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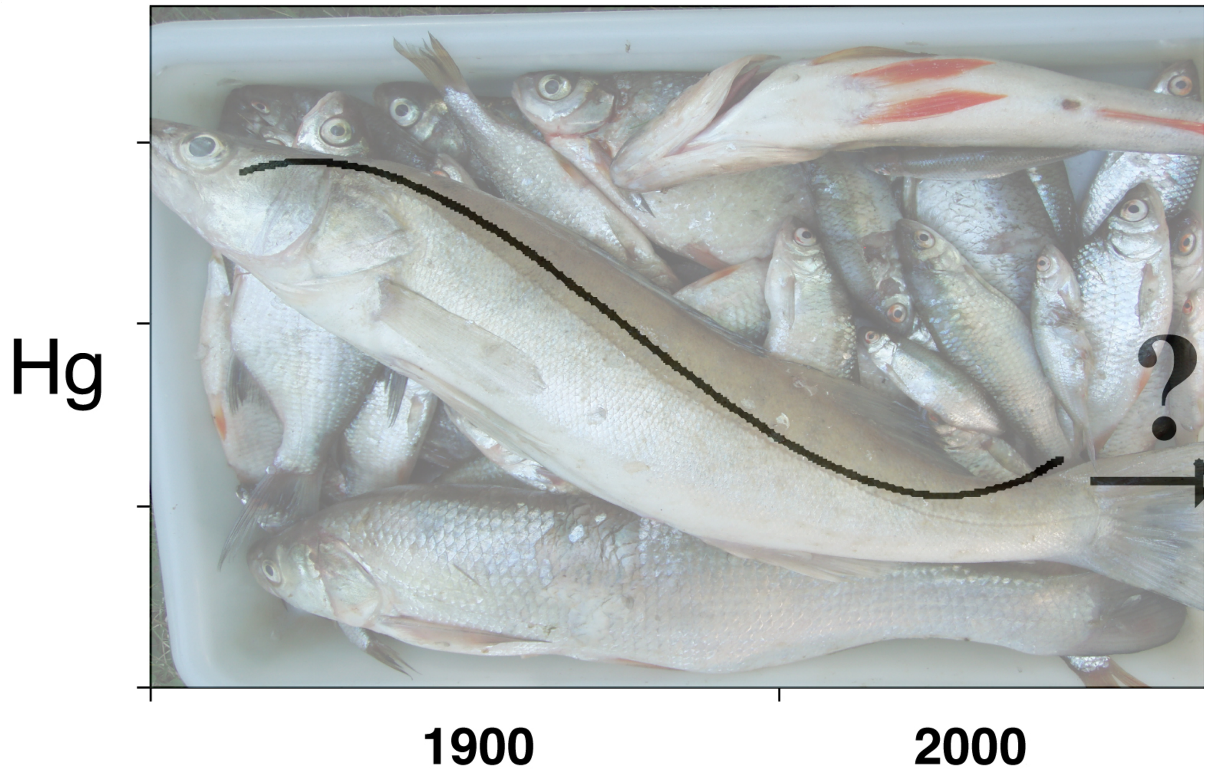
The Performance of Environmental Monitoring Programmes of Hg in Freshwater Ecosystems

Conclusions from the workshop held November 25, 2010



Av:
Staffan Åkerblom

Institutionen för vatten och miljö, SLU — Rapport 2011:8

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Innehåll

Bakgrund

Övervakning av kvicksilver (Hg) i sötvattensekosystem är grundläggande för att hantera föroreningar av Hg i enlighet med EU: s ramdirektiv för vatten. På grund av den globala karaktären med gränsöverskridande långspridda Hg föroreningar är det nödvändigt med en samordnad, långsiktig miljöövervakning. I Sverige har arbetet med analyser av tidsmässiga trender och geografiska mönster av Hg under flera decennier varit baserad på insamling och analys av gädda i hundratals sjöar. Numera är övervakningen av Hg främst inriktad på insamling av abborre (storlek 12-18 cm) från 30 sjöar i samband med övervakning av andra toxiska ämnen. Konsekvenserna av denna förändring i metoder inom miljöövervakningen är ännu inte utvärderade.

Utformningen av övervakningsprogrammen är avgörande för att upptäcka långsiktiga naturliga variationer och avvikelser från regionala bakgrundsnivåer. Nya gränsvärden för mänsklig hälsa tas fram, men tendens till lägre acceptabla nivåer än tidigare. Den typ av sötvattenekosystem och arter som används kommer att avgöra effektiviteten av övervakningsprogram och om de kan bedöma hur effektiva samhällets åtgärder är för att minska Hg kontaminering. Nya kunskaper om processer som avgör känsligheten hos sötvattensekosystem att ackumulera Hg gör det möjligt att skilja naturlig variation från variation som beror på mänsklig påverkan.

För att planera för den framtida miljöövervakningen av Hg i sötvattenekosystem har Naturvårdsverket i samarbete med Sveriges Lantbruksuniversitet och Naturhistoriska riksmuseet hållit en workshop på svenska Naturhistoriska riksmuseet i Stockholm den 25 november, 2010. Workshopen inleddes med presentationer under förmiddagen följt av gruppdiskussioner på eftermiddagen. Denna rapport är en sammanfattning av workshopen och slutsatserna i slutet av detta dokument baseras på resultaten från presentationerna och diskussionerna.

Frågor som behandlas i workshopen:

- Vilka frågor bör miljöövervakningen av Hg besvara på nationell och internationell nivå?
- Vad visar befintliga data och vilken typ av statistik behövs för att beskriva:
    - Rumslig och tidsmässig variation?
    - Regionala bakgrundsnivåer?
    - Variation i exponeringen av Hg på grund av variation i landskapet, klimatet och lokala föroreningskällor etc.?
- Vilken utformning behövs av miljöövervakningen av Hg i sötvattenekosystem för att långsiktigt besvara ovanstående frågor?
    - Vilken typ av ekosystem (typ av sjö)?
    - Vilka organismer (gädda/abborre (andra fiskarter)) och storlek (vikt/längd/ålder)?
    - Hur ska bakgrundsnivåer bedömas när man jämför gamla och nya data från miljöövervakningen?
    - Hur ska miljöövervakningen av Hg integreras med andra övervakningsprogram och forskning?
- Vad bör göras i framtiden?

- Hur ska samordningen av miljöövervakning på regional, nationell och internationell nivå genomföras?

Slutsatser från presentationer och diskussioner under workshopen

- Miljöövervakningen ska syfta till att undersöka temporala och spatiala variationer samt avvikelser från bakgrundshalter.
- Tidsmässiga trender i Hg koncentrationer i sötvattenbiota varierar mellan de nordiska länderna. Dessa variationer beror främst på skillnader i valet av arter som analyseras i trendanalysen.
- Regionala bakgrundsnivåer med avseende på abborre uppgifter måste bedömas och jämföras med gäddata. Nuvarande bakgrundshalter baserade på data från 1-kilos gädda är 0.05-0.2 mg/kg.
- Sjöarna som används i miljöövervakning bör vara typiska och representativa för de nordiska länderna och passa in i den övervakningshierarki som presenteras i rapporten.
- Samordning av långsiktiga övervakningen måste inriktas på jämförbara fiskarter inom en definierad storleksklass för temporala och spatiala undersökningar.
- Mellan de nordiska länderna bör det finnas en enhetlig strategi där abborre används inom miljöövervakningsprogrammen.
- Tidsmässig variation upptäcks lättast i små abborrar (0-12 cm) medan eventuella hälsoaspekter och ekologiska effekter mest effektivt övervakas i större abborrar (eller andra rovfiskar, t.ex. gädda).
- Hg data för abborre i storleksintervallet mellan dessa två grupper (12-18 cm) är svåra att utvärdera på grund av variation i födosök och Hg exponering. Detta är just den storlek som svensk och delar av den nordiska övervakningen av kvicksilver är baserad på sedan början av 2000-talet.
- Samordning mellan övervakningsprogram av populationsbiologi av fisk rekommenderas.
- Samordning av miljöövervakning av Hg på regional och nationell nivå kommer att behövas för att nå målen inom ramdirektivet för vatten. Flera av de regionala myndigheterna sade att på grund av höga kostnader för analys av Hg så var detta inte prioriterat och gjordes om det fanns utrymme att göra detta inom andra övervakningsåtgärder av till exempel organiska föroreningar. Ramdirektivet för vatten måste ta upp miljöproblemen med Hg tydligare för att driva provtagning av fisk med utgångspunkt från förorening av Hg och även utveckla samordning av miljöövervakningen.

Rekommendationer för miljöövervakning

- På grund av problem att bedöma Hg-exponeringen inom storleksintervallet 12-18 cm bör tidsmässiga trender som härrör från data inom denna storleksklass hanteras med försiktighet. Exponeringen av Hg i denna storleksklass kan variera över tid på grund av förändringar i den ekologiska strukturen i ett sjöekosystem.
- För den framtida planeringen av miljöövervakning av Hg bör man välja en storleksklass av abborre där man har mindre variation i Hg exponering med avseende på trofinivå. För att undersöka förändringar över tid bör mindre

abborrar användas. För att undersöka eventuella hälsoaspekter för mänsklig konsumtion bör större abborrar användas.

- Användningen av mellanstora abborrar (12-18 cm) inom miljöövervakning av Hg möjliggör jämförelse mellan sjöar. Data från abborrar i andra storlekar ska inte jämföras med data från denna storleksklass.
- Samordning av miljöövervakning av vattenkemi, fiskpopulationsbiologi samt föroreningar rekommenderas för att fastställa referensförhållanden.
- Finansieringen av miljöövervakningen bör vara riktad mot Hg i sötvattenekosystem för att utformningen av miljöövervakningsprogram blir anpassade för utvärdering av temporala och spatiala mönster.

Background

Monitoring of Hg exposure in freshwater ecosystems is fundamental to the efforts to mitigate Hg pollution in accordance with the EU Water Framework Directive (WFD). Due to the global nature of transboundary Hg pollution there are strong reasons for coordinated, long-term regional monitoring strategies. In Sweden, several decades of work with trends and spatial patterns of Hg pollution have been based on collection of Pike. Now, though, monitoring of Hg in freshwater ecosystems is based primarily on the collection of mid-sized Perch in 30 lakes in conjunction with monitoring of other toxic substances. The consequences of this shift in monitoring methodology remain to be assessed.

The design of monitoring programmes is crucial to detecting long-term natural variation and also deviations from regional background levels. Further, the situation with respect to new health advisory limits is changing with a tendency to lower acceptable levels. The type of freshwater ecosystem and biota used will determine the efficiency of the monitoring programmes and if they respond to societal actions to reduce Hg contamination. New scientific understanding of critical processes that determine the sensitivity of freshwater ecosystems to Hg bioaccumulation may help in distinguishing natural variation from anthropogenic influences.

In order to plan for the future of Hg monitoring in freshwater ecosystems, the Swedish Environmental Protection Agency in cooperation with the Swedish University of Agricultural Sciences and the Swedish Museum of Natural History held a workshop at the Swedish Museum of Natural History in Stockholm on November 25, 2010. The day-long workshop started with a set of invited lectures followed by disussions in the afternoon. This report is a summary of the workshop and the conclusions in the end of this document is based on the outcome of the presentations and discussions.

Questions to be addressed in the workshop:

- What questions should be answered by environmental monitoring programmes of Hg in freshwater ecosystems at national and international level?
- What does existing data show and what type of data and statistics are needed to describe:
    - Spatial and temporal variation?
    - Regional background levels?
    - Variation in Hg exposure due to variation in landscape, climate and local point sources etc.?
- What design of environmental monitoring programmes for Hg in freshwater ecosystems in the long-term perspective are needed to answer the above questions?
    - Which ecosystems (type of lake)?
    - Which organisms (pike/perch (other)) and size (weight/length/age)?
    - How should reference and background levels be evaluated when comparing old and new environmental monitoring programme data?
    - How should environmental monitoring programmes of Hg in freshwater ecosystems be integrated with other monitoring programmes and research activities?
- What should be done in the future?

- How should regional, national and international monitoring efforts be coordinated?

Nordic Monitoring Programmes

The following section will present the design of national monitoring programmes in the Nordic countries.

Sweden

Beside regional monitoring actions, national monitoring of Hg in freshwater biota in Sweden has been coordinated by the Swedish Museum of Natural History. Hg has been analysed annually in perch muscle tissue from two sites (lake Bälgsjön and lake Skärgölen) from the mid 1980´s. Since 1995 and 1996, mercury analyses have also been carried out in samples of arctic char from lake Abiskojaure and lake Tjulträsk and since 1996 also in pike muscle from lake Bolmen and lake Storvindeln. Since 2006 perch collected from 27 lakes are analysed for Hg. With the introduction of new monitoring stations the collection of pike is limited to Bolmen and Storvindeln and perch is more frequently collected in the other stations. The perch collected are in the size range 12-18 cm. Mercury analyses have typically been based on samples of muscle tissue from individual fish. Since 2003, stable istope signatures ($\delta^{13}C$ and $\delta^{15}N$) has been determined in the same samples.. This expansion in monitoring data has been introduced to enable normalisation of Hg concentrations to the trophic position of individual fish. Trophic position can vary considerably within and among lakes, especially for perch within the current size range.

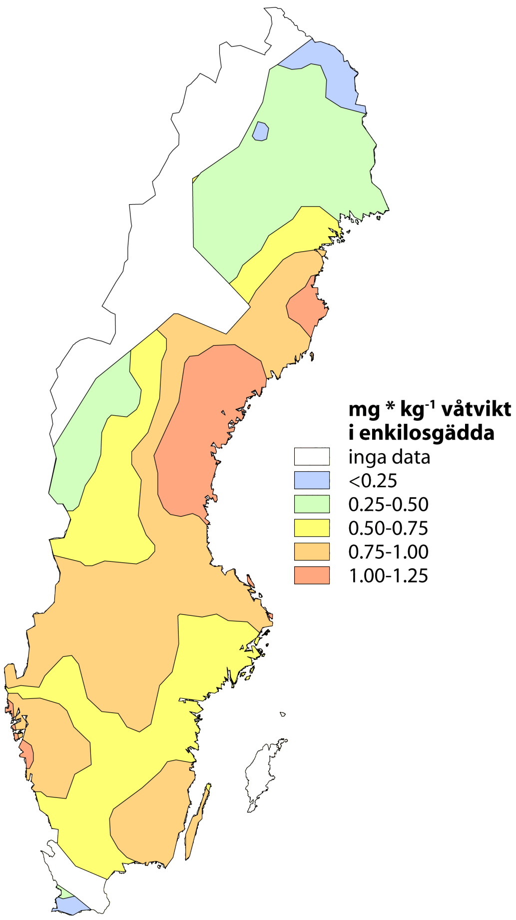

Figure 1. Hg concentration in freshwater Pike (Esox lucius L.) in Sweden. Values normalised to 1-kg pike.

Norway

Norway have introduced analysis of Hg in national monitoring programmes of air, atmospheric deposition and water column in rivers since 1990. Several one-off surveys of biota and sediments have been done in several lakes over the years, but there is only in Lake Mjøsa there is annual trend monitoring of freshwater biota (fish and zooplankton). This has been ongoing since 2003. In 2008 Norway performed a study on Hg in perch from 30 lakes in southern Norway, this study was followed up in five of these lakes in 2010. Collection of freshwater samples (water samples) are done annually within the Riverine Inputs and Direct Discharges (RID) programme. 12 rivers are sampled 12-16 times per year and 36 rivers are sampled four times per year.

Finland

Monitoring of Hg in freshwater biota in Finland during the last decades have been based on collection and analysis of pike. As is the case in Sweden, monitoring in the future (2010-) will be based on collection of perch (length range 15-20 cm) with no systematic pike fishing. Monitoring stations will be seleced where biological and fish population monitoring is already in progress. Biological data on species composition, abundance and age structure are valuable information in the evaluation of data of Hg in fish. Contaminated sites are monitored frequently at 3 years intervals while surveys are done in 60-90 reference lakes and streams with intervals of 10 years.

Evaluation of Monitoring Programme Data

Decreases in Swedish freshwater Pike Hg concentration during the late 20th century have shifted to increased Hg concentrations in more recent periods (1995-2006). However, temporal trend analysis of Perch data from the national monitoring stations in Sweden shows a different picture with decreases in Perch Hg concentration over a period between 1990 and 2002. AND AFTER 2002??? Some of the temporal variation detected in perch Hg concentration could be explained by temperature during some years.

In Norway fish (Perch) from 28 lakes were monitored in 2008. Out of these, 10 of them had also been monitored in 1991. In 8 out of these 10 lakes an increase was detected. Data of Hg in fresh water pike from Finnish reference stations between the periods 1980-1983 and 2000-2002 detected decreasing trends in Hg concentration in ½, no change in 1/3 and increasing trends in 1/6 of the lakes. Trends were also studied with respect to lake size and the major temporal variation were detected in small lakes while the temporal variation was less in larger lakes.

The between-year variation in Hg concentration is larger in small-sized perch compared to large-sized perch which have large individual variation. These differences in variation are of interest since intermediate sized perch show most individual variation in foraging habits. This leads to weak dependence between fish size (length) and Hg concentration within intermediate sized perch. Normalisation of perch Hg concentration data with $\delta^{15}N$ is useful if the ontogenetic diet shifts needs to be taken into account. Perch Hg concentration is correlated with the spatial location in the landscape and land use within the catchment of the lake. However, with increasing size of the perch the Hg concentration becomes correlated with the growth rate of the fish rather than Hg loading. Results presented show that small sized perch are suitable in environmental monitoring to evaluate temporal variation in Hg loads to freshwater ecosystems. However, if potential ecological and human health issues are to be assessed perch of large size are to be preferred in monitoring programmes. Unfortunately mid-sized perch, the size class currently monitored in Sweden, was not good for either of these purposes.

A possible Hg monitoring strategy

Jaakko Mannio (Finnish Environment Institute SYKE, Contaminants Division) presented "the Hg monitoring pyramid" (Fig. 1). The monitoring pyramide is a monitoring strategy that is directly related to CLRTAP/ ICP Waters (and IM) programme monitoring of acidification, which has used this framework successfully since the late 1980's. It is organised in a three-level hierarchy with components focusing on processes, "reality check" and extent of the problem. All levels are needed to get a picture of the magnitude and distribution of environmental problems. The different levels in the pyramide refer to:

Level I:

Focus on processes:

- tries to understand what is happening and why
- including short term fluctuations and as many as possible parameters/ ancillary information
- Focus probably Integrated monitoring/ PMK –type
- short&long-term climate, deposition etc.
- Risk: lack of representativity
- coordination: national

Level II:

Focus on WFD:

- Extends the information to more types of environments
- both environmental quality standards and long-term trend analyses
- Should be based on lake types and take into account especially land-use
- Risk: lack of resources to have enough types
- lack of possibility/resources to have annual monitoring
- coordination: regional

Level III:

National survey:

- also human exposure aspect
- possibly several fish species
- national/regional coordination with food authorities.
- Possibility to harmonized NMR-coordinated Lake Survey. Lakes could preferably be surveyed with resampling every 5th year.

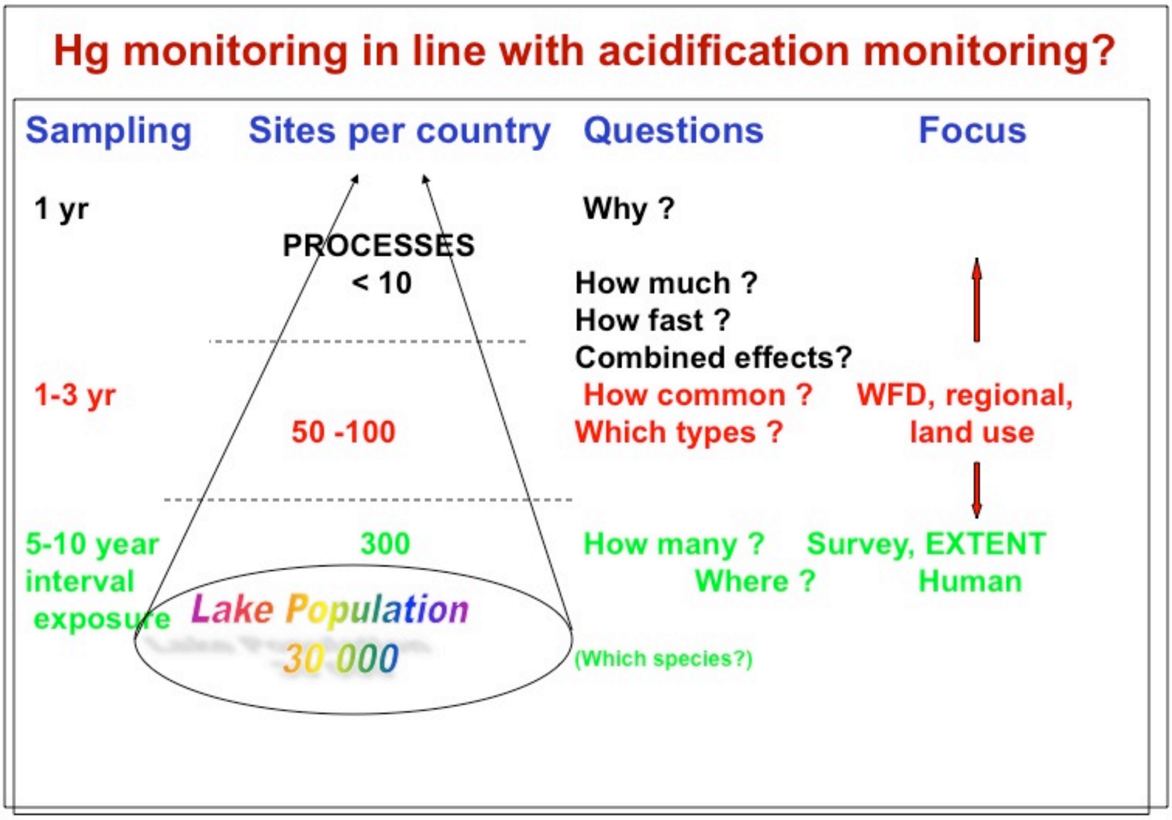

Figure 1. Hg monitoring pyramid (From Jaakko Mannio; Finnish Environment Institute SYKE, Contaminants Division).

Conclusions from presentations and discussions during the workshop

- Environmental monitoring should aim to describe temporal and spatial variation and deviations from background concentration values.
- Temporal trends in Hg concentration of freshwater biota varies among the Nordic countries. These variations were mainly ascribed to differences in the freshwater species analysed in the temporal trend analysis.
- Regional background levels with respect to perch data needs to be assessed and compared with pike data. Current background values varies between 0.05-0.2 mg Hg/kg based on 1-kg pike.
- The lakes used in monitoring programmes should be typical and representative over the Nordic countries and should fit into the monitoring hierarchy of the monitoring pyramide presented above.
- Coordination of longterm monitoring have to be focused on comparable fish species and size groups for comparison over time and space.
- Between the Nordic countries there should be a consistent monitoring strategy with perch as the main freshwater species collected within the monitoring programmes.
- Temporal variation is most easily detected in perch of small (0-12 cm) size while possible health aspects and ecological effects are most effectively monitored in larger perch (or other predatory fish, i.e. pike).
- Perch in the size range between these two groups (12-18 cm) are not suitable for monitoring purposes due to variation in foraging habits and Hg exposure.
- Coordination with freshwater monitoring of fish population biology are advised.
- Coordination of freshwater Hg monitoring on regional and national level will be needed to reach the goals set in the WFD. Several of the regional authorities said that due to high costs of Hg analysis these analysis were not prioritized and were done if this could be done in other monitoring actions of i.e. organic pollutants. Work within the WFD needs to address the Hg environmental problem towards freshwater ecosystems to implement better coordination of monitoring actions.

Recommendations for monitoring in practice

- There are problems related to variation in Hg exposure within the size range 12-18 cm. Temporal and spatial trends derived from data within this size range should be handled with care. The exposure of Hg within this size category can vary over time due to changes in the ecological structure in a lake ecosystem.

- In the planning of environmental monitoring of Hg in the future the choice of a size class of perch should be made where there is less variation in Hg exposure with respect to trophic level. To study changes over time smaller perches should be used. In order to study health concerns for human consumption larger perch should be used.

- The use of mid size perch (12-18 cm) in Hg monitoring in freshwater biota enables comparison between several lakes within the Swedish monitoring network. Perch Hg data from other size ranges should not be mixed with data from this defined size range.

- Coordination of monitoring with water chemistry, fish population biology and contaminants within lakes used to monitor reference conditions is advised.

- The funding of environmental monitoring should be directed towards Hg in freshwater ecosystems for the design of environmental monitoring programs will be adapted for evaluation of temporal and spatial patterns.

Appendix

Presentations

References

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Appendix 1. Presentations held at the workshop ”The performance of Environmental Monitoring Programmes of Hg in Freshwater Ecosystems”

1a. **Monitoring in Sweden**. Anders Bignert (Swedish Museum of Natural History)

1b. **Monitoring in Norway**. Jon L. Fuglestad (Climate and Pollution Agency)

1c. **Monitoring in Finland.** Matti Verta (*Finnish Environment Institute SYKE, Contaminants*)

1d. **Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden.** Staffan Åkerblom (*Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences*)

1e. **Fish Hg levels and fish size relationships in lakes.** Lars Sonesten (*Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences*)

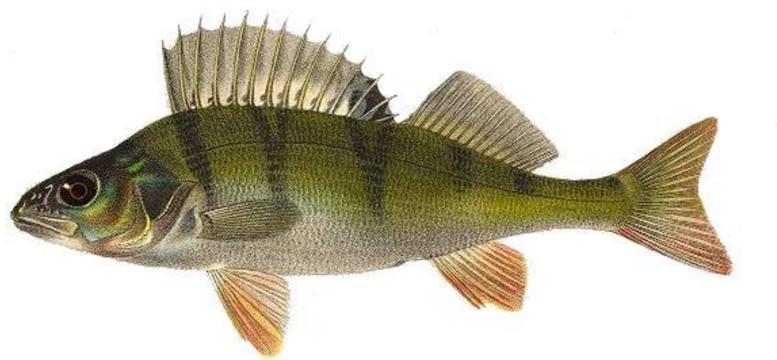
1f. **Factors influencing the annual variations of Hg levels in freshwater fish.** Göran Lithner (*Department of Applied and Environmental Research, Stockholm University*)

1g. **Trade-offs between individual and interannual variation – experiences from monitoring Hg concentrations in trophically confined but rapidly equilibrating young perch.** Marcus Sundbom (*Department of Applied and Environmental Research, Stockholm University*)

1a. **Monitoring in Sweden**. Anders Bignert (Swedish Museum of Natural History)

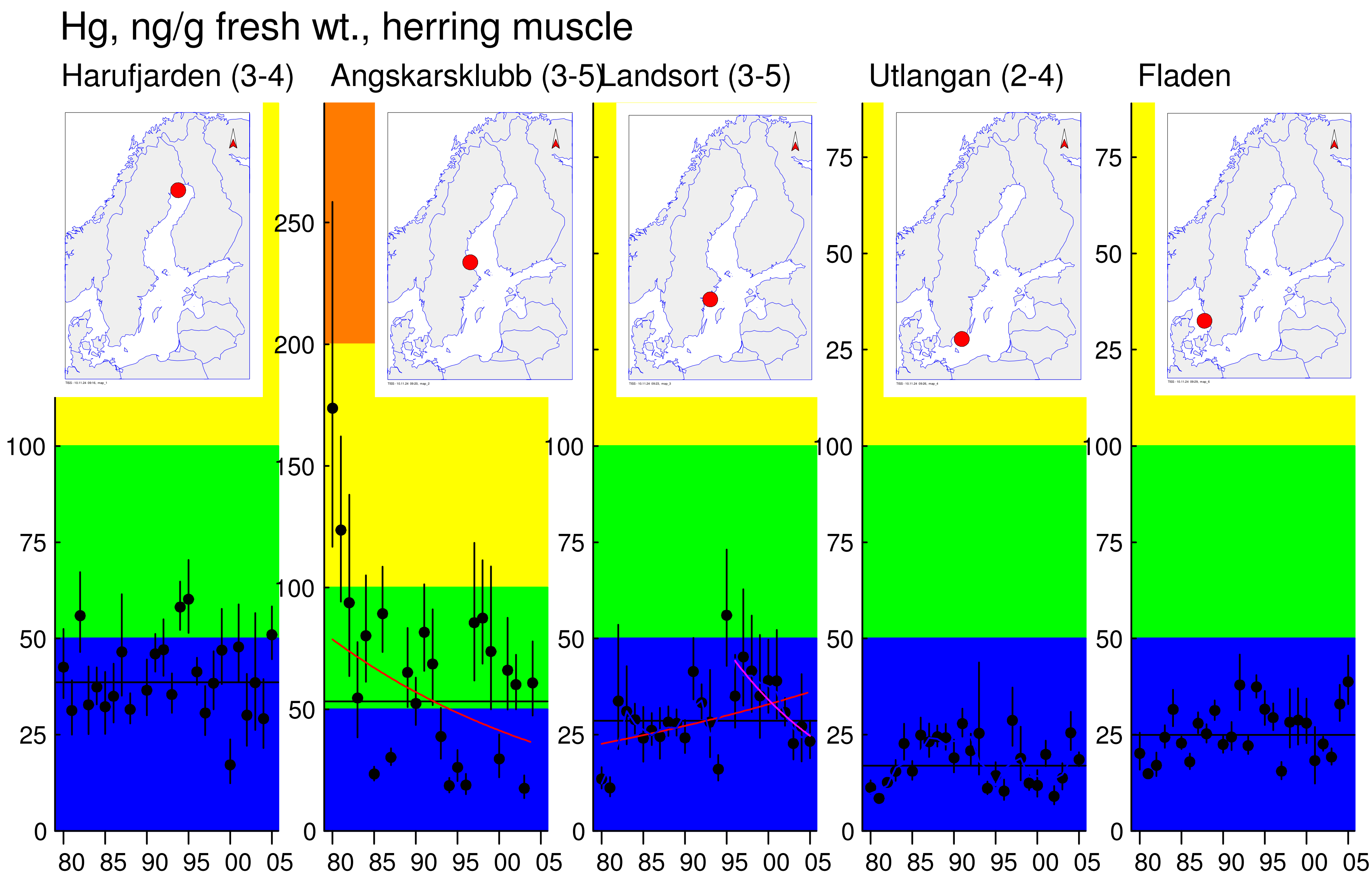
Monitoring of Mercury in biological samples in Sweden

Sara Danielsson , Nicklas Gustavsson , Jenny Hedman, Anna-Karin Johansson, Elin Boalt, Anders Bignert, *Dep. of Contaminant Research,Swedish Museum of Natural History*

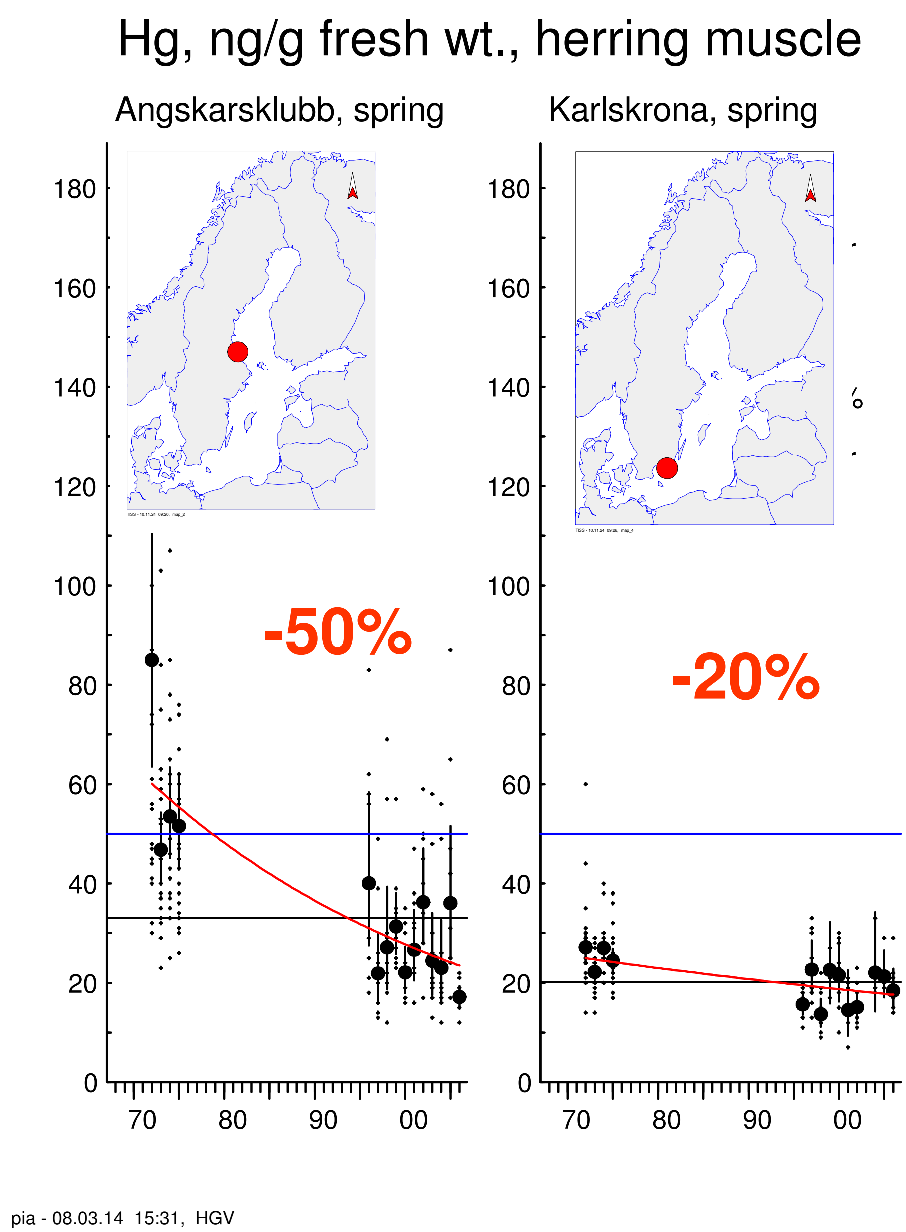


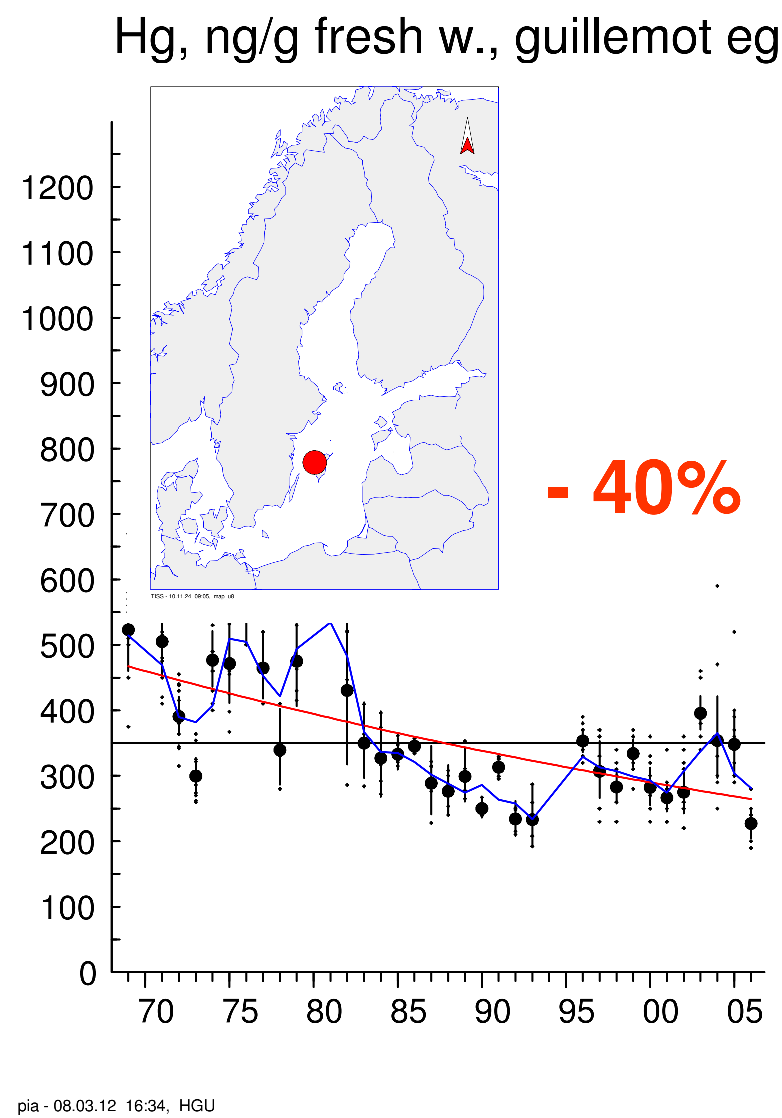
Hg Workshop, Stockholm, 2010

Temporal trends in the marine ecosystem

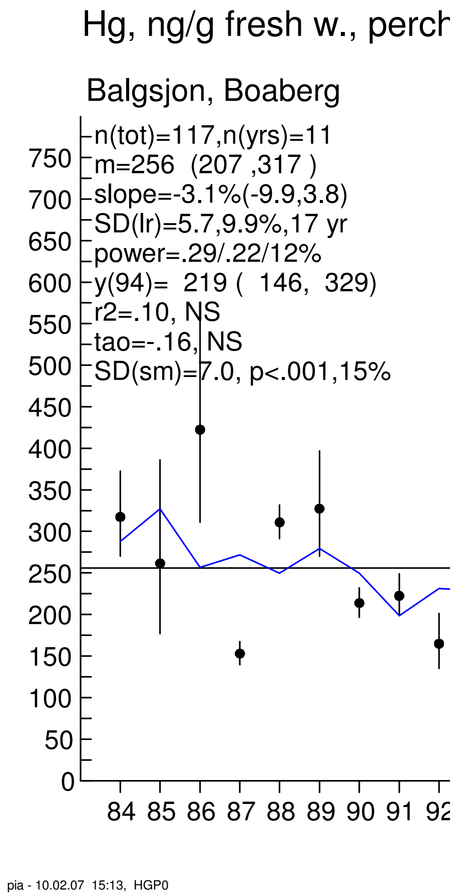


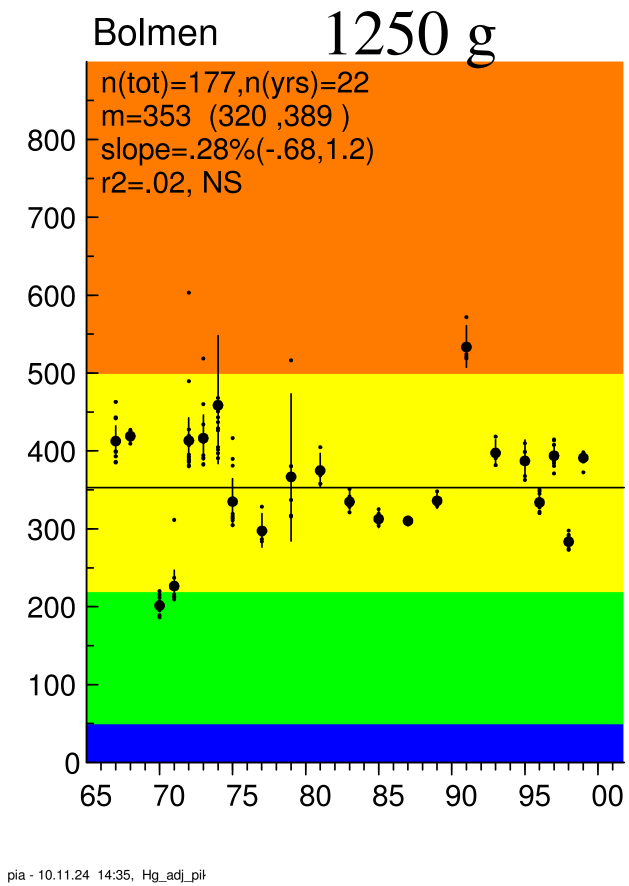
Temporal trends in the marine ecosystem

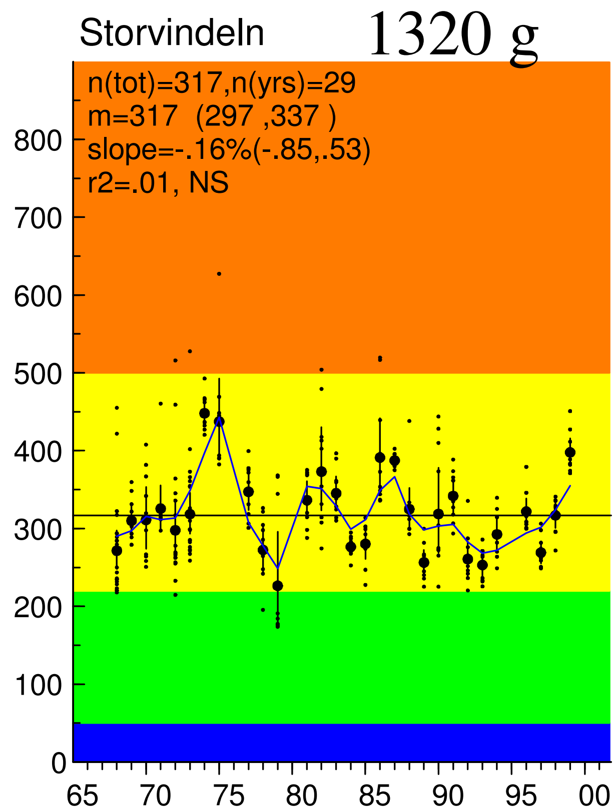


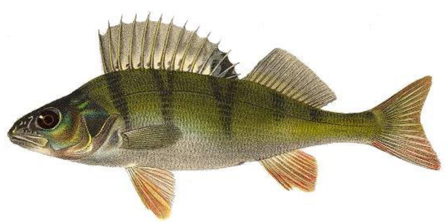


Temporal trends in freshwater fish

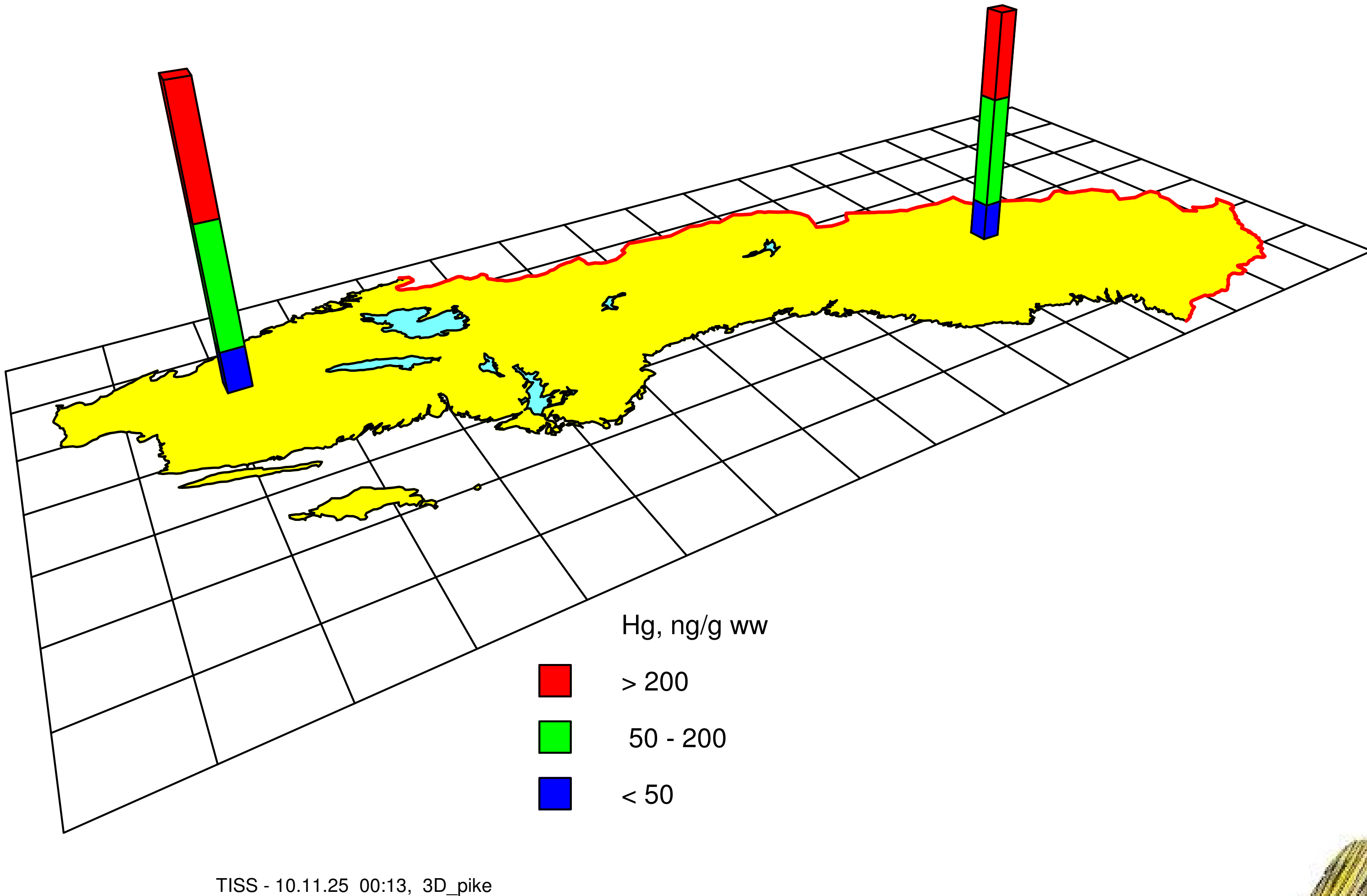


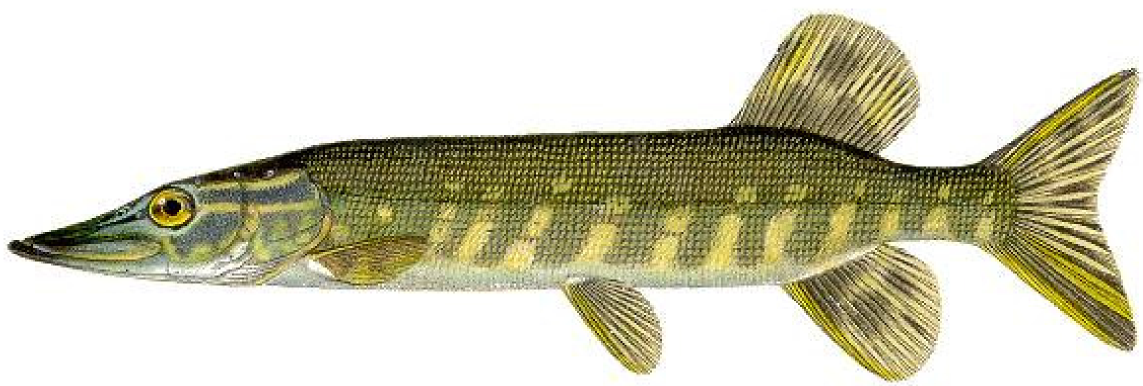




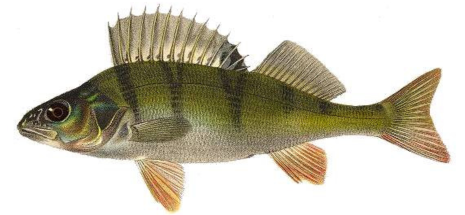


Pike



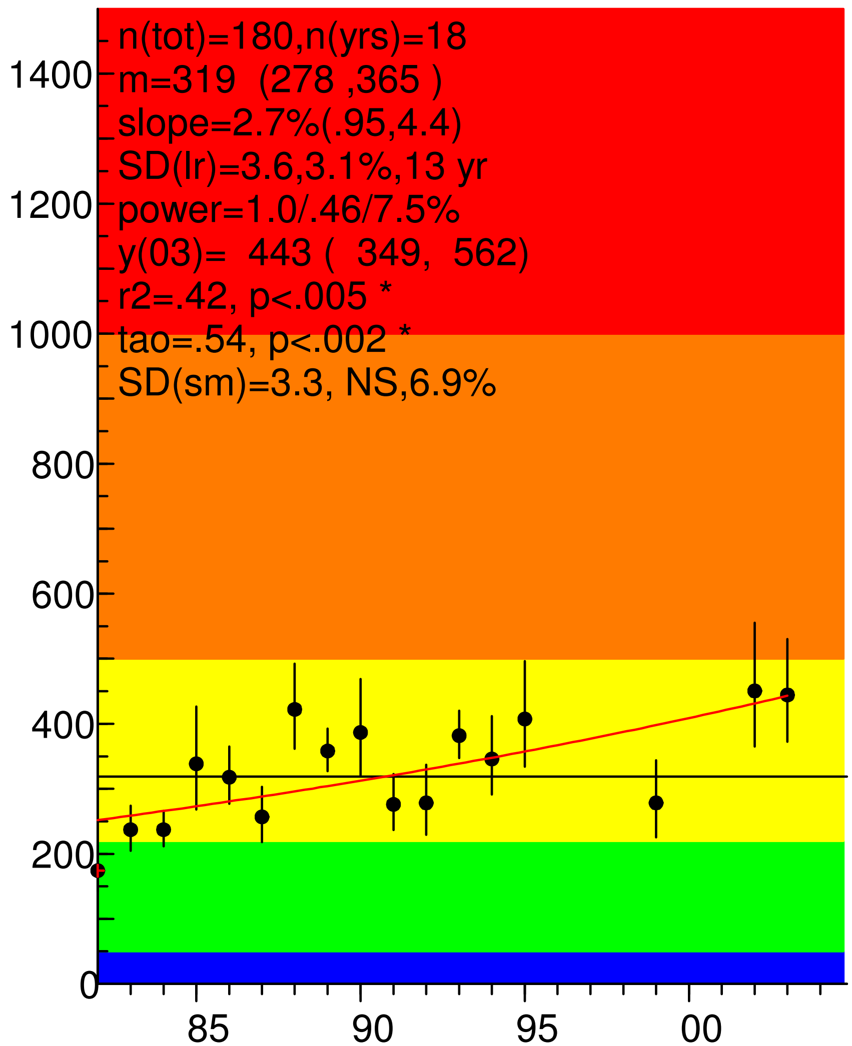


Temporal trends in freshwater fish

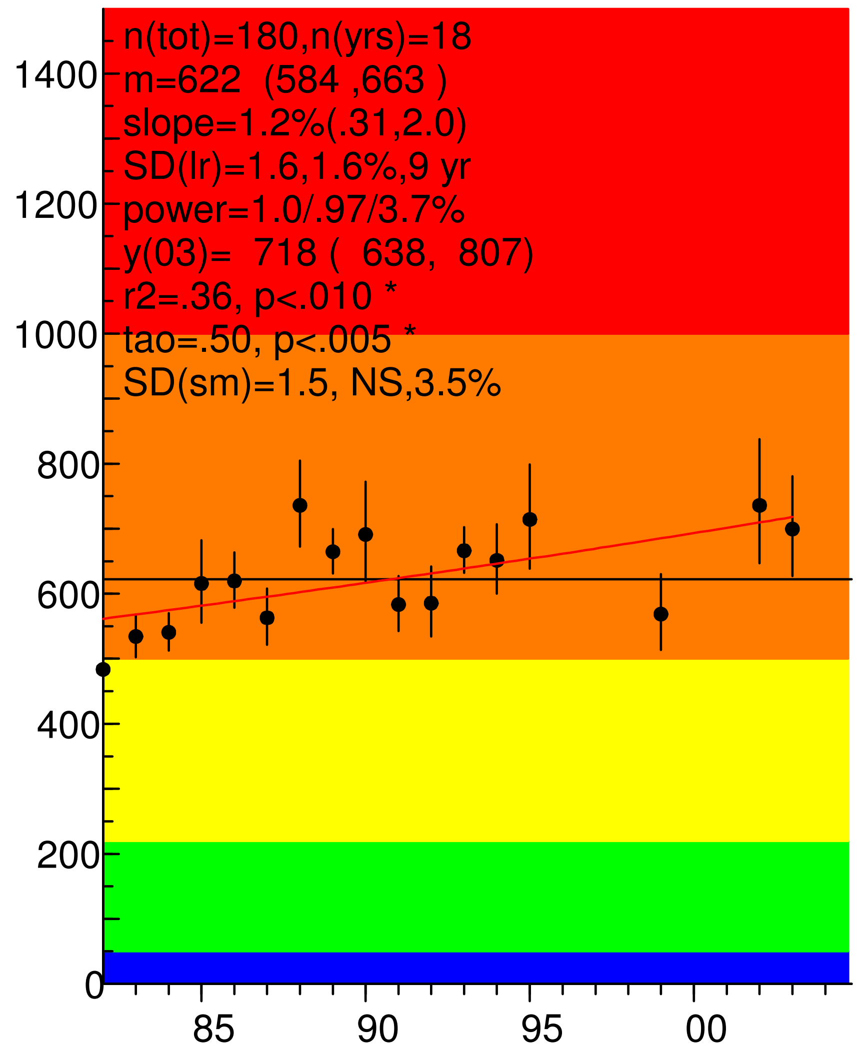


Hg, ng/g fresh w., perch muscle.

