Water Air Soil Pollut (2013) 224:1472
DOI 10.1007/s11270-013-1472-x

Mercury in Perch (*Perca fluviatilis*) from Sweden and Finland

Aroha Miller · Anders Bignert · Petri Porvari · Sara Danielsson · Matti Verta

Received: 9 October 2012 / Accepted: 4 February 2013

Abstract High mercury concentrations in freshwater fish from the Nordic region have been of concern for a long time. Ongoing monitoring of key ecological species occurs in these countries to follow the situation. Here, we investigated spatial and temporal trends in mercury concentrations in European perch (*Perca fluviatilis*) within the Swedish and Finnish aquatic environments, collated from national monitoring programmes collected between 1974 and 2005 (n=5,172). Data were length and weight adjusted to remove perch size as a confounding factor. Temporal trend analyses and t tests comparing pre- and post-1996 mercury concentrations for each country (1974–1995; 1996–2005; perch adjusted to 200 g/25 cm), showed a significant decrease in mercury concentration in perch from Sweden (p<0.001) and a possible increase in mercury concentration in perch from Finland (p<0.001). No statistically significant geographical trends were seen. Average mercury concentrations exceeded both the current environmental quality standard (EQS) of 20 ng/g wet weight (ww) and a discussed EQS for the Nordic region of 200–250 ng/g ww. Despite large reductions in mercury use and production in these countries, concentrations in perch continue to be higher here than in other European areas, posing a continued environmental risk.

Keywords Finland · Mercury · *Perca fluviatilis* · European perch · Sweden

A. Miller (✉) · A. Bignert · S. Danielsson
Department of Contaminant Research,
Swedish Museum of Natural History,
P.O. Box 50007, 10405 Stockholm, Sweden
e-mail: Aroha.Miller@nrm.se

A. Bignert
e-mail: Anders.Bignert@nrm.se

S. Danielsson
e-mail: Sara.Danielsson@nrm.se

P. Porvari · M. Verta
Finnish Environment Institute (SYKE),
P.O. Box 140, 00251 Helsinki, Finland

P. Porvari
e-mail: Petri.Porvari@ymparisto.fi

M. Verta
e-mail: Matti.Verta@ymparisto.fi

1 Introduction

Anthropogenic mercury emissions in Europe have been decreasing over the last few decades, largely due to a reduction in emissions from industrial sources (e.g. Pacyna et al. 2001, 2006). This decreasing trend in emissions is also observed in the Nordic region (e.g. Iverfeldt et al. 1995; Mukherjee et al. 2000; Wängberg et al. 2010); however, a corresponding decrease in mercury concentration in freshwater fish has not been detected in this area (Voigt 2001; Sonesten 2003a; Munthe et al. 2004; Åkerblom and Johansson 2008). By contrast, increasing mercury concentrations in populations of European perch (*Perca fluviatilis*) and brown trout (*Salmo trutta*) from south-eastern Norway have been observed (NIVA 2009a, b). Reasons for these increases have not yet been established. Thus, contamination of freshwater fish by mercury has been, and continues to be, an environmental and human health

Published online: 19 February 2013

concern in the Nordic region (Munthe et al. 2004), and continual monitoring of key ecological fish species for mercury is therefore important.

To assess the status of environmentally harmful chemicals, including mercury, in water bodies, various assessment criteria and standards have been implemented within the European Union's Water Framework Directive. Among these, environmental quality standards (EQS) have been developed (2008/105/EC). EQSs are set with the aim of achieving good surface water chemical status, to protect organisms from the harmful effects of hazardous substances (Law et al. 2010). These organisms include benthic and pelagic marine and freshwater organisms, piscivorous consumers, e.g. fish, seals, birds and humans. Currently, the official EQS for mercury in biota is set at 20 ng/g wet weight (ww) (2008/105/EC), a concentration that is frequently exceeded in freshwater fish in the Nordic region (Munthe et al. 2007). Discussion surrounding an increase in EQS to about 220 ng/g ww for the Nordic region to reflect background concentrations of mercury has been ongoing since at least as early as 2008 (Åkerblom and Johansson 2008; Verta et al. 2010). In the Finnish proposal for the implementation of the directive, the background mercury concentration (80th percentile) for perch was suggested as 180, 200 and 230 ng/g ww, respectively, for low humic, humic and highly humic lakes. When the EQS of 20 ng/g (2008/105/EC) is added to this, the overall EQS was suggested as 200, 220 and 250 ng/g ww for perch from lakes with different humic status in Finland (Verta et al. 2010).

Animals in aquatic systems tend to exhibit more intense mercury bioaccumulation and biomagnification effects compared to terrestrial species, with methyl mercury showing a greater tendency for accumulation in fish muscle. Biomagnification, or the increasing concentration of persistent contaminants through successively higher trophic levels, has a more pronounced effect in piscivorous fish compared to those feeding at lower trophic levels (e.g. Watras et al. 1998; da Silva et al. 2005; Dušek et al. 2005), although actual mercury concentrations can vary for a range of reasons.

