



Naturhistoriska  
riksmuseet

## ***Sakrapport***

# ***Övervakning av metaller och organiska miljögifter i limnisk biota, 2012***

*Överenskommelse 216 1111, dnr 51-480-11Mm*

*Överenskommelse 216 1148, dnr 51-481-11Mm*

Report nr 13:2012

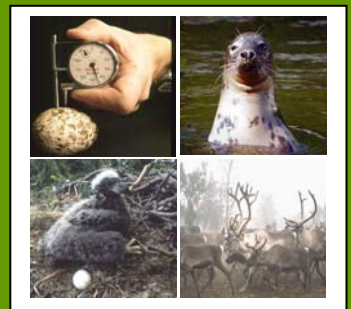
Swedish Museum of Natural History

Department of Contaminant Research

P.O.Box 50 007

SE-104 05 Stockholm

Sweden



# **The National Swedish Contaminant Monitoring Programme for Freshwater Biota, 2012**

2012-10-31

**Elisabeth Nyberg, Suzanne Faxneld, Sara Danielsson, Anders Bignert**  
The Department of Contaminant Research, Swedish Museum of  
Natural History

**Ulla Eriksson, Karin Holm, Hans Borg and Urs Berger**  
Department of Applied Environmental Science, Stockholm University

**Peter Haglund**  
Department of Chemistry, Umeå University

**Chemical analysis:**

**Organochlorines/bromines, perfluorinated substances and trace metals**  
Department of Applied Environmental Science, Stockholm University

**PCDD/PCDF**  
Department of Chemistry, Umeå University

# Contents

<b>CONTENTS</b>	<b>3</b>
<b>LIST OF FIGURES</b>	<b>12</b>
<b>1 INTRODUCTION</b>	<b>18</b>
<b>2 SUMMARY</b>	<b>21</b>
<b>3 SAMPLING</b>	<b>24</b>
3.1 Collected specimens	24
3.2 Number of samples and sampling frequency	24
3.3 Sample preparation and registered variables	25
3.4 Age determination	25
3.5 Data registration	25
<b>4 SAMPLE MATRICES</b>	<b>26</b>
4.1 Pike ( <i>Esox lucius</i> )	26
4.2 Arctic char ( <i>Salvelinus alpinus</i> )	27
4.3 Perch ( <i>Perca fluviatilis</i> )	27
<b>5 SAMPLING SITES</b>	<b>29</b>
<b>6 ANALYTICAL METHODS</b>	<b>32</b>
<b>6.1 Organochlorines and brominated flame retardants</b>	<b>32</b>
6.1.1 Quality assurance	32
6.1.2 Standards	32
6.1.3 Selectivity	32
6.1.4 Reference Material	33
6.1.5 Proficiency testing	33
6.1.6 Quantification limits and uncertainty in the measurements	33
<b>6.2 Dioxins, dibenzofurans and dioxin-like PCBs</b>	<b>34</b>
<b>6.3 Perfluoroalkyl substances</b>	<b>34</b>
6.3.1 Sample preparation and instrumental analysis	34
6.3.2 Quality control	35
<b>6.4 Trace metals</b>	<b>35</b>
6.4.1 Sample preparation and instrumental analysis	35
6.4.2 Quality control	35

6.4.3	Reference Material	35
<b>7</b>	<b>STATISTICAL TREATMENT AND GRAPHICAL PRESENTATION</b>	<b>37</b>
<b>7.1</b>	<b>Trend detection</b>	<b>37</b>
7.1.1	Log-linear regression analyses	37
7.1.2	Non-parametric trend test	37
7.1.3	Non-linear trend components	38
<b>7.2</b>	<b>Outliers and values below the detection limit</b>	<b>38</b>
<b>7.3</b>	<b>Plot Legends</b>	<b>38</b>
<b>7.4</b>	<b>Legend for the three dimensional maps</b>	<b>40</b>
<b>8</b>	<b>THE POWER OF THE PROGRAMME</b>	<b>41</b>
<b>9</b>	<b>POLLUTANT REGULATION: CONVENTIONS AND LEGISLATION</b>	<b>45</b>
<b>9.1</b>	<b>The Stockholm Convention on Persistent Organic Pollutants</b>	<b>45</b>
<b>9.2</b>	<b>The Convention on Long-Range Trans boundary Air Pollution</b>	<b>45</b>
<b>9.3</b>	<b>EU chemical legislation</b>	<b>46</b>
9.3.1	REACH	46
9.3.2	RoHS directive	46
9.3.3	Water Framework Directive	46
9.3.4	Marine Strategy Framework Directive	46
<b>9.4</b>	<b>Swedish chemical legislation</b>	<b>47</b>
<b>10</b>	<b>TARGET LEVELS FOR CHEMICAL STATUS ASSESSMENT</b>	<b>48</b>
<b>10.1</b>	<b>Metals</b>	<b>49</b>
10.1.1	Cadmium	49
10.1.2	Lead	49
10.1.3	Mercury	50
10.1.4	Nickel	50
<b>10.2</b>	<b>Pesticides</b>	<b>50</b>
10.2.1	DDTs, (DDT, DDE and DDD)	50
10.2.2	HCH	50
<b>10.3</b>	<b>PCBs</b>	<b>50</b>
<b>10.4</b>	<b>Brominated flame retardants</b>	<b>51</b>
10.4.1	BDEs	51
10.4.2	HBCDD	51
<b>10.5</b>	<b>Other</b>	<b>51</b>
10.5.1	Dioxins, furans and dioxin-like PCBs.	51
10.5.2	HCB	51

10.5.3	PFOS	51
<b>11</b>	<b>BIOLOGICAL VARIABLES</b>	<b>52</b>
<b>11.1</b>	<b>Results</b>	<b>52</b>
11.1.1	Spatial Variation	52
11.1.2	Temporal variation	54
<b>11.2</b>	<b>Summary</b>	<b>55</b>
<b>12</b>	<b>MERCURY - HG</b>	<b>56</b>
<b>12.1</b>	<b>Introduction</b>	<b>56</b>
12.1.1	Usage, Production and Sources	56
12.1.2	Environmental Fate	56
12.1.3	Toxic Effects	57
12.1.4	Conventions, aims and restrictions	58
12.1.5	Target Levels	58
<b>12.2</b>	<b>Results</b>	<b>58</b>
12.2.1	Spatial Variation	58
12.2.2	Temporal variation	59
12.2.3	Comparison to thresholds	61
<b>12.3</b>	<b>Summary</b>	<b>62</b>
<b>13</b>	<b>LEAD - PB</b>	<b>63</b>
<b>13.1</b>	<b>Introduction</b>	<b>63</b>
13.1.1	Usage, Production and Sources	63
13.1.2	Environmental Fate	63
13.1.3	Toxic Effects	63
13.1.4	Conventions, Aims and Restrictions	64
13.1.5	Target Levels	64
<b>13.1</b>	<b>Results</b>	<b>65</b>
13.1.1	Spatial Variation	65
13.1.2	Temporal variation	65
13.1.3	Comparison to thresholds	68
<b>13.2</b>	<b>Summary</b>	<b>68</b>
<b>14</b>	<b>CADMIUM - CD</b>	<b>69</b>
<b>14.1</b>	<b>Introduction</b>	<b>69</b>
14.1.1	Usage, Production and Sources	69
14.1.2	Environmental Fate	69
14.1.3	Toxic Effects	69
14.1.4	Conventions, Aims and Restrictions	70
14.1.5	Target Levels	70
<b>14.2</b>	<b>Results</b>	<b>71</b>
14.2.1	Spatial Variation	71
14.2.2	Temporal variation	71
14.2.3	Comparison to thresholds	74

<b>14.3</b>	<b>Summary</b>	<b>74</b>
<b>15</b>	<b>NICKEL - NI</b>	<b>75</b>
<b>15.1</b>	<b>Introduction</b>	<b>75</b>
15.1.1	Usage, Production and Sources	75
15.1.2	Environmental Fate	75
15.1.3	Toxic Effects	75
15.1.4	Target Levels	76
<b>15.2</b>	<b>Results</b>	<b>76</b>
15.2.1	Spatial Variation	76
15.2.2	Temporal variation	77
<b>15.3</b>	<b>Summary</b>	<b>79</b>
<b>16</b>	<b>CHROMIUM - CR</b>	<b>80</b>
<b>16.1</b>	<b>Introduction</b>	<b>80</b>
16.1.1	Usage, Production and Sources	80
16.1.2	Environmental Fate	80
16.1.3	Toxic Effects	80
16.1.4	Conventions, Aim, and restriction	81
<b>16.2</b>	<b>Results</b>	<b>82</b>
16.2.1	Spatial Variation	82
16.2.2	Temporal variation	82
<b>16.3</b>	<b>Summary</b>	<b>85</b>
<b>17</b>	<b>COPPER - CU</b>	<b>86</b>
<b>17.1</b>	<b>Introduction</b>	<b>86</b>
17.1.1	Usage, Production and Sources	86
17.1.2	Conventions, Aims and Restrictions	86
17.1.3	Target Levels	86
<b>17.2</b>	<b>Results</b>	<b>87</b>
17.2.1	Spatial Variation	87
17.2.2	Temporal variation	87
<b>17.3</b>	<b>Summary</b>	<b>90</b>
<b>18</b>	<b>ZINC - ZN</b>	<b>91</b>
<b>18.1</b>	<b>Introduction</b>	<b>91</b>
18.1.1	Usage, Production and Sources	91
18.1.2	Environmental Fate	91
18.1.3	Conventions, Aims and Restrictions	91
<b>18.2</b>	<b>Results</b>	<b>92</b>
18.2.1	Spatial Variation	92
18.2.2	Temporal variation	92
<b>18.3</b>	<b>Summary</b>	<b>95</b>

<b>19</b>	<b>ARSENIC - AS</b>	<b>96</b>
<b>19.1</b>	<b>Introduction</b>	<b>96</b>
19.1.1	Uses, Production and Sources	96
19.1.2	Toxicological Effects	96
19.1.3	Conventions, Aims and Restrictions	96
19.1.4	Target Levels	97
<b>19.2</b>	<b>Results</b>	<b>97</b>
19.2.1	Spatial Variation	97
19.2.2	Temporal variation	98
<b>19.3</b>	<b>Summary</b>	<b>100</b>
<b>20</b>	<b>SILVER - AG</b>	<b>101</b>
<b>20.1</b>	<b>Introduction</b>	<b>101</b>
20.1.1	Uses, Production and Sources	101
20.1.2	Toxicological Effects	101
20.1.3	Conventions, Aims and Restrictions	101
20.1.4	Target Levels	102
<b>20.2</b>	<b>Results</b>	<b>102</b>
20.2.1	Spatial Variation	102
20.2.2	Temporal variation	103
<b>20.3</b>	<b>Summary</b>	<b>105</b>
<b>21</b>	<b>ALUMINIUM - AL</b>	<b>106</b>
<b>21.1</b>	<b>Introduction</b>	<b>106</b>
21.1.1	Uses, Production and Sources	106
21.1.2	Environmental Fate	106
21.1.3	Toxicological Effects	106
21.1.4	Conventions, Aims and Restrictions	107
21.1.5	Target Levels	107
<b>21.2</b>	<b>Results</b>	<b>107</b>
21.2.1	Spatial Variation	107
21.2.2	Temporal variation	108
<b>21.3</b>	<b>Summary</b>	<b>110</b>
<b>22</b>	<b>BISMUTH - BI</b>	<b>111</b>
<b>22.1</b>	<b>Introduction</b>	<b>111</b>
22.1.1	Uses, Production and Sources	111
22.1.2	Toxicological Effects	111
22.1.3	Target Levels	111
<b>22.2</b>	<b>Results</b>	<b>112</b>
22.2.1	Spatial Variation	112
22.2.2	Temporal variation	112
<b>22.3</b>	<b>Summary</b>	<b>115</b>

<b>23</b>	<b>TIN – SN</b>	<b>116</b>
<b>23.1</b>	<b>Introduction</b>	<b>116</b>
23.1.1	Uses, Production and Sources	116
23.1.2	Environmental Fate	116
23.1.3	Toxicological Effects	117
23.1.4	Target Levels	117
<b>23.2</b>	<b>Results</b>	<b>118</b>
23.2.1	Spatial variation	118
23.2.2	Temporal variation	118
<b>23.3</b>	<b>Summary</b>	<b>121</b>
<b>24</b>	<b>PCBS, POLYCHLORINATED BIPHENYLS</b>	<b>122</b>
<b>24.1</b>	<b>Introduction</b>	<b>122</b>
24.1.1	Usage, Production and Sources	122
24.1.2	Toxicological Effects	122
24.1.3	Conventions, Aims and Restrictions	122
24.1.4	Target Levels	122
<b>24.2</b>	<b>Results</b>	<b>123</b>
24.2.1	Spatial Variation	123
24.2.2	Temporal variation	124
24.2.3	Comparison to thresholds	127
<b>24.3</b>	<b>Summary</b>	<b>127</b>
<b>25</b>	<b>DDTS, DICHLORODIPHENYLETHANES</b>	<b>128</b>
<b>25.1</b>	<b>Introduction</b>	<b>128</b>
25.1.1	Usage, Production and Sources	128
25.1.2	Toxicological Effects	128
25.1.3	Conventions, Aims and Restrictions	128
25.1.4	Target Levels	129
<b>25.2</b>	<b>Results</b>	<b>129</b>
25.2.1	Spatial Variation	129
25.2.2	Temporal variation	130
25.2.3	Comparison to thresholds	133
<b>25.3</b>	<b>Summary</b>	<b>133</b>
<b>26</b>	<b>HCHS, HEXACHLOROCYCLOHEXANES</b>	<b>134</b>
<b>26.1</b>	<b>Introduction</b>	<b>134</b>
26.1.1	Uses, Production and Sources	134
26.1.2	Conventions, Aims and Restrictions	134
26.1.3	Target Levels	134
<b>26.2</b>	<b>Results</b>	<b>135</b>
26.2.1	Spatial Variation	135
26.2.2	Temporal variation	135
26.2.3	Comparison to thresholds	138
<b>26.3</b>	<b>Summary</b>	<b>138</b>



<b>27</b>	<b>HCB, HEXACHLOROBENZENE</b>	<b>139</b>
<b>27.1</b>	<b>Introduction</b>	<b>139</b>
27.1.1	Uses, Production and Sources	139
27.1.2	Conventions, Aims and Restrictions	139
27.1.3	Target Levels	139
<b>27.2</b>	<b>Results</b>	<b>140</b>
27.2.1	Spatial Variation	140
27.2.2	Temporal variation	140
27.2.3	Comparison to thresholds	141
<b>27.3</b>	<b>Summary</b>	<b>141</b>
<b>28</b>	<b>PFASS, PERFLUOROALKYL SUBSTANCES</b>	<b>142</b>
<b>28.1</b>	<b>Introduction</b>	<b>142</b>
28.1.1	Uses, Production and Sources	142
28.1.2	Toxicological Effects	143
28.1.3	Conventions, aims and restrictions	143
28.1.4	Target Levels	143
<b>28.2</b>	<b>Results</b>	<b>144</b>
28.2.1	Spatial variation	144
28.2.2	Temporal variation	149
28.2.3	Comparison to threshold	152
<b>28.3</b>	<b>Summary</b>	<b>153</b>
<b>29</b>	<b>PCDD/PCDF, POLYCHLORINATED DIOXINS AND DIBENZOFURANS</b>	<b>154</b>
<b>29.1</b>	<b>Introduction</b>	<b>154</b>
29.1.1	Uses, Production and Sources	154
29.1.2	Toxicological Effects	154
29.1.3	Conventions, aims and restrictions	154
29.1.4	Target Levels	155
<b>29.2</b>	<b>Results</b>	<b>155</b>
29.2.1	Spatial variation	155
29.2.2	Temporal variation	156
29.2.3	Comparison to thresholds	160
<b>29.3</b>	<b>Summary</b>	<b>160</b>
<b>30</b>	<b>POLYBROMINATED FLAME RETARDANTS</b>	<b>161</b>
<b>30.1</b>	<b>Introduction</b>	<b>161</b>
30.1.1	Uses, Production and Sources	161
30.1.2	Toxicological effects	161
30.1.3	Conventions, aims and restrictions	161
30.1.4	Target Levels	162
<b>30.2</b>	<b>Results</b>	<b>162</b>
30.2.1	Spatial variation	162
30.2.2	Temporal variation	165

30.2.3	Comparison to thresholds	167
<b>30.3</b>	<b>Summary</b>	<b>167</b>
<b>31</b>	<b>PRIORITY SUBSTANCES 2007 AND 2011</b>	<b>168</b>
<b>31.1</b>	<b>Chloroalkanes</b>	<b>169</b>
31.1.1	Usage	169
31.1.2	Toxicological effects	169
31.1.3	Conventions, aims and restrictions	169
31.1.4	Target level	169
31.1.5	Results	170
<b>31.2</b>	<b>Di-(2-ethylhexyl)-phthalate (DEHP)</b>	<b>171</b>
31.2.1	Usage	171
31.2.2	Toxicological effects	171
31.2.3	Conventions, aims and restrictions	171
31.2.4	Target level	171
31.2.5	Results	171
<b>31.3</b>	<b>Hexachlorobutadiene (HCBd)</b>	<b>172</b>
31.3.1	Usage	172
31.3.2	Toxicological effects	172
31.3.3	Conventions, Aims and restrictions	172
31.3.4	Target level	172
31.3.5	Results	172
<b>31.4</b>	<b>Pentachlorobenzene</b>	<b>172</b>
31.4.1	Usage	172
31.4.2	Toxicological effects	173
31.4.3	Conventions, aims and restrictions	173
31.4.4	Target level	173
31.4.5	Results	173
<b>31.5</b>	<b>Organotin compounds (OTCs)</b>	<b>173</b>
31.5.1	Usage	173
31.5.2	Toxicological effects	174
31.5.3	Conventions, aims and restrictions	174
31.5.4	Target level	174
31.5.5	Results	174
<b>32</b>	<b>CONFOUNDING FACTORS</b>	<b>176</b>
<b>32.1</b>	<b>Introduction</b>	<b>176</b>
<b>32.2</b>	<b>Methods</b>	<b>176</b>
32.2.1	Data compilation	176
32.2.2	Statistical analysis	177
<b>32.3</b>	<b>Results</b>	<b>178</b>
32.3.1	Environmental confounding factors	178
32.3.2	Physiological factors	181
<b>32.4</b>	<b>Discussion</b>	<b>184</b>
<b>33</b>	<b>REFERENCES</b>	<b>186</b>



# List of Figures

<b>Figure 5.1.</b> Map showing lake location, including species and year, within the Swedish National Monitoring Programme. ....	30
<b>Figure 5.2.</b> 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. ....	31
<b>Figure 11.1.</b> Spatial variation in mean fat percentage in perch muscle. ....	52
<b>Figure 11.2.</b> Spatial variation in mean age (year) in perch. ....	52
<b>Figure 11.3.</b> Spatial variation in mean total length (cm) in perch. ....	53
<b>Figure 11.4.</b> Spatial variation in mean total weight (g) in perch. ....	53
Some variation is seen for the total weight but no clear spatial pattern is observed (Fig. 11.4). ....	54
<b>Figure 11.5.</b> Fat content in arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln). ....	54
<b>Figure 11.6.</b> Fat content in perch muscle (Lake Skärgölen and Lake Stensjön). ....	55
<b>Figure 12.1.</b> Spatial variation in concentration (ng/g wet weight) of Hg in perch muscle. ....	58
<b>Figure 12.2.</b> 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. ....	59
<b>Figure 12.3.</b> Mercury concentrations (ng/g fresh weight) in perch muscle from Lake Bysjön, Lake Stora Envättern and Lake Särgölen. The green area denotes the levels below the suggested target value for mercury in fish. ....	60
<b>Figure 12.4.</b> 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. ....	60
<b>Figure 12.5.</b> Mercury concentrations (ng/g fresh weight) in perch muscle from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for mercury in fish. ....	61
<b>Figure 12.6.</b> 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. ....	61
<b>Figure 13.1.</b> Spatial variation in concentration (ug/g dry weight) of Pb in perch liver. ....	65
<b>Figure 13.2.</b> Lead concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln). ....	66
<b>Figure 13.3.</b> Lead concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen. The green area denotes the levels below the suggested target value for lead in fish. ....	66
<b>Figure 13.4.</b> 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. ....	67
<b>Figure 13.5.</b> Lead concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for lead in fish. ....	67
<b>Figure 14.1.</b> Spatial variation in concentration (ug/g dry weight) of Cd in perch liver. ....	71
<b>Figure 14.2.</b> Cadmium concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln). ....	72
<b>Figure 14.3.</b> Cadmium concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen. The green area denotes the levels below the suggested target value for cadmium in fish. ....	72
<b>Figure 14.4.</b> Cadmium 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 cadmium in fish. ....	73
<b>Figure 14.5.</b> Cadmium concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for cadmium in fish. ....	73

<b>Figure 15.1.</b> Spatial variation in concentration (ug/g dry weight) of Ni in perch liver.....	76
<b>Figure 15.2.</b> Nickel concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	77
<b>Figure 15.3.</b> Nickel concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen. The green area denotes the levels below the suggested target value for nickel in fish.....	78
<b>Figure 15.4.</b> Nickel 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 nickel in fish. ....	78
<b>Figure 15.5.</b> Nickel concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for nickel in fish.....	79
<b>Figure 16.1.</b> Spatial variation in concentration (ug/g dry weight) of Cr in perch liver.....	82
<b>Figure 16.2.</b> Chromium concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	83
<b>Figure 16.3.</b> Chromium concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen.....	83
<b>Figure 16.4.</b> Chromium concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	84
<b>Figure 16.5.</b> Chromium concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. ....	84
<b>Figure 17.1.</b> Spatial variation in concentration (ug/g dry weight) of Cu in perch liver. ....	87
<b>Figure 17.2.</b> Copper concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	88
<b>Figure 17.3.</b> Copper concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen.....	88
<b>Figure 17.4.</b> Copper concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	89
<b>Figure 17.5.</b> Copper concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. ....	89
<b>Figure 18.1.</b> Spatial variation in concentration (ug/g dry weight) of Zn in perch liver. ....	92
<b>Figure 18.2.</b> Zinc concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	93
<b>Figure 18.3.</b> Zinc concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen.....	93
<b>Figure 18.4.</b> Zinc concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	94
<b>Figure 18.5.</b> Zinc concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön.....	94
<b>Figure 19.1.</b> Spatial variation in concentration (ug/g dry weight) of As in perch liver. ....	97
<b>Figure 19.2.</b> Arsenic concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	98
<b>Figure 19.3.</b> Arsenic concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen.....	99
<b>Figure 19.4.</b> Arsenic concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	99
<b>Figure 19.5.</b> Arsenic concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. ....	100
<b>Figure 20.1.</b> Spatial variation in concentration (ug/g dry weight) of Ag in perch liver....	102
<b>Figure 20.2.</b> Silver concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	103
<b>Figure 20.3.</b> Silver concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.....	104
<b>Figure 20.4.</b> Silver concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	104
<b>Figure 20.5.</b> Silver concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön.....	105
<b>Figure 21.1.</b> Spatial variation in concentration (ug/g dry weight) of Al in perch liver....	107

<b>Figure 21.2.</b> Aluminium concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	108
<b>Figure 21.3.</b> Aluminium concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.....	109
<b>Figure 21.4.</b> Aluminium concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	109
<b>Figure 21.5.</b> Aluminium concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. ....	110
<b>Figure 22.1.</b> Spatial variation in concentration (ug/g dry weight) of Bi in perch liver. ....	112
<b>Figure 22.2.</b> Bismuth concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	113
<b>Figure 22.3.</b> Bismuth concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.....	113
<b>Figure 22.4.</b> Bismuth concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	114
<b>Figure 22.5.</b> Bismuth concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. ....	114
<b>Figure 23.1.</b> Spatial variation in concentration (ug/g dry weight) of Sn in perch liver....	118
<b>Figure 23.2.</b> Tin concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).....	119
<b>Figure 23.3.</b> Tin concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.....	119
<b>Figure 23.4.</b> Tin concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.....	120
<b>Figure 23.5.</b> Tin concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön.....	120
<b>Figure 24.1.</b> Spatial variation in concentration (ug/g lipid weight) of CB-118 in perch muscle.....	123
<b>Figure 24.2.</b> Spatial variation in concentration (ug/g lipid weight) of CB-153 in perch muscle.....	123
<b>Figure 24.3.</b> CB-118 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-118 in fish. ..	125
<b>Figure 24.4.</b> 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.....	125
<b>Figure 24.5.</b> 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. ..	126
<b>Figure 24.6.</b> CB-153 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-153 in fish.....	126
<b>Figure 24.7.</b> 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.....	127
<b>Figure 25.1.</b> Spatial variation in concentration (ug/g lipid weight) of DDE in perch muscle. ....	129
<b>Figure 25.2.</b> Spatial variation in concentration (ug/g lipid weight) of DDT in perch muscle. ....	130
<b>Figure 25.3.</b> 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.....	131
<b>Figure 25.4.</b> 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. ....	132
<b>Figure 25.5.</b> DDT concentrations (ug/g lipid weight) in arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln). ....	132

<b>Figure 25.6.</b> DDT concentrations (ug/g lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön).	133
<b>Figure 26.1.</b> Spatial variation in concentration (ug/g lipid weight) of $\alpha$ -HCH in perch muscle.	135
<b>Figure 26.2.</b> Lindane concentrations (ug/g lipid weight) in arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln).	136
<b>Figure 26.3.</b> Lindane concentrations (ug/g lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön).	137
<b>Figure 26.4.</b> sHCH 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 sHCH in fish.	137
<b>Figure 26.5.</b> sHCH 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 sHCH in fish.	138
<b>Figure 27.1.</b> 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.	140
<b>Figure 27.2.</b> 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.	141
<b>Figure 28.1.</b> Spatial variation in concentration (ng/g wet weight) of PFOS in perch liver.	144
<b>Figure 28.2.</b> Spatial variation in concentration (ng/g wet weight) of FOSA in perch liver.	145
<b>Figure 28.3</b> Spatial variation in concentration (ng/g wet weight) of PFNA in perch liver.	145
<b>Figure 28.4</b> Spatial variation in concentration (ng/g wet weight) of PFDA in perch liver.	146
<b>Figure 28.5</b> Spatial variation in concentration (ng/g wet weight) of PFUnDA in perch liver.	146
<b>Figure 28.6</b> Spatial variation in concentration (ng/g wet weight) of PFDoDA in perch liver.	147
<b>Figure 28.7</b> Spatial variation in concentration (ng/g wet weight) of PFTrDA in perch liver.	147
<b>Figure 28.8</b> Spatial variation in concentration (ng/g wet weight) of PFTeDA in perch liver.	148
<b>Figure 28.9</b> Spatial variation in concentration (ng/g wet weight) of PFPeDA in perch liver.	148
<b>Figure 28.10.</b> PFOS, PFNA, PFDA and PFUnDA concentrations (ng/g wet weight) in arctic char liver from Lake Abiskojaure (1980-2011).	150
<b>Figure 28.11.</b> PFDoDA, PFTrDA, FOSA concentrations (ng/g wet weight) in arctic char liver from Lake Abiskojaure (1980-2011).	151
<b>Figure 28.12.</b> PFOS, PFNA, PFDA and PFUnDA concentrations (ng/g wet weight) in perch liver from Lake Skärgölen (1980-2011).	151
<b>Figure 28.13.</b> PFDoDA, PFTrDA, FOSA concentrations (ng/g wet weight) in perch liver from Lake Skärgölen (1980-2011).	152
<b>Figure 28.14.</b> 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.	153
<b>Figure 29.2.</b> Spatial variation in concentration (pg/g wet weight) of WHO05-TEQ (PCDD/PCDF) in perch muscle.	156
<b>Figure 29.3</b> 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.	157
<b>Figure 29.4.</b> 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.	157

<b>Figure 29.5.</b> 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. ....	158
<b>Figure 29.6.</b> 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. ....	158
<b>Figure 29.7.</b> PCDD/PCDF concentrations (pg/g wet weight) in perch muscle from Lake Skärgölen. 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. ....	159
<b>Figure 29.8.</b> PCDD/PCDF concentrations (pg/g lipid weight) in perch muscle from Lake Skärgölen. 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. ....	159
<b>Figure 30.1.</b> Spatial variation in concentration (ng/g lipid weight) of BDE-47 in perch muscle. ....	162
<b>Figure 30.2.</b> Spatial variation in concentration (ng/g lipid weight) of BDE-99 in perch muscle. ....	163
<b>Figure 30.3.</b> Spatial variation in concentration (ng/g lipid weight) of BDE-100 in perch muscle. ....	163
<b>Figure 30.4.</b> Spatial variation in concentration (ng/g lipid weight) of BDE-153 in perch muscle. ....	164
<b>Figure 30.5.</b> Spatial variation in concentration (ng/g lipid weight) of BDE-154 in perch muscle. ....	164
<b>Figure 30.6.</b> BDE-47, -99, -100 concentrations (ng/g lipid weight) in arctic char muscle from Lake Abiskojaure. ....	165
<b>Figure 30.7.</b> BDE-153, -154 concentrations (ng/g lipid weight) in arctic char muscle from Lake Abiskojaure. ....	166
<b>Figure 30.8.</b> BDE-47, -99, -100 concentrations (ng/g lipid weight) in pike muscle from Lake Bolmen. ....	166
<b>Figure 30.9.</b> BDE-153, -154 concentrations (ng/g lipid weight) in pike muscle from Lake Bolmen. ....	167
<b>Figure 31.1.</b> Lakes monitored for Chloroalkanes, Di-(2-ethylhexyl)-phthalate, Hexachlorobutadiene, Pentachlorobenzene, and Organotin compounds in 2007 and 2010. Lakes from north to south: Abiskojaure, Tjulträsket, Brännträsket, Remmarsjön, Stor-Backsjön, Stensjön, Övre Skärsjön, Tärnan, Bysjön, Lilla Öresjön, Bästeträsk, Fiolen, Stora Skärsjön, Sännen, and Krageholmssjön. ....	168
<b>Figure 30.2.</b> Spatial variation in concentration (ng/g wet weight) of SCCP in perch liver, arithmetic mean 2007 and 2010. ....	170
<b>Figure 32.1.</b> Secchi depth in the studied lakes. ....	178
<b>Figure 32.2.</b> Concentration of total organic carbon (TOC) in the studied lakes. ....	178
<b>Figure 32.3.</b> Time trends of unadjusted (left) and age-adjusted (right) cadmium levels in perch from Lakes Fiolen and Hjärtsjön. ....	183
<b>Figure 32.4.</b> Time trends of unadjusted (left) and age-adjusted (right) mercury levels in perch from Lakes Fiolen and Hjärtsjön. ....	183



# List of Tables

<b>Table 4.1.</b> Number of individual specimens of various species sampled for analysis of contaminants within the base programme.....	26
<b>Table 4.2.</b> 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.....	26
<b>Table 4.3.</b> 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-Björnsjön.....	27
<b>Table 4.4.</b> 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.....	28
<b>Table 6.3.</b> Expanded uncertainty.....	34
<b>Table 7.1.</b> The approximate number of years required to double or half the initial concentration, assuming a continuous annual change of 1, 2, 3, 4, 5, 7, 10, 15 or 20% a year.....	37
<b>Table 8.1.</b> Number of years that various contaminants have been analysed and detected. .	42
<b>Table 8.2.</b> The number of years required to detect an annual change of 10% with a power of 80%.....	43
<b>Table 8.3.</b> The lowest trend possible to detect (in %) within a 10 year period with a power of 80% for the entire time series. ....	43
<b>Table 8.4.</b> 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.....	44
<b>Table 10.1.</b> Target levels for various environmental pollutants.....	49
<b>Table 32.1.</b> Results for PFAS.....	179
<b>Table 32.2.</b> Results for chlorinated organic compounds, PCBs, a-HCH, DDTs.....	180
<b>Table 32.3.</b> Results for brominated flame retardants, PBDEs.....	180
<b>Table 32.4.</b> Results for metals.....	181
<b>Table 32.5.</b> Combinations of contaminants and physiological confounding factors tested. For each combination the total number of analyzed lakes ( <i>n</i> ), is shown. ....	182
<b>Table 32.6.</b> Results from the unadjusted and age-adjusted time series of cadmium and mercury in Lakes Fiolen and Hjärtsjön.....	182

# 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 Contaminant Research* 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. Mats Hjelmberg and Henrik Dahlgren 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. No trend in fat content could be seen for arctic char. 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 50 % 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 from 40 % of the lakes.

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 Störvindeln.

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 pike from Lake Bolmen and 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.

#### *PFASs*

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 seen 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 many cases contains higher concentrations of PFASs than muscle tissue.

*Priority substances 2007 and 2010*

For four of the five priority substances - DEHP, HCB, 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.

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.

Species	N of individual specimen	Percent of total %
Pike	1236	24
Char	625	12
Perch	3337	64
Total	<b>5198</b>	<b>100</b>

### 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 4.1). 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.

	Lake Bolmen (95% c.i)	Lake Storvindeln (95% c.i)
<b>n samples</b>	557	679
<b>n years</b>	44	43
<b>Age (years)</b>	5.2 (5.0-5.4)	5.7 (5.5-5.9)
<b>Length (cm)</b>	54.3 (53.4-55.2)	60.3 (59.4-61.2)
<b>Weight (g)</b>	1158 (1087-1230)	1383 (1325-1442)

## 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-Björnsjön since 2007 (table 4.2).

**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-Björnsjön.

	Lake Abiskojaure (95% c.i)	Lake Tjulträsk (95% c.i)	Lake Stor-Björnsjön (95% c.i)
<b>n samples</b>	348	162	57
<b>n of years</b>	31	30	5
<b>Age (years)</b>	5.2 (5.0-5.3)	5.2 (5.1-5.3)	5.6 (5.1-5.9)
<b>Length (cm)</b>	27.4 (27.0-27.9)	26.6 (25.9-27.3)	27.0 (26.1-27.9)
<b>Weight (g)</b>	226 (212-240)	197 (178-215)	177 (159-196)

## 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 4.3). 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.

<b>LAKE</b>	<b>N SAMPLES</b>	<b>N OF YEARS</b>	<b>AGE (YEARS)</b>	<b>LENGTH (CM) 95% C.I.</b>	<b>WEIGHT (G) 95% C.I.</b>
Allgjuttern	87	9	4.5 (4.3-4.7)	18.3 (17.9-18.7)	60.0 (55.7-64.2)
Brännträsket	68	8	7.5 (7.1-8.0)	18.9 (18.5-19.2)	69.3 (64.3-74.3)
Bysjön	127	12	5.4 (5.2-5.7)	17.3 (17.1-17.5)	56.2 (54.0-58.3)
Bästräsk	66	8	4.0 (3.8-4.2)	17.8 (17.4-18.1)	57.0 (53.4-60.5)
Degervattnet	128	12	5.9 (5.6-6.2)	17.9 (17.6-18.1)	63.1 (60.1-66.1)
Fiolen	118	12	5.0 (4.7-5.3)	18.2 (17.2-18.6)	69.1 (63.2-75.1)
Fräcksjön	68	7	5.2 (4.9-5.5)	16.6 (16.4-16.9)	46.8 (44.5-49.2)
Fysingen	58	7	4.5 (4.2-4.8)	16.9 (16.6-17.2)	49.9 (46.4-53.3)
Gipsjön	67	8	6.2 (5.9-6.4)	17.6 (17.3-17.9)	58.9 (55.5-62.2)
Hjärtsjön	127	12	4.2 (3.9-4.4)	18.5 (18.2-18.8)	69.8 (65.4-74.3)
Horsan	81	7	5.4 (5.1-5.7)	18.2 (17.8-18.5)	60.5 (56.9-64.1)
Krageholmsjön	128	12	2.9 (2.6-3.1)	17.0 (16.7-17.4)	63.0 (57.9-68.2)
Krankesjön	70	6	3.0 (2.8-3.1)	17.2 (16.9-17.6)	59.9 (55.8-64.0)
Lilla Öresjön	58	8	5.6 (5.3-5.9)	18.5 (18.0-19.0)	65.2 (59.3-71.0)
Limmingsjön	68	7	5.0 (4.8-5.2)	17.5 (17.2-17.8)	55.2 (52.8-57.6)
Remmarsjön	128	12	6.7 (6.4-6.9)	19.3 (18.8-19.9)	84.0 (76.0-92.0)
Skärgölen	425	31	4.6 (4.5-4.7)	15.1 (15.0-15.3)	39.2 (37.6-40.8)
Spjutsjön	56	5	3.6 (3.4-3.8)	18.1 (17.8-18.4)	61.2 (57.5-64.9)
Stora Envättern	127	12	5.9 (5.7-6.2)	17.1 (16.8-17.3)	52.8 (50.1-55.5)
Stensjön	171	15	7.0 (6.7-7.2)	18.2 (18.0-18.4)	60.7 (58.7-62.6)
Stora Skärsjön	88	11	6.4 (6.1-6.6)	16.8 (16.5-17.1)	52.3 (48.9-55.7)
Stor-Backsjön	68	8	6.1 (5.9-6.4)	18.0 (17.8-18.3)	59.8 (57.2-62.4)
Svartsjön	58	6	6.0 (5.4-6.6)	15.6 (14.6-16.6)	43.9 (32.0-55.9)
Sännen	68	8	5.5 (5.2-5.8)	17.0 (16.7-17.3)	47.7 (43.8-51.6)
Tärnan	88	12	6.1 (5.7-6.5)	17.4 (17.0-17.8)	55.3 (50.8-59.9)
Älgsjön	78	7	5.8 (5.4-6.2)	17.0 (16.7-17.3)	50.5 (47.7-53.3)
Övre Skärsjön	108	12	6.9 (6.5-7.3)	17.9 (17.6-18.1)	58.9 (56.4-61.4)

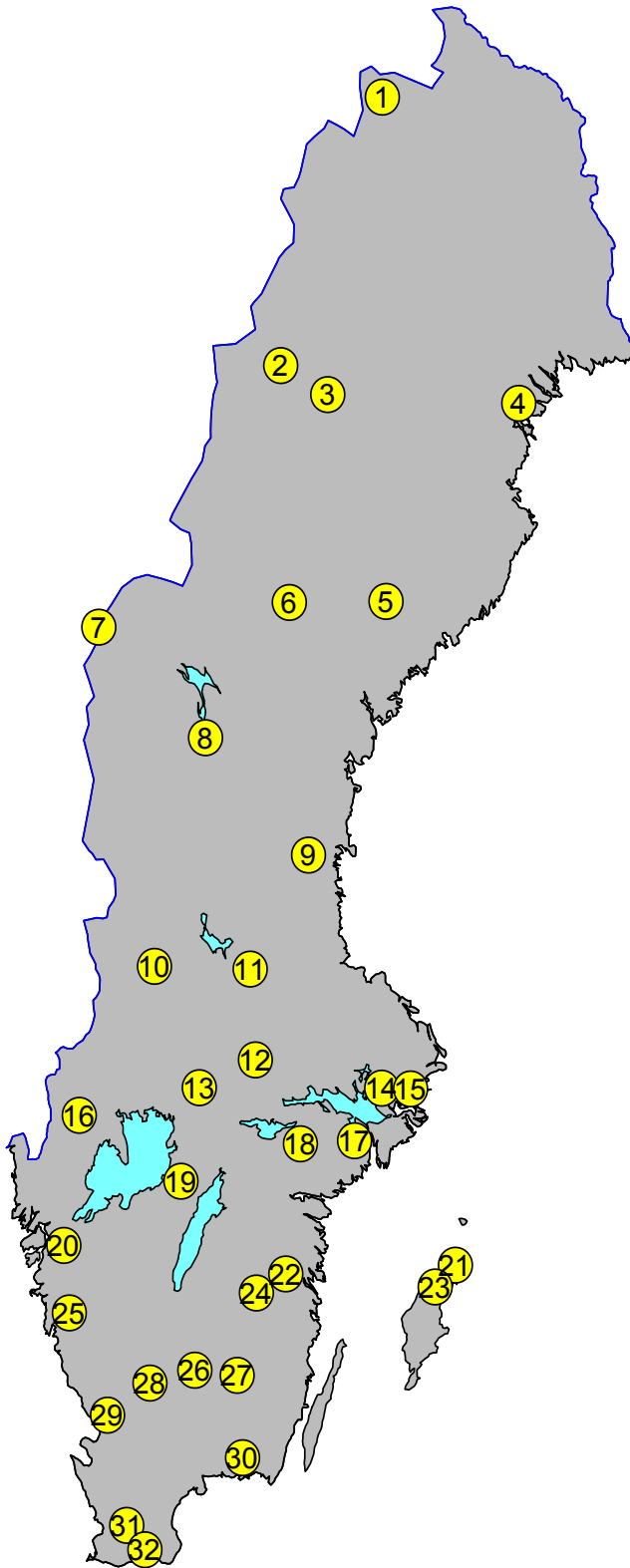
## 5 Sampling sites

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 (2011) 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.

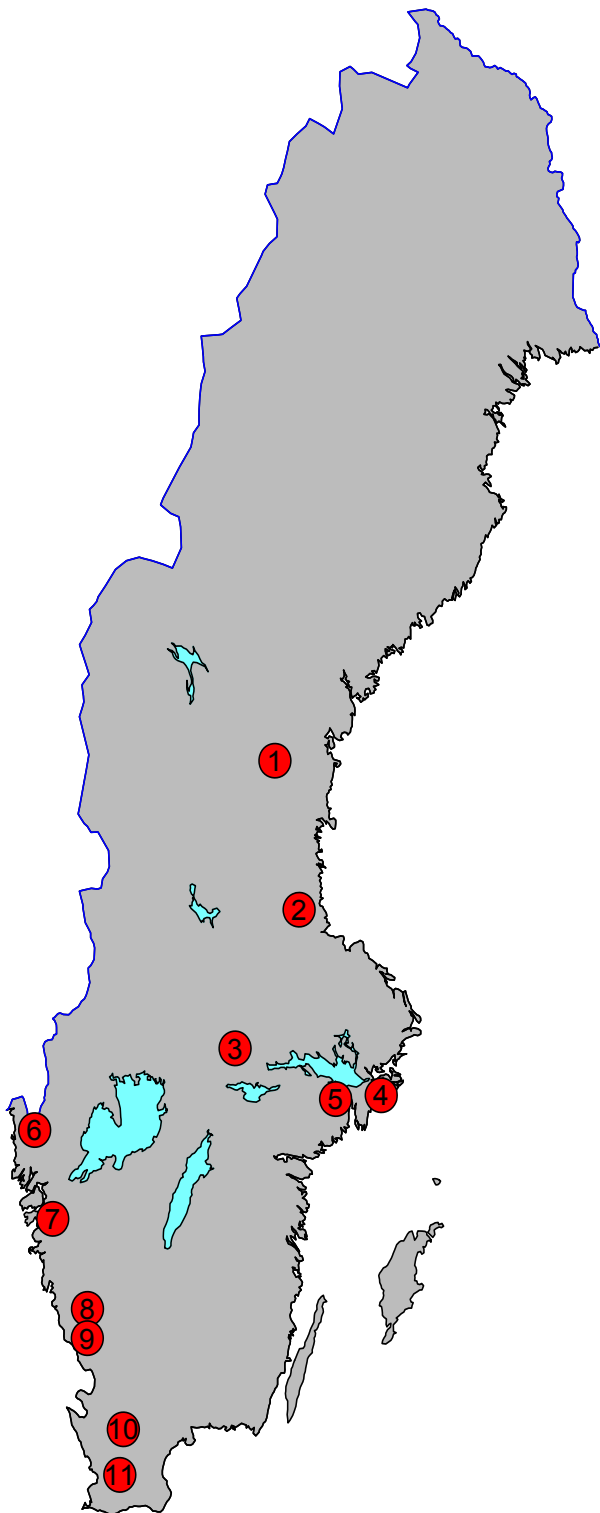


NR	Sampling site	Species	Since
1	Abiskojaure	Char	1981-
2	Tjulträsk	Char	1982-
3	Storvindeln	Pike	1968-
4	Brännträsket	Perch	2004-
5	Remmarsjön	Perch	2000-
6	Degervattnet	Perch	2000-
7	Stor-Björnsjön	Char	2007-
8	Stor-Backsjön	Perch	2004-
9	Stensjön	Perch	1997-
10	Gipsjön	Perch	2004-
11	Spjutsjön	Perch	2007-
12	Övre Skärsjön	Perch	2000-
13	Limmingsjön	Perch	2005-
14	Fysingen	Perch	2005-
15	Tärnan	Perch	2000-
16	Bysjön	Perch	2000-
17	Stora Envättern	Perch	2000-
18	Älgsjön	Perch	2005-
19	Svartsjön*	Perch	1982-
20	Fräcksjön	Perch	2005-
21	Bästräsk	Perch	2004-
22	Allgjutten	Perch	97-99,06-
23	Horsan*	Perch	2005-
24	Skärgölen	Perch	1981-
25	Lilla Öresjön	Perch	2004-
26	Fiolen	Perch	2000-
27	Hjärtsjön	Perch	2000-
28	Bolmen	Pike	1967-
29	Stora Skärsjön	Perch	97-99,04-
30	Sännen	Perch	2004-
31	Krankesjön*	Perch	2006-
32	Krageholmsjön	Perch	2000-

4 12:35, KNC LIMN

**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.



NR	Sampling site	Species	Year
1	Stormyr tjärn	Perch	1990-1996
2	Bysjön, Ockelbo	Perch	2005-2006
3	Ämten	P,R,P	1982-2000
4	Bylsjön	Perch	1982-96, 2006
5	Norra Yngern	Perch	2005-2006
6	Rotehogstjärn	Perch	1997-99
7	Kvarnsjön	Perch	1981-96
8	Stora Bälgsjön	Perch	1984-96
9	Stora Pipsjön	Perch	1987-96
10	Fågelsjön	Perch	2005-2006
11	Krankesjön	Roach	1980-2007

**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.

## 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  $\mu$ -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 ISO/IEC 17025:2005. The accreditation is valid for CB28, 52, 101, 118, 153, 138, 180, HCB, *p,p'*-DDE, *p,p'*-DDD, *p,p'*-DDT and  $\alpha$ ,  $\beta$ - and  $\gamma$ -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 DB-5 and the more polar DB-1701. 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 7000 PCB- and pesticide values during a period of nearly 20 years and around 1500 BDE- and HBCD values during 10 years. The bias is estimated from proficiency testing of more than 8 samples during at least 4 years. Only within-laboratory reproducibility is used 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 follows the theory stated by Horwitz where the relative standard deviation increase when the concentration level decrease (Horwitz and Albert, 2006).

