lake Storvindeln, Lake Tjulträsk and Lake Abiskojaure) are of similar magnitude (0.01 ug/g lipid weight), but about three times higher than in perch from the lakes monitored within the programme (Fig. 27.1-27.2).
27.2.2 Temporal variation

Temporal trends of HCB in char from Lake Abiskojaure and in perch from Lake Skärgölen and Lake Stensjön show similar patterns (Fig. 27.1, 27.2). HCB has decreased during the period 1981/86/97/99-2012, with an annual change of between 2.6 and 3.4%. No such trend is detected in char from Lake Tjulträsk or in pike from Lake Bolmen and Lake Storvindeln (Fig. 27.1), instead a significant increase during the last ten years is seen in pike from Lake Bolmen, with an annual change of 9.3% (Fig. 27.1).

The number of years required to detect an annual change of 10% for HCB varies between 4-17 years for the pike, char and perch time series.

Figure 27.1. HCB concentrations (ug/g lipid weight) in Arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln). The green area denotes the levels below the suggested target value for HCB in fish.

Figure 27.2. HCB concentrations (ug/g lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön). The green area denotes the levels below the suggested target value for HCB in fish.
27.2.3 Comparison to thresholds
In all areas and species, HCB concentration is below the suggested target level based on the EQS_{biota} of 0.010 ug/g wet weight (Fig. 27.1 and 27.2).

27.3 Summary
The HCB concentrations varied in some cases between species and sites. However temporally, the concentration has decreased by approximately 3 % per year in one of the char time series since the end of the 1970s and at the same magnitude for perch since the end of 1990s.

In all areas and species, HCB concentration is below the suggested target level.
28 PFASs, Perfluoroalkyl substances

28.1 Introduction

The different PFASs monitored in the freshwater programme include PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFPeDA, PFBS, PFHxS, PFOS, PFDS and FOSA.

28.1.1 Uses, Production and Sources

Perfluoroalkyl substances (PFASs) are anthropogenic surfactants with exceptional stability and surface tension lowering potential. PFASs have been used industrially (e.g., production of fluoropolymers) and commercially (water and stain proofing agents and fire-fighting foams) since the beginning of the 1950s. It was not until recently (2000) that the main producer, 3M, started to phase out production of the main compounds of concern, perfluorooctane sulfonate (PFOS) and PFOS derivatives, perfluorooctanoate (PFOA) as well as perfluorohexane sulfonate (PFHxS) (Buck et al. 2011).

Environmental PFAS contamination has multiple emission sources. These include primary emissions of PFASs to air and water from industrial production and application, as well as secondary emissions from consumer products or sewage treatment plant effluents. For the persistent perfluoroalkyl acids (PFAAs) a further distinction can be made between direct sources from manufacturing and use of PFAAs and indirect sources from degradation of semi-volatile precursor compounds (Buck et al. 2011). PFOA (perfluorooctanoate) and PFNA (perfluorononanoate) are intentionally produced and therefore a large portion of the PFOA and PFNA found in the environment probably originates from direct sources (mainly the production process of fluoropolymers, Prevedouros et al. 2006), and waterborne transport to remote locations. Therefore, sewage treatment plant effluent from industry or larger cities could represent hot-spots. In contrast, longer-chain perfluoroalkyl carboxylates (PFCAs) such as PFUnDA (perfluoroundecanoate) and PFTrDA (perfluorotridecanoate) are unintentionally produced substances, and their presence in the environment is probably due to both direct sources (impurities in PFOA and PFNA productions) and indirect sources (atmospheric transport and degradation of precursors). Also the role of PFOS derivatives for the distribution and accumulation of PFOS in the environment is currently under investigation (Martin et al. 2010). Perfluorooctane sulfonamide (FOSA) is an intermediate product in the degradation of many PFOS precursors to PFOS, and is often analysed together with PFOS in the environment.

28.1.2 Toxicological Effects

Exponentially increasing concentrations of PFOS in wildlife were reported during the 1990s (Holmström et al. 2005). In biota, PFASs tend to accumulate in protein rich tissues such as blood, liver and eggs. Toxic effects in laboratory experiments with mostly rodents include weight loss, liver enlargement, immunotoxicity and a number of developmental effects such as postnatal mortality. The common carp (Cyprinus carpio) exposed in lab to different PFOS concentrations experienced decreases in glycogen, and declines in condition factor and hepatosomatic index with increases in PFOS concentrations (Hagenaars et al. 2008). Due to
large inter-species variations and even gender differences in toxicological effects, it is difficult to extrapolate observed effects to potential effects in humans. However, epidemiological studies on humans have increased in recent years. For instance, concentrations of PFOA in maternal blood and PFOA and PFOS in cord blood during pregnancy have been found to be negatively associated with birth weight (Apelberg et al. 2007; Fei et al. 2007), ponderal index, head circumference (Apelberg et al. 2007), and birth length (Fei et al. 2008a). In contrast, no associations between concentrations of PFOA and PFOS in maternal plasma during pregnancy and developmental milestones in early childhood have been found (Fei et al. 2008b). Current human exposure to PFASs is believed to be primarily the result of dietary intake (Vestergren and Cousins 2009). Intake of contaminated fish from the Baltic Sea is one source of human exposure to PFASs (Berger et al. 2009).

28.1.3 Conventions, aims and restrictions
Perfluorooctane sulfonic acid, its salts, and perfluorooctane sulfonyl fluoride are among the nine new Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs, an international agreement requiring measures for reducing or preventing release of dangerous substances to the environment. Production and use of PFOS is regulated in some countries (e.g., Canada and the EU), but large scale production continues in other parts of the world.

Due to their concentrations and/or temporal trends, PFOS, PFOA and PFNA are currently the PFASs of most concern for the Baltic Sea environment (HELCOM, 2010). Based on their documented relevance for the marine environment long-chain PFCAs and FOSA are additionally included in this report.

28.1.4 Target Levels
The target level used for PFOS in perch liver is 9.1 µg/kg wet weight. For further information on target levels and selection of target level see chapter 10.

28.2 Results

28.2.1 Spatial variation
The concentrations of PFHxA, PFHpA, PFOA, PFBS, PFHxS and PFDS (with the exception of few samples) were all under LOQ in perch liver during the period 2010-2012, and are therefore not reported in the maps below.
Figure 28.1. Spatial variation in concentration (ng/g wet weight) of PFOS in perch liver.

Figure 28.2. Spatial variation in concentration (ng/g wet weight) of FOSA in perch liver.
**Figure 28.3** Spatial variation in concentration (ng/g wet weight) of PFNA in perch liver.

**Figure 28.4** Spatial variation in concentration (ng/g wet weight) of PFDA in perch liver.
Figure 28.5 Spatial variation in concentration (ng/g wet weight) of PFUnDA in perch liver.

Figure 28.6 Spatial variation in concentration (ng/g wet weight) of PFDoDA in perch liver.
Figure 28.7 Spatial variation in concentration (ng/g wet weight) of PFTrDA in perch liver.

Figure 28.8 Spatial variation in concentration (ng/g wet weight) of PFTeDA in perch liver.
Of the fifteen PFASs that are measured, PFOS is the substance found in the highest concentrations in perch liver.

For PFOS (as well as for most other PFASs), a pattern of increasing concentration from north to the south western parts of Sweden is seen (Fig. 28.1), with exceptions for Lake Fysingen, Lake Hjärtsjön, and Lake Limningsjön with comparably high PFOS concentrations, probably originating from local sources. The highest concentration of PFOS in perch liver was found in Lake Fysingen close to Stockholm (91 ng/g ww) in 2010-2012, and the lowest concentration in Lake Remmarsjön (1.95 ng/g ww) in Västernorrland County. Lake Fysingen is located close to the fire-fighting training sites at Rosersberg and also close to Arlanda airport, which most possibly explains the high concentrations.

The highest concentration of FOSA in perch liver in 2010-2012, 0.30 ng/g ww, was found in Lake Bysjön in Värmland County and the lowest concentration, 0.027 ng/g ww, was found in Lake Horsan on Gotland (Fig. 21.2).

The highest concentration of PFNA in perch liver in 2010-2012 was found in Lake Degervattnet in Jämtland County (1.78 ng/g ww) and the lowest concentration was found in Lake Svartsjön in Västra Götaland County (0.16 ng/g ww) (Fig. 28.3).

The highest concentration of PFDA in perch liver in 2010-2012, 7.54 ng/g ww, was found in Lake Hjärtsjön in Kronobergs County and the lowest concentration, 0.70 ng/g ww, was found in Lake Remmarsjön in Västernorrland County (Fig. 28.4).

The highest concentration of PFUnDA in perch liver in 2010-2012 was found in Lake Hjärtsjön (20.1 ng/g ww) and the lowest concentration was found in Lake Krankesjön in Skåne County (1.26 ng/g ww) (Fig. 28.5).

The highest concentration of PFDoDA in perch liver in 2010-2012 (11.39 ng/g ww) was found in Lake Hjärtsjön and the lowest concentration (0.45 ng/g ww) was found in Lake Kragelholmsjön in Skåne County (Fig. 28.6).
The highest concentration of PFTrDA in perch liver in 2010-2012, 13.1 ng/g ww, was found in Lake Hjärtsjön and the lowest concentration, 0.47 ng/g ww, was found in Lake Krageholmssjön (Fig. 28.7).

The highest concentration of PFTeDA in perch liver in 2010-2012 was found in Lake Hjärtsjön (2.58 ng/g ww) and the lowest concentration was found in Lake Remmarsjön (0.00 ng/g ww) (Fig. 28.8).

The highest concentration of PFPeDA in perch liver in 2010-2012, 1.1 ng/g ww, was found in Lake Hjärtsjön and the lowest concentration, 0.059 ng/g ww, was found in Lake Krankesjön (Fig. 28.9).

For most of the long-chain PFCAs, Lake Hjärtsjön in Kronobergs County had the highest concentrations.

28.2.2 Temporal variation
PFASs monitored within the programme but not presented as time trends are at concentrations below LOQ in the majority of the investigated years.

PFNA, PFDA, and PFUnDA all show significantly increasing concentrations of about 4-6 % per year in Arctic char liver from Lake Abiskojaure in 1980-2012. In perch liver from Lake Skärgölen increasing concentrations in 1980-2012 are seen for PFDA, PFUnDA, PFDoDA, and PFTrDA with about 4-7 % per year. However, a decreasing trend in concentration of PFOS is indicated for the whole time period and for the last ten years in perch liver from Lake Skärgölen (Fig. 28.10-28.13).

The number of years required to detect an annual change of 10% for PFASs varies between 12-20 years for the char and perch time series.

Figure 28.10. PFOS, PFNA, PFDA and PFUnDA concentrations (ng/g wet weight) in Arctic char liver from Lake Abiskojaure (1980-2011).
Figure 28.11. PFDoDA, PFTrDA, FOSA concentrations (ng/g wet weight) in Arctic char liver from Lake Abiskojaure (1980-2011).

Figure 28.12. PFOS, PFNA, PFDA and PFUnDA concentrations (ng/g wet weight) in perch liver from Lake Skärgölen (1980-2011).
28.2.3 Comparison to threshold

The suggested target level for PFOS based on ECs EQS\textsubscript{biota} (Environmental Quality Standards) of 9.1 ng/g wet weight for \textit{whole fish} was exceeded in about 40\% of the lakes (Fig. 28.12). PFOS is measured in perch liver so the results have to be interpreted with caution, especially since liver contains higher concentrations of PFASs than muscle tissue.

![PFOS, perch liver](image)

**Figure 28.13.** PFDoDA, PFTrDA, FOSA concentrations (ng/g wet weight) in perch liver from Lake Skärgölen (1980-2011).

![Spatial variation in concentration (ng/g wet weight) of PFOS in perch liver. The green sections of the bars are representing concentrations under the threshold level (9.1 ng/g wet weight) and the red sections concentrations above.](image)

**Figure 28.14.** Spatial variation in concentration (ng/g wet weight) of PFOS in perch liver. The green sections of the bars are representing concentrations under the threshold level (9.1 ng/g wet weight) and the red sections concentrations above.
28.3 Summary

The highest concentration of PFOS in perch liver (2010-2012) was found in Lake Fysingen, close to Stockholm. It is probably influenced by local fire-fighting activities and Arlanda airport.