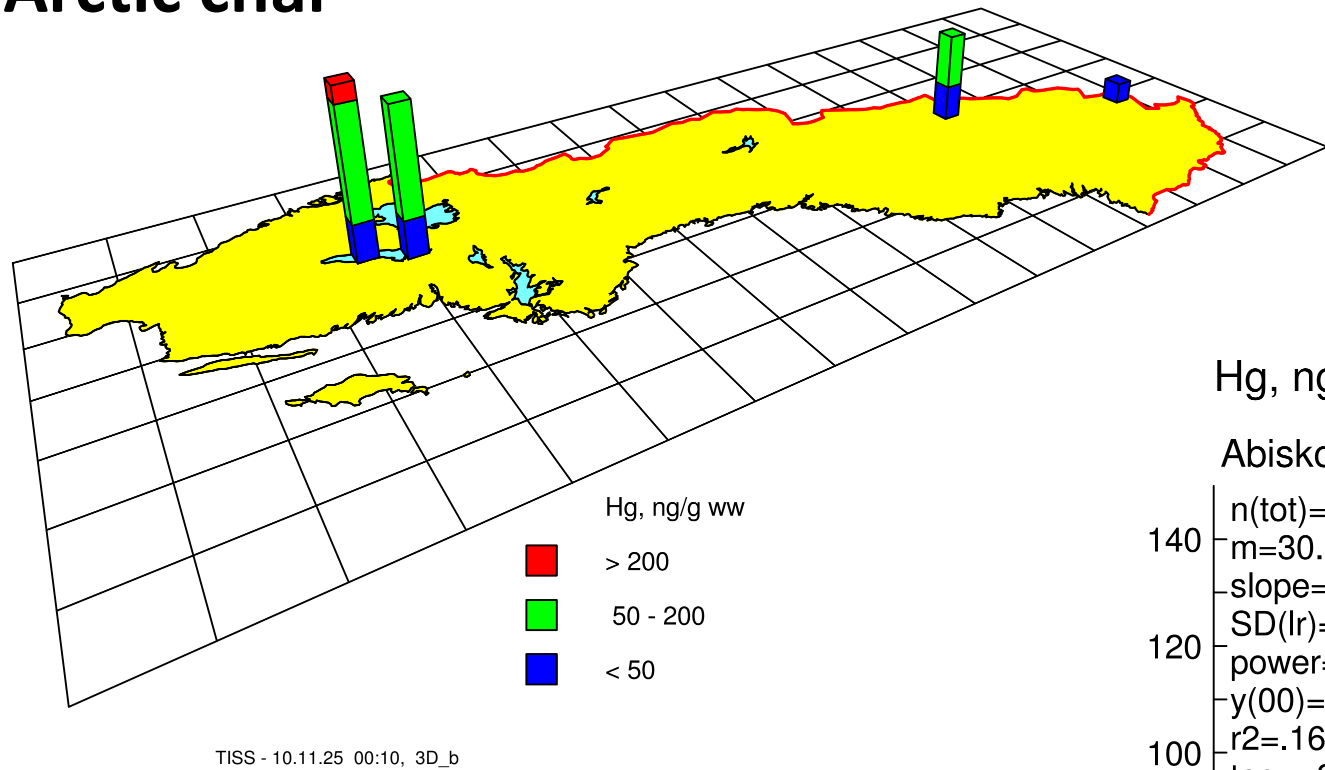
Skargolen, unadj



Skargolen, weight-adj (300g)



Arctic char


Hg, ng/g ww
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50 - 200
< 50
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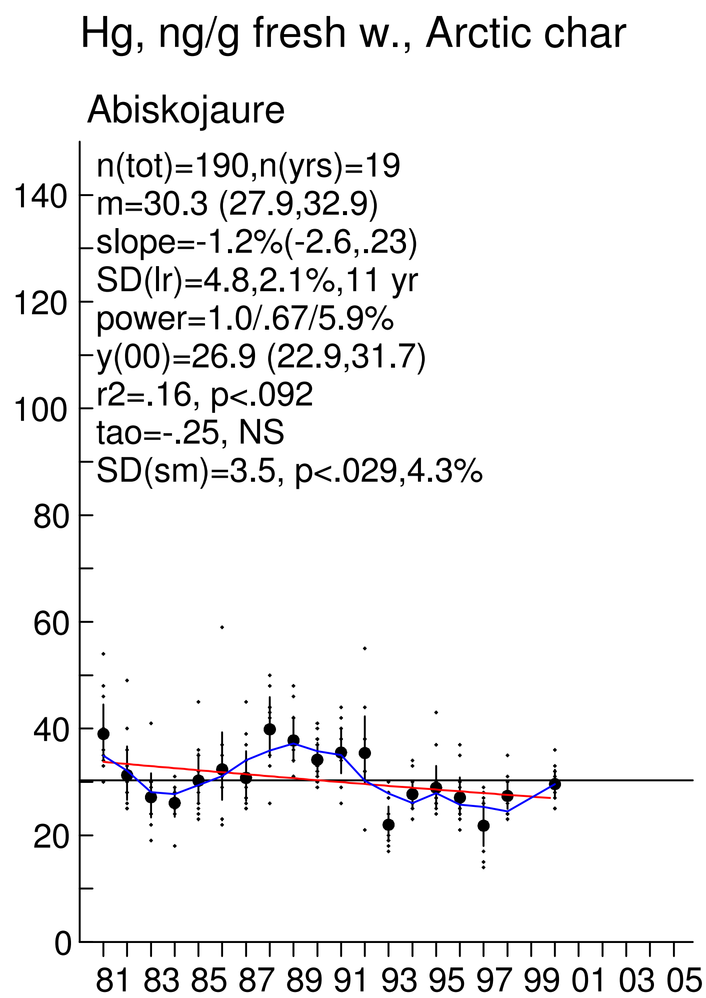
Hg, ng/g fresh w., Arctic char
Abiskojaure
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m=30.3 (27.9,32.9)
slope=-1.2%(-2.6,.23)
SD(lr)=4.8,2.1%,11 yr
power=1.0/.67/5.9%
y(00)=26.9 (22.9,31.7)
r2=.16, p<.092
tao=-.25, NS
SD(sm)=3.5, p<.029,4.3%
140
120
100
80
60
40
20
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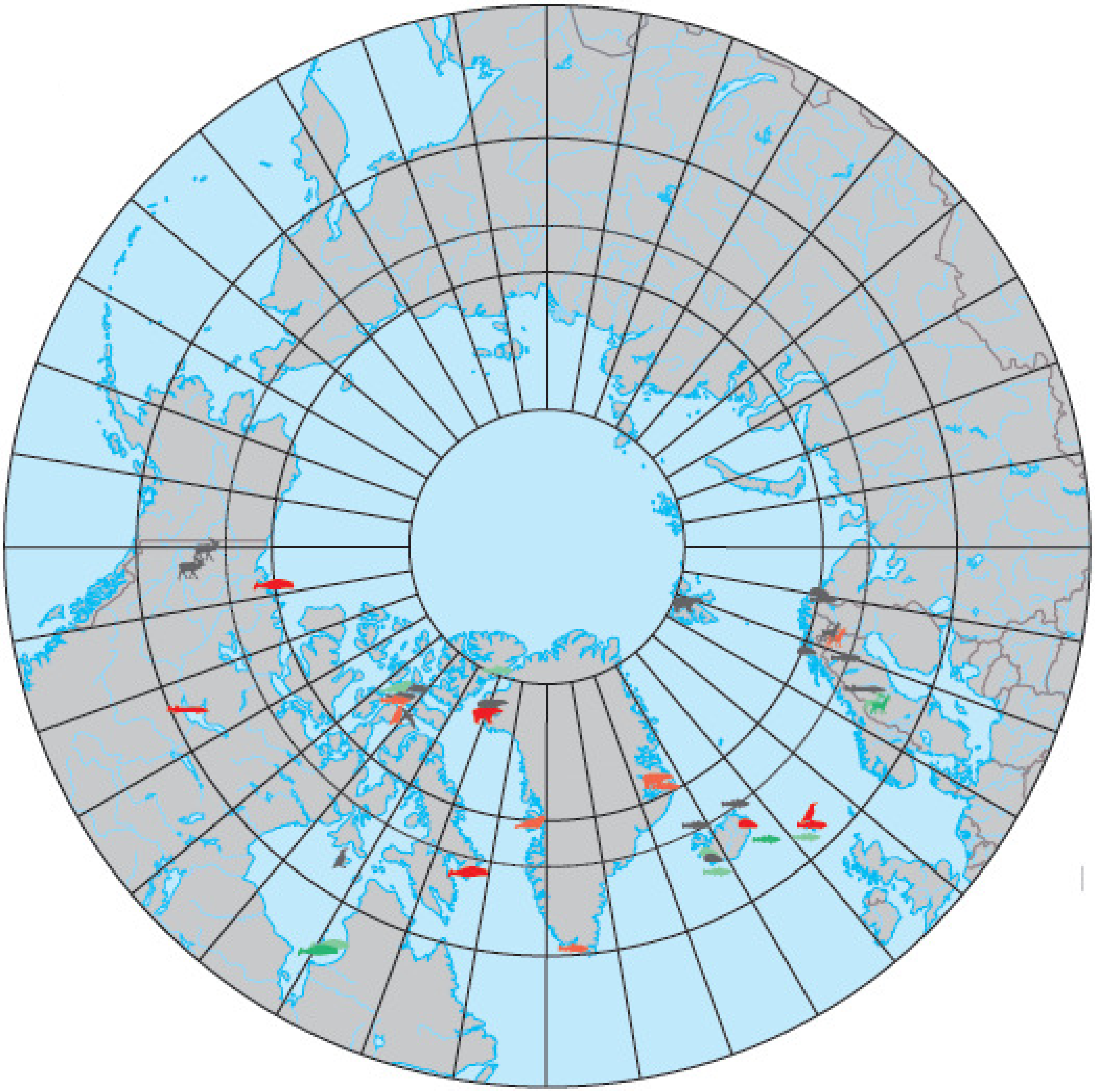
81 83 85 87 89 91 93 95 97 99 01 03 05

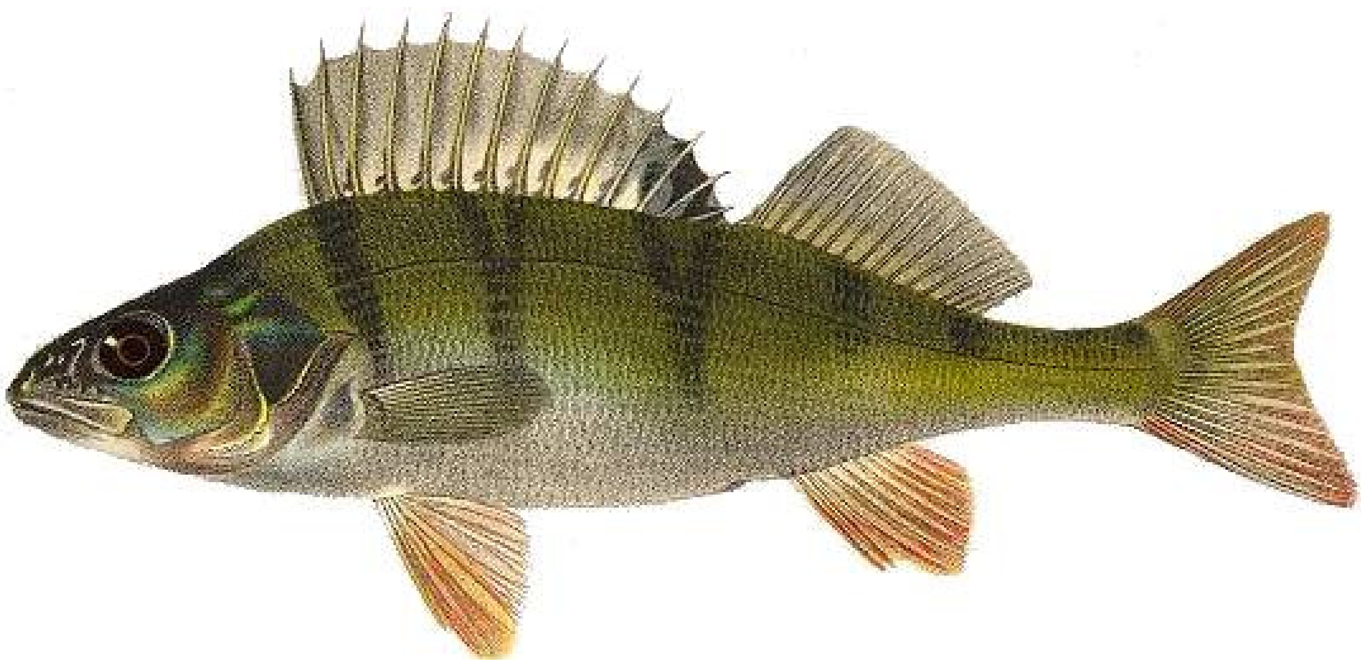
AMAP



Mercury in Perch from Norway, Sweden and Finland – Geographical Patterns and Temporal Trends

Jenny Hedman, Sara Danielsson, Anders Bignert

Dep. of Contaminant Research, Swedish Museum of Natural History

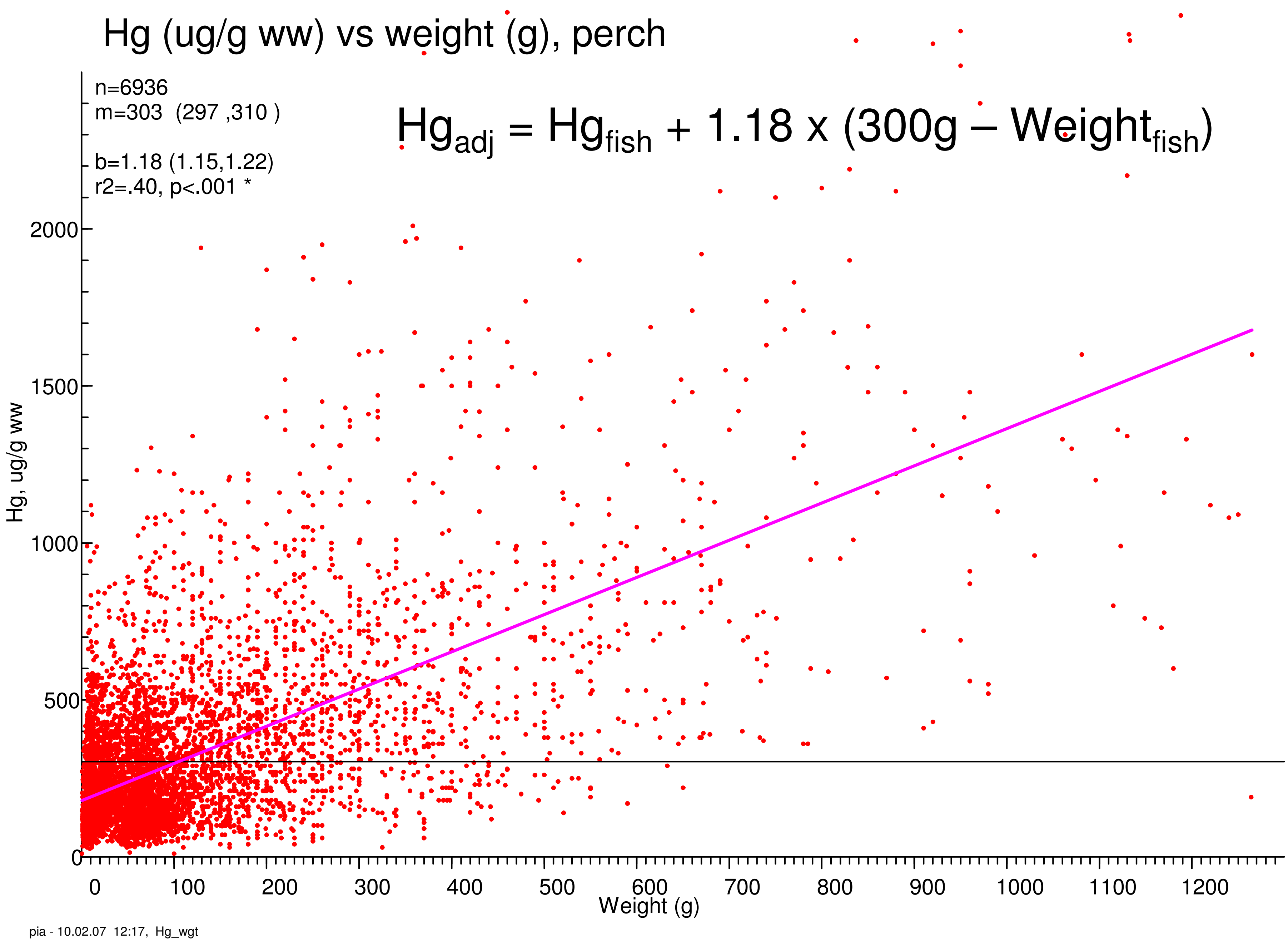


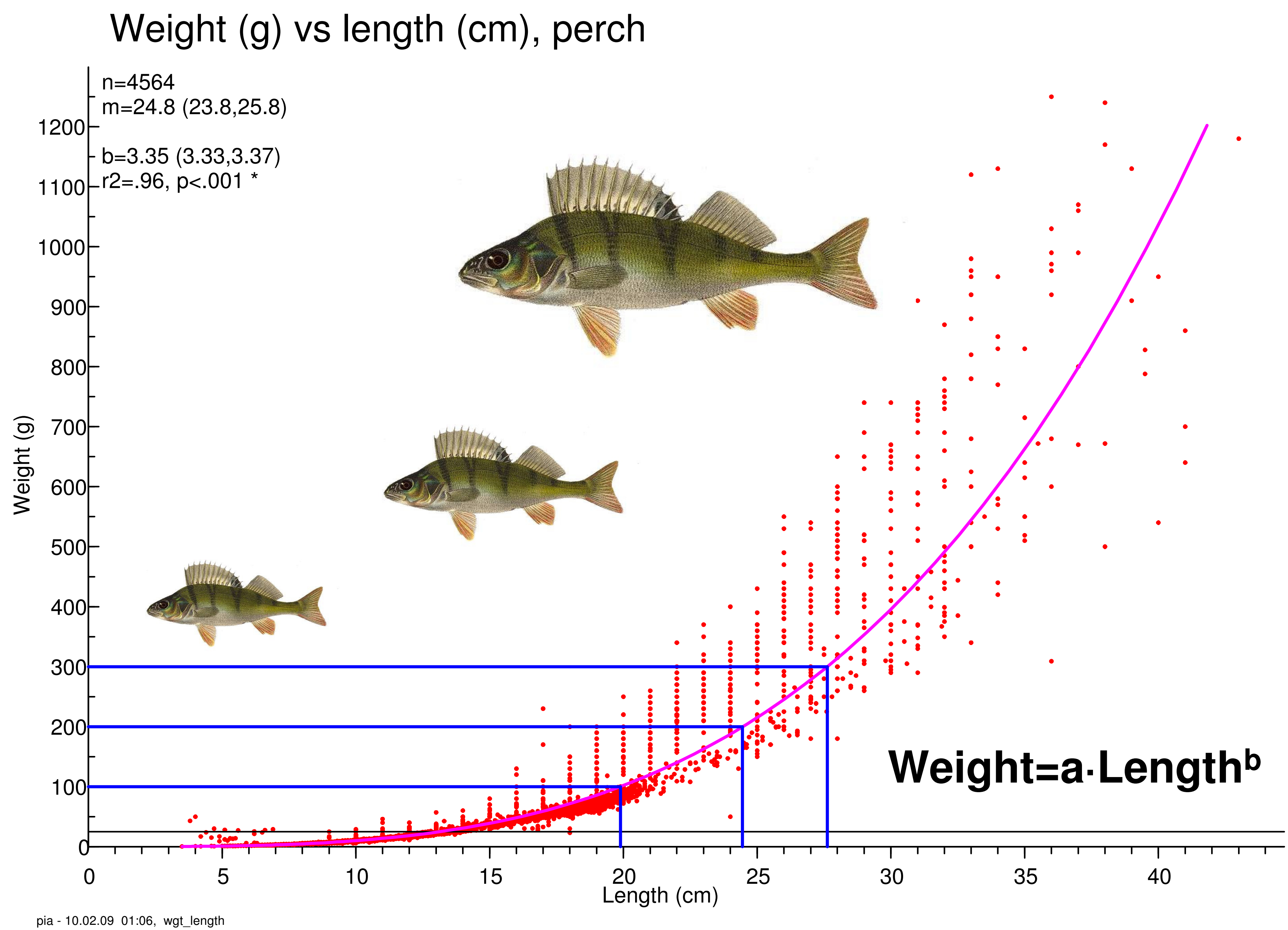
Number of analyzed perch samples in each country

	Year	Total	N of perch specimen before 1995	N of perch specimen after 1995
Sweden	1972-2005	(5113) 4684	1323	3361
Finland	1968-2002	(902) 849	648	201
Norway	1985-1998	(1302) 1246	948	298

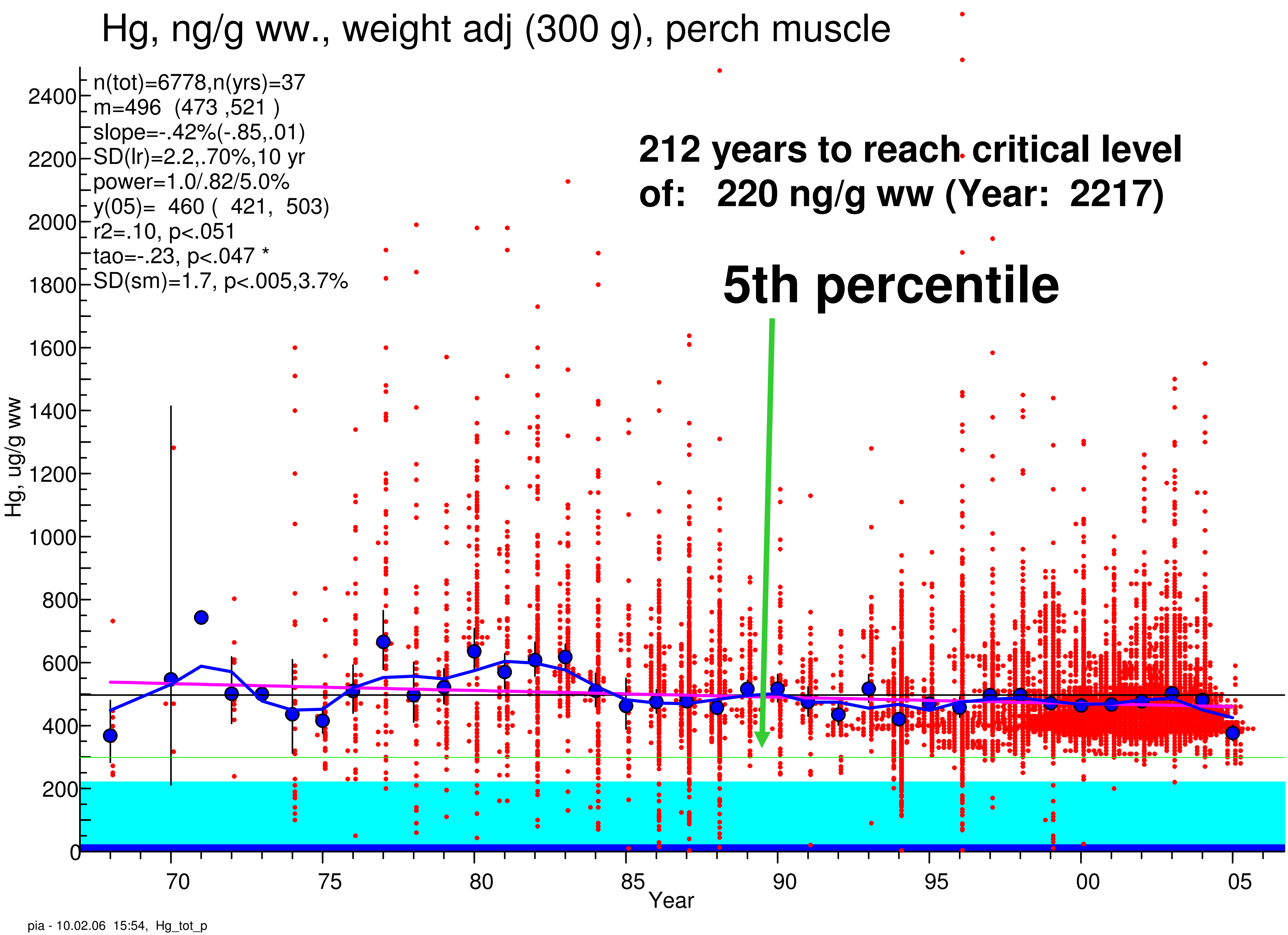
Mercury concentration in perch (standardized to300 g) between 1968-2005 in Scandinavia

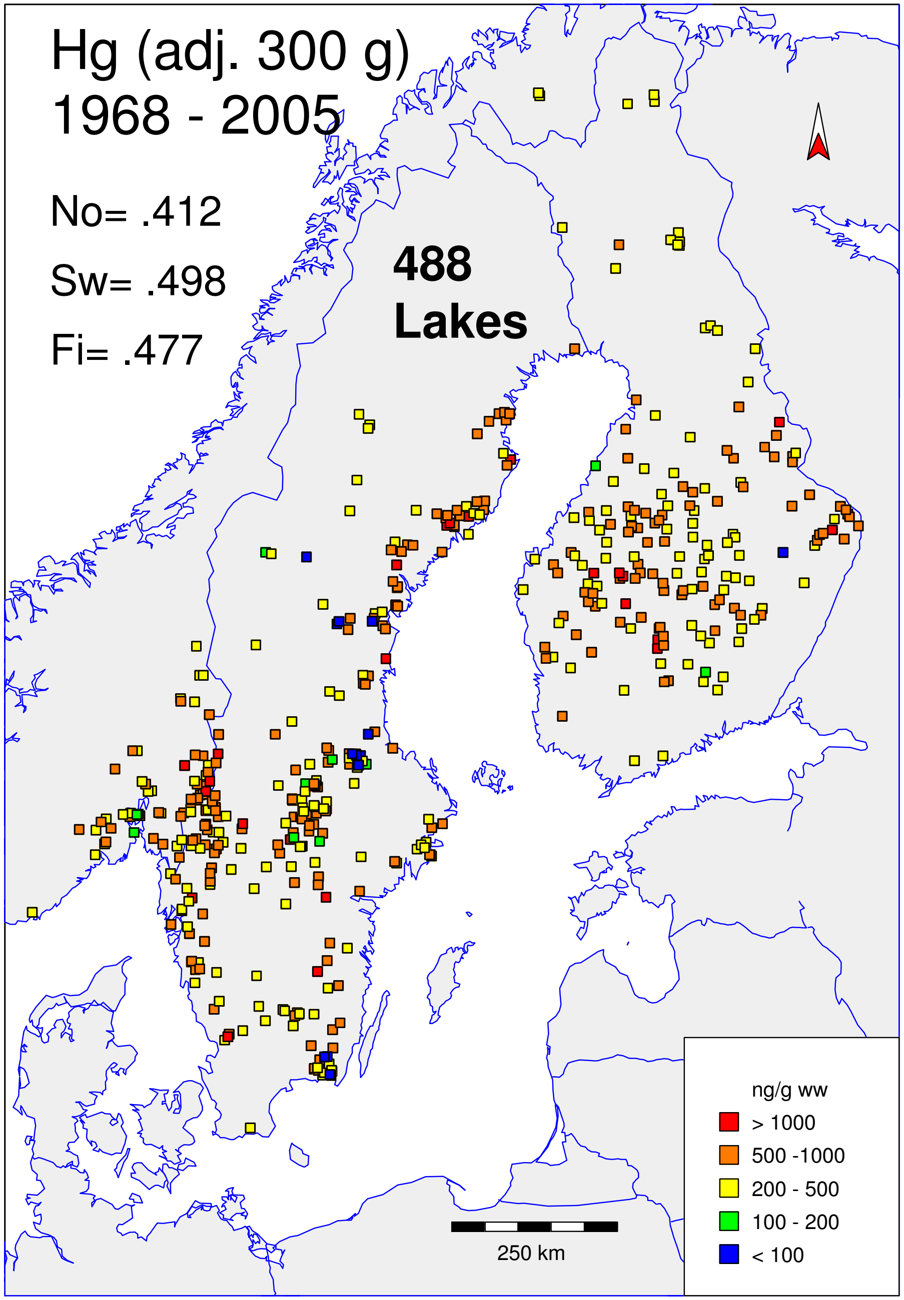
	Hg (ug/g w.w.)	
	Arithmetic mean ± standard deviation	Median (25% and 75% quartile)
Sweden	0,53 ± 0,21	0,47 (0,41-0,59)
Finland	0,51 ± 0,20	0,48 (0,38-0,61)
Norway	0,49 ± 0,23	0,46 (0,37-0,59)


Hg (ug/g ww) vs weight (g), perch
n=6936
m=303 (297 ,310)
b=1.18 (1.15,1.22)
r2=.40, p<.001 *
$Hg_{adj} = Hg_{fish} + 1.18 \times (300g - Weight_{fish})$
Hg, ug/g ww
0
500
1000
1500
2000
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Weight (g)
pia - 10.02.07 12:17, Hg_wgt

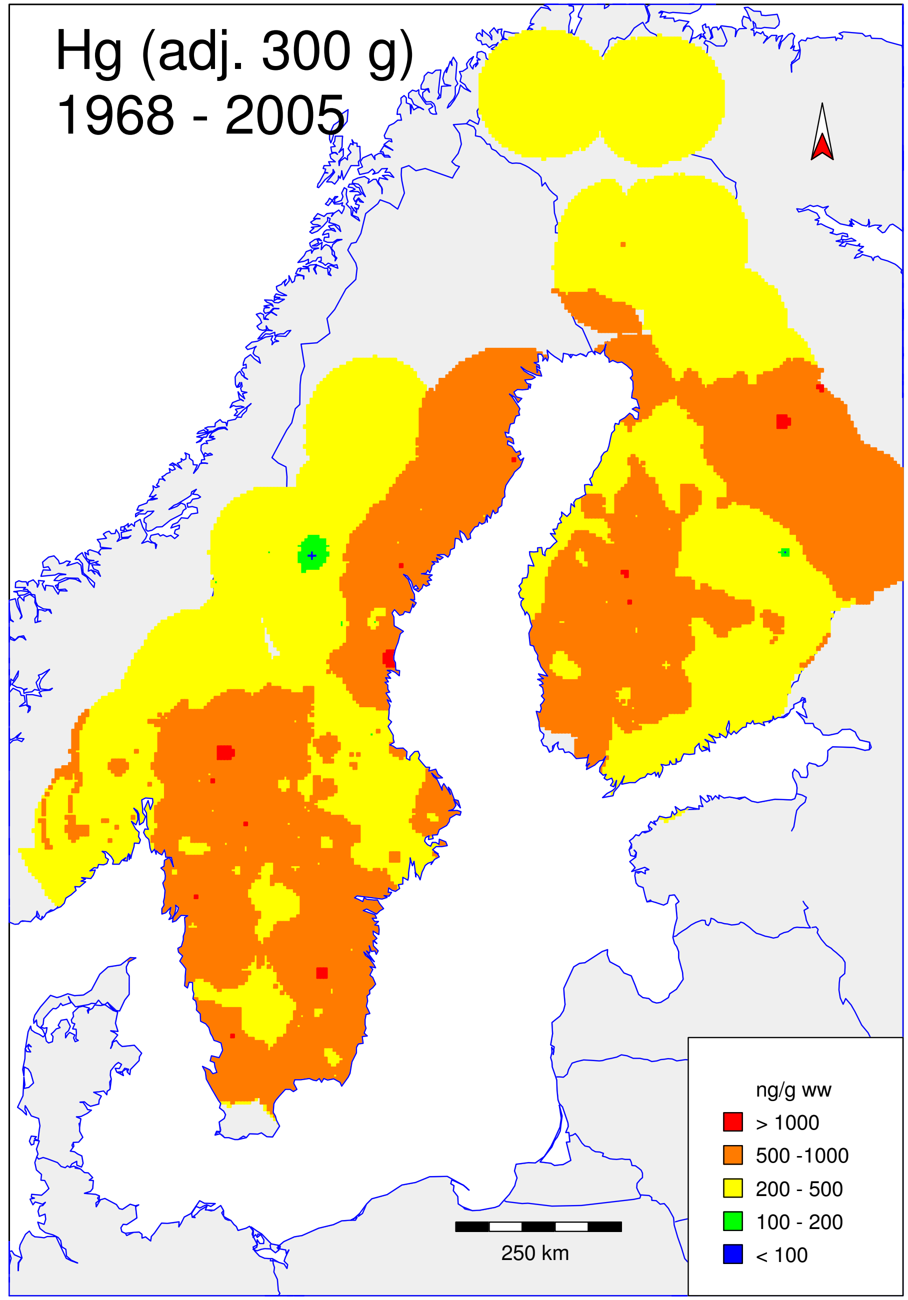


Weight (g) vs length (cm), perch
n=4564
m=24.8 (23.8,25.8)
b=3.35 (3.33,3.37)
r2=.96, p<.001 *
Weight (g)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Length (cm)
0
5
10
15
20
25
30
35
40
Weight=a·Length^b
pia - 10.02.09 01:06, wgt_length

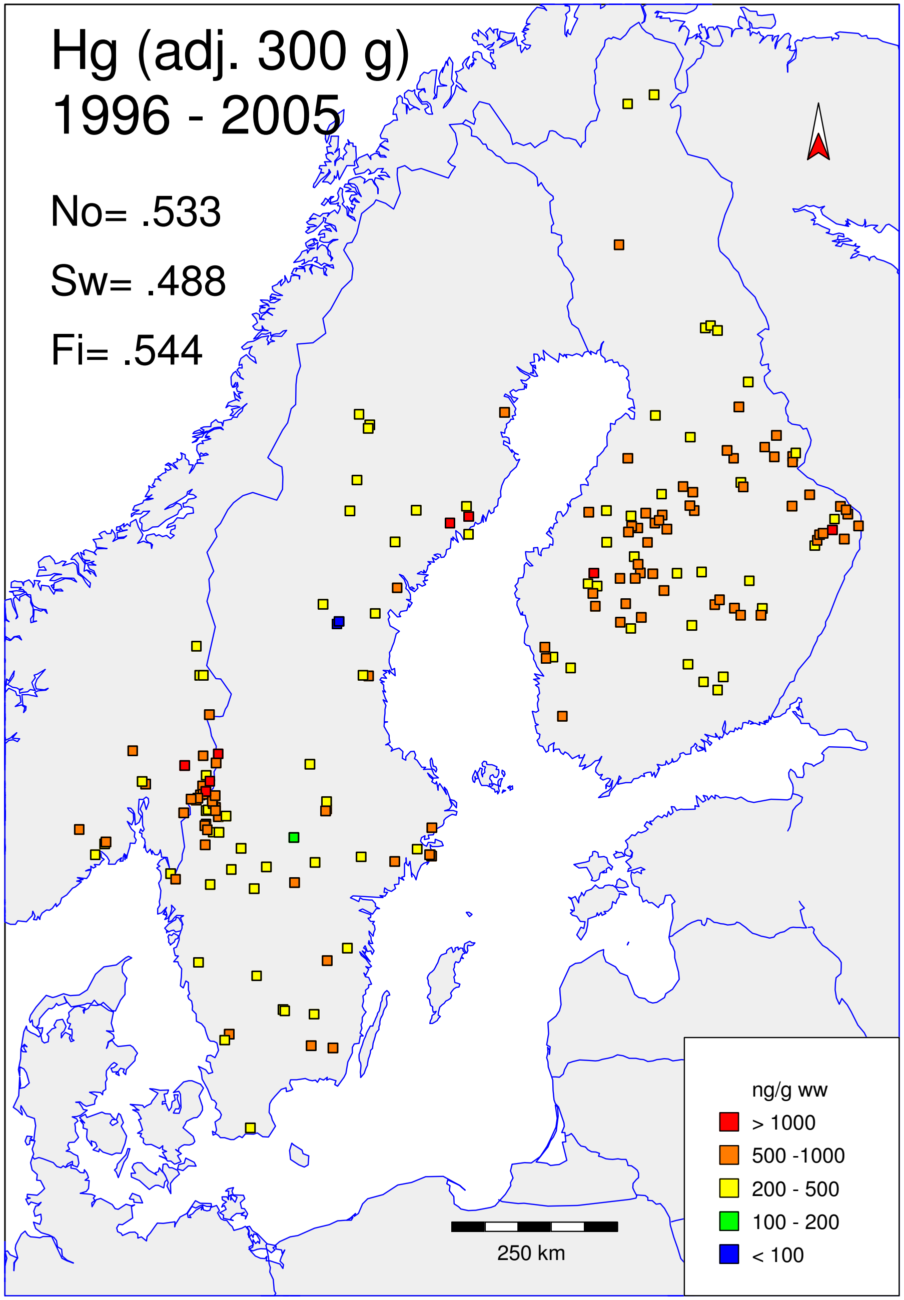

Hg, ng/g ww., weight adj (300 g), perch muscle
n(tot)=6778,n(yrs)=37
m=496 (473 ,521)
slope=-.42%(-.85,.01)
SD(lr)=2.2,.70%,10 yr
power=1.0/.82/5.0%
y(05)= 460 (421, 503)
r2=.10, p<.051
tao=-.23, p<.047 *
SD(sm)=1.7, p<.005,3.7%
212 years to reach critical level
of: 220 ng/g ww (Year: 2217)
5th percentile
Hg, ug/g ww
Year
pia - 10.02.06 15:54, Hg_tot_p