**Table 6.3.** Expanded uncertainty

	PBDEs	HBCD		PCBs	HCHs	DDTs
ng/g lw	rsd%	rsd%	ng/g lw	rsd%	rsd%	rsd%
0.2-1	63		3-10	35	43	40
1-10	62		10-100	32	38	37
>10	28		> 100	14	10	30
> 4		56				

Quantification limits and other comments are reported under each contaminant description.

## 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 graphitised 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 (PFOSA), 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 7.1.** The approximate number of years required to double or half the initial concentration, assuming a continuous annual change of 1, 2, 3, 4, 5, 7, 10, 15 or 20% a year.

	1%	2%	3%	4%	5%	7%	10%	12%	15%	20%
Increase	70	35	24	18	14	10	7	6	5	4
Decrease	69	35	23	17	14	10	7	6	4	3

### 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 ' $\tau$ ', and the corresponding p-value. The Kendall's ' $\tau$ ' 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  $\tau$ -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**%=... Tv 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,  $\alpha=0.05$ . 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,  $\alpha=0.05$ .

**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% a 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;

**r<sup>2</sup>**= reports the coefficient of determination ( $r^2$ ) together with a p-value for a two-sided test ( $H_0$ : 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 ' $\tau$ ', 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 ' $\tau$ ' 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 asterisk 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 Tabel 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.

<b>Contaminant</b>	<b>Lake Abiskojaure</b>	<b>Lake Storvindeln</b>	<b>Lake Bolmen</b>	<b>Lake Skärgölen</b>
Hg	30	39	31	25
Pb	30	40	14	11
Cd	30	40	14	11
Ni	30	40	14	11
Cr	30	40	14	11
Cu	30	40	14	11
Zn	30	40	14	11
As	12	11	9	10
Ag	9	8	8	10
Al	12	11	9	10
Bi	7	6	6	8
Sn	8	7	7	9
CB-153	22	21	20	6
DDE	26	40	41	12
$\gamma$ -HCH	22	14	20	6
HCB	22	21	20	6
TCDD-eqv (PCDD/PCDF)	-	11	10	16
PFOS	18	-	-	17
BDE-47	21	-	36	-

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%.

Contaminant	Lake Abiskojaure	Lake Storvindeln	Lake Bolmen	Lake Skärgölen
Hg	9	10	9	11
Pb	14	14	15	10
Cd	16	11	14	13
Ni	14	12	16	14
Cr	16	17	20	24
Cu	13	10	10	9
Zn	9	9	13	6
As	12	13	8	18
Ag	13	7	11	8
Al	13	15	10	12
Bi	7	13	10	13
Sn	14	16	12	13
CB-153	11	9	12	8
DDE	13	26	13	16
$\gamma$ -HCH	17	12	10	5
HCB	9	11	12	4
TCDD-eqv (PCDD/PCDF)	-	13	11	13
PFOS	14	-	-	15
BDE-47	24	-	15	-

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.

Contaminant	Lake Abiskojaure	Lake Storvindeln	Lake Bolmen	Lake Skärgölen
Hg	7.0	9.1	6.9	12
Pb	17	16	19	9.4
Cd	21	11	18	15
Ni	17	13	21	16
Cr	23	24	31	45
Cu	15	9.3	9.8	7.1
Zn	7.3	7.2	15	3.5
As	12	15	6.0	27
Ag	16	4.4	11	6.5
Al	15	18	12	13
Bi	4.0	14	8.3	15
Sn	17	21	12	14
CB-153	11	7.0	12	5.8
DDE	15	55	15	22
$\gamma$ -HCH	25	13	8.8	2.0
HCB	6.9	10	13	0.73
TCDD-eqv (PCDD/PCDF)	-	15	11	14
PFOS	17	-	-	19
BDE-47	46	-	18	-

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.

<b>Contaminant</b>	<b>Lake Abiskojaure</b>	<b>Lake Storvindeln</b>	<b>Lake Bolmen</b>	<b>Lake Skärgölen</b>
Hg	1.0	1.0	1.0	1.0
Pb	1.0	1.0	0.76	0.94
Cd	1.0	1.0	0.81	0.59
Ni	1.0	1.0	0.70	0.55
Cr	1.0	1.0	0.38	0.13
Cu	1.0	1.0	1.0	1.0
Zn	1.0	1.0	0.90	1.0
As	0.87	0.58	0.97	0.19
Ag	0.33	0.99	0.38	0.99
Al	0.73	0.45	0.67	0.60
Bi	0.95	0.13	0.26	0.26
Sn	0.21	0.072	0.24	0.38
CB-153	1.0	1.0	1.0	0.46
DDE	1.0	1.0	1.0	0.44
$\gamma$ -HCH	0.99	0.96	1.0	1.0
HCB	1.0	1.0	1.0	1.0
TCDD-eqv (PCDD/PCDF)	-	0.59	0.75	1.0
PFOS	0.98	-	-	0.97
BDE-47	0.63	-	1.0	-

## **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 (hexa-/heptabromodiphenylether, tetra-/pentabromodiphenylether, chlordecone, hexabromobiphenyl, lindane,  $\alpha$ - and  $\beta$  – hexachlorocyclohexane, pentachlorobenzene 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 naphthalenes, hexachlorobutadiene, and pentachlorophenol) ([www.pops.int](http://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](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](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](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](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](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](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 (2008/105/EC) 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 Lepper (2005). Substance EQS Data Sheets (SDS) contains background information regarding the development of EQS (available at CIRCAS webpage). Here, data from ecotoxicological studies are compiled to Specific Quality Standards (QS), derived for water, sediment, biota ( $QS_{\text{biota}}$  set to protect for secondary poisoning in predators), and human health ( $QS_{\text{hh}}$ ). So far, EQS have mainly been available for monitoring in water, and only a handful EQS have been available for biological samples.

Additional EQSs for several substances have recently been proposed by the EC, also for monitoring in biota (COM 876, 2011), but they have not yet been adopted and may change.

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.

Group of substance		Target levels	
		Fish ( $\mu\text{g}/\text{kg ww}$ )	Background reference
Metals	Cadmium	160	QS <sub>biota</sub>
	Lead	1000	QS <sub>biota</sub>
	Mercury	20	EQS
	Nickel	730	QS <sub>biota</sub>
Pesticides	DDE (p,p')	5	EAC
	HCH (incl. lindane)	2.6/26	IVL
PCBs	CB-28	64 lw	EAC
	CB-52	108 lw	EAC
	CB-101	120 lw	EAC
	CB-105		EAC
	CB-118	24 lw	EAC
	CB-138	316 lw	EAC
	CB-153	1600 lw	EAC
	CB-156		EAC
	CB-180	480 lw	EAC
Other	BDEs (congeners 28, 47, 99, 100, 153, and 154)	0.0085	EQS
	HBCDD	167	EQS
	$\Sigma$ PCDDs+PCDFs	0.0035	EQS
	HCB	10	EQS
	PFOS	9.1	EQS

## 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  $\mu\text{g}/\text{kg}$  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:  $QS_{biota}$*

### **10.1.3 Mercury**

The EQS 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: EQS*

### **10.1.4 Nickel**

There is no EQS or EAC developed for nickel. The  $QS_{biota}$  is set at 0.73 mg/kg prey tissue wet weight. The  $QS_{hh}$  is set at 0.67 mg/kg fishery product wet weight. There is no EC foodstuff regulation developed for nickel.

*Selected target level:  $QS_{biota}$*

## **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  $\gamma$ HCH 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 draft EQS for concentrations of sumBDEs is set at 0.0085 µg/kg wet weight. The EQS proposal document (EC, proposal for a Directive 31/1 2012) does not state for which compartment this EQS has been developed. There are no EAC or EC foodstuff regulation developed for BDEs. The EQS is based on QS set for human health.

*Selected target level: proposed EQS*

### **10.4.2 HBCDD**

The draft EQS for concentrations of HBCDD is based on biota and set at 167 µg/kg fresh weight. There are no EAC or EC foodstuff regulation developed for HBCDD.

*Selected target level: proposed EQS*

## **10.5 Other**

### **10.5.1 Dioxins, furans and dioxin-like PCBs.**

The EQS for concentrations of dioxins is based on human health and set at  $\Sigma$  PCDDs+PCDFs: 0.0035 µgWHO05-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. poasn.

*Selected target level: proposed EQS*

### **10.5.2 HCB**

The EQS for HCB is based on human health,  $QS_{hh}$  and set at 10 µg/kg fishery product wet weight. There is no EC foodstuff regulation developed for HCB.

*Selected target level: EQS*

### **10.5.3 PFOS**

The draft EQS 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 HBCDD.

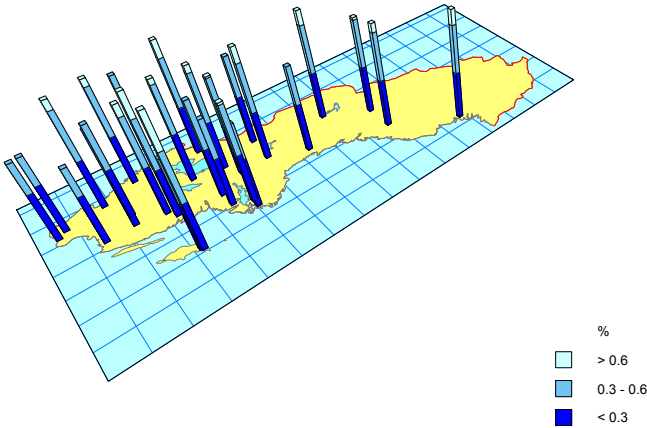
*Selected target level: proposed EQS*

# 11 Biological variables

## 11.1 Results

### 11.1.1 Spatial Variation

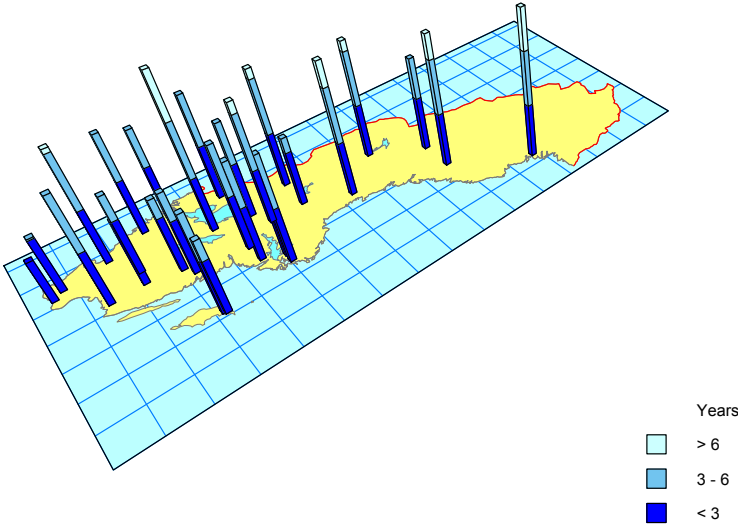
Fat %, perch muscle



TISS - 12.10.16 10:31, FAT

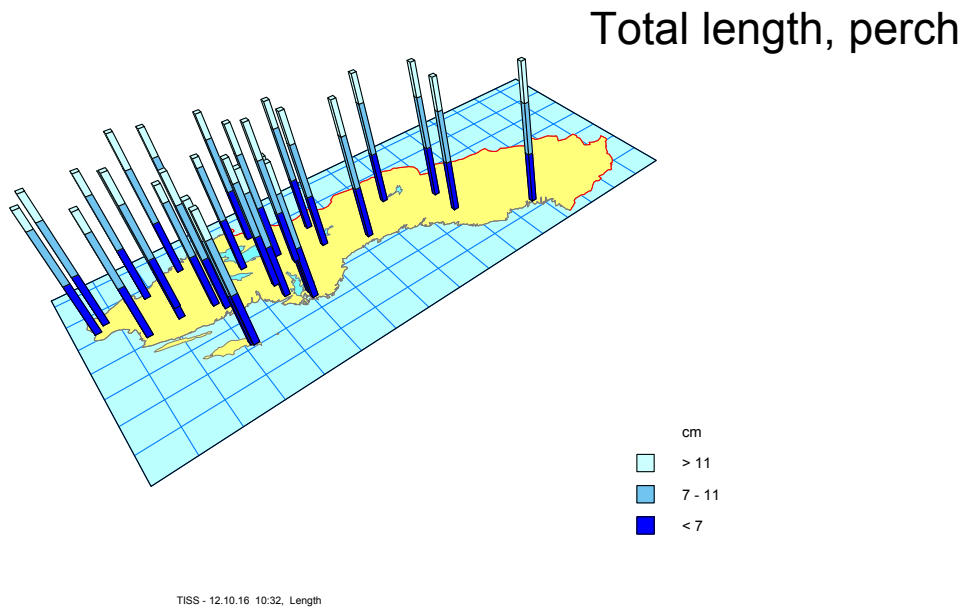
Figure 11.1. Spatial variation in mean fat percentage in perch muscle.

Age, perch

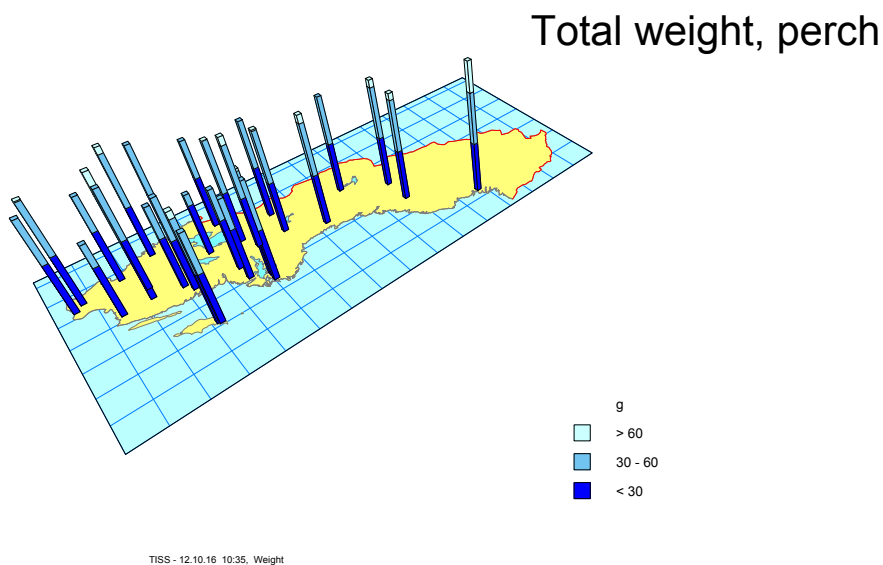


TISS - 12.10.16 10:31, Age

Figure 11.2. Spatial variation in mean age (year) in perch.



**Figure 11.3.** Spatial variation in mean total length (cm) in perch.



**Figure 11.4.** Spatial variation in mean total weight (g) 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 Bästeträsk (0.82%) in Gotland and the lowest (0.47%) in Lake Sännen in Blekinge County and in Lake Krankesjön in Skåne 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).

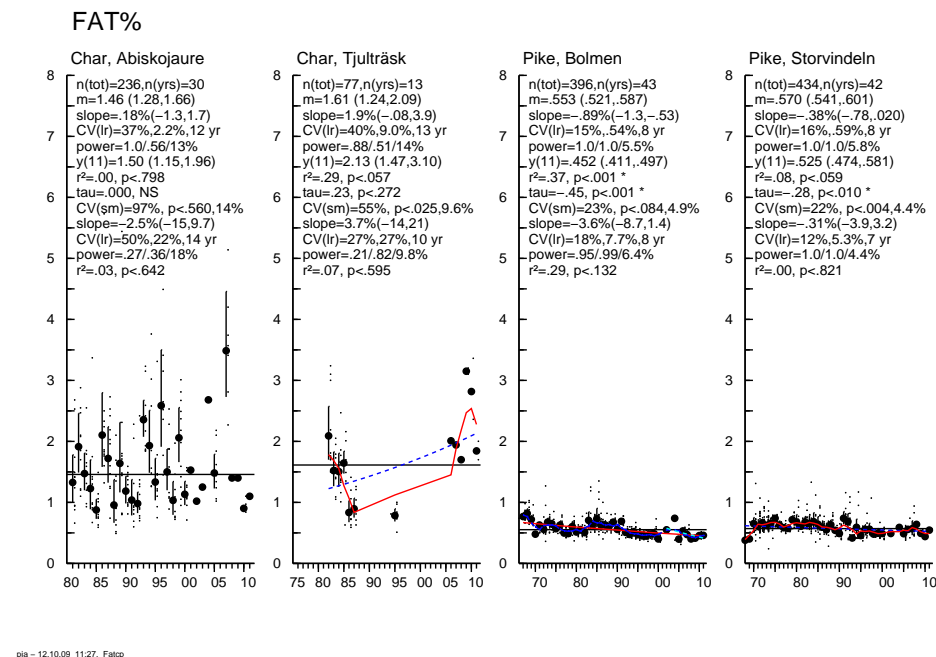
Some variation is seen for the total weight but no clear spatial pattern is observed (Fig. 11.4).

### 11.1.2 Temporal variation

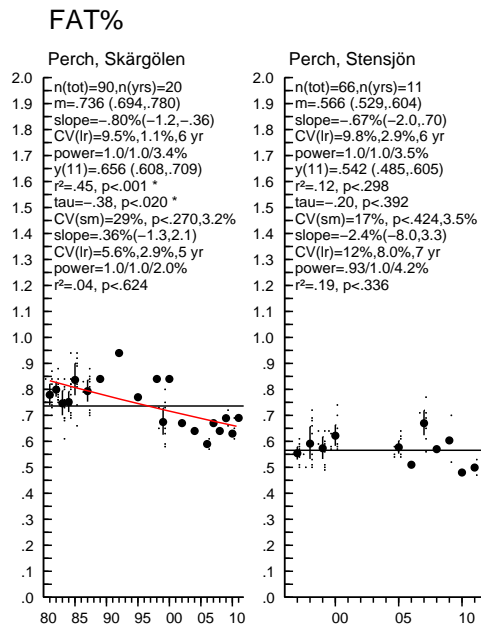
Fat content in pike from Lake Bolmen shows significant decreasing trends during the time period 1967/68 – 2011 (Fig. 11.5), while no trend was detected for pike in Lake Storvindeln. The annual decrease was 0.89%. No such trends could be detected in arctic char from Lake Abiskojaure and Lake Tjulträsk during the somewhat shorter monitoring period (1980/82 – 2011).

The fat content in perch from Lake Skärgölen (Fig.11.6) shows a significant decreasing trend of 0.80% per year during the time period 1980-2011.

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).



plg - 12.10.09 12:54, FATp

**Figure 11.6.** Fat content in perch muscle (Lake Skärgölen and Lake Stensjön).

## 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 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.

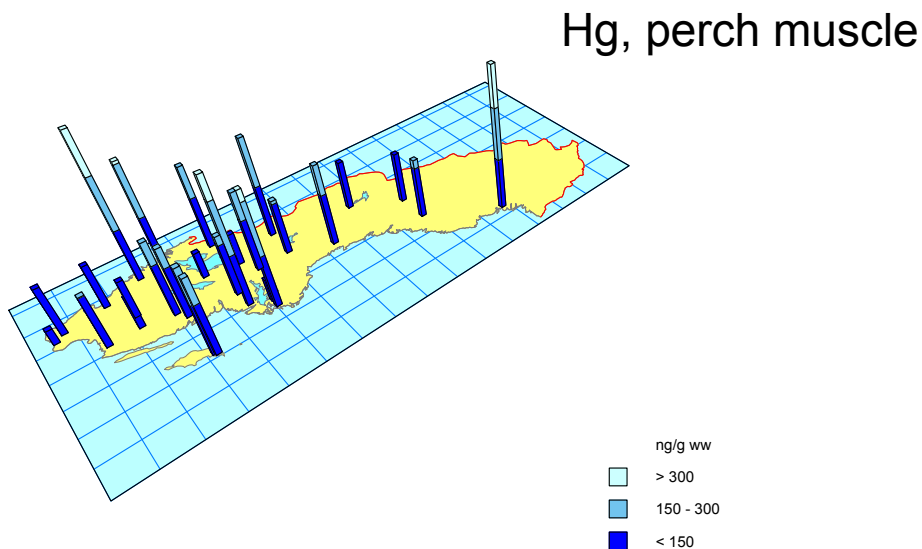
According to a governmental proposition (1993/94:163), the aim was that all mercury usage in Sweden should have ceased by 2000.

### 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



TISS - 12.10.22 15:10, Hg

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

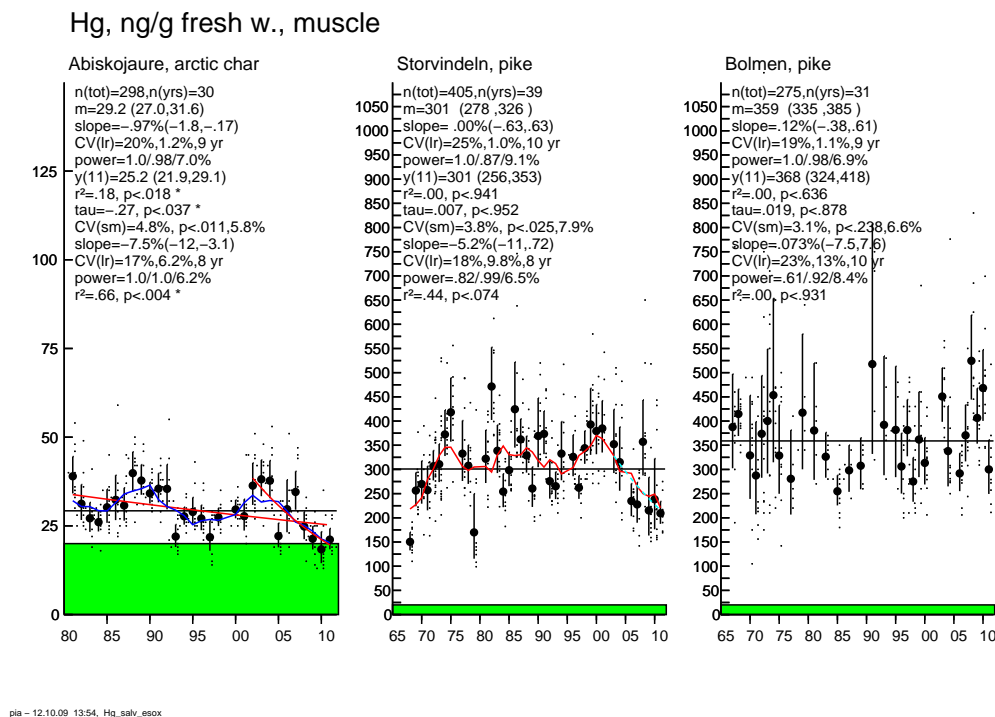
The highest concentration of Hg was found in perch from Lilla Öresjön (419 ng/g wet weight) close to Gothenburg and in Lake Brännträsket (417 ng/g wet weight) in Norrbotten County in 2009-2011. The lowest concentration of Hg (42 ng/g wet weight) in perch muscle was from Lake Krageholmssjön in the county 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

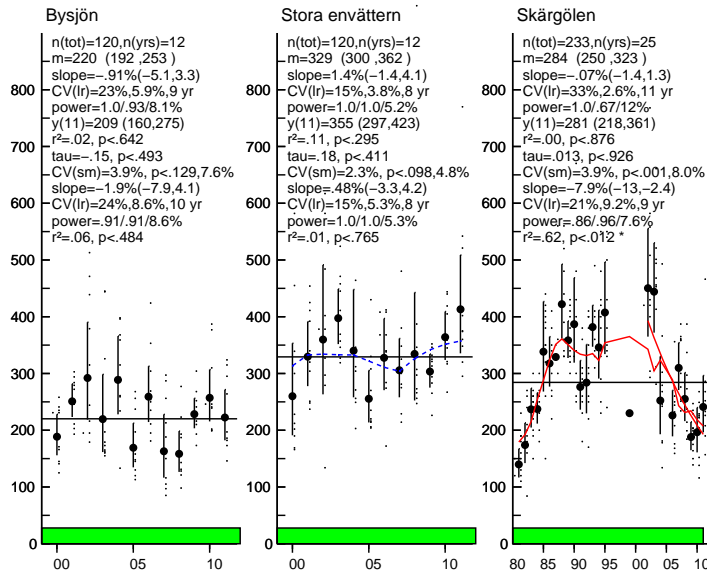
The time series for arctic char from Lake Abiskojaure show a significant decreasing trend for Hg of 0.97% per year for the whole time period (Fig. 12.2). No significant trend is detected for Hg in pike from Lake Bolmen and Lake Storvindeln and in the majority of the perch time series (Fig. 12.2-12.5). However, during the last ten years significant decreasing trends are seen for pike in Lake Storgölen and Lake Hjärtsjön. The decrease varies between 6 and 7.9%. In addition, a majority 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.

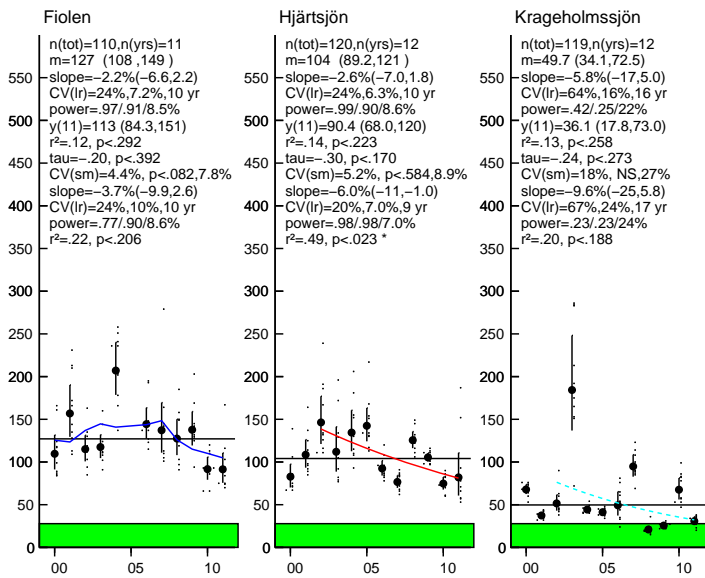
### Hg, ng/g fresh w., perch muscle



pla - 12.10.11 13:24, Hg\_bysj\_senv\_skar

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

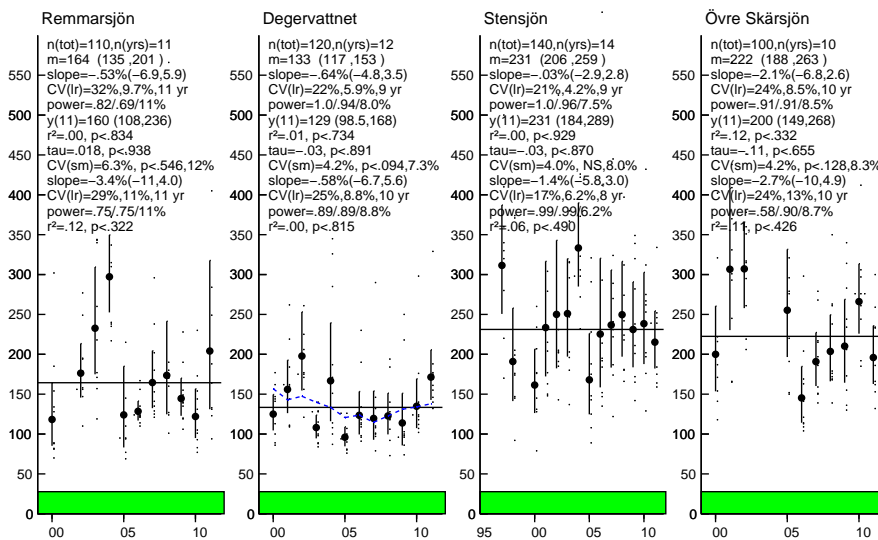
### Hg, ng/g fresh w., perch muscle



pla - 12.10.11 13:24, Hg\_fiol\_hjar\_krag

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

### Hg, ng/g fresh w., perch muscle



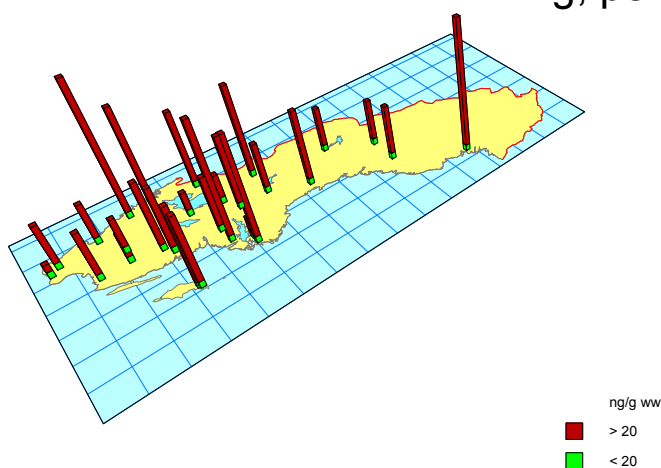
pla - 12.10.09 15:31, Hg\_remm\_degstn\_ovsk

**Figure 12.5.** Mercury concentrations (ng/g fresh weight) in perch muscle from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skårsjön. 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 (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 2011 was below the target level (Fig. 12.2-12.6).

### Hg, perch muscle



TISS - 12.10.16 10:44, Hggv1

**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 (2009-2011) was found in Lake Lilla Öresjön, close to Gothenburg and in Lake Brännträsket in Norrbotten 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 and Lake Hjärtsjön 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 road side 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 *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).

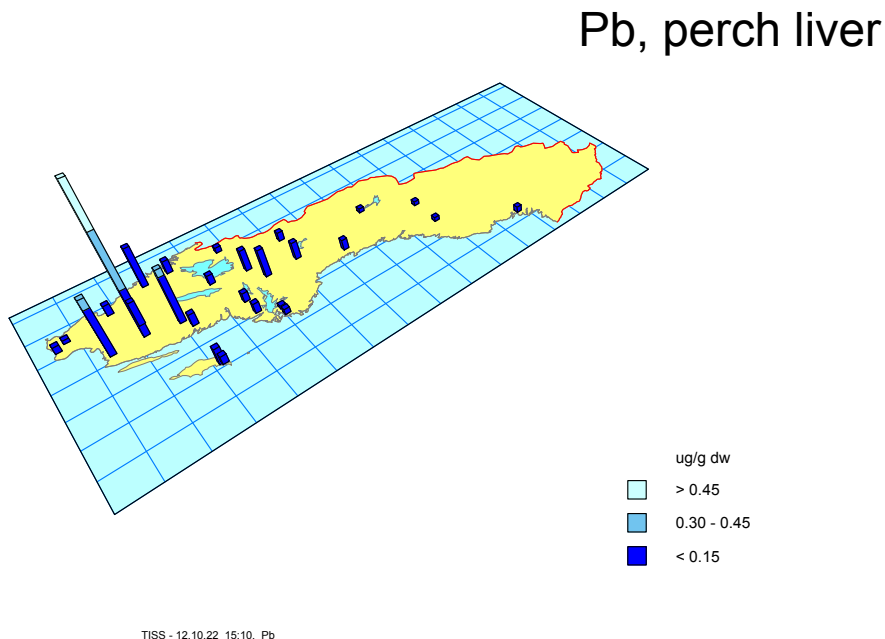
#### **13.1.5 Target Levels**

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 (0.43 ug/g dry weight) was found in perch liver from Lake Hjärtsjön in the county of Småland (2009-2011). 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 2011) (Fig. 13.2).

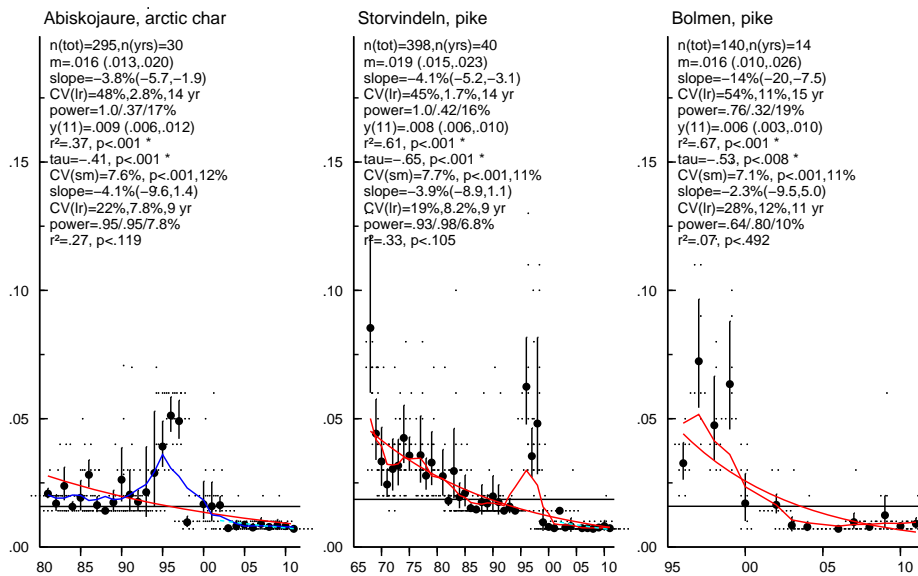
### 13.1.2 Temporal variation

The pike and char time series show significant decreasing trends for Pb of about 4-14% per year in all monitored lakes (Fig. 13.2) from 1969/1980/1998-2011. A significant decreasing trend is also observed in perch from Lake Stensjön (1997-2011) (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.

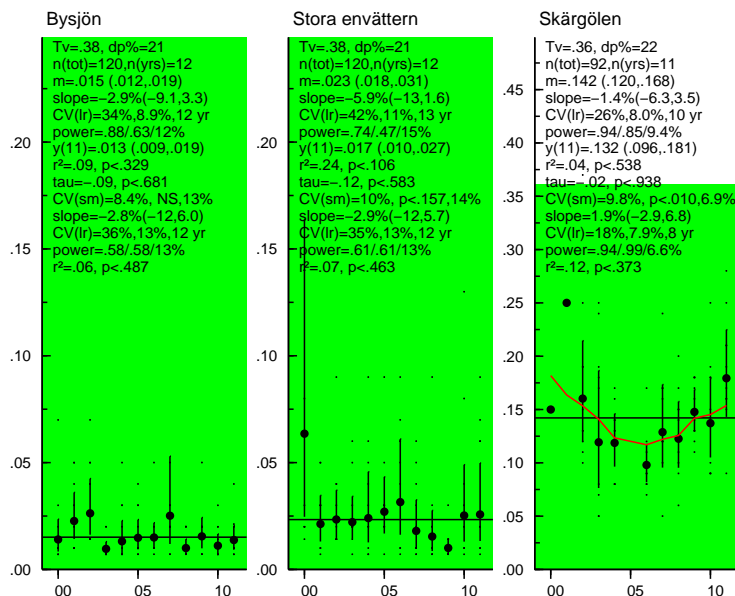
### Pb, µg/g dry w., liver



pla - 12.10.09 15:15, Pb\_salv\_esox

**Figure 13.2.** Lead concentrations (µg/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

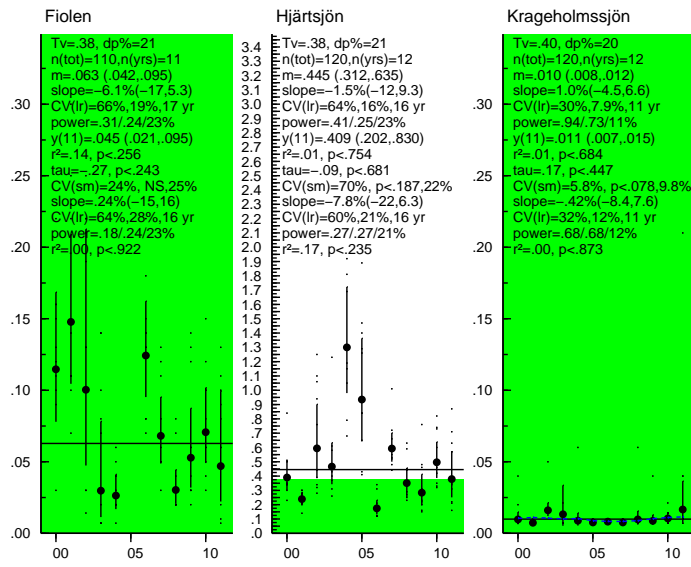
### Pb, µg/g dry w., perch liver



pla - 12.10.10 10:10, Pb\_bysj\_senv\_skar

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

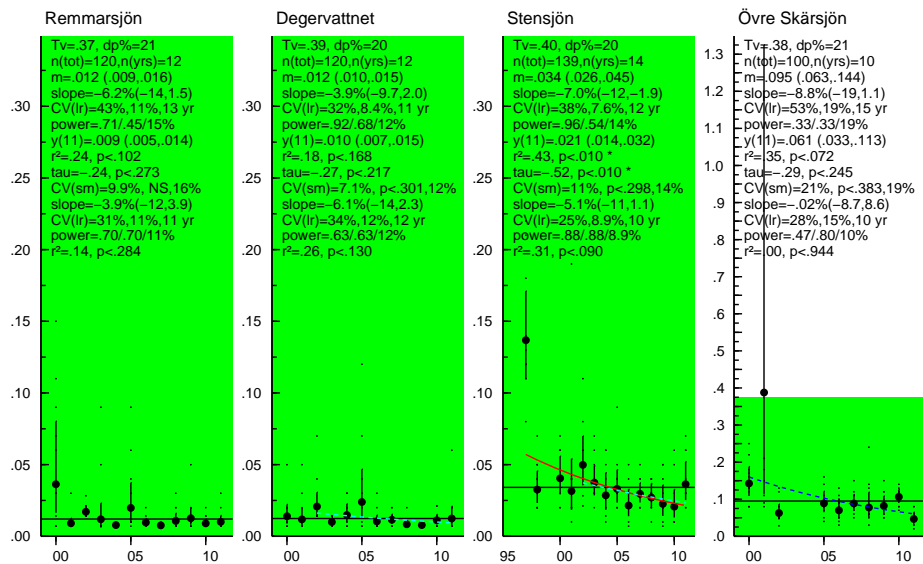
Pb, µg/g dry w., perch liver



piä - 12.10.10 10:16, Pb\_fiol\_hjar\_krag

**Figure 13.4.** Lead concentrations (µg/g dry weight) in perch liver from Lake Fiolen, Lake Hjartsjön and Lake Krageholmssjön. The green area denotes the levels below the suggested target value for lead in fish.

Pb, µg/g dry w., perch liver



piä - 12.10.10 10:29, Pb\_remm\_dege\_sten\_ovsk

**Figure 13.5.** Lead concentrations (µg/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, 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  $QS_{\text{biota}}$  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 2009-2011.

Lead concentrations varied between species and sites; however temporally, Pb concentration has decreased by approximately 4-14% 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.

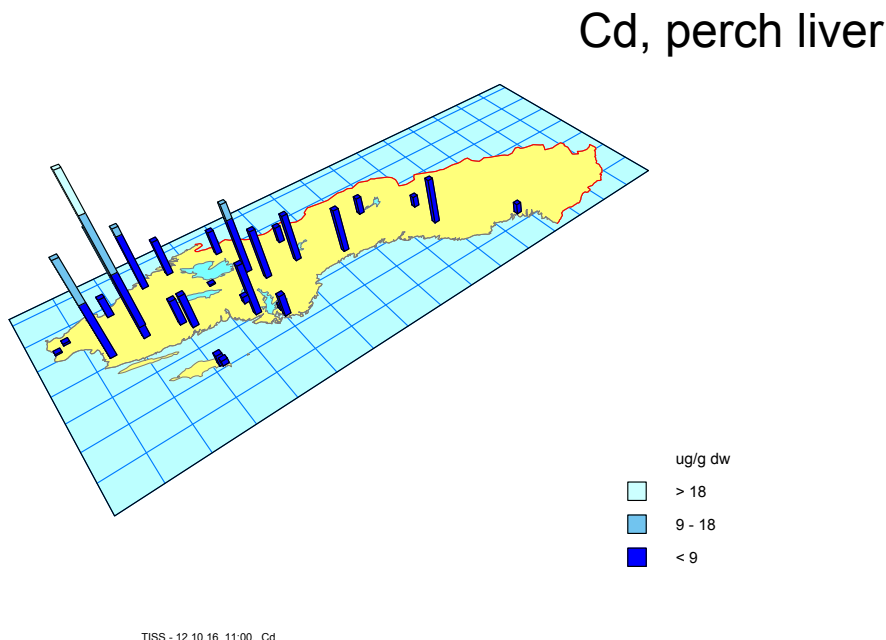
Since 2009, Sweden has followed the cadmium restrictions in fertilizers within REACH.

#### **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 (2009-2011). The lowest concentration of Cd (0.23 ug/g dry weight) in perch liver from Lake Krageholmssjön 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.

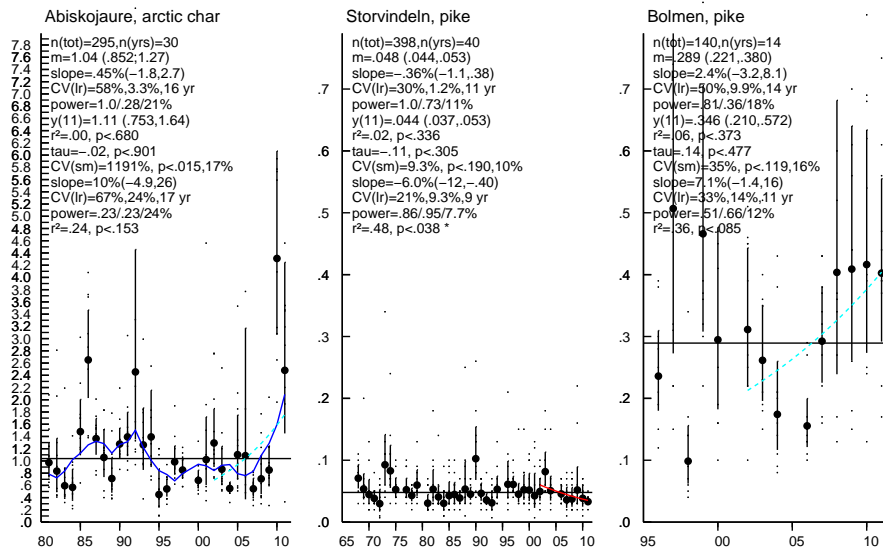
The concentration of Cd varies between species and sites (Fig. 14.1-14.5).