For several of the PFASs (PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, and PFPeDA), Lake Hjärtsjön in Kronobergs County had the highest concentrations in 2012.

PFNA, PFDA, and PFUnDA all show significantly increasing concentrations in Arctic char liver from Lake Abiskojaure. In perch liver from Lake Skärgölen PFDA, PFUnDA, PFDoDA, and PFTrDA also show increasing trends. In addition, there is indication of a decrease in PFOS concentration in perch liver from Lake Skärgölen.

In about 40% of the perch lakes, the PFOS concentration is above the suggested target level for PFOS in whole fish. This result has to be interpreted with caution since no recalculation for the results from the liver analysis has been made, especially since liver contains higher concentrations of PFASs than muscle tissue.
29 PCDD/PCDF, Polychlorinated Dioxins and Dibenzofurans

29.1 Introduction

29.1.1 Uses, Production and Sources
Dioxins are unintentionally created during combustion of organic materials. They are highly toxic and carcinogenic.

Polychlorinated dibenzo-\(p\)-dioxins (PCDD) and dibenzofurans (PCDF) consist of 17 congeners considered to be of toxicological importance (210 congeners in total). PCDD/Fs are formed in several industrial processes and from most combustion processes (e.g., municipal waste incineration and small scale burning in poorly controlled conditions). The use of chlorine gas during pulp bleaching processes was formerly an important producer of PCDD/Fs.

Atmospheric deposition is the most important active source of PCDD/Fs to the Baltic Sea today (Sellström et al. 2009). The origin of the substances in air is, however, not fully known, although there are indications of strong impact of long-range atmospheric transport from south-western and southern Europe. It is also uncertain how historical emissions and secondary sources contribute, and how PCDD/Fs are accumulated in the food chain.

29.1.2 Toxicological Effects
The most relevant toxic effects of PCDD/Fs and dl-PCBs are developmental toxicity, carcinogenicity and immunotoxicity. The most relevant health effect seems to be developmental problems in children, where exposure can take place both during pregnancy and breast-feeding. A positive effect of restrictions and prohibitions of PCDD is that levels are decreasing in mother’s breast milk in Sweden (Norén and Meironyté 2000).

29.1.3 Conventions, aims and restrictions
Releases of dioxins from industrial installations are mainly regulated by the IPPC Directive and the Waste Incineration Directive.

Dioxins are comprised by the objective of HELCOM’s strategy for hazardous substances that is to continuously reduce discharges, emissions and losses of hazardous substances, with a goal of their eventual cessation by the year 2020. The ultimate aim is to achieve concentrations in the environment near background values for naturally occurring substances and close to zero for man-made synthetic substances. This objective was adopted in 1998, and dioxins have been selected as one of the priority substances for immediate action.

PCDD/PCDF are part of the initial 12 Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs, an international agreement requiring measures for reducing or preventing release of dangerous substances to the environment.
A dioxin and PCB strategy, including actions in the area of feed and food contamination and actions related to the environment including release reduction, was adopted by the EU in 2001.

29.1.4 Target Levels
The target level used for the sum of PCDD/F in WHO98-TEQ in the time series for fish is 3.5 ng/kg wet weight (WHO05-TEQ). The TEFs (Toxic equivalent factors) from 2005 do not differ to a high extent for the PCDDs and PCDFs compared to the TEFs from 1998 so, the WHO98-TEQs in the time series are therefore compared directly with the target level in WHO05 TEQ since older data on WHO05 TEQs is not available. The original target level has been recalculated for each time series based on the lipid percentage. The recalculated target level (Tv) together with the lipid percentage (lp) is shown above the statistical information in each time series. See chapter 10 for more information.

29.2 Results

29.2.1 Spatial variation

Figure 29.1 Spatial variation in concentration (pg/g lipid weight) of WHO05-TEQ (PCDD/PCDF) in perch muscle.
For PCDD/PCDF, a pattern of increasing concentration from north to the southern parts of Sweden is seen (Fig. 29.1-29.2). The spatial pattern for perch is consistent with the spatial pattern for pike (Fig. 29.4, 29.6) The levels of TCDD-equivalents in pike from Bolmen is more than three times higher than in pike from Storvindeln, which is located further north.

The highest concentration on a lipid weight basis of TCDD-equivalents (WHO05) (56 pg/g lw) in perch muscle was found in Lake Sännen in Blekinge County (Fig. 29.1) in 2010-2012. The lowest concentration (4.4 pg/g lw) in perch during the same period was found in Lake Remmarsjön in Västernorrland County (Fig. 29.1).

### 29.2.2 Temporal variation

Temporal trends of TCDD and TCDF on a lipid weight basis in pike from Lake Bolmen and in perch from Lake Skärgölen show similar patterns (Fig. 29.4, 29.8). TCDD and TCDF have decreased significantly during the period 1967/1980-2012, with an annual change of about 2% for TCDD and about 1.5% for TCDF. No trend for TCDD or TCDF on a lipid weight basis is observed in pike from Lake Storvindeln (Fig. 29.6).

Temporal trends of TCDD-equivalents for dioxinlike PCB on a lipid weight basis are decreasing significantly in pike from Lake Storvindeln and Lake Bolmen, and in perch from Lake Skärgölen during the period 1980/1990-2012 of about 3-6% (Fig. 29.4, 29.6 and 29.8).

The number of years required to detect an annual change of 10% for PCDD/PCDF varies between 11 - 13 years for the pike and perch time series (Fig. 29.3-29.8).
Figure 29.3. PCDD/PCDF concentrations (pg/g wet weight) in pike muscle from Lake Bolmen. The TCDD-EQVs are calculated using the WHO98 TEF. The green area denotes the levels below the suggested target value for PCDD/Fs in fish.

Figure 29.4. PCDD/PCDF concentrations (pg/g lipid weight) in pike muscle from Lake Bolmen. The TCDD-EQVs are calculated using the WHO98 TEF. The green area denotes the levels below the suggested target value for PCDD/Fs in fish.
Figure 29.5. PCDD/PCDF concentrations (pg/g wet weight) in pike muscle from Lake Storvindeln. The TCDD-EQVs are calculated using the WHO98 TEF. The green area denotes the levels below the suggested target value for PCDD/Fs in fish.

Figure 29.6. PCDD/PCDF concentrations (pg/g lipid weight) in pike muscle from Lake Storvindeln. The TCDD-EQVs are calculated using the WHO98 TEF. The green area denotes the levels below the suggested target value for PCDD/Fs in fish.
29.2.3 Comparison to thresholds

In all areas and species, TCDD equivalent concentration is below the suggested target level based on the EC EQS (Environmental Quality Standard) of 3.5 pgWHO05-TEQ/g wet weight.
29.3 Summary

The highest concentration of TCDD-equivalents in perch muscle was found in Lake Sännén in Blekinge County in 2010-2012.

PCDD/PCDF concentrations varied between species and sites; however temporally, the concentration of TCDF and TCDD has decreased at the southern sampling sites (i.e. Bolmen and Skärgölen) and the concentration of TCDD-equivalents for dioxinlike PCB has decreased in perch from Lake Skärgölen, and in pike from Lake Storvindeln and Lake Bolmen.

In all areas and species, TCDD-equivalent concentration (PCDD/PCDF) is below the suggested target level.
30 Polybrominated flame retardants

30.1 Introduction

30.1.1 Uses, Production and Sources
Polybrominated diphenyl ethers (PBDEs) are produced as three different technical products: penta-, octa and deca bromo diphenyl ethere (BDE). Each of these products includes a few major congeners. For pentaBDE these are BDE-47, -99, and-100. OctaBDE contains mainly BDE-183, while decaBDE includes almost exclusively BDE-209 (LaGuardia et al. 2006). Hexabromocyclododecan (HBCDD) is produced as a mixture of three stereoisomers - α-, β- and γ-HBCDD (Covaci et al. 2006). Both PBDEs and HBCDD are used as additive flame retardants incorporated into materials such as plastics and textiles in products that need to be prevented from catching fire.

PBDEs leak into the environment during production, use, or disposal of such products. PBDEs are mainly spread via diffuse distribution in the atmosphere and in rivers. HBCDD is bioaccumulative, lipophilic and persistent, and accumulates in the food-web.

30.1.2 Toxicological effects
Several PBDE congeners and HBCDD have been shown to cause neurotoxic effects in rats and mice. In mammals, behaviour, learning (Eriksson et al. 2006) and affects on hormonal functions have been reported (Legler 2008). Animals exposed to PBDEs and HBCDD during a sensitive stage of brain development have later shown reduced memory and learning disabilities (Viberg 2004; Eriksson et al. 2006). In birds, several aspects regarding reduced reproductive success has been documented (Fernie et al. 2009). Chemical products and goods containing concentrations over a certain level of these BDEs are banned in the EU. Brominated flame retardants (BFR) are also considered to be endocrine disruptors, and in particular, affects on the thyroid hormone system are seen (Darnerud 2008).

30.1.3 Conventions, aims and restrictions
The PBDEs tetrabromodiphenyl ether, pentabromodiphenyl ether, hexabromodiphenyl ether and heptabromodiphenyl ether are among the nine new Persistent Organic Pollutants (POPs) included in The Stockholm Convention on POPs. Within the EU, the penta- and octaBDE products were banned for use in 2004.

A Swedish ban of decaBDE was established in 2007, but this ban was withdrawn when decaBDE was included in the RoHS directive in 2008. PBDEs are also on the list of prioritized substances within the Water Framework Directive.

HBCDD is under review by the Persistent Organic Pollutants Review Committee (POPRC) as a proposed substance to be listed under the Stockholm Convention (Arnot et al. 2009).
30.1.4 Target Levels

The target level (TL) used for HBCDD in the time series for fish is 167 µg/kg wet weight. The target level used for the sum of BDE-28, 47, 99, 100, 153 and 154 (0.0085 µg/kg) for fish is not evaluated in time series since BDE-28 is not included in the analysis for BDEs. For further information on TL and selection of target level see chapter 10. The original TL has been recalculated for each time series based on the lipid percentage. The recalculated target level (Tv) together with the lipid percentage (lp) is shown above the statistical information in each time series.

30.2 Results

The concentration of HBCDD is under LOQ in a majority of the samples for all matrices and sites and is therefore not presented in the spatial maps and time trends.

30.2.1 Spatial variation

Figure 30.1. Spatial variation in concentration (ng/g lipid weight) of BDE-47 in perch muscle.
**Figure 30.2.** Spatial variation in concentration (ng/g lipid weight) of BDE-99 in perch muscle.

**Figure 30.3.** Spatial variation in concentration (ng/g lipid weight) of BDE-100 in perch muscle.
BDE-47, BDE-99, BDE-100, BDE-153 and BDE-154 generally show higher concentrations in perch muscle from lakes in the Stockholm area and in the southern part of Sweden compared to the northern part, with a few exceptions.

Of the five BDEs that are measured, BDE-47 is the substance found in the highest concentrations in perch muscle.

The highest concentration of BDE-47 in perch muscle was found in Lake Stora Envättern in Stockholm County (15.9 ng/g lw) in 2010-2012, and the lowest concentration in Lake Degervattnet (1.0 ng/g lw) in Jämtland County (Fig. 30.1).
30.2.2 Temporal variation

No general linear trend is observed during the whole monitoring period for the BDEs in Arctic char from Lake Abiskojaure (1980-2012) and in pike from Lake Bolmen (1966-2012). However, for Arctic char in Abiskojaure, there is a decreasing trend during the last ten years for all BDEs, but in pike from Lake Bolmen no such trend is seen, which is most likely due to that analyses were not conducted in five out of these ten years. The concentrations of BDEs in Lake Bolmen increased from the start of the monitoring period until the late 80s to the mid 90s with an annual increase of about 16-21% and appear to have decreased since then. The lower brominated flame retardants, tetra- and penta-BDEs (BDE-47, BDE-99 and BDE-100) peaked earlier than the higher brominated, hexa-BDEs (BDE-153 and BDE-154) (Fig. 30.6-30.9). The concentrations are however still at higher levels compared to the start of the monitored period.