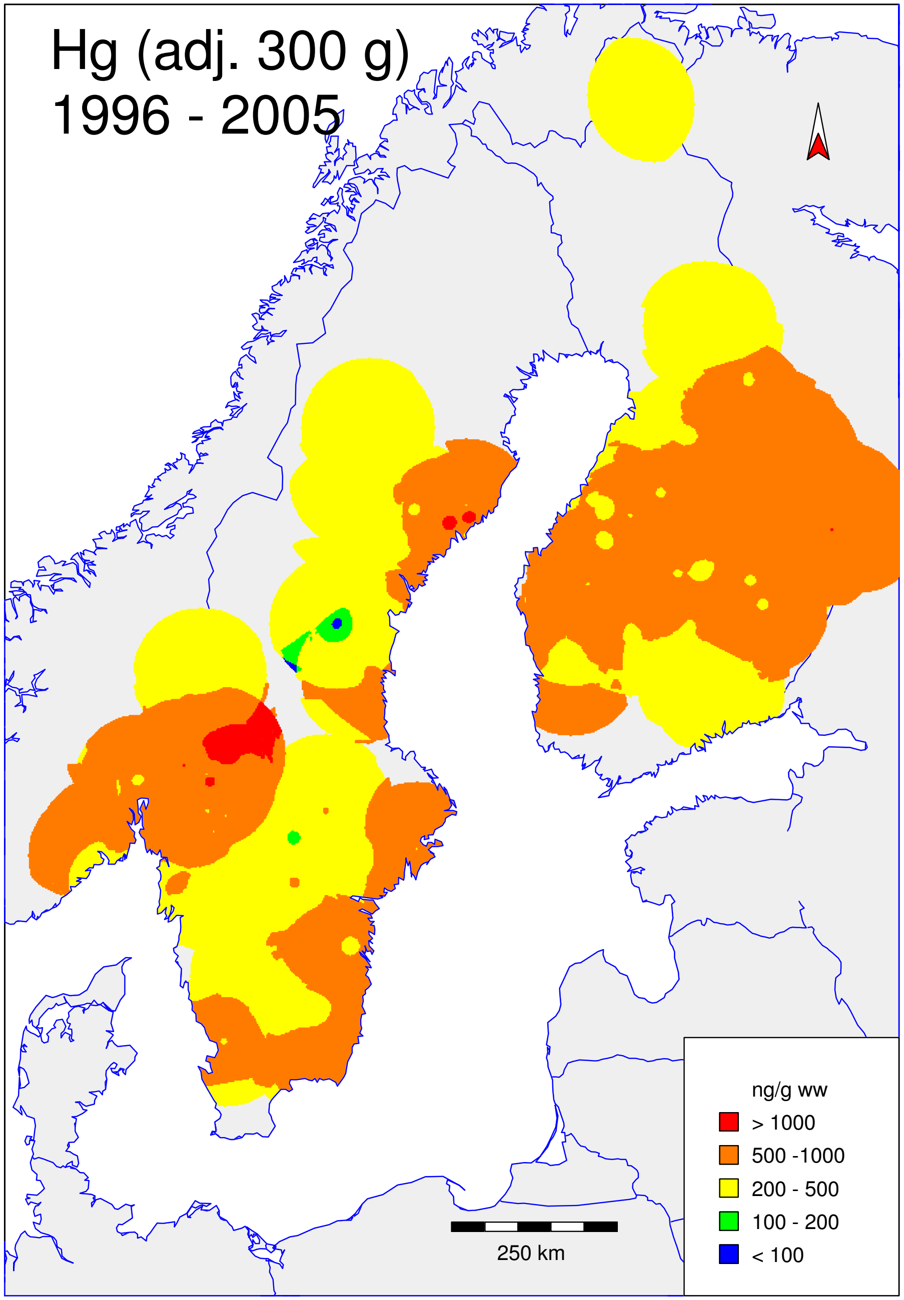
TISS - 10.02.07 18:21, Hg_300_gr



TISS - 10.02.07 21:02, Hg_300_0_sm



TISS - 10.02.09 15:26, Hg_300_gr_96_



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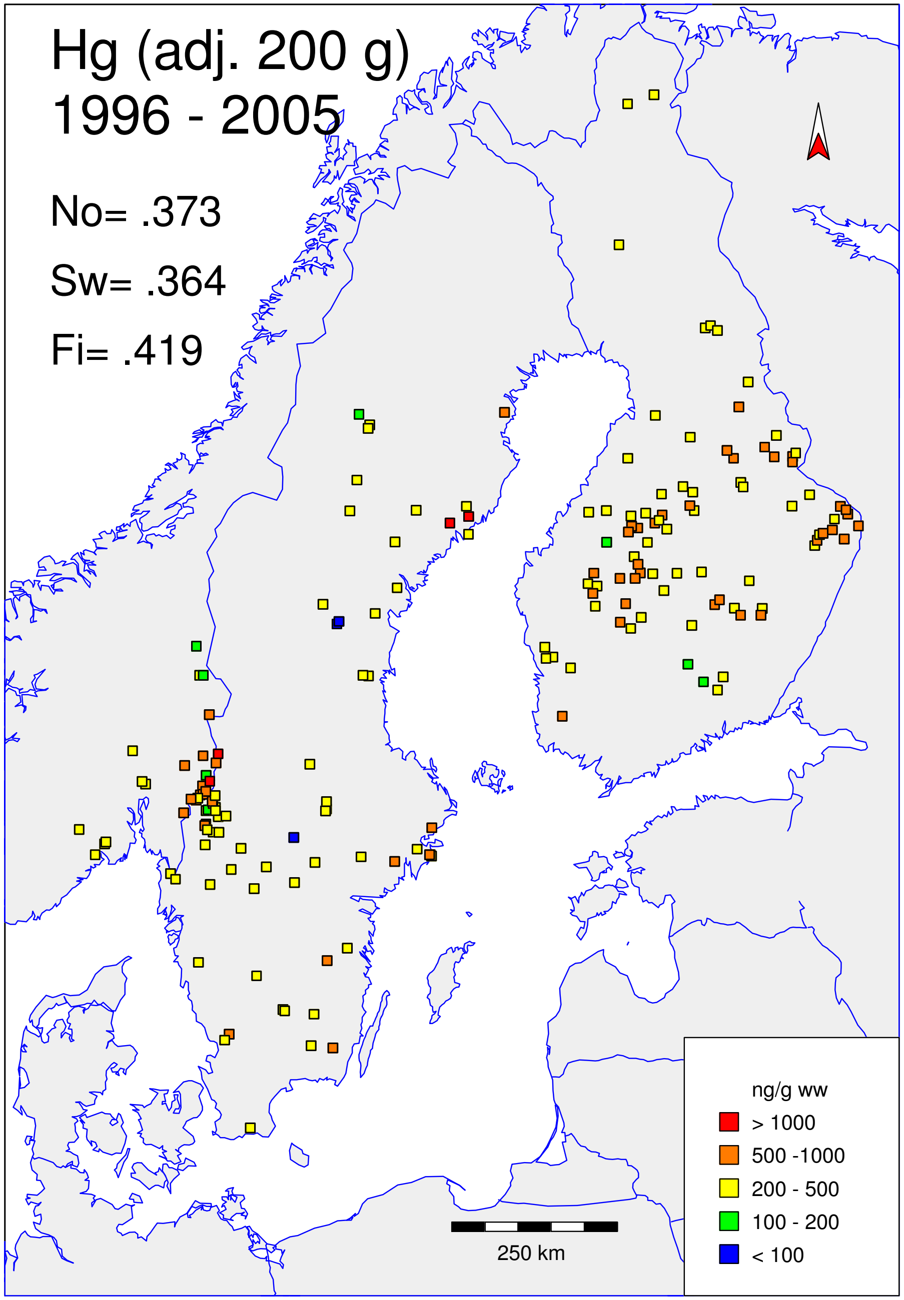
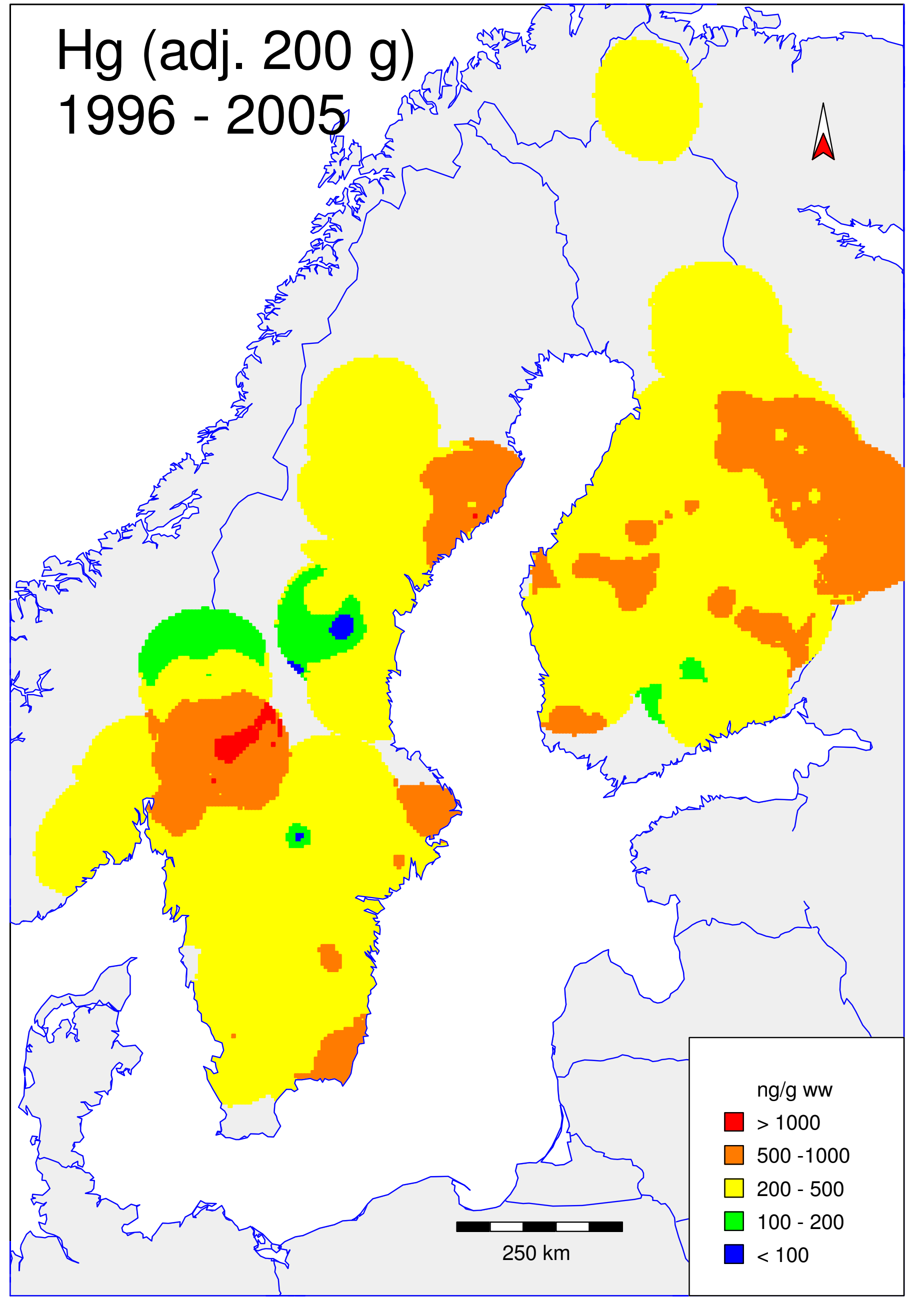


TISS - 10.02.09 22:13, Hg_200_gr_96



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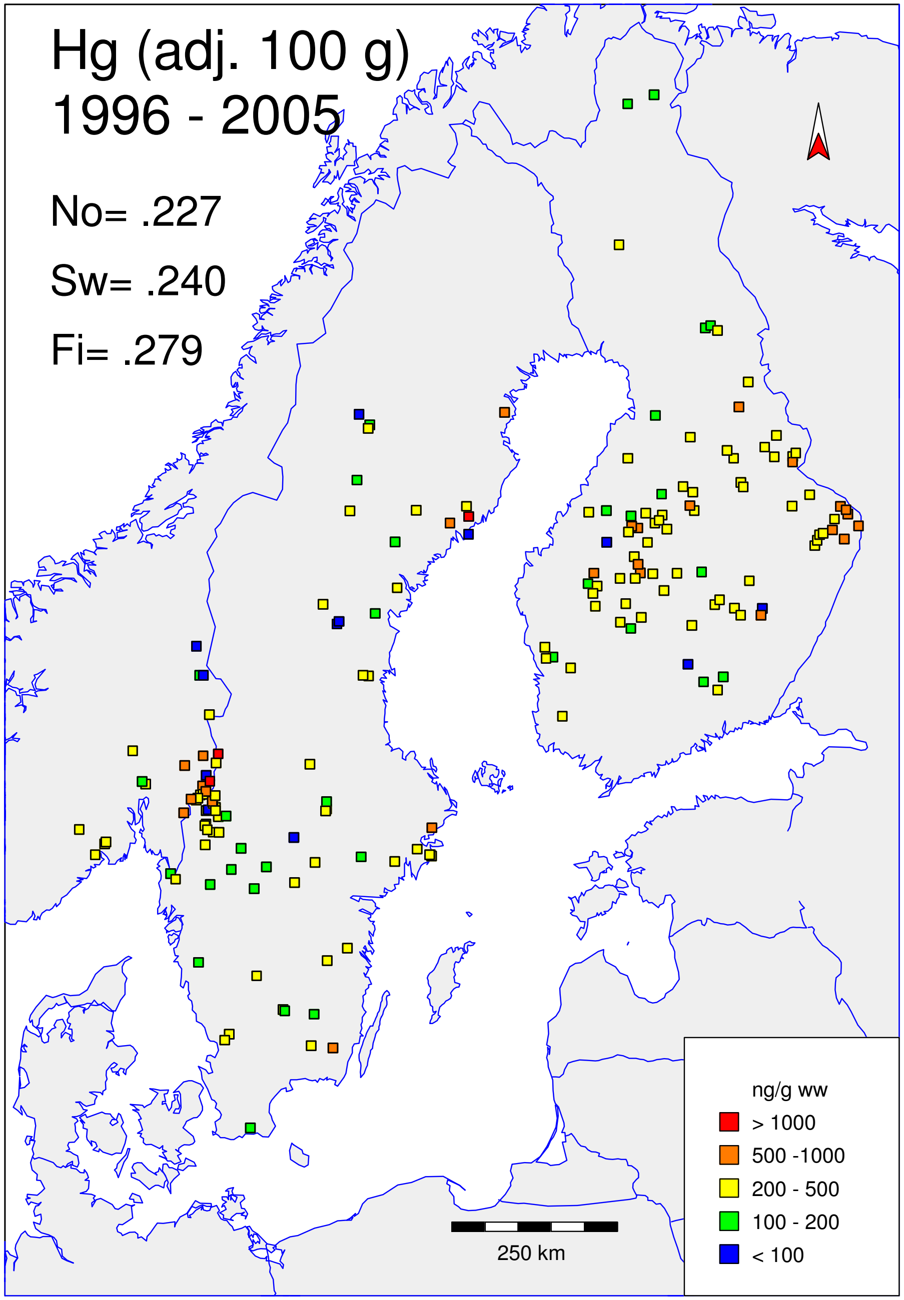

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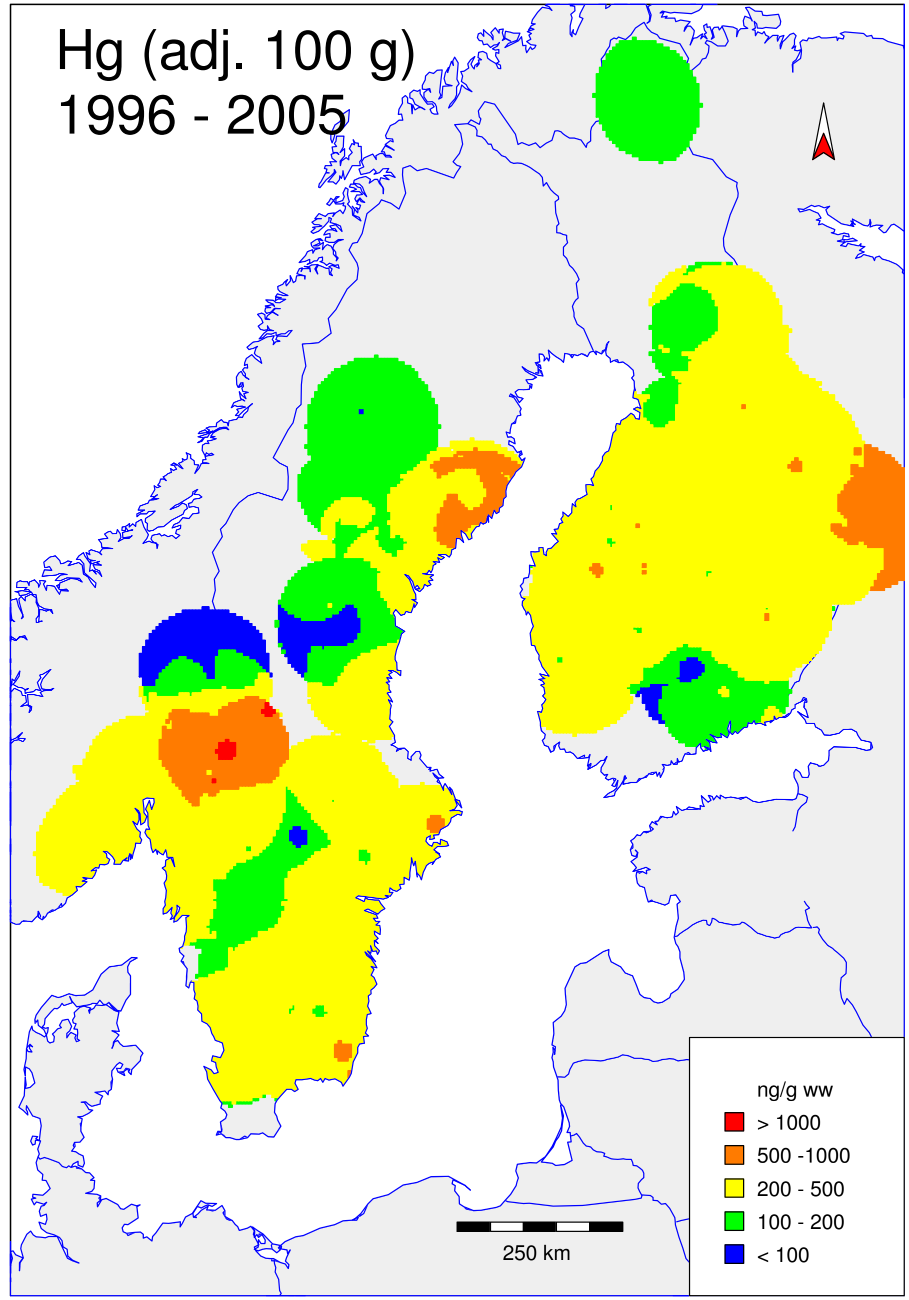
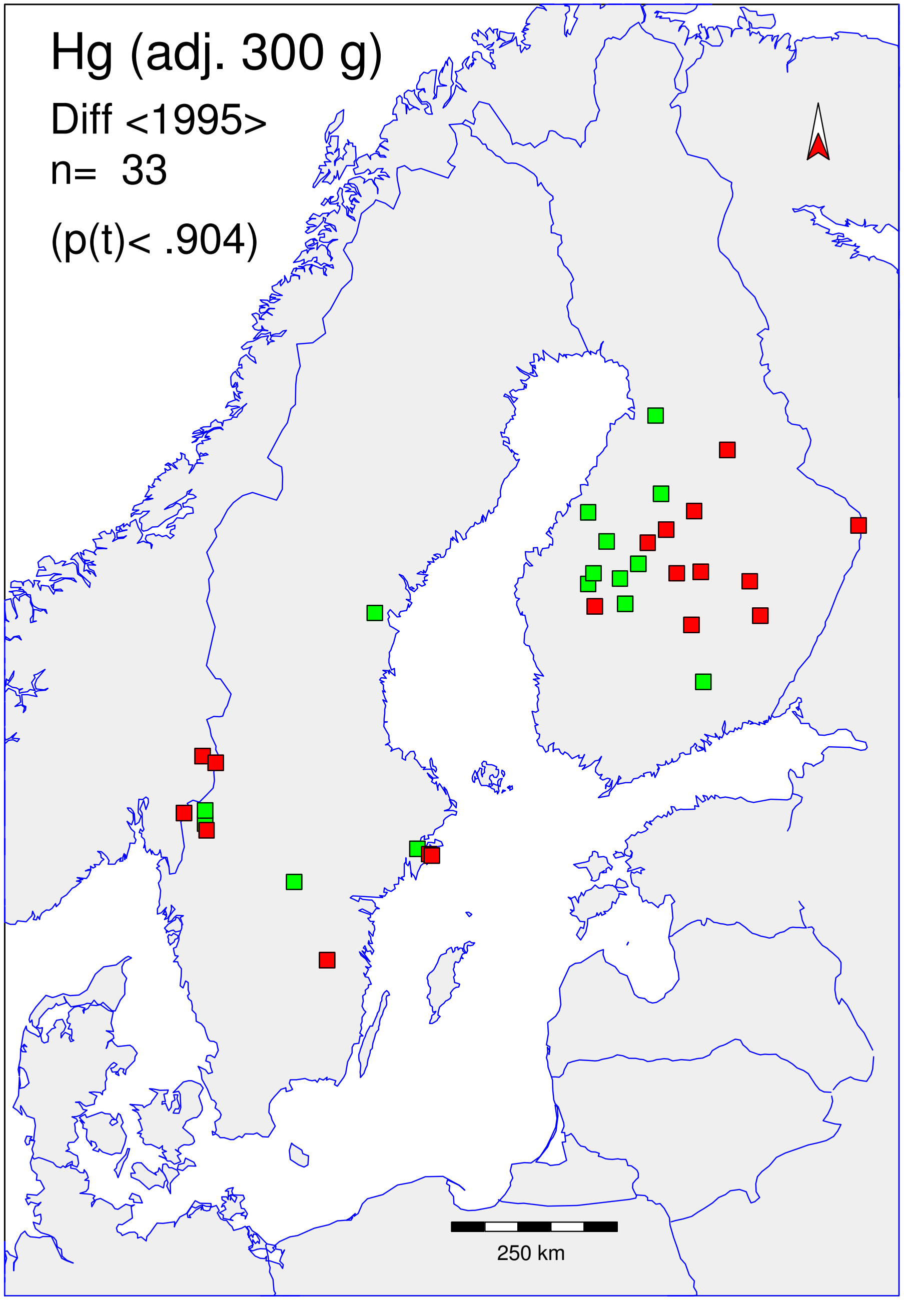


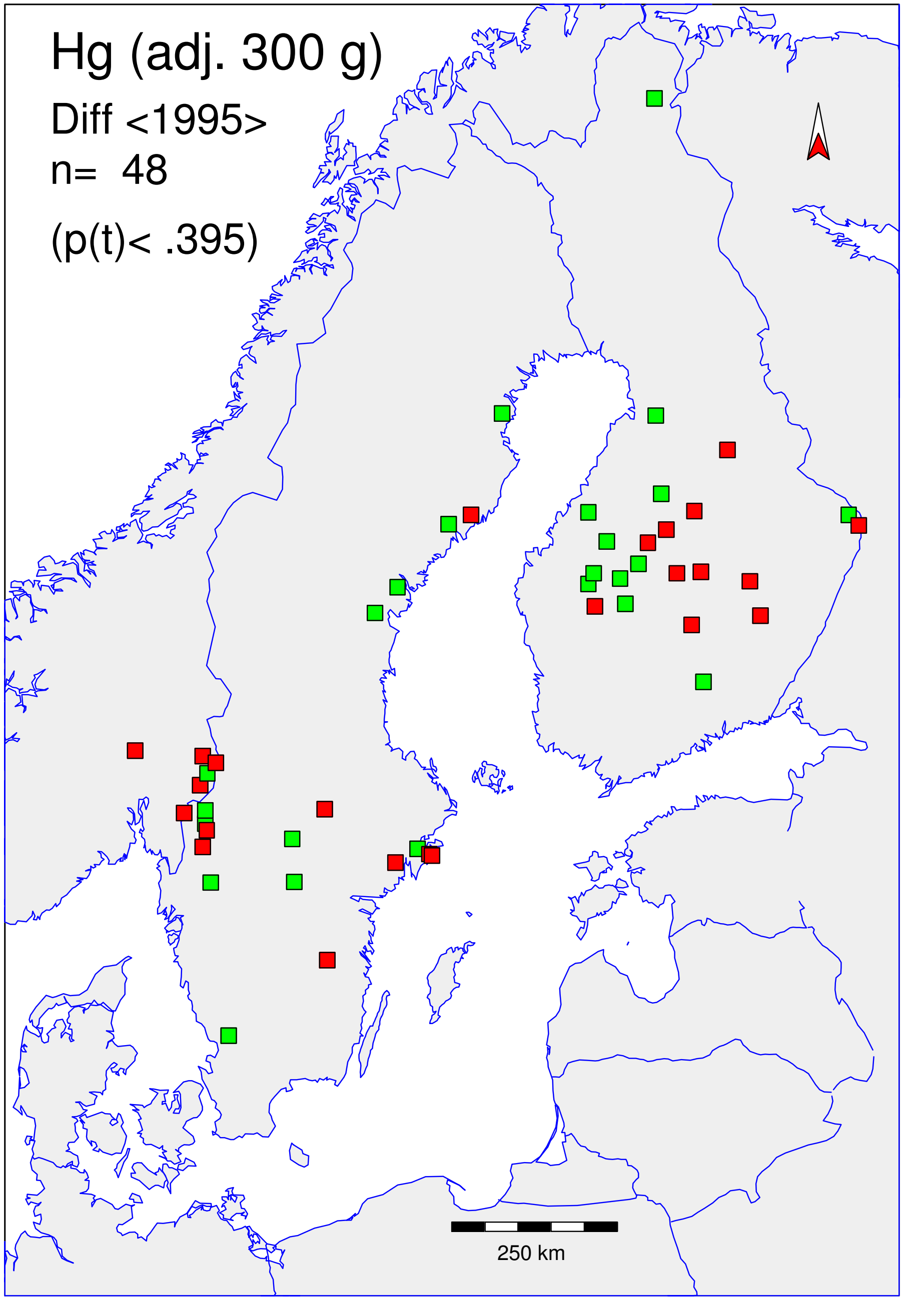
TISS - 10.02.09 22:25, Hg_100_96_sm

	Hg (ng/g w.w.) Geometric mean		
	300 g	**200 g**	**100 g**
Norway	412	267	149
Sweden	498	368	243
Finland	477	351	203
	462	329	198

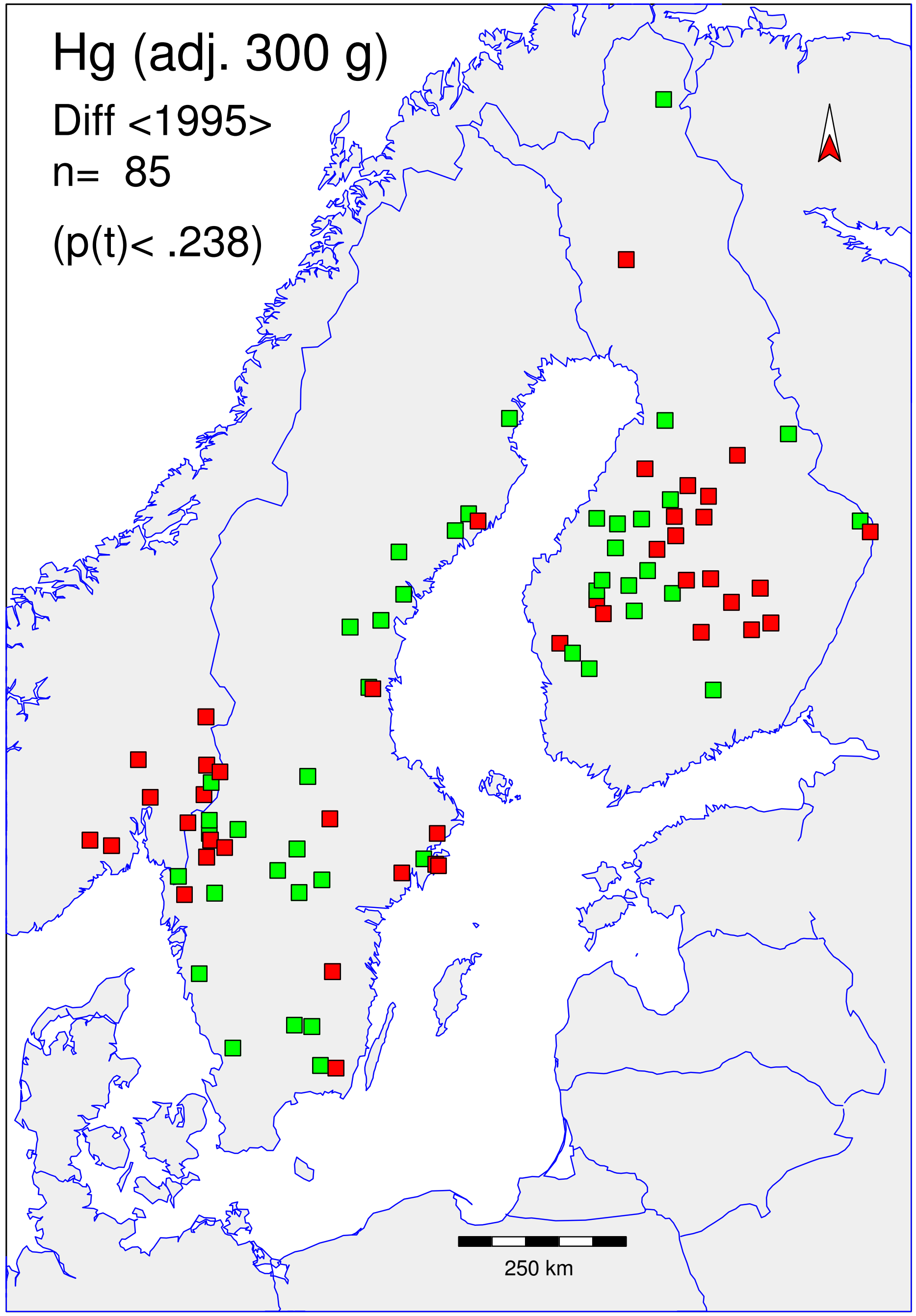
Mercury concentration in perch, standardized to weight, between 1968-2005 in Scandinavia



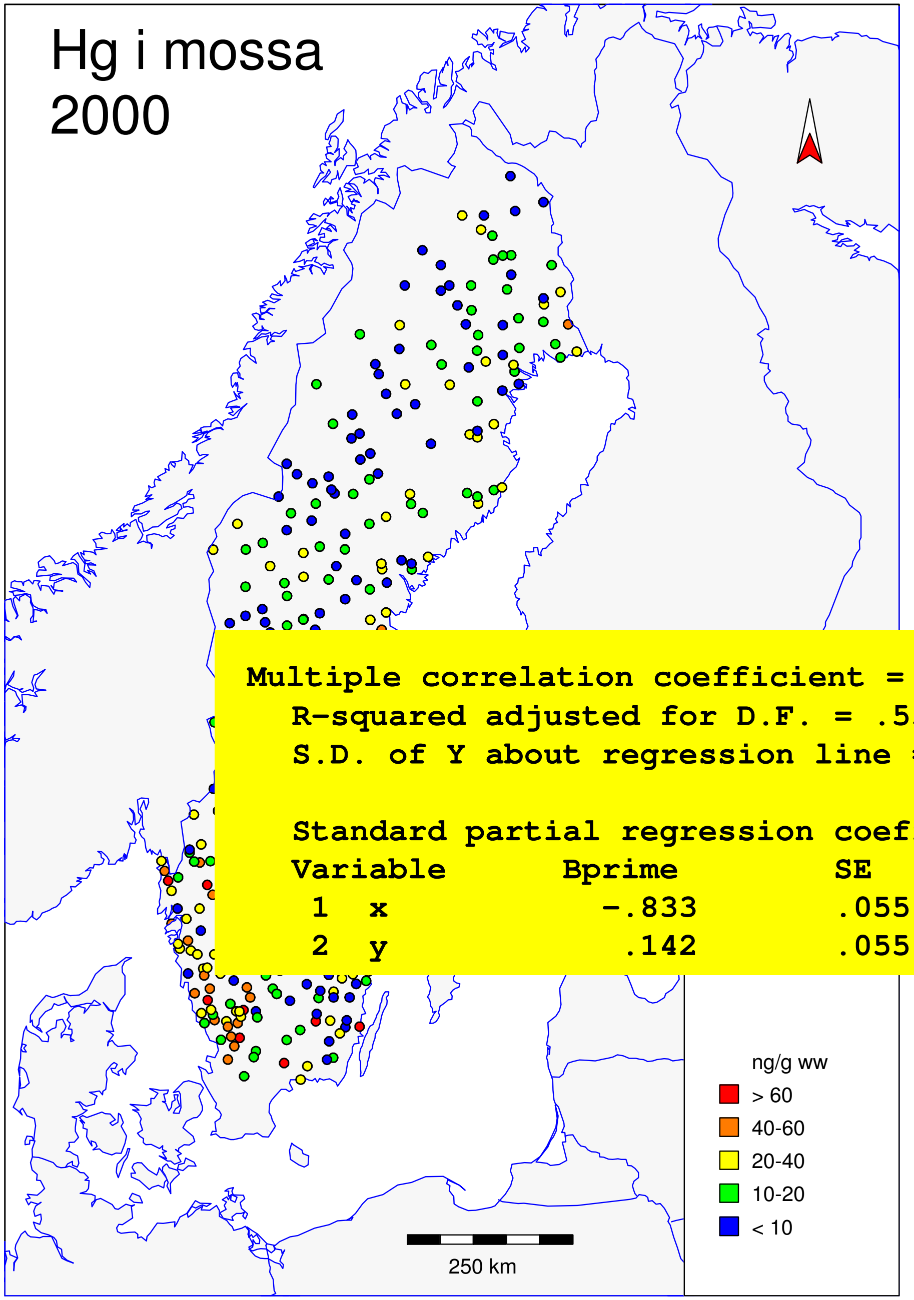
TISS - 10.02.06 23:42, diff_05



TISS - 10.02.06 23:38, diff_10km



TISS - 10.02.06 23:45, diff_50km

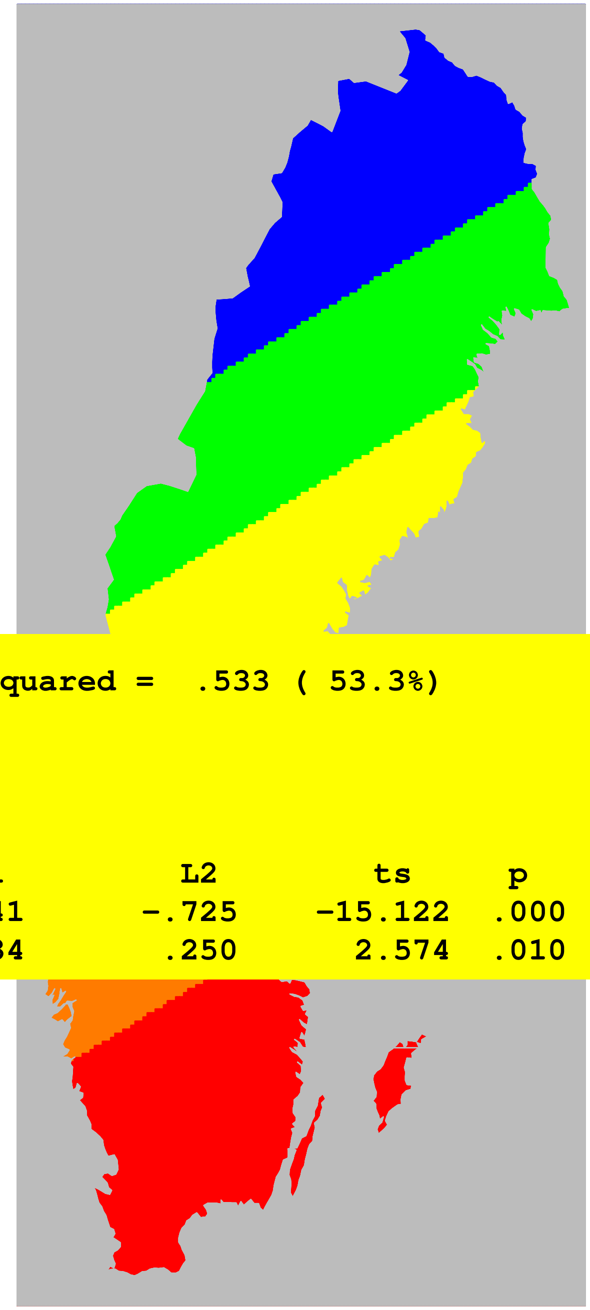


TISS - 09.11.06 00:50, mossa_2000

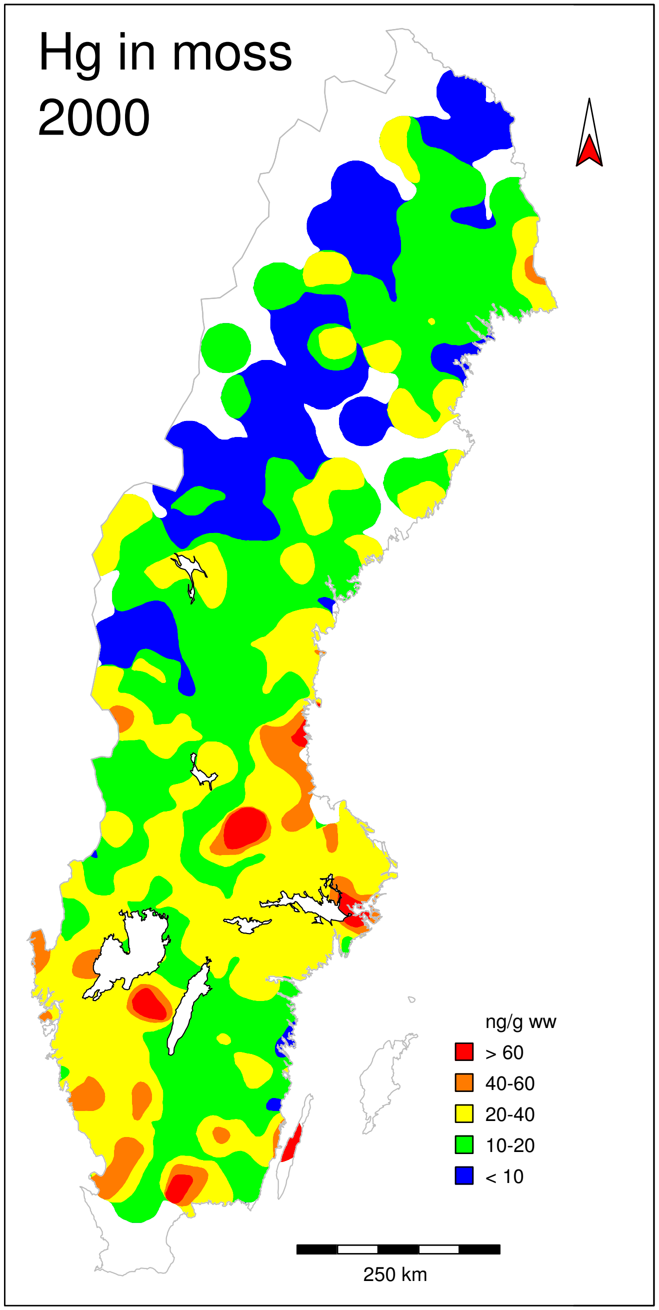
Multiple correlation coefficient = .730 squared = .533 (53.3%)
R-squared adjusted for D.F. = .531
S.D. of Y about regression line = .037

Standard partial regression coefficients

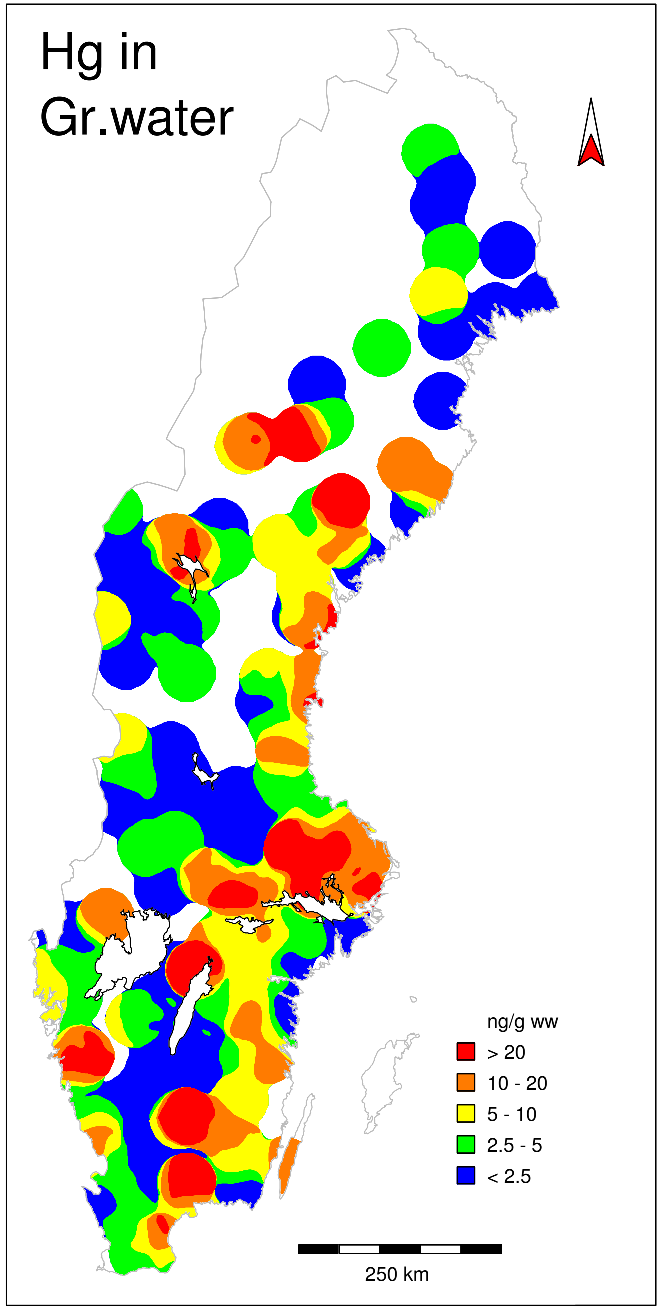
	Variable	Bprime	SE	L1	L2	ts	p
1	x	-.833	.055	-.941	-.725	-15.122	.000
2	y	.142	.055	.034	.250	2.574	.010