### 14.2.2 Temporal variation

Significant decreasing trends were observed in perch liver from Lake Skärgölen (Fig. 14.3) and Lake Övre Skärsjön (Fig. 14.5) from 2000-2011. The decrease varied between about 6-8% per year. For the last ten years decreasing trends were observed for perch at Lake Stensjön (Fig. 14.5) and for pike at Lake Storvindeln (Fig. 14. 2). The decrease varied between 6-7% per year. No significant trends were observed for the other sites and matrices within the programme (Fig. 14.2-14.5) for Cd.

The number of years required to detect an annual change of 10% for Cd varies between 8-16 years for the pike, char and perch time series.

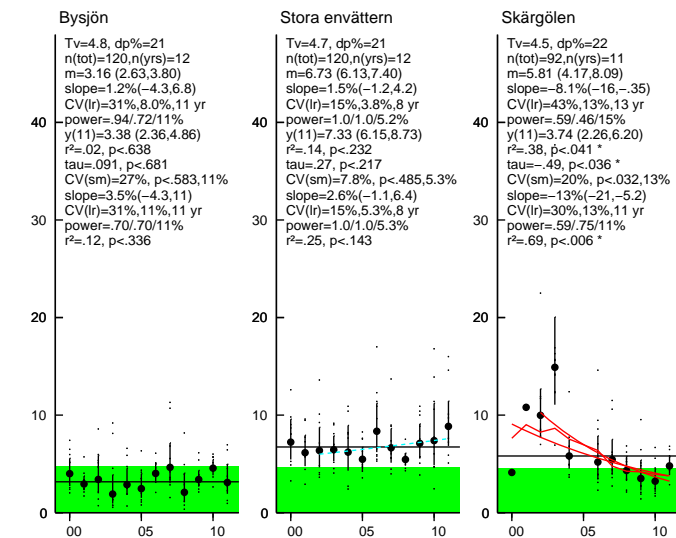
Cd, µg/g dry w., liver



plä - 12.10.10 12:45, Cd\_salv\_esox

**Figure 14.2.** Cadmium concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Cd, µg/g dry w., perch liver

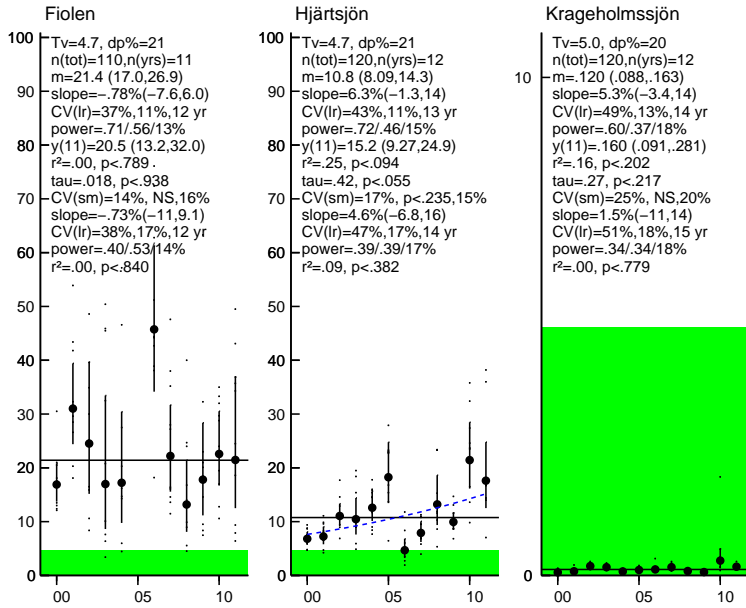


plä - 12.10.10 12:50, Cd\_bysj\_senn\_skar

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



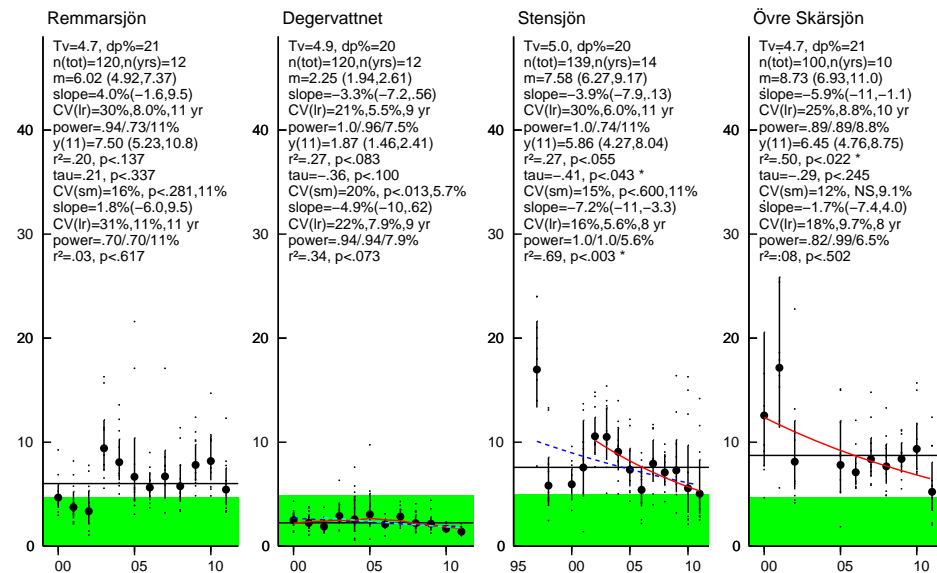
### Cd, µg/g dry w., perch liver



plä - 12.10.10 12:57, Cd\_fiol\_hjar\_krag

**Figure 14.4.** Cadmium 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 cadmium in fish.

### Cd, µg/g dry w., perch liver



plä - 12.10.10 13:01, Cd\_remm\_dege\_sten\_ovsk

**Figure 14.5.** Cadmium concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for cadmium in fish.

### **14.2.3 Comparison to thresholds**

In 50 % of the lakes, Cd concentration in perch is above the suggested target level based on the  $QS_{\text{biota}}$  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 2009-2011.

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

In 50 % 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).

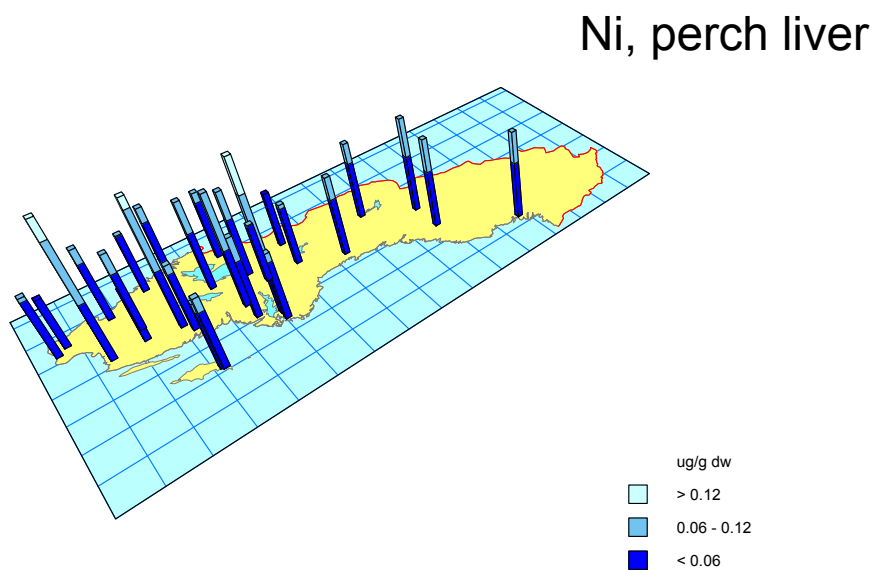
Allergic skin reactions by nickel has been reported as one of the most common causes of allergic contact dermatitis (Andrea, 2005). Erythema, eczema and lichenification can be produced once skin is in contact with nickel. Nickel compounds have been exhibited as carcinogenic in some animals and modes 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  $\mu\text{g}/\text{kg}$  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



TISS - 12.10.16 11:06, Ni

**Figure 15.1.** Spatial variation in concentration ( $\mu\text{g}/\text{g}$  dry weight) of Ni in perch liver.

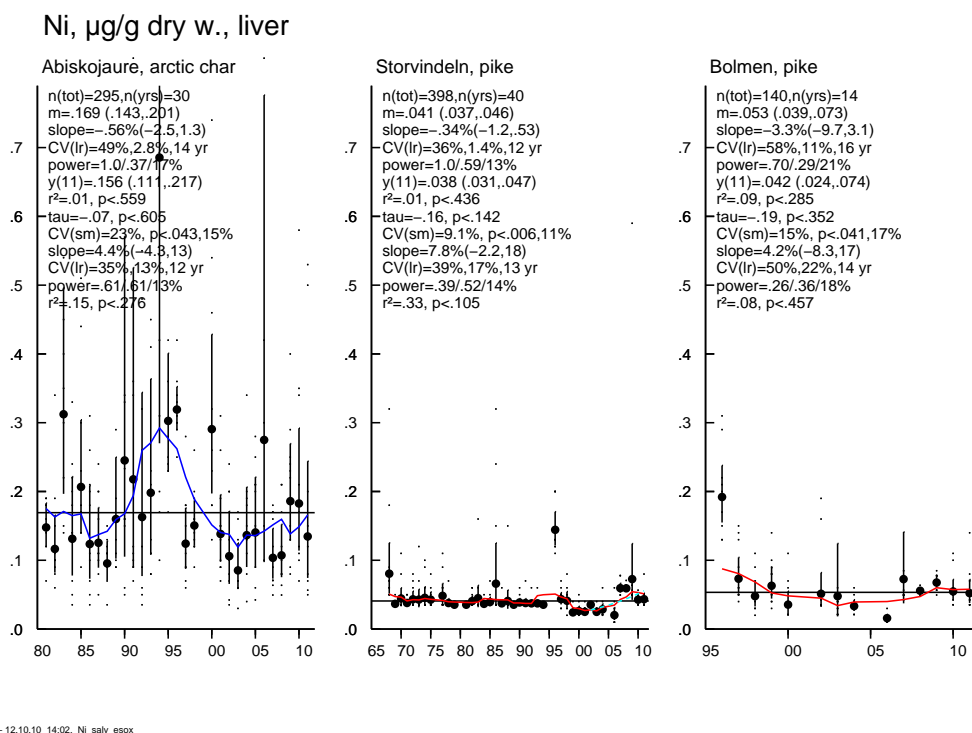
No general spatial pattern was observed for Ni in perch liver. The highest concentration of Ni (0.15 ug/g dry weight) was found in perch liver from Lake Fysingen close to Stockholm in 2009-2011. The lowest concentration of Ni (0.053 ug/g dry weight) in perch liver came from Lake Krankesjön in the county of Skåne (Fig. 15.1).

The concentration of Ni in arctic char from Lake Abiskojaure with a mean concentration of 0.16 ug/g dry weight is 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

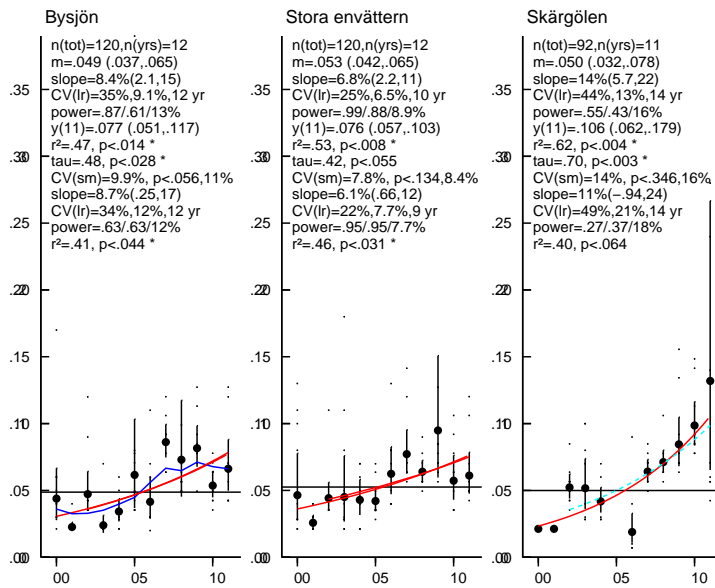
The concentration of nickel in perch liver increased significantly, by about 7-14% per year, in Lake Bysjön, Lake Stora Envättern, Lake Skärgölen and Lake Krageholmssjön (Fig. 15.2-15.3) from 2000-2011. Moreover, a decreasing trend for the last ten years was observed for pike at Lake Degervattnet (Fig. 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 - 16 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).

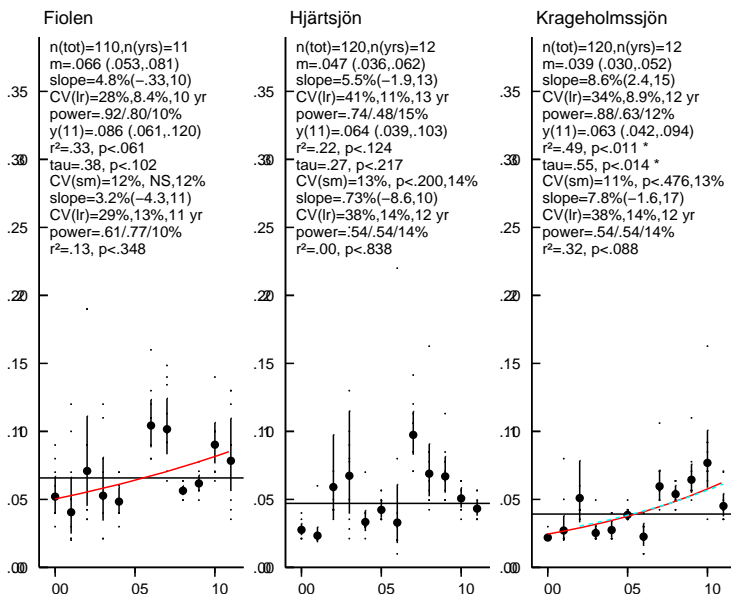
### Ni, µg/g dry w., perch liver



pla - 12.10.11 13:25, Ni\_bysj\_senv\_skar

**Figure 15.3.** Nickel concentrations (µg/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särögölen. The green area denotes the levels below the suggested target value for nickel in fish.

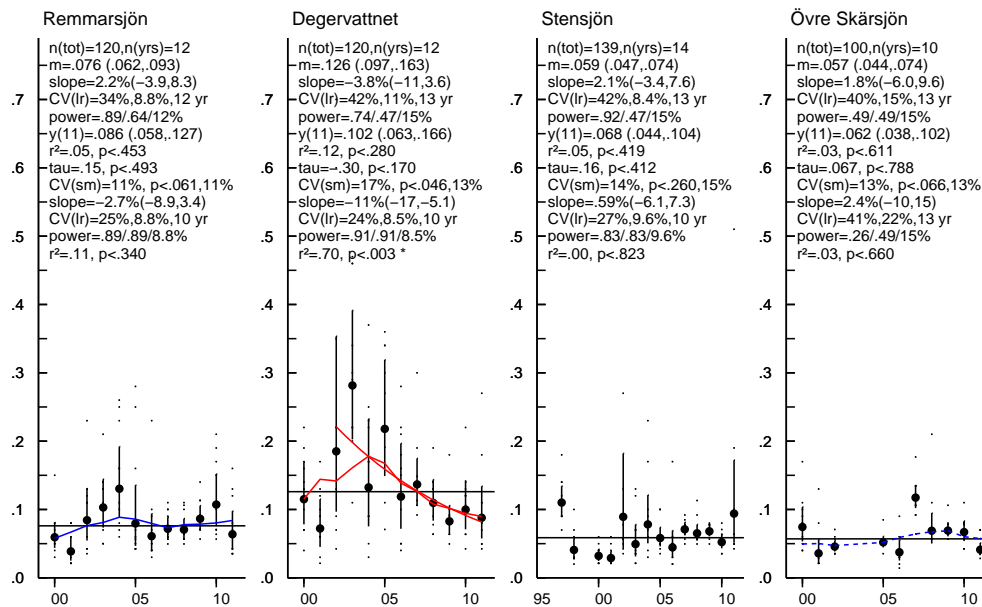
### Ni, µg/g dry w., perch liver



pla - 12.10.11 13:25, Ni\_fiol\_hjar\_krag

**Figure 15.4.** Nickel concentrations (µg/g dry weight) in perch liver from Lake Fiolen, Lake Hjartsjön and Lake Krageholmssjön. The green area denotes the levels below the suggested target value for nickel in fish.

## Ni, µg/g dry w., perch liver



plia - 12.10.11 13:25, Ni\_remm\_dege\_sten\_ovsk

**Figure 15.5.** Nickel concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön. The green area denotes the levels below the suggested target value for nickel in fish.

## 15.3 Summary

The highest concentration of Ni in perch liver was found in Lake Fysingen close to Stockholm in 2009-2011.

Nickel concentrations varied between species and sites and showed a general increasing trend in perch during the last ten years.

# 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 ( $\text{FeCr}_2\text{O}_4$ ). 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  $\text{Cr}^{3+}$  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



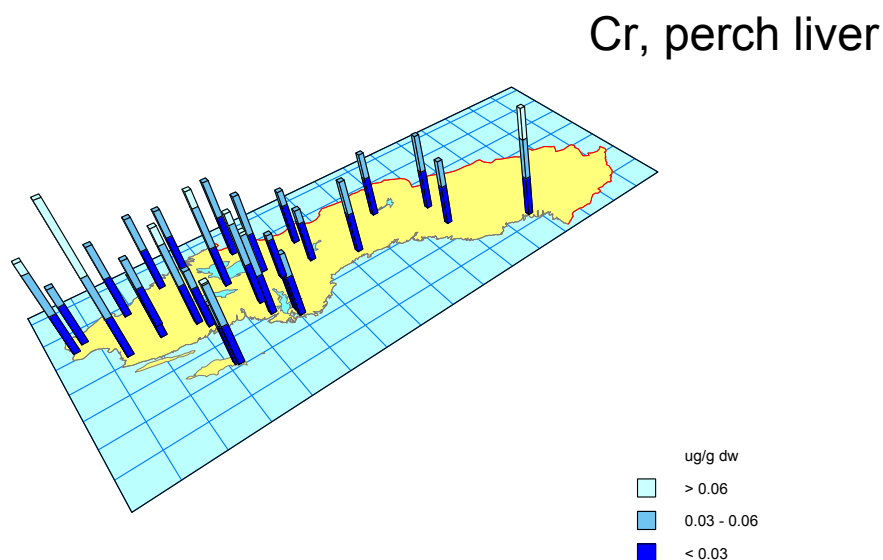
plants and animals, including humans; however, Cr (VI) has been reported to be toxic to bacteria, plants, and animals (Richard and Bourg, 1991). Environmental properties, i.e. hardness, temperature, pH, and salinity of water, in combination with biological factors, i.e. species, life stage, sensitivities 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).

## 16.2 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 concentration of Cr (0.11 ug/g dry weight) was found in perch liver from Lake Sannen in the county of Blekinge in 2009-2011. The lowest concentration of Cr (0.034 ug/g dry weight) found in perch liver came from Lake Fysingen and Lake Övre Skärsjön close to Stockholm (Fig. 16.1).

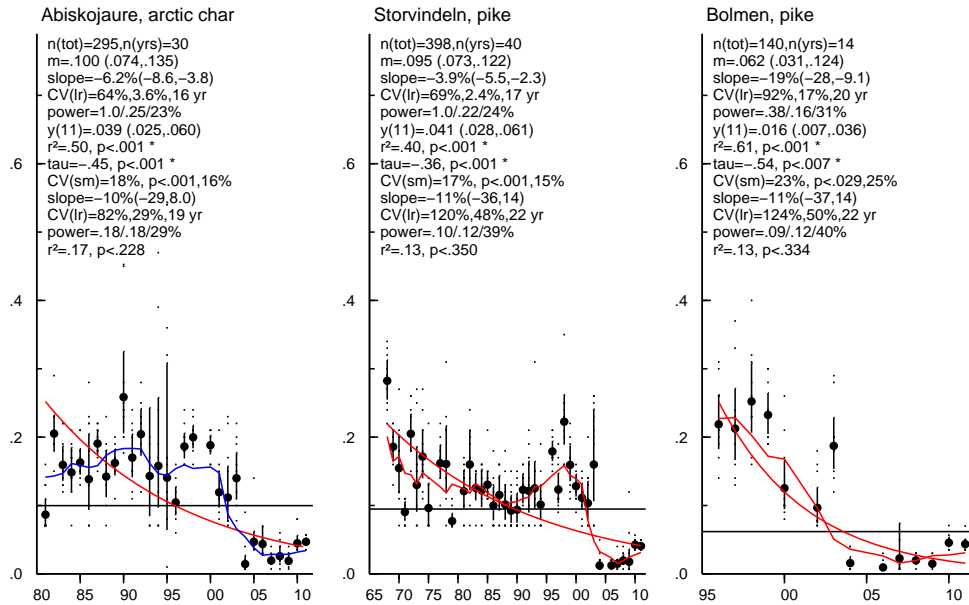
The concentration of Cr in pike from Lake Storvindeln is almost twice as high as in pike from Lake Bolmen (Fig. 16.2).

### 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 14-24 years for the pike, char and perch time series.

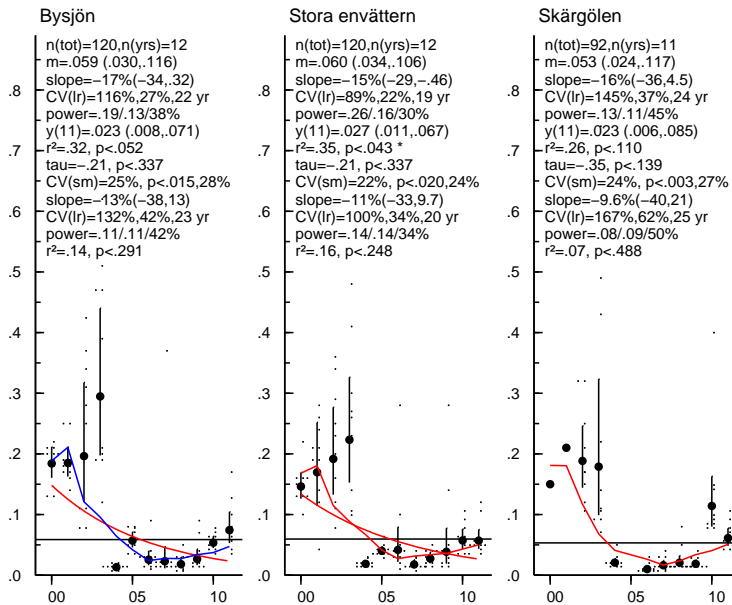
## Cr, µg/g dry w., liver



plä - 12.10.10 14:25, Cr\_saliv\_esox

**Figure 16.2.** Chromium concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

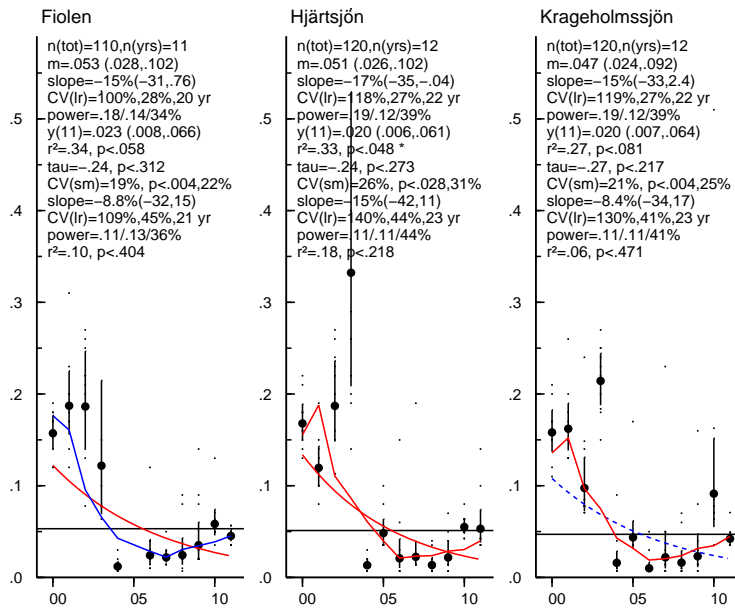
## Cr, µg/g dry w., perch liver



plä - 12.10.11 13:21, Cr\_byssj\_serv\_skar

**Figure 16.3.** Chromium concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särögölen.

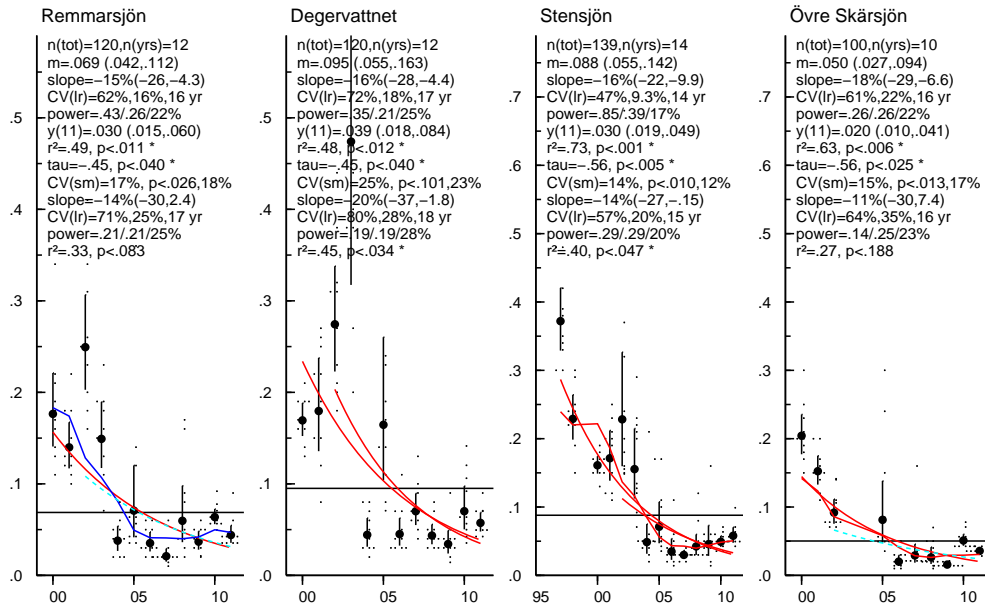
Cr, µg/g dry w., perch liver



pia - 12.10.11 13:21, Cr\_fiol\_hjar\_krag

**Figure 16.4.** Chromium concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.

Cr, µg/g dry w., perch liver



pia - 12.10.11 13:22, Cr\_remm\_dege\_sten\_ovsk

**Figure 16.5.** Chromium concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, 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 in 2009-2011.

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.

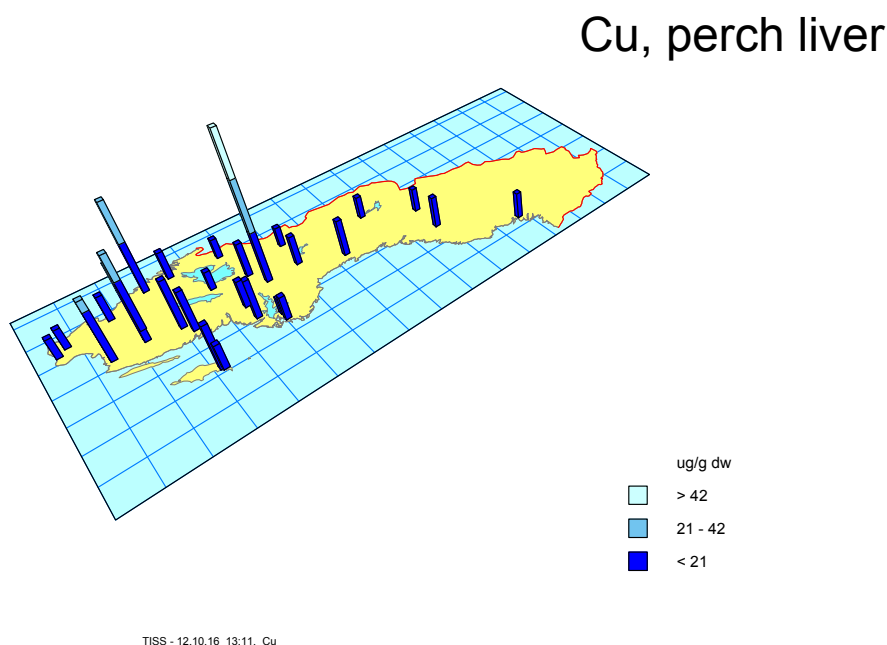
### 17.1.3 Target Levels

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



**Figure 17.1.** Spatial variation in concentration (ug/g dry weight) of Cu in perch liver.

No general spatial pattern was observed for Cu in perch liver. The highest concentration of Cu (60 ug/g dry weight) was found in perch liver from Lake Övre Skärsjön in Västmanland County in 2009-2011. The lowest concentration of Cu (6.5 ug/g dry weight) was found in perch liver from Lake Fysingen close to Stockholm (Fig. 17.1).

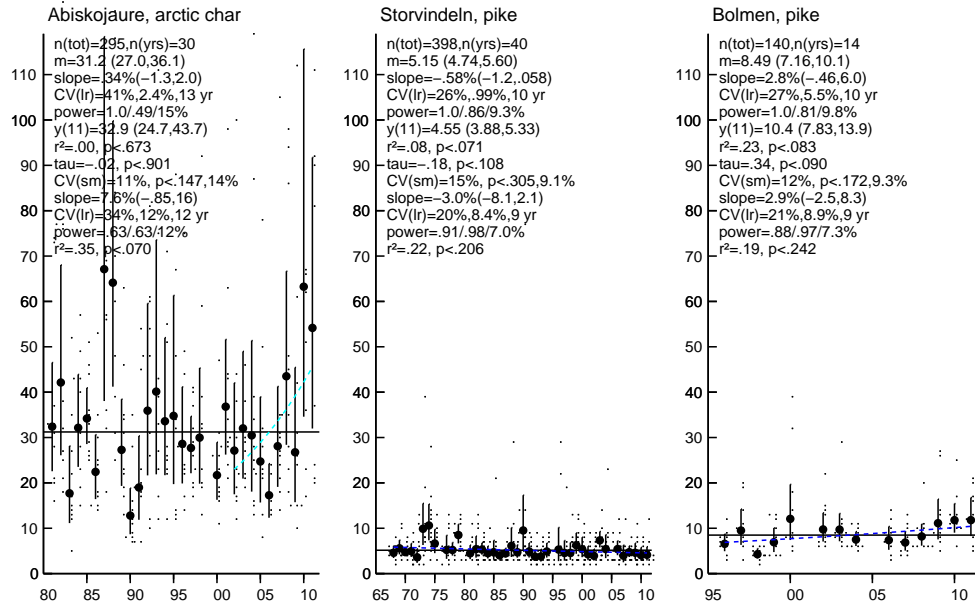
The concentration of Cu in pike from Lake Bolmen is almost twice as high as in pike from Lake Storvindeln (Fig. 17.2).

### 17.2.2 Temporal variation

A significant decreasing trend of 6.3% is observed for copper in perch liver from Lake Bysjön during 2000-2011 (Fig. 17.4). Also, a significant decreasing trend for the last ten years is seen at Stensjön, with an annual decrease of 4.3% (Fig. 17.5). 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.

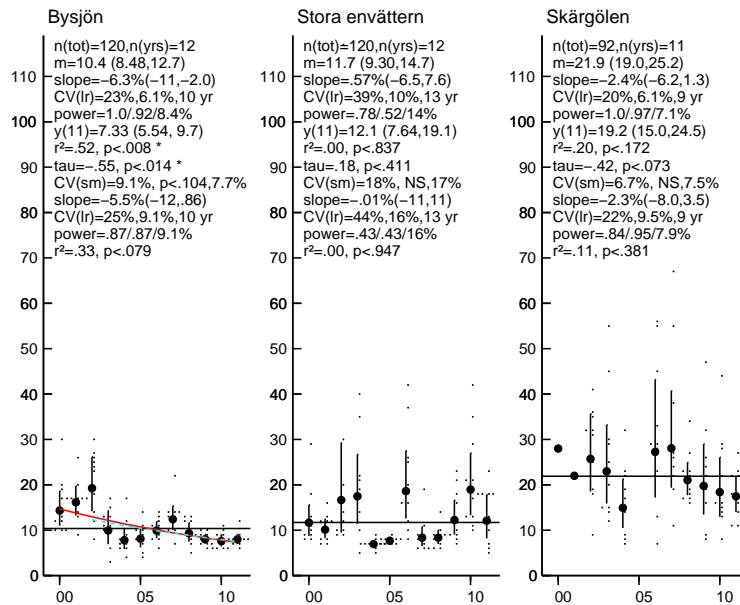
## Cu, µg/g dry w., liver



pia - 12.10.10 15:01, Cu\_saly\_esox

**Figure 17.2.** Copper concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

## Cu, µg/g dry w., perch liver

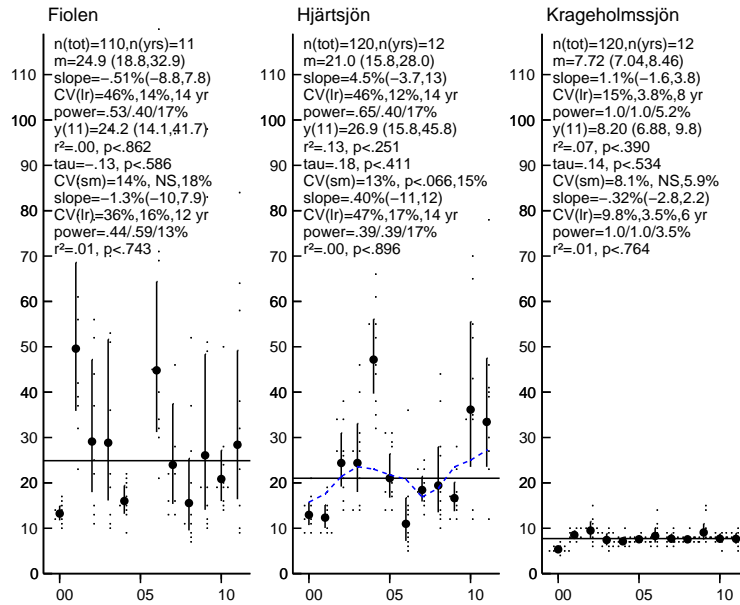


pia - 12.10.11 13:22, Cu\_bysj\_senv\_skar

**Figure 17.3.** Copper concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särögölen.



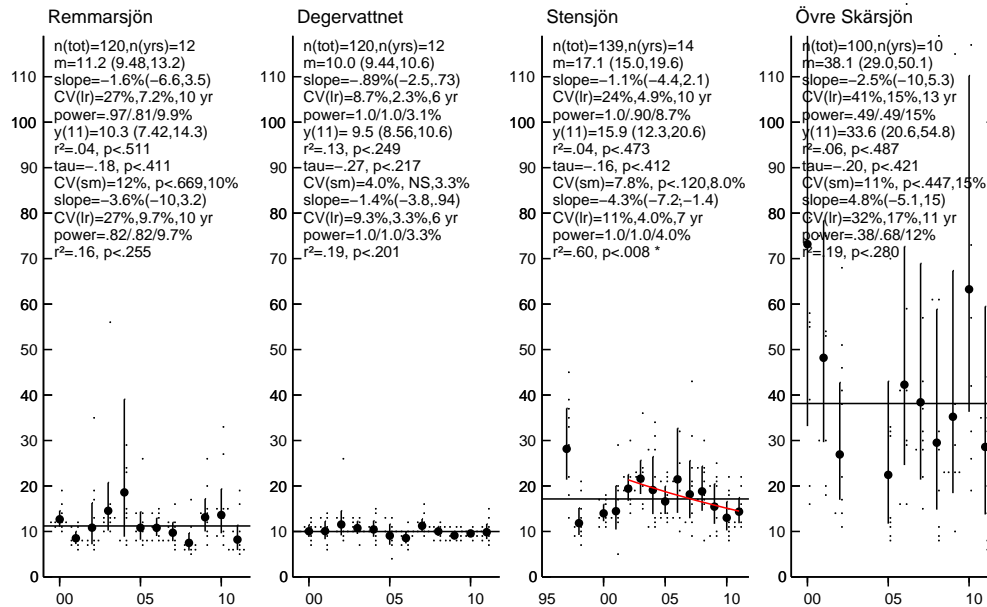
### Cu, µg/g dry w., perch liver



plä - 12.10.11 13:23, Cu\_fiol\_hjar\_krag

**Figure 17.4.** Copper concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.

### Cu, µg/g dry w., perch liver



plä - 12.10.11 13:23, Cu\_remm\_dege\_sten\_ovsk

**Figure 17.5.** Copper concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, 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 2009-2011.

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

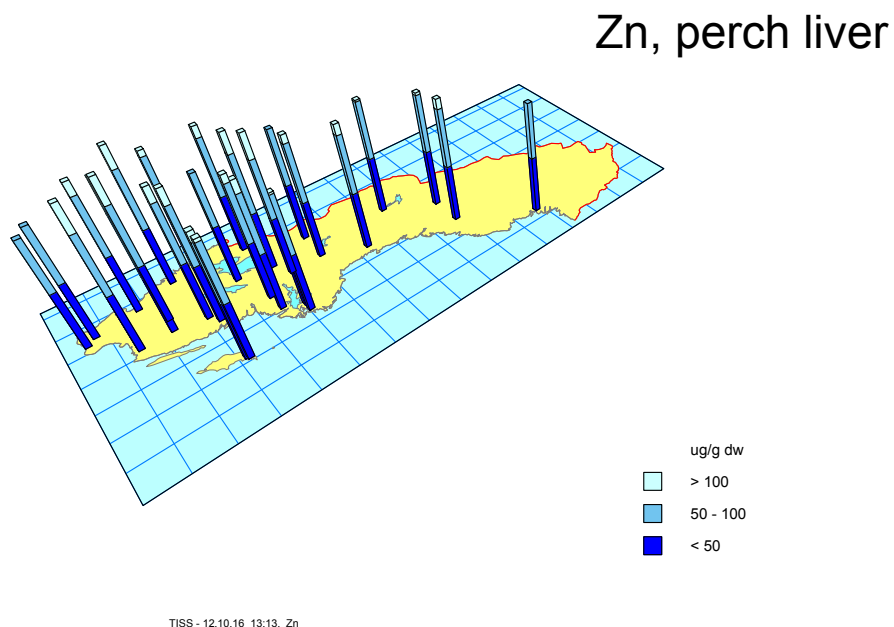
Zinc is present in water, air and soil. In air, zinc is present mostly as small particles that fall to the earth and drain into waterways with precipitation. Most of this zinc ends up settling in sediment at the bottom of water bodies; however some zinc can remain bound to the soil. Dissolved zinc in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

## 18.2 Results

### 18.2.1 Spatial Variation



**Figure 18.1.** Spatial variation in concentration (ug/g dry weight) of Zn in perch liver.

No general spatial pattern was observed for Zn in perch liver. The highest concentration of Zn (127 ug/g dry weight) was found in perch liver from Lake Hjärtsjön in Småland County in 2009-2011. The lowest concentration of Zn (94 ug/g dry weight) came from perch liver from Lake Krageholmssjön in Skåne County (Fig. 18.1).

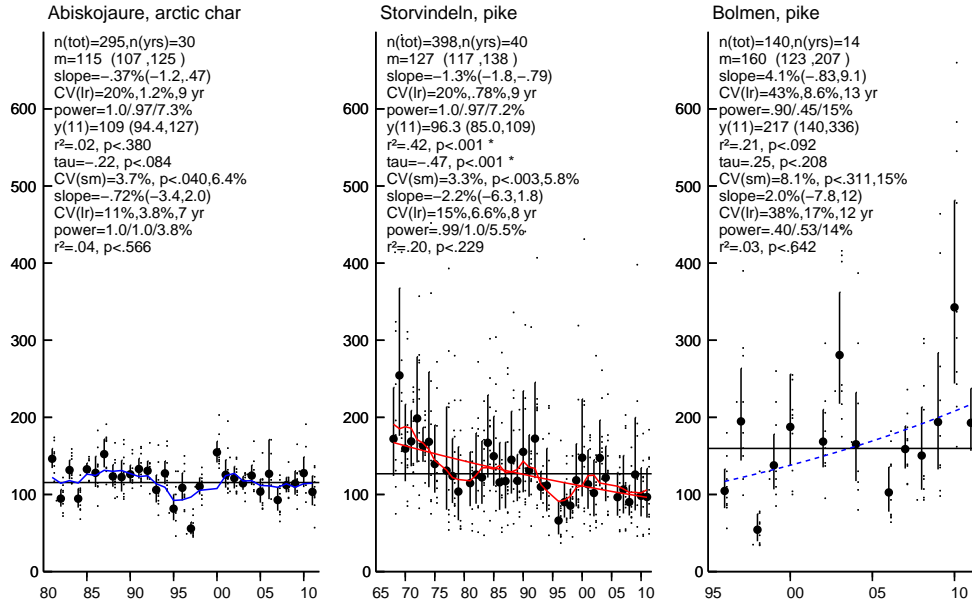
Pike in Lake Bolmen had twice as high concentration (217 ug/g dry weight) in 2011 compared to pike in Lake Storvindeln, arctic char in Lake Abiskojaure and perch from the lakes in the monitoring programme (Fig. 18.2-18.5).

### 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.

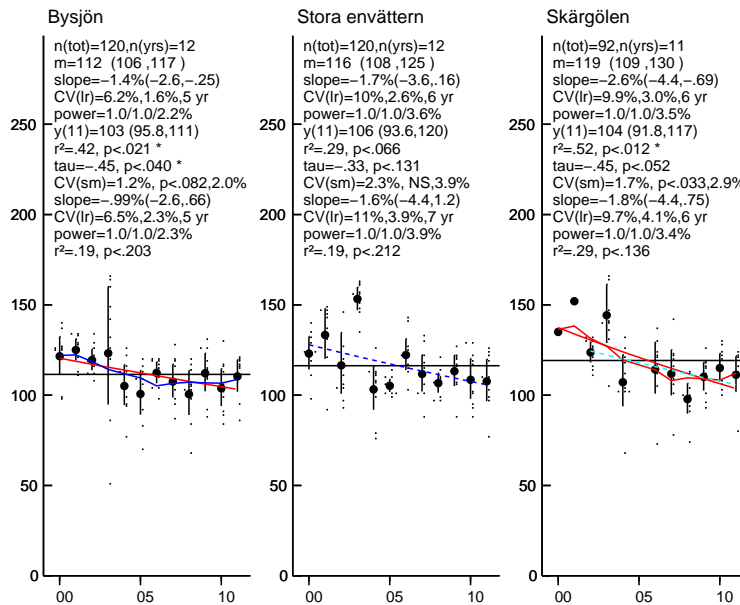
## Zn, µg/g dry w., liver



pia - 12.10.11 09:37, Zn\_sahv\_esox

**Figure 18.2.** Zinc concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

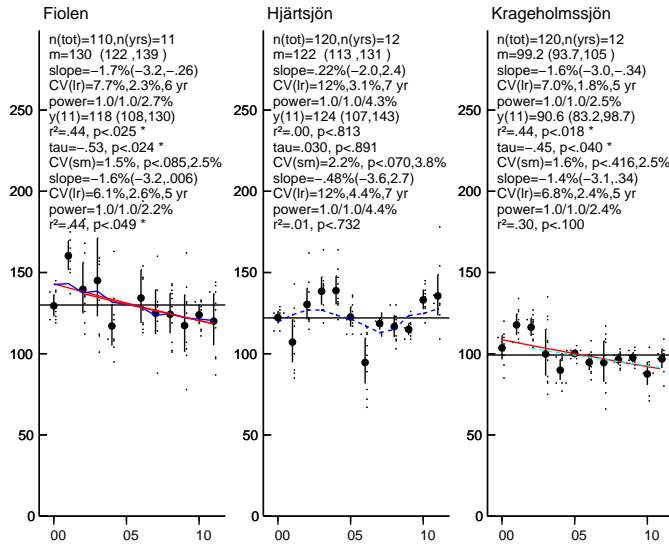
## Zn, µg/g dry w., perch liver



pia - 12.10.11 09:42, Zn\_bysj\_serv\_skar

**Figure 18.3.** Zinc concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen.

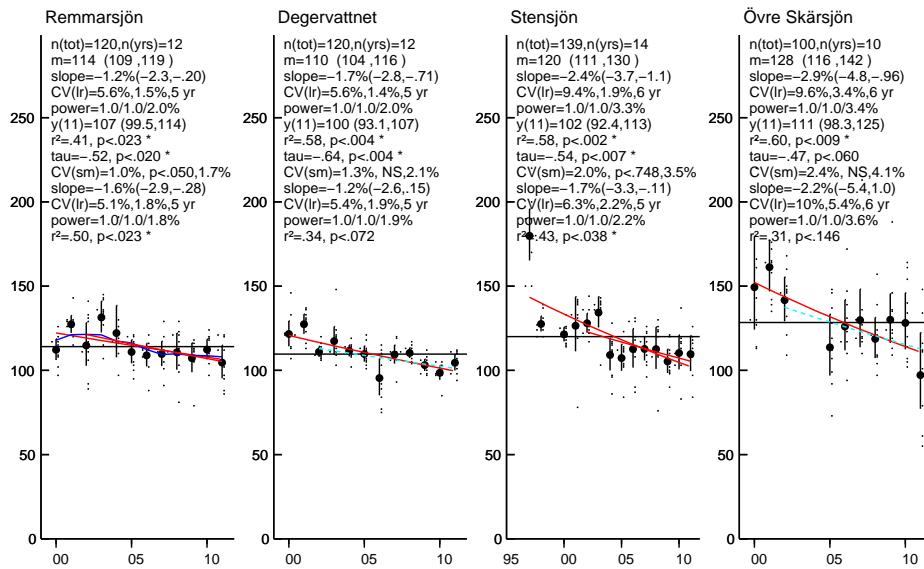
Zn, µg/g dry w., perch liver



pia - 12.10.11 09:44, Zn\_fiol\_hjar\_krag

**Figure 18.4.** Zinc concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjartsjön and Lake Krageholmssjön.

Zn, µg/g dry w., perch liver



pia - 12.10.11 09:47, Zn\_yerm\_deg\_sten\_ovsk

**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 Småland County in 2009-2011. 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 ( $\text{As}_2\text{O}_3$ ) 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 (20<sup>th</sup> 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.