The number of years required to detect an annual change of 10% for BDEs varies between 13-28 years for the char and pike time series.

![Graph showing the concentrations of BDEs in Arctic char muscle from Lake Abiskojaure.](image)

Figure 30.6. BDE-47, -99, -100 concentrations (ng/g lipid weight) in Arctic char muscle from Lake Abiskojaure.
Figure 30.7: BDE-153, -154 concentrations (ng/g lipid weight) in Arctic char muscle from Lake Abiskojaure.

Figure 30.8: BDE-47, -99, -100 concentrations (ng/g lipid weight) in pike muscle from Lake Bolmen.
30.2.3 Comparison to thresholds
In all areas, the BDE-47 concentration is above the suggested target level for the sum of BDE-28, 47, 99, 100, 153 and 154 of 0.0085 ng/g wet weight.

30.3 Summary

BDE-47, BDE-99, BDE-100, BDE-153 and BDE-154 generally show higher concentrations in perch muscle from lakes in the Stockholm area and in the southern part of Sweden, with a few exceptions.

The highest concentration of BDE-47 in perch muscle was found in Lake Stora Envättern in Stockholm County in 2010-2012.

No general linear trend is observed during the whole monitoring period for the BDEs in Arctic char from Lake Abiskojaure and in pike from Lake Bolmen. But in Lake Abiskojaure there are decreasing trends in concentrations of BDEs for the last ten years. Moreover, the concentrations of BDEs in Lake Bolmen increased from the start of the monitoring period until the late 80s to the mid 90s and appear to have decreased since then. The lower brominated flame retardants (BDE-47, BDE-99 and BDE-100) peaked earlier than the higher (BDE-153 and BDE-154).

In all areas, the BDE-47 concentration is above the suggested target level for the sum of BDE-28, 47, 99, 100, 153 and 154 of 0.0085 ng/g wet weight.
31 Priority substances 2007 and 2011

The aim with this extended part is to investigate temporal and spatial trends of five groups of priority substances within the Water Framework Directive (WFD) in 15 (2 Arctic char lakes and 13 perch lakes) of the 32 lakes that are monitored annually (Fig. 31.1). It is important to investigate concentrations of different substances regularly since that can give us the possibility to make trend analyses in a longer perspective. Thus, retrospective studies in perch from 2007 and 2010 have been analysed in 15 lakes. The analysed substances are Chloroalkanes, Di-(2-ethylhexyl)-phthalate (DEHP), Hexachlorobutadiene (HCBD), Pentachlorobenzene, and organotin compounds. Perch muscle was analysed for DEHP, hexachlorobutadiene, and pentachlorobenzene, while perch liver was used for analyses of organotin compounds and chloroalkanes. The analyses were performed at IVL (Swedish Environmental Research Institute). In 2004 three of the priority substances were analysed - HCBD and Pentachlorobenzene were analysed in the lakes Abiskojaure, Remmarsjön, Stensjön, Lilla Öresjön, Stora Skärsjön, Sännren, and Krageholmsjön and DEHP were only analysed in Bysjön and Stensjön.

31.1 Chloroalkanes

Chloroalkanes are polychlorinated paraffins and they can be divided into short-chained (SCCP, C10-13), medium-chained (MCCP, C14-17), and long-chained (LCCP, C18-20) chlorinated paraffins.

31.1.1 Usage
Chloroalkanes have been used in rubber and PVC plastics industry as flame retardant, plasticizer and adhesive, in paint industry and for treating and coating metals (Naturvårdsverket, 2008; HELCOM, 2009).

31.1.2 Toxicological effects
Chloroalkanes will most likely be deposited into soil and sediment after released into the environment (HELCOM, 2009). However, they are not easily biodegradable and bioaccumulates (Naturvårdsverket, 2008). They are very toxic to water organisms and can cause long-term harmful effects in the water environment (Loh & Andersson Ovuka, 2005).

31.1.3 Conventions, aims and restrictions
Chloroalkanes are listed as one group of substances of the 33 priority substances in the Water Framework Directive (WFD) (Directive 2008/105/EC). Short-chained chlorinated paraffins are also under review for inclusion in the Stockholm convention of POPs and they have also been proposed to be added to the list of substances subject to authorization under REACH-regulation (1907/2006). Since 2002 short-chained chlorinated paraffins has been banned in EU for usage in leader oils and for treating metals (Bergbäck & Jonsson, 2008).

31.1.4 Target level
No EQS for biota is available for chloroalkanes.
31.1.5 Results

31.1.5.1 Spatial variation

Figure 30.2. Spatial variation in concentration (ng/g wet weight) of SCCP in perch liver, arithmetic mean 2007 and 2010.

There was no consistent spatial variation in concentration of SCCP. However, two lakes had higher concentrations compared to the rest of the investigated lakes (Fig. 30.2). The highest concentrations were found in Lake Stor-Backsjön (28 ng/g ww) in Jämtland County and in Lake Fiolen (30 ng/g ww) Kronobergs County and the lowest concentrations were found in Lake Övre Skärsjön the county of Västmanland and Lake Stensjön in Gävleborgs County (0.55 ng/g ww) (Fig. 31.2). For Arctic char no result from Lake Tjulträsk was obtained in 2010, thus, only data from 2007 is compared. Lake Abiskojaure had twice as high concentration (2.7 ng/g ww) compared to Lake Tjulträsk (1.2 ng/g ww).

A paired t-test was conducted in order to investigate if there was a change in SCCP concentration between the year 2007 and 2010, however, no statistical difference was found (p>0.5).

Almost all values in most lakes for MCCP were below LOQ (LOQ ranges between 0.2-0.4 ng/g ww). However, perch in Lake Stensjön in 2007 had a concentration of 2 ng/g ww, perch in Lake Sännen in 2010 had a concentration of 2.2 ng/g ww, and Arctic char in Lake Tjulträsk in 2007 had a concentration of 1.2 ng/g ww.
31.2 Di-(2-ethylhexyl)-phthalate (DEHP)

31.2.1 Usage
DEHP is the most commonly used plasticizer in PVC plastics. It is used as softener in plastics and rubber, in medical devices, construction products, and children’s toys. DEHP is also used in non-polymer materials such as lacquers and paints, adhesives, fillers and printing ink, cosmetics and clothing (Huang et al., 2008; Naturvårdsverket, 2008; Carnevali et al., 2010). It is the most abundantly used of all phthalates.

31.2.2 Toxicological effects
Phthalates are mixed with raw-materials and not chemically bound, therefore they can easily leak out or be released during the life cycle of plastic products (Huang et al., 2008). DEHP is hydrophobic but can be deposited in sediment.

DEHP can be found in higher concentrations close to point sources. It mainly binds to sediment and not to a high extent in biota. Studies on animals have shown that DEHP is an endocrine disruptor (Borch et al., 2006; Carnevali et al., 2010). For instance, Carnevali et al. (2010) found in an experimental study with zebrafish that exposure to DEHP led to impairment of the reproduction, e.g. inhibition of ovulation and impair oocyte maturation.

31.2.3 Conventions, aims and restrictions
DEHP is on REACH Authorization list under Annex XIV (www.dehp-facts.com). The compound will be phased out in EU and no later than 2015 special permission is necessary in order to use or sale this compound (KEMI, 2012). However, DEHP is already banned in EU for use in children’s toys and childcare articles (EU decision 1998/815/EG; EU Directive 2005/84/EC).

31.2.4 Target level
No EQS for biota is available for DEHP.

31.2.5 Results
In 2004 all results were below LOQ. Also in 2007 and 2010 the majority of the results were under LOQ (LOQ was <2 ug/kg ww). However, perch in Lake Bysjön in 2010 had a concentration of 6.1 ug/kg ww, perch in Lake Bästeträsk in 2007 had a concentration of 5.8 ug/kg ww, perch from Lake Krageholmssjön in 2007 had a concentration of 13 ug/kg ww, perch in Lake Lilla Öresjön in 2007 had a concentration of 11 ug/kg ww, perch in Lake Stora Backsjön had a concentration of 3.7 ug/kg w both in 2007 and in 2010, perch in Lake Tärnan in 2007 had a concentration of 7.4 ug/kg ww, and perch in Lake Stor-Backsjön in 2007 had the highest concentration, 16 ug/kg ww.
31.3 Hexachlorobutadiene (HCBD)

31.3.1 Usage
HCBD has been used as solvents for textile products such as colour, or different impregnation agents (Naturvårdsverket 2008). It has also been used as a chemical intermediate in rubber compounds manufacturing (Vorkamp et al 2004). Thus, higher concentrations can be found e.g. around industries or other point sources. HCBD can also be formed as a by-product in the manufacture of chlorinated hydrocarbons (Stockholm Convention of POPs, 2011).

31.3.2 Toxicological effects
HCBD is relatively hydrophobic. It has potential for long-ranged transportation and it bioaccumulates in the aquatic food chain (Stockholm Convention of POPs, 2011).

31.3.3 Conventions, Aims and restrictions
Hexachlorobutadiene is under review for inclusion in the Stockholm Convention of POPs.

31.3.4 Target level
EQS\textsubscript{biota} for HCBD is set to 55 \textmu g/kg ww by the EC.

31.3.5 Results
The concentrations of HCBD were below LOQ both in 2004, 2007, and 2010 for perch from all lakes investigated (LOQ was <0.1\textmu g/kg ww). The concentrations of HCBD in perch and Arctic char are under the target level.

31.4 Pentachlorobenzene

31.4.1 Usage
There is no known usage of pentachlorobenzene in Sweden. But it might indirectly be a decay product in Quintozene (a fungicide) and in hexachlorobenzene, which was used during the 1960s to 1980s. Pentachlorobenzene is otherwise used in dielectric fluids. It has also been used as intermediary in flame retardants and for production of other chemicals (Naturvårdsverket, 2008). Pentachlorobenzene is also a metabolite to Lindane. The use of lindane was restricted in 1970 in Sweden, and in 1988/1989 it was totally banned. In Sweden the usage of pentachlorobenzene has been very limited compared to several other countries and therefore low amounts of this compound will probably be found in the environment (Esbjörnsson, 2002).

31.4.2 Toxicological effects
Pentachlorobenzene metabolizes to pentachlorophenol. Pentachlorobenzene is persistent in soil and it strongly bioaccumulates in the aquatic food chain (Esbjörnsson, 2002). The compound accumulates in fatty tissue. Exposure to even low doses of pentachlorobenzene has affected liver, kidneys, mucus membranes and nerve cells in
the brain. Pentachlorobenzene is also transported through the placenta to the offspring and it can also be transferred via breast milk (Esbjörnsson, 2002).

### 31.4.3 Conventions, aims and restrictions
Pentachlorobenzene is listed as one of the nine new POPs under the Stockholm Convention of POPs.

### 31.4.4 Target level
No EQS for biota is available for pentachlorobenzene.

### 31.4.5 Results
The concentrations of pentachlorobenzene were below LOQ both in 2004, 2007, and 2010 for perch from all lakes investigated (LOQ was <0.1ug/kg ww).

### 31.5 Organotin compounds (OTCs)

The two most common OTC’s are Tributyltin (TBT) and Triphenyltin (TPhT). They are organometallic chemicals with the presence of one or more carbon-tin bonds (C-Sn) (Murata et al., 2008). In water TBT decomposes into less toxic DBT (Dibutyltin) and MBT (Monobutyltin) species, however, in sediment this decomposition takes place far more slowly, which creates an ecotoxicological risk long after it has been released. Recently, DBT and MBT have been found to leach into the environment from PVC (Tesfalidet, 2004).