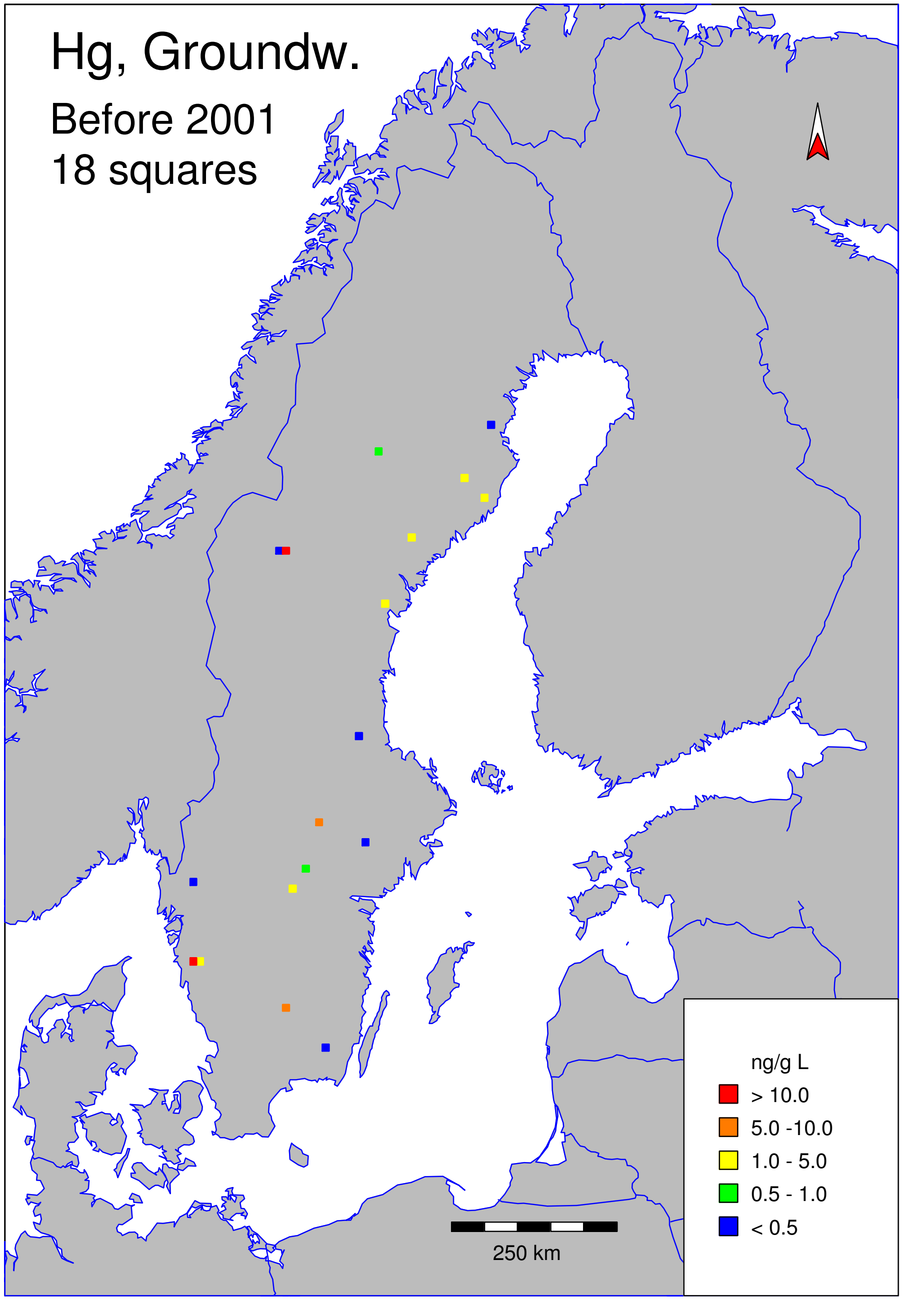
TISS - 10.02.09 03:30, TS_moss_3



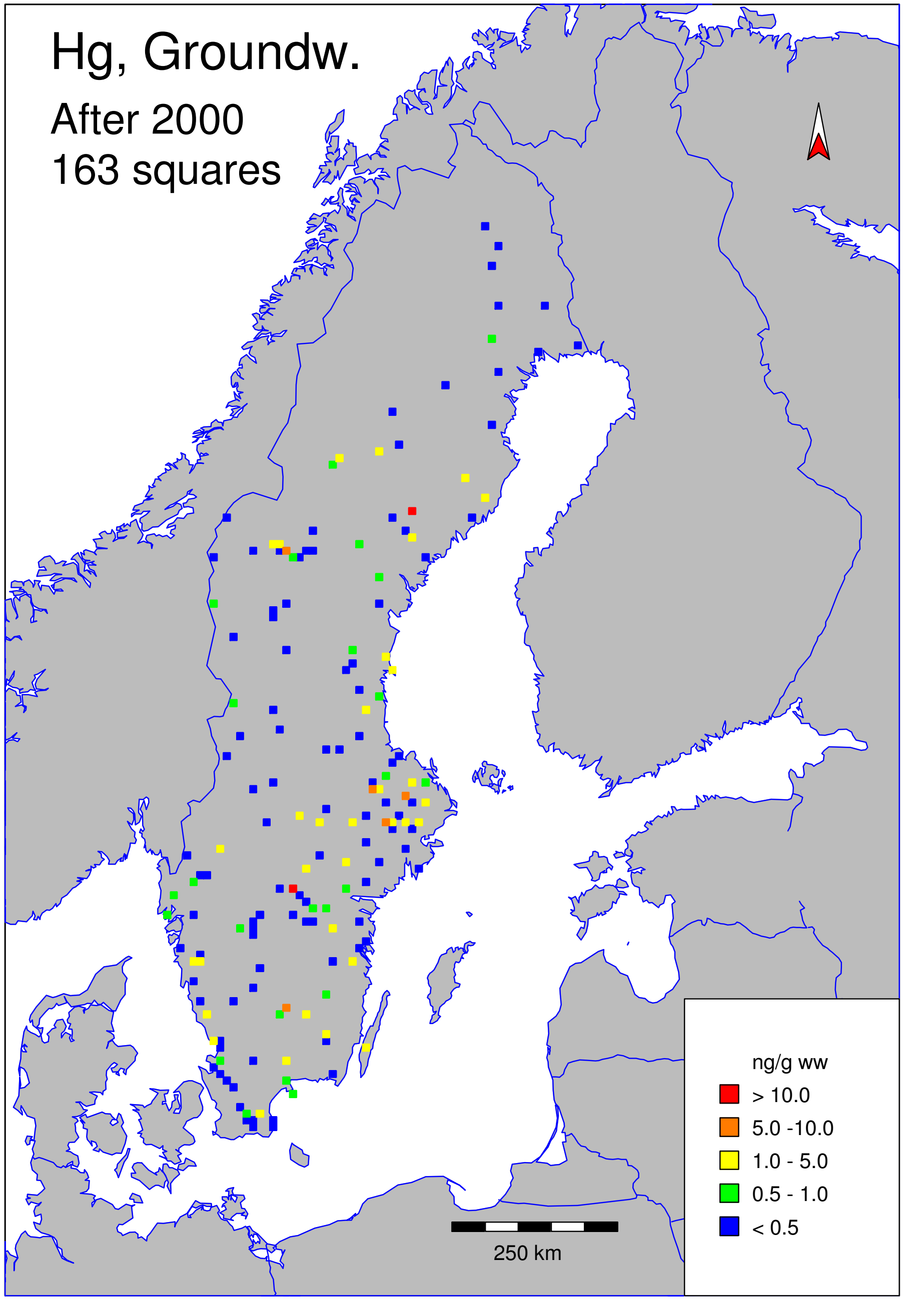
TISS - 10.11.24 22:47, Kr_moss_2



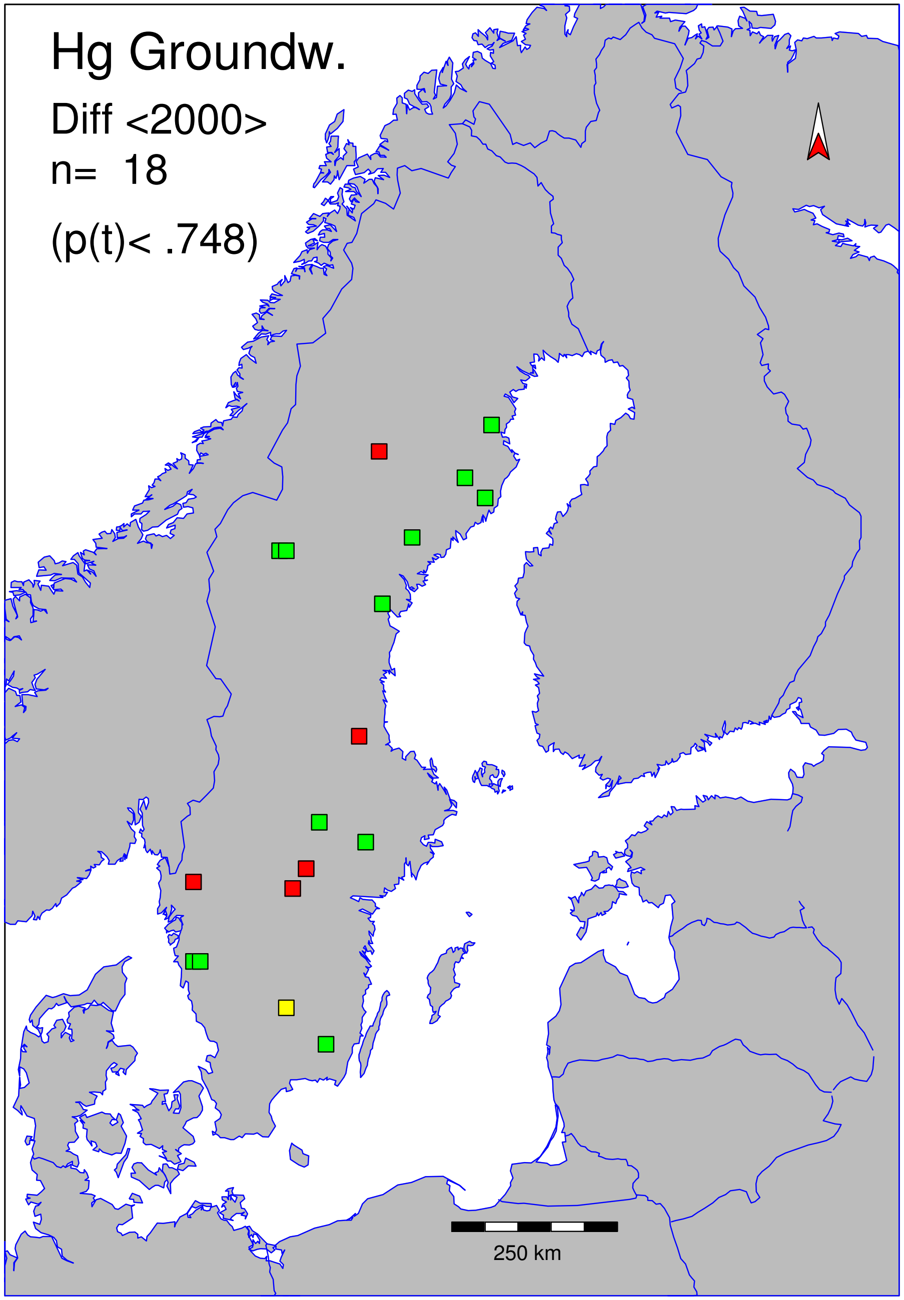
TISS - 10.11.24 23:29, Kr_GW_2



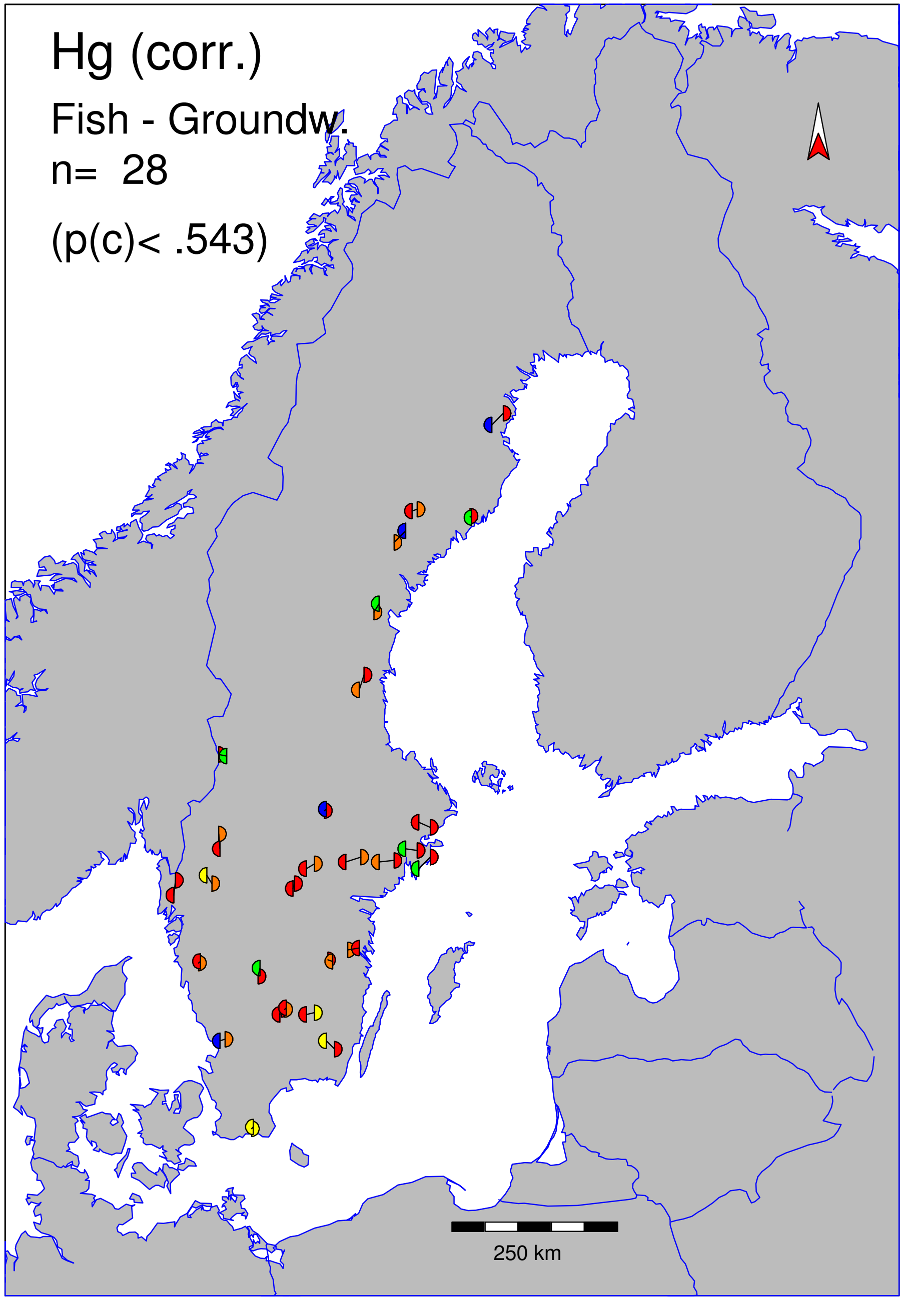
TISS - 09.11.28 20:45, Hg_SGU_a



TISS - 09.11.28 20:47, Hg_SGU_b

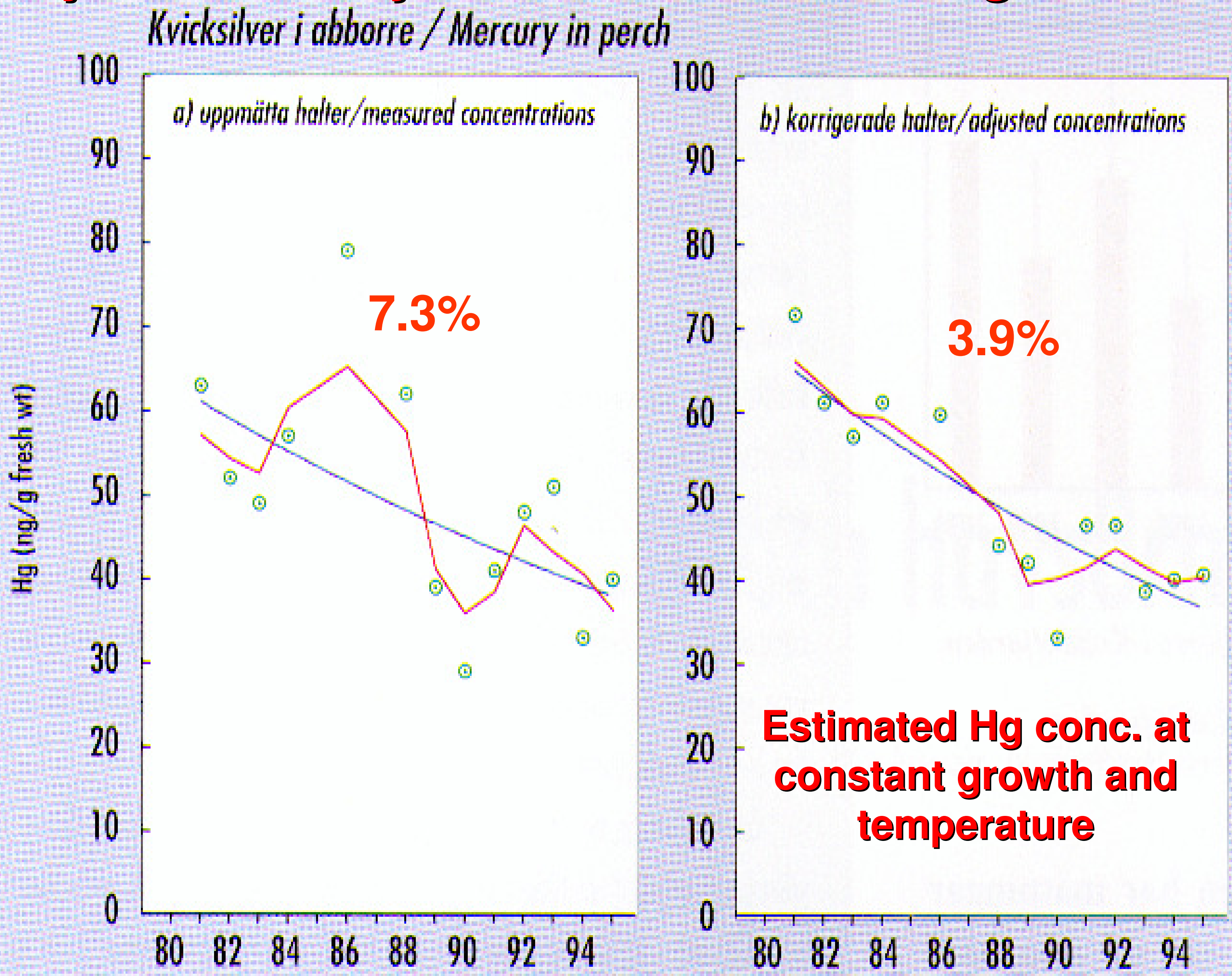


TISS - 09.11.28 23:55, diff_SGU



TISS - 09.11.29 15:26, corr_fish_SGU

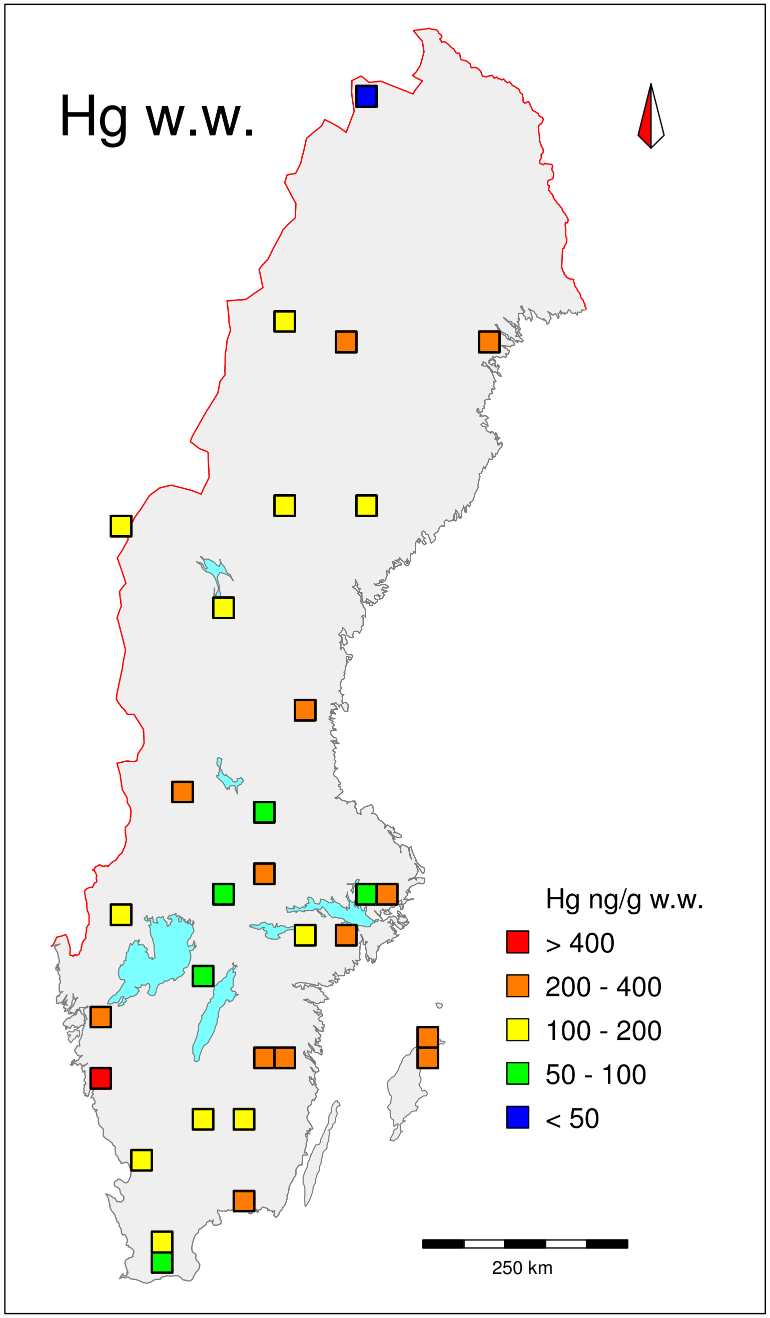
Adjustments by means of a bio-energetic model



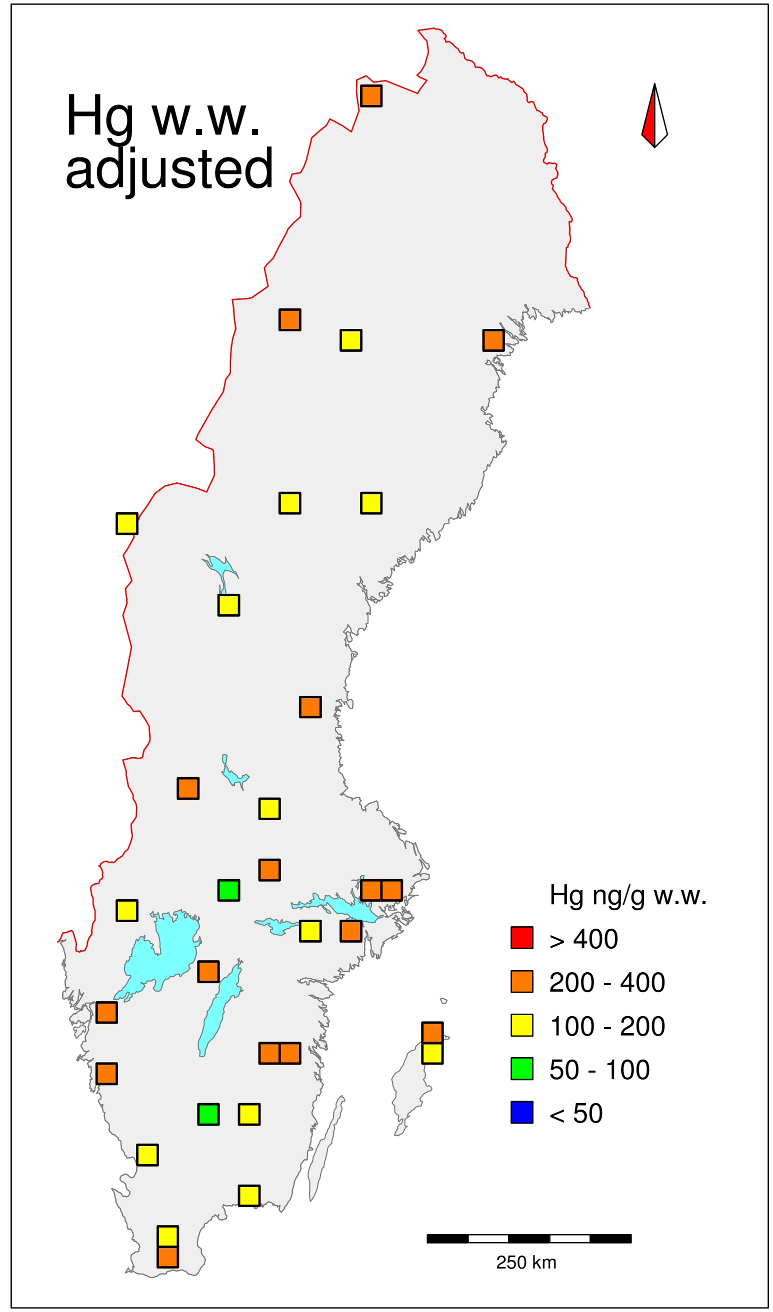
Multiple correlation coefficient, squared = .334
R-squared adjusted for D.F. = .321

Standard partial regression coefficients

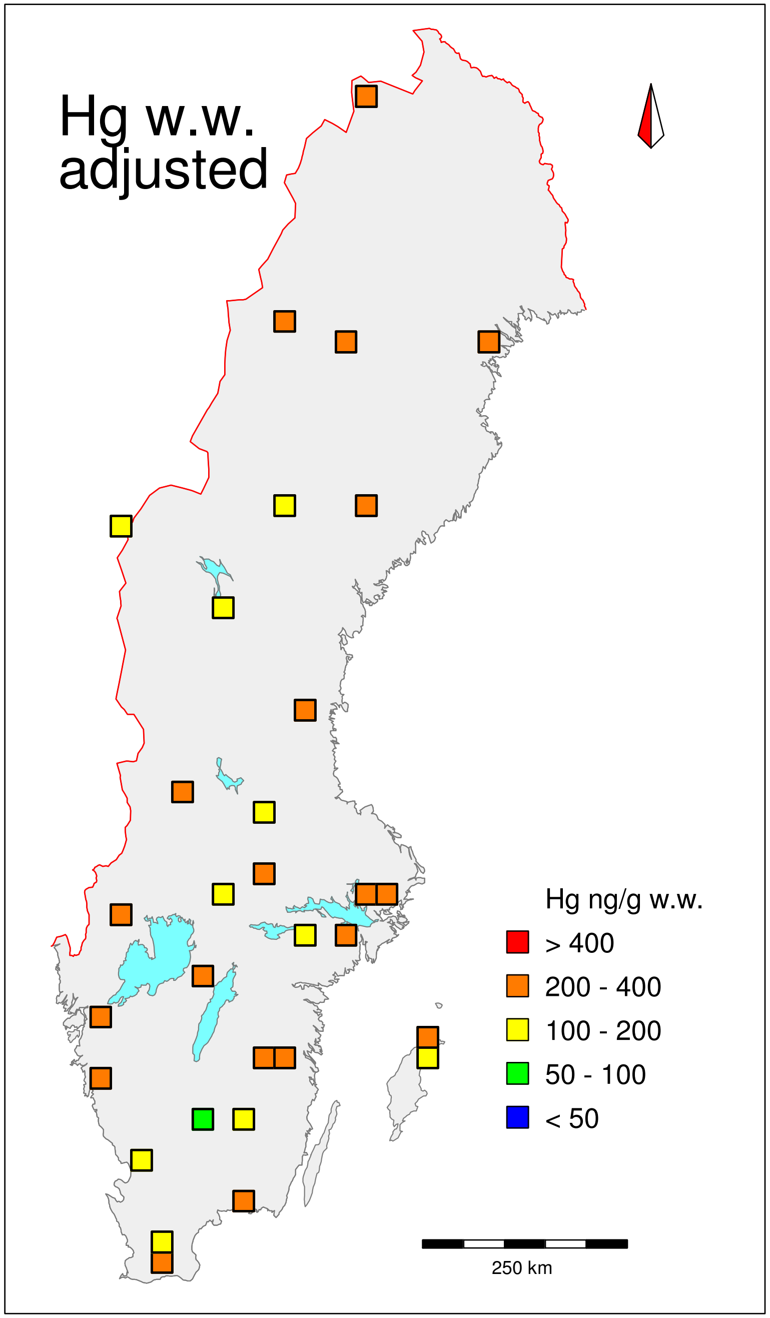
Variable	Bprime	p<
1 Tot weight	.221	.000 ***
2 Secchi depth	-.251	.000 ***
3 TOC	.555	.000 ***
4 Conductivity	1.611	.000 ***
5 Alkalinity	-1.575	.000 ***
6 SO4	-.803	.000 ***
7 PO4P	.201	.001 ***
8 ABS420	-.415	.000 ***
9 Si	-.150	.002 **
10 Chlorofyll	-.359	.000 ***



TISS - 10.11.23 22:27, Hg_map1



TISS - 10.11.24 19:00, Hg_map_adj

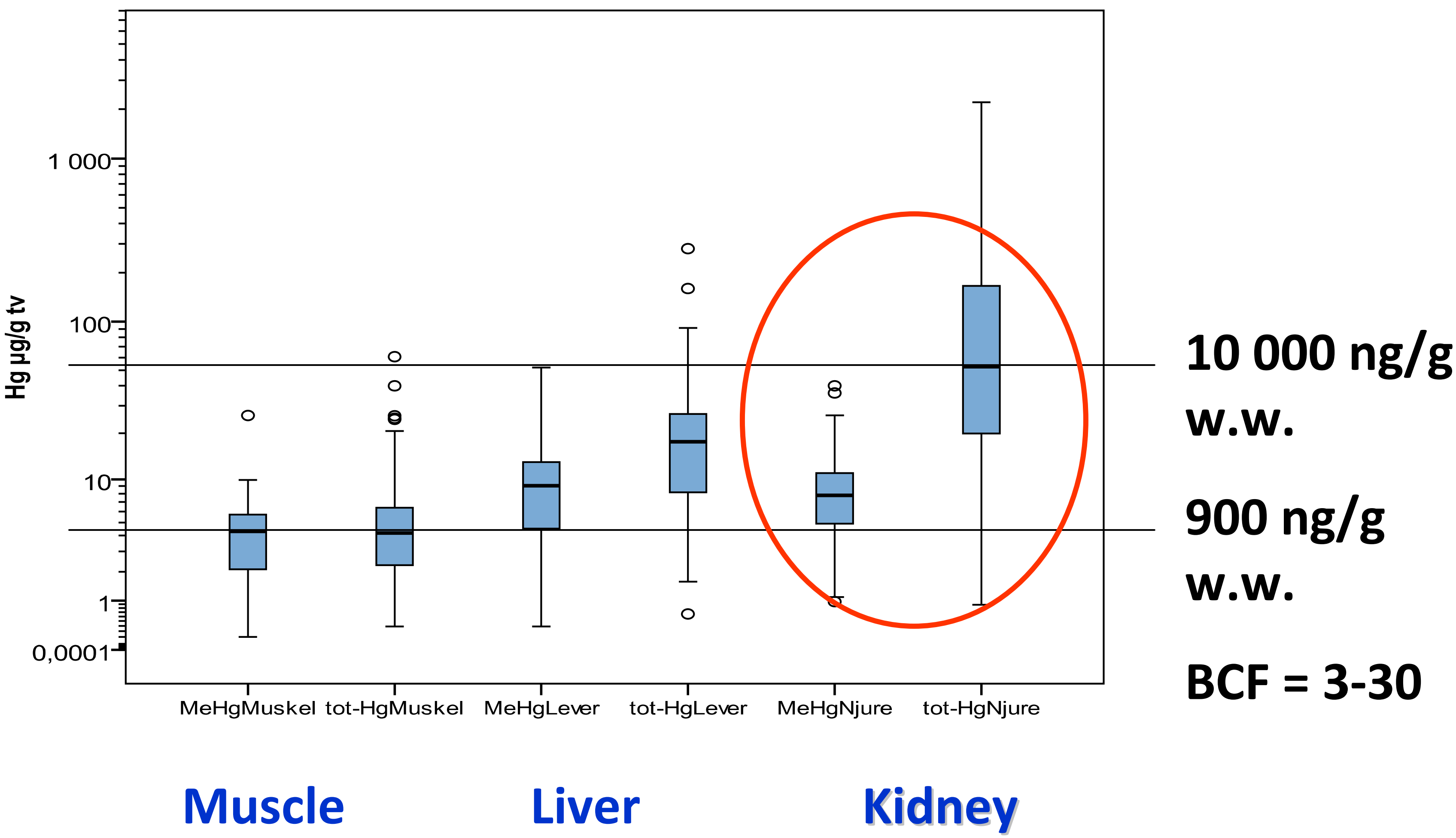


TISS - 10.11.24 18:56, Hg_map_adj

Adjusted for various water chemistry variables and to 500 g total weight

Mercury and Me-Hg in White-tailed Sea Eagle

Björn Helander, NRM & Hans Borg, ITM



Conclusions

- Too few time-series of Hg in freshwater
- Poor spatial resolution in the north
- Hg-concentrations considerably above the suggested level of 220 ng/g
- No clear, consistent temporal Hg-trend in freshwater perch
- No spatial trend in perch Hg-conc (confounders like production, temperature, pH etc more important for the measured conc. Than atmospheric deposition)
- No correlation with moss nor with groundwater

Thank’s to:

Björn Helander, NRM
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Hans Borg, ITM
Helene Lager, NV
Håkan Marklund, NV
Jaakko Mannio, SYKE
Karin Holm, ITM
Kjell Johansson, NV
Kerttu Åslund, SLU
Matti Verta, SYKE
Mikaela Gönczi, NV
Simon Wilson, AMAP
Susan Londesborough, SYKE
Ulrika Stensdotter, NV

1b. **Monitoring in Norway**. Jon L. Fuglestad (Climate and Pollution Agency)

CLIMATE AND
POLLUTION
AGENCY

Environmental Monitoring of Hg in Norwegian Freshwater Ecosystems

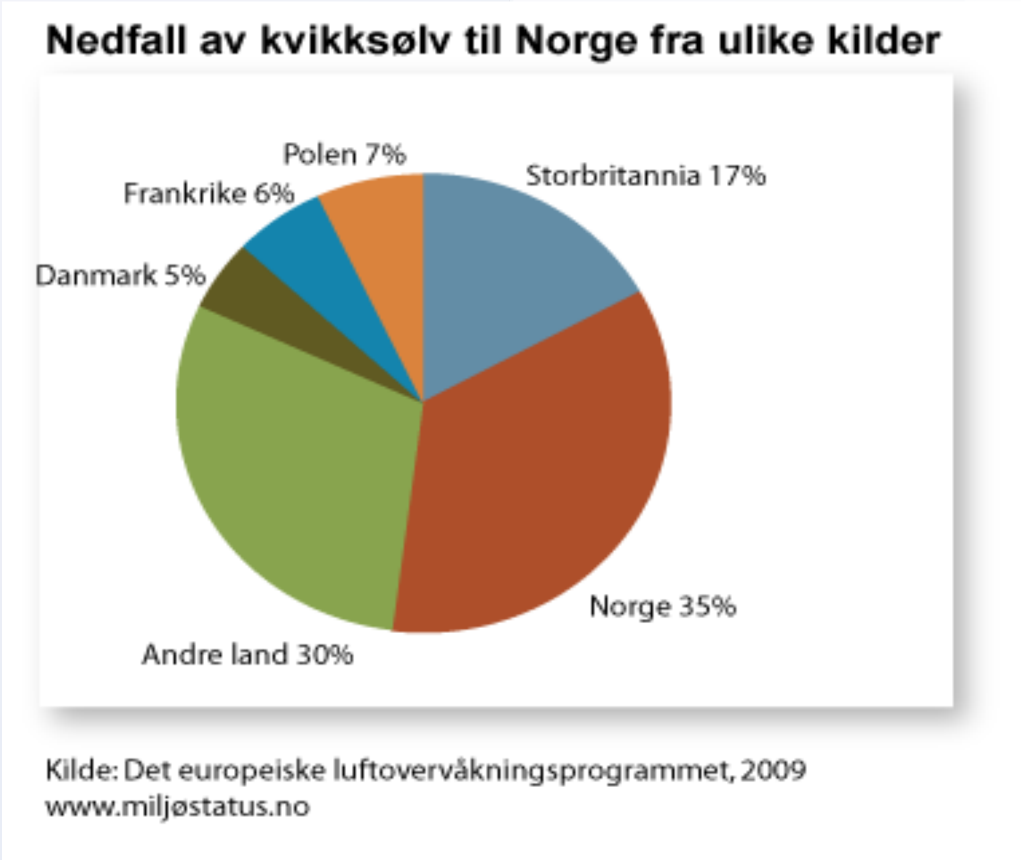
Workshop Stockholm 25 November 2010

Jon L. Fuglestad

Content of presentation

- Background
- Former, present and future monitoring studies on Hg in freshwater ecosystems in Norway

Deposition of mercury i Norway

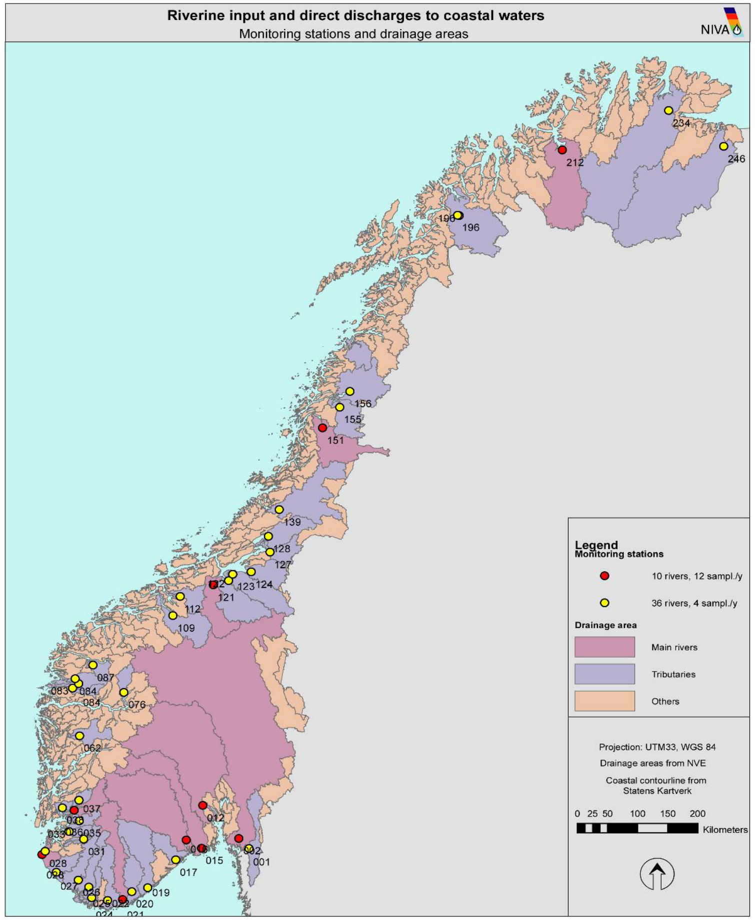


Emissions and discharges

- Emissions and discharges from Norwegian sources
- Ca. 7 tonnes in 1985,
  2,5 tonnes in 1985 and
  1 tonne in 2007

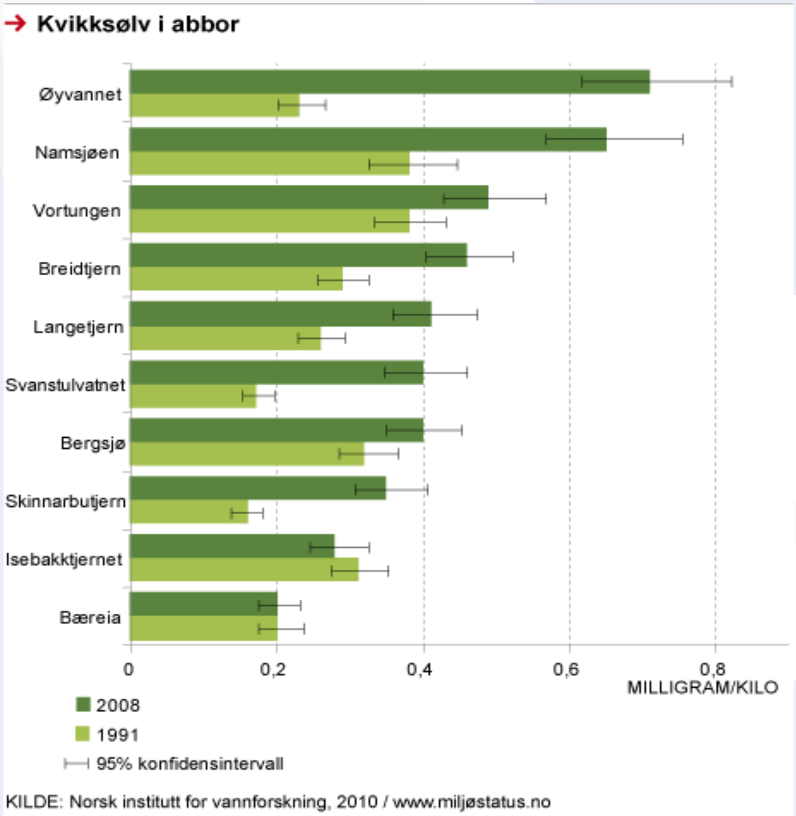
Former and present studies

- Hg included in annual RID programme since 1990
- Included in annual monitoring of atmospheric deposition and in air
- Several one-off surveys in biota and sediments

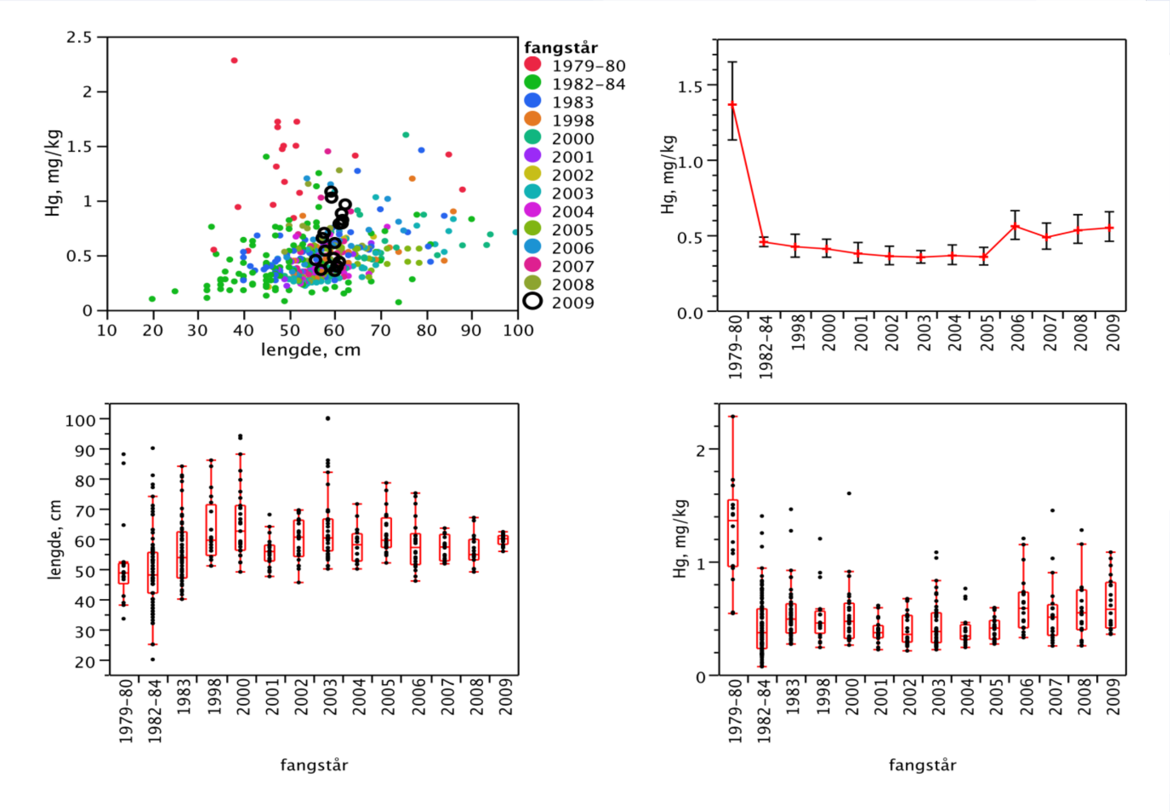


Increase concentrations in perch 1990-2008

- **Fish from 28 lakes monitored in 2008, ten of them also monitored in 1991**



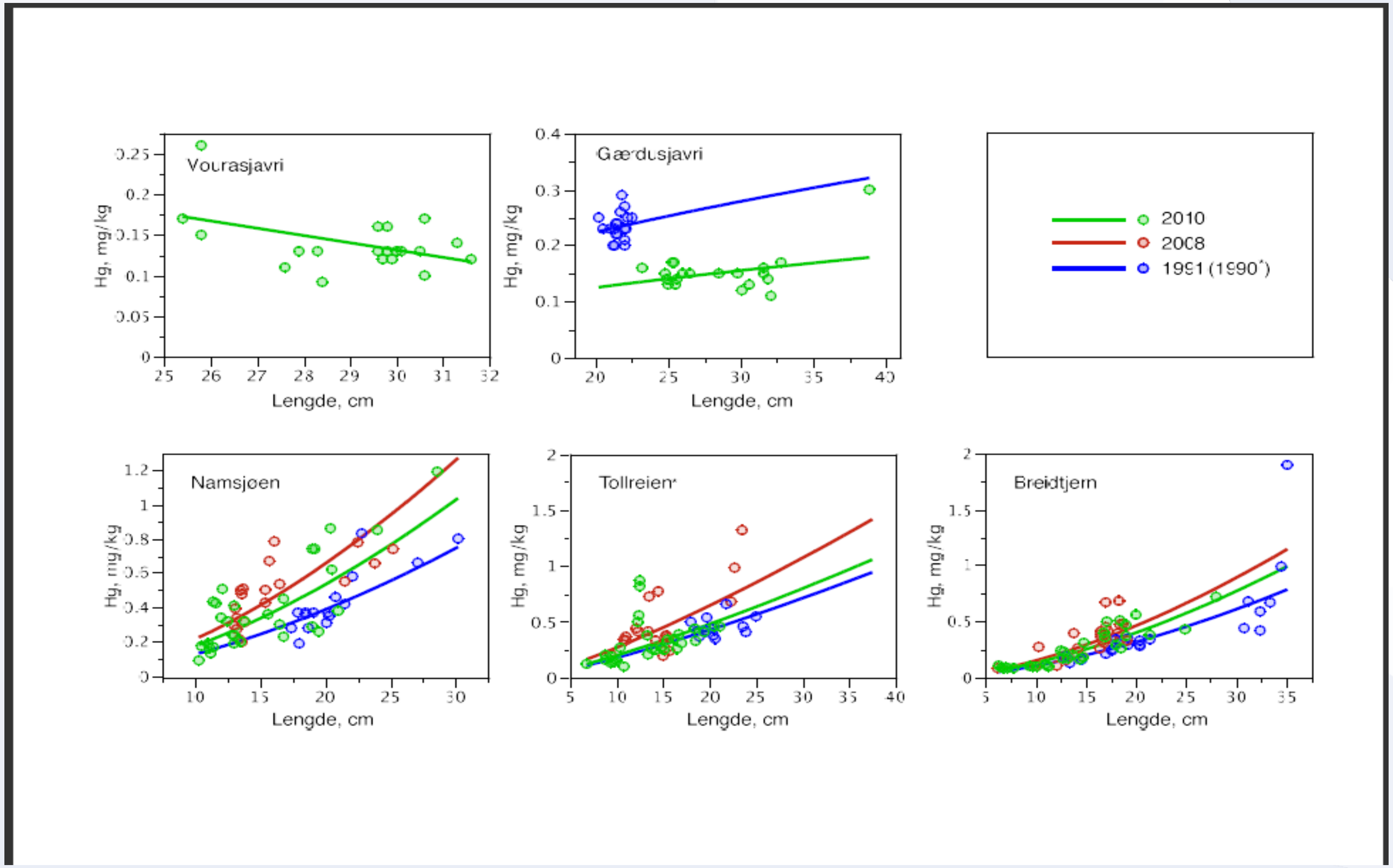
Trend monitoring of trout in lake Mjøsa



Monitoring of Hg in perch 2010

- Five lakes, three in southern Norway, two far north
- Report finalised primo December
- Feed into NIVA research project

Results 2010 monitoring



Conlusions

- There is no trend monitoring programme in freshwater biota or sediments
- Several single or short term monitoring surveys
- Trend monitoring of Hg deposition and riverine inputs
- Klif evaluate all our monitoring programmes
- ESB can in the future be valuable for Hg monitoring and research

1c. **Monitoring in Finland**. Matti Verta (*Finnish Environment Institute SYKE, Contaminants*)

National Monitoring of Contaminants in Aquatic Environment in Finland- with special focus on Hg

Matti Verta, Jaakko Mannio (SYKE)

Stockholm

Nov. 25. 2010

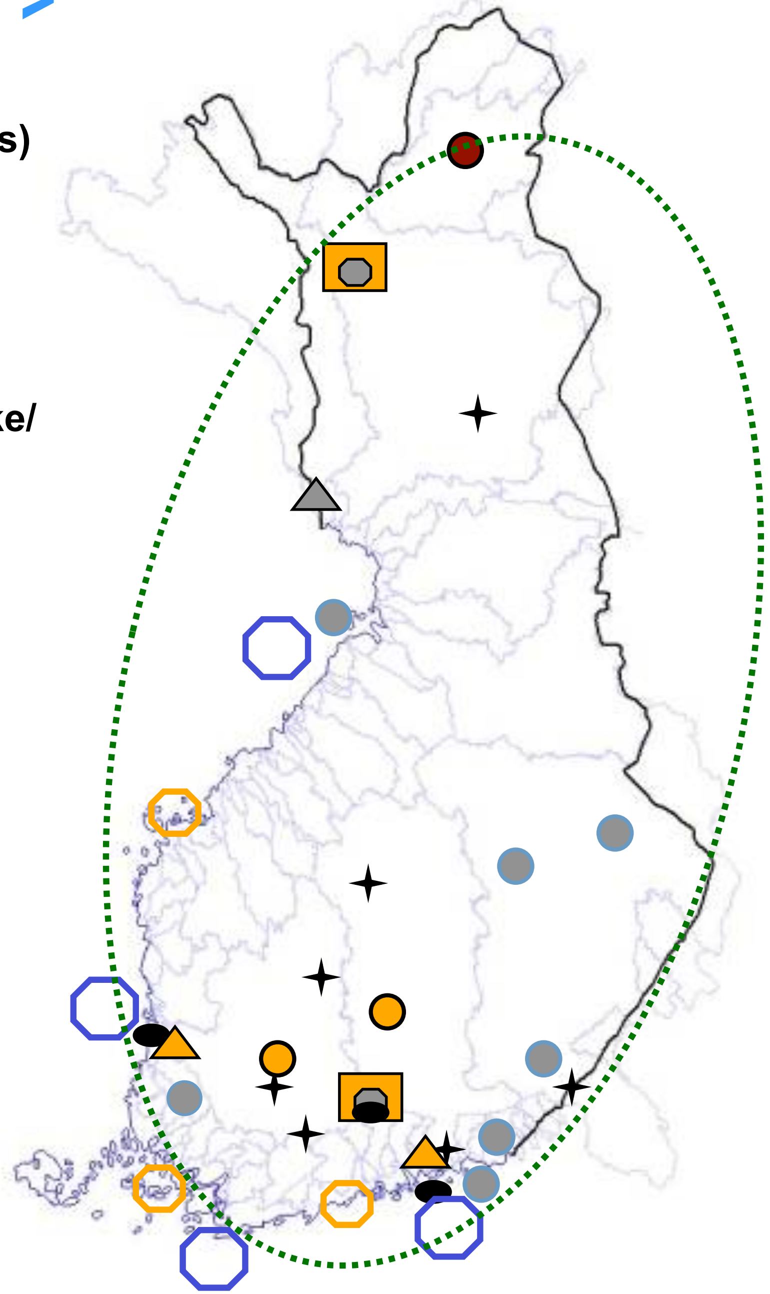
Contaminant monitoring 2009 = >

- **4+3 coastal areas** (HELCOM + three estuaries)
- **3 lakes** (Inari, Päijänne, Pyhäjärvi)
- **2 rivers** (Kokemäki, Kymi)
- **2 background sites** (perch, deposition)
- **Low frequency sites** (3 up to 10 yr interval; pike/ perch/vendace)

MATRICE	frequency
herring, perch, brown trout	yearly (4+3+3+2 sites)
sediment (lakes)	>10 yr
sedimentation (2 rivermouth, 1 lake)	1-3 m (summer)
mussel incubation (Anodonta)	1 m (Aug)
Hg fish/sedim/water screening	10 yr (80 lakes?)