A number of physical and ecological factors are known to be correlated to mercury concentration in freshwater fish, e.g. land use around lakes, total organic carbon/humic matter, the total concentration of nutrients in a lake (Sonesten 2003a), fish size and diet. By contrast, the relationship between mercury concentration and, e.g. pH and dissolved organic carbon, has often varied depending on study site and physical conditions (e.g. Fjeld and Rognerud 1993; Lange et al. 1993; Driscoll et al. 1994). Chen and Folt (2005) suggest that phytoplankton and zooplankton density can play a role in diluting mercury accumulation in lakes. With such a range of interacting factors, it is difficult to set an EQS for mercury that takes into account the natural variation within different water bodies over a large geographic region; hence, key environmental species need to be monitored over large areas to give as accurate an indication of the situation as possible.

The European perch, *P. fluviatilis*, is a freshwater fish; however, it can tolerate salinities up to 10‰ and is therefore able to survive in the Baltic Sea (Collette et al. 1977). It is native to the Northern Hemisphere, reasonably abundant throughout many parts of the Nordic region, and has also been introduced to a number of other countries (McDowell 1990; Orban et al. 2007). It is well-known that perch undergo an ontogenetic shift in diet (Collette et al. 1977; Sonesten 2003a). Juvenile perch (5–30 mm) begin as pelagic zooplankton feeders, shift to being benthic invertebrate feeders at intermediate sizes (30–80 mm) and, when large enough (130–180 mm and larger), switch to a piscivorous diet (Hjelm et al. 2000; Closs et al. 2001; Rezsu and Specziár 2006). Thus, large perch are exposed to mercury and other biomagnifying substances at higher aquatic trophic levels. Perch are not known to be migratory and tend to remain in the same areas (Collette et al. 1977), making them an ideal study species for examining patterns in local bioavailable mercury concentrations.

Here, we present the results of a combined data set from Sweden and Finland of mercury concentrations in perch collected between 1974 and 2005. This work has two main aims: (1) to identify temporal and spatial patterns in the examined area and (2) to consider the implications of the observed mercury concentrations in relation to the current EQS of 20 ng/g ww.

2 Methods

2.1 Data Compilation

Data on mercury concentration in perch were collected from national and regional monitoring programmes within Sweden and Finland, and regional surveys conducted

by county and local administrations, and compiled to form a single database. Swedish data, contributed by multiple organisations over time, came from the national database for contaminants in biota, hosted by the Swedish Environmental Research Institute (IVL, http://www.ivl.se) through Sveriges Lantbruksuniversitet (SLU) (Åkerblom and Johansson 2008). After removing unsuitable data (see below), data from at least eight organisations remained for this study (including, but not limited to, County Administration Boards (CABs) of Dalarna, Stockholm, Västerbotten and Västernorrland; CABs with territory that include Lake Mälaren; Swedish Museum of Natural History; SLU and Nyköping Vattenvårdsförbund). Finnish data were provided by the Finnish Environment Institute, SYKE (Porvari and Verta). All perch included in this study were caught in reference lakes with no known local contaminant sources.

The initial data set comprised 6,024 individuals spanning from 1968 to 2005. Finnish data recorded year of sampling, while Swedish data recorded both month and year, thus, no seasonal investigation of data was conducted. From the Swedish data, perch were sampled in varying months over the years; however, the most common months for sampling in Swedish lakes were May–October, and sampling occurred in some of these months in every year. Individuals without weight (n=321, Sweden; n=48, Finland) or length recorded (n=532, Sweden; 141 Finland) and those caught from 1968 to 1973 (n=17, Sweden; n=20, Finland) were removed due to the small number collected over those years. Individuals over 500 g weight were removed (n=156, Sweden; n=9, Finland), as they were relatively rare in the Finnish data set. The majority of the removed data came from pre-1996 samples. Most of the omitted data fell into more than one criterion for removal, e.g. both length and weight were missing. This left a total of 5,172 individuals that were sampled between the two countries (Table 1). A total of 341 lakes were sampled, 215 from Sweden and 128 from Finland.

Table 1 Number of analysed perch samples in Sweden and Finland

	Year	No. of perch sampled pre-1996	No. of perch sampled post-1996	Total
Sweden	1974–2005	1,202	3,232	4,434
Finland	1974–2002	554	184	738

2.2 Sample Preparation and Analysis

Muscle tissue was sampled from all fish. Within Sweden, multiple organisations were involved in contributing data over a time period spanning more than 30 years; thus, specific preparation methods are unknown. Names of laboratories where mercury analyses were undertaken were not available for all data used here. However, five laboratories used by various contributing institutes over time were known, and include the Analytical Environmental Chemistry Unit at the Department of Applied Environmental Science (ITM), Stockholm University (retrospective analysis from 1980 onwards); Environmental Monitoring and Assessment (EMA), Swedish University of Agricultural Sciences, Uppsala; Meana-Konsult, Uppsala; ELK AB, Ljungsbro (1997, 2000) and Alcontrol Laboratories, Linköping (2003–2006).