#### 31.5.1 Usage
The main usage of both TBT and TPhT was as antifouling agents in paints for preventing the attachment of barnacles and slime on boats. The paint was primarily used on ship hulls, docks, buoys, and fishnets, and from where it could slowly leach into the waters. TBT and TPhT has also been used as wood preservative in industry and agriculture and as a stabilizer in PVC plastics manufacturing (Encinar et al., 2001; Naturvårdsverket, 2008; Sternberg et al., 2010).

#### 31.5.2 Toxicological effects
TBT belongs to one of the most toxic substances that is released into the environment, and it is said to be almost as toxic as dioxins and furans (Cato et al., 2007). It is toxic already at very low doses. TBT bioaccumulates in gastropods and the highest concentrations have been measured in the digestive/reproductive complex where levels up to 100 000 higher than what has been measured in the aquatic environment have been found (Sternberg et al., 2010). TBT is an endocrine disruptor and it has been found to induce imposex (females with male sexual characteristics) in gastropods (Smith, 1981). Imposer gastropods are globally distributed and at least 195 species of prosobranch gastropods are known to be affected (reviewed in Sternberg et al., 2010). Imposer appears to be irreversible and thus this can have long-term impacts on the organism fitness.
31.5.3 Conventions, aims and restrictions
Since 1989 the usage of TBT on small boats (less than 25 m) has been banned in Sweden and since 1993 all usage of TBT has been prohibited. In EU a ban on small boats came in 1999. In 1998 the Marine Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO) voted to impose a worldwide prohibition on the application and presence of TBT and other organotin compounds within 5 years (2003, painting with TBT-based paint on boats) and 10 years (2008, total ban on the presence of TBT and other OTC’s). The total international ban on TBT and other OTC’s entered into force in September 2008.

31.5.4 Target level
No EQS for biota is available for organotin compounds.

31.5.5 Results
For all organotin compounds analysed (MBT, DBT, TBT, MPhT, DPhT, TPhT, MOT, and DOT) most results were below LOQ (LOQ was <0.5ng/g ww).

MBT in Lake Övre Skärsjön in 2010 had a concentration of 0.52 ng/g ww.

TBT in perch in Lake Bysjön in 2007 and in Lake Lilla Öresjön in 2007 had concentrations of 0.54 and 0.58 ng/g ww respectively.

DPhT in perch in Lake Bysjön 2007 had a concentration of 0.72 ng/g ww, perch in Lake Lilla Öresjön in 2007 had a concentration of 0.75 ng/g ww, perch in Lake Stora Skärsjön had concentrations of 0.79 and 0.56 ng/g ww in 2007 and 2010 respectively, perch in Lake Sännen in 2010 had a concentration of 1.1 ng/g ww, perch in Lake Övre Skärsjön had a concentration of 0.6 ng/g ww, and perch in Lake Tärnan had concentrations of 1.3 and 1.5 ng/g ww in 2007 and 2010 respectively, which also was the highest concentrations observed.

TPhT in perch in Lake Stor-Backsjön in 2010 had a concentration of 0.84 ng/g ww.

Perch in Lake Övre Skärsjön in 2010 had a concentration of 4.1 ng/g ww of MOT and 4.5 ng/g ww of DOT.
32 Extra project 2013

32.1 Introduction

Evaluation of environmental status is important to reach the goals set within the Water Framework Directive (WFD). Within this directive, environmental status should be classified according to target levels for specific compounds. Target levels have been set without making any specific requires concerning fish species, trophic level or physiology (e.g. sex, age, condition) of the monitored fish species. This can cause differences in the evaluation of the environmental status depending on the study design. To evaluate temporal and geographical differences in contaminant load, the contaminant concentration needs to be compared between years and between different locations. These comparisons, if not evaluated thoroughly, can come to reflect differences in fish physiology or environmental factors (e.g. pH and nitrogen), instead of differences in contaminant load due to direct anthropogenic impact.

Lakes in the Swedish National Monitoring Programme for Contaminants in Freshwater Biota (SNMPCFB) have been chosen to represent lakes that are not influenced by local sources. Thus, the assumption has been that the majority of the contaminant load is due to air deposition from diffuse sources. However, there might still be a number of sources in the surrounding region that might influence the monitored lakes.

The overall aim of this project is to improve the evaluation of contaminants in the limnic environment.

Three different tasks were conducted:

1) Investigate if different abiotic factors affect contaminant concentrations  
2) Investigate spatial trends of contaminants  
3) Investigate possible correlations between contaminants and relevant industrial establishments

32.1.1 Data compilation

Data from lakes included in the SNMPCFB were used in this study. Only contaminant data in perch (Perca fluviatilis) was used to avoid confusion caused by species differences.

For all the three tasks, the same contaminants were used in the data analyses. For metals, Hg, Pb, Cd, Cu, Ag, and As were used. The chlorinated and brominated substances included DDE, CB-118, CB-153, sum of PCDD/F, sum of dl-PCBs, and BDE-47. Perfluorinated substances comprised of PFOS, PFNA, and PFUnDA (PFDA was also used in one analysis). The substances were chosen since they are the most important and also because they are found in the highest concentrations within their substance group.
32.2 Abiotic factors

32.2.1 Method

32.2.1.1 Abiotic data compilation

Water chemistry data came from the Swedish University of Agricultural Science (http://www.slu.se). For the water chemistry, only data from August were used, as this was the only month where data was consistent for all lakes and since this is also the month when fish is usually sampled. A depth of 0.5 m was used for all the variables. In order to limit the number of variables (to avoid influence on multiple regression analyses), only variables that earlier have shown to influence certain compounds were used. In total 19 out of the 27 perch lakes were included in the analyses, since only lakes where abiotic data was available could be used in the analyses.

It is known that various abiotic factors can affect the uptake of different contaminants. Fish in water with low pH have shown to be more tolerant to exposure of certain metals (e.g., Cd, Cu, and Zn) compared to fish in higher pH (Cusimano and Brakke, 1986). Fish in nutrient rich lakes as well as lakes with high chlorophyll α contents have been shown to have lower concentrations of organochlorines, such as PCB and DDE, in their muscle compared to fish from nutrient poor lakes (Larsson et al., 1992). Also, the uptake of e.g., DDT has shown to decrease with increased humic acid (Ke et al., 2007). Moreover, temperature can affect the uptake of contaminants. For every 10 degree increase in temperature, biological processes typically double in rate, up to a certain point (Luoma, 1983). The uptakes of metals are regulated by two different processes, influx and efflux. Both of these processes can however be affected by a temperature increase, which in that case leads to zero effect on the bioaccumulation (Luoma, 1983). However, Somero et al. (1977) detected a two-fold increase of lead uptake in fish when the temperature increased from 10°C to 20-25°C.

As contaminant data is often right skewed, geometric means were calculated for each substance and lake for each year.

32.2.1.2 Statistical analysis

Data was analysed using Principal Component Analysis (PCA) and multiple linear regression. The water chemistry data that was used for these analyses were: temperature, pH, chlorophyll α, secchi depth, tot-N, tot-P, and total organic carbon (TOC). A PCA plot was conducted and thereafter multiple linear regressions were performed on the PCA-scores for the two first Principal Components. The test was performed with one contaminant at a time as a dependent variable versus all the water chemistry data as independent variables. The time period was limited to 2000-2012 to reduce the influence of changes over longer time periods. A 5% level of significance was used. There is a gradient in contaminant concentration from north to south for many contaminants in Sweden (see example in figure 13.1, 14.1, 28.5, 29.1), with lower concentrations in the north. Thus, the north coordinate for each lake was included in the multiple linear regression analyses as independent variables, to control for an influence of a south to north gradient.
### 32.2.2 Results

The PCA biplot (Fig. 32.1) shows how the different abiotic factors are related to each other. According to the eigenvalues (i.e. the amount of variation in the total sample accounted for by the factor) PC1 (52%) and PC2 (27%) together explains 79% of the variation in the PCA, and thus only these two axes will be used when interpreting the multiple linear regression analyses below.

![PCA biplot showing the relationships between the abiotic factors.](image)

**Figure 32.1.** PCA biplot showing the relationships between the abiotic factors.

**Table 32.1.** Factor loadings for PC1 and PC2 for each abiotic factor.

<table>
<thead>
<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secchi depth</td>
<td>0.889</td>
<td>0.316</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.837</td>
<td>-0.009</td>
</tr>
<tr>
<td>pH</td>
<td>0.819</td>
<td>-0.303</td>
</tr>
<tr>
<td>tot-N</td>
<td>-0.125</td>
<td>-0.922</td>
</tr>
<tr>
<td>tot-P</td>
<td>-0.789</td>
<td>0.206</td>
</tr>
<tr>
<td>TOC</td>
<td>-0.49</td>
<td>-0.778</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>-0.791</td>
<td>0.454</td>
</tr>
</tbody>
</table>
There are no clear results for the multiple linear regression analyses (table 32.2-32.4). For metals (table 32.2), lead and cadmium were negatively correlated with the north coordinate; hence, concentrations are decreasing with latitude. Furthermore, lead, cadmium, copper, and silver were positively correlated with PC1. When examining the loading factors of PC1 (table 32.1), secchi depth, temperature, and pH were the factors that seemed to influence the metal concentrations most. Cadmium was also influenced by PC2, where tot-N seemed to be the most important factor. For mercury and arsenic no correlations were found.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Independent variable</th>
<th>Standardised beta coefficients</th>
<th>$R^2_{adj}$ (%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg</td>
<td></td>
<td>n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>North coordinate PC1</td>
<td>-0.561 0.493</td>
<td>36</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>PC1</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cd</td>
<td>North coordinate PC1</td>
<td>-0.698 0.334 0.303</td>
<td>47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>PC2</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cu</td>
<td>PC1</td>
<td>0.294</td>
<td>7.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ag</td>
<td>PC1</td>
<td>0.276</td>
<td>8.3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>As</td>
<td></td>
<td>n.s.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Most of the organic and brominated substances (table 32.3) (DDE, TCDDEQV, CBEQV, and BDE-47) except PCB’s, were negatively correlated with the north coordinate. This means that all these substances decrease in concentration with latitude. In addition, DDE was also positively correlated with PC2, where tot-N explained most of the variation. Moreover, CBEQV and BDE-47 were positively correlated with PC1, where secchi depth, temperature and pH were the most important factors for the variation seen. The PCB’s CB-118 and CB-153 did not correlate with any of the abiotic factors.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Independent variable</th>
<th>Standardised beta coefficients</th>
<th>$R^2_{adj}$ (%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDE</td>
<td>North coordinate PC2</td>
<td>-0.806 0.479</td>
<td>29.6</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>CB-118</td>
<td></td>
<td>n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CB-153</td>
<td></td>
<td>n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCDDEQV</td>
<td>North coordinate</td>
<td>-0.581</td>
<td>24.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CBEQV</td>
<td>North coordinate PC1</td>
<td>-0.614 0.265</td>
<td>31</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>BDE-47</td>
<td>North coordinate PC1</td>
<td>-0.463 0.318</td>
<td>17.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

For PFOS, no correlations with the abiotic factors or the north coordinate were found (table 32.4). Both PFNA and PFUnDA were correlated with PC1, where secchi depth, temperature and pH were the most important explaining factors (table 32.1). Also, PFUnDA was negatively correlated with the north coordinate. Only a few perfluoroalkyl substances (PFASs) were chosen for this analysis since several of the long-chain carboxylates (e.g. PFDA, PFUnDA, PFDoDA, PFTrDA) show similar spatial trends (see fig. 28.4-28.9).
Table 32.4. Multiple linear regression results for perfluoroalkyl substances.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Independent variable</th>
<th>Standardised beta coefficients</th>
<th>$R^2_{\text{adj}}$ (%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFOS</td>
<td>n.s.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFNA</td>
<td>PC1</td>
<td>0.411</td>
<td>20.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PFUnDA</td>
<td>North coordinate PC1</td>
<td>-0.396 0.430</td>
<td>25.1</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

32.2.3 Summary

Several of the contaminants, Pb, Cd, DDE, TCDDEQV, CBEQV, BDE-47, and PFUnDA were negatively correlated with the north coordinate, which means that the concentrations of these substances decreases with latitude. For many of these compounds this reflects both the contaminant load and atmospheric deposition. For cadmium, it is probably mainly due to its usage in agriculture, and most agriculture takes place in the middle and southern parts of Sweden. For lead, which earlier was used in gasoline, the decrease with latitude is probably a result of population density. The same is possibly true for TCDDEQV, CBEQV, BDE-47, and PFUnDA, but the higher concentrations of these substances in southern Sweden are also a result of long range transportation.