SUBSTANCES

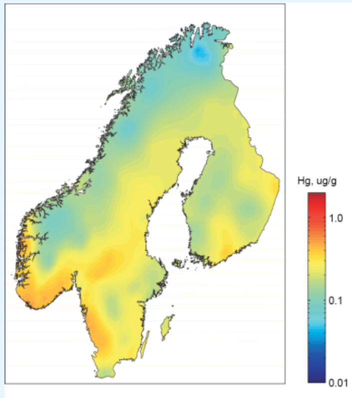
- Hg, other trace metals
- PCB, PCDD/F, DDT, HCB, HCH, chlord.
- new: PBDE, OTC, + PFC (in 2009/10)
- only sediments: PAH, phthalates



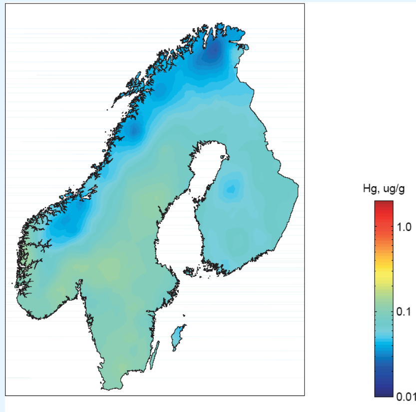
- **Mercury has been deposited on soils and lakes**
- **Large predatory fish exceed the quidelines**

Lake sediments in Scandinavia

2000 ~0,3 < 1800 ~0,07



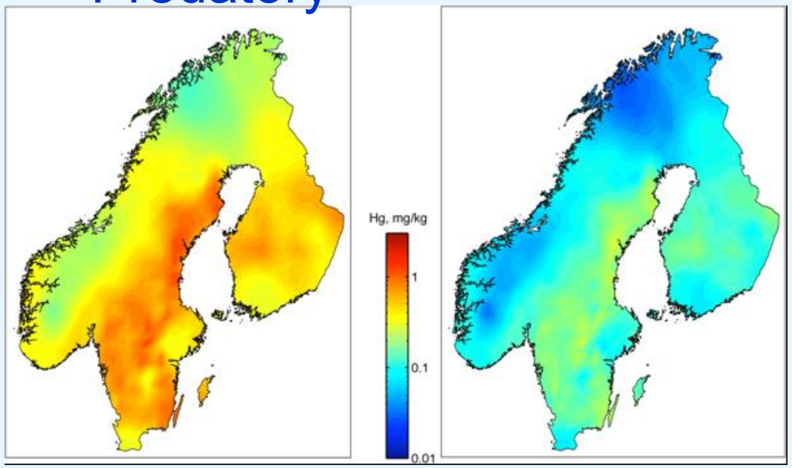
Hg µg/g



Fish Hg in Scandinavia mg/kg

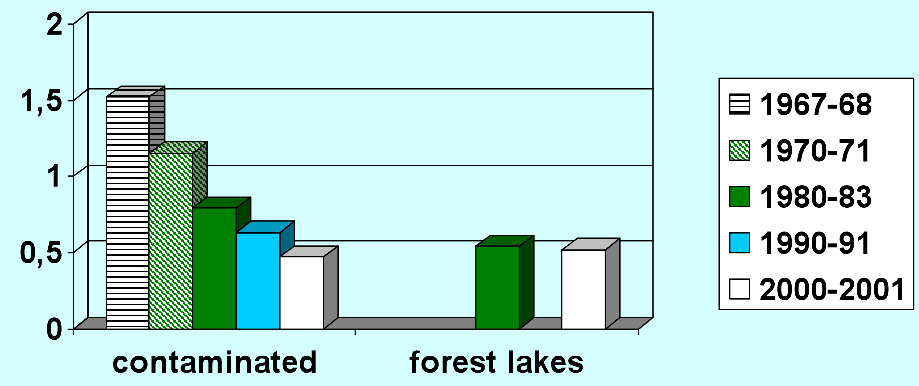
Predatory

Non predatory



History of Hg monitoring in fish

- **Monitoring based on pike**
- **Main contaminated districts: 3 y intervals**
  - Kymijoki and Kokemäenjoki river basins
- **Surveys from 60-90 sites: 10 y intervals (last one 2000-2002),**
  - Number of reference sites increase from 1980 on
- **Change pike to perch (2010-)**
  - **Operational monitoring need to be approved between authorities and industry**
  - **Reference sites: Responsibility under negotiations** (River Basin Districts, SYKE)



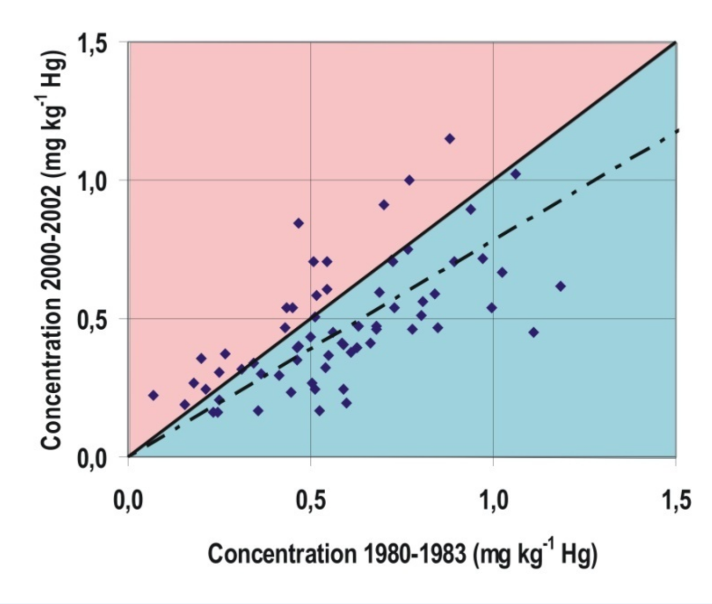
Mean Hg concentration in pike in contaminated and in reference sites in Finland from late 1960's

Hg concentration change in reference lakes in Finland (pike, weight standardized,1980-2000)

	N	Increasing	Decreasing	No change
Small lakes	25	5	12	8
Intermediate	29	6	13	10
Large lakes	12	0	8	4
All	66	11	33	22

- 1/2 Hg decreasing
- 1/3 Hg no change
- 1/6 Hg increasing
- No increase in large lakes

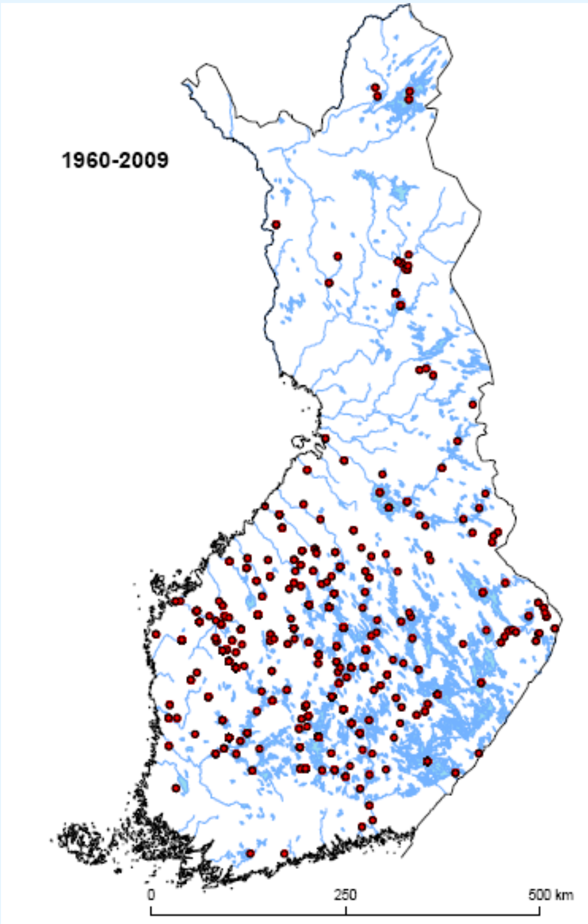
- 2000-2010???

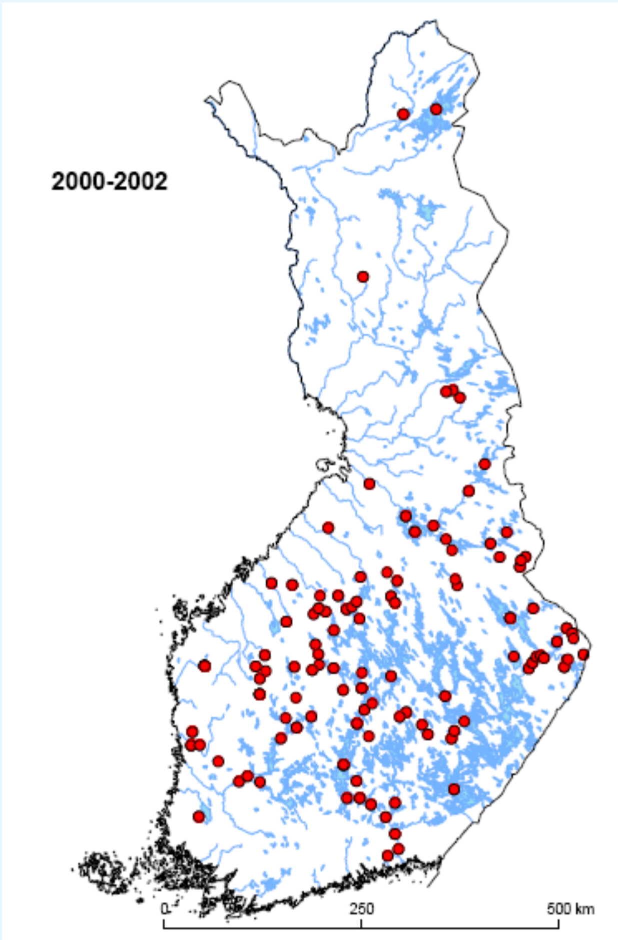


Factors affecting the change (Tukey test)

	Hg increase	Hg decrease
Small lakes	•High % of coniferous forests on peat soil •Location east	
Intermediate lakes	•Small volume, shallow	•Less sulphate
Large lakes		•Deepest •High pH •Less humics •Less peat soil
All lakes	•High % of coniferous forests on peat soil •Location east •Small	

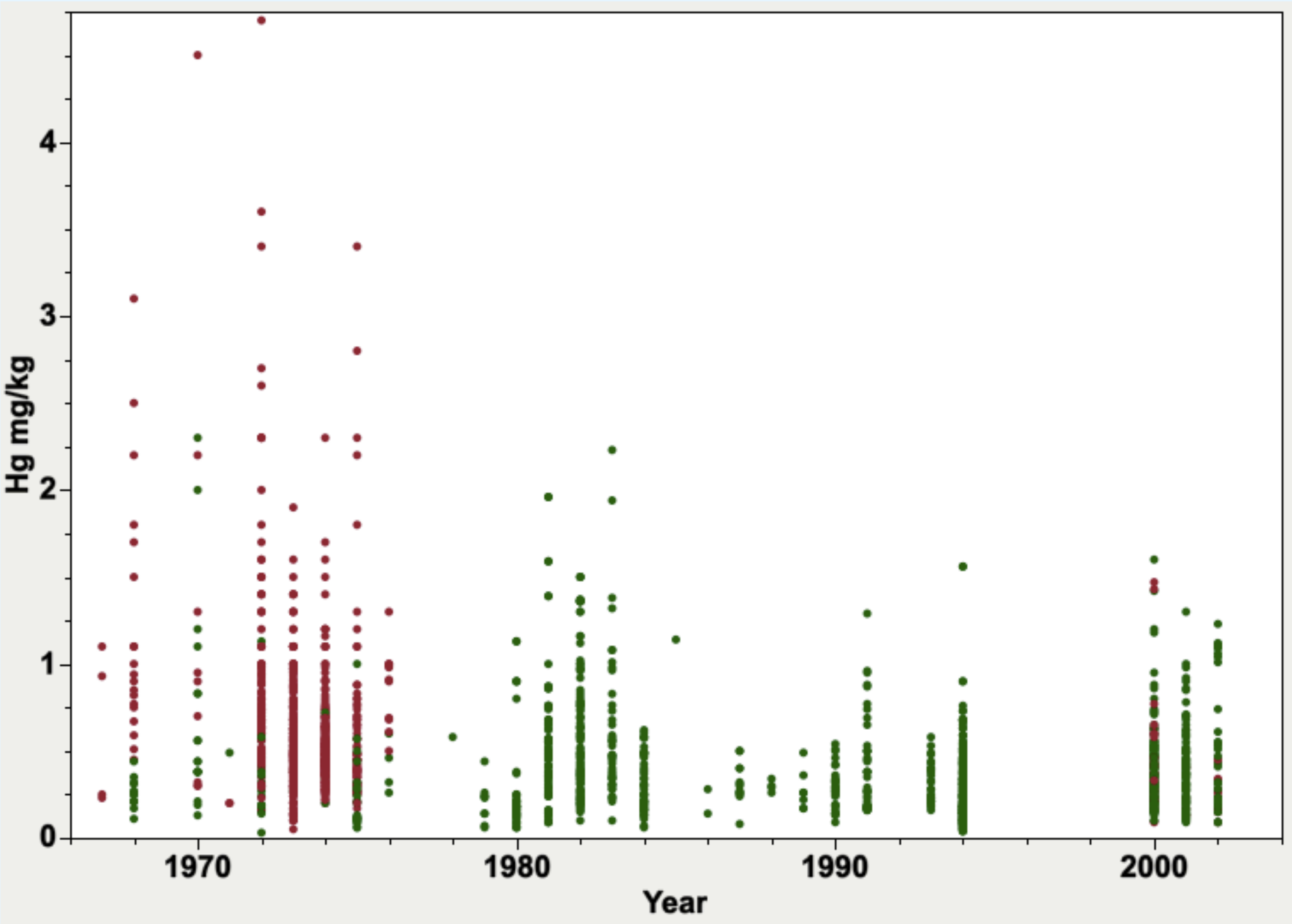
Sites of perch Hg data from Finland 1960's-2002





SYKE

Time trend for Hg in perch, whole data



- Contaminated
- Reference lakes

Perch Hg, reference lakes, all data
length < 26 cm, weigth < 250 g

	N	Min	Md	80%
By size				
Large lakes	260	0,04	**0,19**	
Other lakes	448	0,03	**0,31**	
By humus content				
Low humic (Pt<30)	238	0,04	**0,17**	0,35
Humic (Pt 30-90)	155	0,03	**0,23**	0,36
Dystrophic (Pt >90)	233	0,05	**0,37**	0,56
Total	638	0,03	**0,26**	0,44
Lappland	44	0,03	**0,20**	0,29

Proposal for EQS (natural plus 0.02 mg/kg) in Finland and present exceedance

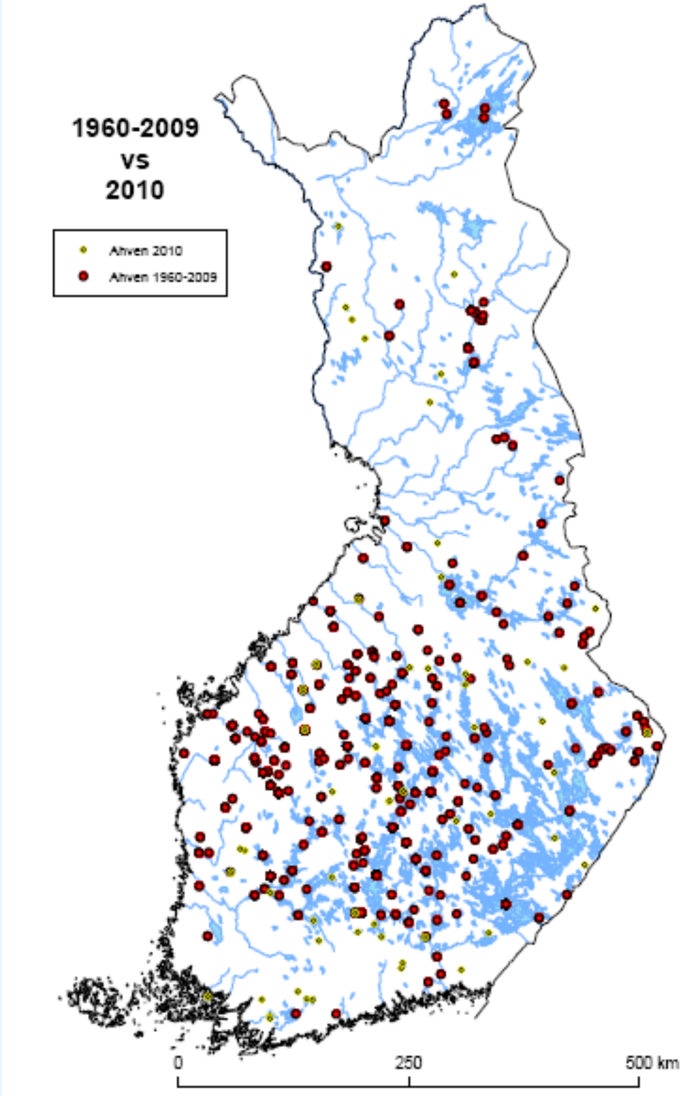
	Low humic Pt < 30	Humic Pt 30-90	Dystrophic Pt > 90
Natural 80 %	**0,18**	**0,20**	**0,23**
EQS	**0,20**	**0,22**	**0,25**

	Low humic	Humic	Dystrophict
Present 80 %	0,35	0,36	0,56
Present Md	0,17	0,23	0,37
Number of samples above EQS	44 %	52 %	75 %

SYKE

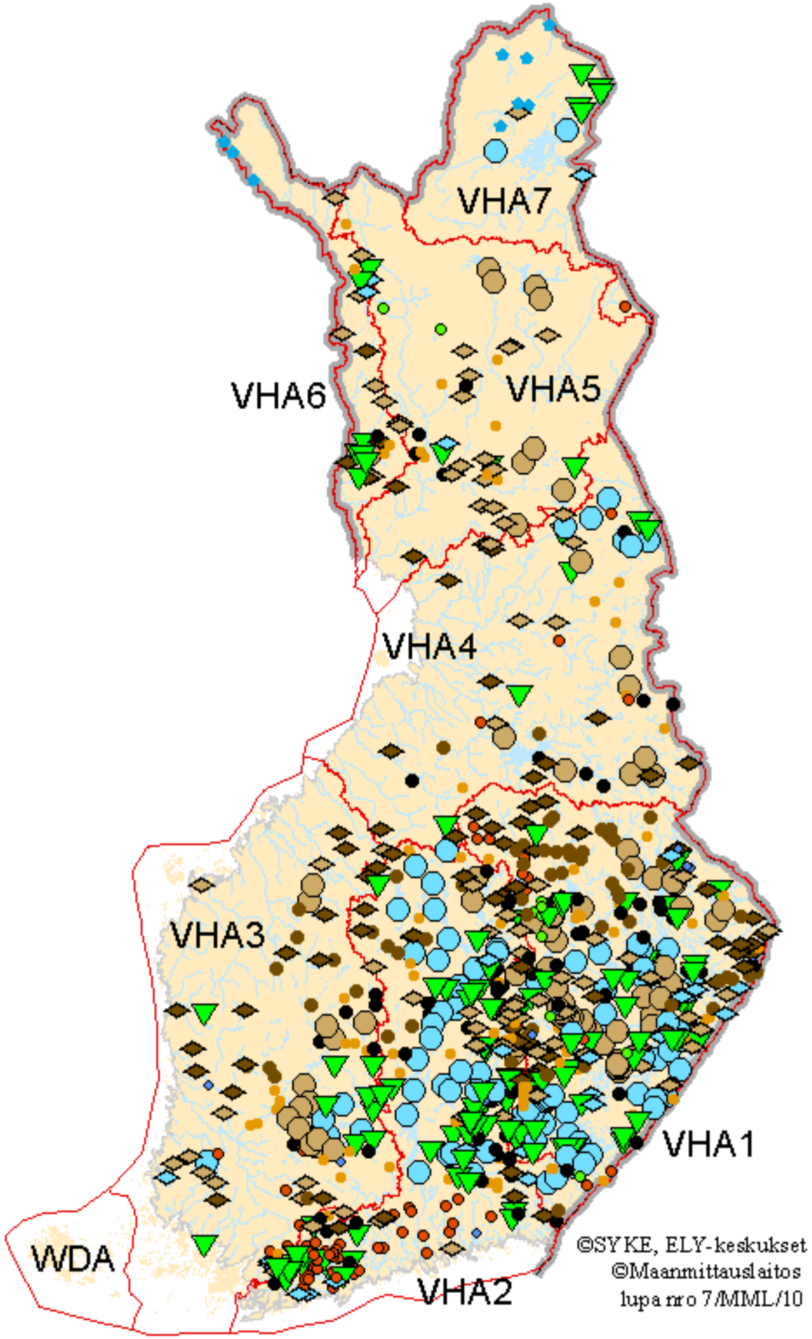
Hg monitoring in perch 2010-

- **Future monitoring is focussed on lakes with biological and fish population monitoring**
- **Mainly 3 y intervals (under discussion)**
- **Includes ”contaminated /operational” sites**
  - **Presently no major local source**
  - **Contaminated sediments as secondary sources**
- **Target 80-90 lakes/rivers**
- **First fish collection 2010** (July-Aug.)
  - **Perch, 15-20 cm long**
  - **Includes pike when caught**
  - **No systematic pike fishing**
  - **Sample preparation/analysis not started**



Finnish lake types

- Medium-sized humic lakes
- Lakes with very short water retention
- Shallow humus-rich lakes
- Shallow humus-poor lakes
- Shallow humic lakes
- Small humic lakes
- Lakes in N. Lapland
- Humus-rich lakes
- Naturally nutrient rich lake
- Naturally nutrient rich lake (lime)
- Naturally nutrient rich lake (clay)
- Large humus-poor lakes
- Large humic lakes
- Small and medium-sized humus-poor lakes
- River basin district



SYKE

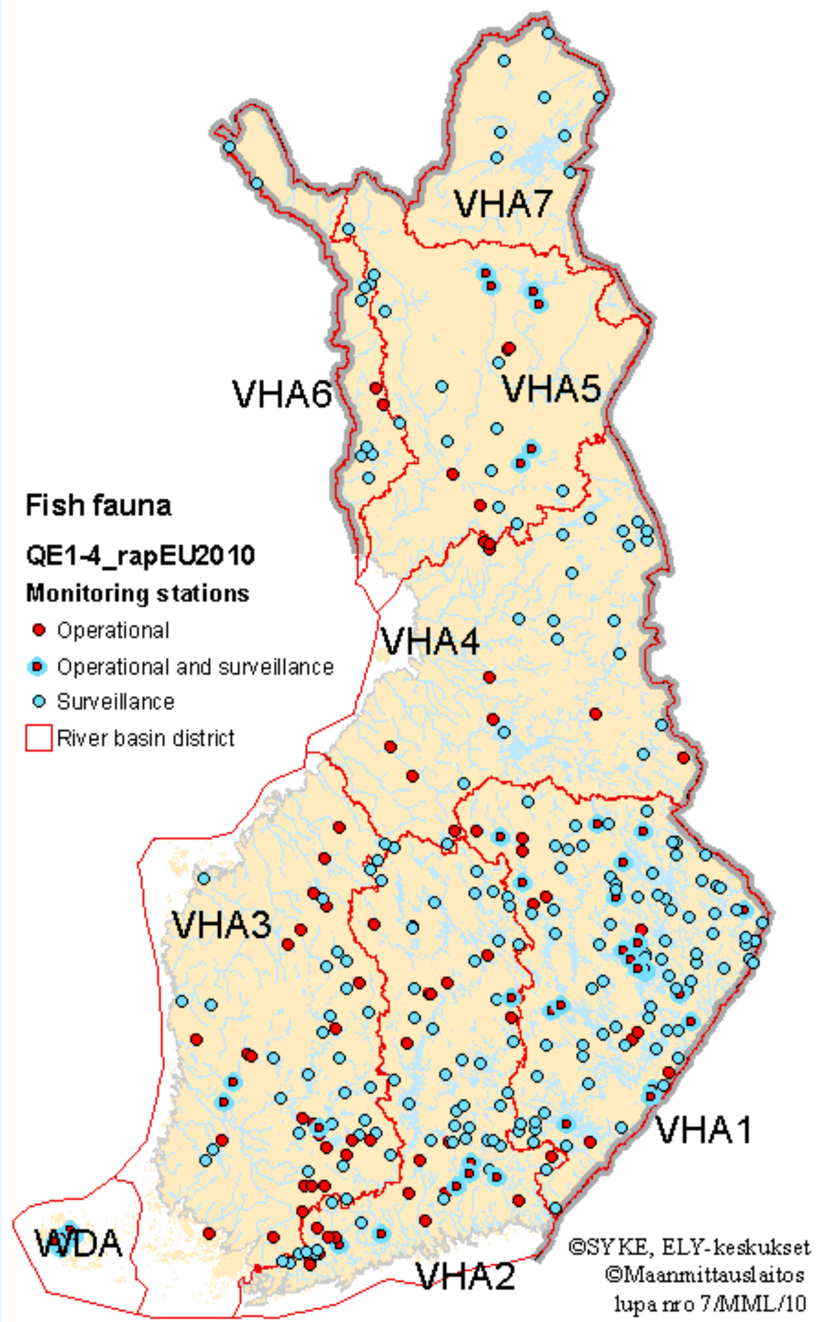
Fish fauna

Quality element 4-1

- Species composition
- Abundance
- Age structure

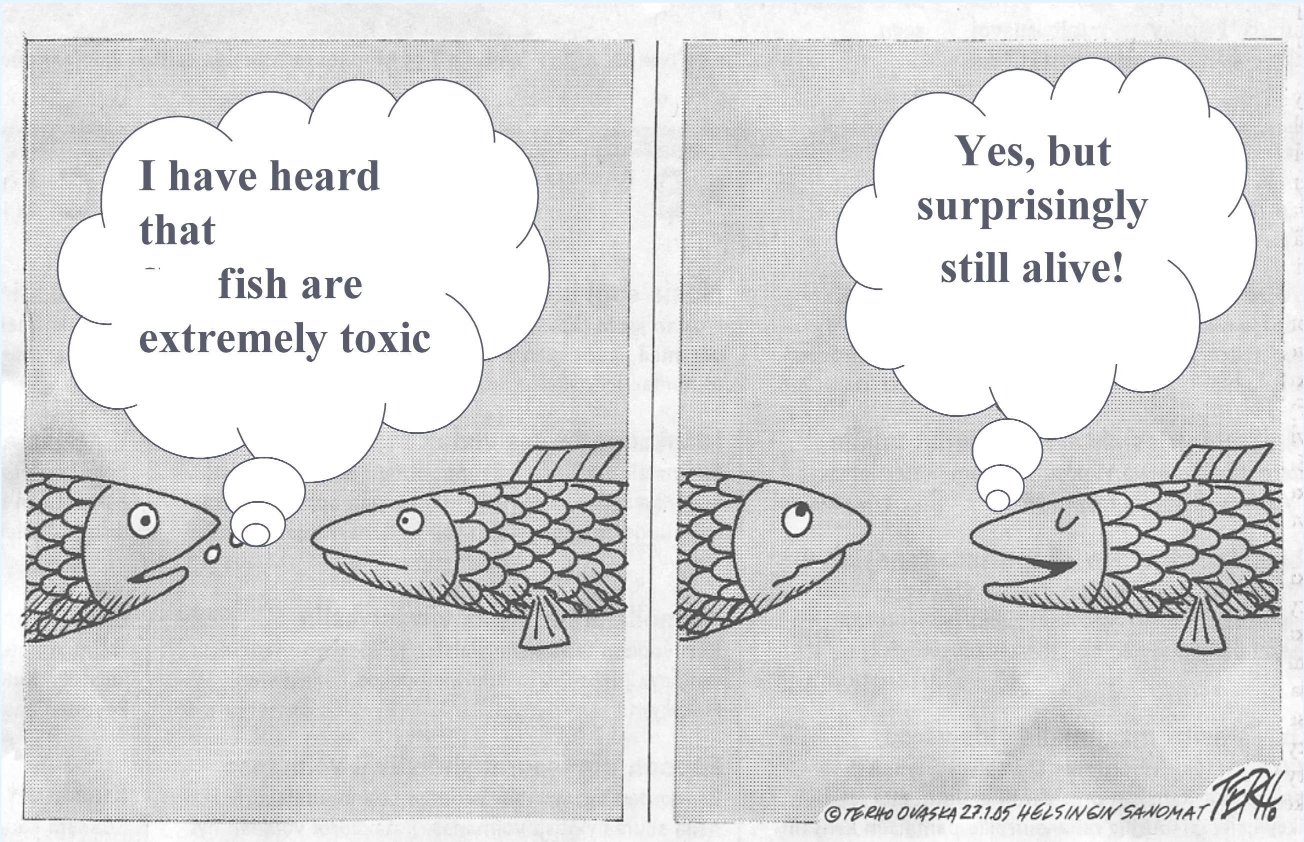
Number of monitoring stations = 314

- Operational = 72
- Surveillance = 199
- Operational and surveillance = 43



SYKE

Thank You!



Terho Ovaska, Helsingin Sanomat, Jan 27 2005

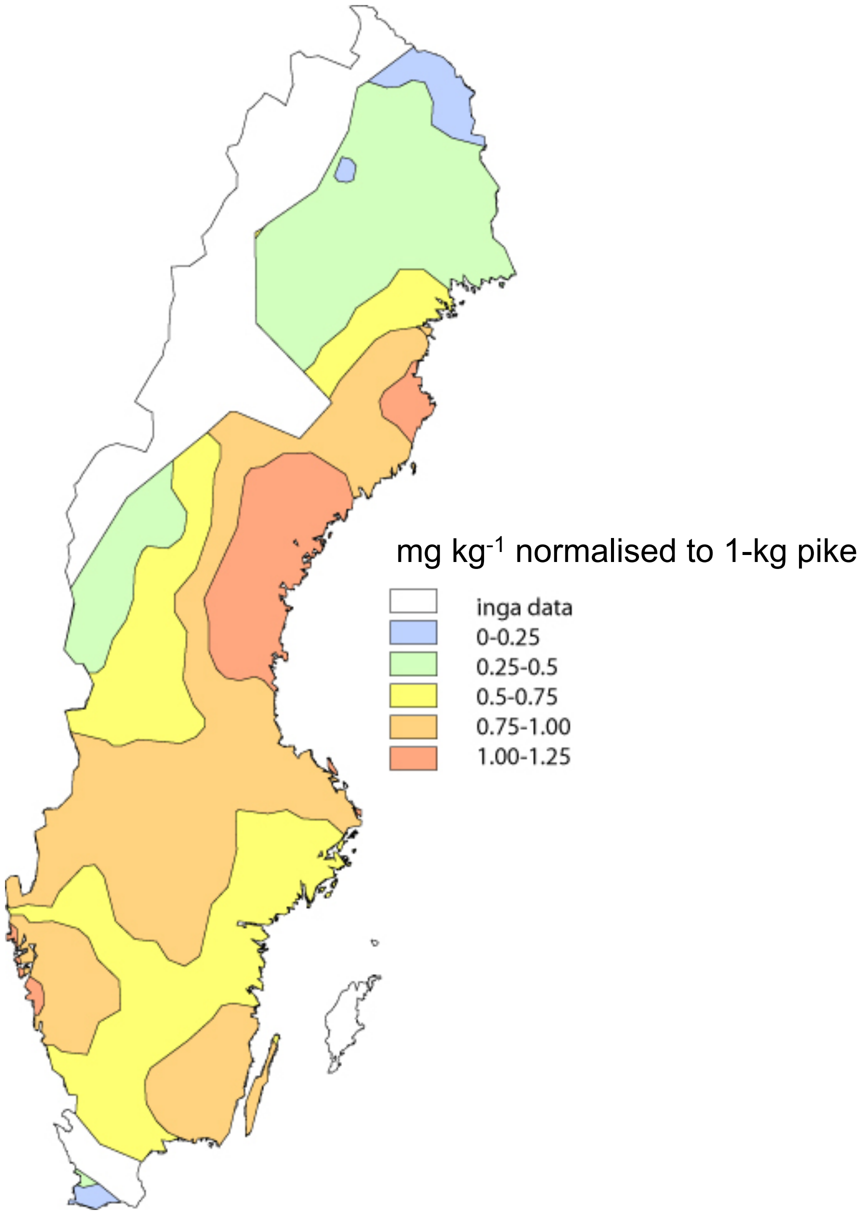
1d. **Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden.** Staffan Åkerblom (*Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences*)

Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden

Staffan Åkerblom[a,b]
Mats Nilsson[b]
Jun Yu[c]
Bo Raneby[c]
Kjell Johansson[a]

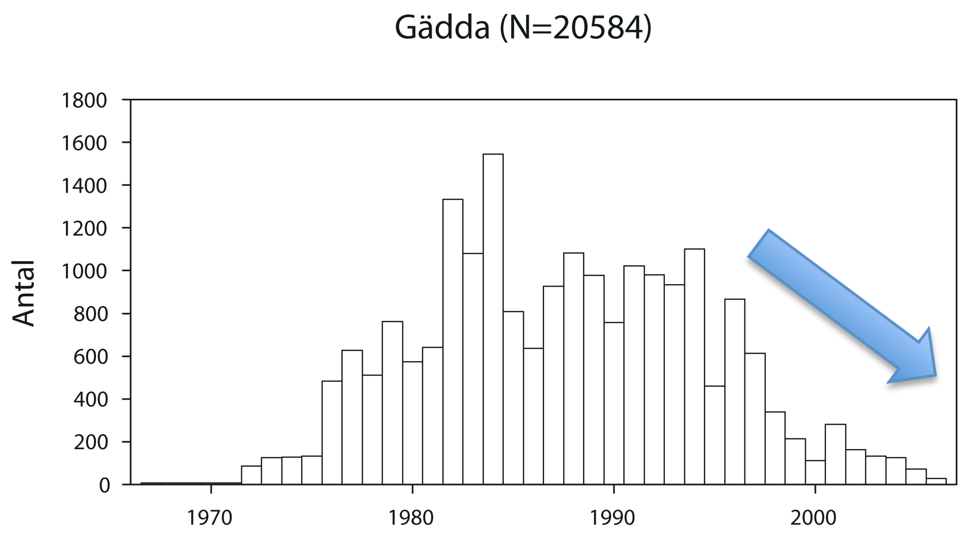
[a]Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences, Uppsala
[b]Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Umeå
[c]Centre of Biostochastics, Swedish University of Agricultural Sciences, Umeå

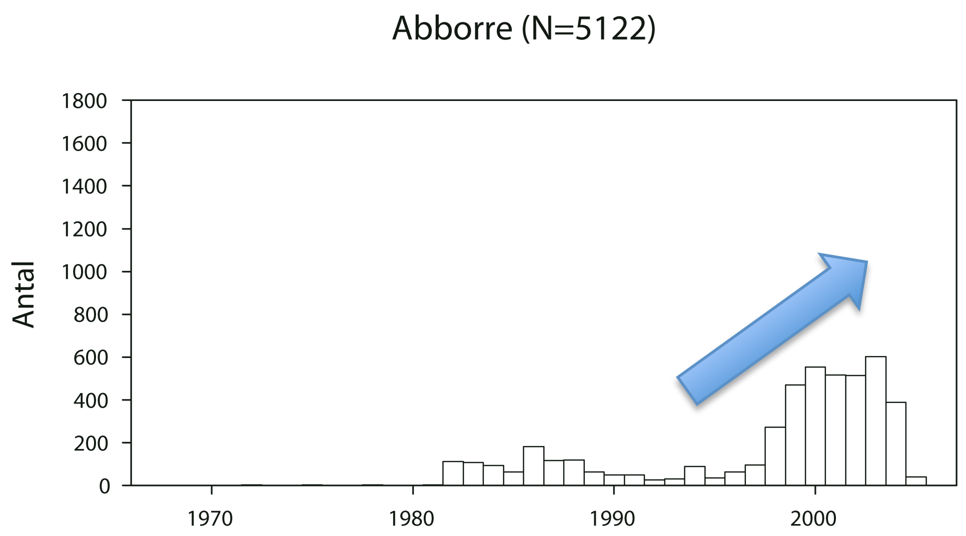
Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden



Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden

Hg monitoring in Swedish freshwater fish:
A history of change (…or not)





Compare Hg concentrations in northern pike between two 5-year periods covering the period 1993-2008

Primary dataset consists of data from 815 lakes with 4959 fishdata

2 criteria needs to be met to let lakes and fishdata enter the dataset:

•The lake should have been sampled at least once during each of two five year periods and….
•within each 5 year period at least three pikes should have been sampled (actually it was 5 in the final datasets)

Number of lakes (number of fishdata entries)

	2001-2005	2002-2006	2003-2007
1994-1998	25 (498)	17 (366)	8 (262)
1995-1999	23 (490)	15 (373)	8 (274)
1996-2000	26 (548)	19 (439)	11 (318)

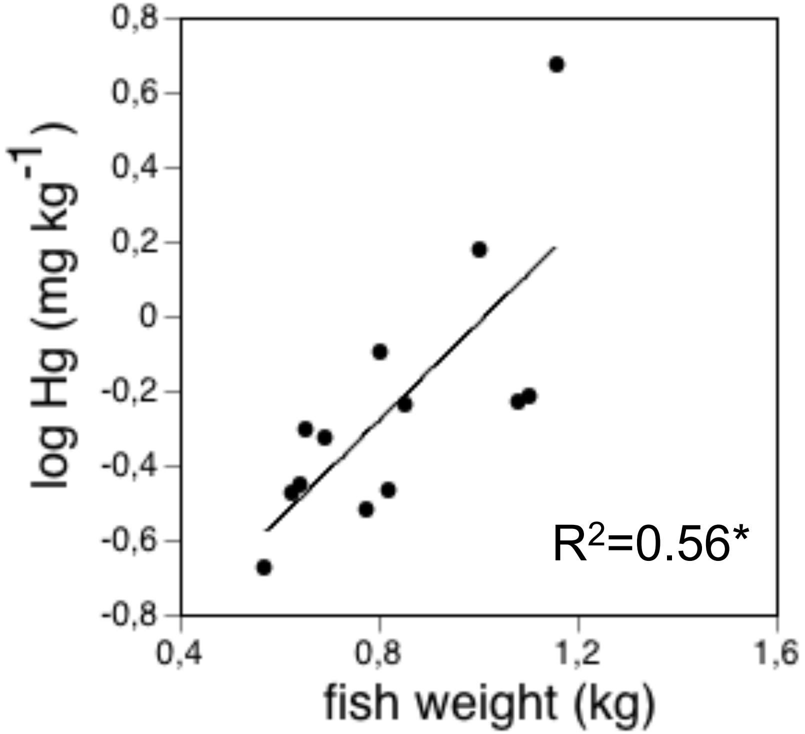
3% of lakes and 10% of fish data entries in the primary dataset!

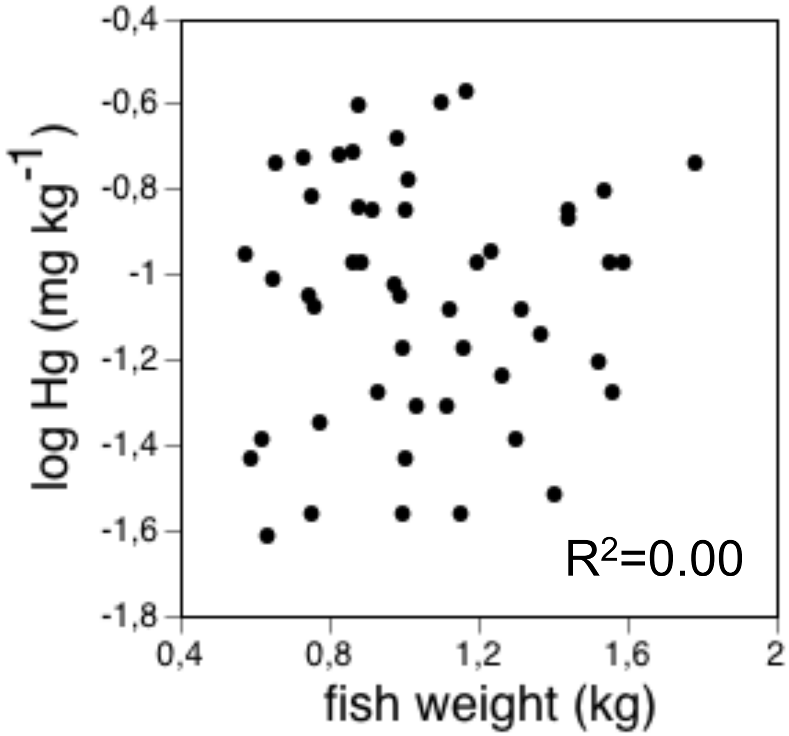
NORMALISATION OF FISH Hg CONCENTRATION!!!???

- Fish size and Hg-covariation due to bioaccumulation of Hg
- Negate variation in fish Hg data that depend on fish size

Normalisation of data to:
Weight? Length? Age?
and…. different models with respect to sex?

What does data from monitoring lakes in Sweden tell us about the fish size and Hg covariation?

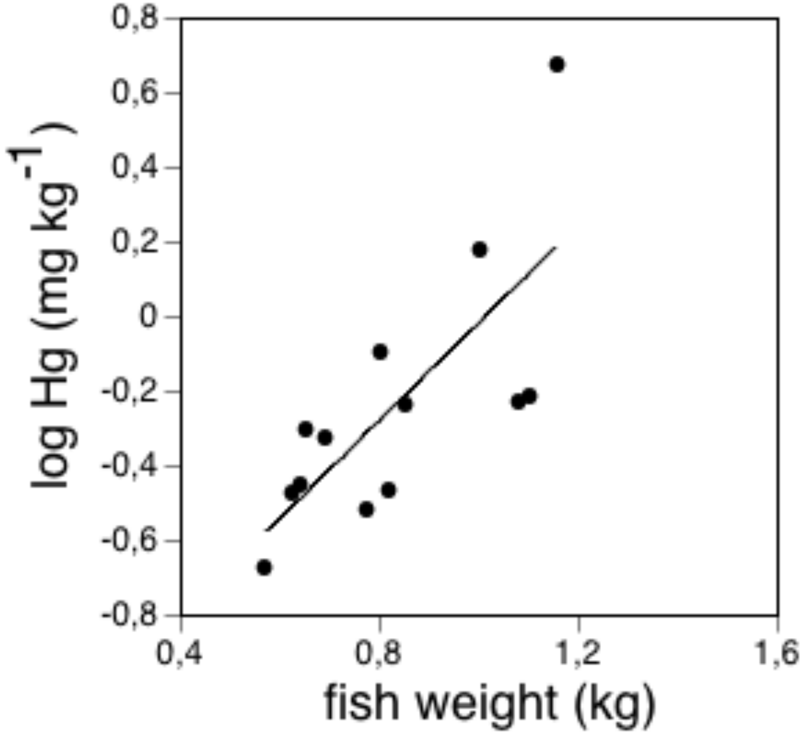




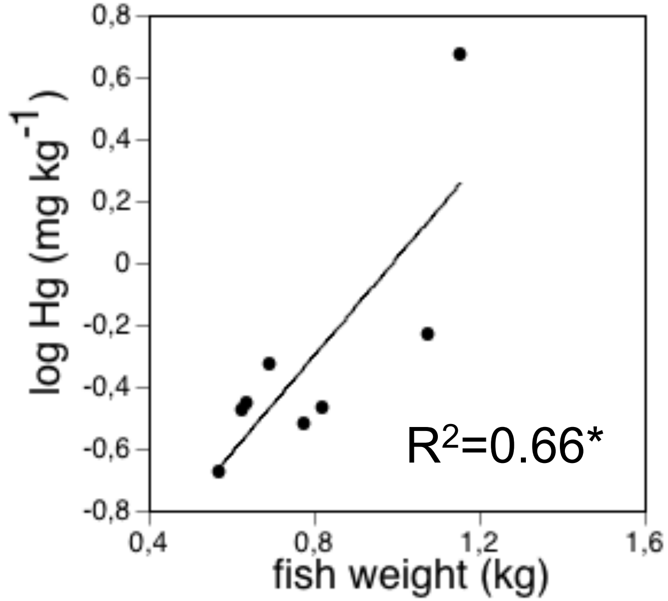
Data from 1994-2005

Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden

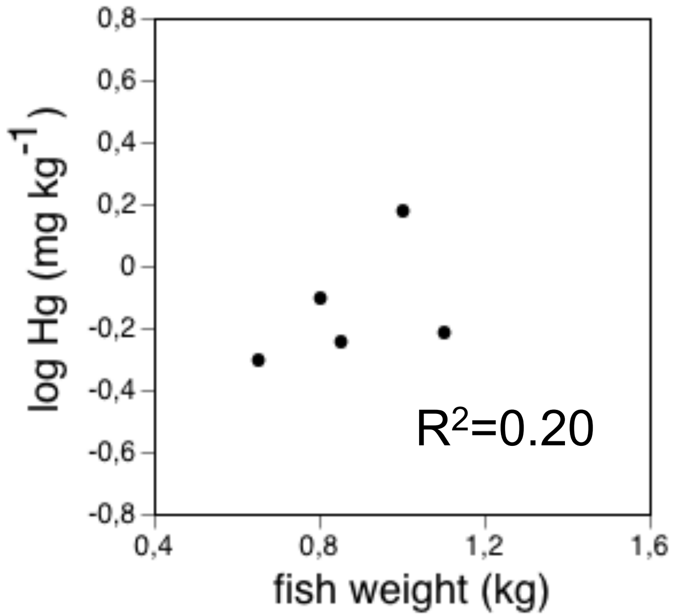
If we compare covariation between time periods?