At ITM, tissue samples were freeze dried and stored in a constant environment room with low humidity. Precisely, 2 ml of HNO_3 and 200 μl of H_2O_2 were added to approximately 100 mg of tissue (dried weight). Tissue was digested using a microwave oven at 180 °C and then diluted to the final volume using Milli-Q water. Determinations were performed using inductively coupled plasma mass spectrometry (Thermo xSeries 2). Mercury was measured by atomic absorption using US EPA method 7473 (2007) (mercury in solids and solutions by thermal decomposition, amalgamation and atomic absorption spectrophotometry). For each series of analyses conducted, at least three blanks and some internal tests were run, using dogfish muscle as certified reference material to ensure good analytical quality. At EMA, tissue samples were freeze dried and stored over silica gel. Digestion of samples was carried out by adding 3 ml HNO_3 and heating in incremental steps of 5 °C, from 55 °C to an end temperature of 120 °C. Solution was evaporated to approximately 0.5 ml, whereupon 1 ml of H_2O_2 was added, and after further evaporation, an additional 1 ml of H_2O_2 was added. The residue was acidified with HNO_3 and diluted to a known volume using Milli-Q water. Determinations were performed using a Philips PU 9200 atomic absorption spectrophotometer with a Philips PU 9390 thermal atomiser and autosampler (Borg et al. 1981). For each series of analyses, a blank (HNO_3 and H_2O_2 only) and a certified reference sample (dogfish) was run to ensure good analytical quality. Intercalibration has been conducted between ITM and SLU mercury analyses, and good consistency was seen between results from these two laboratories for mercury (Danielsson et al. 2011).

Meana-Konsult used atomic fluorescence spectrometry with $SnCl_2$ reduction. This company is no longer in business, and as such, further details were not obtained. ELK AB and Alcontrol followed Swedish standards 028150-2/fd 028175–1, mod. Alcontrol used a method called KMM-47 option 1. Approximately 4-5 g of fresh fish muscle was boiled in 10 ml nitric acid for 2 h at 120 °C. The samples were then diluted using distilled water to a volume of 50 ml and filtrated. Further details on analytical methods were unavailable.

Finnish mercury data from the early 1970s were generated using neutron activation analysis (e.g. Steinnes and Johansen 1969), but the majority of fish samples were analysed using cold vapour atomic absorption spectrometry following somewhat different digestion/combustion procedures. Laboratories involved used commercially certified reference samples in order to ensure good analytical quality. Additionally, several intercalibration exercises using reference fish muscle material were conducted during the 1960s (Häsänen 1969) and, on a regular basis, during the 1980s and 1990s. In some cases, the intercalibration results based on different methods have been published (e.g. Surma-Aho et al. 1986). No systematic differences between these different methods have been reported.

2.3 Data Treatment

When comparing different data sets, fish size must be standardised because a strong positive relationship exists between mercury concentration and fish size (length and weight) (Sonesten 2003b). Here, a strong positive correlation between mercury concentration and perch weight and length was seen. We therefore weight and length adjusted the data set to 200 g/25 cm and 100 g/20 cm, to eliminate perch body size as a confounding factor. These sizes were chosen because they reflect perch size commonly consumed by humans, and perch larger than 25 cm are relatively uncommon. Weight and length adjustments were carried out using partial regression coefficients for weight and length, respectively, from multiple regression analysis conducted for each country. Therefore, a perch of, for example, 100 or 200 g body weight, will have an average length of approximately 19.9 and 24.5 cm, respectively (Fig. 1).

Sweden: Adjusted Hg concentration=Observed Hg concentration+0.00164×[Standard weight (e.g. 100 or 200)−Observed weight] −0.0011×[Standard length (e.g. 20 or 25)−Observed length]

Finland: Adjusted Hg concentration=Observed Hg concentration+0.0011×[Standard weight (e.g. 100 or 200)−Observed weight] −0.0022×[Standard length (e.g. 20 or 25)−Observed length]

All analyses were carried out on adjusted data. The authors acknowledge that the data could be split in other ways that could possibly lead to different results; however, they have chosen to treat the data in this way to give an overall perspective on the mercury issue in Sweden and Finland.

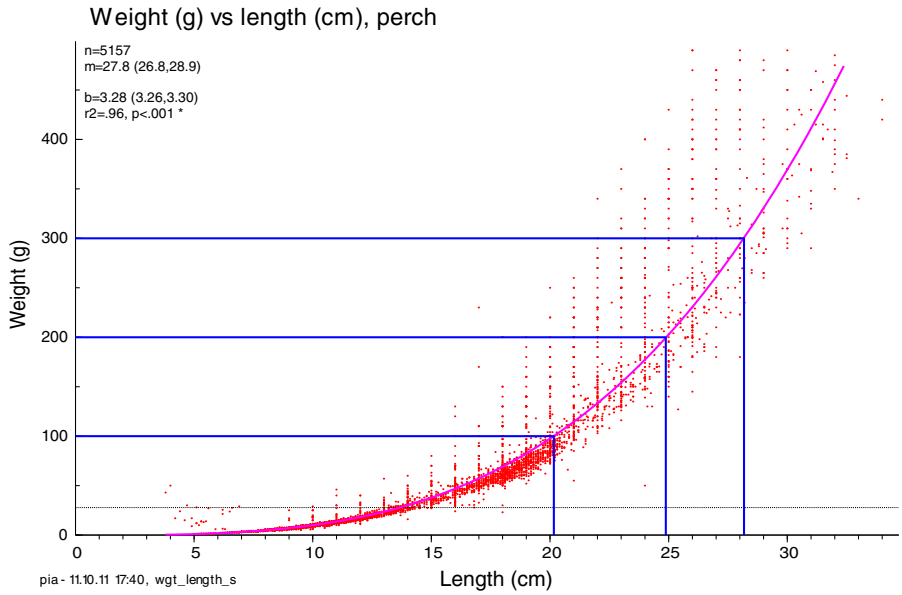

Fig. 1 Weight and length of perch from both Sweden and Finland combined. The *pink line* indicates the regression slope, and *b* (*top left hand corner*) shows the slope of the line. *Blue lines* indicate perch of 100, 200 and 300 g weight and their corresponding length