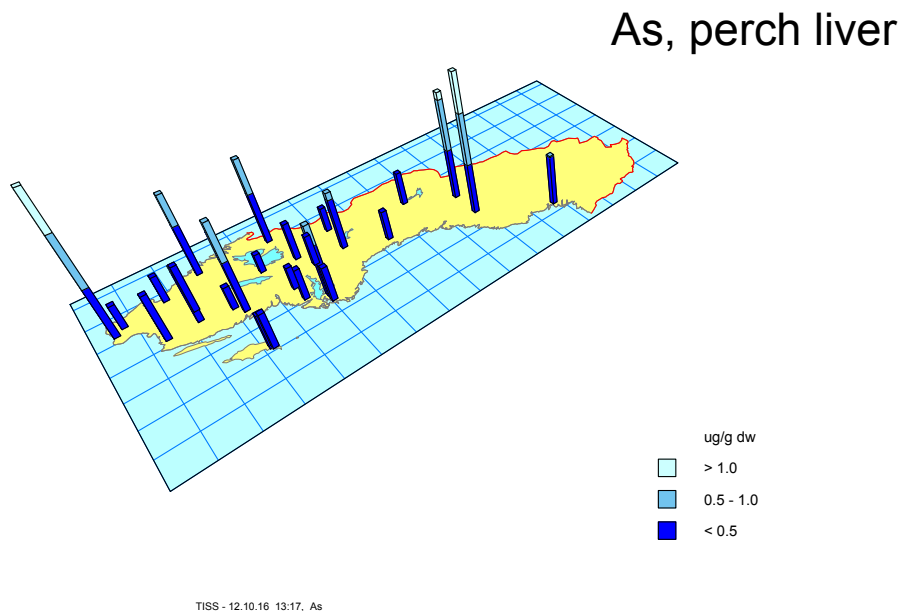
#### 19.1.4 Target Levels

No national target level for biota concerning arsenic is agreed upon.

Concentrations in water are usually  $< 10 \mu\text{g/l}$  (WHO 2001).

## 19.2 Results

### 19.2.1 Spatial Variation



**Figure 19.1.** Spatial variation in concentration (ug/g dry weight) of As in perch liver.

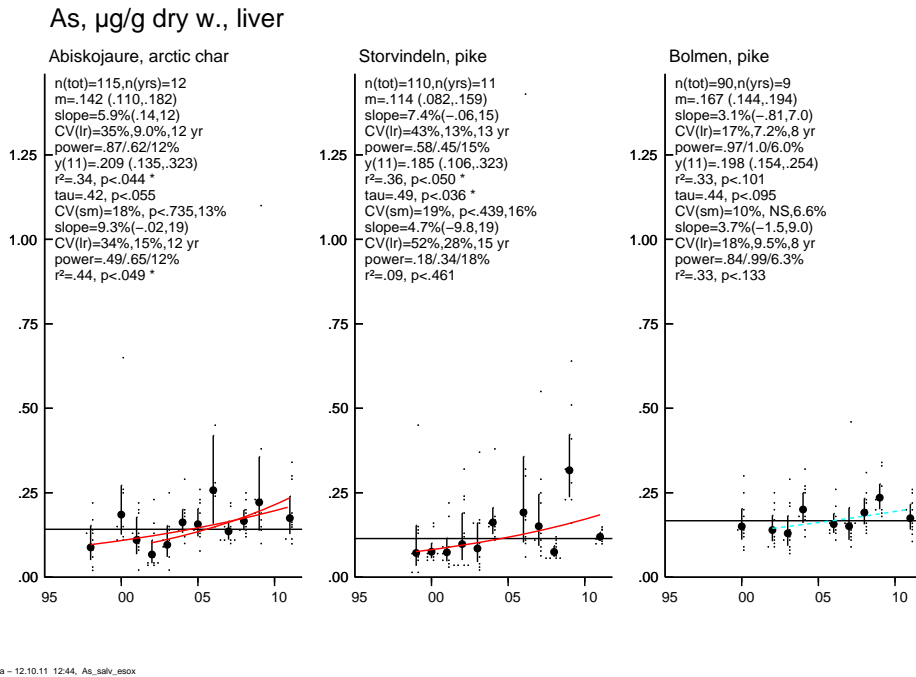
No general spatial pattern was observed for As in perch liver. The highest concentration of As (1.39 ug/g dry weight) was found in perch liver from Lake Krageholmssjön in Skåne County in 2009-2011. The lowest concentration of As (0.18 ug/g dry weight) came from perch liver from Lake Svartsjön in Västra Götaland County (Fig. 19.1).

Arctic char from Lake Abiskojaure and pike from Lake Bolmen and Lake Storvindeln had similar concentrations of As in 2011 (around 0.2 ug/g dry weight) (Fig. 19.2).

## 19.2.2 Temporal variation

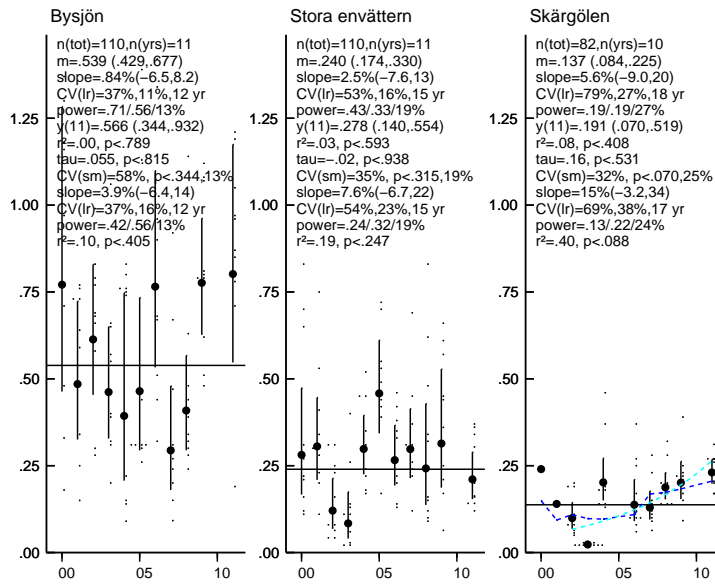
A significant increasing trend was observed for arsenic in pike liver from Lake Storvindeln (about 7%) and in arctic char from Abiskojaure (about 6%) (Fig. 19.2). A significant decreasing trend in perch liver from Lake Övre Skärsjön (8.6%) was found whereas no significant trends were seen for the other 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 (µg/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

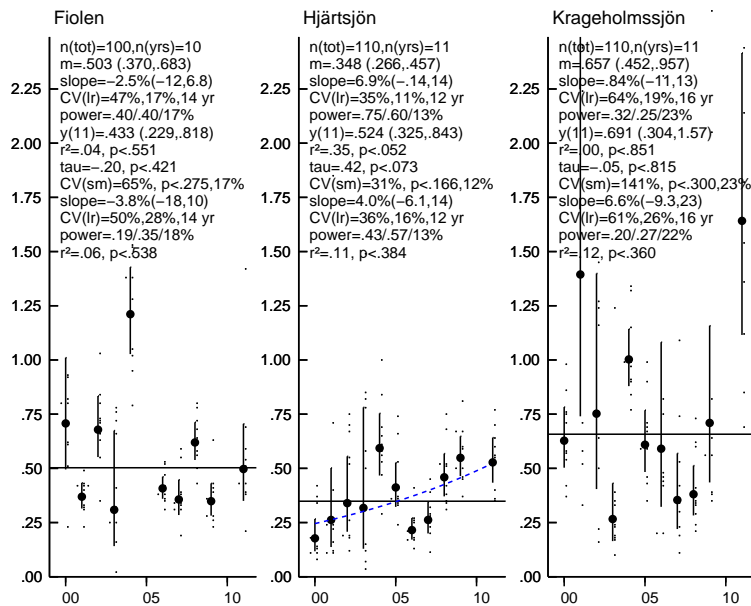
### As, µg/g dry w., perch liver



pla - 12.10.11 12:48, As\_bysj\_senv\_skar

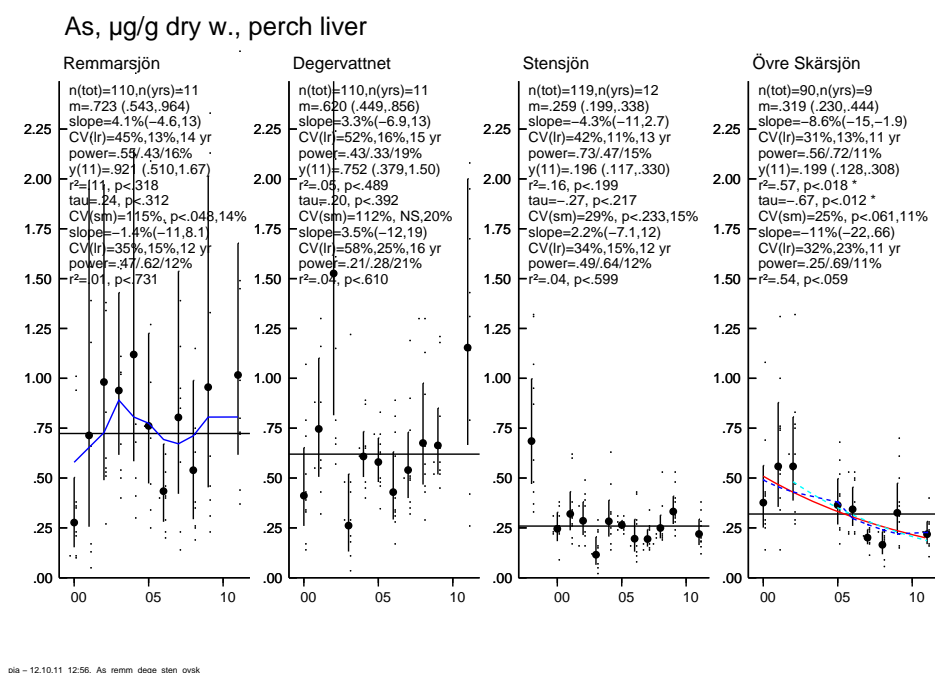
**Figure 19.3.** Arsenic concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Särgölen.

### As, µg/g dry w., perch liver



pla - 12.10.11 12:52, As\_fiol\_hjar\_krag

**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 Skärsjön.

### 19.3 Summary

The highest concentration of As in perch liver was found in Lake Krageholmssjön in Skåne County in 2009-2011.

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 anti-odour 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  $\text{Ag}^0$  and the monovalent ion  $\text{Ag}^+$ . Soluble silver salts are generally more toxic than insoluble salts. Silver as ionic  $\text{Ag}^+$  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.

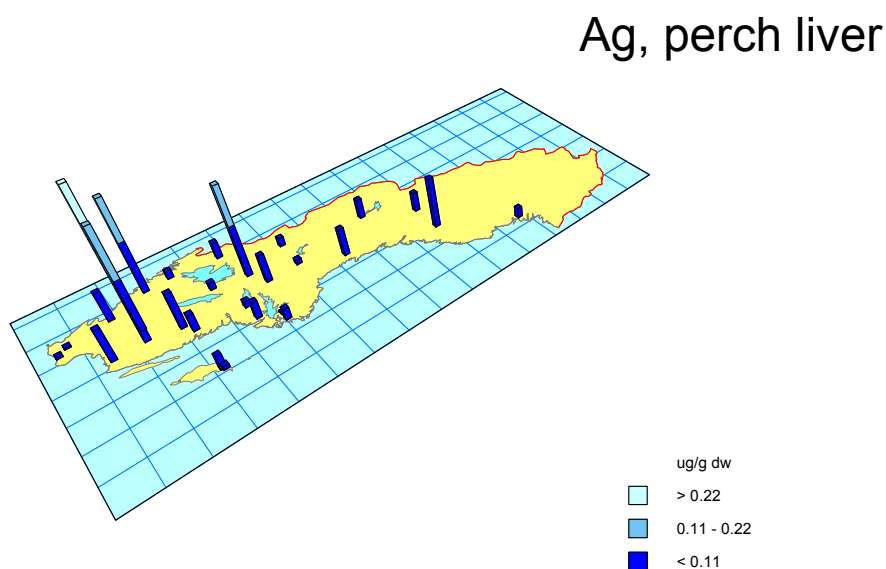
The tolerable daily intake of silver for humans has been set at 5 µg/kg body weight (IRIS 1991). WHO recommendations for the protection of groundwater, reports a critical concentration of 50 µg/l (WHO 2004).

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.

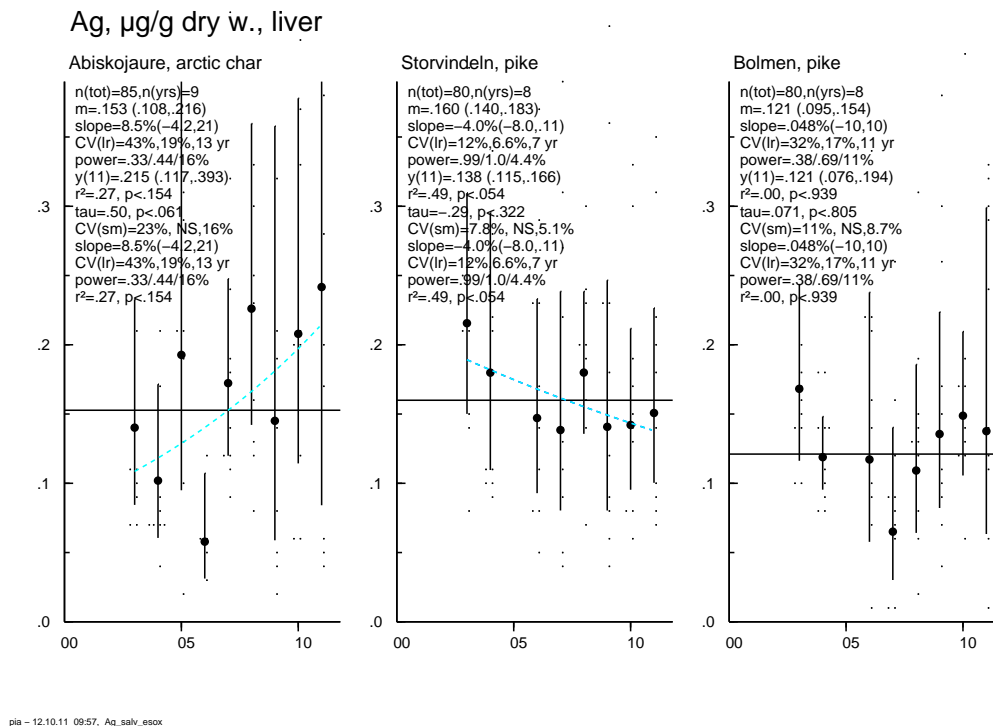
No general spatial pattern was observed for Ag in perch liver. However, a few lakes had higher concentrations compared to the rest of the lakes. The highest concentration of Ag (0.31 ug/g dry weight) was found in perch liver from Lake Hjärtsjön in Småland County in 2009-2011. The lowest concentration of Ag (0.03 ug/g dry weight) came from perch liver from Lake Fysingen close to Stockholm and Lake Krankesjön in Skåne County (Fig. 20.1).

Pike from Lake Storvindeln and Lake Bolmen had similar concentrations of Ag (0.1 ug/g dry weight) and arctic char from Lake Abiskojaure had twice as high concentration in 2011.

### 20.2.2 Temporal variation

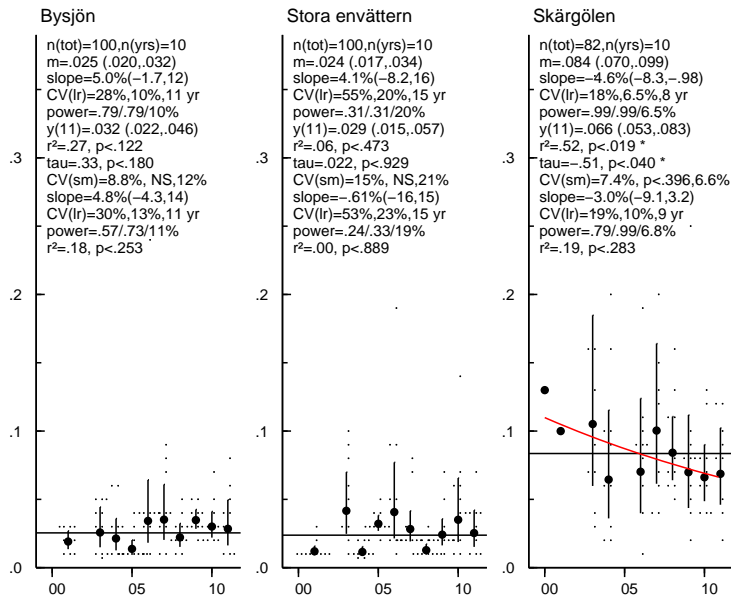
Significant decreasing trends were observed for silver in perch liver from Lake Skärgölen (4.6%) and at Lake Degervattnet for the last ten years (14%), whereas no significant trends were seen for the other matrices and sites within the monitoring programme (Fig. 20.2-20.5).

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 (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

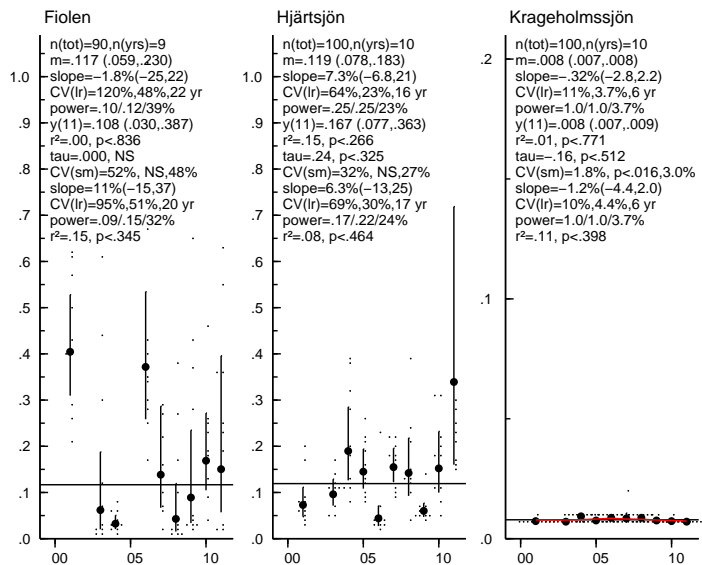
### Ag, µg/g dry w., perch liver



pla - 12.10.11 10:02, Ag\_bysj\_serv\_skar

**Figure 20.3.** Silver concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.

### Ag, µg/g dry w., perch liver

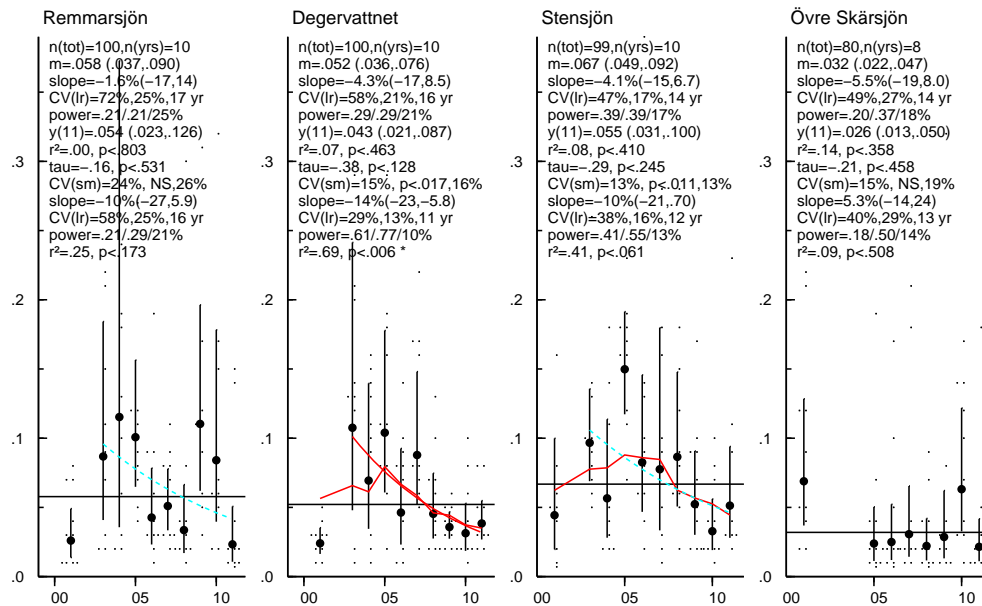


pla - 12.10.11 10:12, Ag\_fiol\_hjar\_krag

**Figure 20.4.** Silver concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjartsjön and Lake Krageholmssjön.



## Ag, µg/g dry w., perch liver



plä - 12.10.11 10:16, Ag\_remm\_dege\_sten\_ovsk

**Figure 20.5.** Silver concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, 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 2009-2011.

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  $^{27}\text{Al}$  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  $\text{pH} < 5$  (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

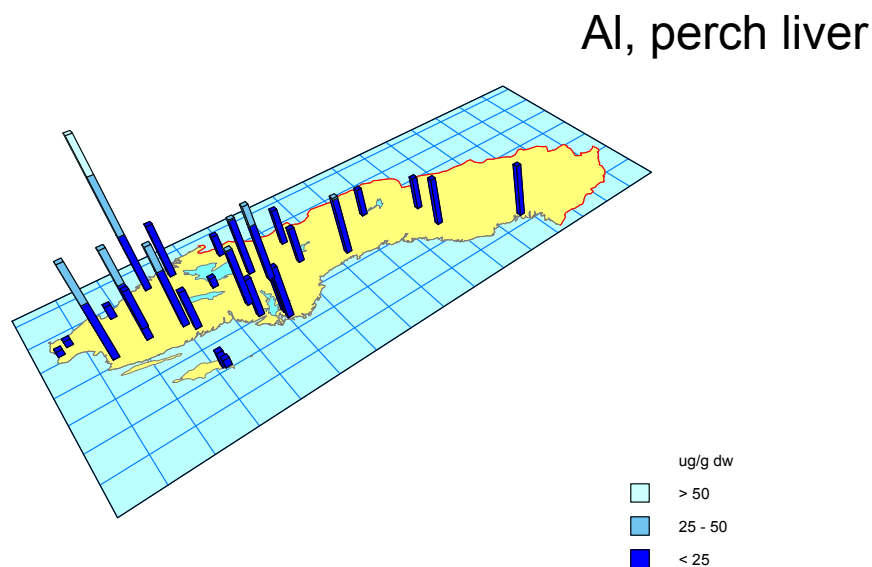
The World Health Organization on esthetic grounds specifies that aluminium concentrations in tap water should not exceed 200 µg/l (Priest, 2005).

#### 21.1.5 Target Levels

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

### 21.2 Results

#### 21.2.1 Spatial Variation



TISS - 12.10.16 13:35, Al

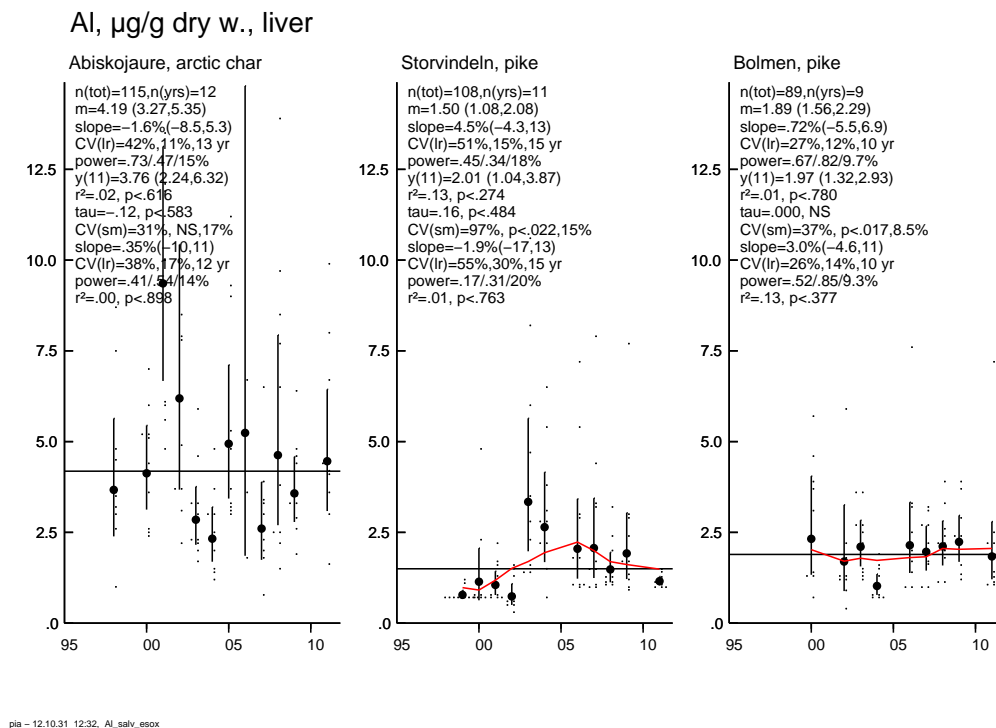
**Figure 21.1.** Spatial variation in concentration (ug/g dry weight) of Al in perch liver.

No general spatial trend for aluminium in perch liver is observed. The highest concentration of Al (65 ug/g dry weight) was found in perch liver from Lake Lilla Öresjön in Halland County in 2009-2011. The lowest concentration of Al (2.3 ug/g dry weight) came from perch liver from Lake Krageholmssjön in Skåne County (Fig. 21.1).

### 21.2.2 Temporal variation

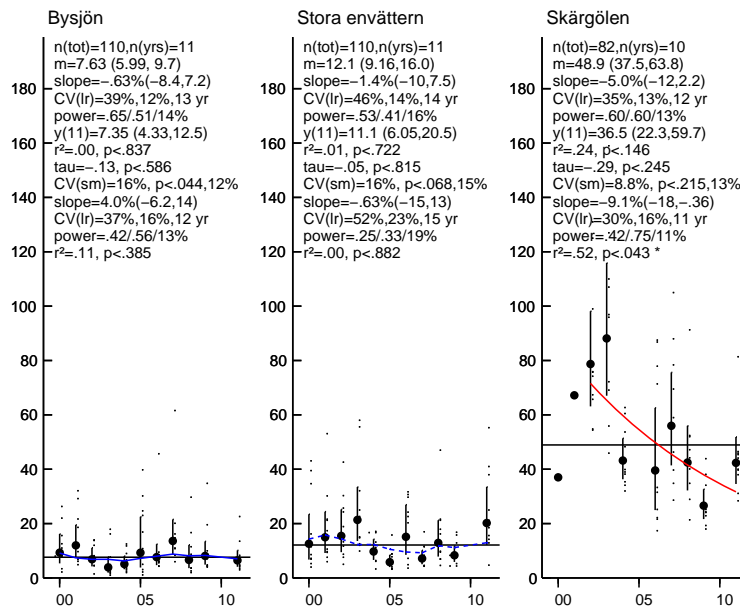
A significant increasing trend of 4% per year was seen for perch liver at Lake Stensjön, while a decreasing trend for the last ten years was seen at Lake Storgölen (9.1%). No significant trends were seen for aluminium for the other matrices and sites within the monitoring programme (Fig. 21.2-21.5).

The number of years required to detect an annual change of 10% for Al varies between 10-15 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).

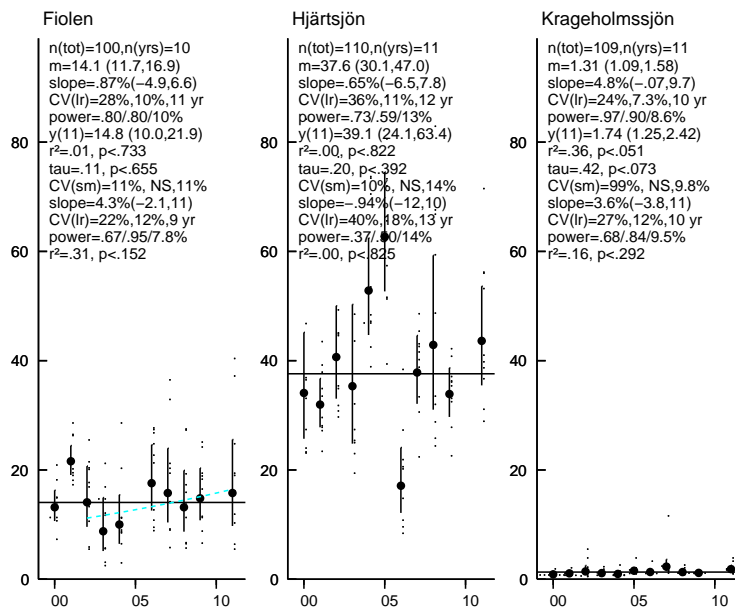
### Al, µg/g dry w., perch liver



plä - 12.10.31 12:31, Al\_bysj\_senv\_skar

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

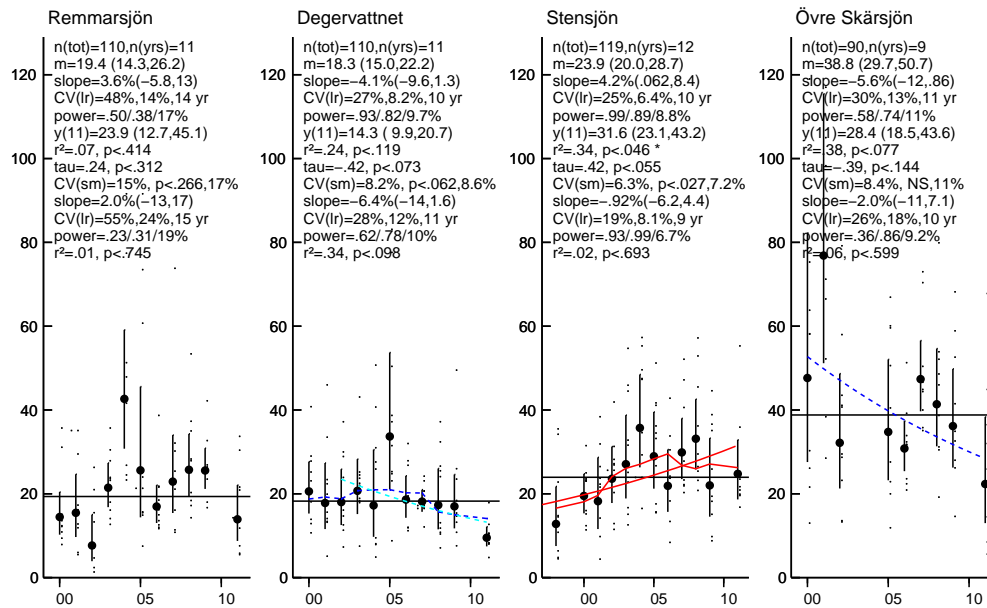
### Al, µg/g dry w., perch liver



plä - 12.10.31 12:31, Al\_fiol\_hjar\_krag

**Figure 21.4.** Aluminium concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.

## Al, µg/g dry w., perch liver



pla - 12.10.31 12:31, Al\_remm\_dege\_sten\_ovsk

**Figure 21.5.** Aluminium concentrations (µg/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön.

## 21.3 Summary

The highest concentration of Al in perch liver was found in Lake Lilla Öresjön in Halland County in 2009-2011.

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 ( $\text{Bi}_2\text{S}_3$ ) and bismite ( $\text{Bi}_2\text{O}_3$ ) (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).

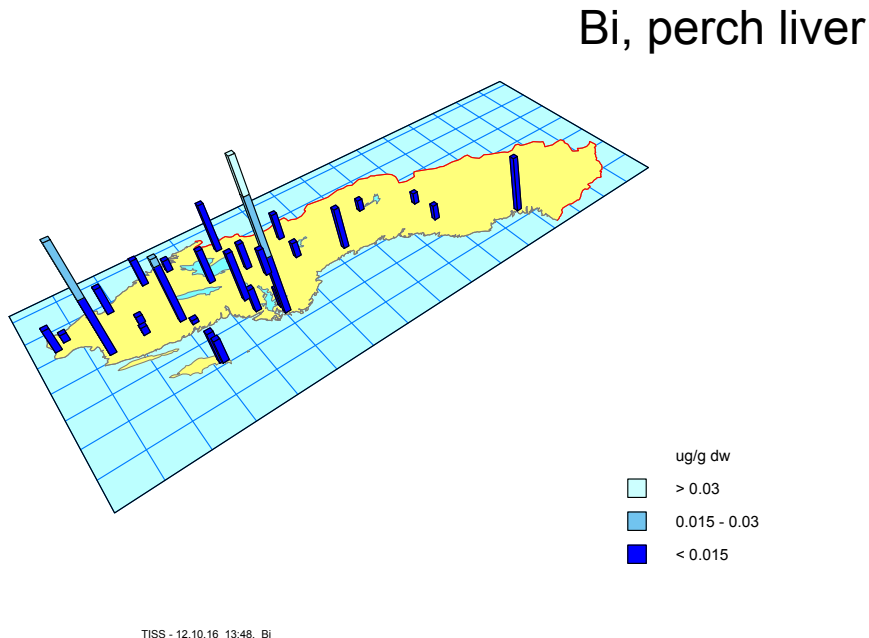
There is limited information on the effects and environmental fate of bismuth, but in general, bismuth is considered to have a small environmental impact and is less toxic than its other neighbours in the periodic table (lead, antimony, polonium).

#### 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 (0.04 ug/g dry weight) was found in perch liver from Lake Tärnan close to Stockholm in 2009-2011. The lowest concentration of Bi (0.002 ug/g dry weight) in perch liver is reported for Lake Algjutten 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 6.9%. 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.



Bi, µg/g dry w., liver

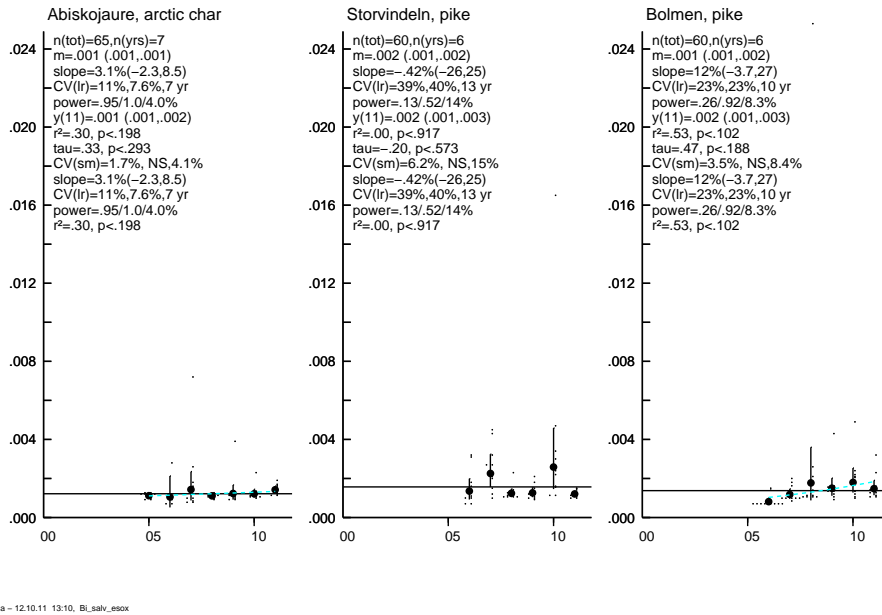


Figure 22.2. Bismuth concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).

Bi, µg/g dry w., perch liver

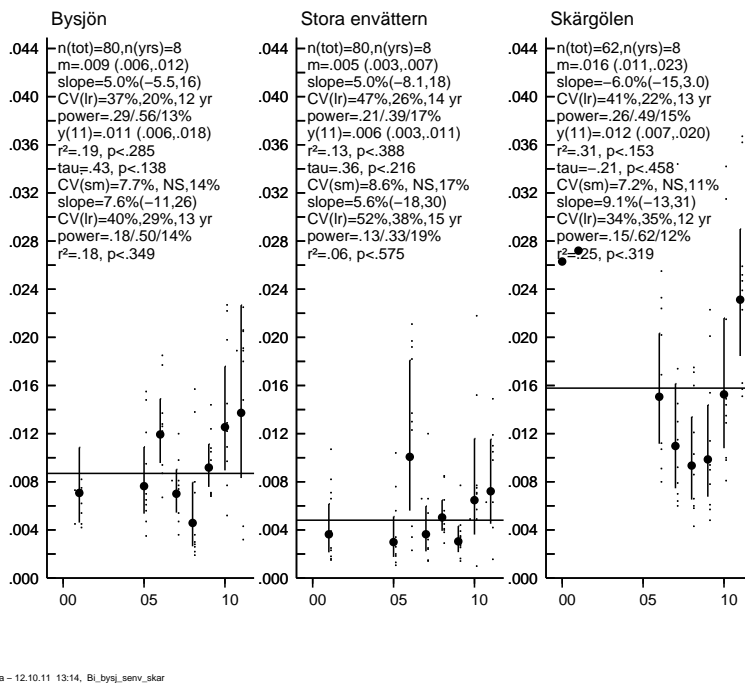


Figure 22.3. Bismuth concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.

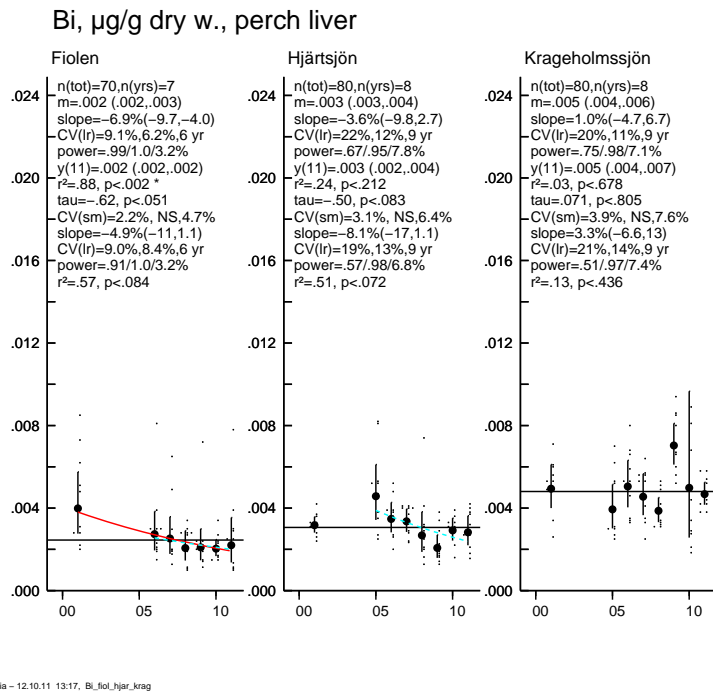


Figure 22.4. Bismuth concentrations (ug/g dry weight) in perch liver from Lake Fiolen, Lake Hjärtsjön and Lake Krageholmssjön.

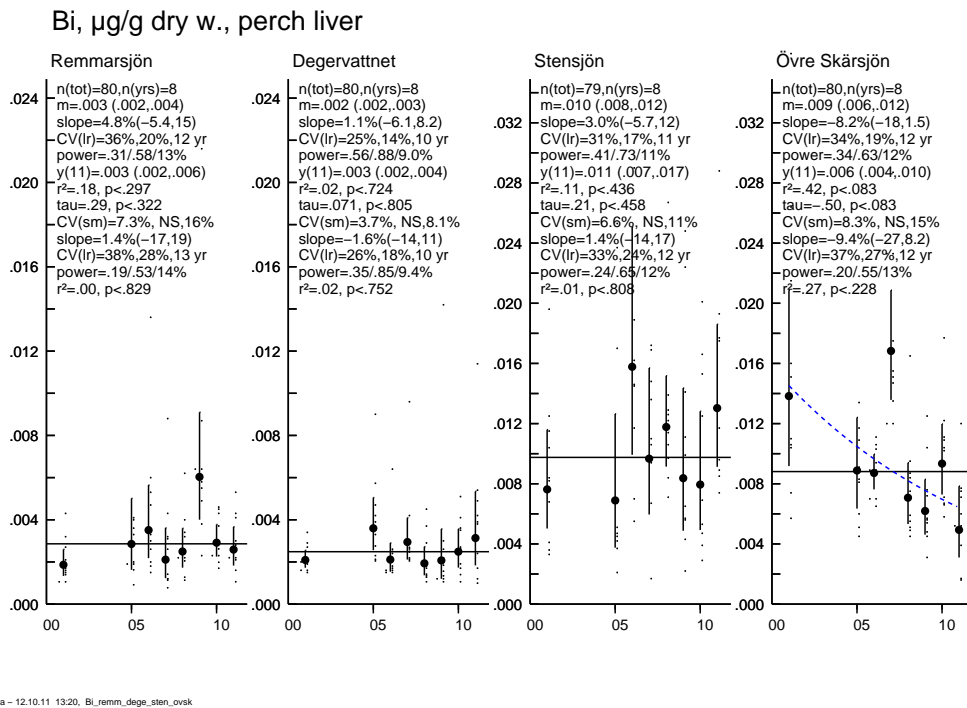


Figure 22.5. Bismuth concentrations (ug/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön.

### **22.3 Summary**

The highest concentration of Bi in perch liver was found in Lake Tärnan close to Stockholm.

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  $\text{Sn}^{+2}$  and stannic  $\text{Sn}^{+4}$ , 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,  $^{10}\text{Sn}$ ,  $^{120}\text{Sn}$ ,  $^{118}\text{Sn}$ ,  $^{116}\text{Sn}$ ,  $^{119}\text{Sn}$ ,  $^{117}\text{Sn}$ ,  $^{124}\text{Sn}$ ,  $^{122}\text{Sn}$ ,  $^{112}\text{Sn}$ ,  $^{114}\text{Sn}$ ,  $^{115}\text{Sn}$ , 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<sub>50</sub> test for fish ranges from 35 mg of tin (II) per litre to > 1000 mg tin (IV) per litre. 7- and 28-day LC<sub>50</sub> embryo-larval test for fish ranged from 0.4 to 2.1 mg/litre for tin (II) (WHO, 2005).

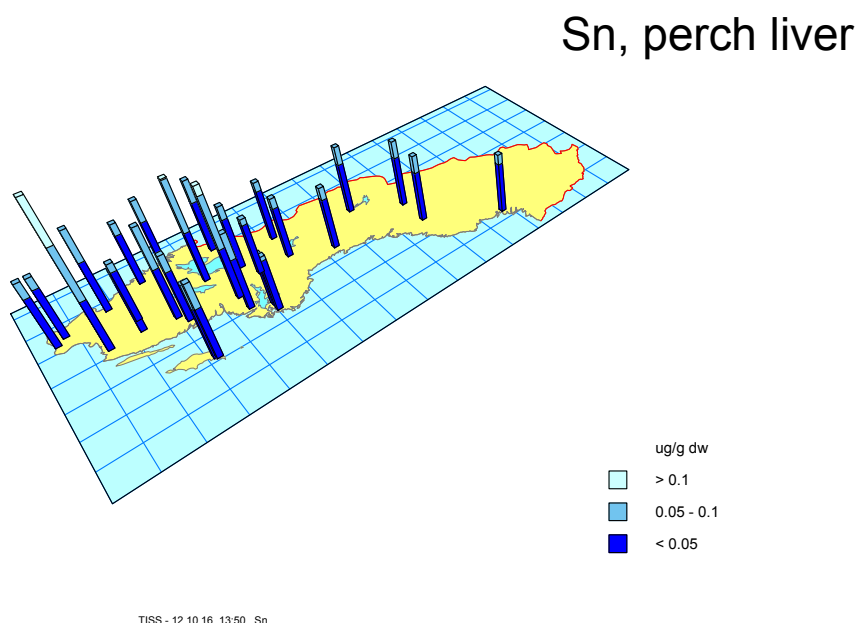
The main human exposure to tin is through food. Those that routinely consume canned fruit, vegetables, and juices from unlacquered cans could ingest 50-60 mg tin daily (WHO, 2005).