Data from 1994-2005



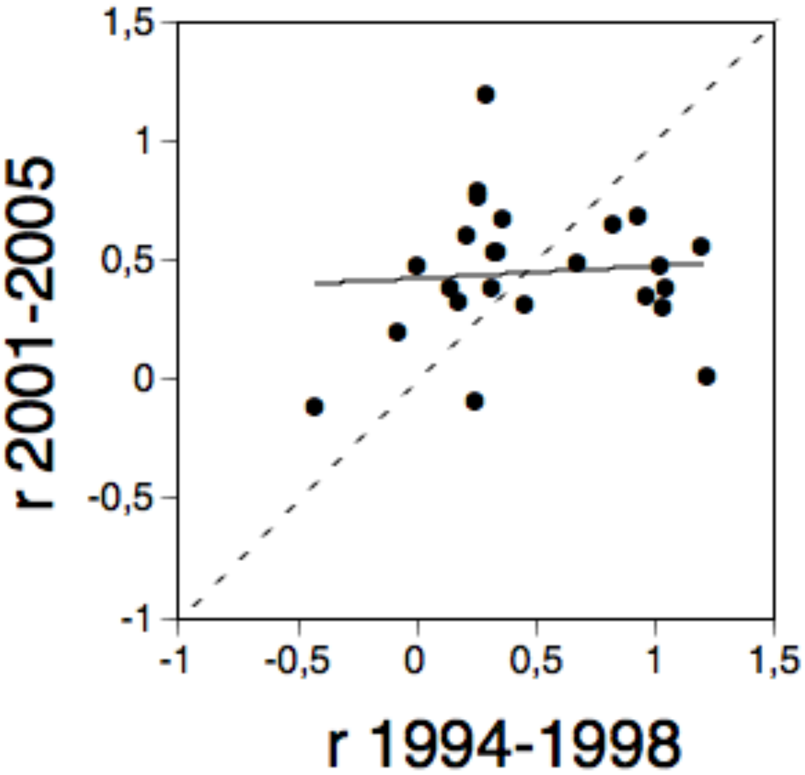
1994-1998



2001-2005

Fish size and Hg-covariation in 25 lakes over the time period 1994-2005

Comparison of regression coefficients (r) for fish size (weight) and Hg concentration (log Hg) in lake datasets divided in two periods



Alternative approach…
Divide fish data set in defined and equally sized weight classes

	Weight range (kg) (n)
Small pikes (W_1)	0.2-0.9 (166)
Middle sized pikes (W_2)	0.9-1.2 (165)
Large pikes (W_3)	1.2-5 (165)

Hg concentration are compared within each weight class between periods of interest (1994-1998 and 2001-2005)

Multiple linear regression model with indicator variables for each lake:

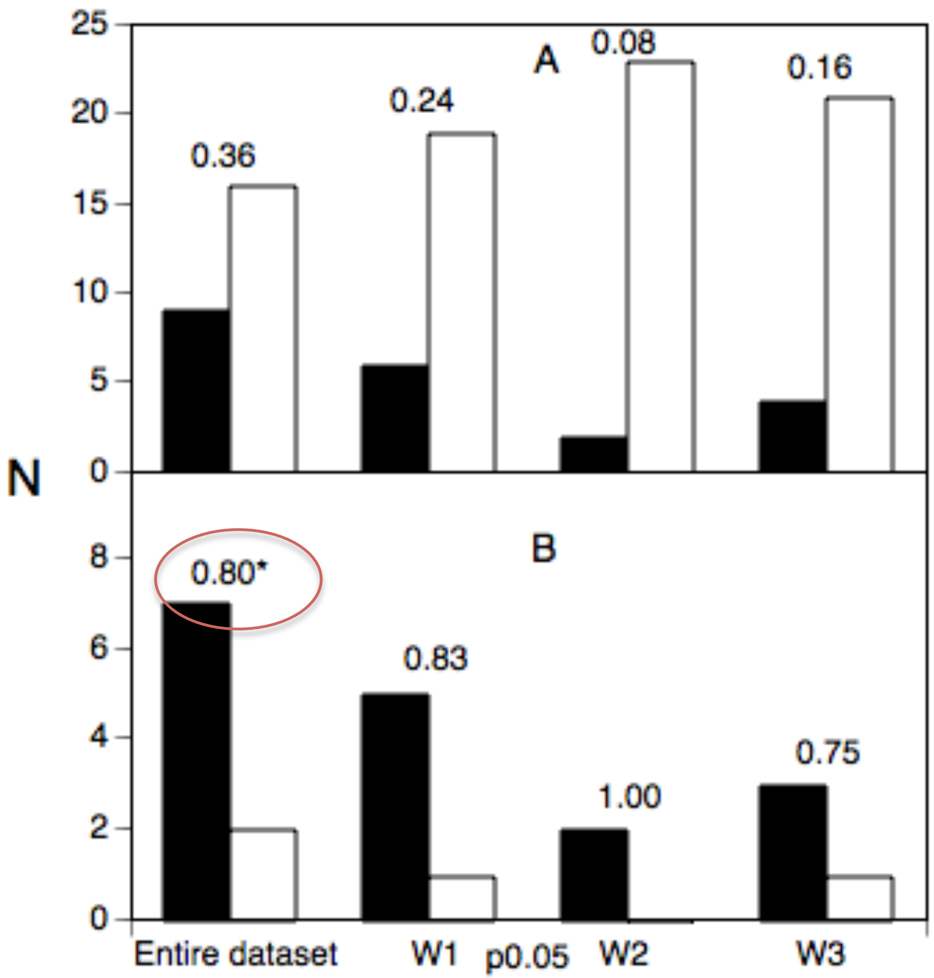
$$\log[Hg] = \beta_1 + \beta_2 W_2 + \beta_3 W_3 + \gamma_1 T + \gamma_2 TW_2 + \gamma_3 TW_3 + \varepsilon$$

W_k=weight class indicator
T=time indicator

Possible to calculate and define the significance of Hg concentration in weight classes at T=0 and T=1 and the difference between them

(details to be presented in coming paper….)

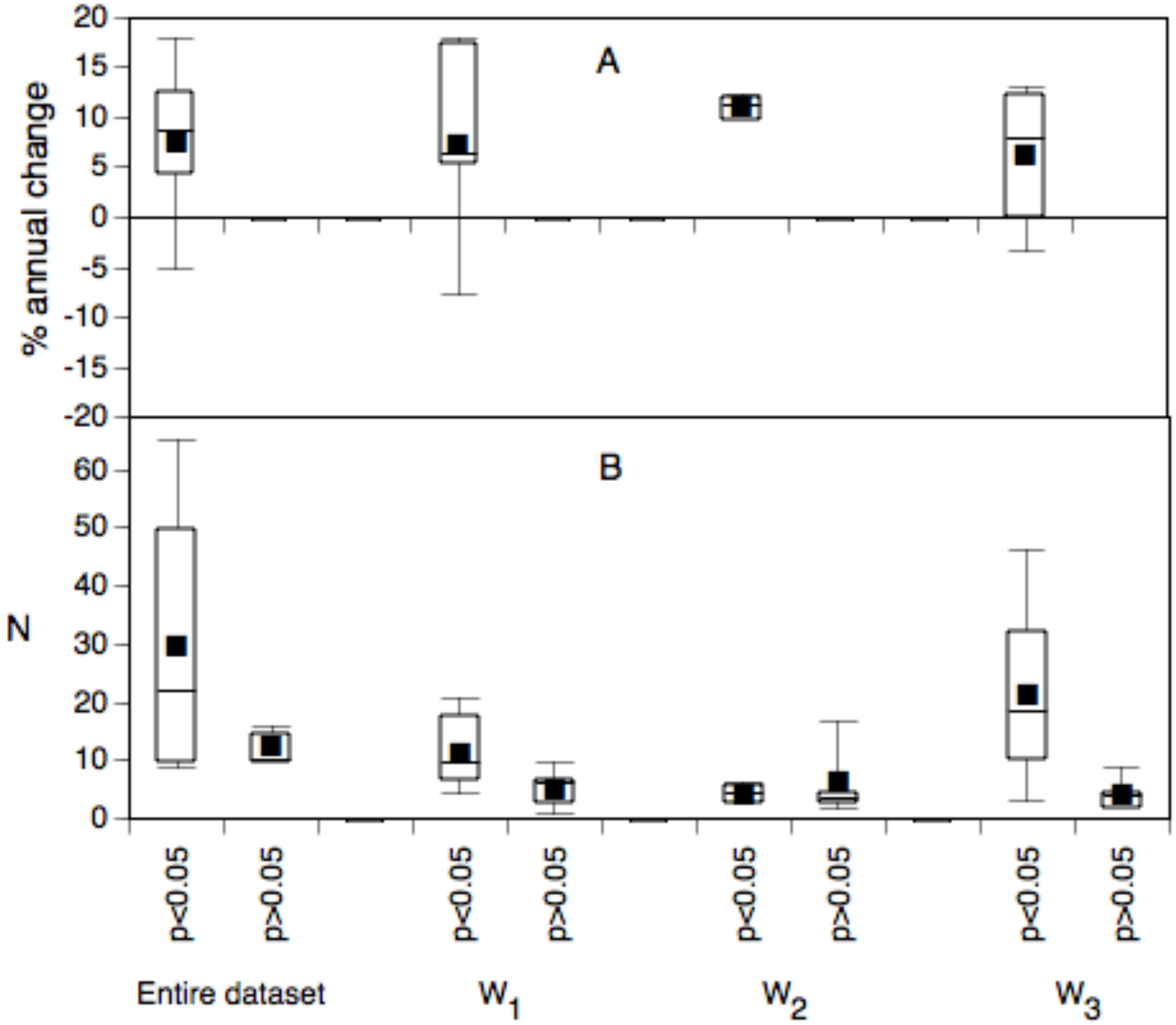
Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden



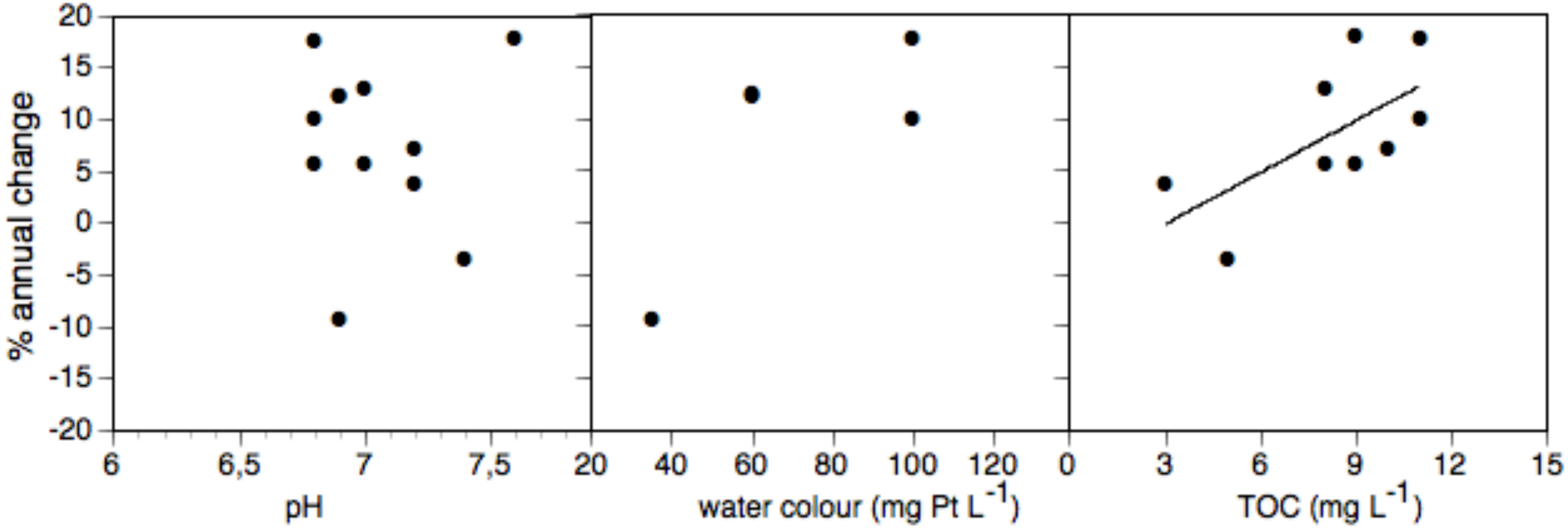
A: Proportion :
Lakes with significant temporal trends (n=9)/ all lakes (n=25)

B: Proportion:
Postive (increasing) temporal trend/
Negative (Decreasing) temporal trend

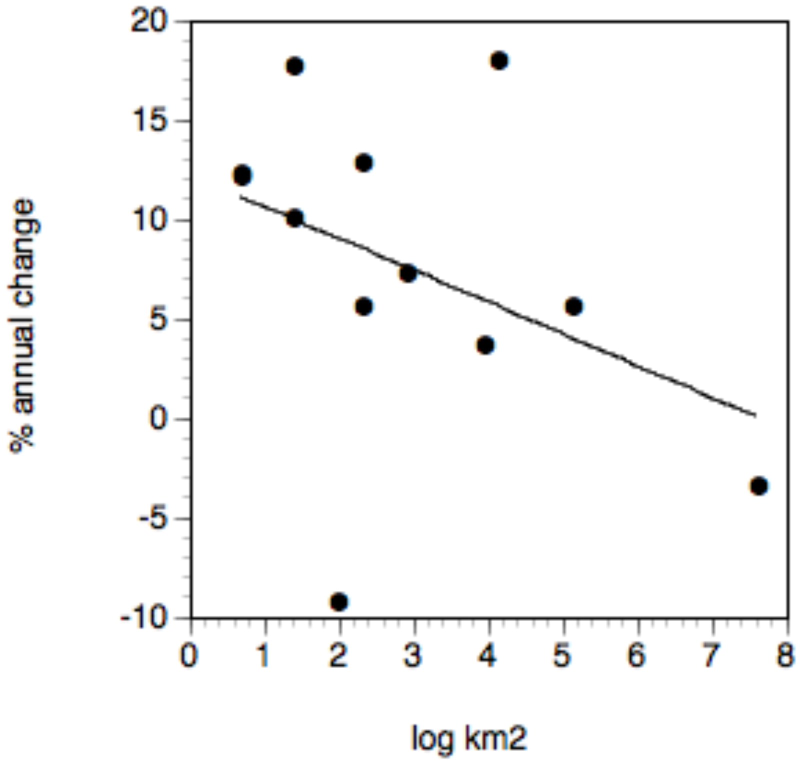
Temporal trend of Hg concentration in freshwater piscivorous fish in Sweden



Water chemistry related to annual change in pike Hg conc.



Lake size related to annual change in pike Hg conc.



Conclusions:

•Normalisation of fish Hg data in temporal trend analysis should be done with great care and is not suitable if comparing several lakes

•Alternative process: compare Hg concentration within defined fish size classes over time

•Hg concentration in Swedish freshwater pike have increased between 1994-2005 (annual increase of 4%)

•Increases most pronounced in humic lakes of small size

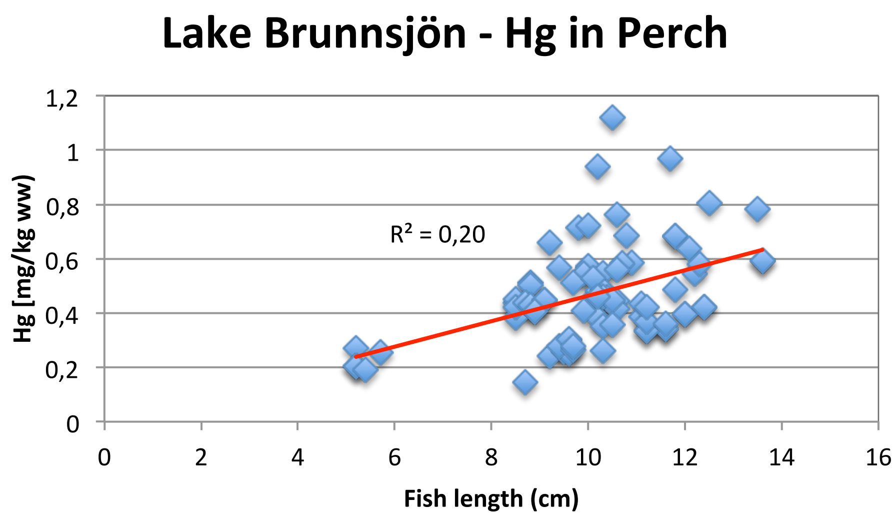
•If the sampling efforts are not adequate existing temporal trends may be concealed in the data

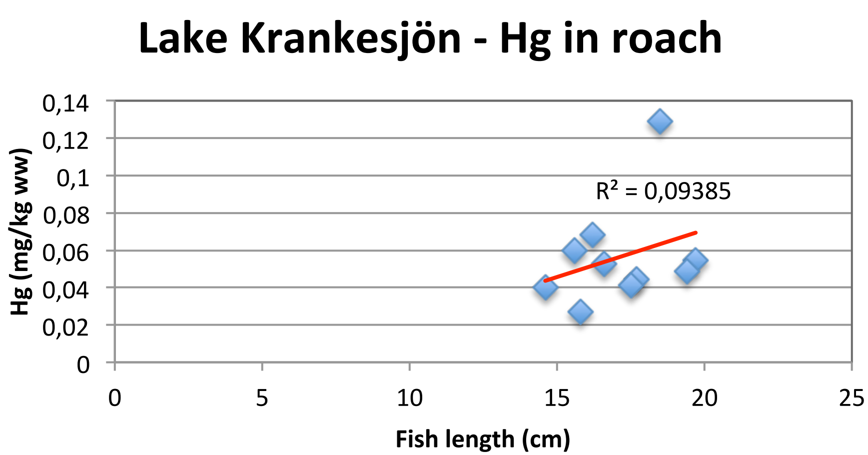
1e. **Fish Hg levels and fish size relationships in lakes.** Lars Sonesten (*Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences*)

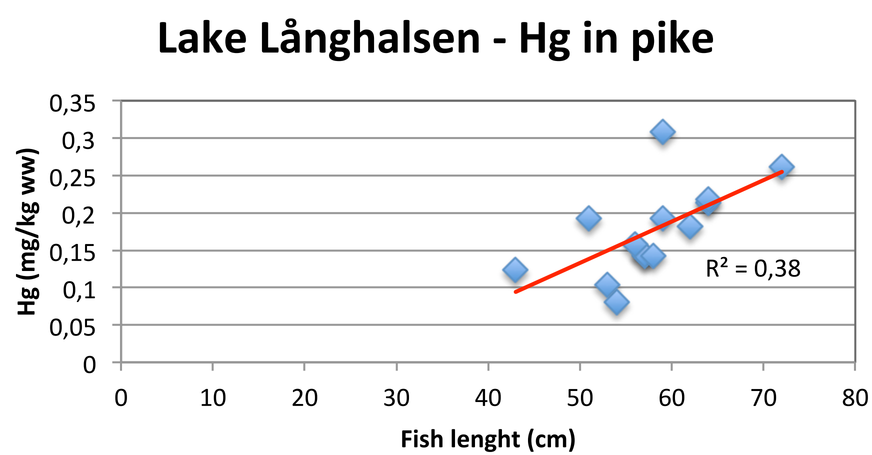
Fish Hg levels and Fish-size Relationships

Lars Sonesten
Department of Aquatic Sciences and Assessment

Fish-size concern – ”A species problem”

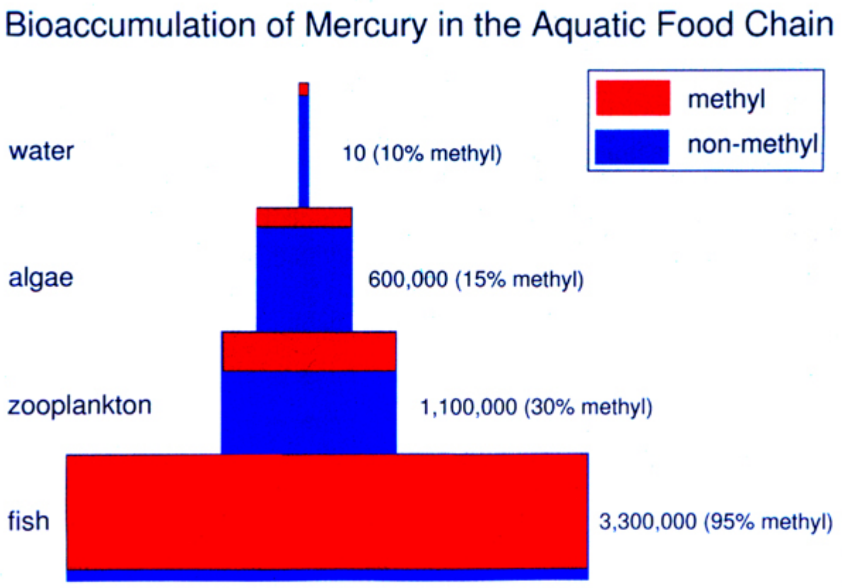






Why is fish-size a problem?

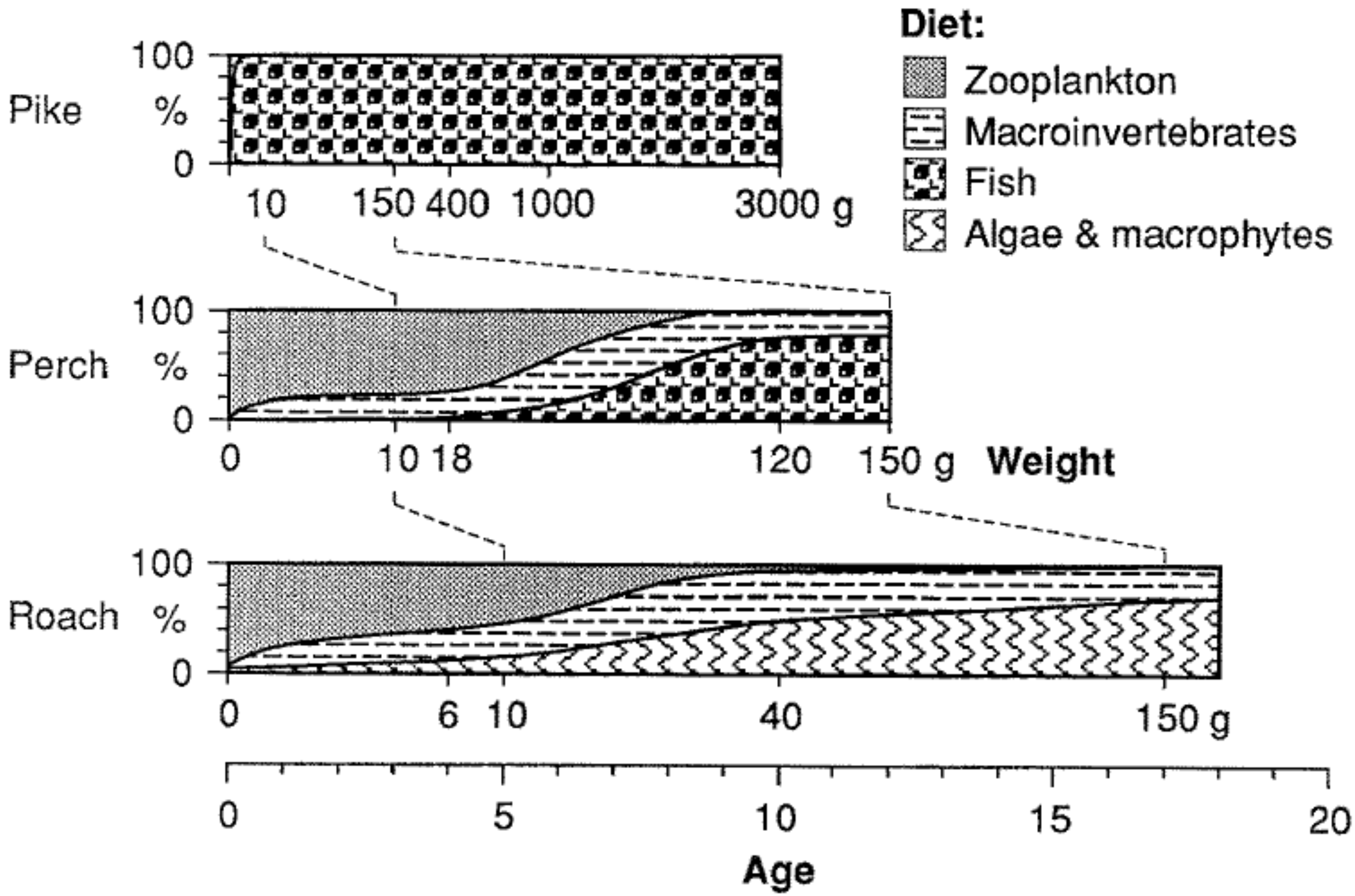
- The inherent chemical properties of esp. Me-Hg
  - Bioconcentration
  - Bioaccumulation
  - Biomagnification



You are what you eat!

Common food items

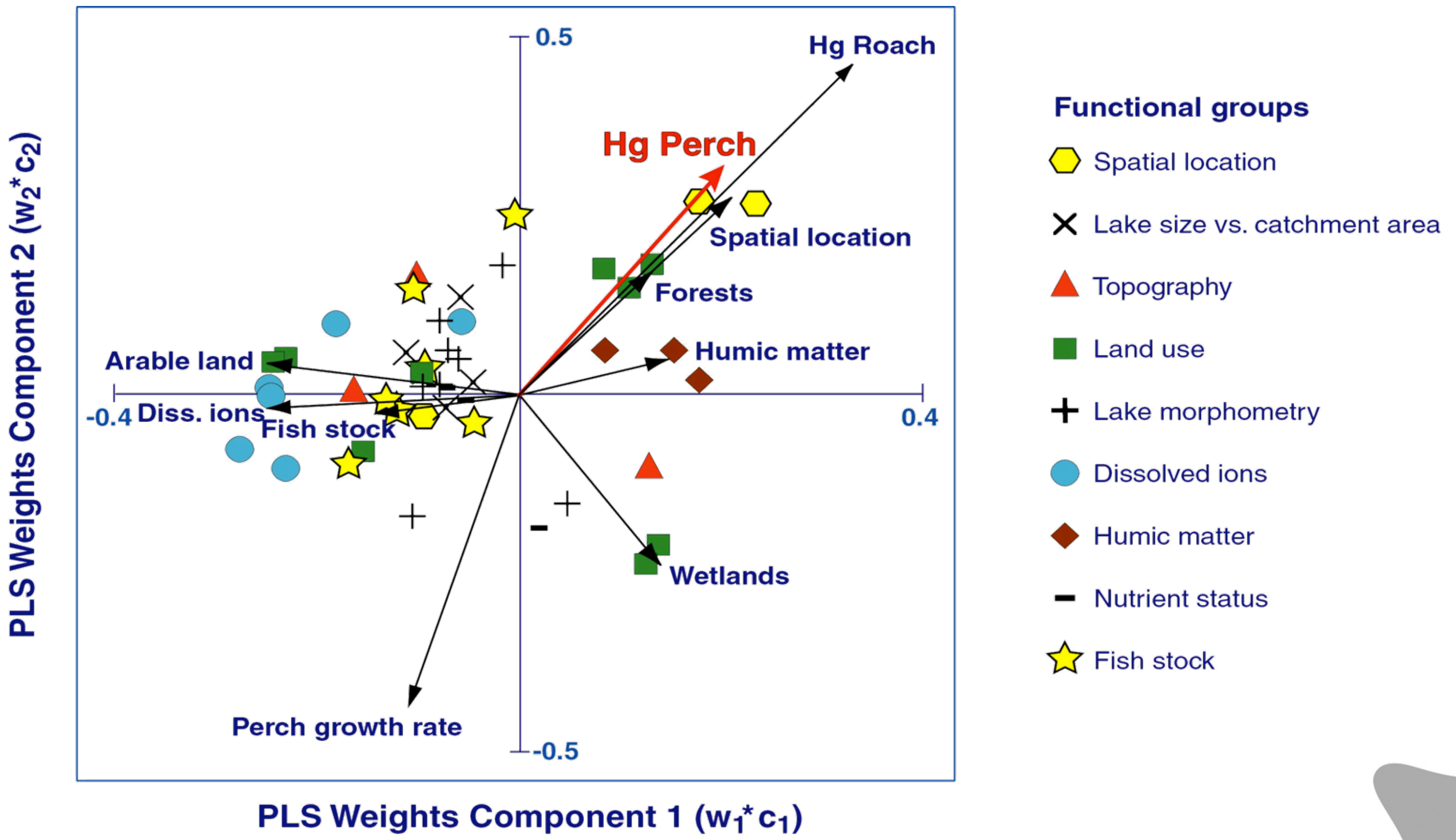
Meili 1991



How to avoid the fish-size issue?

- Normalisation/standardisation
  - Hg/weight
  - ANCOVA
  - Multivariate analysis of summary stats (Somers and Jackson 1993)
  - Polynomial regression (Tremblay et al 1998)
  - Intercept of Hg vs. fish length (Sonesten 2003)
  - Non-parametric regression (Hussian and Grimvall)
- Definite size intervals
  - 1-kg pike (0.6–1.6 kg)
  - “Small perch”

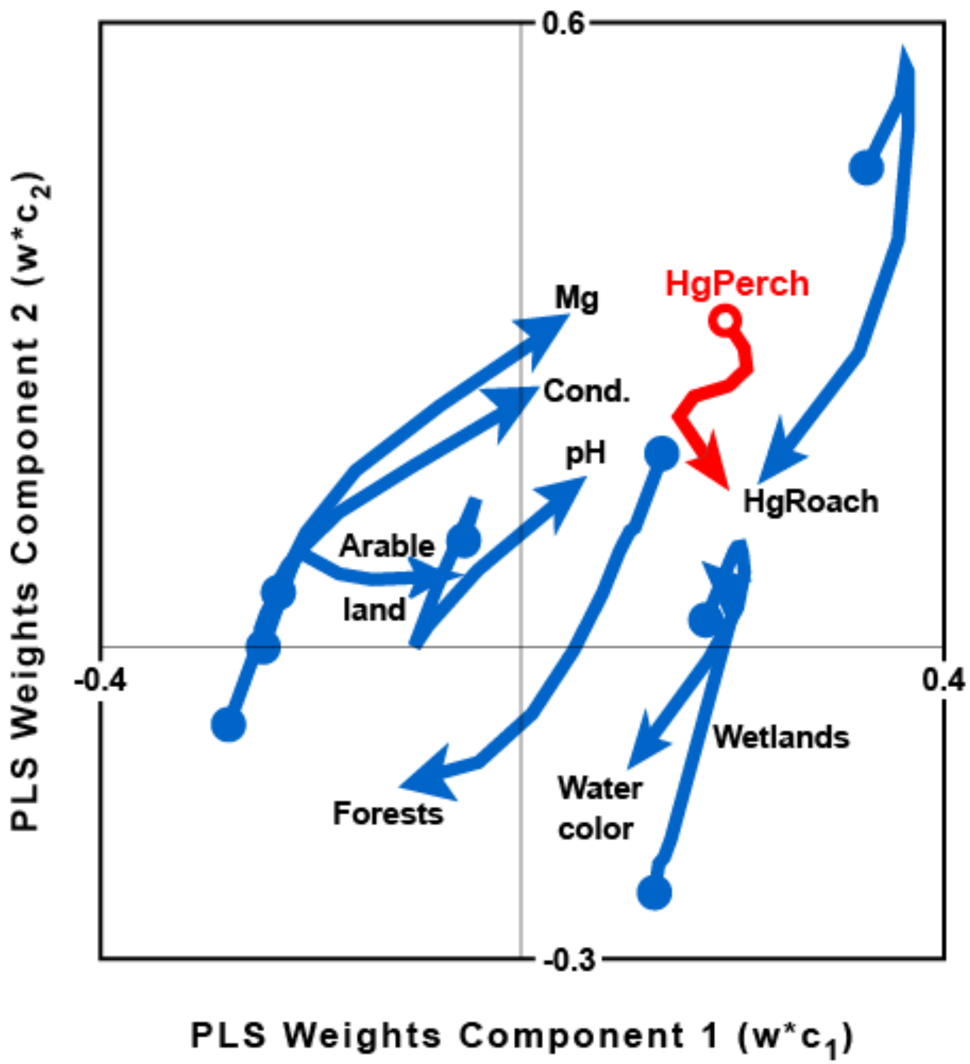
Hg in perch – PLS analysis of the influence of various environmental variables



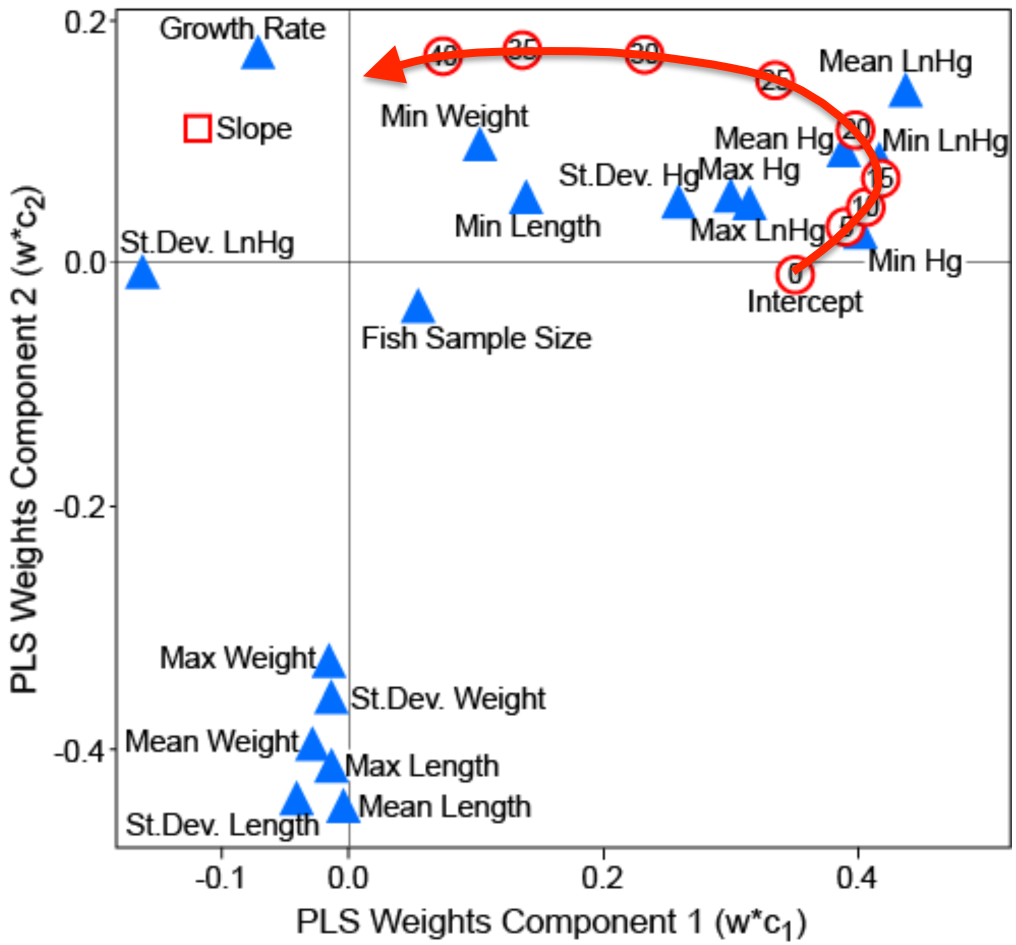
From Sonesten 2003

SLU

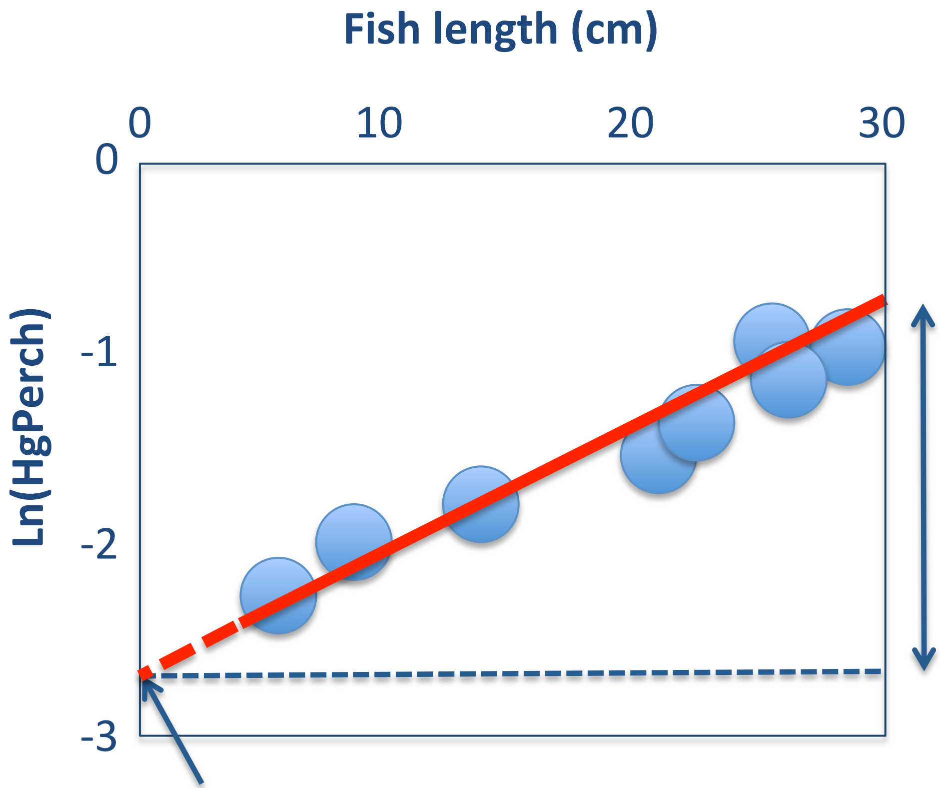
Interpretation confounded by fish-size dependencies



Standardised Hg vs fish-size characteristics



Hg in perch vs. fish-size



Slope – Suggested to mainly depend on the life-history or dietary shift during the perch life-span

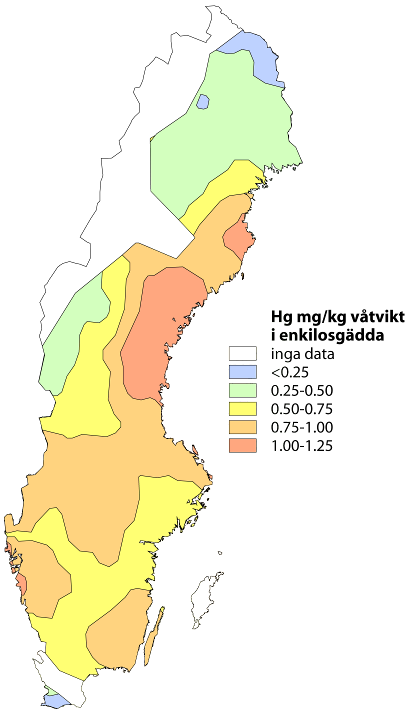
Intercept – Hypothesized to estimate the lake-specific basal Hg level

Focus on the right thing

- The purpose!
  - Environmental influence?
  - Time trends?
  - Geographical comparisons?
  - Health aspects?

Small perch?

Large perch/pike/arctic char?



1f. **Factors influencing the annual variations of Hg levels in freshwater fish.**

Göran Lithner (*Department of Applied and Environmental Research, Stockholm University*)

"Factors influencing the (annual) variations of Hg levels in freshwater fish"

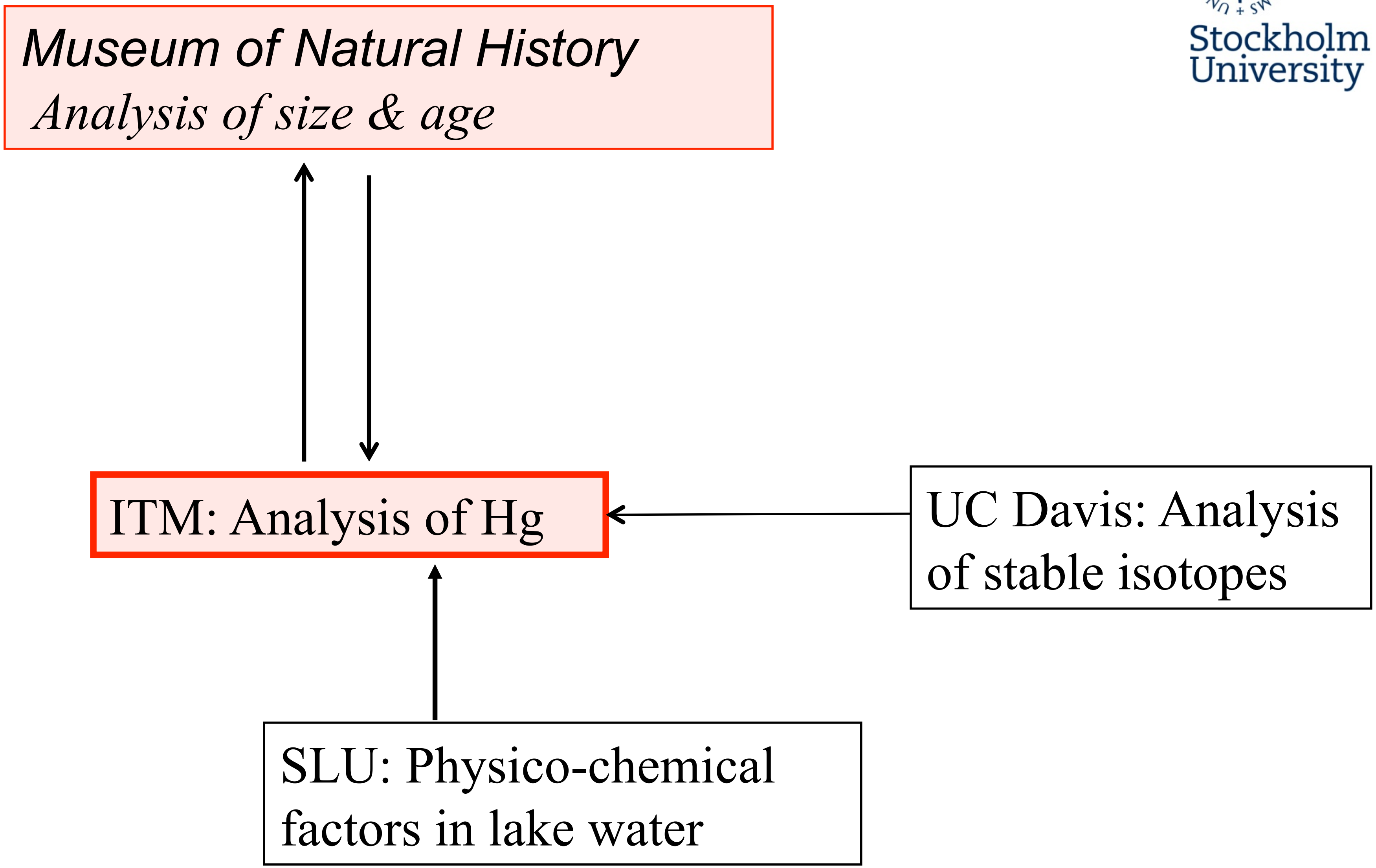
Göran Lithner

Extract from: "Hg and stable isotopes (δC^{13}, δN^{15}) in fish in 32 Swedish lakes 1999-2009 or 2006-2009" (In progress)

Göran Lithner, Pia Kärrhage, Ann-Mari Johansson, Karin Holm a o

Stockholm University

itm. Department of Applied Environmental Science



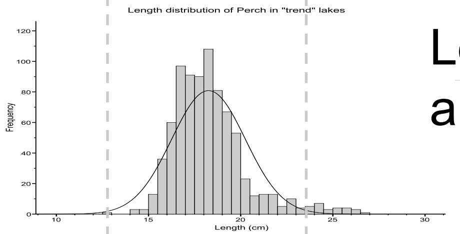
Stockholm University

Stockholm University

Stable isotopes

The analysis of isotopic ratio δN^{15} (N^{15}/N^{14}) in fish muscle will show any effects of ontogenetic diet shifts on the Hg level in fish

Hg vs. Length and ontogenetic diet shift in L Fiolen perch in 2007(Aug)



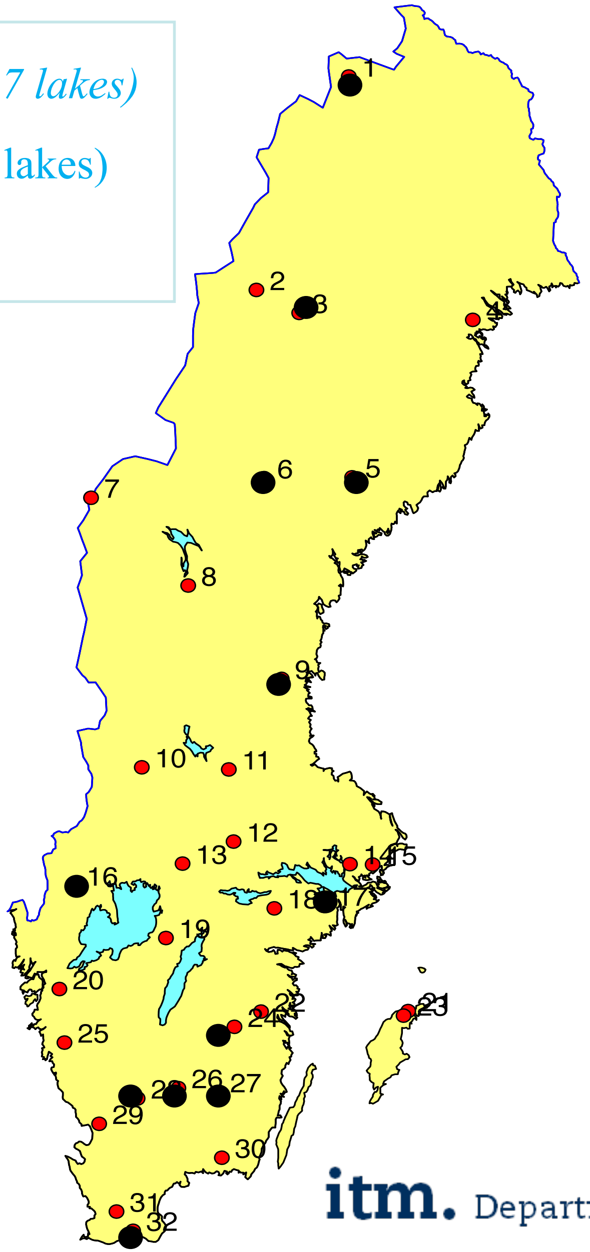
Length distribution in all ”trend” lakes

Stockholm University
itm. Department of Applied Environmental Science

The Swedish national monitoring program (A Bignert)

Stockholm University

* Euroasian Perch *(Perca fluviatilis) (27 lakes)*
* Arctic Char (*Salvelinus alpinus*) (3 lakes)
* Pike *(Esox lucius) (2 lakes)*



Lakes

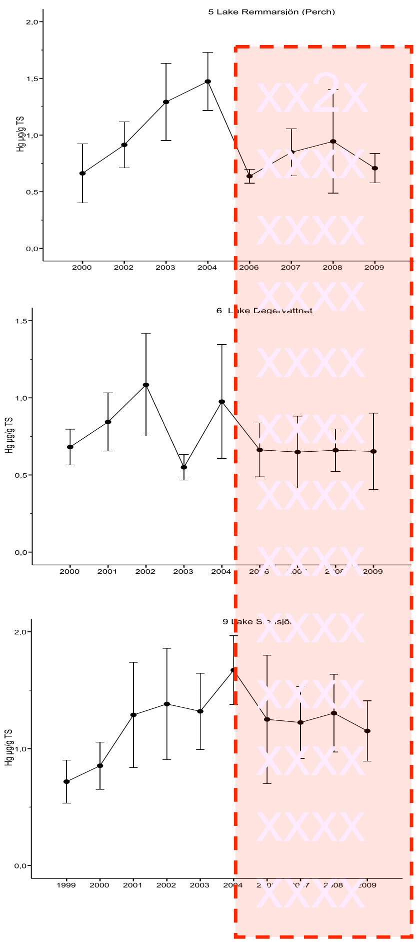
2006-2009

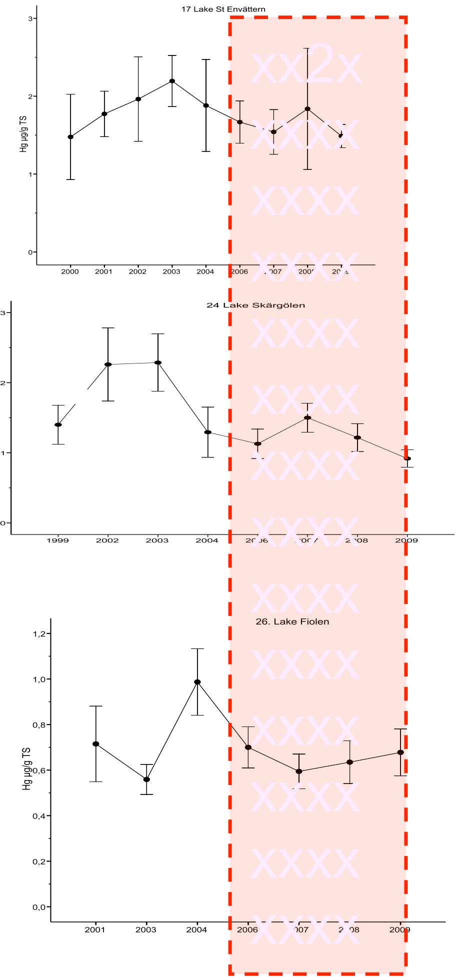
1999/2000-2009 "trend" lakes

itm. Department of Applied Environmental Science

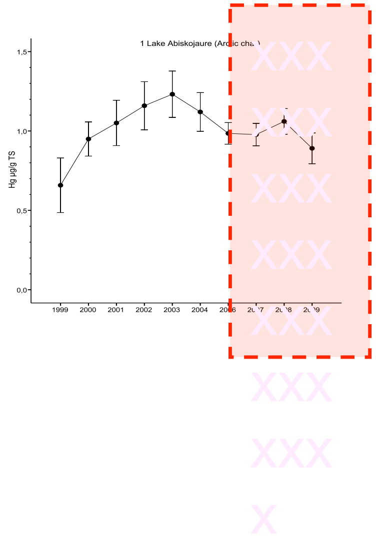
Normalizing Hg in ”trend” lakes, using data from 2006-2009