2.4 Statistical Analyses

Statistical analyses of the data included log-linear regression analysis examining temporal trends in mercury concentration carried out for the complete data set. Mean concentrations pre- and post-1996 for both Sweden and Finland were calculated. The year 1996 was chosen to split the data due to a 5-year gap in Finnish data between 1994 and 1999; hence, trends in the latest 10 years of data could be examined. This gap should therefore be kept in mind when viewing the following results for Finland examining pre- and post-1996 data. Two-tailed *t* tests adjusted for unequal variances between groups were conducted on 200 g/25 cm adjusted data for each country, to investigate if mean mercury concentration had changed between the two periods. The Mantel test was used to examine if nearby lakes were more similar to distant lakes. Temporal trend surface analyses using latitude and longitude as independent variables for perch were carried out to examine general geographical patterns. A significance level of 5 % was used for all tests.

3 Results

Mean mercury concentrations in perch adjusted to 200 g/25 cm caught between 1974 and 2005 in Sweden and Finland were 476 and 402 ng/g ww, respectively (Table 2). Mercury concentrations in perch, adjusted to 200 g/25 cm, from Sweden were significantly higher than those in Finland [t (965)=9.2, p<0.001].

3.1 Temporal Patterns

When perch data from both countries were presented together, adjusted to 200 g/25 cm (Fig. 2) and to 100 g/20 cm (not shown), a significant decreasing log-linear trend is seen for the entire data set for both fish sizes (p<0.01). However, when presented separately, only perch from Sweden show a significant decreasing trend over time (p<0.01, Fig. 3a), while those from Finland show no trend (Fig. 3b), indicating that Swedish data were influencing the whole set. (Graphs for perch adjusted to 100 g/20 cm were not included for each country individually, because they showed similar trends as for 200 g/25 cm adjusted data.)

A two-tailed *t* test adjusted for unequal variances examining pre- and post-1996 data for each country using 200 g/25 cm adjusted data showed that pre-1996 mercury concentrations are significantly higher compared to post-1996 concentrations in Sweden [t (1,477)=12.2, p<0.001; pre-1996=550 ng/g ww, post-1996=454 ng/g ww], but pre-1996 concentrations in Finland are significantly lower than those of post-1996 [t (351)=−3.8, p<0.001; pre-1996=387 ng/g ww, post-1996=448 ng/g ww]. However, it must be kept in mind that post-1996 Finnish data contained only 3 years due to a gap in data. When post-1996 data adjusted to 200 g/25 cm for both countries are mapped (Fig. 4), fewer lakes contain high mercury concentrations compared to the whole time series (Fig. 5). On a percentage basis, fewer lakes in Sweden post-1996 showed mercury concentrations greater than 500 ng/g (22 %) compared to pre-1996 (52 %), while a greater percentage post-1996 showed concentrations between 200 and 500 ng/g (72 %) compared to pre-1996 (35 %) when using 200 g/25 cm adjusted data. By contrast, more lakes post-1996 in Finland showed concentrations greater than 500 ng/g (31 %), while fewer lakes had concentrations below 500 ng/g (68 %) compared to pre-1996 data (Table 3).

Table 2 Arithmetic mean mercury concentrations (nanogram per gram ww) in perch from Sweden and Finland, for the entire data set (1974–2005), pre-1996 and post-1996, using weight- and length-adjusted data

	1974–2005		1974–1995		1996–2005	
	200g/25cm	100g/20cm	200g/25cm	100g/20cm	200g/25cm	100g/20cm
Sweden	476	263	550	381	454	264
Finland	402	221	387	285	448	288

3.2 Geographical Patterns

The Mantel test did not show any significant results. Using trend surface analysis for the whole time period, no statistically significant geographical trends are seen for perch adjusted to 200 g/25 cm (Fig. 5) or 100 g/20 cm (Fig. 6); however, while the trends seen between the two sets of adjusted data are similar, the concentrations differ. Few lakes in either country contained perch with average mercury concentrations below 200 ng/g ww (whole time period, Sweden 12 % for 200 g/25 cm, 28 % for 100 g/20 cm; Finland 7 % for 200 g/25 cm, 30 % for 100 g/20 cm; post-1996, 200 g/25 cm adjusted data, Sweden 7 %, Finland 2 %) (Tables 4 and 3, respectively).