For DDE there was a negative correlation with tot-N. This is in line with other studies showing that DDE concentrations are lower in nutrient rich waters (Larsson et al., 1992). The authors also found the same relationship for PCB’s, while in this study we could not see any correlations with any of the abiotic factors investigated and CB-118 or CB-153.

Some of the metals, Pb, Cd, Cu, and Ag were positively correlated with PC1 (i.e. secchi depth, temperature and pH). This is not in line with other studies, where pH in many cases has been shown to be negatively correlated with certain metals (Cusimano et al. 1986; Spry and Wiener 1991; Haines and Brumbaugh 1994; Köck et al. 1998). When performing a multiple regression analysis directly on the abiotic factors instead of the PCA plot, negative correlations with pH were seen for Cd, Cu and Pb (data not shown). Thus, the different result from the multiple regression analysis on the PCA axes might be a result of a strong correlation between pH and secchi depth (see Fig. 32.1), i.e. higher secchi depth at higher pH. In some way this relationship between the two might balance the effect only pH will have on metals.

Even though higher levels of PFOS is found in southern part of Sweden compared to northern part (Fig. 28.1), the north coordinate did not seem to be an important explanation for that spatial pattern. However, this might be due to the very high concentrations found in Lake Fysingen, close to Stockholm, which disguise the gradient effect. PFUnDA on the other hand, was negatively correlated with the north coordinate, thus lower concentrations were found in the northern part of Sweden. This is also in line with the spatial variation seen in Fig. 28.5. The foremost explanation for that result is due to atmospheric deposition, because the main input to Sweden is thought to be via airborne precursors. Secchi depth also seemed to explain a large part of the variation seen in PFUnDA as well as in PFNA. The same result will
probably be true also for the other long-chain carboxylates, since they show similar spatial patterns.

32.3 Spatial trends

32.3.1 Smoothed maps

32.3.1.1 Method

The map of Sweden was superseded with a grid 5 x 5 km. For each grid cell a distance weighted mean concentration was estimated from concentration measured in fish within a circle with a radius of 200 km. Grid cells with less than 2 hits (analyzed fish samples) within this circle were excluded from the analysis.

One map for each contaminant has been prepared (Fig. 32.2-32.16). The smoothed maps define level limits and corresponding colours. The maps sometimes include thresholds (Hg, CB-118 and PFOS), but normally just show the smoothed concentrations. The lowest level is set to 0 so all values are included (except those below LOQ) from 2007 to 2012.
32.3.1.2 Results

The highest silver concentrations seem to be in the southern part of Sweden (Fig. 32.2), even though elevated concentrations also are seen in the north eastern part.

For arsenic the highest concentrations are observed in the northern part of Sweden, that might be explained by the higher age of the fish (Fig. 32.3). But also the areas around Stockholm, Malmö, and Gothenburg have elevated concentrations.

Figure 32.2. Silver (ug/g dw) in perch liver, 2007-2012.

Figure 32.3. Arsenic (ug/g dw) in perch liver, 2007-2012.
The highest concentrations of cadmium is seen in Småland and Blekinge (Fig. 32.4) while the rest of the country has rather low concentrations.

Most of the country has low concentrations of copper even though elevated levels are seen in Småland, Blekinge and Västmanland (Fig. 32.5).

**Figure 32.4.** Cadmium (ug/g dw) in perch liver, 2007-2012.

**Figure 32.5.** Copper (ug/g dw) in perch liver, 2007-2012.
Concentrations of mercury is high to very high in the whole country (Fig. 32.6). There is no clear spatial pattern, the highest concentrations are seen in the area around Gothenburg and in the northern part of Sweden. The higher concentrations in the north may be explained by the somewhat higher mean age.

For lead, a clear spatial pattern is seen (Fig. 32.7) with decreasing concentrations with latitude, except in Skåne, which also has low concentrations.

**Figure 32.6.** Mercury (ng/g ww) in perch muscle, 2007-2012.

**Figure 32.7.** Lead (ug/g dw) in perch liver, 2007-2012.
The two investigated PCB’s, CB-118 and CB-153 show slightly different patterns in between. Concentrations of CB-153 are very high in the south and middle part of Sweden, also a small part in the north of Sweden shows very high concentrations (Fig. 32.8). For CB-118, there seem to be certain hotspot areas – the areas around Stockholm, Gothenburg, and Karlskrona, while concentrations are rather low in the rest of the country (Fig. 32.9). For CB-118, two out of three lakes in the north are not included in the map since they are below LOQ.

![Figure 32.8](image1.png)  
**Figure 32.8.** CB-153 (ug/g lw) in perch muscle, 2007-2012.  

![Figure 32.9](image2.png)  
**Figure 32.9.** CB-118 (ug/g lw) in perch muscle, 2007-2012.
Concentrations of the sum of PCDD/F expressed in toxic equivalents are decreasing with latitude, and a hotspot is seen in Karlskrona (Fig. 32.10). For the sum of dl-PCBs also expressed in toxic equivalents there is a very clear spatial pattern with elevated concentrations in the area of the two largest cities – Stockholm and Gothenburg, as well as in and around Karlskrona (Fig. 32.11). The lowest concentrations are found in the north of Sweden.

Figure 32.10. TCDDEQV (pg/g lw) in perch muscle, 2007-2012.

Figure 32.11. CBEQV (pg/g lw) in perch muscle, 2007-2012.
The concentration of DDE show a clear spatial pattern with decreasing concentrations with latitude, except for the area around Stockholm, which also has very high concentrations (Fig. 32.12).

Generally, BDE-47 concentration is also decreasing with latitude (Fig. 32.13). However, the highest concentrations are seen in the areas around Stockholm, Gothenburg, Karlskrona, and Helsingborg.

**Figure 32.12.** DDE (ug/g lw) in perch muscle, 2007-2012.

**Figure 32.13.** BDE-47 (ng/g lw) in perch muscle, 2007-2012.
The spatial pattern of PFOS is similar as for BDE-47 – higher concentrations in the southern parts of Sweden and around the larger cities Stockholm/Uppsala, Gothenburg, Malmö, and Helsingborg compared to the north of Sweden (Fig. 32.14). One reason for the higher concentrations seen in these areas are both because large cities inhabit more people that uses/have used products with PFOS but in Skåne it is also due to that Helsingborg has had PFAS production. Airports, such as Arlanda, Landvetter, Skurup, etc. can also contribute to higher PFOS concentrations since it earlier was used in fire fighting foam. For the two carboxylates, PFNA and PFUnDA, the patterns are different. For PFNA (Fig. 32.15) the highest concentrations are found in the north of Sweden, but also a few hot spots in the middle, while for PFUnDA (Fig. 32.16), the highest concentrations are found in the south of Sweden while the northern part has the lowest concentrations. For PFUnDA the main source to Sweden is through airborne precursors, thus decreasing concentrations towards the north. PFNA, in contrast to PFUnDA, was produced intentionally, however, not so much in Europe. Even so, it can occur in imported goods.
32.3.2 Trend surface analysis

32.3.2.1 Method

A gradual change in the occurrence of contaminant concentrations in fish may be detected by a trend surface analysis. The simplest trend surface would be an inclined plane where the height in each point, \( z_i \), is determined from the equation:

\[
z_i = a_0 + a_1 x_i + a_2 y_i + e_i
\]

The program fits a linear trend surface to the data by estimating the constants \( a_0 \), \( a_1 \), and \( a_2 \) in the equation above and reports the gradient and the angle of the slope. A second order polynomial trend is also estimated.

The first order equation gives results for the x and y-axis; x=north/south, y=east/west. The second order polynomial trend gives results both for x- and y-axis, \( x^2 \) and \( y^2 \), and \( x*y \); \( x^2 \) and \( y^2 \) = concave or convex area, \( x*y \) = the area turns.

The data extracted for the metals in perch (Ag, As, Cd, Cu, Hg, Pb) are from 2007-2012, and the data for the organic substances in perch (BDE-47, CB-118, CB-153, sum of dl-PCBs, DDE, PFNA, PFOS, PFUnDA, sum of PCDD/Fs) are from 2005-2012.
32.3.2.2 Results

Cd in Swedish perch shows a significant (p<0.05, \(R^2_{\text{adj}} = 6\%\)) east/west relationship in the first order equation. The concentrations of Cd increases significantly the further to the east the perch is caught (Fig. 32.22).

Figure 32.22. a) Original Cd analyses, b) first order trend surface, y significant, c) second order trend surface, not significant.

For mercury there is also a significant east/west relationship (p<0.01, \(R^2_{\text{adj}} = 18.2\%\)), with increasing concentrations from east towards west, but only for the second order equation (Fig. 32.23).

Figure 32.23. a) original Hg analyses, b) first order trend surface, not significant, c) second order trend surface, \(y, y^2\) significant.
Pb shows a significant north/south relationship (first and second order equation) (p<0.01) and a significant east/west relationship (second order equation) (p<0.05). The $R^2_{\text{adj}}$ is almost twice as high for the second order equation (17.4%) compared to the first order equation (9.3%) indicating that the second order equation most likely is a better explanation for the trends seen in lead (Fig. 32.24).

Figure 32.24. a) original Pb analyses, b) first order trend surface, x significant, c) second order trend surface, x, y, $y^2$ significant.

CB-153 shows a significant east/west relationship (second order equation) (p<0.05, $R^2_{\text{adj}}=3.7\%$) (Fig. 32.25).

Figure 32.25. a) original CB-153 analyses, b) first order trend surface, not significant, c) second order trend surface, y significant.
The sum of dl-PCBs shows a significant (first order equation) east/west (p<0.01) and north/south (p<0.05) ($R^2_{\text{adj}}=29\%$) relationship with higher concentrations the further southeast the perch is caught (Fig. 32.26).

![Figure 32.26. a) original CB-EQV analyses, b) first order trend surface, x, y significant, c) second order trend surface, not significant.](image)

No significant relationships were seen for the other substances, Ag, As, Cu, BDE-47, CB-118, DDE, PFNA, PFOS, PFUnDA, and sum of PCDD/Fs.

In most of the cases above, the $R^2_{\text{adj}}$ were low (4-29\%), which indicates that there are other factors apart from geographical that explains the variation in concentrations.

### 32.3.3 Principal Component Analysis (PCA)

#### 32.3.3.1 Method

The test was performed with one group of contaminants (BDEs, PCDD/F, dl-PCBs, PCBs, and PFASs) at a time against perch from 3 different parts of Sweden (north-south) divided up by RT90 north (610000-650000, 650000-690000, 690000-760000). The time period was limited to 2005-2012 to reduce the influence of changes over longer time periods. Only perch was used for the analysis, to reduce the influence of species differences. For each group of substances the congeners/substances in the highest concentrations were chosen not to lose a large number of analyses due to a congener/substance below LOQ.
32.3.3.2 Results

There are no clear differences seen in the pattern of BDEs in perch from the north, middle and south of Sweden (Fig. 32.17).

Figure 32.17. PCA biplot and Hotelling’s 95% confidence ellipses for center of gravity for each group. The PCA is showing the relationship between BDEs and part of Sweden (north, middle and south) where perch is collected.
For PCBs clear congener patterns were seen for perch from the different areas. Perch from the south and middle have more of CB-180 compared to the north which instead has more of CB-153 (Fig. 32.18).