Perch





Char



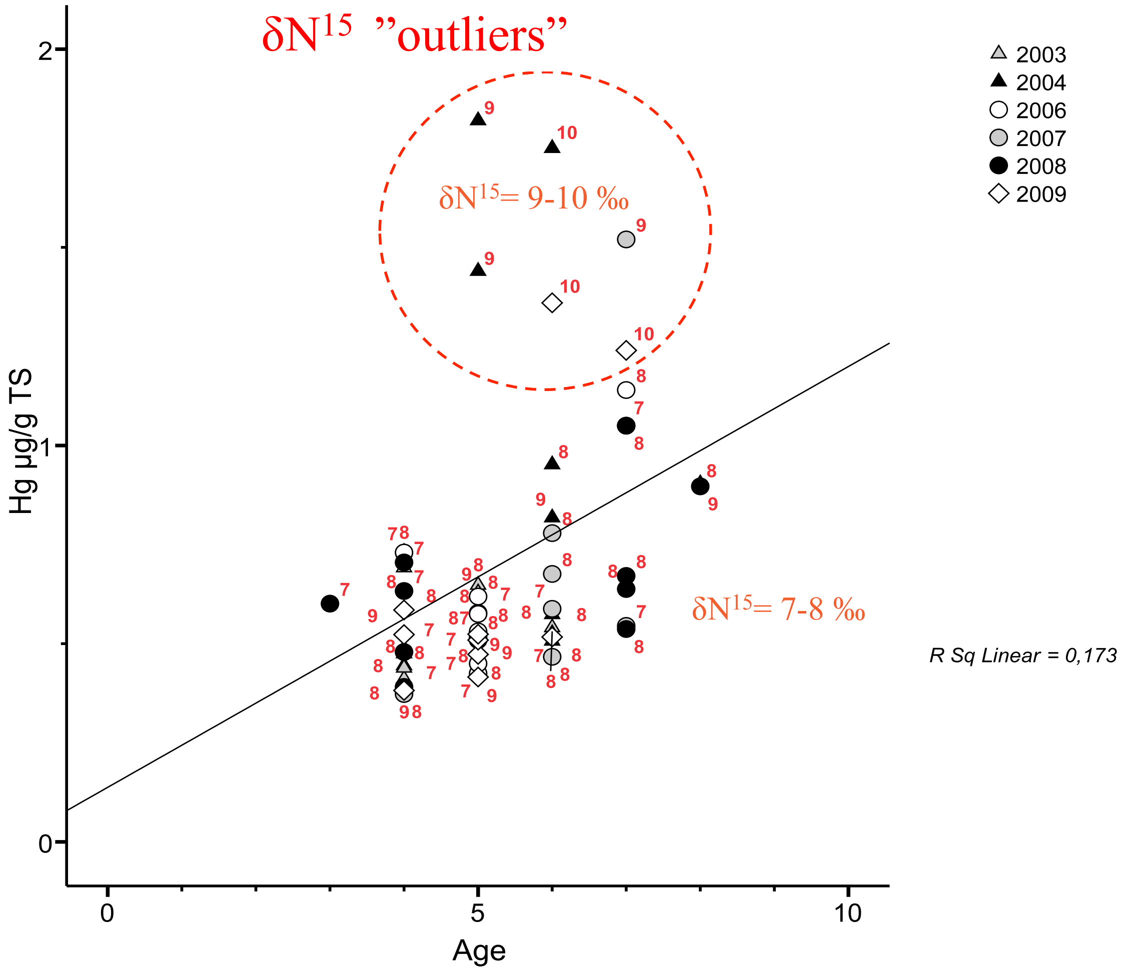
Stockholm University

Strongest correlations in 27 lakes in 2006-2009 (perch, pike)

1. Hg vs. Age (N= 15)
2. Hg vs. δN^{15} (N=8)
3. Hg vs. length (N= 4)

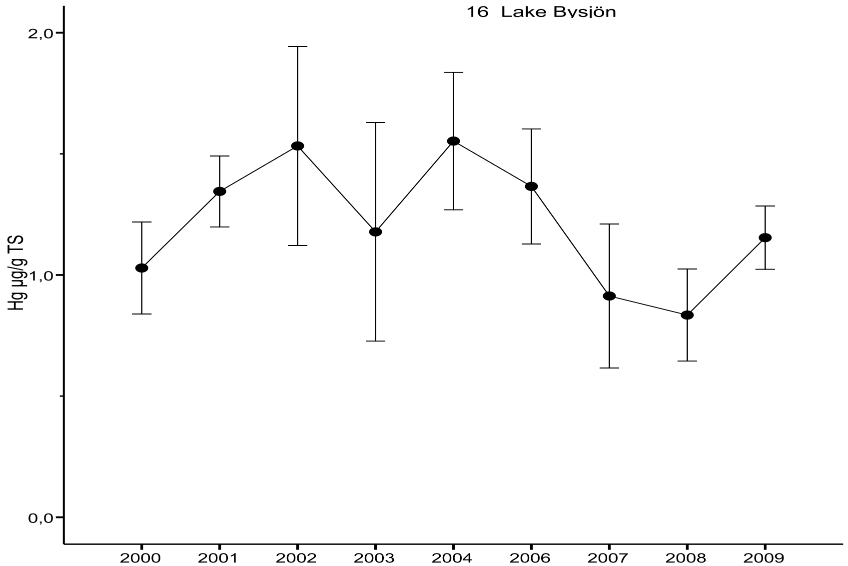
Hg vs age in L Degervattnet perch (No 6)

Stockholm University

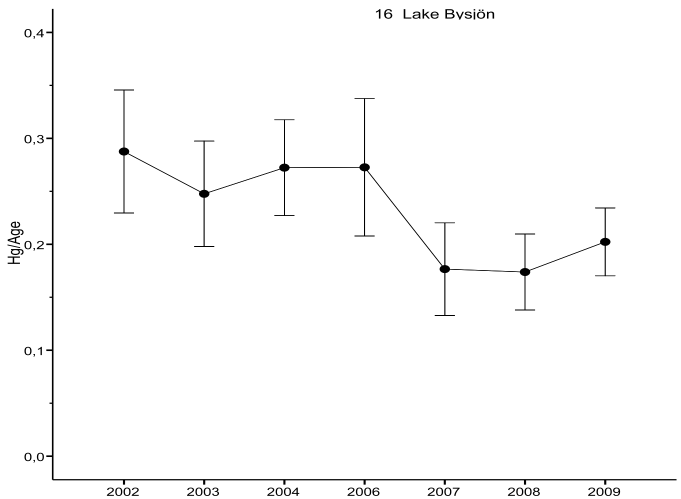


Hg trends in L Bysjön perch 2000-2009 (No 16)

Stockholm University



Hg



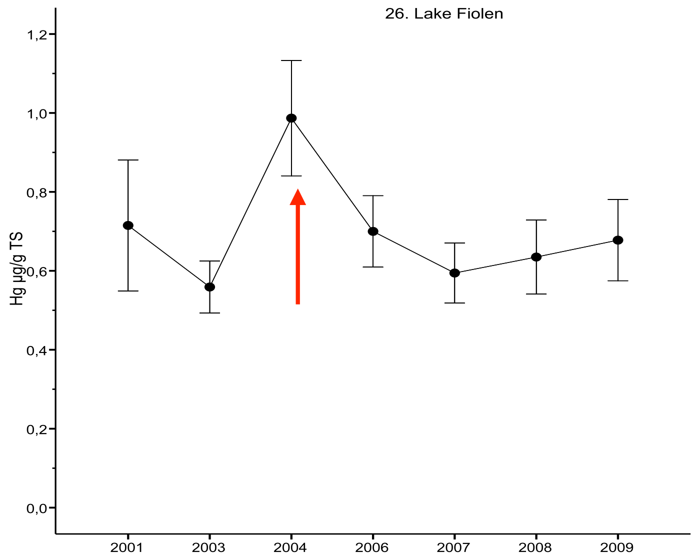
Normalized vs. age

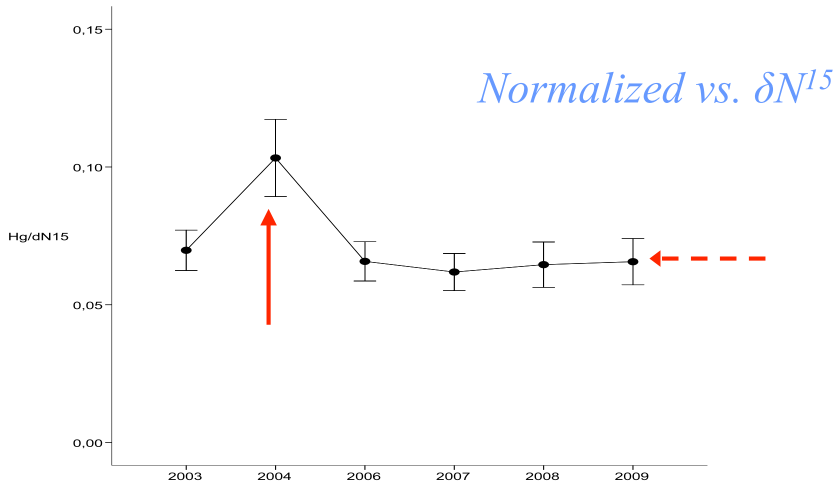
itm. Department of Appl

Hg trends in Lake Fiolen perch (No 26)

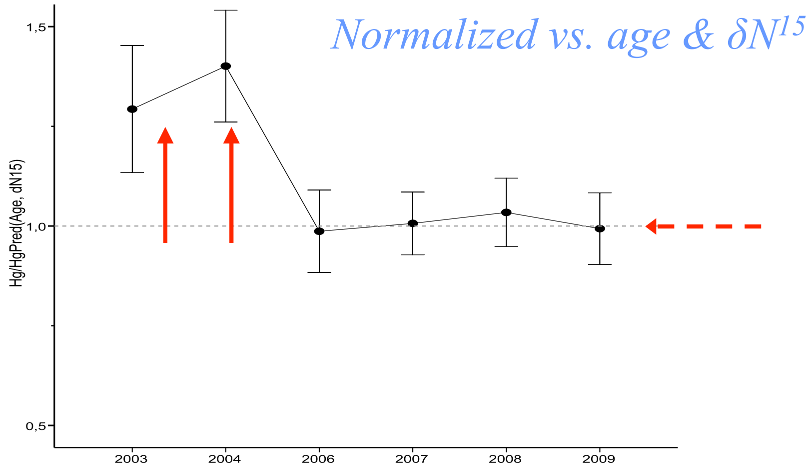
Hg

2001----------------------------------> 2009





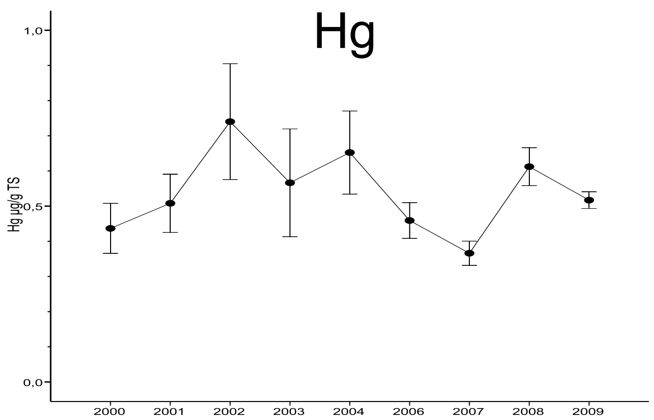
2003----------------------------------->2009

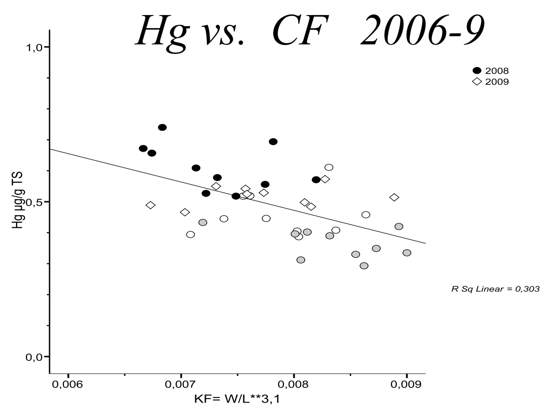


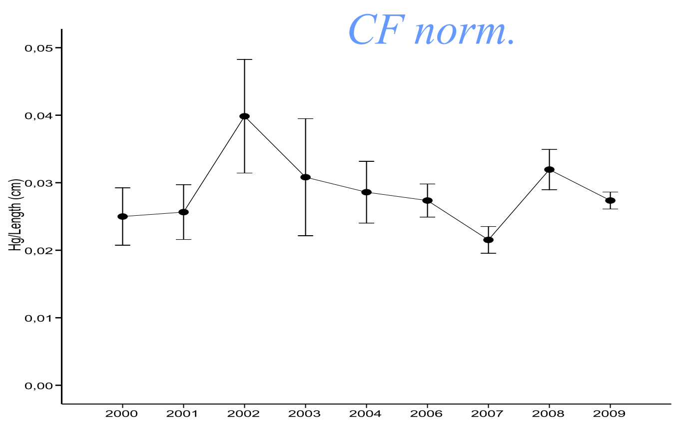
Hg trends in L Hjärtsjön perch 2000-2009 (No 27)

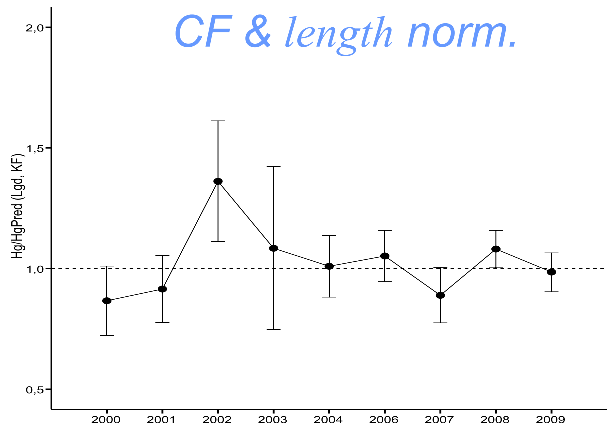
Stockholm University

"Normalizing Hg vs C F ($W/L^{3.1}$) in rapidly growing perch"





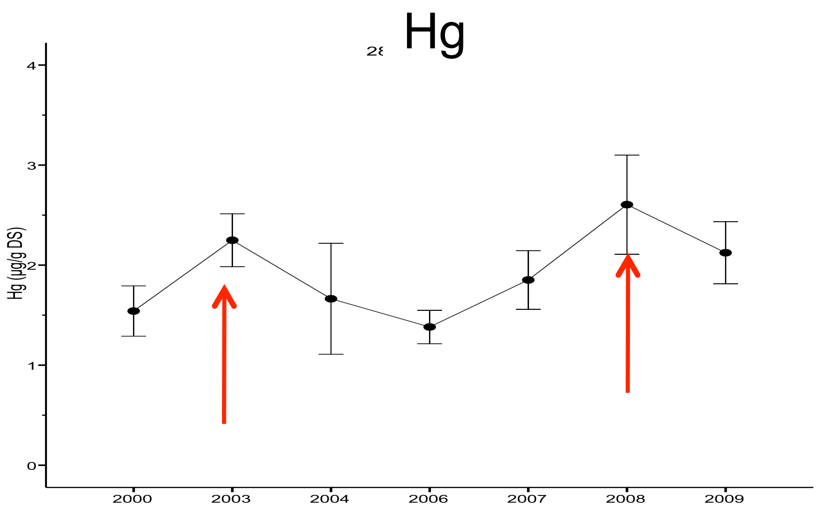


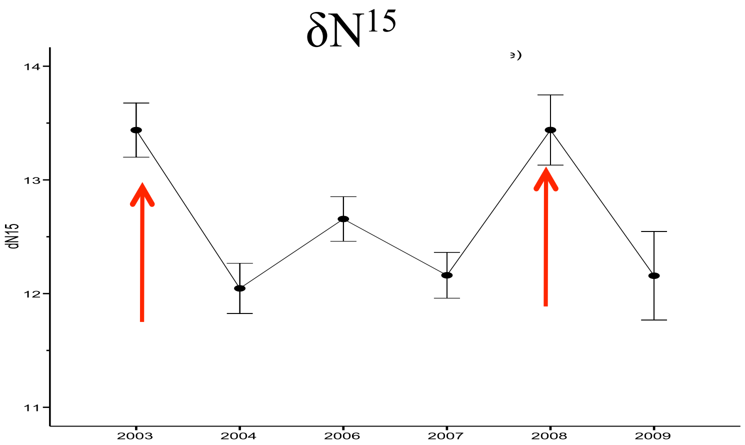


Hg and δN^{15} trends in L Bolmen pike 2003-2009 (No 28)

Stockholm University

"Temporal covariation between Hg and δN^{15}"





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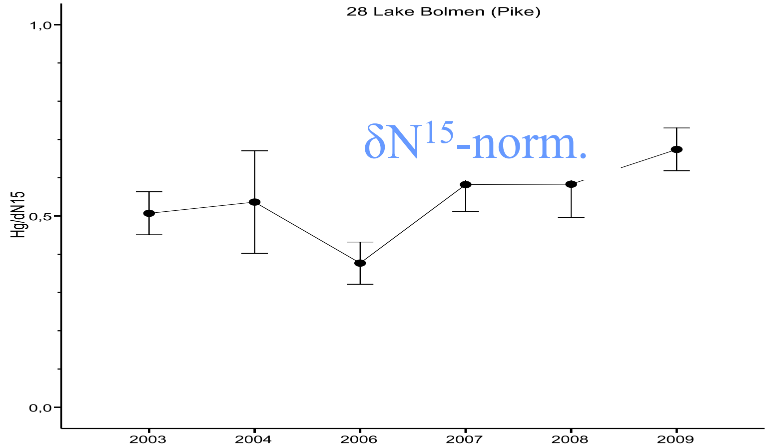
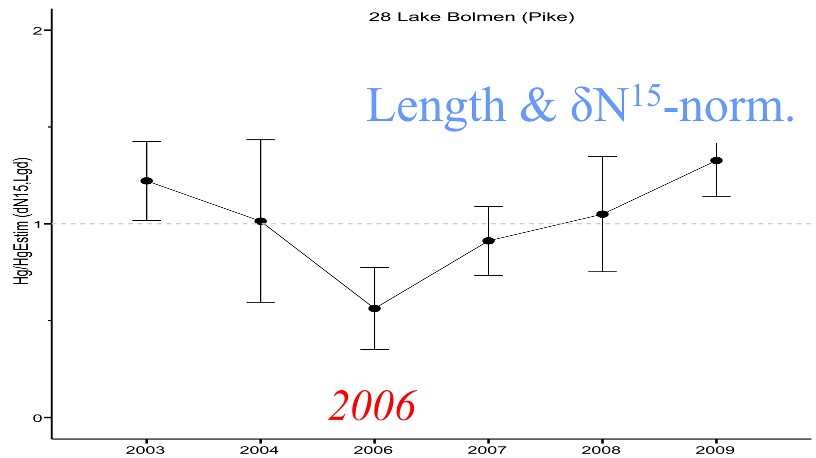
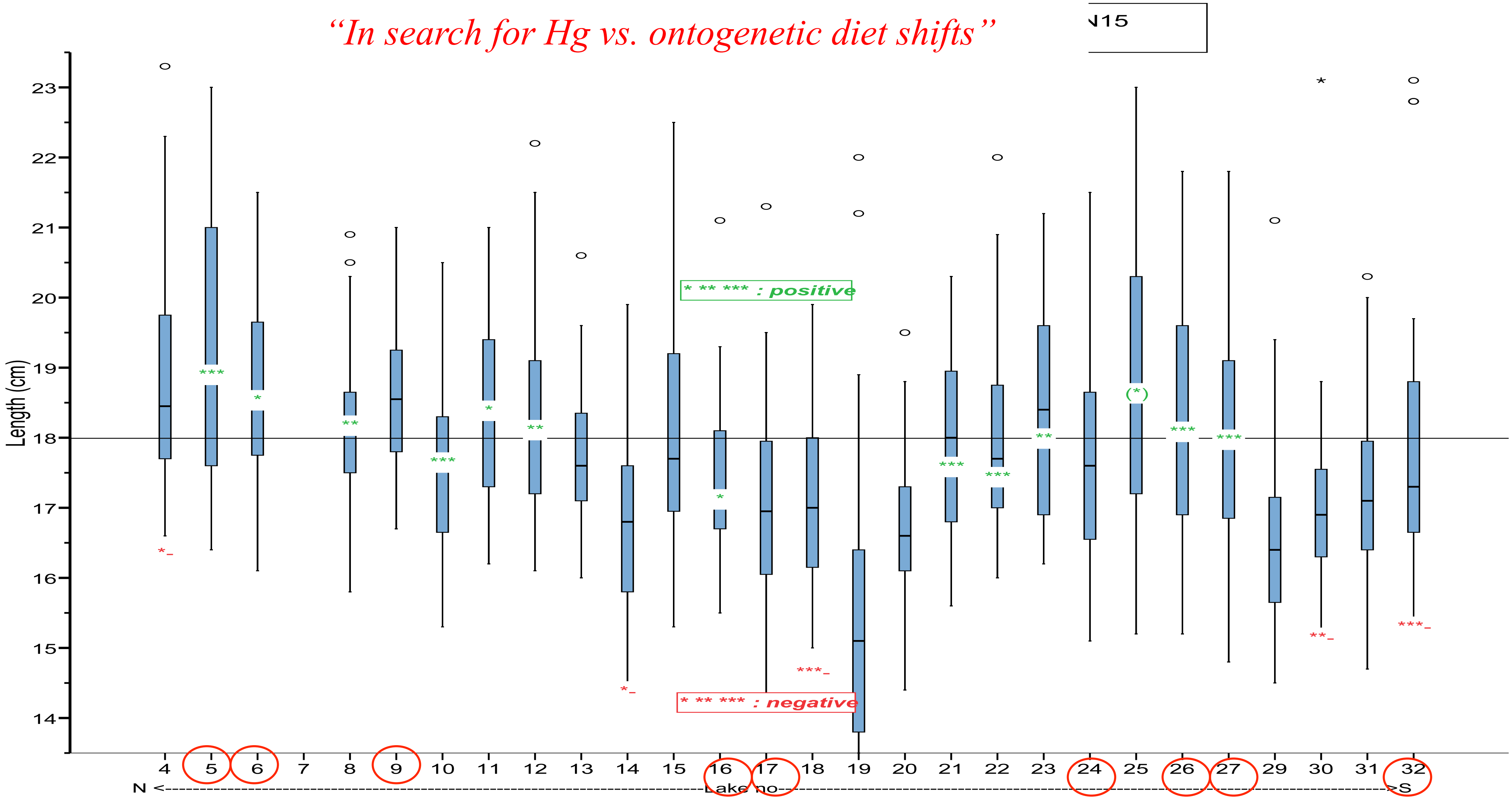
Normalized Hg trends in L Bolmen pike 2003-2009





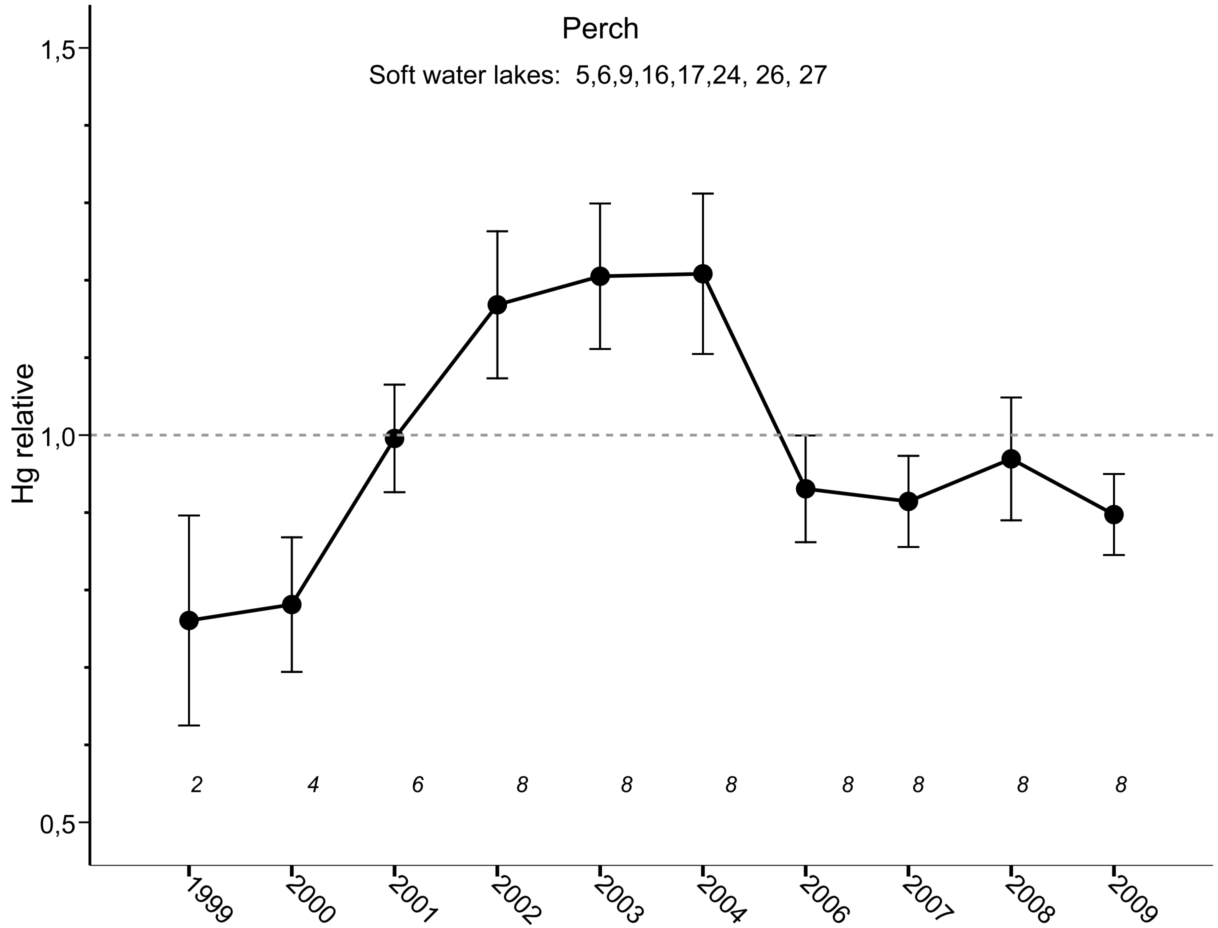
Length distribution of perch 2006-9 and log Hg vs δN[15] (*)

"In search for Hg vs. ontogenetic diet shifts"



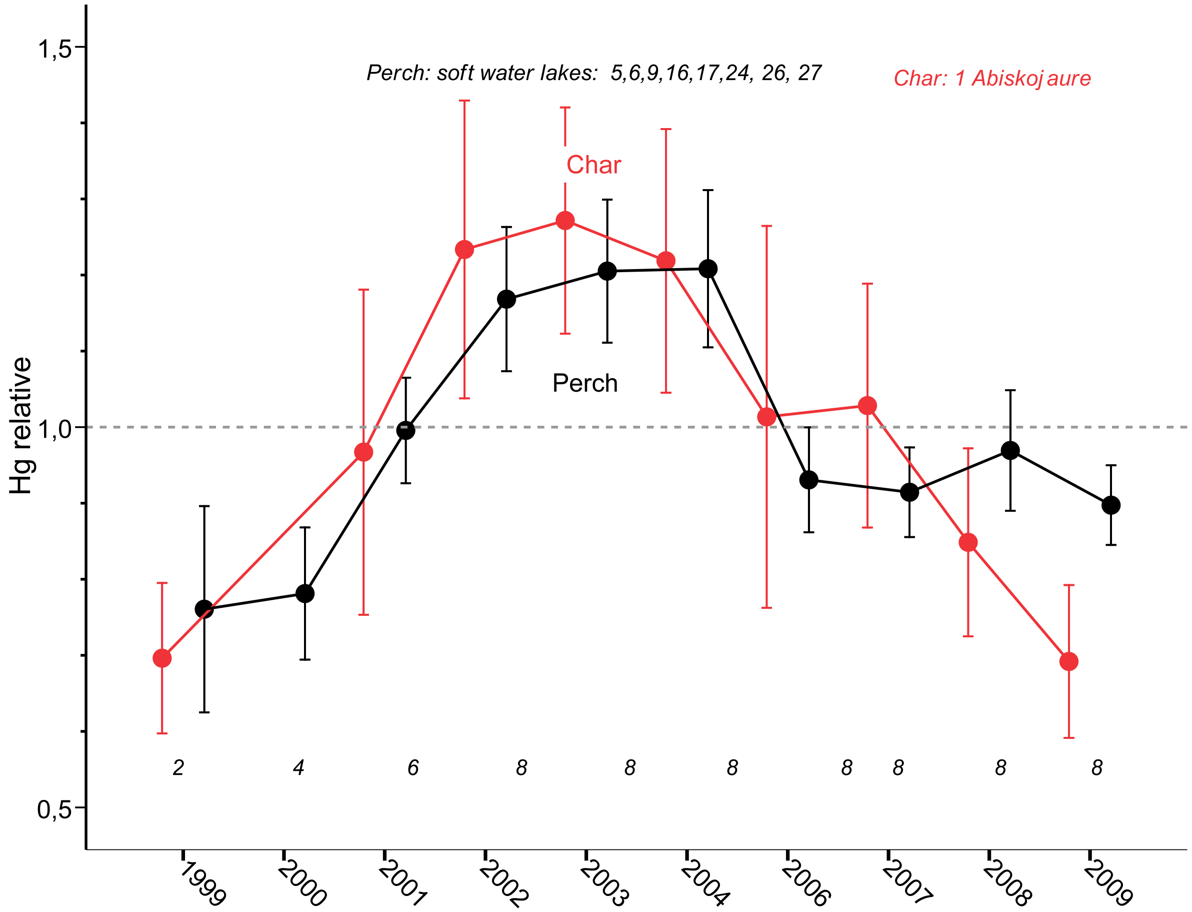
Major time trends of Hg relative to periodic mean 1999-2009

Stockholm University



Major time trends of Hg relative to periodic mean 1999-2009

Stockholm University



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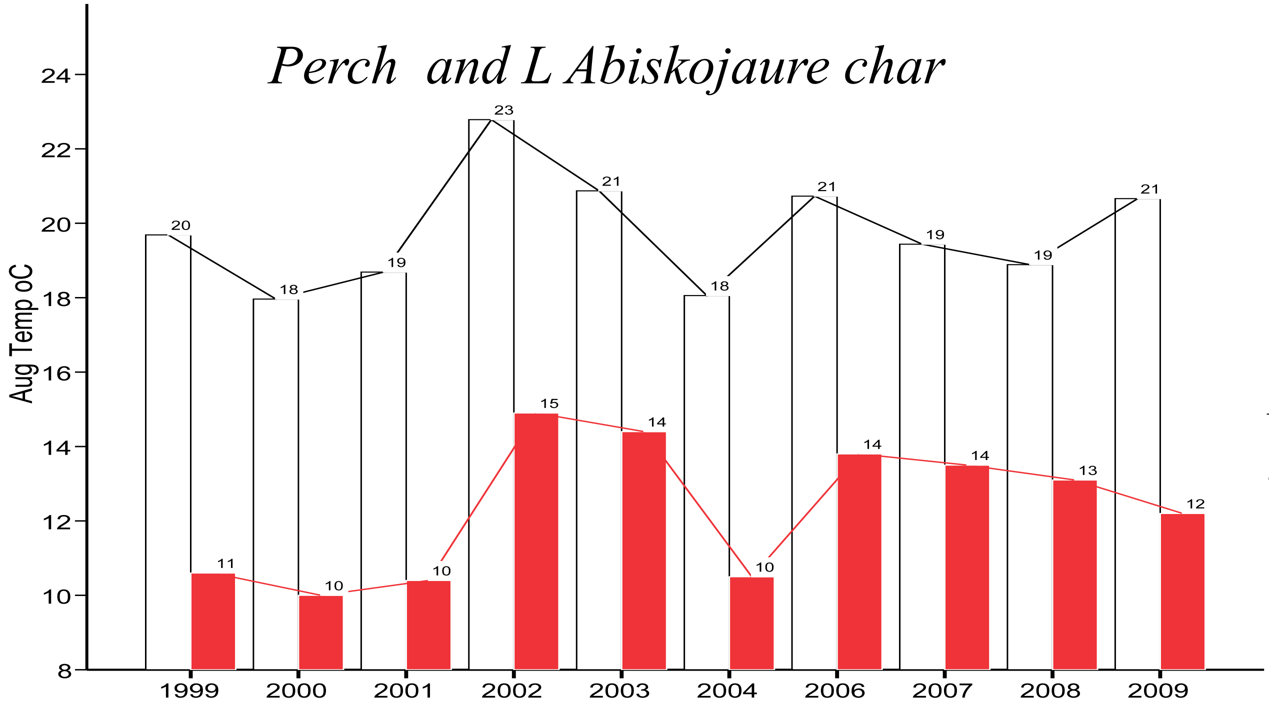
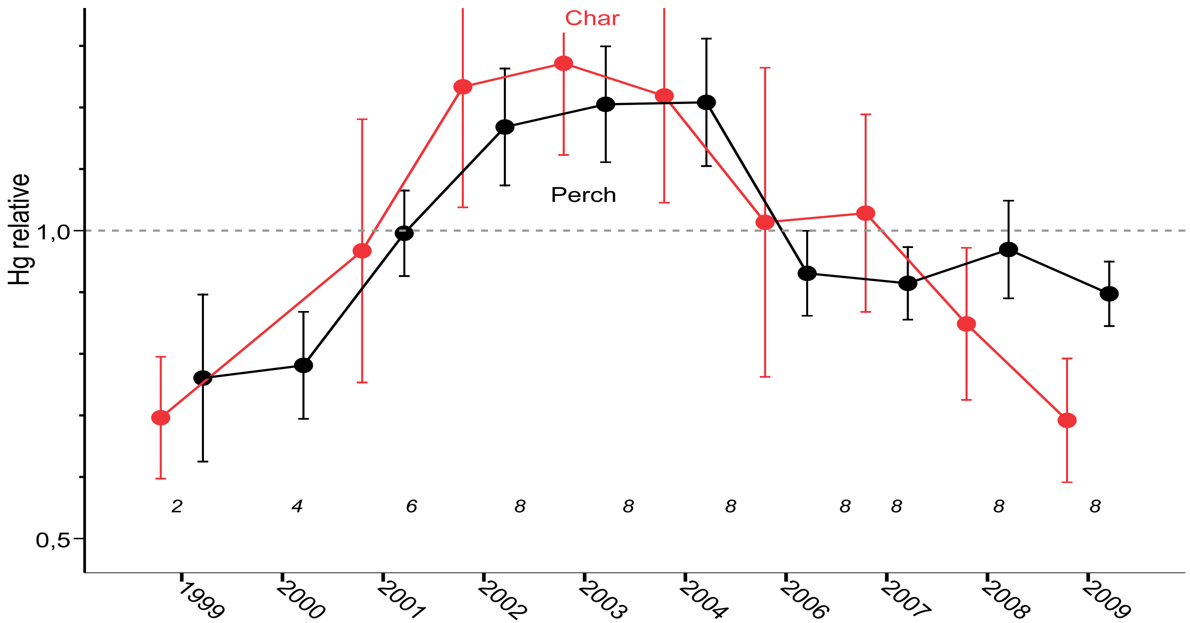
Perch and L Abiskojaure char



Max. litoral temperature



Hg relative to 1999-2009

Conclusions

Stockholm University

- Stable isotopes (δN^{15}) are useful complements for normalization and identification of ”outliers” in Hg

- The Hg and δN^{15} covariations indicates that ontogenetic diet shifts may contribute to the variation of Hg in perch and pike

- High water temperature seems to be a contributing factor to observed Hg maximum in the first decade

1g. **Trade-offs between individual and interannual variation – experiences from monitoring Hg concentrations in trophically confined but rapidly equilibrating young perch.** Marcus Sundbom (*Department of Applied and Environmental Research, Stockholm University*)

Trade-offs between individual and interannual variation

Experiences from monitoring mercury concentrations in trophically confined but rapidly equilibrating young perch.

Marcus Sundbom

Stockholm University

itm. Department of Applied Environmental Science

IKEU – Integrerad kalkningseffektuppföljning

The main objectives are to assess:

- Long-term ecological effects of liming.
- To what extent ecosystems recover to a pre-acidification state.
- Possible detrimental effects of lime treatment.

Hg since 1989

↑1998

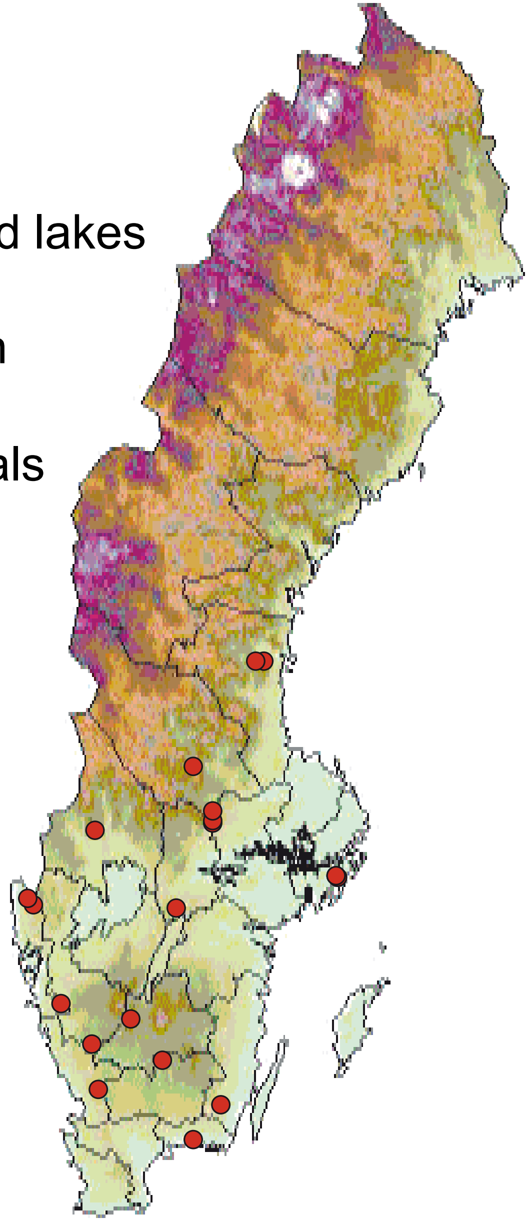
↑2005

↑2007

↓2010

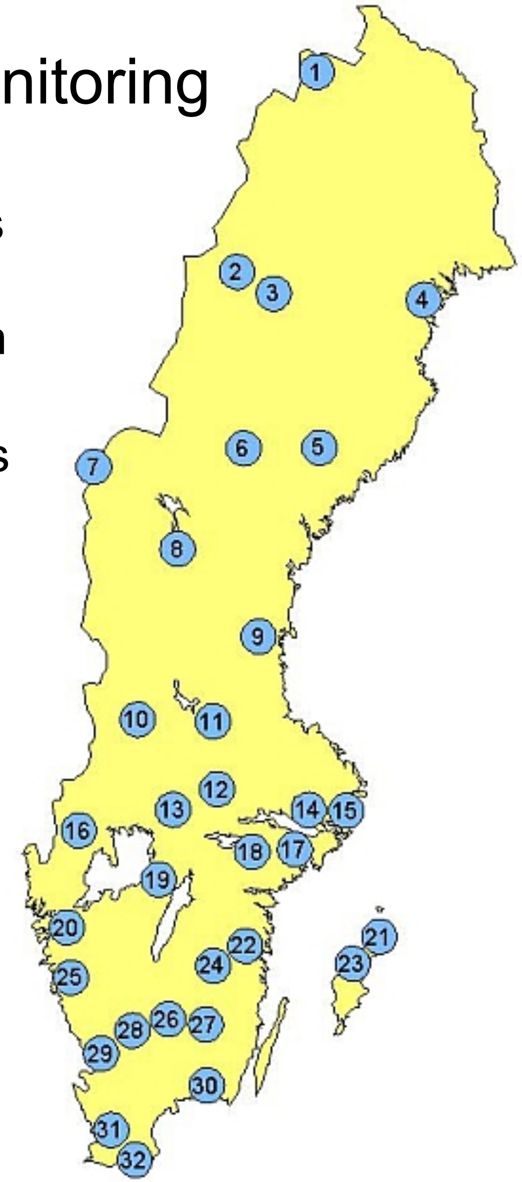
IKEU

- Mostly limed lakes
- Small perch
- 20 individuals



National Monitoring

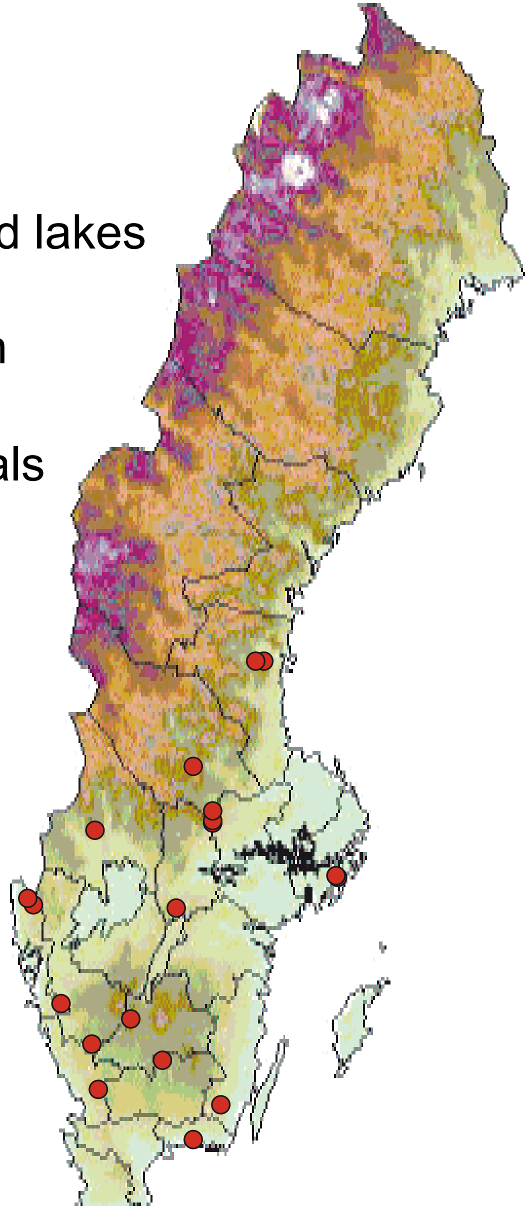
- Pristine lakes
- ”Large” perch
- 10 individuals



This is a large Perch!