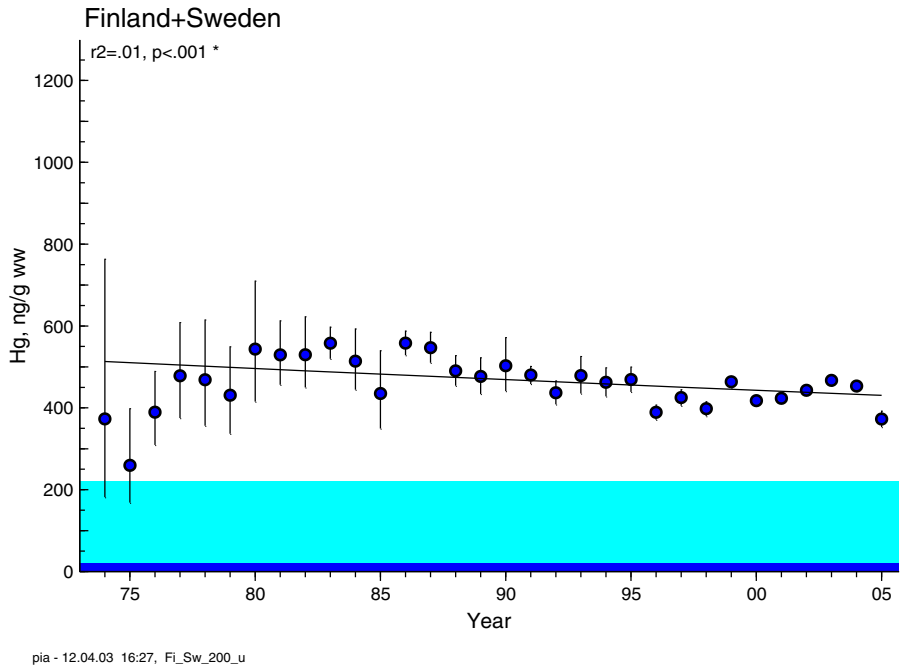

Fig. 2 Mercury concentrations (nanogram per gram ww) adjusted to 200 g/25 cm perch showing changes over time for both countries combined. *Blue circles* show the geometric mean concentrations with 95 % CIs. The *black line* is the log-linear regression line. The *dark blue line* at the bottom of the graph represents the current EU EQS of 20 ng/g ww. The *light blue area* represents the discussed Nordic EQS of 220 ng/g ww

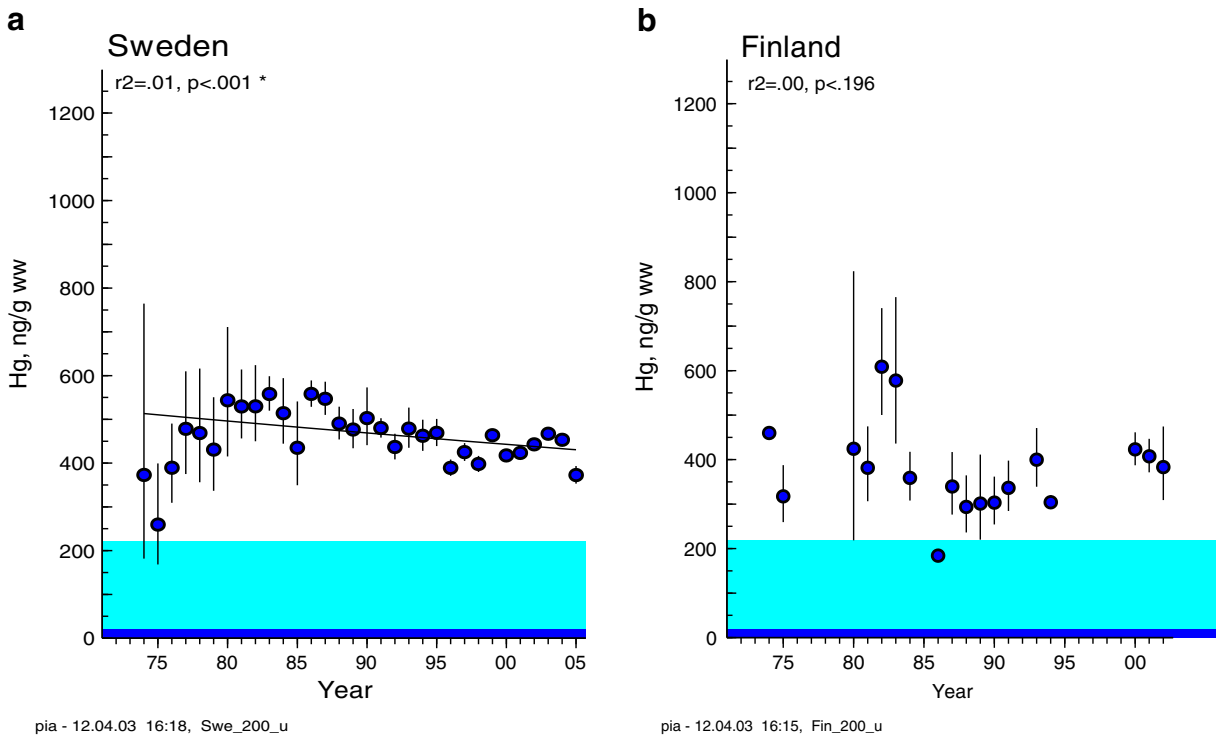

Fig. 3 Mercury concentrations (nanogram per gram ww) adjusted to 200 g/25 cm perch showing changes over time for Sweden (*left*) and Finland (*right*). *Blue circles* show the geometric mean concentrations with 95 % CIs. The *black line* is the log-linear regression line. The *dark blue line* at the bottom of the graph represents the current EU EQS of 20 ng/g ww. The *light blue area* represents the discussed Nordic EQS of 220 ng/g ww