### **23.1.4 Target Levels**

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

## 23.2 Results

### 23.2.1 Spatial variation



**Figure. 23.1.** Spatial variation in concentration (ug/g dry weight) of Sn in perch liver.

Almost all values for Sn were in 2009-2011 below LOQ, regardless of lake. The value for LOQ ranges between 0.04-0.29 ug/g dw.

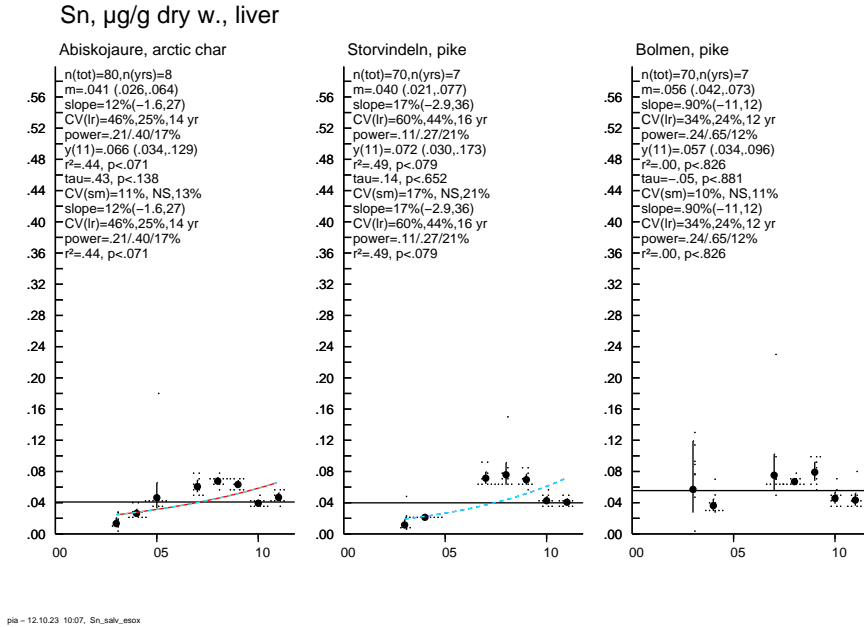
There is no clear spatial pattern for concentration of Sn. The highest concentration in perch liver (0.14 ug/g dw) was found in Lake Sännen in Blekinge County and the lowest concentration (0.052 ug/g dw) was found in Lake Fysingen close to Stockholm in 2009-2011 (Fig. 23.1).

The concentration of Sn in pike liver from Lake Bolmen and Lake Storvindeln and in arctic char liver from Lake Abiskojaure ranges between 0.06-0.07 ug/g dry weight (Fig. 23.2).

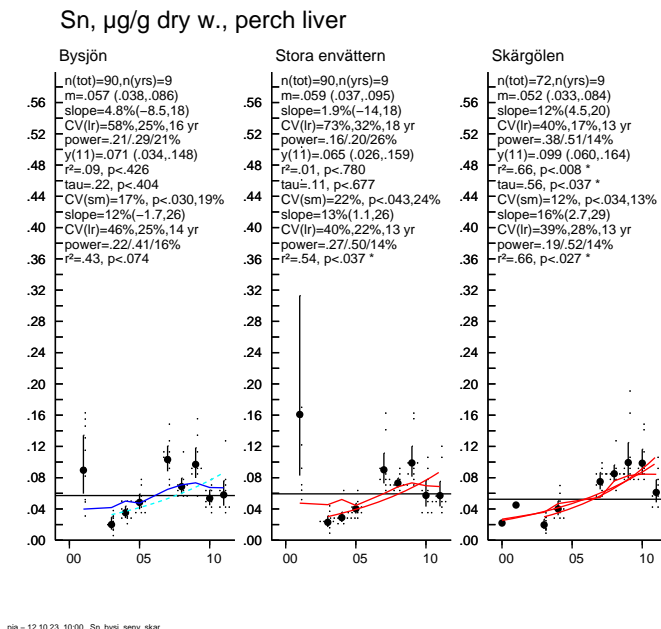
### 23.2.2 Temporal variation

Significant increasing trends for perch were observed in Lake Skärgölen and Lake Remmarsjön from 2000/2001-2011 with an annual increase of between 12-20% (Fig. 23.3- 23.5). In addition, a significant increasing trend for the last ten years of 13% per year was observed for perch in Lake Stora Envättern (Fig. 23.3). No trends in Sn concentrations were observed for arctic char or pike within the monitoring programme (Fig. 23.2).

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.

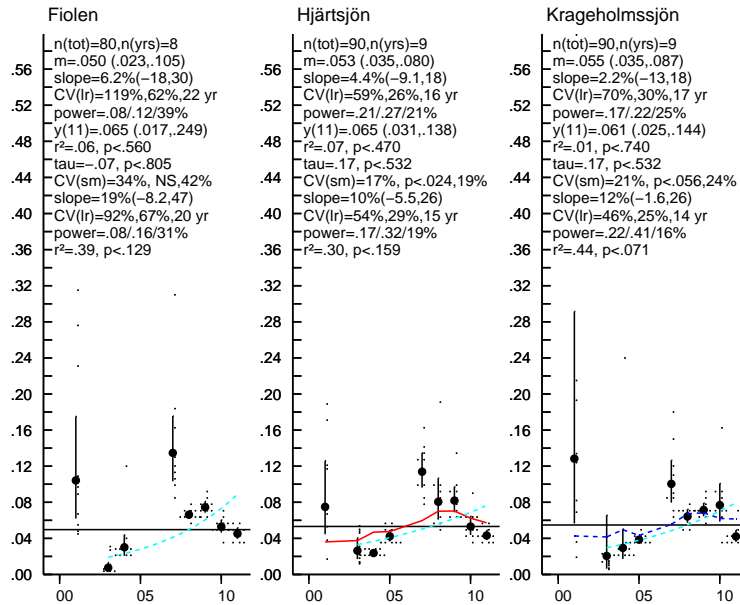


**Figure 23.2.** Tin concentrations (ug/g dry weight) in arctic char liver (Lake Abiskojaure) and in pike liver (Lake Bolmen and Lake Storvindeln).



**Figure 23.3.** Tin concentrations (ug/g dry weight) in perch liver from Lake Bysjön, Lake Stora Envättern and Lake Skärgölen.

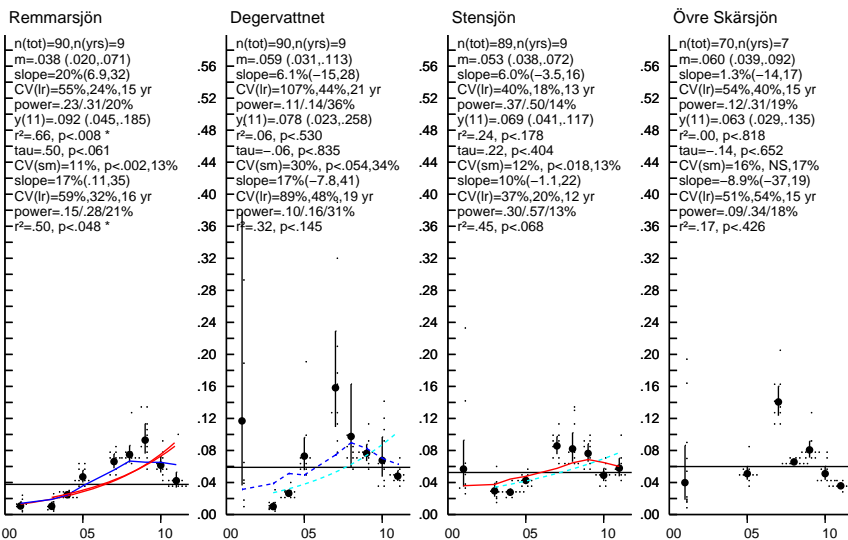
### Sn, µg/g dry w., perch liver



pla - 12.10.30 14:17, Sn\_fiol\_hjar\_krag

**Figure 23.4.** Tin concentrations (µg/g dry weight) in perch liver from Lake Fiolen, Lake Hjartsjön and Lake Krageholmssjön.

### Sn, µg/g dry w., perch liver



pla - 12.10.23 10:06, Sn\_remm\_dege\_sten\_ovsk

**Figure 23.5.** Tin concentrations (µg/g dry weight) in perch liver from Lake Remmarsjön, Lake Degervattnet, Lake Stensjön and Lake Övre Skärsjön.



### **23.3 Summary**

Almost all values of Sn concentrations were below LOQ in 2009-2011. The highest concentration of Sn was found in Lake Sängen in Blekinge County and the lowest concentration was found in Lake Fysingen close to Stockholm.

Arctic char and pike did not show any trends in Sn concentration, while perch from Lake Skärgölen, Remmarsjön and Stora Envättern 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

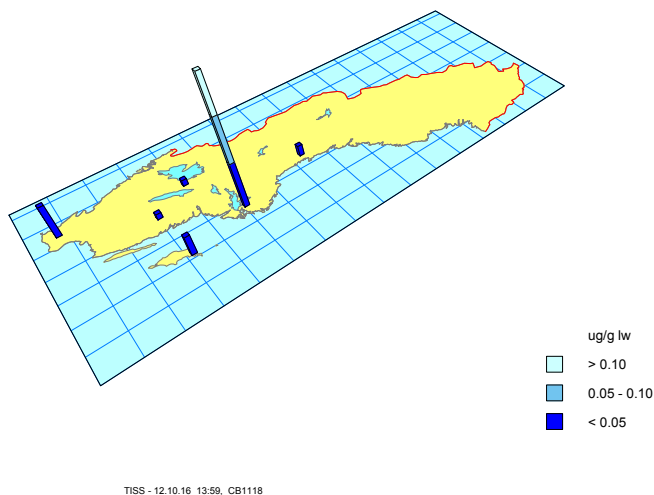
The target levels used for CB-153 and CB-118 in the time series for fish are 1600 and 24 ug/kg lipid weight respectively. For further information on target levels and selection of target level see chapter 10. The original target level has been recalculated for each time series based on the lipid

percentage. The recalculated target level (Tv) together with the lipid percentage (lp) is shown above the statistical information in each time series.

## 24.2 Results

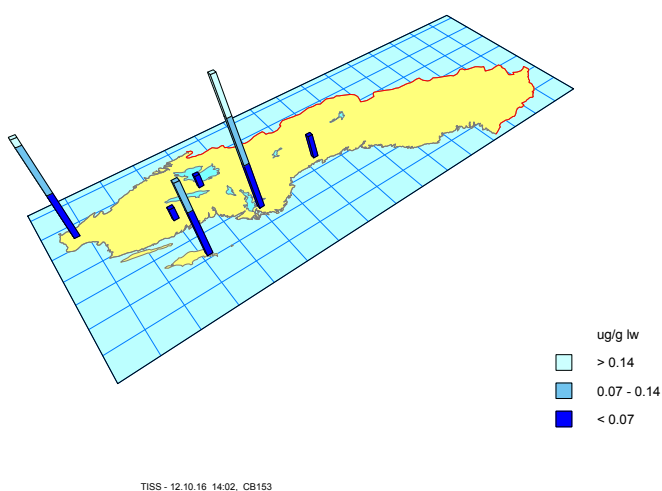
### 24.2.1 Spatial Variation

#### CB-118, perch muscle



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

#### CB-153, 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 and CB-153 (0.14 and 0.20 ug/g lw respectively) was found in perch from Lake Fysingen close to Stockholm in 2009-2011. The lowest concentration of CB-118 and CB-153 (0.0059 and 0.018 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).

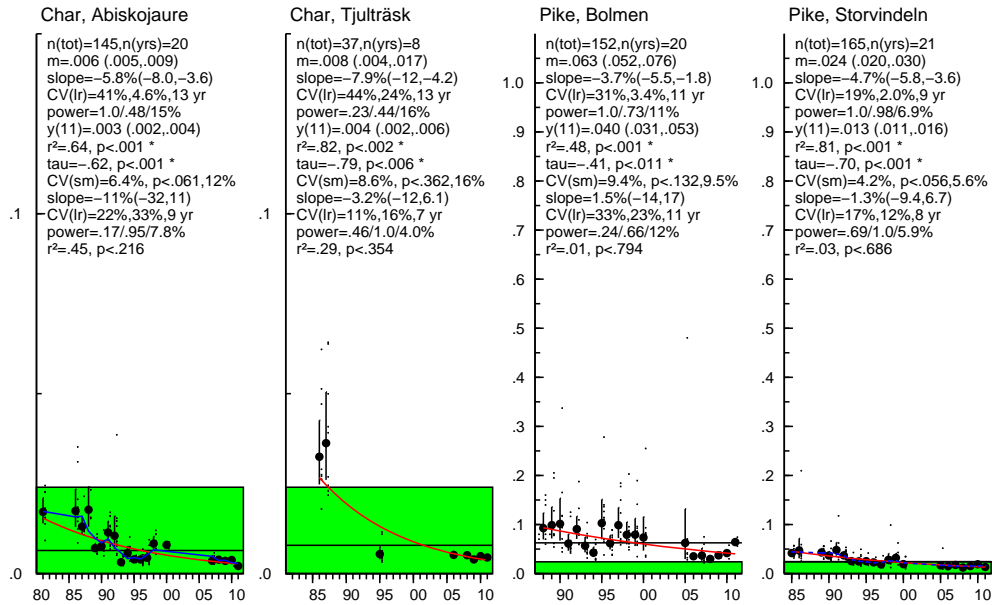
CB-153 shows similar decreasing trends for pike and char as CB-118 (with the exception of pike from Lake Bolmen where no trend is detected), with an annual decrease of about 3-8% (Fig. 24.5). No trend is detected in the perch time series (Fig. 24.6).

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 - 16 years for the pike, char and perch time series.

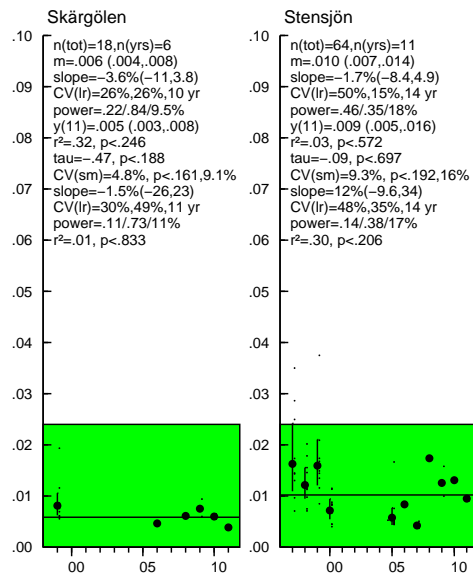
### CB-118 µg/g lipid w, muscle



pla - 12.10.15 10:15, 118pp

**Figure 24.3.** CB-118 concentrations (µg/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-118 in fish.

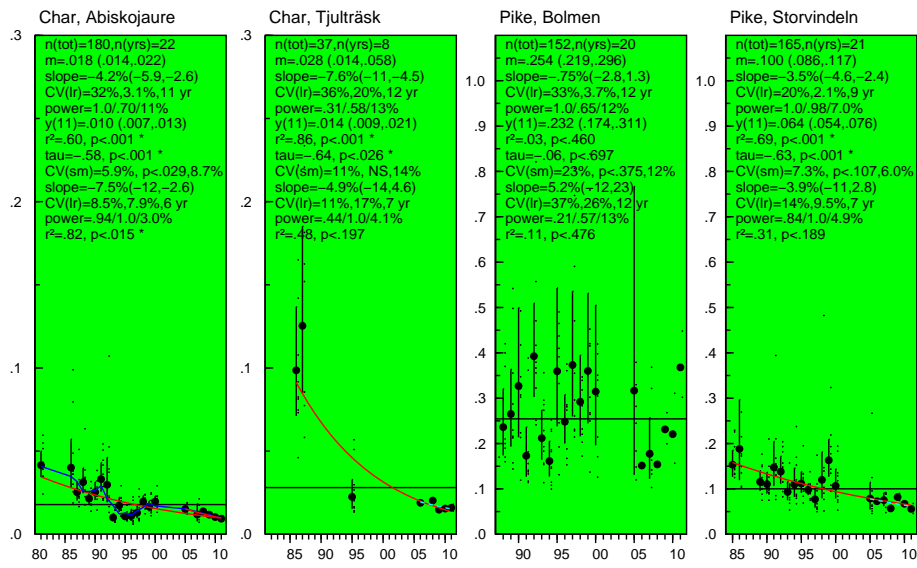
### CB-118 µg/g lipid w., perch muscle



pla - 12.10.15 10:15, 118pp

**Figure 24.4.** CB-118 concentrations (µg/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.

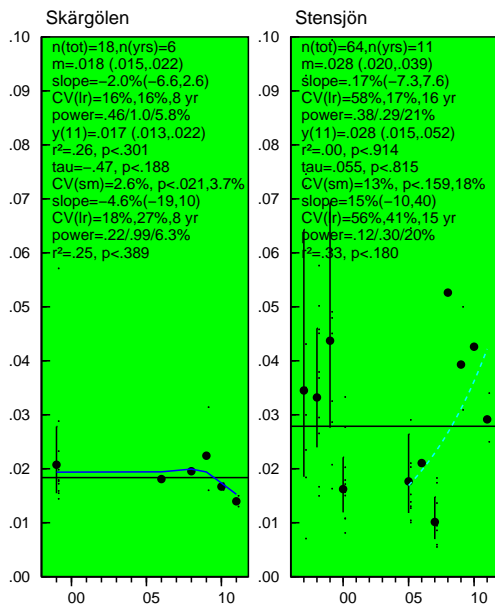
CB-153 µg/g lipid w., muscle



pia - 12.10.15 10:16, 153pp

**Figure 24.5.** CB-153 concentrations (µg/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.

CB-153 µg/g lipid w., perch muscle



pia - 12.10.15 10:17, 153pp

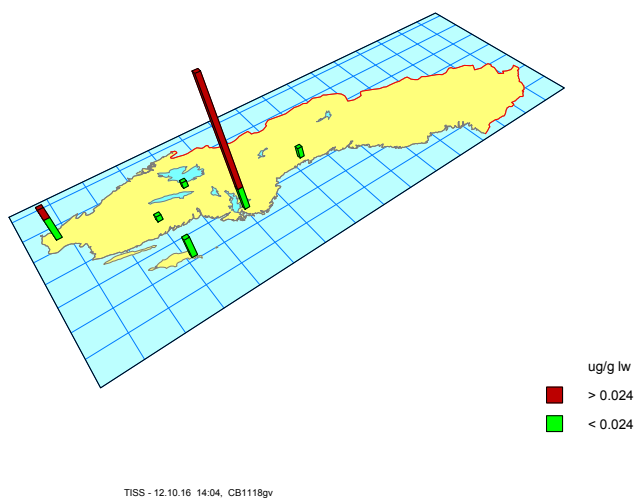
**Figure 24.6.** CB-153 concentrations (µg/g lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön). The green area denotes the levels below the suggested target value for CB-153 in fish.

### 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 pike from Lake Bolmen (Fig. 24.3) and in perch from Lake Krankesjön and Lake Fysingen (Fig. 24.7).

#### CB-118, perch muscle



**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 and CB-153 was found in Lake Fysingen close to Stockholm in 2009-2011.

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 pike from Lake Bolmen and in perch from Lake Krankesjön and Lake Fysingen.

## **25 DDTs, Dichlorodiphenylethanes**

### **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 immunosuppression 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.

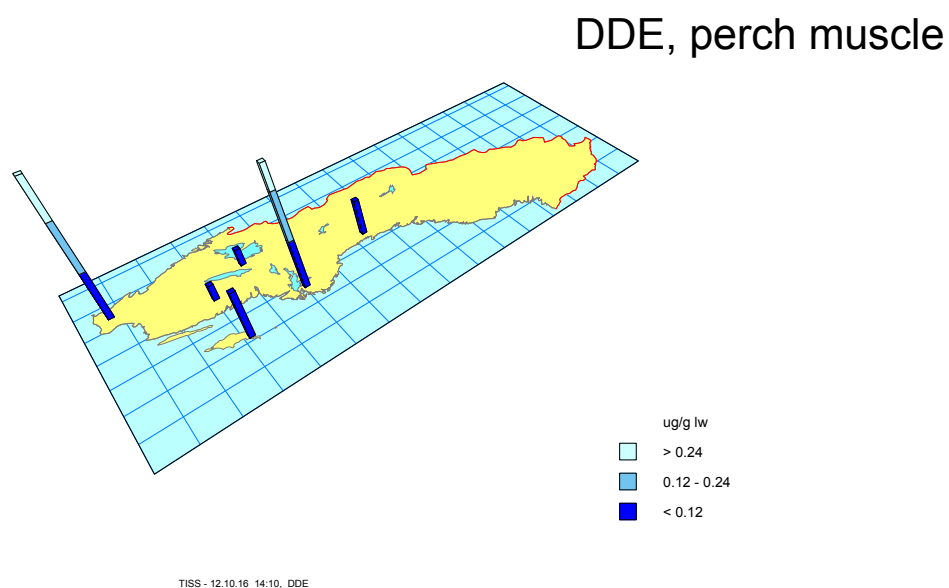


### 25.1.4 Target Levels

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 ( $T_v$ ) together with the lipid percentage ( $l_p$ ) is shown above the statistical information in each time series.

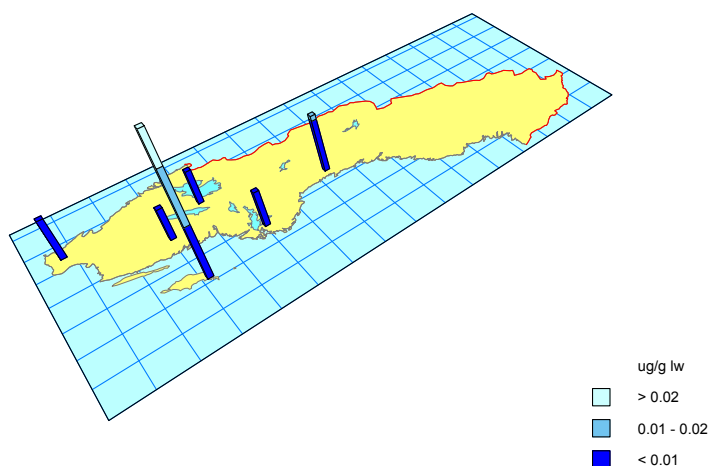
## 25.2 Results

### 25.2.1 Spatial Variation



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

## DDT, perch muscle



TISS - 12.10.16 14:13, DDT

**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 five lakes within the national Swedish monitoring programme for contaminants in freshwater biota. The highest concentration of DDE (0.34 ug/g lw) in perch muscle was found in Lake Krankesjön in Skåne County (Fig. 25.1) in 2009-2011 and the lowest concentration (0.039 ug/g lw) was found in Lake Skärgölen in Kalmar County. The highest concentration of DDT (0.026 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.

The concentration of DDE in pike from Lake Bolmen is about 50 times higher than in pike from Lake Storvindeln and more than 20 times higher than in arctic char and more than three times higher than in perch from the lakes monitored within the programme (Fig. 25.3-25.6).

### 25.2.2 Temporal variation

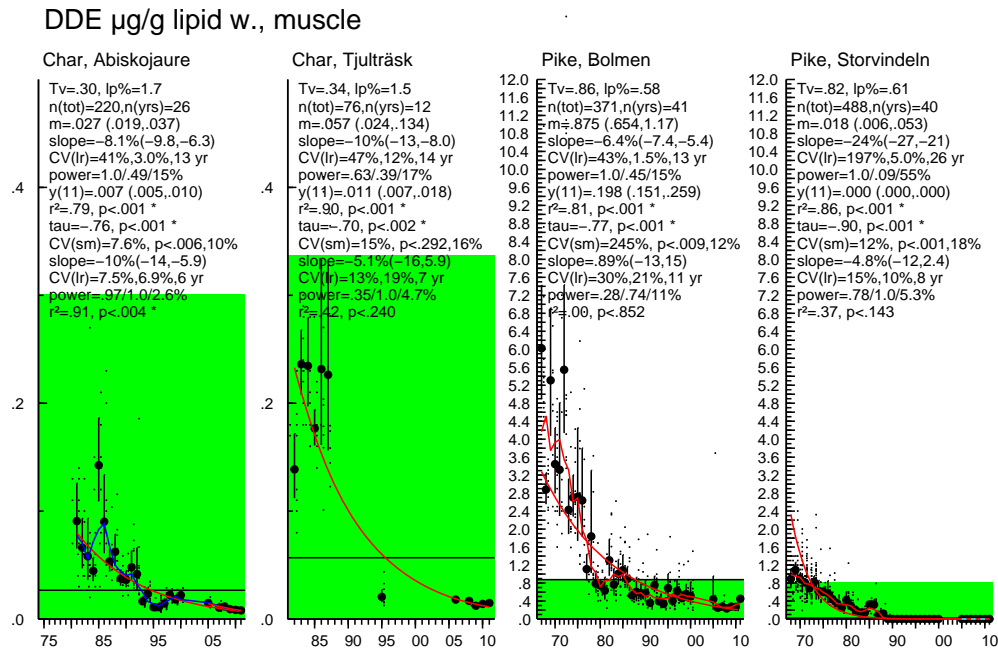
Temporal trends of DDE and DDT in char from Lake Abiskojaure and Lake Tjulträsk and in pike from Lake Bolmen and Lake Storvindeln show similar patterns (Fig. 25.3, 25.5). The pesticide has decreased significantly during the period 1967/68/81-2011, with an annual change of between 6.5-24 %.

DDE and DDT show significant decreasing trends in perch from Lake Skärgölen with an annual change of 5.6 and 7.1 % respectively (Fig. 25.4, 25.6) during the period 1980-2011. 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 13 - 26 years for the pike, char and perch time series.

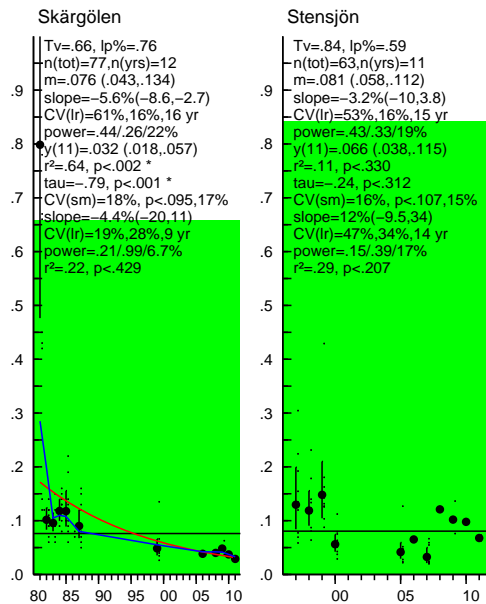
The number of years required to detect an annual change of 10% for DDT varies between 14 - 19 years for the pike, char and perch time series.



plia - 12.10.15 10:17, DDEcp

**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.

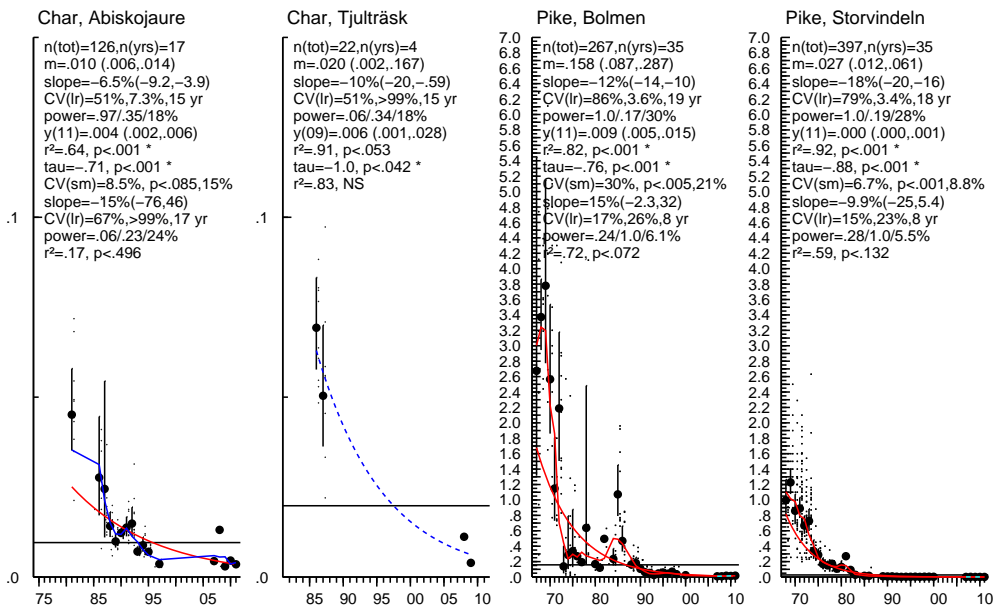
## DDE $\mu\text{g/g}$ lipid w., perch muscle



pla - 12.10.15 10:20, DDEp

**Figure 25.4.** DDE concentrations ( $\mu\text{g/g}$  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.

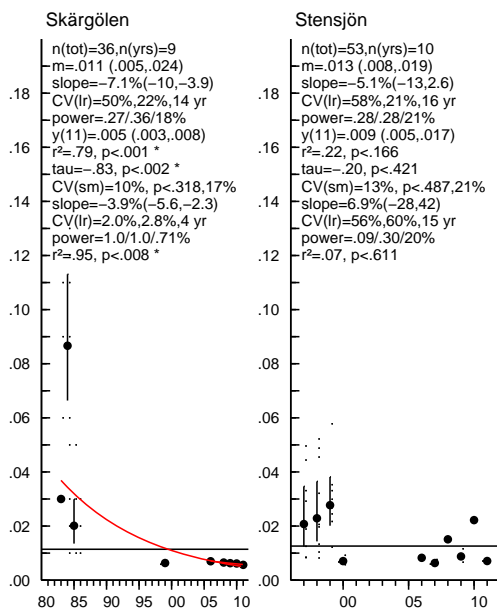
## DDT $\mu\text{g/g}$ lipid w., muscle



pla - 12.10.15 10:51, DDTcp

**Figure 25.5.** DDT concentrations ( $\mu\text{g/g}$  lipid weight) in arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln).

## DDT $\mu\text{g/g}$ lipid w., perch muscle



pla - 12.10.15 10:55, DDTp

**Figure 25.6.** DDT concentrations ( $\mu\text{g/g}$  lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön).

### 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  $\mu\text{g/g}$  wet weight.

## 25.3 Summary

The highest concentration of DDE in perch muscle was found in Lake Krankesjön in Skåne County in 2009-2011, 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 3-24% 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  $\alpha$ -HCH,  $\beta$ -HCH and  $\gamma$ -HCH i.e., lindane, have been analysed in muscle tissue for various fish species since 1980. The concentrations of  $\beta$ -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%  $\alpha$ -HCH; 15%  $\gamma$ -HCH (lindane); 7 -10%  $\beta$ -HCH; 7%  $\delta$ -HCH; and 1 - 2%  $\epsilon$ -HCH, and came into general use in 1950 (Gaul, 1992). The  $\gamma$ -isomer is the most toxic isomer of the HCHs, being 500 - 1000 times as potent as the  $\alpha$ -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.

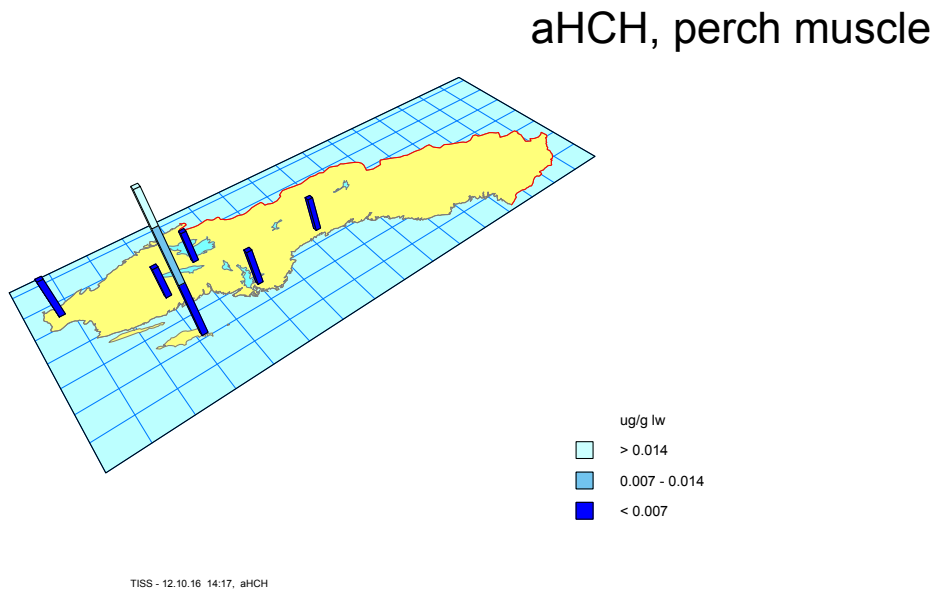
The use of technical HCH stopped in countries around the Baltic between 1970 - 1980. Since 1980, use of lindane in Europe has been allowed only as an insecticide. It was still used to a great extent in France and Italy as recently as 1990 (Yi-Fan et al. 1996).

#### 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 ( $T_v$ ) together with the lipid percentage ( $l_p$ ) is shown above the statistical information in each time series.

## 26.2 Results

### 26.2.1 Spatial Variation



**Figure 26.1.** Spatial variation in concentration (ug/g lipid weight) of  $\alpha$ -HCH in perch muscle.

In recent years HCHs are only analysed in perch from five lakes within the national Swedish monitoring programme for contaminants in freshwater biota. The highest concentration of  $\alpha$ -HCH, 2009-2011 (0.018 ug/g lw) was found in perch from Lake Horsan in Gotland. The levels in the other lakes that are analysed for  $\alpha$ -HCH are close to or at LOQ (Fig. 26.1). The concentrations of  $\beta$ -HCH and lindane in perch muscle were almost all under LOQ in 2009-2011.

The concentration of lindane are 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 1980-2011, with an annual change of between 4.5-11%. During the last ten years, levels of lindane are close to or at LOQ.

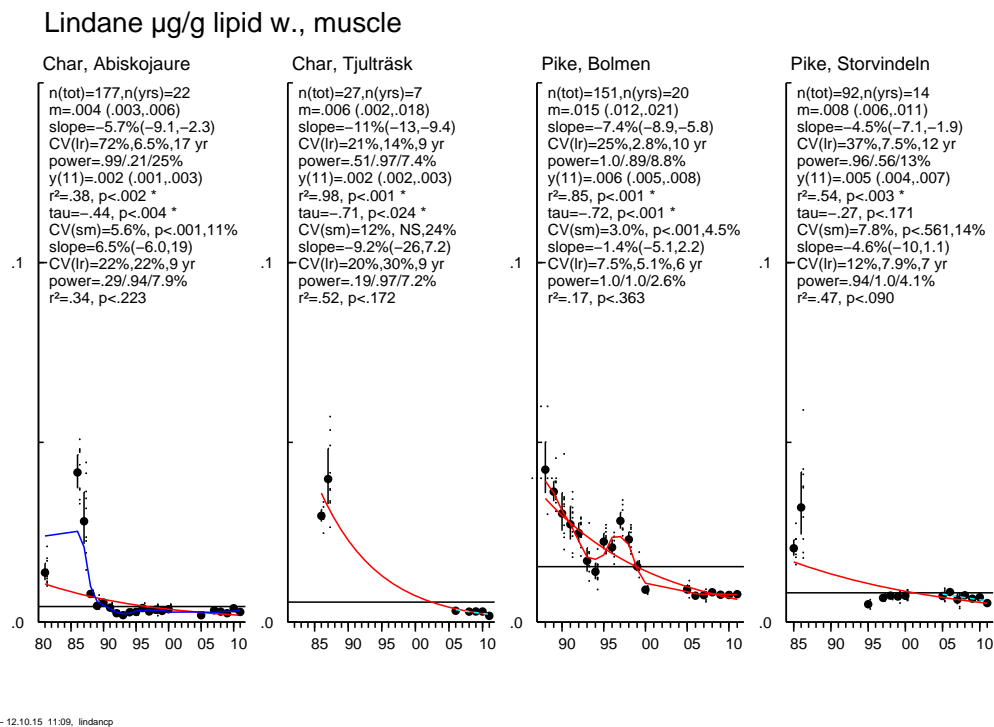
sHCH has decreased significantly in char from Lake Abiskojaure and in pike from Lake Bolmen with an annual change of 6.6 and 4.3 % respectively (Fig. 26.4).

Lindane shows significantly decreasing trends in perch from Lake Stensjön during the whole time period and for the last five years in Lake Skärgölen, with an annual change of 3.7 and 3.2 % respectively (Fig. 26.3) during the period 1980/00-2011.

sHCH is decreasing significantly in perch from Lake Stensjön with an annual change of 1.9% (Fig. 26.5).

The number of years required to detect an annual change of 10% for lindane varies between 5-17 years for the pike, char and perch time series.

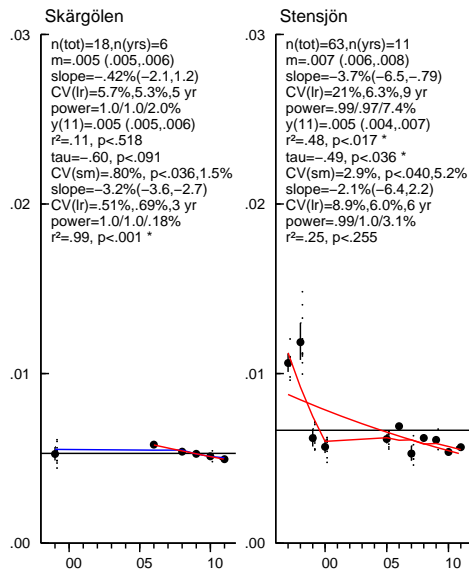
The number of years required to detect an annual change of 10% for sHCH varies between 5-13 years for the pike, char and perch time series.



**Figure 26.2.** Lindane concentrations ( $\mu\text{g/g}$  lipid weight) in arctic char muscle (Lake Abiskojaure and Lake Tjulträsk) and in pike muscle (Lake Bolmen and Lake Storvindeln).



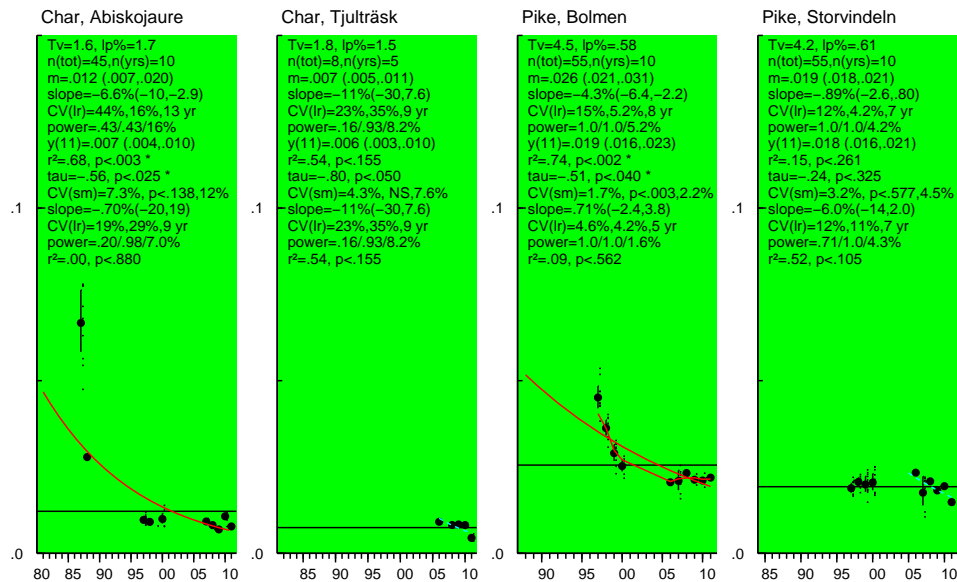
### Lindane $\mu\text{g/g}$ lipid w., perch muscle



pla - 12.10.15 11:11, Lindanp

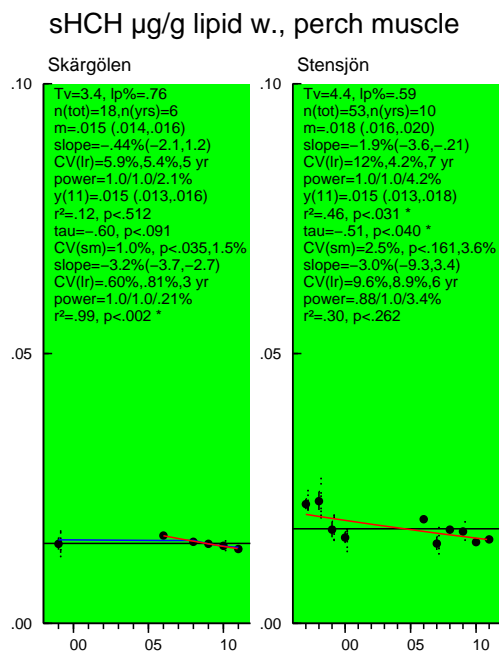
**Figure 26.3.** Lindane concentrations ( $\mu\text{g/g}$  lipid weight) in perch muscle (Lake Skär gölen and Lake Stensjön).

### sHCH $\mu\text{g/g}$ lipid w., muscle



pla - 12.10.15 11:17, sHCHcp

**Figure 26.4.** sHCH concentrations ( $\mu\text{g/g}$  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 sHCH in fish.



pla - 12.10.15 11:21, sHCHp

**Figure 26.5.** sHCH concentrations ( $\mu\text{g/g}$  lipid weight) in perch muscle (Lake Skärgölen and Lake Stensjön). The green area denotes the levels below the suggested target value for sHCH in fish.

### 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  $0.026 \mu\text{g/g}$  wet weight (Fig. 26.4-26.5).

## 26.3 Summary

The highest concentration of  $\alpha$ -HCH in perch muscle was found in Lake Horsan in Gotland in 2009-2011.

The lindane concentrations varied between species and sites; however temporally, the concentration has decreased by approximately 0.4-11% 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 ( $T_v$ ) together with the lipid percentage ( $l_p$ ) is shown above the statistical information in each time series.

## 27.2 Results

### 27.2.1 Spatial Variation

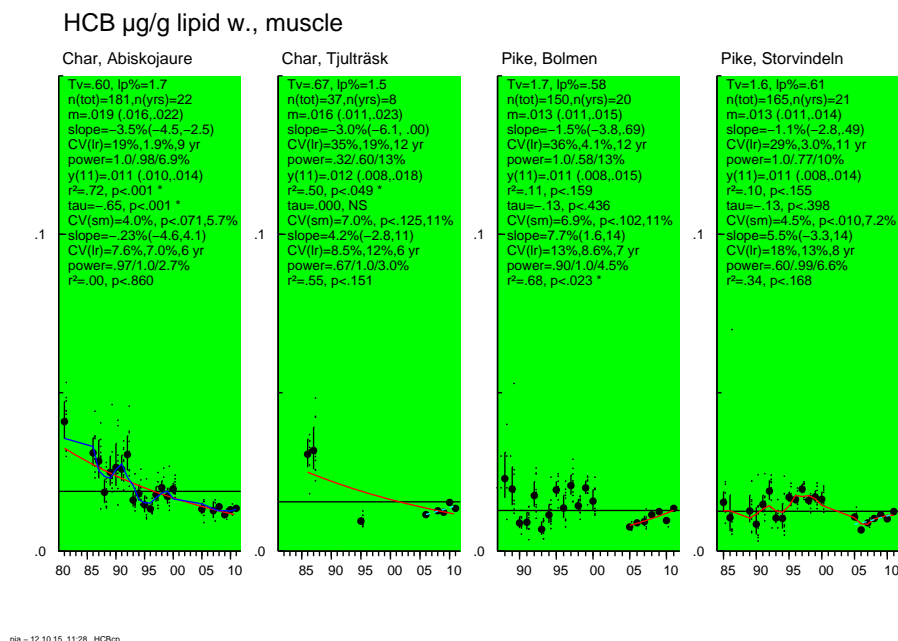
The concentrations of HCB in perch muscle were almost all under the LOQ in 2009-2011.