IKEU

- Mostly limed lakes
- Small perch
- 20 individuals



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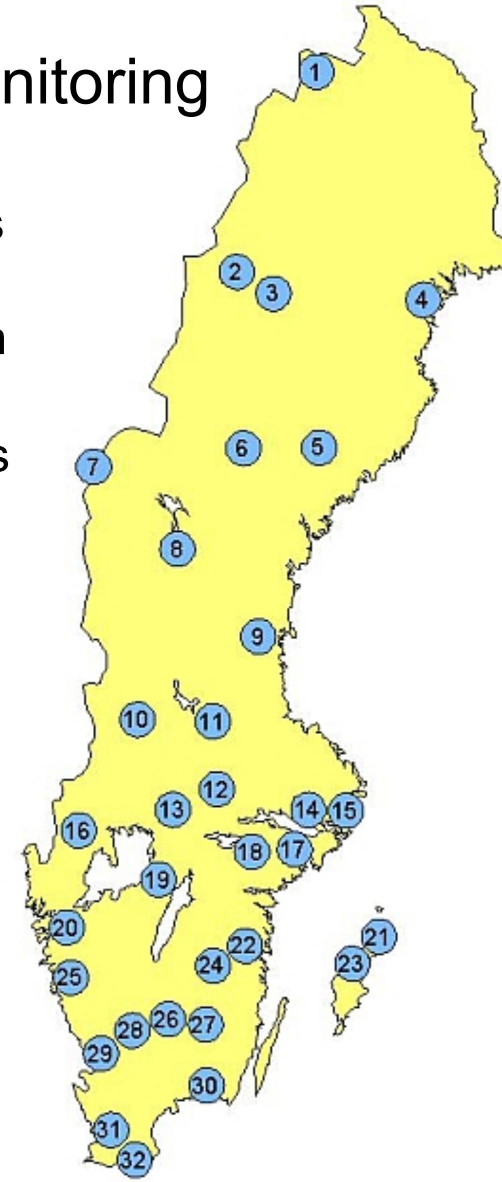
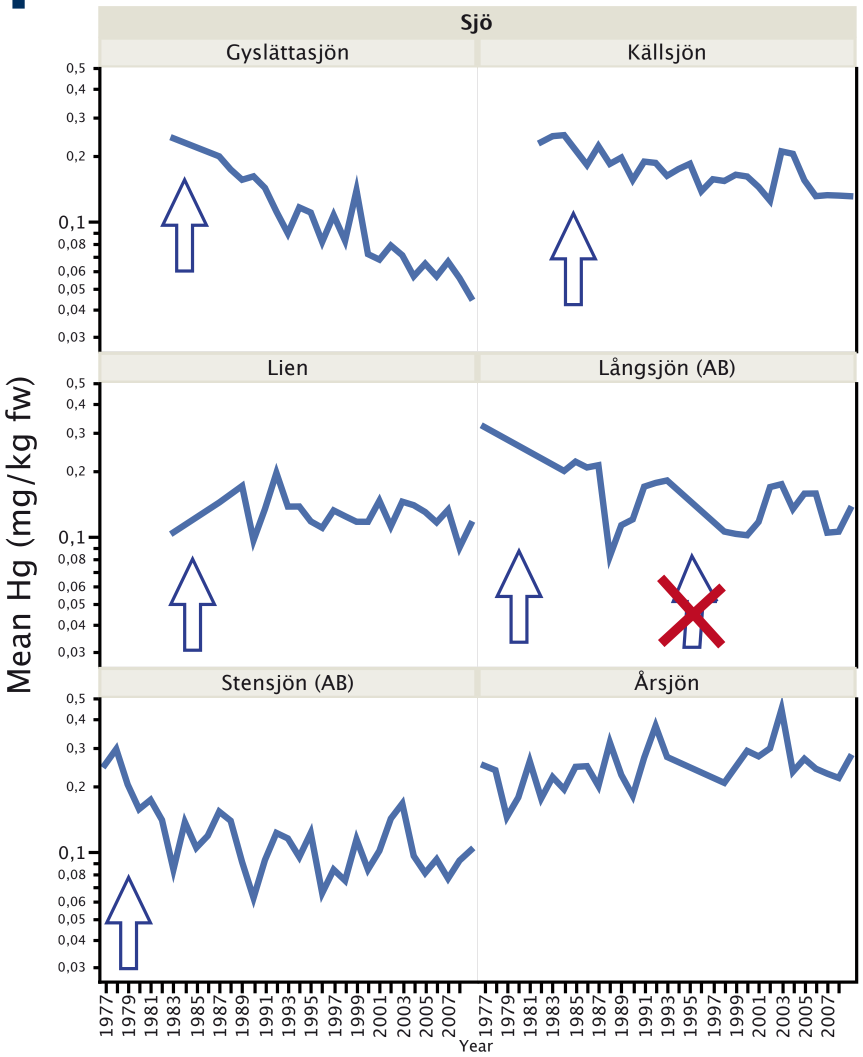


Six long time series 1977-2009 of total Hg in 1+ perch

Mean values

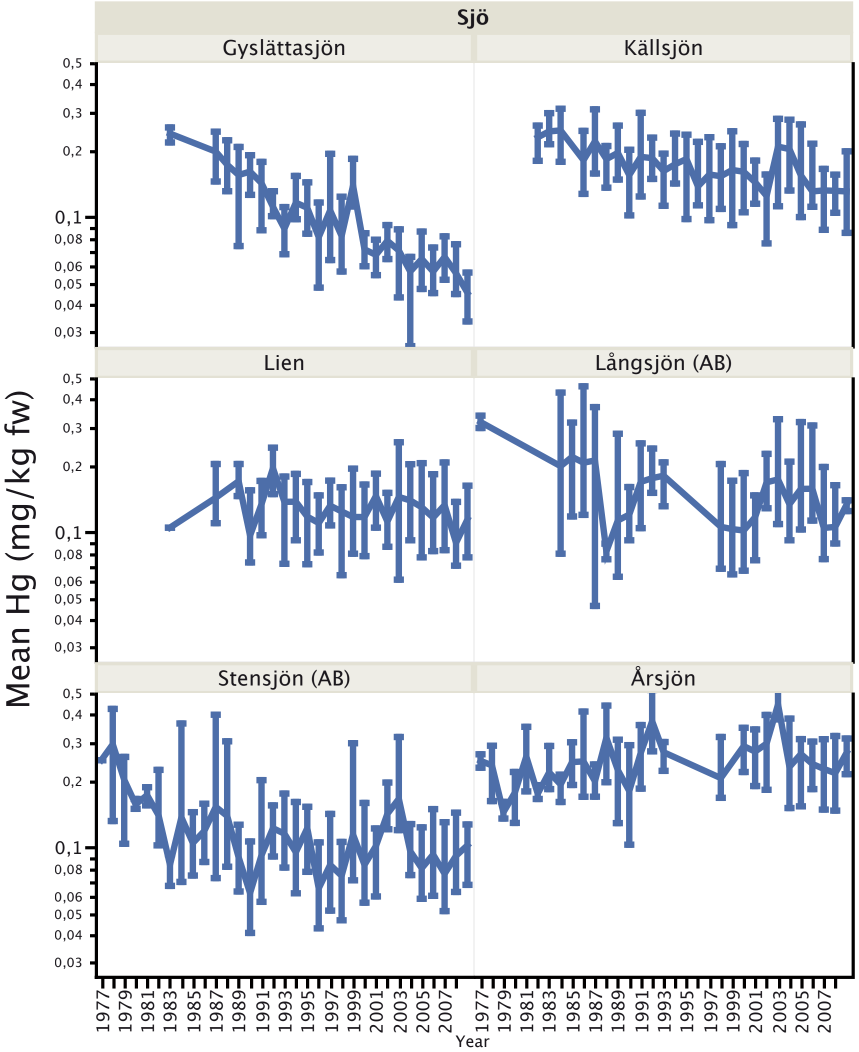
- Liming effects?
- Long term trends?
- Interannual variation?



Six long time series 1977-2009 of total Hg in 1+ perch

Mean values & ranges

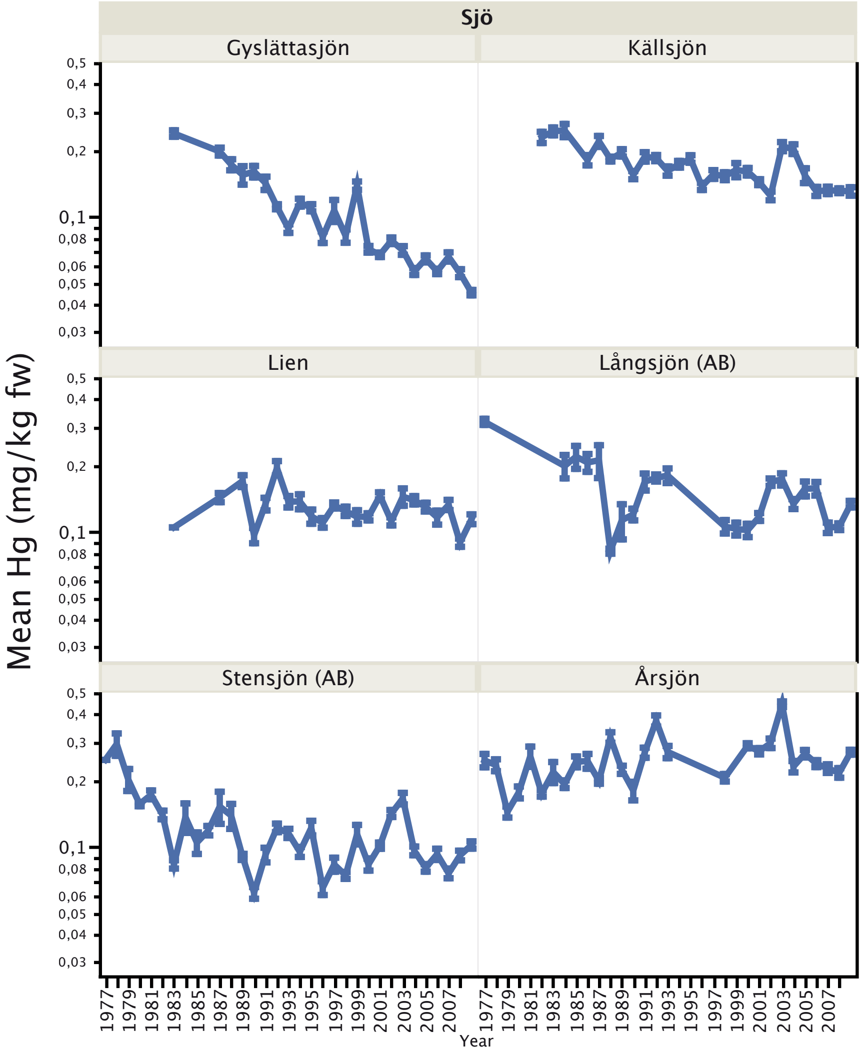
- **Possible** liming effects
- **Probable** long term trends
- **Possible** interannual variation
- **High** individual variation!
- But quite **consistent** among lakes and years = statistical advantages



Six long time series 1977-2009 of total Hg in 1+ perch

Mean values & standard error

- **Variable** liming effects
- **Probable** long term trends
- **Probable** interannual variation
- **Not too high** individual variation!
- Sampling and analysis schemes appear to be adequate



Explain the presentation title please!

Trophically confined?

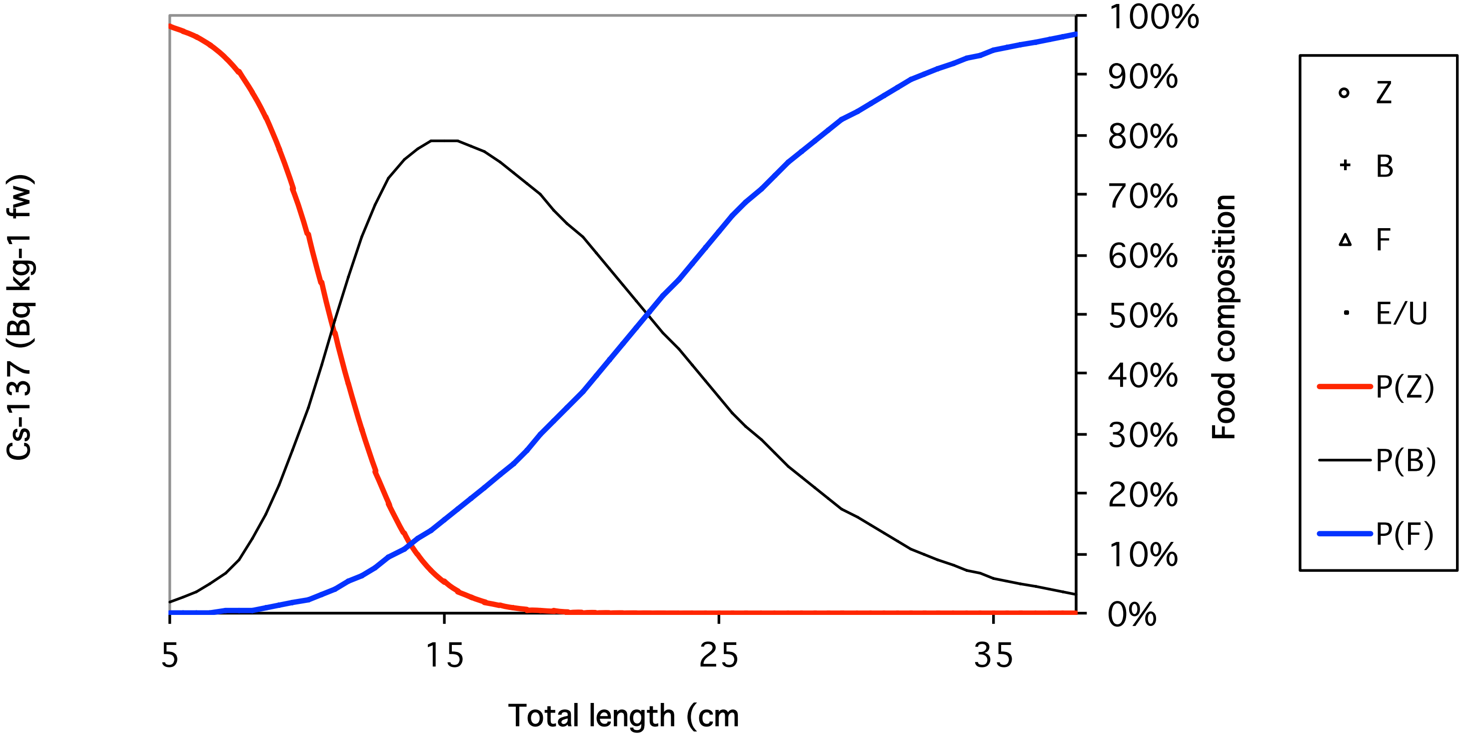
Rapidly equilibrating?

Temporal vs individual variation

Small perch vs. Large perch

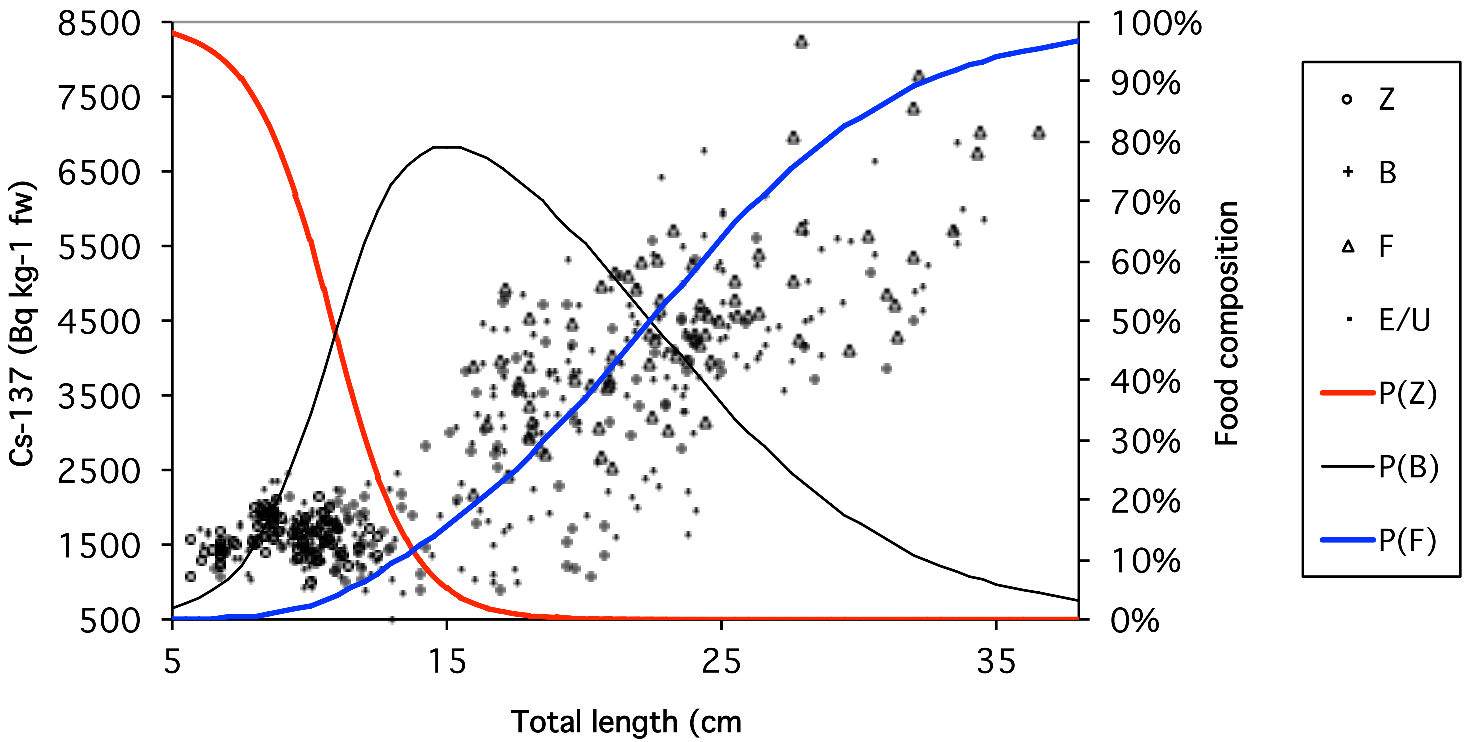
IKEU data vs. National monitoring data

Small perch are **trophically confined** because they are small



^{137}Cs in perch from one lake

- Intermediate size fish show most individual variation
- Individual resource specialisation
- Reproductive strategies?



Small perch are **rapidly equilibrating** because they are small

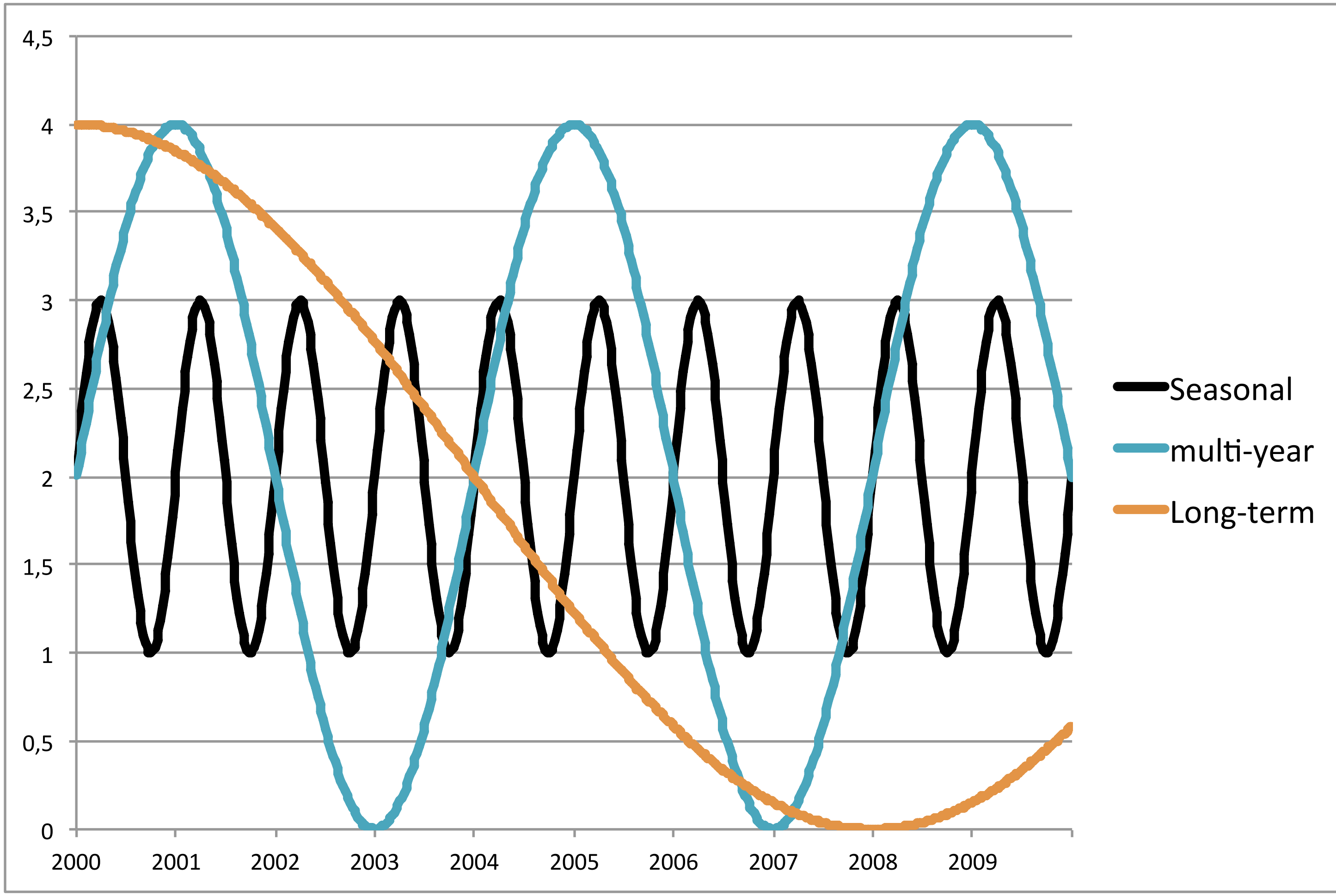
Hg concentration in small fish follow changes in ambient Hg concentration/bioavailability better than in large fish, because:

1. Less temporal buffering by the (shorter) food chain of small perch
2. Faster specific growth and Hg excretion rates in small fish

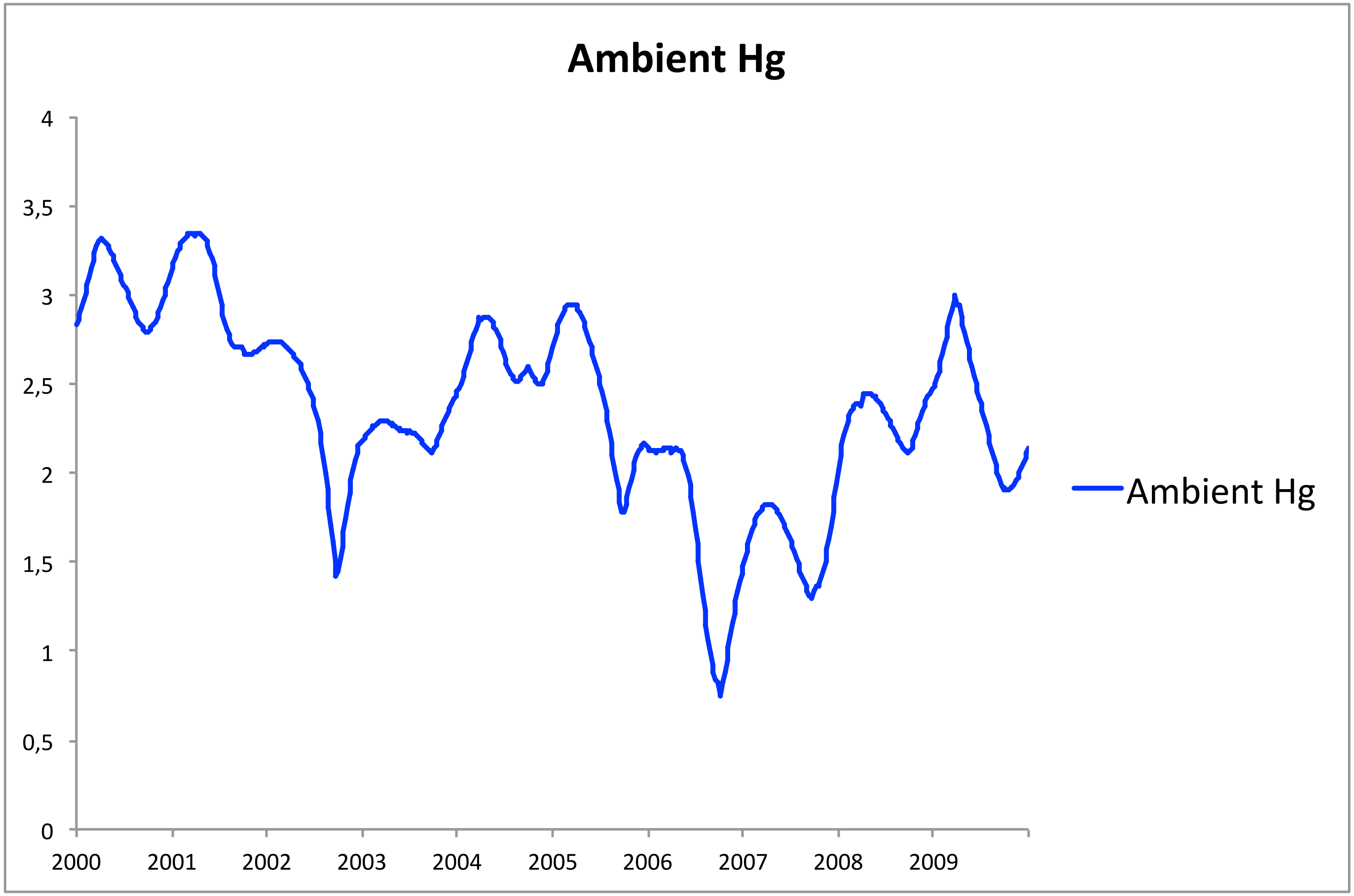
growth + excretion ≈ equilibration rate

$$[Hg]_{fish} = \frac{\alpha I [Hg]_{food}}{G + E}$$

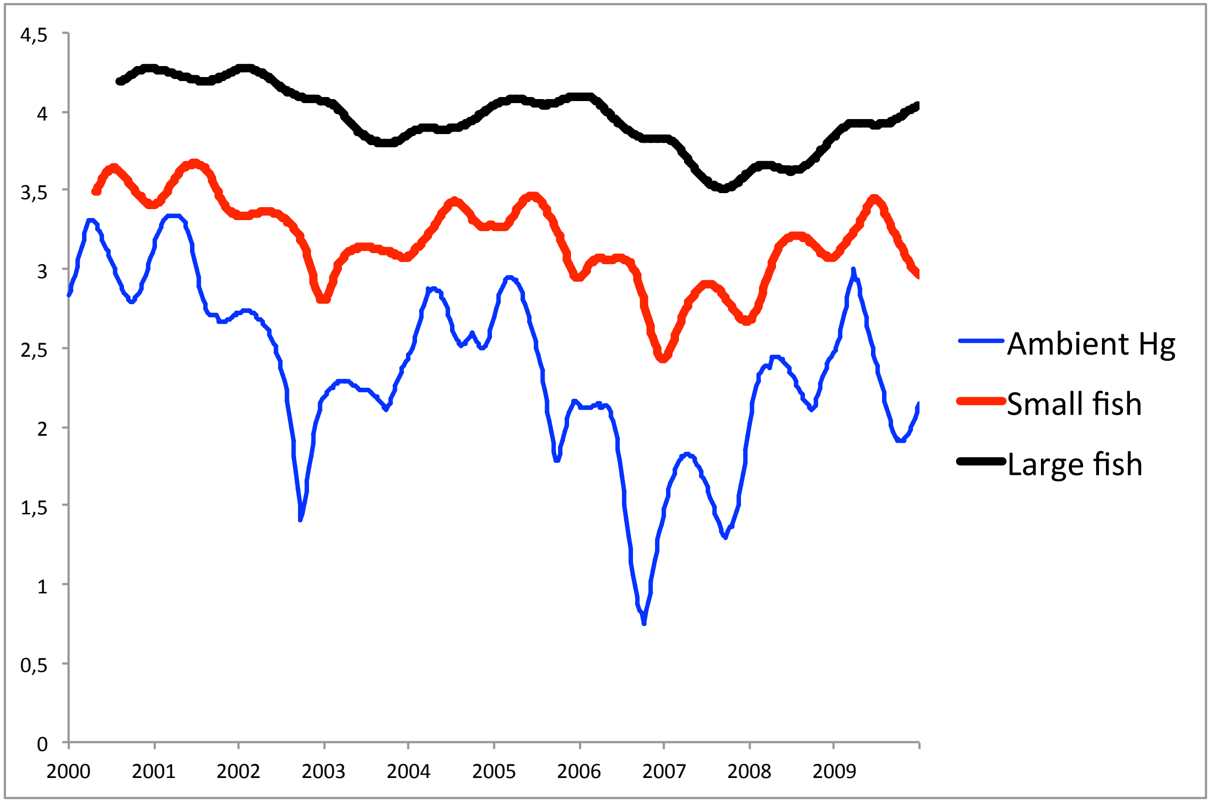
Variabilty patterns in ambient Hg



Sum of patterns plus some stochastic events



”Modelled” temporal patterns small and large perch.



- Delayed and smoother response in large fish to changes in Hg availability
- Simulated sampling 1 August yield similar or higher interannual variation for small than for large fish
- Bioenergetically driven seasonality not included

Predictions about the relative contribution of individual and interannual variation:

Small perch

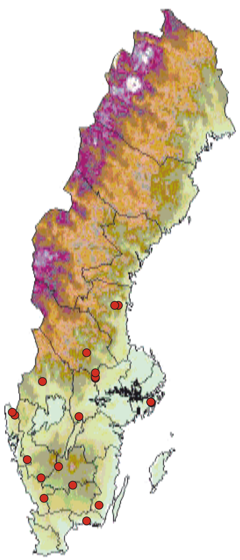
Individual < Interannual

General variation sources

Large perch

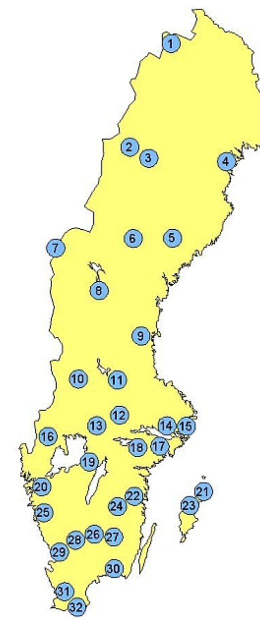
Interannual < Individual

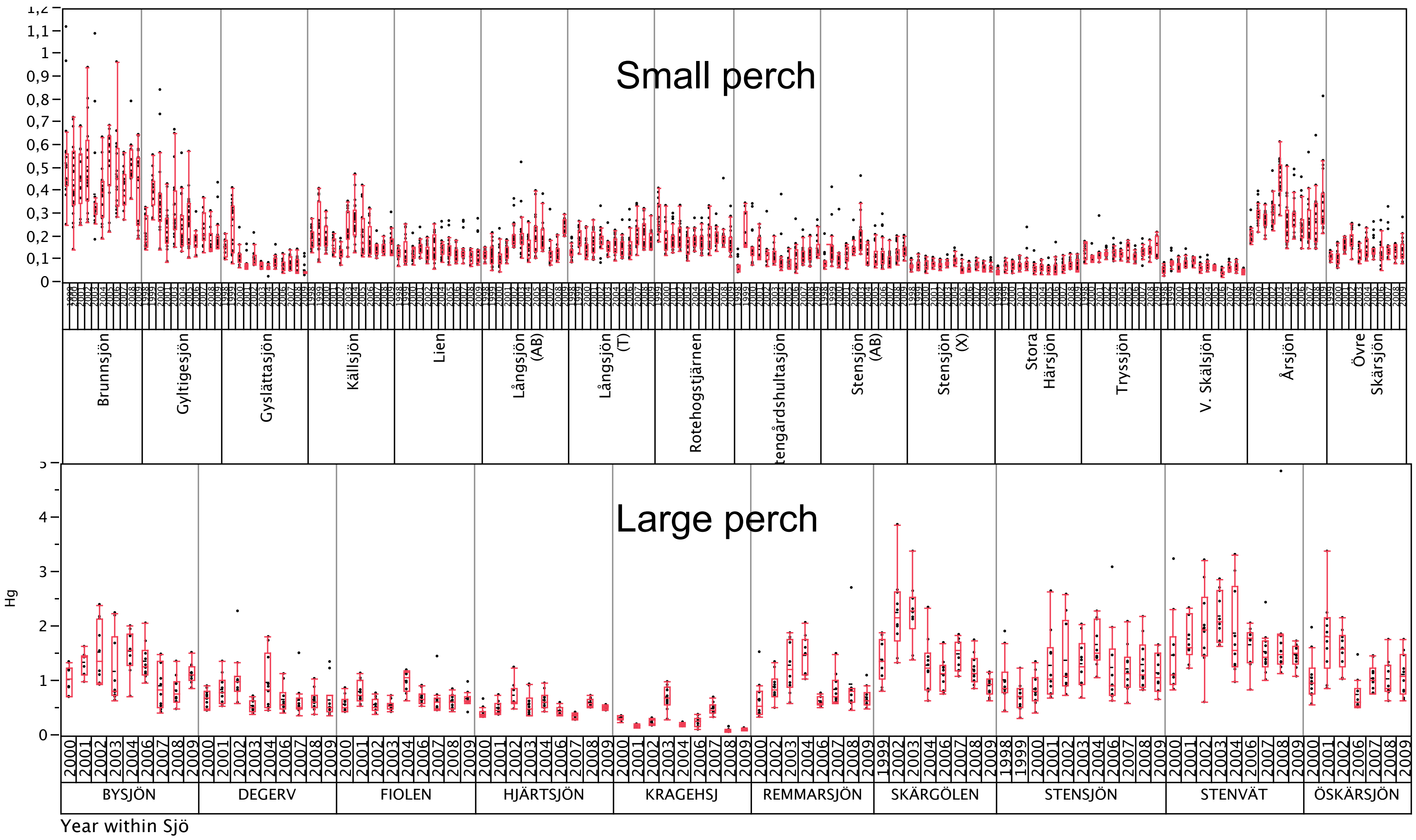
Lake specific patterns



IKEU (16 lakes) and Monitoring (10 lakes) 1998-2009

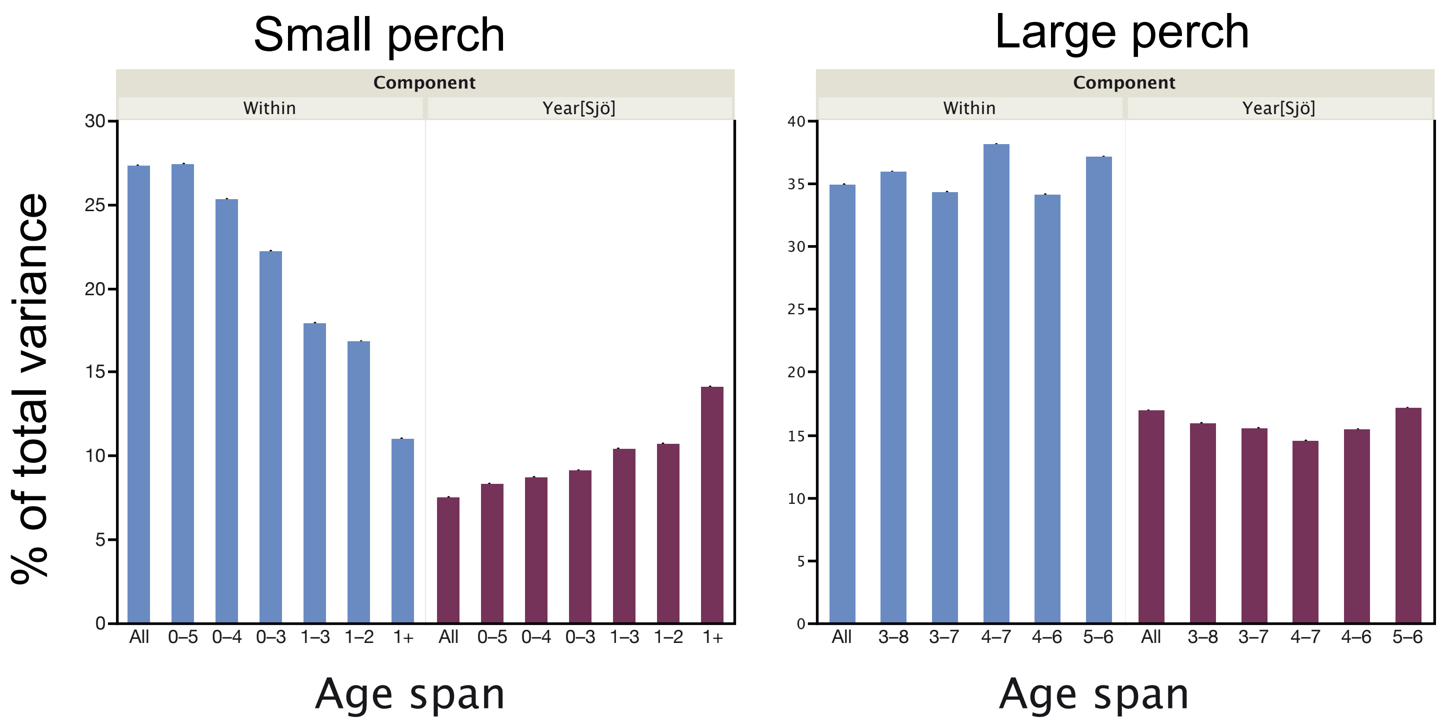
- Variance components (Nested ANOVA, REML)
- Frequency of extreme years (Contingency analysis)
- Validating





Small perch
Large perch
Hg
Brunnsjön
Gyltigesjön
Gyslättasjön
Källsjön
Lien
Långsjön (AB)
Långsjön (T)
Rotehogstjärnen
Stengårdshultasjön
Stensjön (AB)
Stensjön (X)
Stora Härsjön
Tryssjön
V. Skälsjön
Årsjön
Övre Skärsjön
BYSJÖN
DEGERV
FIOLEN
HJÄRTSJÖN
KRAGEHSJ
REMMARSJÖN
SKÄRGÖLEN
STENSJÖN
STENVÄT
ÖSKÄRSJÖN
Year within Sjö

Variance components of individual and interannual variation in Hg

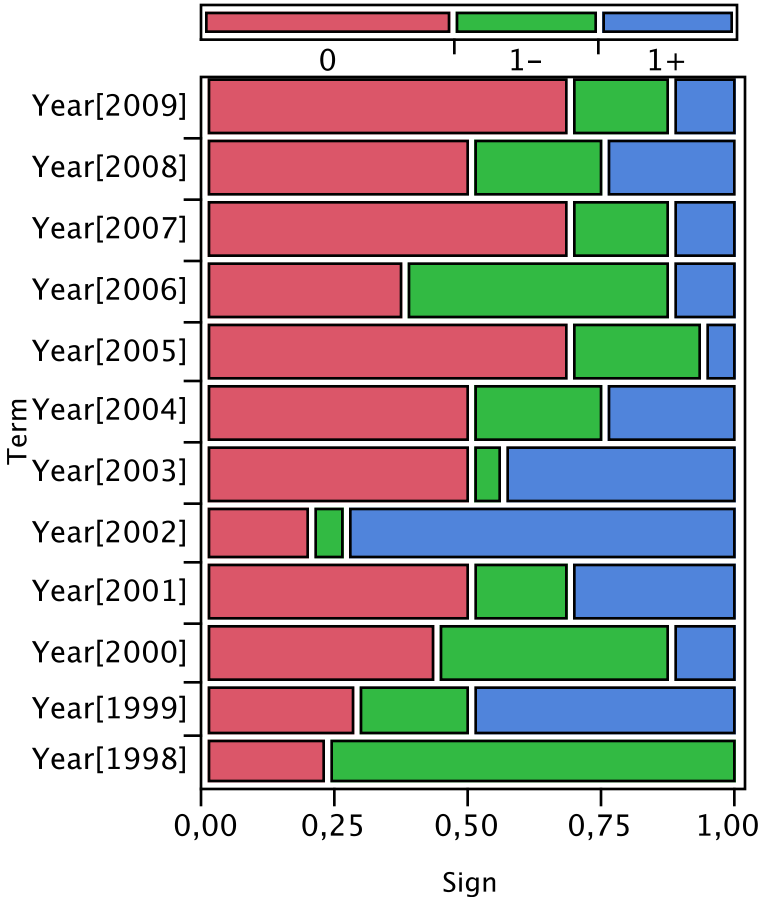


- Individual variation larger than interannual variation in both data sets.
- Age stratification considerably improves the sensitivity of small, but not large, perch to detect temporal changes.

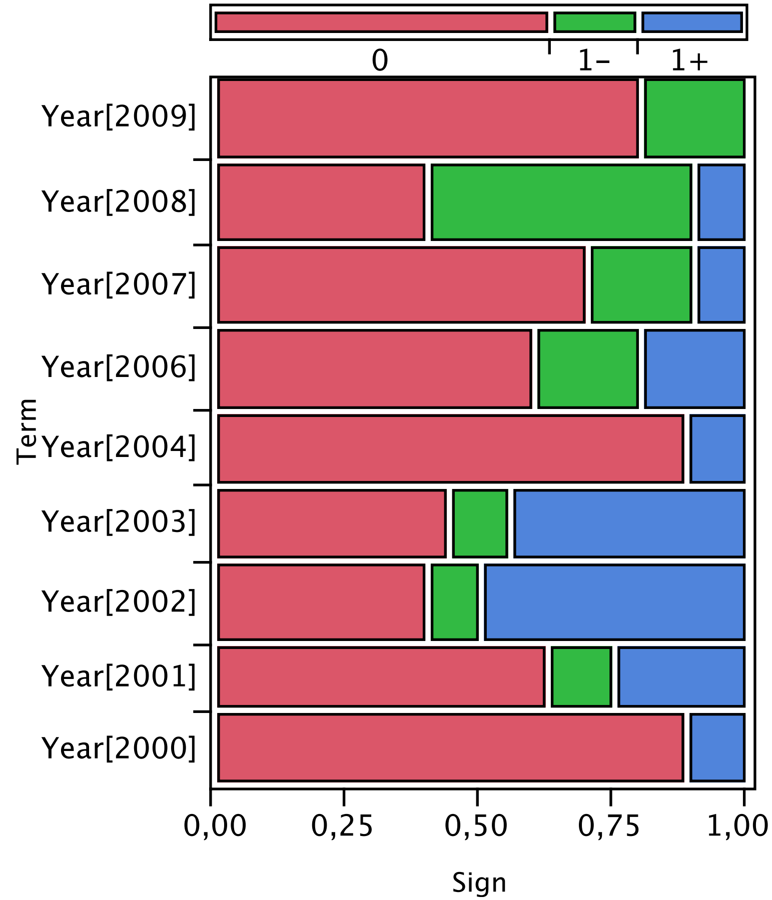
Frequency of extreme years that significantly (α =0,05) deviate from within-lake mean Hg level (logtranformed, de-trended)

Across **lakes**

Small perch p < 0,00002

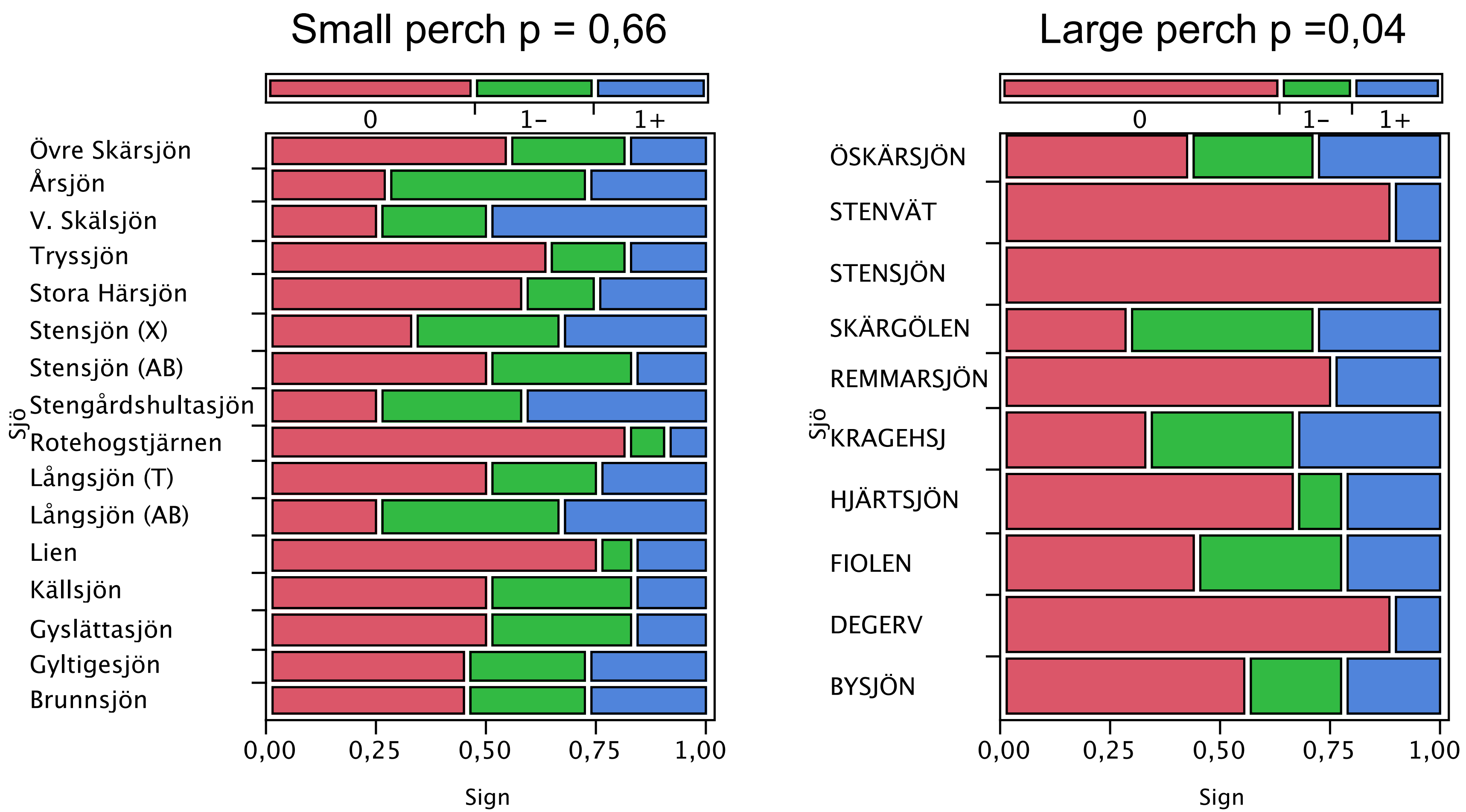


Large perch p = 0,05



Frequency of extreme years that significantly (α =0,05) deviate from within-lake mean Hg level (logtranformed, de-trended)

Across **Years**



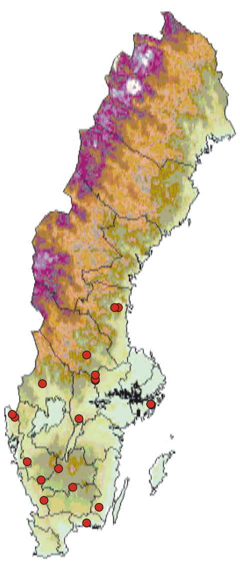
Predictions about the relative contribution of individual and interannual variation:

Small perch

- Individual < Interannual
- General variation sources

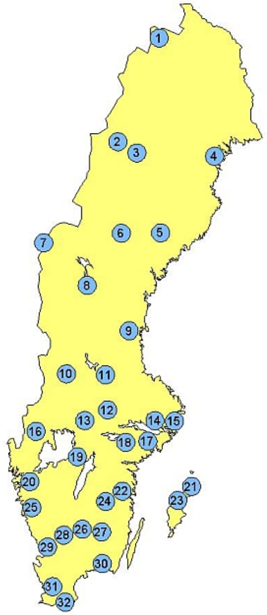
Large perch

- Interannual < Individual
- Lake specific patterns



IKEU (16 lakes) and Monitoring (10 lakes)
1998-2009

- Variance components (Nested ANOVA, REML)
- Frequency of extreme years (Contingency analysis)
- Validation



Predictions about the relative contribution of individual and interannual variation:

Small perch

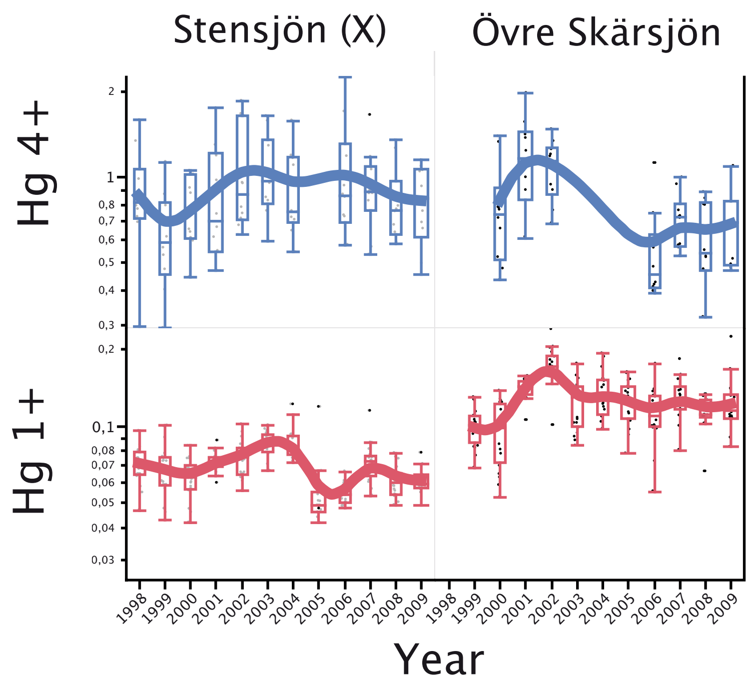
- Individual ≈ Interannual
- “General” variation sources

Large perch

- Interannual < Individual
- Lake specific patterns

A small validation based on two lakes that happen to be included in both monitoring programmes.

A small validation based on two lakes that happen to be included in both monitoring programmes.



Conclusions

Advantages for Hg monitoring

Small perch (8-12 cm, 1-2+)

- Easy to collect in sufficient numbers
- Less individual variability
- More straightforward size/age normalisation
- Possible to detect pulse contamination events in addition to long-term trends

Large perch

- Same individual can be used for other contaminants too
- Better connected with human consumption
- Represent longer time periods