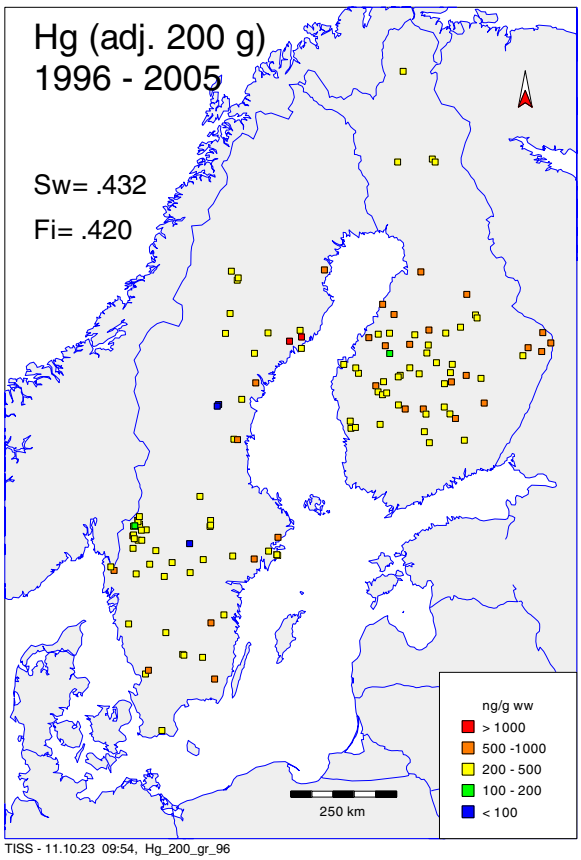

Fig. 4 Mercury concentrations (nanogram per gram ww) in perch from the *last 10 years of data* (1996–2005) adjusted to 200 g/25 cm from all lakes sampled. Geometric mean concentrations for Sweden (*Sw*) and Finland (*Fi*) are displayed in the *upper left corner*

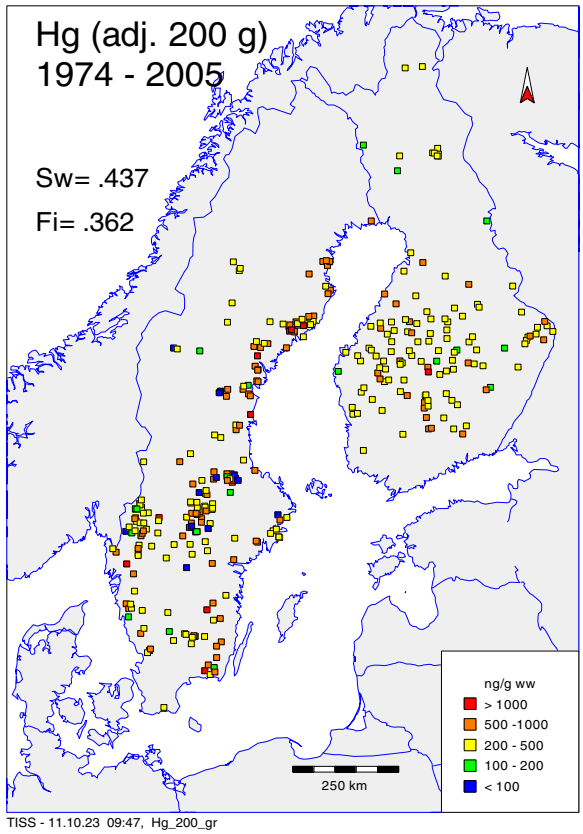

Fig. 5 Mercury concentrations (nanogram per gram ww) in perch for the *entire data set*, adjusted to 200 g/25 cm from all lakes sampled. Geometric mean concentrations for Sweden (*Sw*) and Finland (*Fi*) are displayed in the *upper left corner*

4 Discussion

4.1 Temporal Patterns

Over time, a slow but significant decrease in mercury concentration in perch was seen when data from both countries were combined. This was also the case for perch from Sweden for the whole time period, and when comparing pre- and post-1996 data. Given the measures in place to reduce mercury emissions, e.g. the North Sea Conference 1984, 1987, 1990; the Minister Declaration within HELCOM from 1988, decreases in mercury concentrations in both Sweden (AMAP/UNEP 2008) and Finland (Mukherjee et al. 2000), and elsewhere in Europe (Pacyna et al. 2001, 2006), are expected, but contrary to previous reports (Voigt 2001; Sonesten 2003a; Munthe et al. 2004; Niva 2009a, b). By contrast, mercury concentrations in perch from Finland showed no trend over the whole time period. However, the mean mercury concentration in perch post-1996 was significantly higher compared to pre-1996, which is in agreement with earlier research (Voigt 2001; Sonesten 2003a; Munthe et al. 2004; Niva 2009a, b), although as noted earlier, only 3 years of data were available for Finland post-1996.