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

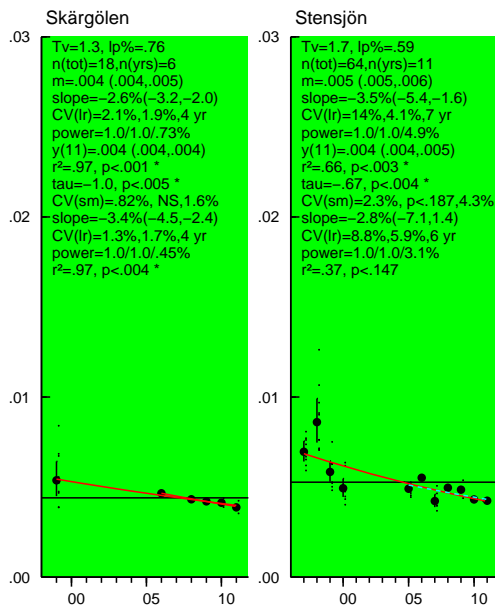
Temporal trends of HCB in char from Lake Abiskojaure and Lake Tjulträsk and in perch from Lake Skärgölen and Lake Stensjön show similar patterns (Fig. 27.1, 27.2). HCB has decreased during the period 1981/86/97/99-2011, with an annual change of between 2.6-3.5 %. No such trend is detected in pike from 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 7.7% (Fig. 27.1).

The number of years required to detect an annual change of 10% for HCB varies between 4-12 years for the pike, char and perch time series.



**Figure 27.1.** HCB concentrations ( $\mu\text{g/g}$  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.

## HCB $\mu\text{g/g}$ lipid w., perch muscle



plia - 12.10.15 11:32, HCBp

**Figure 27.2.** HCB concentrations ( $\mu\text{g/g}$  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  $QS_{\text{hh}}$  set to protect human health of  $0.010 \mu\text{g/g}$  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 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 PFH<sub>x</sub>A, PFH<sub>p</sub>A, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFPeDA, PFBS, PFH<sub>x</sub>S, 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 (PFH<sub>x</sub>S) (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.

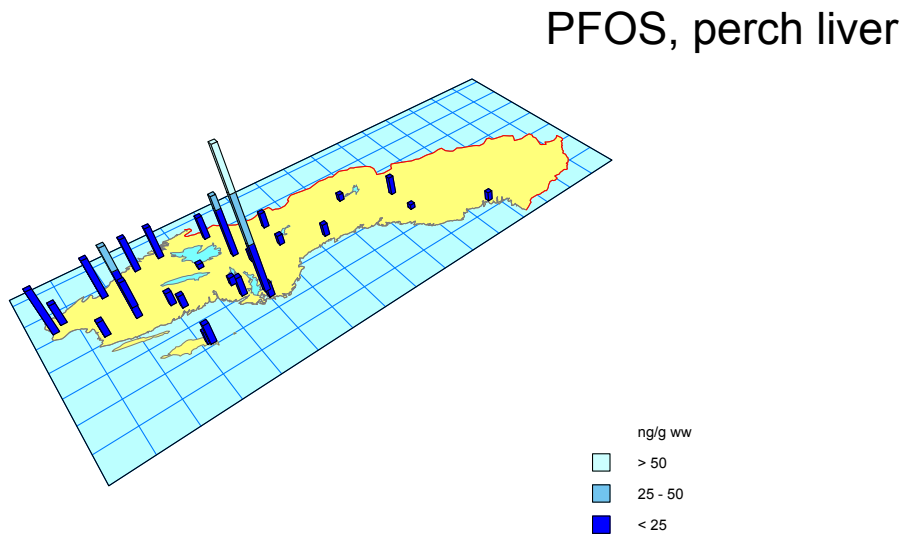
### **28.1.4 Target Levels**

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

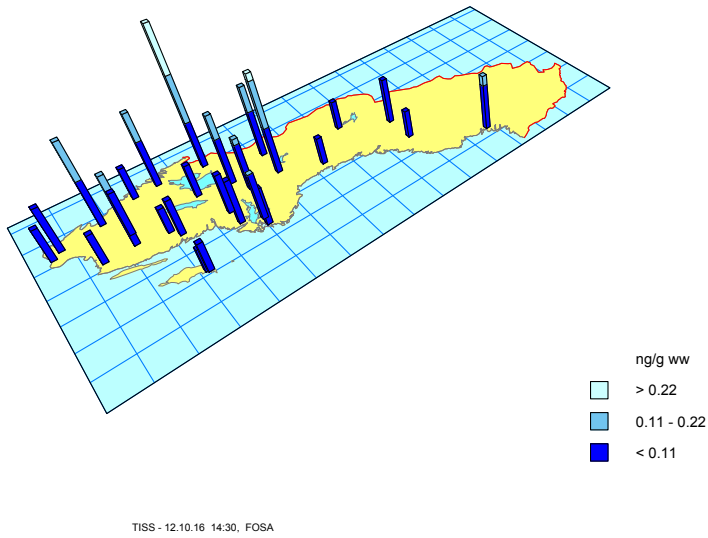
The concentrations of PFHxA, PFHpA, PFOA, PFBS, PFHxS and PFDS (with the exception of few samples) were all under LOQ in perch liver during the period 2009-2011, and are therefore not reported in the maps below.



**Figure 28.1.** Spatial variation in concentration (ng/g wet weight) of PFOS in perch liver.

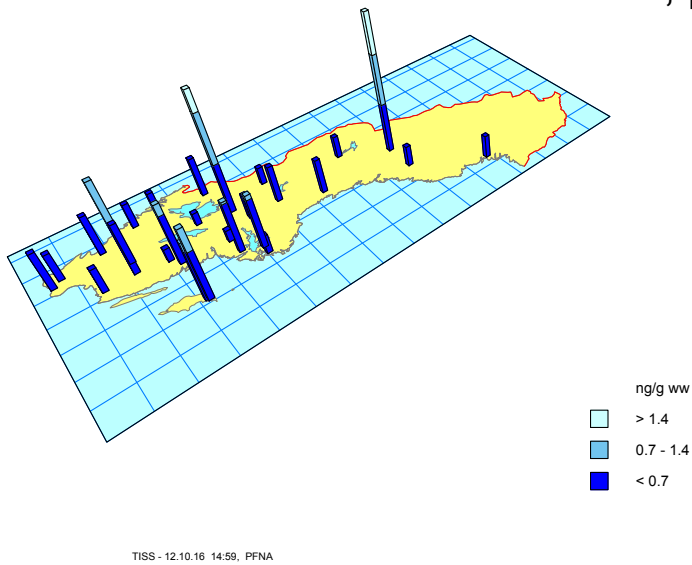


## FOSA, perch liver



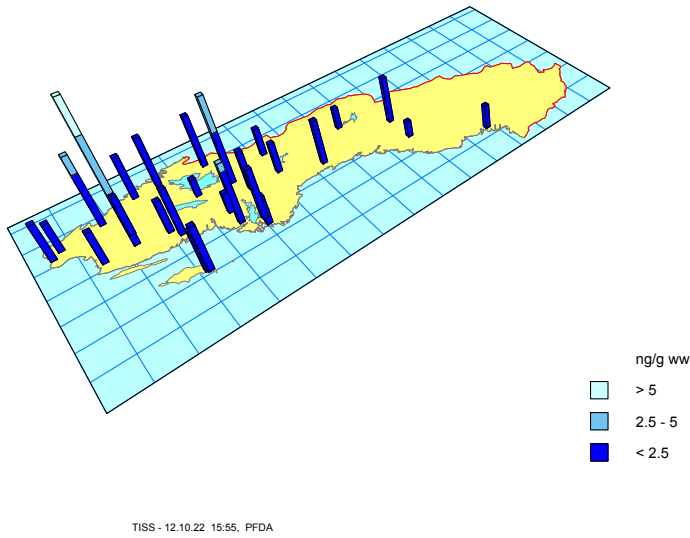
**Figure 28.2.** Spatial variation in concentration (ng/g wet weight) of FOSA in perch liver.

## PFNA, perch liver



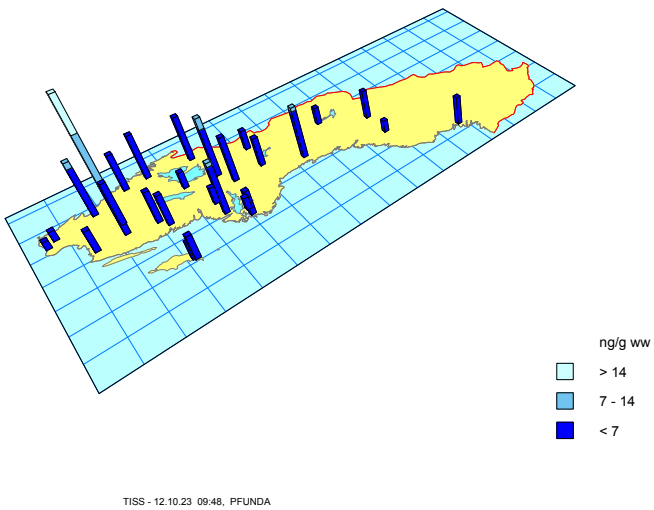
**Figure 28.3** Spatial variation in concentration (ng/g wet weight) of PFNA in perch liver.

## PFDA, perch liver



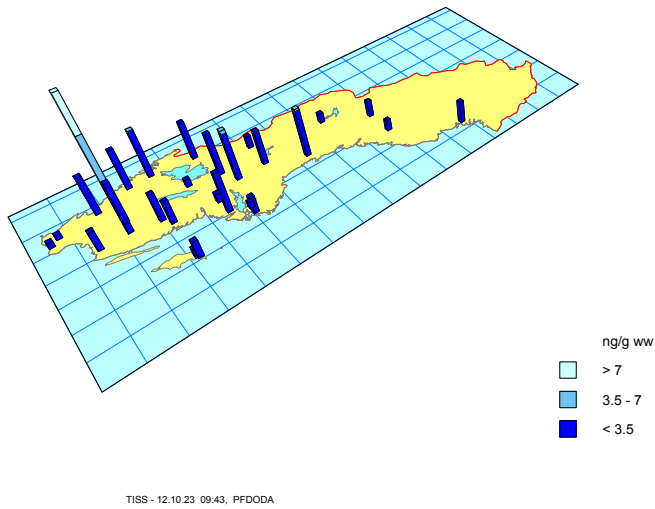
**Figure 28.4** Spatial variation in concentration (ng/g wet weight) of PFDA in perch liver.

## PFUnDA, perch liver



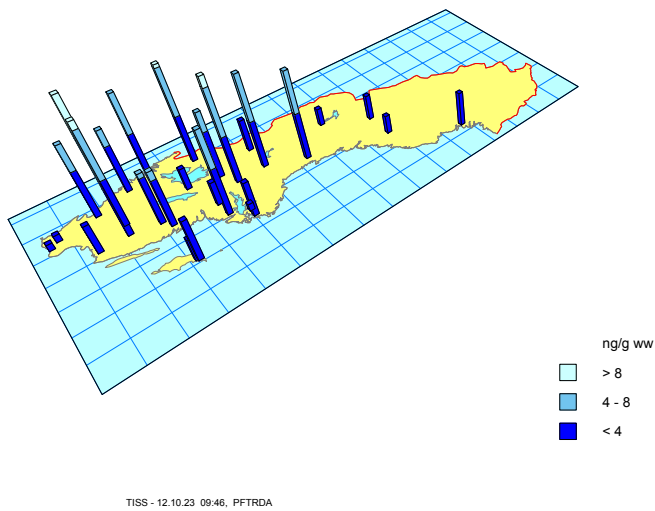
**Figure 28.5** Spatial variation in concentration (ng/g wet weight) of PFUnDA in perch liver.

### PFDoDA, perch liver



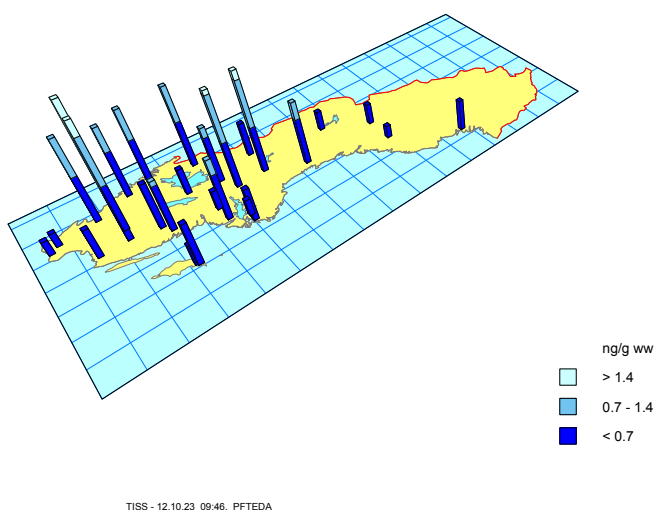
**Figure 28.6** Spatial variation in concentration (ng/g wet weight) of PFDoDA in perch liver.

### PFTTrDA, perch liver



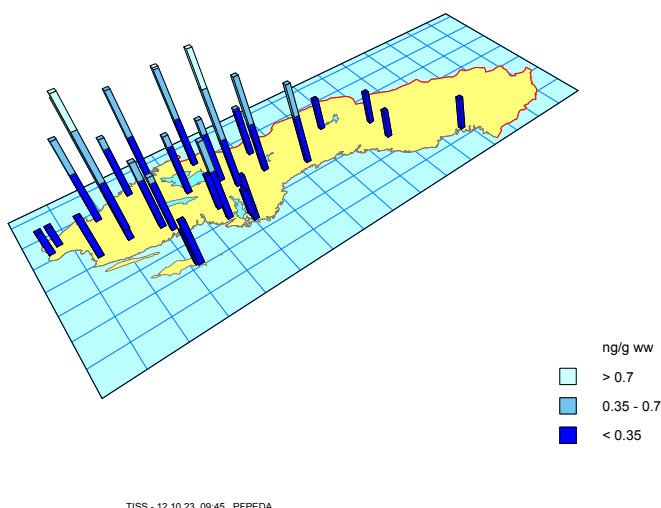
**Figure 28.7** Spatial variation in concentration (ng/g wet weight) of PFTTrDA in perch liver.

## PFTeDA, perch liver



**Figure 28.8** Spatial variation in concentration (ng/g wet weight) of PFTeDA in perch liver.

## PFPeDA, perch liver



**Figure 28.9** Spatial variation in concentration (ng/g wet weight) of PFPeDA 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 Limmingsjön 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 (72 ng/g ww) in 2009-2011, and the lowest concentration in Lake Svartsjön (2.3 ng/g ww) in

Västra Götaland 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 2009-2011, 0.33 ng/g ww, was found in Lake Bysjön in Värmland County and the lowest concentration, 0.055 ng/g ww, was found in Lake Horsan on Gotland (Fig.21.2).

The highest concentration of PFNA in perch liver in 2009-2011 was found in Lake Degervattnet in Jämtland County (1.96 ng/g ww) and the lowest concentration was found in Lake Älgsjön in Södermanland County (0.16 ng/g ww) (Fig. 28.3).

The highest concentration of PFDA in perch liver in 2009-2011, 6.55 ng/g ww, was found in Lake Hjärtsjön in Kronobergs County and the lowest concentration, 0.77 ng/g ww, was found in Lake Remmarsjön in Västernorrland County (Fig. 28.4).

The highest concentration of PFUnDA in perch liver in 2009-2011 was found in Lake Hjärtsjön (18.9 ng/g ww) and the lowest concentration was found in Lake Krageholmssjön in Skåne County (1.17 ng/g ww) (Fig. 28.5).

The highest concentration of PFDoDA in perch liver in 2009-2011 (9.63 ng/g ww) was found in Lake Hjärtsjön and the lowest concentration (0.32 ng/g ww) was found in Lake Krankesjön in Skåne County (Fig. 28.6).

The highest concentration of PFTrDA in perch liver in 2009-2011, 11.2 ng/g ww, was found in Lake Hjärtsjön and the lowest concentration, 0.54 ng/g ww, was found in Lake Krageholmssjön (Fig. 28.7).

The highest concentration of PFTeDA in perch liver in 2009-2011 was found in Lake Hjärtsjön (2.01 ng/g ww) and the lowest concentration was found in Lake Remmarsjön (0.19 ng/g ww) (Fig. 28.8).

The highest concentration of PFPeDA in perch liver in 2009-2011, 0.95 ng/g ww, was found in Lake Övre Skärsjön in Västmanland County and Lake Hjärtsjön and the lowest concentration, 0.14 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**

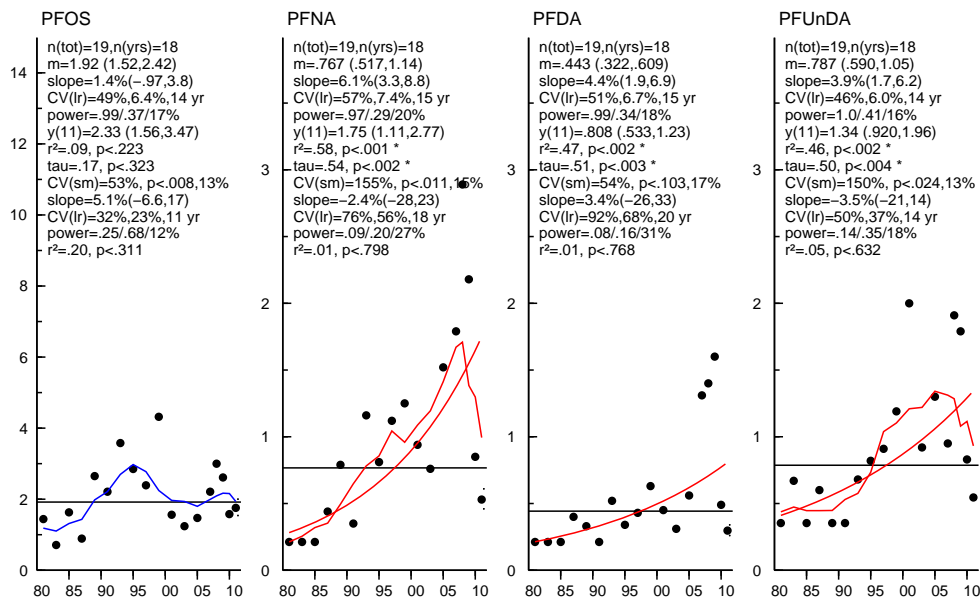
PFASs monitored within the programme but not presented as time trends are at concentrations below LOQ in the majority of the investigated years.

PFNA, PFDA, and PFUnDA all show significantly increasing concentrations of about 4-6 % per year in arctic char liver from Lake

Abiskojaure in 1980-2011. In perch liver from Lake Skärgölen increasing concentrations in 1980-2011 are seen for PFDA, PFUnDA, PFDoDA, and PFTrDA with about 4-7 % per year. However, a decreasing trend in concentration of PFOS is seen for the last ten years in perch liver from Lake Skärgölen, with an annual decrease of about 8 % (Fig. 28.10-28.13).

The number of years required to detect an annual change of 10% for PFASs varies between 12-19 years for the char and perch time series.

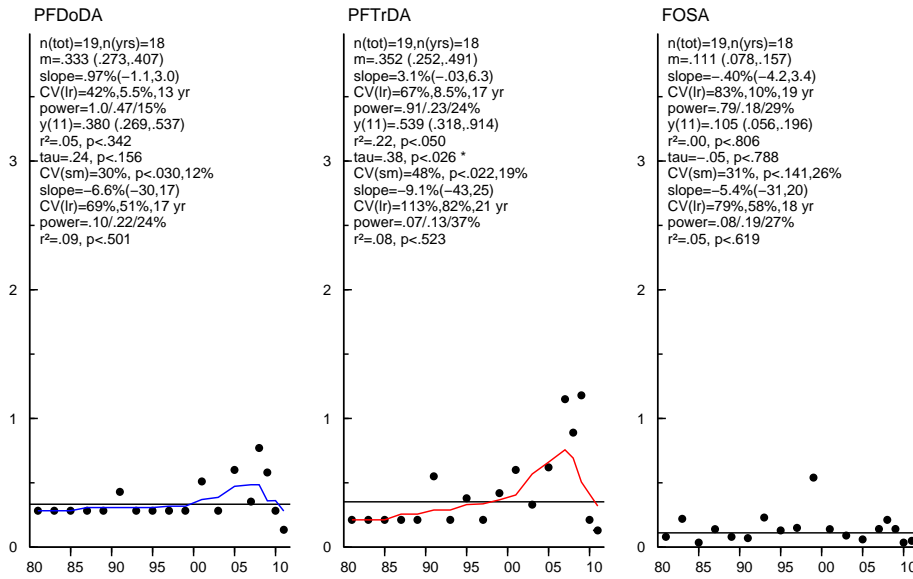
Abiskojaure, arctic char, ng/g wet weight, liver



pla - 12.10.26 14:08, PFOS\_ABIS

**Figure 28.10.** PFOS, PFNA, PFDA and PFUnDA concentrations (ng/g wet weight) in arctic char liver from Lake Abiskojaure (1980-2011).

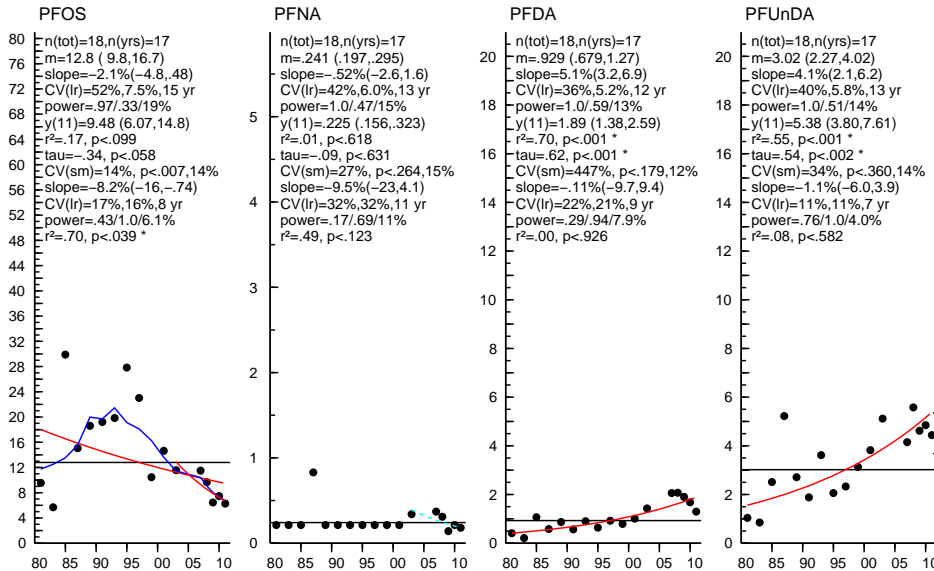
Abiskojaure, arctic char, ng/g wet weight, liver



plä - 12.10.26 14:10, FOSA\_ABIS

**Figure 28.11.** PFDODA, PFTTrDA, FOSA concentrations (ng/g wet weight) in arctic char liver from Lake Abiskojaure (1980-2011).

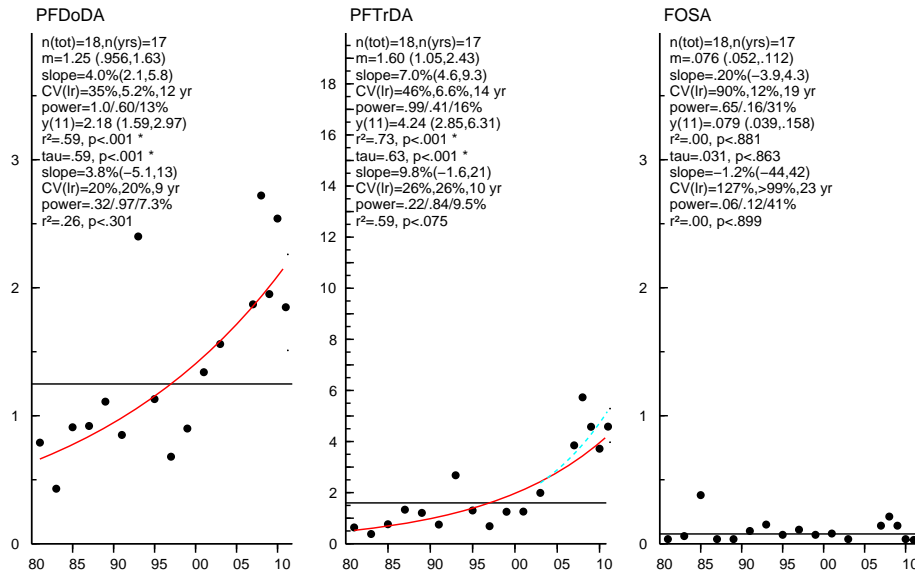
Skärgölen, perch, ng/g wet weight, liver



plä - 12.10.26 14:10, PFOS\_skär

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

Skärgölen, perch, ng/g wet weight, liver



pla - 12.10.26 14:09, FOSA\_skar

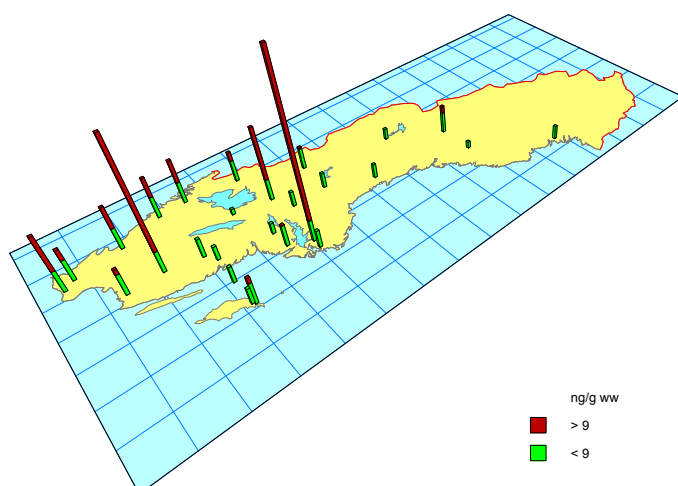
**Figure 28.13.** PFDoDA, PFTTrDA, FOSA concentrations (ng/g wet weight) in perch liver from Lake Skärgölen (1980-2011).

### 28.2.3 Comparison to threshold

The suggested target level for PFOS based on ECs EQS (Environmental Quality Standards) of 9.1 ng/g wet weight for 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 usually contains higher concentrations of PFASs than muscle tissue.



## PFOS, perch liver



**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 (2009-2011) 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 2011.

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, PFOS concentration is decreasing 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 usually 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.

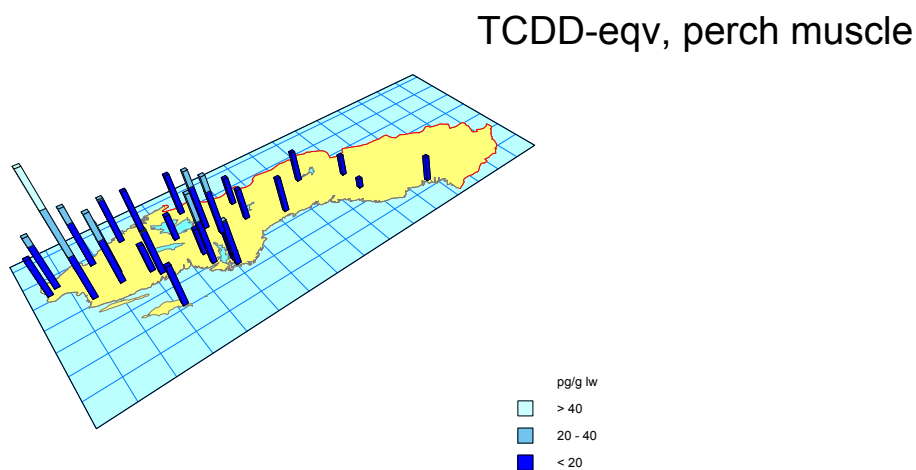
A dioxin and PCB strategy, including actions in the area of feed and food contamination and actions related to the environment including release reduction, was adopted by the EU in 2001.

#### 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

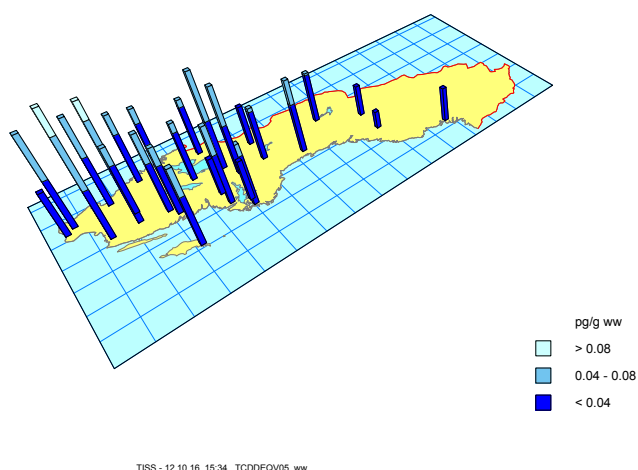
### 29.2.1 Spatial variation



TISS - 12.10.16 15:15, TCDDREQV05

**Figure 29.1** Spatial variation in concentration (pg/g lipid weight) of WHO05-TEQ (PCDD/PCDF) in perch muscle.

## TCDD-eqv, perch muscle



**Figure 29.2.** Spatial variation in concentration (pg/g wet 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 2009-2011. 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).

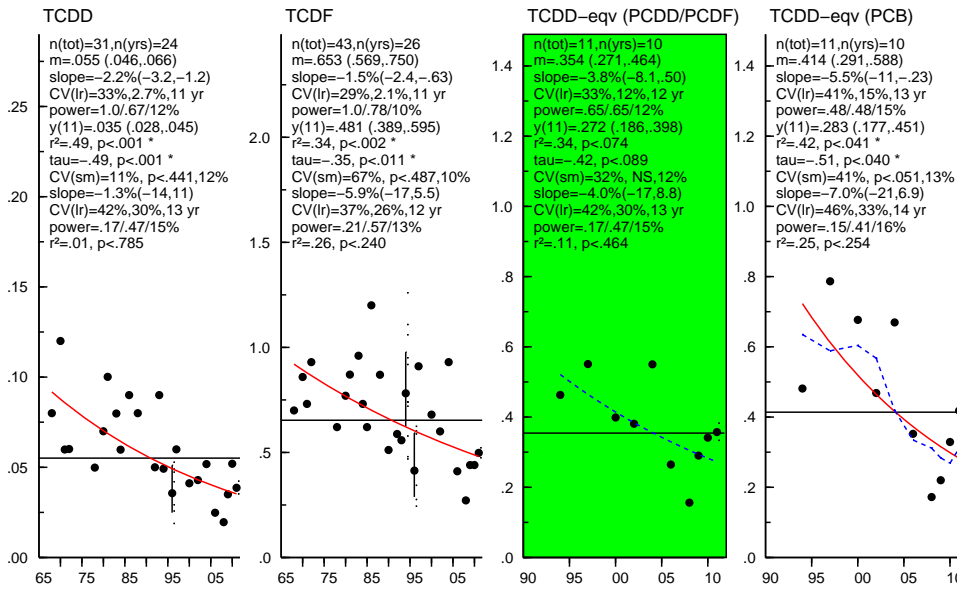
### 29.2.2 Temporal variation

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 1967/1980-2011, with an annual change of about 2% for TCDD and about 1-2% 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 in perch from Lake Skärgölen during the period 1980/1990-2011 of about 3-6% (Fig. 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).

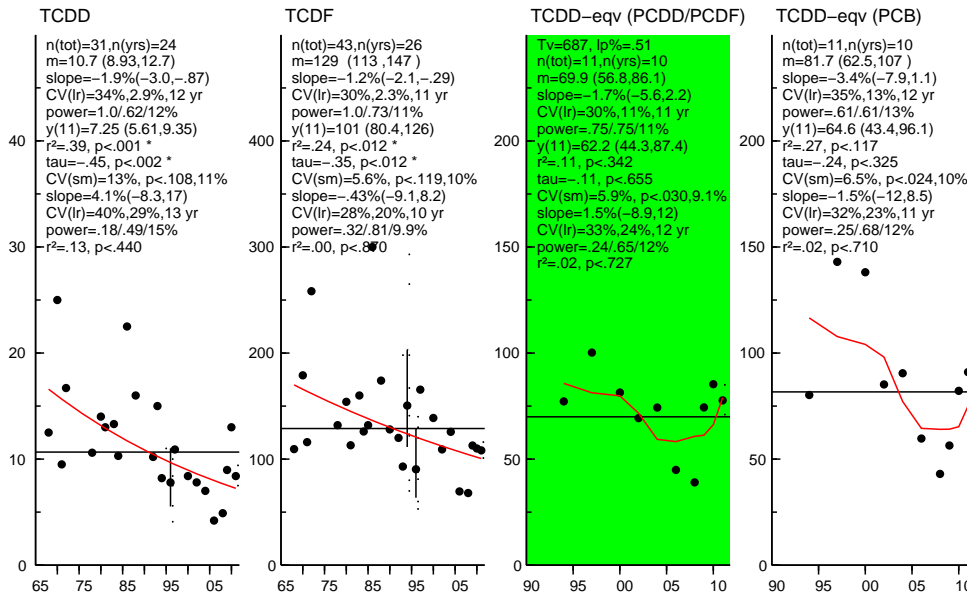
### Bolmen, pike, pg/g wet weight, muscle



pia - 12.10.15 13:03, DIOX\_bolm\_tresh

**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.

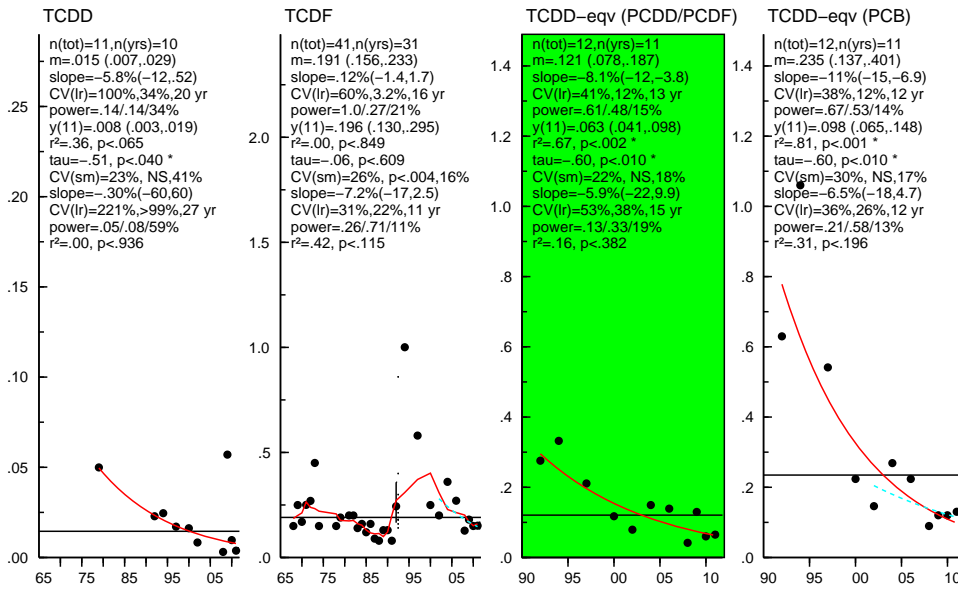
### Bolmen, pike, pg/g lipid weight, muscle



pia - 12.10.15 12:43, DIOX\_bolm

**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.

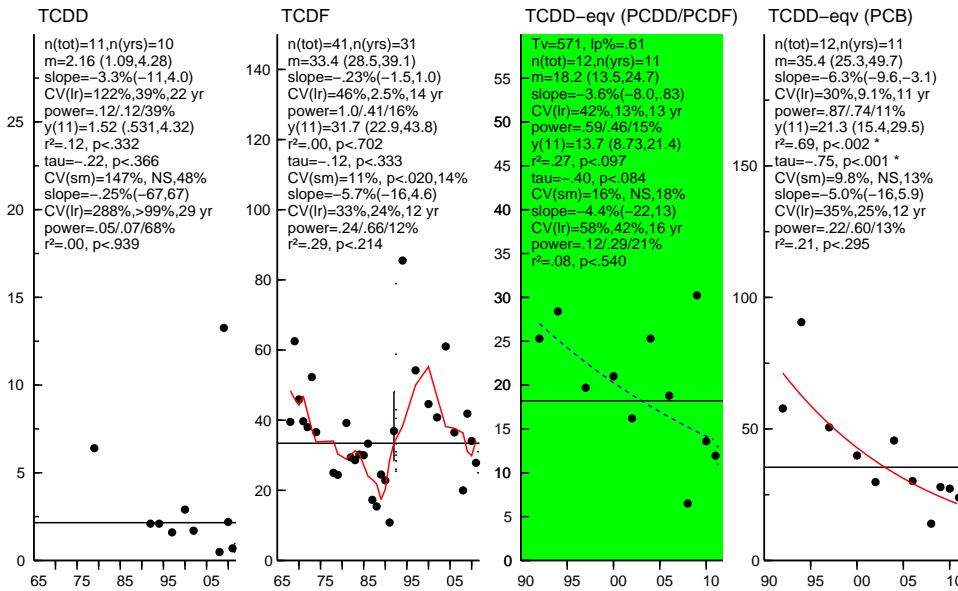
Storvindeln, pike, pg/g wet weight, muscle



pla - 12.10.15 13:51, DIOX\_stvi\_fresh

**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.

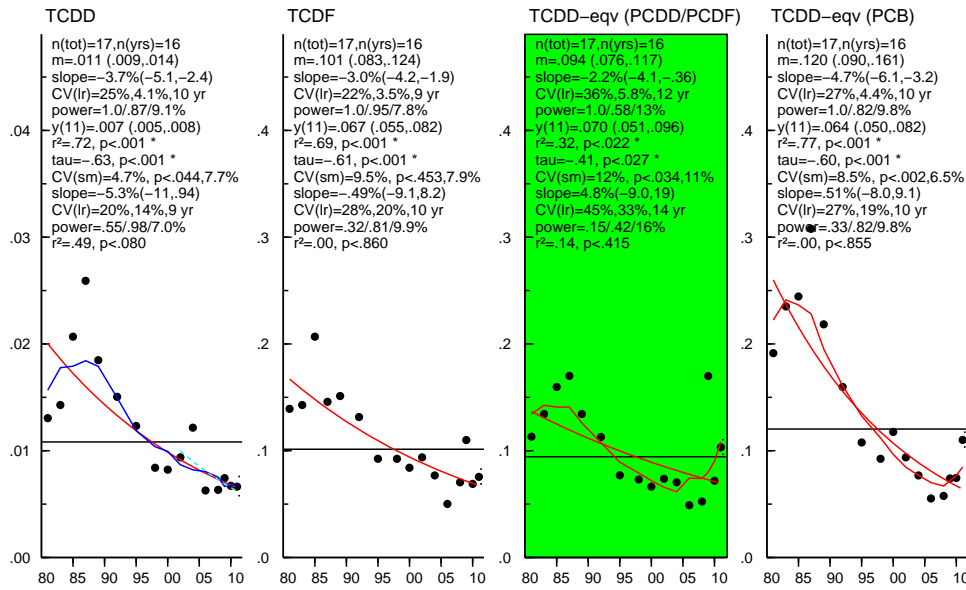
Storvindeln, pike, pg/g lipid weight, muscle



pla - 12.10.15 13:07, DIOX\_stvi

**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.

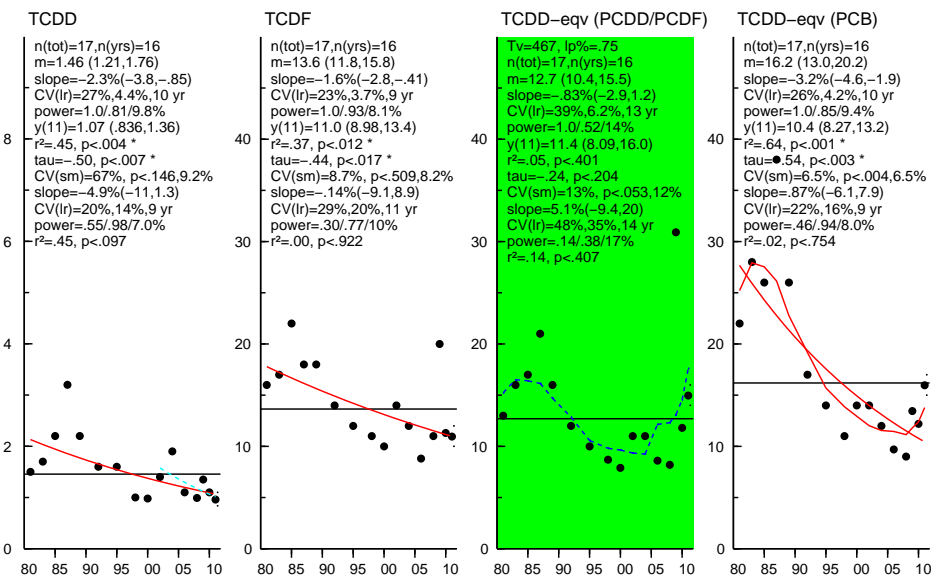
### Skärgölen, perch, pg/g wet weight, muscle



pla - 12.10.15 13.02, DIOX\_skar\_fresh

**Figure 29.7.** PCDD/PCDF concentrations (pg/g wet weight) in perch muscle from Lake Skärgölen. 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.

### Skärgölen, perch, pg/g lipid weight, muscle



pla - 12.10.15 12.55, DIOX\_skar

**Figure 29.8.** PCDD/PCDF concentrations (pg/g lipid weight) in perch muscle from Lake Skärgölen. 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 Sängen in Blekinge County in 2009-2011.

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 in perch from Lake Skärgölen, in pike from Lake Storvindeln, and in pike from Lake Bolmen (only wet weight).

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 ether (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 -  $\alpha$ -,  $\beta$ - and  $\gamma$ -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 effects 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, effects 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).

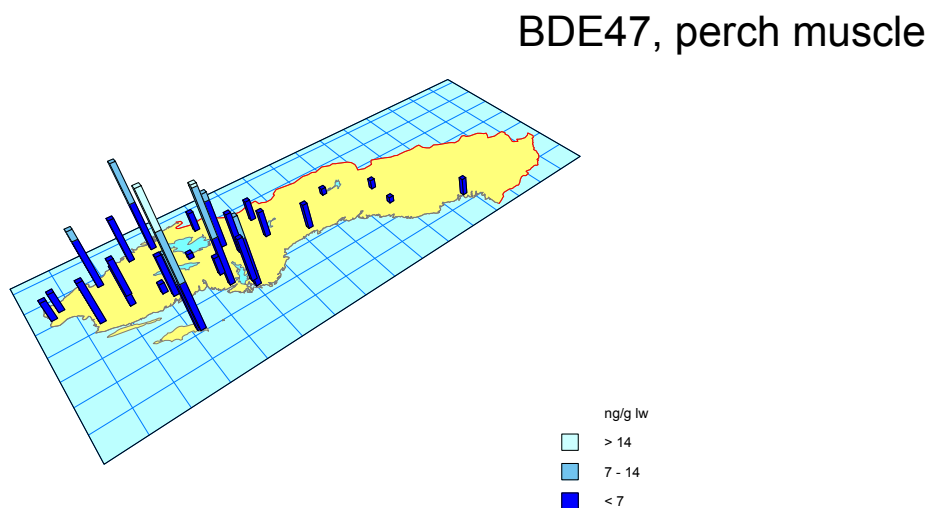
### 30.1.4 Target Levels

The target level (TL) used for HBCDD in the time series for fish is 167  $\mu\text{g}/\text{kg}$  wet weight. The target level used for the sum of BDE-28, 47, 99, 100, 153 and 154 ( $0.0085 \mu\text{g}/\text{kg}$ ) 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

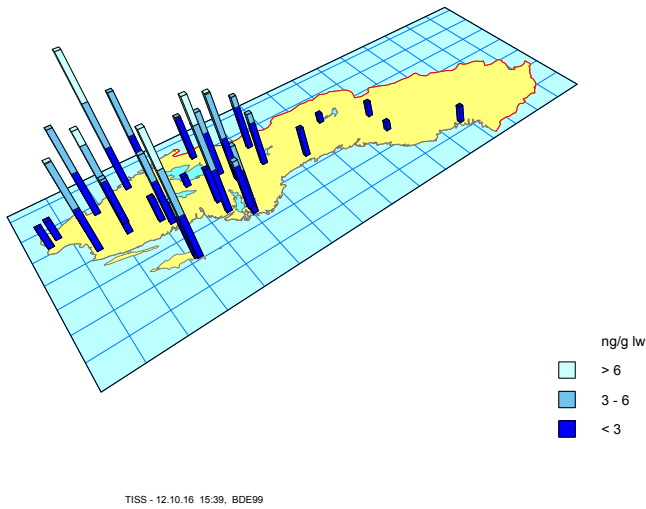
The concentration of HBCDD is under LOQ in a majority of the samples for all matrices and sites and is therefore not presented in the spatial maps and time trends.