Figure 32.18. PCA biplot and Hotelling’s 95% confidence ellipses for center of gravity for each group. The PCA is showing the relationship between PCBs and part of Sweden (north, middle and south) where perch is collected.
There are no clear differences seen in the pattern of PCDD/Fs in perch from the north, middle and south of Sweden (Fig. 32.19).

**Figure 32.19.** PCA biplot and Hotelling’s 95% confidence ellipses for center of gravity for each group. The PCA is showing the relationship between PCDD/Fs and part of Sweden (north, middle and south) where perch is collected.
When including the dl-PCBs in the PCA together with the PCDD/Fs, still no clear differences is seen in perch from the north, middle and south of Sweden (Fig. 32.20).

Figure 32.20. PCA biplot and Hotelling’s 95% confidence ellipses for center of gravity for each group. The PCA is showing the relationship between PCDD/Fs and dl-PCBs and part of Sweden (north, middle and south) where perch is collected.
Clear differences in the pattern of PFASs (Fig. 32.21) were seen for perch from the northern parts of Sweden compared to perch from the south and middle. Perch from the north has in general higher relative concentrations of PFNA and perch from the south and the middle parts of Sweden in general have higher relative concentrations of PFUnDA and PFDA. PFUnDA and PFDA mainly come to Sweden via airborne precursors, hence they are mainly found in the south of Sweden. PFNA, which was mainly found in the north, could be due to some point source. However, we could not find any correlations with the investigated industrial indices (table 32.6).

**Figure 32.21.** PCA biplot and Hotelling’s 95% confidence ellipses for center of gravity for each group. The PCA is showing the relationship between PFASs and part of Sweden (north, middle and south) where perch is collected.
32.3.4 Summary

The smoothed maps seem to be a good tool to find spatial patterns. In this work, clear indications of elevated concentrations around the two largest cities, Stockholm and Gothenburg, but also Karlskrona, were found for CB-118, sum of dl-PCBs, BDE-47, and PFOS. The maps could also give a good overview of spatial gradients. Several of the investigated contaminants show a gradient with increasing concentrations from the north towards the south; these include Cd, Pb, CB-153, sum of PCDD/Fs, DDE, BDE-47, and PFUnDA. Moreover, As and PFNA showed the opposite gradient, i.e. increased concentration with latitude.

For a few compounds it was possible, with the PCA plots, to detect differences between congeners/groups of substances and geographical area. CB-180 was more common in the south and middle parts of Sweden and CB-153 was more common in the north. For the perfluorinated carboxylates, PFNA was more common in the north of Sweden while PFUnDA and PFDA were found to a greater extent in the middle and south.

The trend surface analyses give a very rough estimate of general trends of concentrations south to north, west to east of Sweden. The smoother maps are also generalized but give a picture of spatial differences with a better spatial resolution. For instance, when comparing the smoother map for Cd (Fig. 32.4) with the trend analysis map (Fig. 32.22), the area with very high concentration seen in the smoother map is diluted in the trend analysis map. An analysis of the residuals from the trend surface analyses may improve the possibilities to detect hotspots. Residual analyses were not carried out in this study.

32.4 Industrial activities

32.4.1 Method

Coordinates for all the licensed activities within Sweden were used in order to create an index for industrial strains for each lake. The material used came from a selection from the Swedish portal of environmental report (Svenska miljörapporteringssportalen, SMP, accessed 2013-11-19). Different activity types (table 32.5) have then been chosen in order to investigate if there are any relationships with certain contaminants. Activities of the various strains that are active, dormant, or disused were included in the analyses.
Table 32.5. The different activity types used in the analyses and potential contaminants for the respective activity.

<table>
<thead>
<tr>
<th>Index name</th>
<th>Activity types (^{1a})</th>
<th>Specified codes (^{1b})</th>
<th>Contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>Exploration, mining and processing of peat, oil, gas, coal, ores, minerals, rock, gravel etc. 10. Rock, gravel, peat and other soils 13. Ores and minerals</td>
<td>10, including all sub groups 13, including all sub groups</td>
<td>Metals</td>
</tr>
<tr>
<td>Timber industry</td>
<td>Wooden goods 20.</td>
<td>20.10, treatment of wood with wood preservatives</td>
<td>Dioxins and furans (WHO05-eqv of PCDD/F)</td>
</tr>
<tr>
<td>Pulp industry</td>
<td>Pulp, paper and paper products 21</td>
<td>21, including all sub groups</td>
<td>Dioxins and furans (WHO05-eqv of PCDD/F)</td>
</tr>
<tr>
<td>Surface treatment</td>
<td>Surface treatment of metals, plastics etc. 28</td>
<td>10, facility for surface treatment of metals or plastics</td>
<td>PFAS, PBDE, metals</td>
</tr>
<tr>
<td>Airports</td>
<td>Infrastructure (airports) 63.</td>
<td>63.30, 40, 50</td>
<td>PFAS</td>
</tr>
<tr>
<td>Waste</td>
<td>Waste (except for animal by-products and radioactive waste) 90</td>
<td>90, including all sub groups except 90.240, 250, 260 or 90.460, 470</td>
<td>PCB, PBDE, PFAS, metals</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>Hazardous waste 90</td>
<td>90.50, 60, 130, 140, 180, 190, 200, 210, 220, 270, 280, 320, 330, 340, 350, 360, 370, 375, 380, 390, 400, 440, 450</td>
<td>PCB, PBDE, PFAS, metals</td>
</tr>
<tr>
<td>Combustion</td>
<td>Waste, incineration 90</td>
<td>90.180, 190, 200, 210, 220, 230.</td>
<td>Dioxins and furans (WHO05-eqv of PCDD/F)</td>
</tr>
</tbody>
</table>

\(^{1}\) In order to translate the different codes in the SMP selection, Translation key 1, appendix FMH, section 1, revised 2008-04-08 was used.

\(^{a}\) The numbers in this column represent the code for the specific activity used in the translation key.

\(^{b}\) The numbers in this column represent the sub-activities which have been included in each respective activity type, also taken from the translation key.

For each lake, a circle with the diameter 50 km was made. Within that circle all industrial activities belonging to specific activity types (table 32.5) were used. One index for each activity type was calculated.

\[
\text{Index (S)} = \frac{1}{x_1^2} + \frac{1}{x_2^2} + \ldots
\]

where \(x\) is the distance in km from the lake to the industrial activity.

Thereafter multiple regression analyses were carried out with the fish concentrations of the various substances as dependent variables and the indices of various industrial activities as independent variables. After the first run, industrial activities that did not explain much of the variation in fish concentration were removed from the model and the multiple regression analysis was rerun with fewer indices.
Generalised maps for the different activity types were also constructed in the same manner as described in 1.3.1. For each generalised map there is also a map that shows triangles with sizes proportional to the industry index.

32.4.2 Results

32.4.2.1 Spatial trends of industrial activities

Mining activities, which includes catchment areas for rock and gravel, facilities for breakage of stone and gravel, facilities for production of peat, and varying mining practices, and processing of ores and minerals, scored a high industry index over almost the whole surface of Sweden, except for the north western part. Thus, most of the investigated lakes within the monitoring programme are potentially affected by these activities. All kind of mining activities were included as no effort was made to select especially hazardous activities in this study.

Figure 32.27. A) Mining activity index, B) Potential influence on the monitored lakes.
Timber industry had a very low index and these industries were found to a higher extent in the middle and southern part of Sweden, even though a few industries also were found in the north eastern part (Fig. 32.28).

**Figure 32.28.** A) Timber industry activity index, B) Potential influence on the monitored lakes.
The pulp industry, which includes production of paper products, showed somewhat similar result as the timber industry, even though it covered a smaller area (Fig. 32.29). The index was very low in all places where this activity occurs.

Figure 32.29. A) Pulp industry activity index, B) Potential influence on the monitored lakes.
Surface treatment activity index was low in most places, and as for the pulp and timber industries, it mostly covered the south and middle part of Sweden, with a few places in the north eastern part (Fig. 32.30). However, two hot spot areas, with high index were found – the county of Västmanland and the county of Jönköping.

Figure 32.30. A) Surface treatment industry activity index, B) Potential influence on the monitored lakes.
For the waste, including storage, treatments, processing, recycling, depositing, and hazardous substances (but does not include animal by-products and radioactive waste) higher index scores were seen in the south and middle part of Sweden as well as along the north eastern coastline (Fig. 32.31).

**Figure 32.31.** A) Waste activity index, B) Potential influence on the monitored lakes.
The hazardous waste index also showed higher scores in the south and middle part of Sweden (Fig. 32.32).

Figure 32.32. A) Hazardous waste index, B) Potential influence on the monitored lakes.
Combustion on the other hand, did have fairly low activity index over Sweden (Fig. 32.33).

**Figure 32.33.** A) Combustion index, B) Potential influence on the monitored lakes.
32.4.2.2 *Relationships between industrial activities and contaminants*

The multiple regression analysis did not generate so many significant results (table 32.6). A few compounds are not included in the table below. Cu, Hg, CB-153, CB-118, and sum of PCDD/F were excluded because the overall results were insignificant. DDE was excluded because it was not categorized under any industry.

**Table 32.6.** Correlations between industrial activities and contaminants in fish. Figures show the p-value. • shows p 0.5-0.05, these are included in the model but not significant.

<table>
<thead>
<tr>
<th></th>
<th>Waste</th>
<th>Hazardous Waste</th>
<th>Combustion</th>
<th>Pulp</th>
<th>Surface Handling</th>
<th>Mining</th>
<th>Timber</th>
<th>Airports</th>
<th>R² adj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>•</td>
<td>0.025</td>
<td>•</td>
<td>•</td>
<td>0.016</td>
<td>•</td>
<td>•</td>
<td>0.420</td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>0.020</td>
<td>0.033</td>
<td>0.019</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>Ag</td>
<td>•</td>
<td>0.048</td>
<td>•</td>
<td>0.049</td>
<td>0.441</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td></td>
<td></td>
<td>0.012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.244</td>
<td></td>
</tr>
<tr>
<td>PFOS</td>
<td>0.030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.159</td>
<td></td>
</tr>
<tr>
<td>PFUNDA</td>
<td>0.016</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.195</td>
<td></td>
</tr>
</tbody>
</table>

Lead was found to correlate with the hazardous waste and surface handling index. Also waste, combustion, pulp industry, timber industry and airports seemed to partly influence Pb concentrations. 42 % of the variation in lead concentration in fish was explained by the industrial indices included in the model.

Arsenic correlated with waste, hazardous waste and combustion. Only about 19 % of the variation in arsenic concentration in fish was explained by the industrial indices included in the model.

Silver correlated with combustion and the timber industry. Waste and surface handling also seemed to affect concentrations of Ag. About 44 % of the variation in silver concentration in fish was explained.

Cadmium correlated significantly with surface handling explaining about 24% of the variation.

PFOS was found to be correlated with waste (R²~16%) and PFUnDA was correlated with hazardous waste (R²~20%).

**32.4.3 Summary**

The contaminant concentrations measured in fish, we believe is mainly due to long or short range atmospheric transport. In this subchapter we make a first trial to see to what extent short
range transport may play a role for the measured concentrations. The pulp, mining and airport index did not show any explaining power for the examined contaminant concentrations measured in fish but for lead and silver slightly more than 40% of the variations were explained by the rest of the industrial indices. For the rest of the studied contaminants only less than 25% were explained by the remaining indices.