This indicates that while reductions in mercury emissions seem to be having a positive effect in decreasing mercury concentrations in perch from Swedish lakes, mercury concentrations in perch from Finnish lakes may still be increasing. However, due to the gap in data between 1994 and 1999 and no data after 2002 from Finland, only 3 years were available for examination for post-1996. Thus, results presented here must be interpreted only as indicative of an increase in mercury concentration in the most recent years, rather than being definitive. By contrast, the Swedish data had no missing years and were available up to and including 2005. This

Table 3 Percentage of lakes with average mercury concentrations in each range, pre- and post-1996, using 200 g/25 cm adjusted data, for both countries (2 s.f.). Numbers of lakes are indicated in brackets

	Sweden		Finland	
Mercury (ng/g ww)	Pre-1996	Post-1996	Pre-1996	Post-1996
>1,000 (%)	(11) 7	(2) 3	(3) 3	
500–1,000 (%)	(71) 45	(12) 19	(14) 14	(17) 27
200–500 (%)	(55) 35	(47) 72	(72) 73	(44) 71
100–200 (%)	(10) 6	(1) 2	(10) 10	(1) 2
<100 (%)	(12) 8	(3) 5	0	0
Total no. of lakes	159	65	99	62

possible increase observed in the Finnish data conflicts with the fact that both countries have reduced their mercury emissions in the last 20–25 years (Mukherjee et al. 2000; AMAP/UNEP 2008). A range of reasons could explain this increasing trend, from a time lag effect between peak mercury concentrations and concentrations in fauna, confounding biological factors, increased long-range atmospheric mercury depositions from outside of the Nordic region (Pacyna and Keeler 1995; Munthe et al. 2007), to changes in land and catchment area use around the sampled lakes (Sonesten 2003a; Garcia and Carignan 2000, 2005; Porvari et al. 2003). Many of these reasons could also be valid for explaining the decrease seen in Swedish perch.

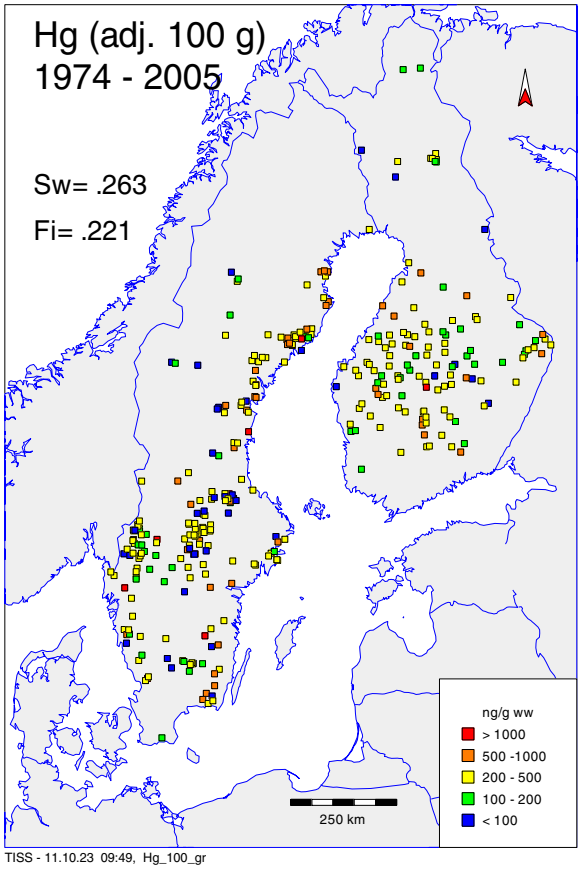

Fig. 6 Mercury concentrations (nanogram per gram ww) in perch for the *entire data set, adjusted to 100 g/20 cm* from all lakes sampled. Geometric mean concentrations for Sweden (*Sw*) and Finland (*Fi*) are displayed in the *upper left corner*

Evidence supporting these changes observed over time in both countries can be seen from the arithmetic mean mercury concentrations observed in perch, adjusted to both 200 g/25 cm and 100 g/20 cm, for the whole time series and pre- and post-1996 (Table 2). Concentrations far exceeded the EQS of 20 ng/g ww (2008/105/EC) and, additionally, exceeded the discussed Nordic EQS of 200–250 ng/g ww in most cases. Also of concern is that the mean concentrations for data adjusted to 200 g/25 cm for post-1996 are not much below the World Health Organisation-based European Union (EU) maximum allowable concentration of mercury in fish for human consumption of 500 ng/g ww—in Sweden, 19 % of lakes, and in Finland, 27 % of lakes contain perch with average mercury concentrations above 500 ng/g ww. Thus, mercury continues to be an environmental and potential human health threat in both countries.