### 30.2.1 Spatial variation



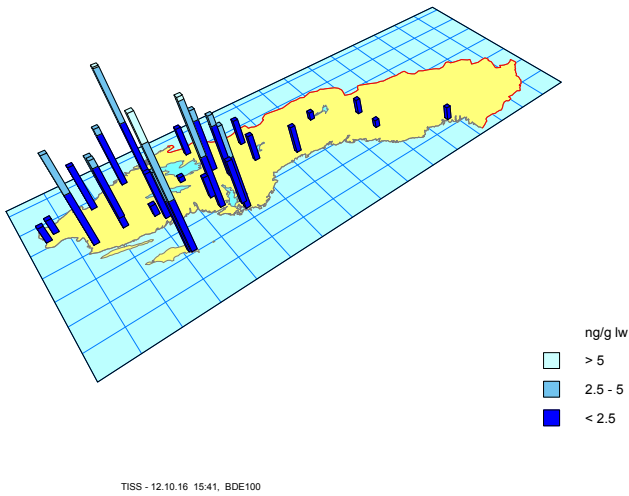
**Figure 30.1.** Spatial variation in concentration (ng/g lipid weight) of BDE-47 in perch muscle.

### BDE99, perch muscle



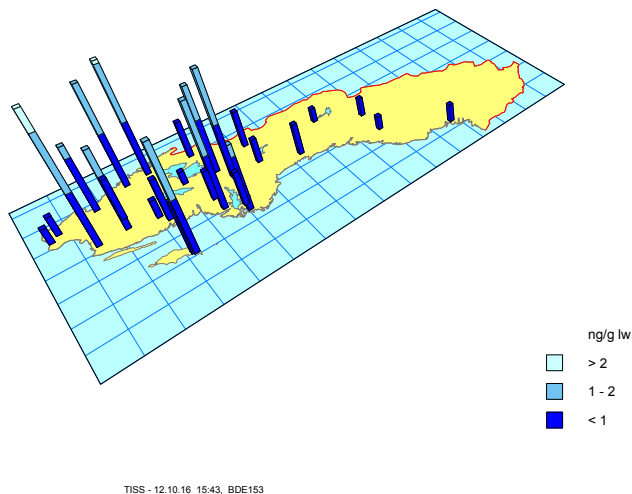
**Figure 30.2.** Spatial variation in concentration (ng/g lipid weight) of BDE-99 in perch muscle.

### BDE100, perch muscle



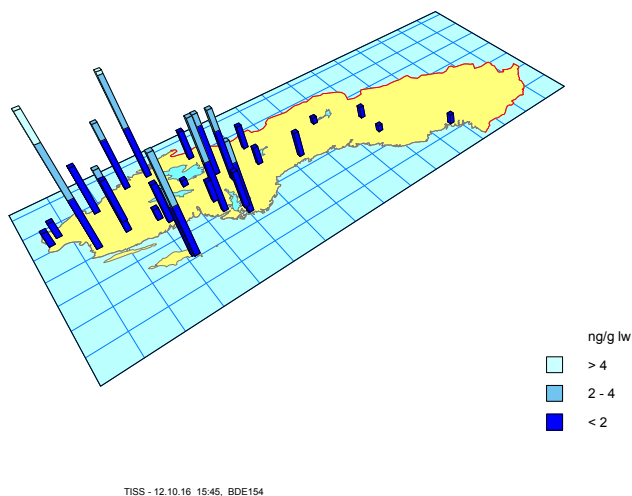
**Figure 30.3.** Spatial variation in concentration (ng/g lipid weight) of BDE-100 in perch muscle.

## BDE153, perch muscle



**Figure 30.4.** Spatial variation in concentration (ng/g lipid weight) of BDE-153 in perch muscle.

## BDE154, perch muscle



**Figure 30.5.** Spatial variation in concentration (ng/g lipid weight) of BDE-154 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.

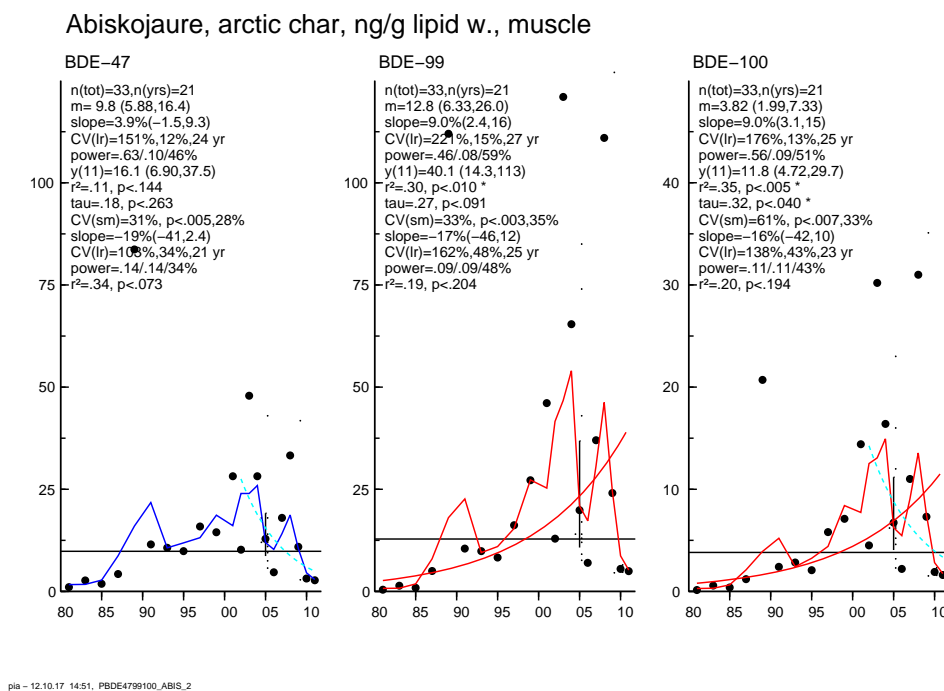
The highest concentration of BDE-47 in perch muscle was found in Lake Bästeträsk in Gotland (19 ng/g lw) in 2009-2011, and the lowest

concentration in Lake Svartsjön (0.75 ng/g lw) in Västra Götaland County (Fig. 30.1).

### 30.2.2 Temporal variation

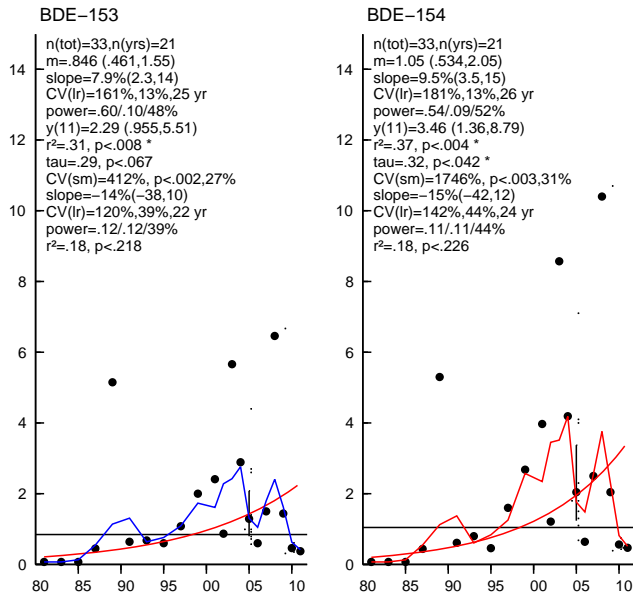
No general linear trend is observed during the whole monitoring period for the BDEs in arctic char from Lake Abiskojaure (1980-2011) and in pike from Lake Bolmen (1966-2011). However the concentrations of BDEs in Lake Bolmen increased from the start of the monitoring period until the late 80s to the 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 11-25 years for the char and pike time series.



**Figure 30.6.** BDE-47, -99, -100 concentrations (ng/g lipid weight) in arctic char muscle from Lake Abiskojaure.

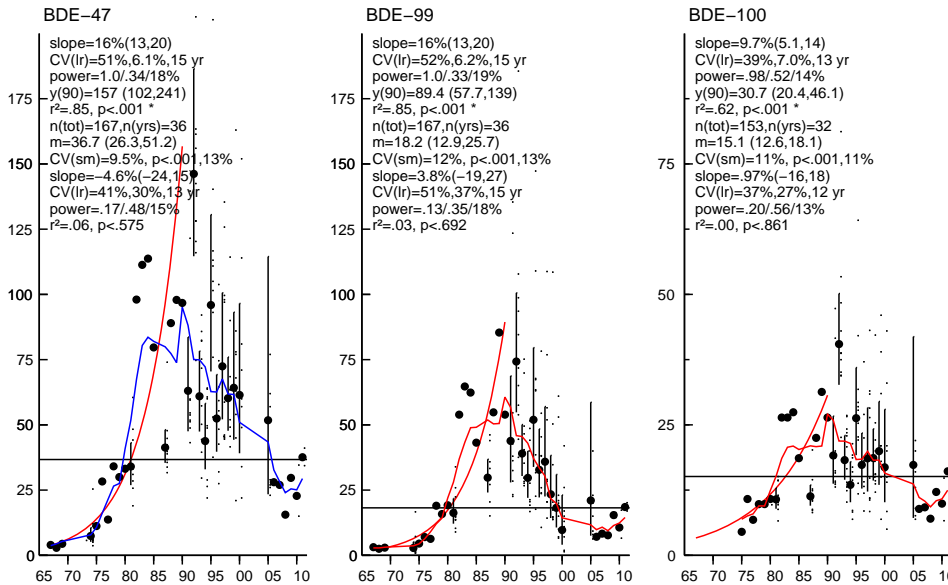
Abiskojaure, arctic char, ng/g lipid w., muscle



pla - 12.10.17 14:50, PBDE153154\_ABIS\_2

Figure 30.7. BDE-153, -154 concentrations (ng/g lipid weight) in arctic char muscle from Lake Abiskojaure.

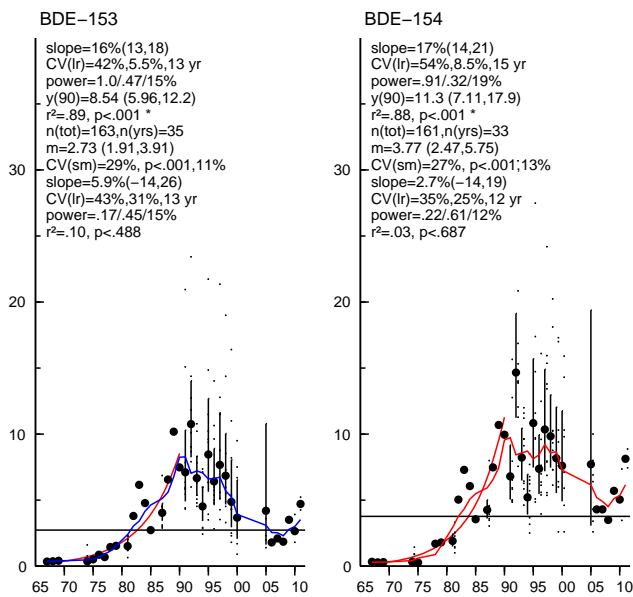
Bolmen, pike, ng/g lipid w., muscle



pla - 12.10.17 14:51, PBDE4799100\_BOLM\_2

Figure 30.8. BDE-47, -99, -100 concentrations (ng/g lipid weight) in pike muscle from Lake Bolmen.

## Bolmen, pike, ng/g lipid w., muscle



pla - 12.10.17 14:51, PBDE153154\_BOLM\_2

**Figure 30.9.** BDE-153, -154 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 Bästeträsk in Gotland in 2009-2011.

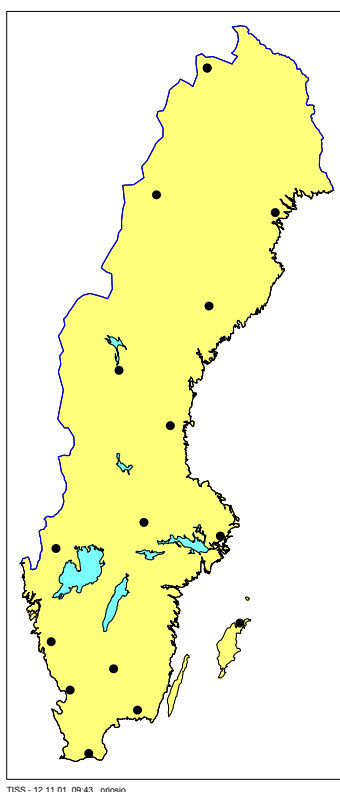
No general linear trend is observed during the whole monitoring period for the BDEs in arctic char from Lake Abiskojaure and in pike from Lake Bolmen. However the concentrations of BDEs in Lake Bolmen increased from the start of the monitoring period until the late 80s to the mid 90s and appear to have 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, 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, Sännen, and Krageholmssjön and DEHP were only analysed in Bysjön and Stensjön.



**Figure 31.1.** Lakes monitored for Chloroalkanes, Di-(2-ethylhexyl)-phthalate, Hexachlorobutadiene, Pentachlorobenzene, and Organotin compounds in 2007 and 2010. Lakes from north to south: Abiskojaure, Tjulträsket, Brännträsket, Remmarsjön, Stor-Backsjön, Stensjön, Övre Skärsjön, Tärnan, Bysjön, Lilla Öresjön, Bästeträsk, Fiolen, Stora Skärsjön, Sännen, and Krageholmssjön.



## **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).

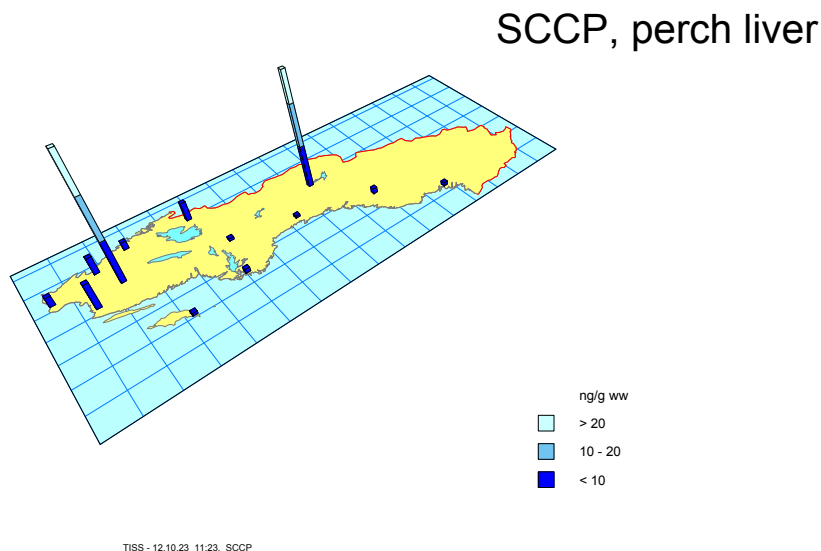
Since 2002 short-chained chlorinated paraffins has been banned in EU for usage in leader oils and for treating metals (Bergbäck & Jonsson, 2008).

### **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](http://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<sub>biota</sub> for HCBD is set to 55 ug/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 <0.1ug/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). Imposex gastropods are globally distributed and at least 195 species of prosobranch gastropods are known to be affected (reviewed in Sternberg et al., 2010). Imposex 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 Confounding factors

### 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 organic carbon content), instead of differences in contaminant load. To avoid this, it might be necessary to adjust measured concentrations of contaminants for confounding factors.

Levels of organic contaminants and metals in fish are assumed to be limited by the amount of bioavailable compound in the lake, but it is also affected by biological factors such as age, size, fat content, and growth etc. of the fish (Bignert et al. 1993, 1994; Danielsson 2007; Olsson et al. 2000). Studies have also shown that trophic position is important, and that concentrations of organic contaminants are lower in shorter food chains (Kidd et al. 1998; Larsson et al. 2000).

A side project to the freshwater monitoring programme was financed by the Swedish Environmental Protection Agency (SEPA) (NR 216 1044) to determine if adjusting for varying environmental or physiological factors is necessary, and could improve the quality of time-series and spatial trends within the monitoring program. If there are statistically significant correlations between different factors and concentrations of contaminants in fish, adjusted values would reflect the anthropogenic influence better and the variation of measurements in time-series and spatial trends would decrease.

### 32.2 Methods

#### 32.2.1 Data compilation

Data from lakes included in the Swedish National Monitoring Programme for Contaminants in Freshwater Biota (SNMPCFB) were used in this study. Only contaminant data in perch (*Perca fluviatilis*) was used to avoid confusion caused by species differences. Data was compiled from different sources - organic contaminant data came from The Swedish Museum of Natural History (SMNH), while water chemistry data came from the

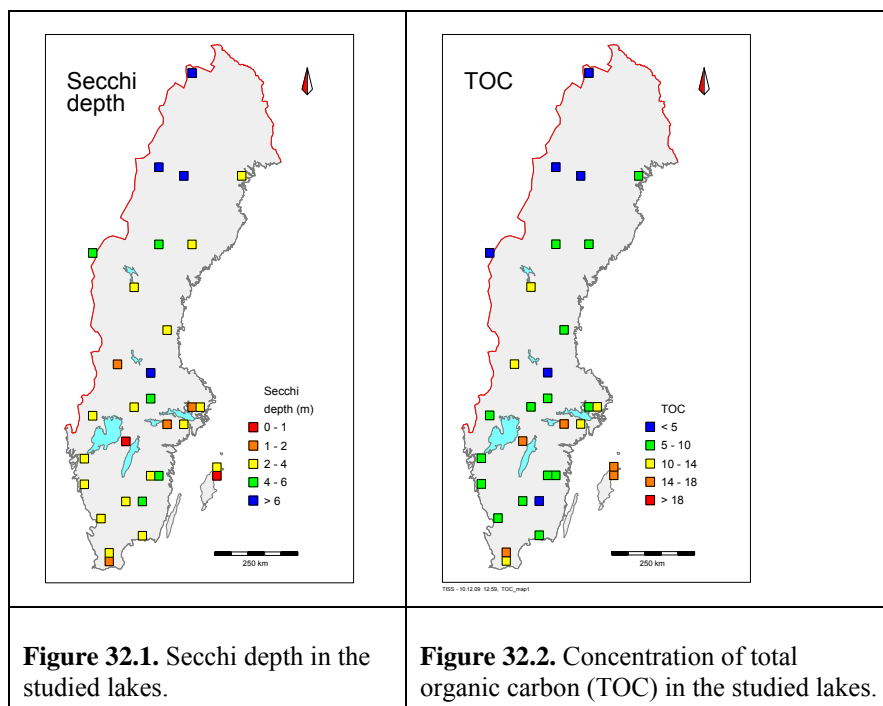


Swedish University of Agricultural Science (<http://www.slu.se>). For the water chemistry, only data from August were used, as this was the only month where data was consistent for all lakes and since this is also the month when fish is usually sampled. If there were several values collected within August for a single year, an arithmetic mean was calculated for the measured values at 0 to 2 m depth. As contaminant data is often right skewed, geometric means were calculated per substance and lake for each year. The physiological data of the fish also came from SMNH.

### 32.2.2 Statistical analysis

**Environmental factors** Data was analysed using multiple linear regression (Sokal & Rohlf 1982). All water chemistry variables (secchi depth, temp, pH, SO<sub>4</sub>, conductivity, alkalinity, absorbance, PO<sub>4</sub>P, NO<sub>2</sub>N, NO<sub>3</sub>N, NH<sub>4</sub>N, silica and chlorophyll a) were tested against one contaminant at a time. The time period was limited to 2000 - 2008 to reduce the influence of changes over longer periods of time. A 5 % level of significance was used. At the starting point, all the water chemistry variables were included in the regression. Those that were non-significant were removed stepwise. In the end, only those variables that were significant were included in the analysis. Lakes in the SNMPCFB have been chosen to represent lakes that are not influenced by local sources (Gustavsson et al. 2009). We therefore assume that the majority of the contaminant load is due to air deposition from diffuse sources. For many of the contaminants there is a gradient in concentrations from north to south, with lower concentrations observed in the north of Sweden (see example in figure 13.1, 14.1, 29.1-5). Many of the studied water chemistry variables also have a geographical gradient, such as temperature, pH, TOC and secchi depth (see examples in figure 31.1 and 31.2). North and east coordinates were therefore included in the regression analysis as independent variables to eliminate the possibility to detect trends that only depend on spatial differences. Lake Fysingen was excluded because of high conductivity values and in many cases a different congener pattern of contaminants (e.g., PCBs) in fish.

**Physiological factors** The evaluation of physiological confounding factors was done using simple linear regression, where the contaminant concentration in each individual fish was regressed against biological variables e.g., age, condition, liver somatic index, percent dry weight in liver (LTPRC), percent dry weight in muscle (MTPRC) and lipid content in the muscle (FPRC). The condition (K) was calculated as  $100W/L^3$ , where W is body weight (g), and L is total length (cm). The liver somatic index (LSI) was calculated as liver weight (g)/body weight (g). One regression was done for each lake. In these regressions, data from all years was included. The contaminant concentration and the physiological variables were normalized to the mean of each year to eliminate correlations that might depend on temporal trends.



## 32.3 Results

### 32.3.1 Environmental confounding factors

In table 31.1-4, significant ( $p < 0.05$ ) water chemistry variables are shown for each group of environmental contaminants, with standardized  $\beta$ -value,  $R^2$ -value and  $p$ -value. The standardized  $\beta$ -value was calculated to make possible to compare different variables with different units. Coordinates have been kept in the model throughout the analysis even though they have not always been significant, but they were not included in a later adjustment of concentrations.

For the PFAS group, it was not possible to see any general trends of significant confounding factors (table 31.1). The studied PCB congeners all show significant relationships with pH, alkalinity and sulfate. All of the PCB congeners are significantly related to north and east coordinates (table 31.2). DDE and  $\alpha$ -HCH both show significant positive relationships with temperature and for DDE, also sulfate (table 31.2). The group of PBDEs show overall negative relationships with alkalinity and absorbance. Within this group, all congeners are also significantly negatively related with north coordinates (table 31.3). For metals, the relationships found are quite diverse for the different metals (table 31.4).

**Table 32.1.** Results for PFAS.

<b>Compound</b>	<b>Independent variable</b>	<b>Standardised beta coefficients</b>	<b>R<sup>2</sup> (adjusted for degrees of freedom)</b>	<b>p-value</b>
PFOS (perfluorooctanesulfonate)	North coordinate	-0.35	0.22	0.01
	TOC	-0.35		0.00
PFDCA (perfluorodecanoate)	East coordinate	0.35	0.10	0.03
	TOC	-0.26		0.05
	conductivity	3.26		0.01
	alkalinity	-2.52		0.01
PFDOA (perfluorododecanoate)	SO <sub>4</sub>	-0.98	0.18	0.00
	pH	-0.42		0.04
PFTEA (perfluorotetradecanoate)	temp	0.23	0.15	0.03
	Secchi depth	0.27		0.03
PFTRIA (perfluorotridecanoate)	pH	-0.28	0.30	0.01
	North coordinate	-0.39		0.00
	alkalinity	-0.46		0.03
	SO <sub>4</sub>	-0.30		0.02
PFUNA (perfluoroundecanoate)	absorbance	-0.26	0.09	0.05
	North coordinate	-0.30		0.04
	TOC	-0.25		0.04
	SO <sub>4</sub>	-0.29		0.04

**Table 32.2.** Results for chlorinated organic compounds, PCBs, a-HCH, DDTs.

<b>Compound</b>	<b>Independent variable</b>	<b>Standardised beta coefficients</b>	<b>R<sup>2</sup> (adjusted for degrees of freedom)</b>	<b>p-value</b>
CB-101	North coordinate	-0.37	0.34	0.02
	East coordinate	0.31		0.02
	pH	0.45		0.02
	alkalinity	-0.91		0.00
	SO <sub>4</sub>	0.54		0.00
CB-118	North coordinate	-0.40	0.34	0.02
	East coordinate	0.40		0.00
	pH	0.45		0.02
	alkalinity	-0.85		0.00
	SO <sub>4</sub>	0.49		0.01
CB-138	North coordinate	-0.36	0.34	0.02
	East coordinate	0.36		0.01
	alkalinity	-0.65		0.00
	SO <sub>4</sub>	0.61		0.00
CB-153	North coordinate	-0.33	0.27	0.04
	East coordinate	0.36		0.01
	alkalinity	-0.57		0.00
	SO <sub>4</sub>	0.56		0.00
CB-180	North coordinate	-0.42	0.29	0.01
	East coordinate	0.37		0.01
	alkalinity	-0.57		0.00
	SO <sub>4</sub>	0.49		0.01
a-HCH	temp	0.33	0.12	0.02
DDE	temp	0.34	0.34	0.00
	SO <sub>4</sub>	0.55		0.00

**Table 32.3.** Results for brominated flame retardants, PBDEs.

<b>Compound</b>	<b>Independent variable</b>	<b>Standardised beta coefficients</b>	<b>R<sup>2</sup> (adjusted for degrees of freedom)</b>	<b>p-value</b>
BDE-47	North coordinate	-0.48	0.19	0.00
	alkalinity	-0.34		0.01
	absorbance	-0.24		0.04
BDE-99	North coordinate	-0.49	0.37	0.00
	alkalinity	-0.52		0.00
	absorbance	-0.30		0.00
BDE-100	North coordinate	-0.53	0.26	0.00
	alkalinity	-0.44		0.00
	absorbance	-0.26		0.02
BDE-153	North coordinate	-0.45	0.35	0.00
	alkalinity	-0.49		0.00
	absorbance	-0.26		0.01
BDE-154	North coordinate	-0.51	0.30	0.00
	alkalinity	-0.46		0.00
	absorbance	-0.25		0.02

**Table 32.4.** Results for metals.

Compound	Independent variable	Standardised beta coefficients	R <sup>2</sup> (adjusted for degrees of freedom)	p-value
Aluminum	pH	-0.58	0.61	0.00
	TOC	-0.18		0.02
	NO <sub>2</sub> /NO <sub>3</sub>	0.35		0.00
Arsenic	North coordinate	0.87	0.26	0.00
	SO <sub>4</sub>	0.96		0.00
	PO <sub>4</sub>	-0.28		0.05
Cadmium	North coordinate	-0.53	0.28	0.00
	alkalinity	-0.57		0.00
Chromium	North coordinate	0.51	0.16	0.00
	Si	-0.32		0.00
	chlorophyll	0.31		0.01
Copper	North coordinate	-0.44	0.43	0.00
	TOC	-0.18		0.04
	conductivity	-0.22		0.04
	NH <sub>4</sub> N	-0.30		0.01
	N:P	0.52		0.00
	absorbance	0.24		0.03
Nickel	North coordinate	0.35	0.14	0.01
	absorbance	0.20		0.05
Lead	North coordinate	-0.33	0.40	0.00
	pH	-0.71		0.00
	absorbance	-0.18		0.04
	chlorophyll	0.22		0.04
Zinc	North coordinate	-0.31	0.29	0.01
	conductivity	-0.45		0.00
	N:P	0.34		0.00
Mercury	East coordinate	0.66	0.41	0.00
	Secchi depth	-0.43		0.01
	pH	-0.44		0.02
	conductivity	3.12		0.00
	alkalinity	-2.77		0.00
	SO <sub>4</sub>	-0.77		0.01
	absorbance	-0.45		0.01

### 32.3.2 Physiological factors

A combination of contaminants and physiological variables were regressed against each other (table 31.5). The combination of variables that show the greatest number of significant relationships is age against mercury, cadmium and aluminum. Increasing concentration with age occurs for these metals. The results from the regressions for age against cadmium and mercury for Lakes Fiolen and Hjärtsjön are shown in table 31.6. The  $\beta$ -values from these regressions were used to adjust the time series for these lakes. Results are shown in table 31.6 and figures 31.3 and 31.4. The contaminant concentrations were adjusted to represent the mean age of the fish in each lake. The results from the age-adjusted time series give somewhat different results. For mercury in Lake Fiolen, there is a decrease in (CV) and also in the number of years it would take to detect a change of 10%. For Hjärtsjön there is no difference in the mercury time-series when

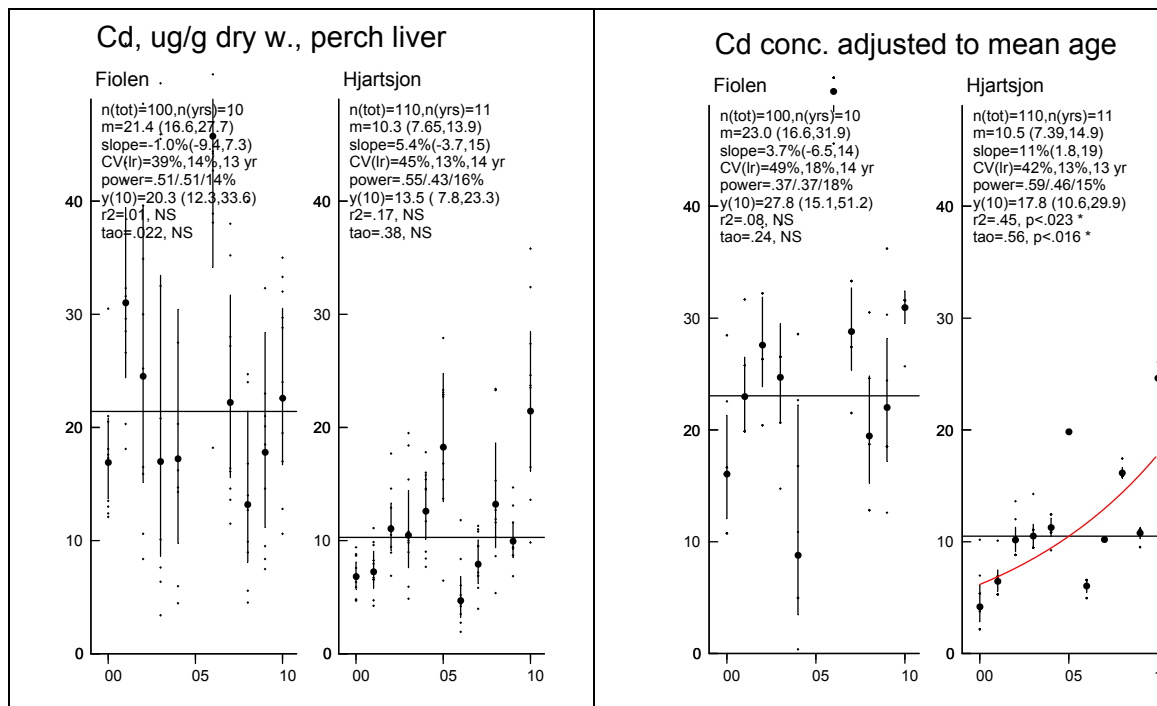
adjusted for age. For cadmium, an improvement is seen in Lake Hjärtsjön but not in Lake Fiolen with age adjustment.

**Table 32.5.** Combinations of contaminants and physiological confounding factors tested. For each combination the total number of analyzed lakes (*n*), is shown.

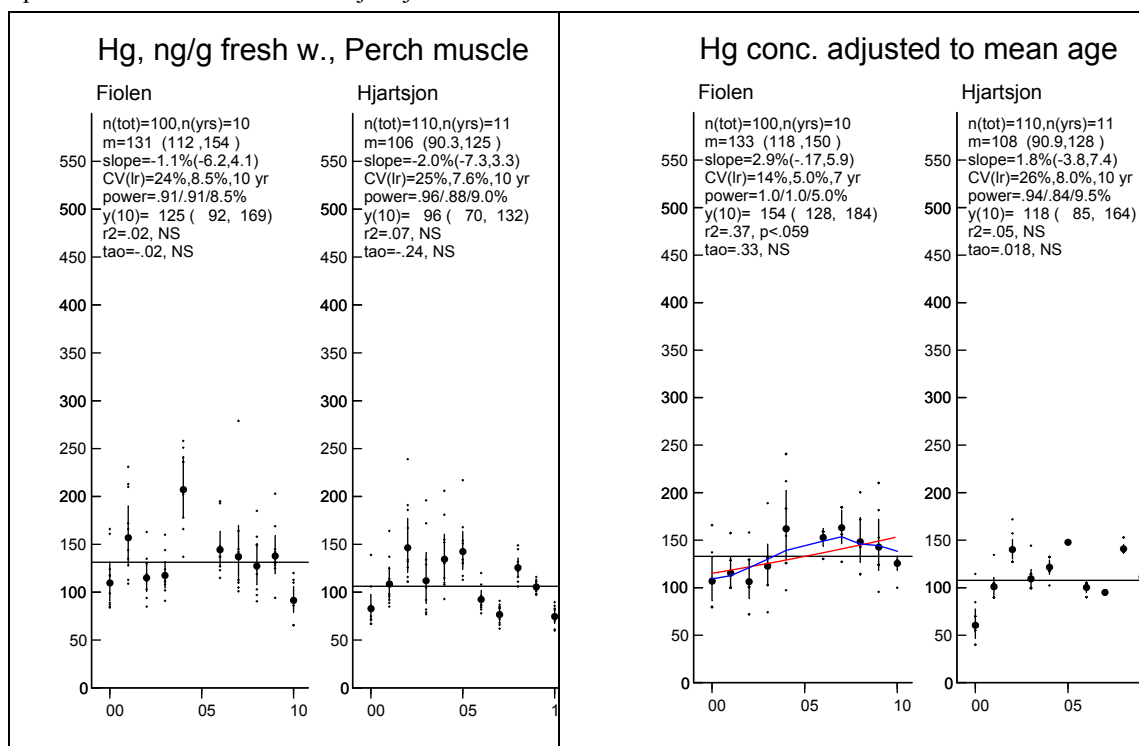
<b>Compound</b>	<b>age</b>	<b>condition</b>	<b>LSI</b>	<b>LTPRC</b>	<b>MTPRC</b>	<b>% lipids</b>
	<i>lakes (n)</i>	<i>lakes (n)</i>	<i>lakes (n)</i>	<i>lakes (n)</i>	<i>lakes (n)</i>	<i>lakes (n)</i>
<b>Silver</b>	24	25	21	25		
<b>Mercury</b>	21	27	26		27	
<b>Cadmium</b>	24	27	20	8		
<b>Aluminium</b>	25	26	21	25		
<b>Arsenic</b>	26	26	21	25		
<b>Vismuth</b>	25	25	19	24		
<b>Lead</b>	24	23	21	23		
<b>Tin</b>	12	16	14	15		
<b>Zinc</b>	27		24			
<b>DDE</b>	7	9	3			9
<b>CB-153</b>	4	4				4

**Table 32.6.** Results from the unadjusted and age-adjusted time series of cadmium and mercury in Lakes Fiolen and Hjärtsjön.

<b>Compound</b>	<b>Lake</b>	<b><math>\beta</math>-value for adj</b>	<b>mean age</b>	<b>CV %</b>	<b>lowest detectable trend %</b>	<b>n years for 10% change</b>
<b>Mercury</b>	Fiolen - unadj	28.7	5.0	24	8.5	10
	Hjärtsjön - unadj	14.9	4.2	25	7.6	10
	Fiolen - adj			14	5	7
	Hjärtsjön - adj			26	8	10
<b>Cadmium</b>	Fiolen - unadj	5.9	5.0	39	14	13
	Hjärtsjön - unadj	1.6	4.2	45	13	14
	Fiolen - adj			49	18	14
	Hjärtsjön - adj			42	13	13



**Figure 32.3.** Time trends of unadjusted (left) and age-adjusted (right) cadmium levels in perch from Lakes Fiolen and Hjartsjön.



**Figure 32.4.** Time trends of unadjusted (left) and age-adjusted (right) mercury levels in perch from Lakes Fiolen and Hjartsjön.

## 32.4 Discussion

For the PCBs, significant relationships with pH, alkalinity and sulphate were found. These variables are all associated with acidification (Bydén et al. 1996). The influence of acidification on the bioavailability of organic contaminants is sparsely studied and it is difficult to explain these results. For the PBDEs, alkalinity, absorbance and sulphate show significant negative relationships. Ford and Young (1994) discusses that acidification could have an effect on the carbon-dynamics of lakes, and because of that, also have an effect on the bioavailability of organic contaminants (Ford and Young 1994; summarised in Mackay & Wania 1999). When modelling the partitioning of neutral organic contaminants in the environment, the amount of organic carbon in the different compartments are regularly accounted for, but factors such as pH and alkalinity are usually not considered (Mackay & Fraser 2000). In this study however, the amount of total organic carbon (TOC) did not seem to be an important factor. For PFAS and the metals, the relationships were not consistent within groups.

The variables that stand out as significant in multiple regressions do not necessarily indicate a causal effect. All of the water chemistry variables are basically related to each other, but also with variables that have not been studied here. A studied variable can therefore act as a proxy for another variable. A variable that has been included in the analysis can partially absorb explanation capacity from another variable that may have been more appropriate from an explanatory point of view, but gets a lower explanation value.

Heavy metals bioaccumulate, and positive relationships of mercury concentration with age and size of perch have been found in other studies (Berninger & Pennanen 1995; Ion et al. 1997; Sonesten 2003a, b). The need to adjust mercury concentrations for these factors has been discussed. Within the SNMPCFB, the collected fish are selected according to size, but sometimes differ in age. The size range is therefore too small to investigate any relationship between mercury concentration and fish size. Age-adjustment would therefore be more appropriate in this case. The relatively weak and inconsistent results of the physiological variables and the organic contaminants could be due to the sparse data set from individual fish for the chlorinated organic compounds.

The  $R^2$ -values of the regressions are relatively low in this study. A low  $R^2$ -value indicates that there are other factors besides the investigated variables, which explain variation of contaminant concentrations within the sample group.

The found relationships require further investigation to be able to implement the results and to calculate correction factors for confounding factors. There are many uncertainties in the relationships found, e.g., that contaminant load at different lakes is unknown. To be able to correct for confounding factors there is a need to evaluate if the correlations found are strong enough, and if



the gain with adjustment is large enough compared to the added uncertainty. It is also important to evaluate if the relationships found are even possible from an environmental chemistry point of view. If contaminant concentrations are corrected for confounding factors and then compared to target levels it is important to remember for what purpose and how the target levels were set. To evaluate environmental status and contaminant load on a specific area or for temporal trends, it could be useful to correct for covariates. Also, when regional differences between monitored regions are to be evaluated, adjusting for geographical differences by considering confounding factors can be helpful. However, if the aim is to protect the most sensitive species or humans from being exposed to contaminants the values should not be corrected.

### 33 References

- Agency for Toxic Substances and Disease Registry (ATSDR). 2000. Toxicological profile for polychlorinated biphenyls. Atlanta: US Department of Health and Human Services. 1-758
- AMAP/UNEP (2008). Technical background report to the global atmospheric mercury assessment. Arctic Monitoring and Assessment Programme/UNEP Chemicals Branch. 159 pp.
- Amin-Zaki L, Alhassani S, Majeed MA, Clarkson TW, Doherty RA, Greenwood M. 1974. Intra-uterine methylmercury poisoning in Iraq. *Pediatrics* 54(5): 587 – 595.
- Andrea, C. 2005. Breaking tolerance to nickel. *Toxicology* 209, 119-121.
- Apelberg BJ., Witter FR., Herbstman JB., Calafat AM., Halden RU., Needham LL., Goldman LR. 2007. Cord serum concentrations of Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoate (PFOA) in relation to weight and size at birth. *Environmental health perspectives* 115 (11):1670-1676.
- Arnot JA., McCarty LS., Armitage J., Toose-Reid L., Wania F., Cousins I. 2009. An evaluation of hexabromocyclododecane (HBCD) for persistent organic pollutant (POP) properties and the potential for adverse effects in the environment. Available at: <http://chm.pops.int/Convention/POPsReviewCommittee/hPOPRCMeetings/POPRC5/POPRC5Documents/tabid/592/language/en-US/Default.aspx>.
- Aulerich RJ., Ringer RK. 1977. Current status of PCB toxicity to mink, and effect on their reproduction. *Arch. Environm. Contam. Toxicol.* 6: 279-292.
- Banks WA., Kastin AJ. 1989. Aluminium-Induced neurotoxicity: Alterations in membrane function at the blood-brain barrier. *Neuroscience & Biobehavioral Reviews* 13: 47-53.
- Bengtsson B-E. 1975. Accumulation in cadmium in some aquatic animals from the Baltic Sea. In: 3rd Soviet-Swedish Symp. on the Baltic Sea pollution, Stockholm. NBL-report.
- Bergbäck B., Anderberg S., Lohm U. 1992. Lead load: Historical pattern of lead use in Sweden. *Ambio* 21(2): 159 – 165.
- Bergbäck B., Jonsson A. (red) 2008. Stockholms väg mot en giftfri miljö. ISBN 978-91-85125-27-2 (in Swedish)
- Berger U., Glynn A., Holmström KE., Berglund M., Halldin Ankarberg E., Törnkvist A. 2009. Fish consumption as a source of human exposure to perfluorinated alkyl substances in Sweden – Analysis of edible fish from Lake Vättern and the Baltic Sea. *Chemosphere*. 76(6): 799-804.
- Bergström S., Matthäus W. 1996. Meteorological and hydrographical conditions. In: 3<sup>rd</sup> Periodic Assessment of the State of the Marine Environment of the Baltic Sea, 1989-93. HELCOM, No 64B.
- Berlin M., Zalups RK., Fowler BA. 2007. Mercury. Chapter 33 *in*: (eds). Nordberg GF, Fowler BA, Nordberg M, Friberg L. Handbook on the toxicology of metals 3<sup>rd</sup> ed. ISBN 978-0-12-3694213-3. Academic Press Publishers, Elsevier. 943pp

- Berninger K., Peannanen J. 1995. Heavy metals in perch (*Perca fluviatilis* L.) from two acidified lakes in the Salpausselkä Esker area in Finland. *Water, Air and Soil Pollution* 81: 283-294.
- Bignert A., Göthberg A., Jensen S., Litzen K., Odsjö T., Olsson M., Reutergårdh L. 1993. The need for adequate biological sampling in ecotoxicological investigations: a retrospective study of twenty years pollution monitoring. *The Science of the Total Environment*, 128:121-139.
- Bignert A., Olsson M., de Wit C., Litzen K., Rappe Ch., Reutergårdh L. 1994. Biological variation – an important factor to consider in ecotoxicological studies based on environmental samples. *Fresenius Journal of Analytical Chemistry*. 348:76-85.
- Bignert A., Danielsson S., Nyberg E., Asplund L., Eriksson U., Berger U., Haglund P. 2010. Comments Concerning the National Swedish Contaminant Monitoring Programme in Marine Biota, 2010. Report to the Swedish Environmental Protection Agency. Report nr 1:2010 154 pp.
- Bleavins MR., Aulerich RJ., Ringer RK. 1980. Polychlorinated biphenyls (Aroclors 1016 and 1242): Effects on survival and reproduction in mink and ferrets. *Arch. Environm. Contam. Toxicol.* 10: 1432-0703.
- Boalt E., Dahlgren H., Miller A. 2011. Cadmium, lead and mercury concentrations in whole-fish, liver, and muscle concentrations of herring (*Clupea harengus*) and perch (*Perca fluviatilis*). Product of the Fourth HELCOM CORESET Expert Workshop on Hazardous Substances Indicators (HELCOM CORESET HS 4/2012), Stockholm, Sweden, 11-12 January 2012
- Borch J., Broeng Metzдорff S., Vinggaard AM., Brokken L et al. 2006. Mechanisms underlying the anti-androgenic effects of diethylhexyl phthalate in fetal rat testis. *Toxicology* 223(1-2):144-155
- Borg H., Andersson P. and Johansson K. 1988. Influence of Acidification on Metal Fluxes in Swedish Forest Lakes. *The Science of the Total Environment*, 87/88 (1989) 241-253.
- Bouquegneau J. M., Gerdy Ch. and Disteche A. 1975. Fish mercury-binding thionein related to adaption mechanism. *FEBS Lett.* 55:173-177.
- Bowdler NC., Beasley DS., Fritze EC., Goulette AM., Hatton JD., Hession J., Ostman DL., Rugg DJ. Schmittiel CJ. 1979. Behavioral effects of aluminium ingestion on animal and human subjects. *Pharmacology Biochemistry and Behavior* 10:505-512.
- Buck RC., Franklin J., Berger U., Conder JM., Cousins IT., de Voogt P., Jensen AA., Kannan K., Mabury SA., van Leeuwen SP. 2011. Perfluoroalkyl and polyfluoroalkyl substances (PFASs) in the environment: terminology, classification, and origins. *Integr. Environ. Assess. Manag.* 7 (4): 513-541.
- Bydén S., Larsson A-M., Olsson M. 1996. Mäta vatten – undersökningar av sött och salt vatten. Institutionen för tillämpad miljövetenskap, Göteborgs universitet. Andra upplagan, pp 1-96. ISBN 91-88376-07-9.
- Burguera JL., Burguera M., Rivas C., Rondon C., Carrero P., Gallignani M. (1999) Determination of bismuth in biological samples using on-line flow-injection microwave-assisted mineralization and precipitation/dissolution for electrothermal atomic absorption spectrometry. *Talanta* 48(4): 885-893.