Two comments should be stressed however: 1) there are several improvement of this study that could be done e.g. the measured concentrations in fish could be adjusted for contaminant factors e.g. age before the analyses of the potential influences of industrial indices 2) as usual in regression analysis, significant correlations may not indicate causal correlation (but the significant variables may act as proxies for causal variables).
33 References


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34 Annex 1

1) Lake Abiskojaure

County: Norrbotten
Main catchment area: Torne älv river (1000)
Physical geographic regions: Alpine-northern boreal zone. High mountain region of Lappland (36B)
Coordinates, RAK: X 7582080, Y 1617490 (30I6d 2584)
Altitude: 487 m
Lake surface: 2.98 sq. km
Max. depth: 35 m
Volume: 31 Mm³
Protection: National park
Sample matrix: Char
Start: 1981
Other monitoring: Fish population investigated (FiV)
pH / alkalinity: 6.9 / 0.16 mekv/L
vegetation: lacking vegetation, surrounded by heath
nutrient status: poor in nutrients, totP = 5.9 ug/L +/− 2.6
other: rocky beaches and lake floor. secchi depth = 9m

2) Lake Tjulträsk

County: Västerbotten County
Main catchment area: Ume älv river
Physical geographic regions: alpine-northern boreal zone
Coordinates, RAK: X 7317990, Y 1511960 (25G3b 2422)
Altitude: 539 m
Lake surface: 5.25 sq. km
Max. depth: 38 m
Volume: 114 Mm³
Protection: Nature reserve
Sample matrix: Roach
Start: 1982
Other monitoring: ca 7 / approximately 0.3 mekv/L
pH / alkalinity: ca 7 / approximately 0.3 mekv/L
vegetation: The Vindelå valley is in south-east constituted of coniferous forest with elements of birch which further north-west passes into moors, with birthforests, rich in mosses. Dispersed are also meadows with birchforest, with high herbs, grasses and ferns with mires and dry bogs.

nutrient status: ca 5 ug/L totP (1999), i.e. oligotrophic
other: Very clear alpine lake with a rich bird life
3) **Lake Storvindeln**

- **County**: Västerbotten County
- **Main catchment area**: Ume älv river / Vindelälven river (28000)
- **Physical geographic regions**: Alpine-northern boreal zone
- **Coordinates, RAK**: X 7282710, Y 157578  (24H7c 2422)
- **Altitude**: 342 m
- **Lake surface**: 53 sq. km
- **Max. depth**: 29 m
- **Volume**: No information found
- **Sample matrix**: Pike
- **Start**: 1968
- **pH / alkalinity**: Hard-bottom lake with beaches rich in species. Together with L. Bolmen, the longest time series of contaminants in freshwater fish, in the world.

4) **Lake Brännträsket**

- **County**: Norrbotten County
- **Main catchment area**: Rosån river
- **Physical geographic regions**: Intermediate boreal
- **Coordinates, RAK**: X 7280950, Y 1759260
- **Altitude**: 82 m
- **Lake surface**: 0.81 sq. km
- **Max. depth**: 6.5 m
- **Volume**: 1.87 Mm³
- **Sample matrix**: Perch
- **Start**: 2004
- **pH / alkalinity**: ca 6.5 / 0.118 mekv/L
- **vegetation**: Very sparse vegetation
- **nutrient status**: totP = 12 ug/L
- **Lake Brännsträsket consists mainly of spruce with elements of pine. The area has mobile soil water and is rich in lime.**

5) **Lake Remmarsjön**

- **County**: Västernorrland County
- **Main catchment area**: Gideälven river (34000)
- **Physical geographic regions**: Intermediate boreal
- **Coordinates, RAK**: X 7086190, Y 1621320
- **Altitude**: 234 m
- **Lake surface**: 1.29 sq. km
- **Max. depth**: 14.4 m
- **Volume**: 7.02 Mm³
- **Sample matrix**: Perch
- **Start**: 2000
- **Other monitoring**: Close 6.5 / 0.05-0.2 mekv / L (i.e. close to neutral with rather good buffer capacity).
- **vegetation**: 1 / 3 of the lake is richly overgrown, the rest consists of steep rocky edges. Lined with wide belts common reed, common club-rush and water horsetail. In the lake, chickweed and plants with floating foliage, can also be found.
- **nutrient status**: Moderately rich in nutrients.
- **other**: Surrounded by coniferous forest, with elements of the cultural landscape. Species-rich in fish.

6) **Lake Degervatnet**
7) Lake Stor-Björsjön
County
Main catchment area.
Physical geographic regions.
Coordinates, RAK
Altitude
Lake surface
Max. depth
Volume
Protection
Sample matrix
Start
pH / alkalinity
Vegetation

Nutrient status
Other

Jämtland County
Ångermanälven river (38000)
intermediat boreal
X 7085120, Y 1520860
852 m
1.6 sq. km
20 m

Perch
2000
pH close to 7 / alkalinity 0.15-0.25 mekv/L

Moderate, mostly clumps of reed in the in- and outlets.
Surrounded by coniferous forests. (Wilander 1999)
Poor in nutrients, totP = below 8 ug/L
narrow with steep and rocky beaches except in the south where
there is one sandy beach.

County
Main catchment area.
Physical geographic regions.
Coordinates, RAK
Altitude
Lake surface
Max. depth
Volume
Protection
Other monitoring
Sample matrix
Start
pH / alkalinity
Vegetation

nutrient status
other

Jämtland County
Indalsälven river
Alpine-Northern Boreal
X 7060830, Y 1322870
567 m
35 ha
15 m

Char
2007
7 / 0.15-0.25 mekv/L

Sedge is growing around the shallow areas and the lake floor is
covered by plants, however these are not classified.
Nutrient-poor, totP < 10 μg/L
Lake Stor-Björsjön is surrounded alternately by mires and
slightly hilly terrain with mixed coniferous and deciduous
forest.
8) Lake Stor-Backsjön

<table>
<thead>
<tr>
<th>County</th>
<th>Jämtland County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main catchment area.</td>
<td>Indalsälven river (40000)</td>
</tr>
<tr>
<td>Physical geographic regions.</td>
<td>Intermediate boreal</td>
</tr>
<tr>
<td>Coordinates, RAK</td>
<td>X 6952200, Y 1433830</td>
</tr>
<tr>
<td>Altitude</td>
<td>426 m</td>
</tr>
<tr>
<td>Lake surface</td>
<td>2.09 sq. km</td>
</tr>
<tr>
<td>Max. depth</td>
<td>5 m</td>
</tr>
<tr>
<td>Volume</td>
<td>3 279</td>
</tr>
<tr>
<td>Sample matrix</td>
<td>Perch</td>
</tr>
<tr>
<td>Start</td>
<td>2004</td>
</tr>
<tr>
<td>pH / alkalinity</td>
<td>High buffering capacity, pH 7.4 Alkalinitet 0.31 mekv/L</td>
</tr>
<tr>
<td>vegetation</td>
<td>No information</td>
</tr>
<tr>
<td>nutrient status</td>
<td>High Secchi depth</td>
</tr>
<tr>
<td>other</td>
<td>Parts of the area consists of virgin forest of both coniferous and deciduous nature. West of the lake is an alkaline fen, with common reed, mountain bladder-fern and early marsh-orchid.</td>
</tr>
</tbody>
</table>

9) Lake Stensjön

<table>
<thead>
<tr>
<th>County</th>
<th>Gävleborgs County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main catchment area.</td>
<td>Ljusnan river</td>
</tr>
<tr>
<td>Physical geographic regions.</td>
<td>Southern boreal</td>
</tr>
<tr>
<td>Coordinates, RAK</td>
<td>X 6836730, Y 1540830</td>
</tr>
<tr>
<td>Altitude</td>
<td>268 m</td>
</tr>
<tr>
<td>Lake surface</td>
<td>0.53 sq. km</td>
</tr>
<tr>
<td>Max. depth</td>
<td>8.5 m</td>
</tr>
<tr>
<td>Volume</td>
<td>2.4 Mm³</td>
</tr>
<tr>
<td>Sample matrix</td>
<td>Perch</td>
</tr>
<tr>
<td>Start</td>
<td>1997</td>
</tr>
<tr>
<td>pH / alkalinity</td>
<td>ca 6/0.05 mekv/L</td>
</tr>
<tr>
<td>vegetation</td>
<td>Sparse, mostly common reed, unbranched bur-reed, water lilies and chickweed, along with isoetids along the beaches. Lake surrounded by pine forest. TotP = 11-12 ug/L</td>
</tr>
<tr>
<td>nutrient status</td>
<td>Bogs, mires, and the quagmire in close vicinity of the lake. Irregular lake bed with rocky beaches.</td>
</tr>
<tr>
<td>other</td>
<td></td>
</tr>
<tr>
<td>Lake Name</td>
<td>County</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td><strong>10) Lake Gipsjön</strong></td>
<td>Dalarna County</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>11) Lake Spjutsjön</strong></td>
<td>Dalarna County</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>12) Övre Skärsjön</strong></td>
<td>Västmanland County</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
13) Lake Limmingssjö

County: Örebro County
Main catchment area: Gullspångsälven
Physical geographic regions: Southern boreal
Coordinates, RAK: X 6608040, Y 1590000
Altitude: 234 m
Lake surface: 1.08 sq. km
Max. depth: 1.08

Volume
Protection
Other monitoring: A part of the environmental monitoring programme “Nationella tidsserier i referens-sjöar” since 1983.

Sample matrix Perch
Start: 2005
pH / alkalinity: 6.67 / 0.091 mekv/L
vegetation
Lake Limmingssjö is surrounded by pine forests with elements of mixed deciduous and coniferous forest as well as mires.

nutrient status Poor in nutrients, totP = 5 ug/L
other Several areas with deforestation can be found in the catchment area, including some very large ones just north of the lake. Secchi depth 3.79 m. South of the lake is a polluted area, that is an old mine.

14) Lake Fysingen

County: Stockholm County
Main catchment area: Oxundaån river
Physical geographic regions: Boreonemoral
Coordinates, RAK: X 6607490, Y 1618850
Altitude: 1.8 m
Lake surface: 4.76 km²
Max. depth: 4.5
Volume: 10 milj m³
Protection -
Other monitoring -
Sample matrix Perch
Start: 2005
pH / alkalinity: 7.9 / 2.05 mekv/L
vegetation
The vegetation around the lake is dominated by grasslands and deciduous trees totP = 18 ug/L

nutrient status
other Lake situated on a plain with shore meadows and mighty reed belts. The area around the lake consists mainly of forest, but also some agricultural land.
15) Lake Tärnan
County Stockholm County
Main catchment area. Coastal region (59060)
Physical geographic regions. Boreonemoral
Coordinates, RAK X 6606880, Y 1644780
Altitude 40 m
Lake surface 1.06 sq. km
Max. depth 12 m
Volume ca 5.1 m^3
Sample matrix Perch
Start 2000
pH / alkalinity ca 7 / 0.35 mekv/L
vegetation
High diversity of bryophytes, isoetides and elodeides. Have been classified as class 2 regarding species richness, where class 1 is very rich in species and class 5 is species poor. Surrounded by common reed, sedge, bulrush, amphibious bistort, water horsetail, rosette plants, Myriophyllum sp. and water lilies.

nutrient status
totP = 10 ug/L
other
Surrounded by older mixed deciduous and coniferous forest (spruce, pine and aspen), arable land and a mire.

16) Lake Bysjön
County Värmland
Main catchment area. Göta älv river (108000)
Physical geographic regions. boreonemoral
Coordinates, RAK X 6580860, Y 1302640
Altitude 123 m
Lake surface 1.18 sq. km
Max. depth 12.7 m
Volume 8.25 Mm^3
Sample matrix Perch
Start 2000
pH / alkalinity 6.5 / 0.1 mekv/L
vegetation
Abundant in some places. Comprised mostly of sedge, common reed and common clubrush, marsh cinquefoil, water horsetail, chickweed, Myriophyllum sp., and yellow- and white water lily.

nutrient status
totP = 12-20 ug/L
other
Surrounding farmland and mixed deciduous and coniferous wood, very close to E18. Divided into two pools.
17) Lake Stora Envättern
County Stockholm County
Main catchment area. Trosaån river (63000)
Physical geographic regions. boreonemoral
Coordinates, RAK X 6555870, Y 1588690
Altitude 62 m
Lake surface 0.38 sq. km
Max. depth 11.2 m
Volume 1.85 Mm³
Sample matrix Perch
Start 2000
pH / alkalinity 6-7 / just over 0.05 mekv/L (close to neutral with low buffering capacity).
vegetation

Lake Stora Envättern is surrounded by pine forests and outcrops. Sparse water vegetation, except in the bays where bulrush, common club-rush, water horsetail, common reed, waterlilies and chickweed can be found. Isoetids can be found along the beaches. Poor in nutrients with high Secchi depth. TotP < 25 ug/L Relatively poor in species.