- Calvert JB. 2007. <http://mysite.du.edu/~jcalvert/phys/mercury.htm#Prod> Calver JB 2002, latest revision 2007, accessed March 9<sup>th</sup> 2011.
- Carnevali O., Tosti L., Speciale C., Peng C., Zhu Y., Maradonna F. 2010. DEHP impairs zebrafish reproduction by affecting critical factors in oogenesis. *PLoS one* 5(4): e10201
- Carpenter DO. 1998. Polychlorinated biphenyls and human health. *Int J Occup Med Environ Health*. 11: 291-303.
- Carpenter DO. 2006. Polychlorinated Biphenyls (PCBs): Routes of Exposure and Effects on Human Health. *Rev Environ Health*. 21(1): 1-23.
- Cato I., Magnusson M., Granmo Å., Borgegren A. 2007. Organiska tennföreningar – ett hot mot livet i våra hav. In: *Havet 2007*. Viklund K., Tidlund A., Brenner U., Lindblom R. (eds) Grafiska punkten, Växjö. P. 77-81. (In Swedish)
- Cempel M., Nikel G. 2006. Nickel: a review of its sources and environmental toxicology. *Polish J. of Environ. Stud* 15: 375-382.
- Choi SC., Bartha R. 1994. Environmental factors affecting mercury methylation in estuarine sediments. *Bulletin of Environmental Contamination and Toxicology* 53: 805 – 812.
- CIRCA's website 2010-05-11 Substance data sheet, priority substance No. 16  
Hexachlorobenzene  
[http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework\\_directive/i-priority\\_substances/supporting\\_background/substance\\_sheets/hxchlbenzene\\_eqsd\\_atashee/EN\\_1.0\\_&a=d](http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/i-priority_substances/supporting_background/substance_sheets/hxchlbenzene_eqsd_atashee/EN_1.0_&a=d)
- Clarkson TW. 1992. Mercury: Major issues in environmental health. *Environmental Health Perspectives* 100: 31 – 38.
- Cook RS., Trainer DO (1966). Experimental lead poisoning of Canada geese. *Journal of Wildlife Management* 30(1): 1 – 8.
- Cook RS., Trainer DO. 1966. Experimental lead poisoning of Canada Geese. *The Journal of Wildlife Management* 30(1): 1 – 8.
- Council TB., Duckenfield KU., Landa ER., Callender E. 2004. Tire-Wear Particles as a Source of Zinc to the Environment. U.S. Geological Survey, MS 430, 12201 Sunrise Valley Drive, Reston, Virginia 20192 Environmental Science and Technology 38 (15): 4206–4214. DOI: 10.1021/es034631f
- Covaci A., Gerecke AC., Law RJ., Voorspoels S., Kohler M., Heeb NV., Leslie H., Allechin CR., de Boer J. 2006. Hexabromocyclododecanes (HBCDs) in the environment and humans: A review. *Environmental Science & Technology* 40:3679-3688.
- Danielsson L-G., Magnusson B., Westerlund S. and Kerong Z. 1983. Trace metals in the Göta River estuary. *Estuar. Coast. Shelf Sci*. 17: 73-85.
- Danielsson C., Wiberg K., Korytar P., Bergek S., Brinkman U.A., Haglund P. 2005. Trace analysis of polychlorinated dibenzo-p-dioxins, dibenzofurans and WHO polychlorinated biphenyls in food using comprehensive two-dimensional gas chromatography with electron-capture detection. *Journal of Chromatography A*. 1086: 61-70.
- Danielsson S. 2007. Impact of biological factors in monitoring of contaminants in Perch (*Perca fluviatilis* L.). Degree project in biology 20p, Department of Biology Education, Stockholm University and The Swedish Museum of Natural History.

- Darnerud P-O. 2008. Brominated flame retardants as possible endocrine disruptors. *International Journal of Andrology* 31: 152-160.
- Das AK., Chakraborty R., Cervera ML., de la Guardia M. 2006 Analytical techniques for the determination of bismuth in solid environmental samples. *TrAC Trends in Analytical Chemistry* 25(6): 599-608.
- Da Silva DS., Lucotte M., Roulet M., Poirier H., Mergler D., Oliveriera Santos E., Crossa M. 2005. Trophic structure and bioaccumulation of mercury in fish of three natural lakes of the Brazilian Amazon. *Water, Air and Soil Pollution* 165: 77 – 94.
- da Silva F., Williams RJP. 1994. *The Biological Chemistry of the Elements. The Inorganic Chemistry of Life.* Clarendon Press. Oxford.
- de Lopez Camelo LG., de Miguez SR. Marban L. 1997. Heavy metals input with phosphate fertilizers used in Argentina. *The Science of the Total Environment* 204: 245-250.
- Denkhaus E., Salnikow K. 2002. Nickel essentiality, toxicity, and carcinogenicity. *Critical Reviews in Oncology/Hematology* 42: 35-56.
- Doetzel LM. 2007. An investigation of the factors affecting mercury accumulation in lake trout, *Salvelinus namaycush*, in Northern Canada. Unpublished PhD thesis, University of Saskatchewan. 141 pp.
- Domy CA. 2001. Trace elements in terrestrial environments: biogeochemistry, bioavailability, and risks of metals. In *Chromium*, pp. 315-348: Springer-Verlag New York Inc.
- Dorsey A., Ingerman L., Swartz S. 2004. Toxicological profile for copper. U.S. Dept of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. 314 pp. Public Report.  
<http://www.atsdr.cdc.gov/toxprofiles/tp132.pdf>
- Draggan S. 2008. "Public Health Statement for Zinc". Agency for Toxic Substances and Diseases, National Center for Environmental Health. *In: Encyclopedia of Earth.* Cleveland CJ, (ed.). (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the *Encyclopedia of Earth* September 12, 2008; Last revised Date January 11, 2011; Retrieved March 25, 2011  
<[http://www.eoearth.org/article/Public\\_Health\\_Statement\\_for\\_Zinc](http://www.eoearth.org/article/Public_Health_Statement_for_Zinc)>
- EC. COM 876, 2011. Directive of the European parliament and of the council – amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy.
- EC. Directive 2008/56/EC of the European parliament and of the council. Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).
- EC. Commission regulation (EC) No 1881/2006 of 19 December 2006. Setting maximum levels for certain contaminants in foodstuffs.
- EC. Directive 2008/105/EC of the European parliament and of the council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council

- EG. 2002. KOMMISSIONENS FÖRORDNING (EG) nr 221/2002 av den 6 februari 2002 om ändring av förordning (EG) nr 466/2001 om fastställande av högsta tillåtna halt för vissa främmande ämnen i livsmedel (in Swedish).
- Eisler R. 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review., (ed., pp. 60 pp): U.S. fish and wildlife service biological.
- Eisler R. 1994. A review of arsenic hazards to plants and animals with emphasis on fishery and wildlife resources. *In: Arsenic in the environment, Part 2: Human Health and Ecosystem Effects.* Nriagu JO, (ed.). John Wiley & Sons, Inc. Pp 185 – 261.
- Eisler R. 1996. Silver hazards to fish, wildlife and invertebrates: A synoptic review. Contaminant Hazards Review Report 32. National Biological Service, U.S. Department of the Interior, Washington, USA.
- Eisler R. 2007. Eisler's encyclopedia of environmentally hazardous priority chemicals. Elsevier, UK. 821 pp.
- Encinar JR., Villar MIM., Santamaría VG., Alonso JIG., Sanz-Medel A. Simultaneous determination of Mono-, Di-, and Tributyltin in sediments by isotope dilution analysis using gas chromatography – ICPMS. *Anal Chem* 73:3174-3180.
- Eriksson P., Fischer C., Fredriksson A. 2006. Polybrominated diphenyl ethers, a group of brominated flame retardants, can interact with polychlorinated biphenyls in enhancing developmental neurobehavioural defects. *Toxi. Sci.* 94(2): 302-309.
- Eriksson P., Fisher C., Wallin M., Jakobsson E., Fredriksson A. 2006. Impaired behavior, learning and memory, in adult mice neonatally exposed to hexabromocyclododecane (HBCDD). *Environmental Toxicology and Pharmacology* 21:317-322
- Eriksson U., Johansson A., Litzén K., Häggberg L., Winberg A., Zakrisson S. 1994. Analysmetod för bestämning av klorerade organiska miljögifter i biologiskt material. ITM rapport 18
- Esbjörnsson C. 2002. Pentaklorbensen och triklorbensen. Redovisning från nationell miljöövervakning 2002. Naturvårdsverket. (In Swedish)
- EU 2006. Directive 2006/12/EG of the European parliament and of the council of 3 February 2006
- European Communities. 2002. Ambient air pollution by mercury (Hg) Position paper. 17 Oct 2001. Prepared by the Working Group on Mercury. ISBN 92-894-4260-3.
- Faiz A., Weaver CS., Walsh MP. 1996. Air pollution from motor vehicles – Standards and technologies for reducing emissions. ISBN: 0-8213-3444-1. The International bank for Reconstruction and Development, Washington DC, USA. 245 pp.
- Farago ME., Thornton I., White ND., Tell I., Mårtensson MB. 1999. Environmental impacts of a secondary lead smelter in Landskrona, Southern Sweden. *Environmental Geochemistry and Health* 21: 67 – 82
- Fei C., McLaughlin JK., Lipworth L., Olsen J. 2008b. Prenatal exposure to Perfluorooctanoate (PFOA) and Perfluorooctanesulfonate (PFOS) and maternally reported developmental milestones in infancy. *Environmental health perspectives* 116 (10):1391-1395.

- Fei C., McLaughlin JK., Tarone RE., Olsen J. 2007. Perfluorinated chemicals and fetal growth: a study within the Danish national birth cohort. *Environmental health perspectives* 115 (11):1677-1682.
- Fei C., McLaughlin JK., Tarone RE., Olsen J. 2008a. Fetal growth indicators and Perfluorinated chemicals: a study in the Danish national birth cohort. *American journal of epidemiology* 168:66-72.
- Fernie KJ., Shutt JL., Letcher RJ., Rithcie IJ., Bird DM. 2009. Environmentally relevant concentrations of DE-71 and HBCD alter eggshell thickness and reproductive success of American kestrels. *Environ. Sci. Technol.* 43:2124-2130.
- Garnaga G., Wyse E., Azemard S., Stankevicius A., de Mora S. 2006. Arsenic in sediment from the southeastern Baltic Sea. *Environmental Pollution* 144(3): 855 – 861.
- Gidlow DA. 2004. Lead toxicity. *Occupational Medicine* 54(2):76 – 81.
- Gilbert RO. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York.
- Godt J., Scheidig F., Grosse-Siestrup C., Ersch V., Brandenburg P., Reich A., Groneberg DA. 2006. The toxicity of cadmium and resulting hazards for human health. *Journal of Occupational Medicine and Toxicology* 1:22 doi:10.1186/1745-6673-1-22
- Gorbach SL. 1990 Bismuth therapy in gastrointestinal diseases. *Gastroenterology* 99(3): 863-75
- Goyer RA., Clarkson TW. 2001. Toxic effects of metals. In: Klaassen, Curtis D (ed). 2001. *Casarett and Doull's Toxicology - The Basic Science of Poisons (6th Edition)*. McGraw-Hill.
- Online version available at:  
[http://www.knovel.com/web/portal/browse/display?\\_EXT\\_KNOVEL\\_DISPLAY\\_bookid=956&VerticalID=0](http://www.knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=956&VerticalID=0)
- Grahn E., Karlson S., Düker A. 2006. Sediment reference concentrations of seldom monitored trace elements (Ag, Be, In, Ga, Sb, Tl) in four Swedish boreal lakes - Comparison with commonly monitored elements. *Science of the Total Environment* 367:778 - 790.
- Gustavsson N., Bignert A., Boalt E., Nyberg E., Stempa Tocca, J. Comments concerning the national Swedish contaminant monitoring programme in freshwater biota 2009. The Department of Contaminant Research, Swedish Museum of Natural History.
- Hagenaars A., Knapen D., Meyer IJ., van der Ven K., Hoff P., De Coen W. 2008. Toxicity evaluation of perfluorooctane sulfonate (PFOS) in the liver of common carp (*Cyprinus carpio*). *Aquatic toxicology* 88:155-163.
- Hamlin HJ., Guillette Jr LJ. 2010. Wildlife as sentinels of environmental impacts on reproductive health and fertility. In : Woodruff, T. J., Janssen, S., Guillette L. J. (Eds), *Environmental impacts on reproductive health and fertility*. Cambridge University Press, New York, pp 103-110.
- Hammond CR. 2004. Handbook of chemistry and physics. in 81st (ed.) *The elements*. CRC press.

- Helander B., Bignert A., Asplund L. 2008. Using raptors as environmental sentinels: monitoring the White-tailed sea eagle *Haliaeetus albicilla* in Sweden. *AMBIO*. 37(6): 425-431.
- HELCOM. 2009. Hazardous substances of specific concern to the Baltic Sea – Final report of the HAZARDOUS project. *Balt. Sea Environ. Proc. No. 119*.
- HELCOM. 2010. Baltic Sea Environment Proceedings No. 120B. Hazardous substances in the Baltic Sea. An integrated thematic assessment of hazardous substances in the Baltic Sea. 119pp.
- Helsel DR., Hirsch RM. 1995. *Statistical Methods in Water Resources, Studies in Environmental Sciences 49*. Elsevier, Amsterdam
- Hoaglin DC., Welsch RE.. 1978. The hat matrix in regression and ANOVA. *Amer. Stat.* 32:17-22.
- Holmström K., Järnberg U., Bignert A. 2005. Temporal trends of PFOS and PFOA in Guillemot Eggs from the Baltic Sea, 1968-2003. *Environ. Sci. Technol.* 39 (1): 80-84.
- Horwitz W., Albert R. 2006. The Horwitz ratio (HorRat): a useful index of method performance with respect to precision. *J.AOAC Int.* 89: 1095-1109.
- Huang P-C., Tien C-J., Sun Y-M., Hsieh C-Y., Lee C-C. 2008. Occurrence of phthalates in sediment and biota: relationship to aquatic factors and the biota-sediment accumulation factor. *Chemosphere* 73:539-544
- Huber K. 1998. Wisconsin Mercury SourceBook, chapter 1. Wisconsin Department of Natural Resources, Madison, Wisconsin.  
<http://www.epa.gov/glnpo/bnsdocs/hgsbook/> accessed 9<sup>th</sup> March 2011.
- ICES. 2008. Report of the working group on biological effects of contaminants (WGBEC). ICES CM 2008/MHC:07
- Ion J., de Lafontaine Y., Dumont P., Lapierre, L. 1997. Contaminant levels in St Lawrence River yellow perch (*Perca flavescens*): spatial variation and implications for monitoring. *Canadian Journal of Fisheries and Aquatic Sciences.* 54: 2930-2946.
- IRIS. 1991. Integrated Risk Information System. <http://www.epa.gov/iris>
- IVL. 2007. Results from the Swedish National Screening Programme 2007. Subreport 5: Silver. IVL Swedish Environmental Research Institute Ltd., report B1826.
- IVL. 2010. Bedömning av miljögiftspåverkan i vattenmiljö. IVL Rapport B 1891
- Jayasinghe R., Tsuji LJS., Gough WA., Karagatzides JD., Perera D., Nieboer E. (2004) Determining the background levels of bismuth in tissues of wild game birds: A first step in addressing the environmental consequences of using bismuth shotshells. *Environmental Pollution* 132(1): 13-20.
- Jensen S., Renberg L., Reutergårdh L. 1977. Residue analysis of sediment and sewage sludge for organochlorides in the presence of element sulfur. *Anal. Chem.* 49: 316-318.
- Jensen S., Reutergårdh L., Jansson B. 1983. Analytical methods for measuring organochlorines and methyl mercury by gas chromatography. *FAO Fish. Technical paper*, 212: 21-33.



- Jin CW., Zheng SJ., He YF., Zhou GD., Zhou ZX. 2005. Lead contamination in tea garden soils and factors affecting its bioavailability. *Chemosphere* 59(8): 1151 – 1159.
- Jones KC., Bennett BG. 1986. Exposure of man to environmental aluminium- An exposure commitment assessment *The Science of the Total Environment* 52: 65-82.
- Jorhem L., Sundström B. 1993. Levels of Lead, Cadmium, Zinc, Copper, Nickel, Chromium, Manganese and Cobalt in Foods on the Swedish Market, 1983 - 1990. *Journal of Food Composition and Analysis* 6: 223-241.
- Kasprzak, K. S., Sunderman, F. W. and Salnikow, K. 2003. Nickel carcinogenesis. *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis* 533, 67-97.
- KEMI. 2012. Kemikalieinspektionen. <http://www.kemi.se/sv/Innehall/Lagar-och-andra-regler/Reach/Tillstand-bilaga-XIV/>. Accessed October 30th 2012
- Key BD., Howell RD., Criddle CS. 1997. Fluorinated Organics in the Biosphere. *Environ. Sci. Technol.* 31 (9):2445-2454.
- Kidd K., Schindler R., Hesslein R., Muir D. 1998. Effects of trophic position and lipids on organochlorine concentrations in fishes from subarctic lakes in Yukon Territory. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 869-881.
- Kimbrough DE., Cohen Y., Winer AM., Creelman L., Mabuni, C. 1999. A Critical Assessment of Chromium in the Environment. *Critical Reviews in Environmental Science and Technology* 29:1-46.
- Klaassen CD., Rozman K. 1991. Absorption, Distribution and Excretion of Toxicants. In: Casarett and Doull's Toxicology - The Basic Science of Poisons. Pergamon Press.
- Knutzen J., Skei J. 1992. Preliminary proposals for classification of marine environmental quality respecting micropollutants in water, sediments and selected organisms. Norwegian Institute for Water Research, Report O-862602/O-89266, 22 p.
- Koren G., Bend JR. 2010. Fish consumption in pregnancy and fetal risks of methylmercury toxicity. *Canadian Family Physician* 56: October 2010.
- LaGuardia MJ., Hale RC., Harvey E. 2006. Detailed polybrominated diphenyl ether (PBDE) congener composition of the widely used penta-, -octa and deca-PBDE technical flame-retardant mixtures. *Environmental Science & Technology* 40:6247-6254.
- Larsen B., Riego J. 1990. Interference from 2,3,4,5,6-3',4'-Hexachlorobiphenyl (CB 163) in the determination of 2,3,4-2',4',5'-Hexachlorobiphenyl (CB 138) in environmental and technical samples. *International Journal of Environmental Analytical Chemistry* 40: 59 – 68.
- Larsson P., Andersson A., Broman D., Nordbäck J., Lundberg, E. 2000. Persistent organic pollutants (POPs) in pelagic environments. *Ambio*, 29(4/5): 202-209.
- Legler J. 2008. New insights into the endocrine disrupting effects of brominated flame retardants. *Chemosphere* 73(2): 216 – 222.
- Lepper P. 2005. Manual on the methodological framework to derive Environmental Quality Standards for priority substances in accordance with Article 16 of the Water Framework Directive (2000/60/EC). Fraunhofer-Institut Molecular Biology and Applied Ecology, Schmallingenberg, Germany.

- Liljelind P., Soederstroem G., Hedman B., Karlsson S., Lundin L., Marklund S. 2003. Method for Multiresidue Determination of Halogenated Aromatics and PAHs in Combustion-Related Samples Environmental Science and Technology 37: 3680-3686.
- Lilja K., Andersson H., Woldegiorgis A., Jönsson A., Palm-Cousins A., Hansson K., Brorström-Lundén E. 2010. Bedömning av miljögiftspåverkan i vattenmiljö, samordnad metodutveckling. Rapport B1891.
- Locke LN., Kerr SM., Zoromski D. 1981. Lead poisoning in common in the Southern Bight of the North Sea. Mar. Pollut. Bull., 17: 113-117.
- Loh C., Anersson Ovuka M. 2005. Litteraturstudie av prioriterade ämnen: information om prioriterade ämnen listade i bilaga 10 till ramdirektivet för vatten. Naturvårdsverket. Dokumentnummer 1003-02/10/01/rap001. (In Swedish)
- Mackay D., Fraser A. 2000. Bioaccumulation of persistent organic chemicals: mechanisms and models. Environmental Pollution., 110: 375-391.
- Martin JW., Asher BJ., Beeson S., Benskin JP., Ross MS. 2010. PFOS or PreFOS? Are perfluorooctane sulfonate precursors (PreFOS) important determinants of human and environmental perfluorooctane sulfonate (PFOS) exposure? J. Environ. Monit. 12 (11): 1979-2004.
- McKinney JD., Darden T., Lysterly MA., Pedersen LG. 1985. PCB and related compound binding to the Ah receptor(s) theoretical model based on molecular parameters and molecular mechanisms. Quantitative Structure – Activity Relationships 4(4): 166 – 172.
- Mitkus RJ., King D., Hess MA., Forshee R., Walderhaug M. O. 2011. Updated aluminium pharmacokinetics following infant exposures through diet and vaccination. Vaccine.
- Miu AC., Andreescu CE., Vasii R., Olteanu AI. 2003. A behavioral and histological study of the effects of long/term exposure of adult rats to aluminium. International Journal of Neuroscience 113: 1197-1211.
- Murata S., Takahashi S., Agusa T., Thomas NJ., Kannan K., Tanabe S. 2008. Contamination status and accumulation profiles of organotins in sea otters (*Enhydra lutris*) found dead along the coasts of California, Washington, Alaska (USA), and Kamchatka (Russia). Marine pollution bulletin 56:641-649.
- Naturvårdsverket. 2008. Övervakning av prioriterade miljöfarliga ämnen listade i Ramdirektivet för vatten. Rapport 5801. (In Swedish)
- Norén K., Meironyté D. 2000. Certain organochloride and organobromine contaminants in Swedish human milk in perspective of past 20-30 years. Chemosphere. 40(9–11):1111–1123.
- Odsjö T. 1993. The Swedish Environmental Specimen Bank with reference to the National Contaminant Monitoring Programme in Sweden. The Science of the Total Environment, 139/140: 147-156.
- Olsson A., Valters K., Burreau S. 2000. Concentration dynamics of organochlorine substances in relation to fish size and trophic position – A study on perch (*Perca fluviatilis* L.). Environmental Science and Technology, 34 (23): 4878-4886.
- Osmond MJ., McCall MJ. 2010. Zinc oxide nanoparticles in modern sunscreens: an analysis of potential exposure and hazard. Nanotoxicology 4(1):15-41.

- OSPARCOM. 1996. OSPARCOM—Oslo and Paris Conventions for the Prevention of Marine Pollution (1996).
- OSPAR. 2005. Assessment of data collected under the Co-ordinated Environmental Monitoring Programme. Publication Number : 2005/235.
- OSPAR Commission. 2005. Overview of Past Dumping at Sea of Chemical Weapons and Munitions in the OSPAR Maritime Area. 13pp. ISBN 1-904426-59-X.
- OSPAR. 2009. Agreement on CEMP Assessment Criteria for the QSR 2010. Agreement number: 2009-2.
- OSPAR Commission. 2009. CEMP assessment report: 2008/2009. Assessment of trends and concentrations of selected hazardous substances in sediments and biota.
- Pattee OH., Wiemeyer SN., Mulherne BM., Sileo L., Carpenter JW. 1981. Experimental lead-shot poisoning in bald eagles. *Journal of Wildlife Management* 45(3):806 – 810.
- Peryea FJ., Creger TL. 1993. Vertical distribution of lead and arsenic in soils contaminated with lead arsenate pesticide residues. *Water, Air and Soil Pollution* 78: 297 – 306.
- Peryea FJ., Kammereck R. 1995. Phosphate-enhanced movement of arsenic out of lead arsenate-contaminated topsoil and through uncontaminated subsoil. *Water, Air and Soil Pollution* 93: 253 – 254.
- Pohl C., Hennings U. 2006. Trace metal concentrations and trends in Baltic surface and deep waters, 1993 – 2006. HELCOM Indicator Fact Sheets 2006. Online. [accessed March 10th 2011], [http://www.helcom.fi/environment2/ifs/en\\_GB/cover/](http://www.helcom.fi/environment2/ifs/en_GB/cover/).
- Poléo ABS. 1995. Aluminium polymerization — a mechanism of acute toxicity of aqueous aluminium to fish. *Aquatic Toxicology* 31: 347-356.
- Powley CR., Buck RC. 2005. Matrix-effect free analytical methods for determination of perfluorinated carboxylic acids in biological samples. Poster presented at the Society of Environmental Toxicology and Chemistry (SETAC), 15<sup>th</sup> Annual Meeting of SETAC Europe, Lille, France, May 22–26, 2005.
- Prevedouros K., Cousins IT., Buck RC., Korzeniowski SH. 2006. Sources, fate and transport of perfluorocarboxylates. *Environ. Sci. Technol.* 40: 32-44.
- Priest ND. 2005. Aluminium. In *Encyclopedia of Human Nutrition (Second Edition)*, (ed. C. Editor-in-Chief: Benjamin), pp. 69-76. Oxford: Elsevier.
- Ratcliffe HE., Swanson GM., Fischer LJ. 1996. Human exposure to mercury: A critical assessment of the evidence of adverse health effects. *Journal of Toxicology and Environmental Health* 49(3): 221 – 270.
- Renberg I., Brännvall ML., Bindler R., Emteryd O. 2000. Atmospheric lead pollution history during four millennia (2000 BC to 2000 AD) in Sweden. *Ambio* 29(3): 150 – 156.
- Rice KC., Conko KM., Hornberger GM. 2002. Anthropogenic sources of arsenic and copper to sediments in a suburban lake, Northern Virginia. *Environmental Science and Technology* 36 (23): 4962 – 4967.

- Richard FC., Bourg ACM. 1991. Aqueous geochemistry of chromium: A review. *Water Research* 25: 807-816.
- Roos A., Kienhuis P., Traag W. and Tuistra W. 1989. Problems encountered in the determination of 2,3,4-2',4',5' hexachlorobiphenyl (CB-138) in environmental samples. *Intern. J. Env. Anal. Chem.* 36:155.
- Ross JF., Switzer RC., Poston MR., Lawhorn GT. 1996. Distribution of bismuth in the brain after intraperitoneal dosing of bismuth subnitrate in mice: Implications for routes of entry of xenobiotic metals into the brain. *Brain Research* 725(2): 137-154.
- Rustam H., Hamdi T. 1974. Methylmercury poisoning in Iraq: a neurological study. *Brain* 97: 499 – 510.
- Schantz MM., Parris RM., Kurz J., Ballschmiter K., Wise SA. 1993. Comparison of methods for the gas-chromatographic determination of PCB congeners and chlorinated pesticides in marine reference materials. *Fresenius Z. Anal. Chem.* 346:766-78.
- Scott-Fordsmand JJ. 1997. Toxicity of nickel to soil organisms in Denmark. *Rev. Environ. Contam. Toxicol* 148: 1-34.
- Sellström U. 1996. Polybrominated diphenyl ethers in the Swedish environment. ITM-Report. Stockholm University.
- Sellström U., Egebäck A-L., McLachlan M. S. 2009. Identifying source regions for the atmospheric input of PCDD/Fs to the Baltic Sea. *Atmos. Env.* 43: 1730-1736.
- Sellström U., Kierkegaard A., De Wit C., Jansson B. 1998. Polybrominated diphenyl ethers and hexabromocyclododecane in sediment and fish from a Swedish river. *Environmental Toxicology and Chemistry* 17: 1065-1072.
- SLVFS. 1993. Livsmedelsverkets föreskrifter om vissa främmande ämnen i livsmedel (1993:36); Report from the Swedish Food Administration (in Swedish).
- Smith BS. 1981. Tributyltin compounds induce male characteristics on female mud snails *Nassarius obsoletus* = *Ilyanassa obsolete*. *Journal of applied toxicology* 1 (3):141-144.
- Sokal RR., Rohlf FJ.. 1981. *Biometry*. 2nd ed. W.H. Freeman and Company, San Francisco. Pp 1-859. ISBN 0-7167-1254-7.
- Sonesten L. 2003a. Catchment area composition and water chemistry heavily affects mercury levels in perch (*Perca fluviatilis* L.) in circumneutral lakes. *Water, Air and Soil Pollution* 144: 117-139.
- Sonesten L. 2003b. Fish mercury levels in lakes – adjusting for Hg and fish size covariation. *Environmental Pollution* 125: 255-265.
- Spry D., Wiener JG. 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review. *Environmental Pollution* 71: 243 – 304.
- Sternberg RM., Gooding MP., Hotchkiss AK., LeBlanc GA. 2010. Environmental-endocrine control of reproductive maturation in gastropods: implications for the mechanism of tributyl-induced imposex in prosobranchs. *Ecotoxicology* 19:4-23.

- Stockholm Convention on Persistent Organic Pollutants (POPs). 2011. Proposal to list hexachlorobutadiene in Annex A, B and/or C. Persistent Organic Pollutants Review Committee, Seventh meeting, Geneva 10-14 October, 2011.
- Stoeppler M., Burow M., Backhaus F., Schramm W., Nürnberg WH. 1986. Arsenic in seawater and brown algae of the Baltic and the North Sea Marine Chemistry 18 (2-4): 321 – 334.
- Strandmark A., Danielsson S., Holm K., Bignert A. 2008. Metaller i strömming och abborre – en jämförelse mellan retrospektiva analyser i muskel och existerande tidsserier för leverkoncentrationer. Rapport till Naturvårdsverket, Överenskommelse nr 212 0639.
- Suzuki T., Imura N., Clarkson TW. 1991. Overview. 32 pp. *Chapter in:* Suzuki T, Imura N, Clarkson TW (eds.). Advances in Mercury Toxicology. Plenum press, New York. Proceedings of a Rochester International Conference in Environmental Toxicology, Tokyo, Japan, August 1-3 1990. 489 pp.
- Sveriges Geologiska Undersökning. 2005. Mineralmarknaden. Tema: Arsenik. Per. publ. 2005:4. 50pp. ISSN 0283-2038. In Swedish.
- Swertz O. 1995. Trend assessment using the Mann-Kendall test. Report of the Working Group on Statistical Aspects of Trend Monitoring. ICES CM 1995/D:2.
- Technical Guidance for Deriving Environmental Quality standards (TGD EQS). 2009. Chemicals and the water framework directive; Revised draft July 2009
- TemaNord 1995:543. Manual for Nordic Environmental Specimen Banking.
- Tesfalidet S. 2004. Screening of organotin compounds in the Swedish environment. SNV Contract 219 0102. Analytical Chemistry, Umeå University.
- Tewari H., Gill TS., Pant J. 1987. Impact of chronic lead poisoning on the hematological and biochemical profiles of a fish, *Barbus conchoni* (Ham). Bulletin of Environmental Contamination and Toxicology 38: 748 – 752.
- Towill LE., Shriner CR., Drury JS., Hammons AS., Holleman JW. 1978. Reviews of the environmental effects of pollutants. III. Chromium, (ed., pp. Medium: X; Size: Pages: 303.
- Van den Berg M., Birnbaum LS., Denison M., De Vito M., Farland W., Feeley M., Fiedler H., Hakansson H., Hanberg A., Haws L., Rose M., Safe S., Schrenk D., Tohyama C., Tritscher A., Tuomisto J., Tysklind M., Walker N., Peterson RE. 2006. Review: The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds. *Tox Sci* 93(2): 223-241 (2006)
- Van Leeuwen SPJ., Swart CP., van der Veen I., de Boer J. 2009. Significant improvements in the analysis of perfluorinated compounds in water and fish: Results from an interlaboratory method evaluation study. *Journal of Chromatography A*, 1216: 401–409.
- Vestergren R. Cousins IT. 2009. Tracking the Pathways of Human Exposure to Perfluorocarboxylates *Environ. Sci. Technol.* 43 : 5565-5575.
- Viberg H. Neonatal developmental neurotoxicity of brominated flame retardants, the polybrominated diphenyl ethers (PBDEs). 2004. Doctoral thesis pp 1-62. Department of Environmental Toxicology, Uppsala University.

- Vorkamp K., Riget F., Glasius M., Pécseli M., Lebeuf M., Muir D. 2004. Chlorobenzenes, chlorinated pesticides, coplanar chlorobiphenyls and other organochlorine compounds in Greenland biota. *Science of the total environment* 331:157-175.
- Wania F., Mackay D. 1999. The evolution of mass balance models of persistent organic pollutant fate in the environment. *Environmental Pollution* 100: 223-240.
- Welch HE., Muir DC., Billeck BN., Lockhart WL., Brunskill GJ., Kling H. J. 1991. Brown snow: a long-range transport event in the Canadian Arctic. *Sci. Technol.* 25(2): 280-286.
- WHO. 1981. Environmental Health Criteria 18. Arsenic.
- WHO. 1991. Environmental health criteria 108. Nickel. In Nickel, (ed. Geneva).
- WHO. 2001. Environmental Health Criteria 224 Arsenic and arsenic compounds. 2nd edition.
- WHO. 2002 Concise International Chemical Assessment Document 44. Silver and silver compounds: environmental aspects.
- WHO 2005. Concise international chemical assessment document 65. Tin and inorganic tin compounds. World Health Organization 2005. pp 1-81
- Wiberg K., Oehme M., Haglund P., Karlsson H., Olsson M., Rappe C. 1998. Enantioselective analysis of organochlorine pesticides in herring and seal from the Swedish marine environment. *Marine Pollution Bulletin*, 1998, Vol. 36: 345-353.
- Widell A. 1990. Pollution load compilation. SNV.
- Widell A. 1992. Correction to Pollution load compilation 1990. SNV.
- Winship KA. 1988. Toxicity of tin and its compounds. Adverse drug reactions and acute poisoning review. 7:19-38
- Wängberg I, Munthe J. 2001. Atmospheric mercury in Sweden, Northern Finland and Northern Europe. Results from National Monitoring and European Research. IVL Svenska Miljöinstitutet AB. Report number B1399. 19pp.
- Zafar, T. A., Teegarden, D., Ashendel, C., Dunn, M. A. and Weaver, C. M. 2004. Aluminium negatively impacts calcium utilization and bone in calcium-deficient rats. *Nutrition Research* 24, 243-259.
- Zinc Factsheet 2011. <http://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/> Last updated April 18 2011. Accessed May 27<sup>th</sup> 2011.

## 34 Annex 1

### 1) Lake Abiskojaure

County	Norrbottnen
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 Mm <sup>3</sup>
Protection	National park
Sample matrix	Char
Start	1981
Other monitoring	Fish population investigated (FiV)
pH / alkalinity	6.9 / 0.16 mekv/L
vegetation	
nutrient status	lacking vegetation, surrounded by heath
other	poor in nutrients, totP = 5.9 ug/L +- 2,6 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 Mm <sup>3</sup>
Protection	Nature reserve
Sample matrix	Roach
Start	1982
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 birchforests, 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  
Main catchment area.  
Physical geographic regions.  
Coordinates, RAK  
Altitude  
Lake surface  
Max. depth  
Volume  
Sample matrix  
Start  
pH / alkalinity  
vegetation  
nutrient status  
other

Västerbotten County  
Ume älv river / Vindelälven river (28000)  
Alpine-northern boreal zone  
X 7282710, Y 157578 (24H7c 2422)  
342 m  
53 sq. km  
29 m  
No information found  
Pike  
1968

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  
Main catchment area.  
Physical geographic regions.  
Coordinates, RAK  
Altitude  
Lake surface  
Max. depth  
Volume  
Sample matrix  
Start  
pH / alkalinity  
vegetation  
nutrient status  
other

Norrbottn County  
Rosån river  
Intermediate boreal  
X 7280950, Y 1759260  
82 m  
0.81 sq. km  
6.5 m  
1.87 Mm<sup>3</sup>  
Perch  
2004  
ca 6.5 / 0.118 mekv/L  
Very sparse vegetation  
totP = 12 ug/L

Lake Brännträsket consists mainly of spruce with elements of pine. The area has mobile soil water and is rich in lime.

### 5) Lake Remmarsjön

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

Västernorrland County  
Gideälven river (34000)  
Intermediate boreal  
X 7086190, Y 1621320  
234 m  
1.29 sq. km  
14.4 m  
7.02 Mm<sup>3</sup>  
Perch  
2000

Close 6.5 / 0.05-0.2 mekv / L (i.e. close to neutral with rather good buffer capacity).  
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.  
Moderately rich in nutrients.  
Surrounded by coniferous forest, with elements of the cultural landscape. Species-rich in fish.



## 6) Lake Degervattnet

County	Jämtland County
Main catchment area.	Ångermanälven river (38000)
Physical geographic regions.	intermediat boreal
Coordinates, RAK	X 7085120, Y 1520860
Altitude	852 m
Lake surface	1.6 sq. km
Max. depth	20 m
Volume	
Protection	
Sample matrix	Perch
Start	2000
pH / alkalinity	pH close to 7 / alkalinity 0.15-0.25 mekv/L
Vegetation	Moderate, mostly clumps of reed i the in- and outlets. Surrounded by coniferous forests. (Wilander 1999)
Nutrient status	Poor in nutrients, totP = below 8 ug/L
Other	narrow with steep and rocky beaches except in the south where there is one sandy beach.

## 7) Lake Stor-Björnsjön

County	Jämtland County
Main catchment area.	Indalsälven river
Physical geographic regions.	Alpine-Northern Boreal
Coordinates, RAK	X 7060830, Y 1322870
Altitude	567 m
Lake surface	35 ha
Max. depth	15 m
Volume	
Protection	
Other monitoring	
Sample matrix	Char
Start	2007
pH / alkalinity	7 / 0.15-0,25 mekv/L
vegetation	Sedge is growing around the shallow areas and the lake floor is covered by plants, however these are not classified.
nutrient status	Nutrient-poor, totP < 10 µg/L
other	Lake Stor-Björnsjön is surrounded alternately by mires and slightly hilly terrain with mixed coniferous and deciduous forest.

### 8) Lake Stor-Backsjön

County	Jämtland County
Main catchment area.	Indalsälven river (40000)
Physical geographic regions.	Intermediate boreal
Coordinates, RAK	X 6952200, Y 1433830
Altitude	426 m
Lake surface	2.09 sq. km
Max. depth	5 m
Volume	3 279
Sample matrix	Perch
Start	2004
pH / alkalinity	High buffering capacity, pH 7.4 Alkalinitet 0.31 mekv/L
vegetation	No information
nutrient status	High Secchi depth
other	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.

### 9) Lake Stensjön

County	Gävleborgs County
Main catchment area.	Ljusnan river
Physical geographic regions.	Southern boreal
Coordinates, RAK	X 6836730, Y 1540830
Altitude	268 m
Lake surface	0.53 sq. km
Max. depth	8.5 m
Volume	2,4 Mm <sup>3</sup>
Sample matrix	Perch
Start	1997
pH / alkalinity	ca 6/0.05 mekv/L
vegetation	Sparse, mostly common reed, unbranched bur-reed, water lilies and chickweed, along with isoetids along the beaches. Lake surrounded by pine forest.
nutrient status	TotP = 11-12 ug/L
other	Bogs, mires, and the quagmire in close vicinity of the lake. Irregular lake bed with rocky beaches.

### 10) Lake Gipsjön

County

Main catchment area.

Physical geographic regions.

Coordinates, RAK

Altitude

Lake surface

Max. depth

Volume

Sample matrix

Start

pH / alkalinity

vegetation

nutrient status

other

Dalarna County

Göta älv river (108000), consisting in equal parts of mires and coniferous forest.

Intermediate boreal

X 6727290, Y 1380820

376 m

67 ha

14 m

Perch

2004

pH 5-6 / 0 mekv/L

Sparse, composed primarily of greater bladderwort, yellow and white water lily, broad-leaved pondweed, common club-rush and common reed.

totP = 12.4 ug/L

Diversified lake floor profile, with several depths and shallows. Water very rich in humus, with several quagmires along the water's edge. Secchi depth about 1m.

### 11) Lake Spjutsjön

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

Dalarna County

Dalälven river

Southern Boreal

X 6724670, Y 1480310

0.4 sq. km

21.3 m

Perch

2007

### 12) Övre Skärsjön

County

Main catchment area.

Physical geographic regions.

Coordinates, RAK

Altitude

Lake surface

Max. depth

Volume

Sample matrix

Start

pH / alkalinity

vegetation

nutrient status

other

Västmanland County

Norrström river (61000)

boreonemoral - southern boreal

X 6635320, Y 1485710

219 m

1.70 sq. km

32 m

9.9 Mm<sup>3</sup>

Perch

2000

ca 5.3 / ca 0.003 mekv/L

Surrounded by mixed deciduous and coniferous forest and some mires. Sparse lake vegetation. Mostly sedge, yellow and white water lilies, as well as isoetids and mosses (Fontinalis).

totP = 8-9 ug/L

Water rich in humus, coloured brown. Surrounded by undulating landscape. Undulating lake floor.

### 13) Lake Limmingssjön

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	
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 Limmingssjön 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 km <sup>2</sup>
Max. depth	4.5
Volume	10 milj m <sup>3</sup>
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
nutrient status	totP = 18 ug/L
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 mM <sup>3</sup>
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 <sup>3</sup>
Protection	
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.
Nutrients status	moderat in nutrients. 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 Mm <sup>3</sup>
Sample matrix	Perch
Start	2000
pH / alkalinity	6-7 / just over 0.05 mekv/L (close to neutral with low buffering capacity).
vegetation	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.
nutrient status	Poor in nutrients with high Secchi depth. TotP < 25 ug/L
other	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
Lake surface	0.36 sq. km
Max. depth	7 m
Volume	1,31 Mm <sup>3</sup>
Protection	
Other monitoring	
Sample matrix	Perch
Start	2005
pH / alkalinity	6-7 / 0.2 mekv/L
vegetation	Surrounded for the most part of mixed coniferous and deciduous forest. In the north part there are two shallow bays overgrown with water lilies, common reed and common club-rush.
nutrient status	totP = 20-30 ug/L
other	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
vegetation	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.
nutrient status	totP = 10 ug/L
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

Main catchment area.

Physical geographic regions.

Coordinates, RAK

Altitude

Lake surface

Max. depth

Volume

Sample matrix

Start

Other monitoring

pH / alkalinity

vegetation

nutrient status

other

Kalmar County

Motala ström river (67000)

boreonemoral

X 6406090, Y 1486730 (07F1h 0884)

72 m

16 hectare

13

1.08 Mm<sup>3</sup>

Perch

1981

Close to 7 / close to 0.15 mekv/L

Surrounded by mires and coniferous forest. Sparce veg at the beach edge, however, the rich in species of common reed, bulrush, chickweed, yellow and white waterlily, sedge and isoetids.

Poor in nutrients, totP often below 10 ug/L

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	
Sample matrix	Perch
Start	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 Mm <sup>3</sup>
Protection	
Sample matrix	Perch
Start	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 Mm <sup>3</sup>
Protection	
Sample matrix	Perch
Start	2000
pH / alkalinity	below 5.5 / under 0 mekv/L
Vegetation	Moderat, mostly rosette plants, yellow and white waterlilies and bogbeans.
nutrient status	Poor in nutrients, totP often below 10 ug/L
Other	Surrounded by coniferous forestes and mires. Secchi depht above 6m

### 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 Mm <sup>3</sup>
Protection	
Sample matrix	Pike
Start	1967
Other monitoring	
pH / alkalinity	ca 7 / 0.14-0.18 mekv/L
vegetation	
nutrient status	moderat in nutrients. totP = 0.009-0.011 mg/L
other	Lake floors poor in oxygen. Secchi depth = 2-3m in august

### 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 Mm <sup>3</sup>
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 depth.
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 Mm <sup>3</sup>
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 ug/L
other	Secchi depth 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.
	Eutrophicated, totP = ca 40 ug/L
nutrient status	One of the country's richest bird lakes.
other	

### 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.
	Extremely rich in nutrients, totP = 91 ug/L
nutrient status	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.
other	