18) Lake Älgsjön
County Södermanland County
Main catchment area. Nyköpingsån river
Physical geographic regions. Southern boreal
Coordinates, RAK X 6552750, Y 1532340
Altitude 49 m
Lake surface 0.36 sq. km
Max. depth 7 m
Volume 1.31 Mm³
Protection
Other monitoring
Sample matrix Perch
Start 2005
pH / alkalinity 6-7 / 0.2 mekv/L
vegetation

Surrounded by pine forests and outcrops. Sparse water vegetation, except in the bays where bulrush, common club-rush, water horsetail, common reed and common club-rush can be found. Isoetids can be found along the beaches. Secchi depth ca 2 m. Lake Älgsjön is a long narrow lake where the water is coloured brown due to humic substances. The lake floor profile is reminiscent of a soap cup; the beaches descend steep downhill to flatten out against the middle of the lake.

19) Lake Svartsjön
County Västra Götaland County
Main catchment area. Motala Ström River (108138)
Physical geographic regions. Boreonemoral zone
Coordinates, RAK X 6516090, Y 1408390 (09E3b 1663)
Altitude 125 m
Lake surface 0.07 sq. km
Max. depth 5 m
Volume
Sample matrix Roach
Start 1982
pH / alkalinity 6.9 / 0.27 mekv/L (high alkalinity)
vegetation

Surrounding mires (colours the water)
nutrient status
dystrophic, totP = 21 ug/L (high amounts of phosphorous)
other
Secchi depht = 0.8 m. Strongly colored water with high levels ammonium. There is probably a lack of oxygen on the bottom for much of the year, which may be a reason behind the ammonium levels.

20) Lake Fräcksjön
County
Västra Götaland County
Main catchment area.
Göta älv river (?)
Physical geographic regions.
boreonemoral
Coordinates, RAK
X 6452890, Y 1286650
Altitude
63 m
Lake surface
0.27 sq. km
Max. depth
15m
Volume
Protection
Other monitoring
Sample matrix
Perch
Start
2005
pH / alkalinity
Since the early 1980s, the pH has often been around 6.5 and alkalinity 0.05 mekv/L
vegetation
Surrounded by mixed coniferous and deciduous forest. The water vegetation is abundant in the bays and consists of yellow- and white water lilies, various species of chickweed, isoetids, common reed, common club-rush and sedge.

nutrient status
totP = 9.8 ug/L
other
Humic forest lake, consisting of two pools that are separated by a narrow strait. The rocky beaches are steep and there are no larger shallows in the area.
21) Bästeträsk

County: Gotland County
Main catchment area: Coastal region (118117)
Physical geographic regions: boreonemoral
Coordinates, RAK: X 6425550, Y 1685530
Altitude: 6 m
Lake surface: 0.67 sq. km
Max. depth: 4.5 m
Volume: No information
Protection: Nature reserve
Sample matrix: Perch
Start: 2004

pH / alkalinity: 8.2 / 2.3 mekv/L

The lake lacks higher water vegetation to a large extent, but stands of reed and great fen-sedge occurs both in the south-west of the lake, and north of the Stor- and Lillholmen. Large parts of the central lake have vegetation consisting of charales.

nutrient status: totP = 6.9 ug/L. Nutrientpoor lake with higher Secchi depth, than maximum depth.

other: The lake floor consists in part of rocky hard-bottom and in part of suspension-bottom with a sediment layer up to 1.5 meters in thickness. The lake is surrounded by limestone outcrops, pine forests, mires with great fen-sedge growing in them, and ephemeral water bodies.
22) Lake Allgjuttern

County: Kalmar County
Main catchment area: Botorpströmmen
Physical geographic regions: Boreonemoral
Coordinates, RAK: X 6424870, Y 1517240
Altitude: 131 m
Lake surface: 18 ha
Max. depth: 40 m
Volume

Protection

Other monitoring
Sample matrix: Perch
Start: 2006
pH / alkalinity: 6.5 – 7 / 0.05 mekv/L
vegetation
The vegetation can mainly be found in the shallow bays and consists primarily of common reed, common club-rush and common chickweed.
totP = 10 ug/L

nutrient status
other

23) Lake Horsan

County: Gotland County
Main catchment area: Coastal region (118117), dominated by forest
Physical geographic regions: boreonemoral
Coordinates, RAK: X 6420080, Y 1680130 (07J4g 0980)
Altitude: 5 m
Lake surface: 0.56 sq. km
Max. depth: 1.5 m
Volume

Sample matrix: Roach, Perch
Start: 1980
pH / alkalinity: Ca 8.2 / ca 2.2 mekv/L
vegetation
Very sparse, consisting mainly of reeds and green fen-sedge. Primarily charales sp. below the water surface. Pine forest around the lake.

Nutrient status
Low in nutrients
Other
Suspension-bottom, with elements of hard bottom along the shores. The lake consists of two pools. Secchi depth exceeding maximum depth.
24) Lake Skärgölen

County
Kalmar County

Main catchment area.
Motala ström river (67000)

Physical geographic regions.
boreonemoral

Coordinates, RAK
X 6406090, Y 1486730 (07F1h 0884)

Altitude
72 m

Lake surface
16 hectare

Max. depth
13

Volume
1.08 Mm³

Sample matrix
Perch

Start
1981

Other monitoring
Close to 7 / close to 0.15 mekv/L

pH / alkalinity
Surrounded by mires and coniferous forest. Sparce veg at the

vegetation
beach edge, however, the rich in species of common reed,
bulrush, chickweed, yellow and white waterlily, sedge and

isoetids.

nutrient status
Poor in nutrients, totP often below 10 ug/L

other
Becomes deep very quickly, which might affect the amount of

vegetation along the shores.
25) Lake Lilla Öresjön
County: Halland County
Main catchment area: Rolfsån river (106000)
Physical geographic regions: boreonemoral
Coordinates, RAK: X 6952200, Y 1433830
Altitude: 107 m
Lake surface: 0.61 sq. km
Max. depth: 17 m
Volume: Perch
Sample matrix: 2004
pH / alkalinity: ca 5.5 - 6 / 0.2 – 0.25 mekv/L
vegetation: No information
nutrient status: 5 ug/L
other: Secchi depth about 3.8 m. Forest lake, poor in nutrients.

26) Lake Fiolen
County: Kronobergs county
Main catchment area: Mörrumsån river (86000)
Physical geographic regions: Boreonemoral
Coordinates, RAK: X 6330250, Y 1422670
Altitude: 226 m
Lake surface: 1.55 sq. km
Max. depth: 10
Volume: 6.21 Mm³
Protection: Perch
Sample matrix: 2000
pH / alkalinity: 6.5 / 0.05 mekv/L
vegetation: Moderate but with plants like shoreweed and quillwort, reed and waterlilies.
Nutrient status: Poor in nutrients
other: Surrounded by coniferous forests, farmland and mires.
27) Lake Hjärtsjön

County: Kronobergs County
Main catchment area: Alsterån river (75)
Physical geographic regions: boreonemoral
Coordinates, RAK: X 6325150, Y 1466750
Altitude: 274 m
Lake surface: 1.37 sq. km
Max. depth: 7 m
Volume: 4.6 Mm³
Protection: Perch
Sample matrix: Perch
Start: 2000
pH / alkalinity: below 5.5 / under 0 mekv/L
Vegetation: Poor in nutrients, totP often below 10 ug/L
Other: Surrounded by coniferous forestes and mires. Secchi depth above 6 m

nutrient status
Other

28) Lake Bolmen

County: Kronobergs, Hallands, Jönköpings län
Main catchment area: Lagan river (98000) /Bolmån river
Physical geographic regions: boreonemoral
Coordinates, RAK: X 6295110, Y 1368660
Altitude: 141 m
Lake surface: 184 sq. km
Max. depth: 37 m
Volume: 1260 Mm³
Protection: Pike
Sample matrix: Pike
Start: 1967
pH / alkalinity: ca 7 / 0.14-0.18 mekv/L
Vegetation: moderat in nutrients. totP = 0.009-0.011 mg/L
Other: Lake floors poor in oxygen. Secchi depth = 2-3m in august

nutrient status
Other
29) **Lake Stora Skärsjön**

- **County**: Halland County
- **Main catchment area**: Genevadsån river (99000)
- **Physical geographic regions**: boreonemoral
- **Coordinates, RAK**: X 6286060, Y 1332050
- **Altitude**: 60 m
- **Lake surface**: 0.28 sq. km
- **Max. depth**: 11.5 m
- **Volume**: 1.172 Mm³
- **Sample matrix**: Perch
- **Start**: 1997
- **pH / alkalinity**: pH close to 7 / alkalinity about 0.1 mekv/L (i.e. fairly good buffer capacity)
- **vegetation**: Abundant with common reed, common club-rush, Myriophyllum spp. and water lilies. Isoetides along the water's edge. The surrounding pine forests.
- **nutrient status**: Relatively high Secchi depht.
- **other**: Several deeps and shallows. Not a good reference lake, near an incinerating plant.

30) **Lake Sännen**

- **County**: Blekinge County
- **Main catchment area**: Coastal region (81082)
- **Physical geographic regions**: nemoral - boreonemoral
- **Coordinates, RAK**: X 6244210, Y 1472340
- **Altitude**: 62.7 m
- **Lake surface**: 0.99 sq. km
- **Max. depth**: 13 m
- **Volume**: 3.9 Mm³
- **Sample matrix**: Perch
- **Start**: 2004
- **pH / alkalinity**: ca 5-6 / ca 0.02 – 0.04 mekv/L. Lake Sännen is an acidified, limed lake.
- **vegetation**: Surrounded largely by mixed coniferous and deciduous forest. Bunches of common reed, common spike- and club-rush as well as bottle- and slender sedge occurs sparingly.
- **nutrient status**: totP = 15 - 21 µg/L
- **other**: Secchi depht 4.7 m.
31) Lake Krankesjön
County
Skåne County
Main catchment area.
Kävlingeån river (92000)
Physical geographic regions.
nemoral
Coordinates, RAK
X 6177970, Y 1353390 (02D5a 1281)
Altitude
19 m
Lake surface
3.31 sq. km
Max. depth
3 m
Volume
Protection
Nature reserve
Sample matrix
Roach
Start
1980
Other monitoring
pH / alkalinity
No information
vegetation
Lake surrounded by willow and swamp forest consisting of birch and alder, lined with common reed. Very rich bentic vegetation with chickweed and charales.
nutrient status
Eutrophicated, totP = ca 40 ug/L
other
One of the country's richest bird lakes.

32) Lake Krageholmssjön
County
Skåne County
Main catchment area.
Coastal region (89090)
Physical geographic regions.
nemoral
Coordinates, RAK
X 6153750, Y 1370870
Altitude
43 m
Lake surface
2.05 sq. km
Max. depth
9 m
Volume
Protection
Nature reserve
Sample matrix
Perch
Start
2000
Other monitoring
pH / alkalinity
No information
vegetation
Surrounded by beech forest. Varied vegetation. Dominated by plants growing above water surface. Abundant in common chickweed and two species Charales.
nutrient status
Extremely rich in nutrients, totP = 91 ug/L
other
Affected by agriculture however, one of Scania's least affected lakes. Very high natural value. Rich in fish. Surrounding land is the mostly agricultural land and mires / wetland.