Mercury levels reported here agree fairly well with an earlier study on pike and perch in Sweden, which used much of the same perch data as used here, but were not adjusted for fish size (average range in southern Sweden 500–1,000 ng/g ww; in northern Sweden 250 ng/g ww) (Åkerblom and Johansson 2008). The few published perch data outside of this work from Finland also agree (mean concentration in a 15-cm-long perch between 1991 and 1994, 100–200 ng/g ww in a reference lake, 400–800 ng/g ww in three small forestry lakes with

Table 4 Percentage of lakes in each country containing perch below the specified average mercury concentration and cumulative for the whole time period (adjusted to 200 g/25 cm and 100 g/20 cm) (2 s.f.)

Mercury concentration (ng/g ww)	Sweden		Finland	
	200 g/25 cm	100 g/20 cm	200 g/25 cm	100 g/20 cm
<100 (%)	7	16		6
<200 (%)	12	28	7	30
<300 (%)	18	49	30	63
<400 (%)	35	67	63	81
<500 (%)	57	80	81	88
>500 (%)	43	20	20	12
Total no. of lakes	215	215	128	128

clear cutting and scarification) (Rask et al. 1998). The data sets of Munthe et al. (2007) and the current study partly overlapped, but more data from recent years were included in the present study, and a variety of data controls was used before data adjustment occurred, e.g. removal of fish greater than 500 g (see 2.1). Nonetheless, the concentrations reported in this study, by Åkerblom and Johansson (2008) and by Munthe et al. (2007), are higher compared to reports of mercury levels in, for example, perch from three lakes in Italy (range 60–227 ng/g^{-1} wet fillet weight) (Orban et al. 2007), perch from the Pomeranian Bay and Szczecin Lagoon from Poland (individual concentration range 25–215 ng/g ww) (Szefer et al. 2003) or perch from lakes in Switzerland (range 77.5–173 ng/g ww) (Haldimann et al. 2006).

Mercury concentration in fish has often been reported to be highly correlated to water pH, with acidic conditions favouring mercury methylation (e.g. Lindqvist 1991). By contrast, Sonesten (2003a) found that lake pH did not have any large effect on perch in circumneutral lakes in Uppsala, Sweden. It was instead found that catchment area composition and land use around lakes, the negative influence of dissolved ions and lake trophic status and the positive influence of total organic carbon/humic matter, all strongly influenced mercury concentrations in perch (Sonesten 2003a). These factors were not available or examined in the current data set, but all must be considered as possible reasons for the somewhat higher concentrations observed post-1996 in the Finnish data.

Diet is one of the reasons for observed differences in mercury levels between fish species. Biomagnification occurs through diet (Rincón-León et al. 1993; Dušek et al. 2005), with a greater effect seen in organisms feeding at higher trophic levels (e.g. piscivorous fish) compared to those at lower trophic levels (e.g. zooplankton) (da Silva et al. 2005). The more trophic levels present, the greater the biomagnification effect (Dietz et al. 2000). As large perch are piscivorous, they should contain higher concentrations of mercury than fish feeding at lower trophic levels, such as small conspecifics that feed on pelagic zooplankton or invertebrates (Collette et al. 1977; Hjelm et al. 2000; Closs et al. 2001; Sonesten 2003a; Rezsu and Specziár 2006). A study by Rognerud et al. (2002) recorded generally low mercury concentrations in brown trout (*Salmo trutta*) and Arctic char (*Salvelinus alpinus*) (14–441 ng/g^{-1} ww), which feed mainly on insects and herbivorous zooplankton, as opposed to perch. The highest mercury concentration measured in a single fish (441 ng/g^{-1} ww) came from a lake in Norway (Rognerud et al. 2002), reiterating the often elevated mercury concentrations seen in the Nordic region. As mercury concentrations in perch from other EU countries (e.g. Italy, Poland, Switzerland) are lower than those observed here, it highlights the fact that a greater amount of bioavailable mercury is present in the Nordic countries, either via anthropogenic or elevated natural sources. It also serves to emphasise that mercury concentrations in top trophic level feeders, such as otter (e.g. Haines et al. 2010) or the white-tailed sea eagle, will be higher still, highlighting the risks of mercury biomagnification in the environment.

4.2 Geographical Patterns

No statistically significant geographical patterns were found in mercury concentrations in perch from either country. In Scandinavia, a south–north gradient exists in atmospheric mercury concentration and deposition,

with lower concentrations and deposition in the north due to being further from European source points (Wängberg and Munthe 2001; Munthe et al. 2007; Wängberg et al. 2010). This gradient has been observed in mercury concentrations in perch before (Åkerblom and Johansson 2008) but was not observed here, possibly due to the data adjustment undertaken. However, fish biology can also influence mercury levels, with age, size (Sonesten 2003a; Simonin et al. 2008) and diet (Rincón-León et al. 1993; Dušek et al. 2005) affecting bioaccumulation rates.

5 Conclusion

Perch from Sweden showed significantly decreasing mercury concentrations for the whole time series and when comparing pre- and post-1996 data, reflecting the decreasing mercury emissions recorded across Europe. By contrast, perch from Finland showed no trend over the whole time period and a possible increasing trend in mercury concentrations in post-1996 data, although this requires validation with more complete, recent data. Mean mercury concentrations for weight- and length-adjusted perch showed that average mercury concentrations in perch over the entire period examined far exceed the EQS (20 ng/g ww) (2008/105/EC) and also the discussed Nordic EQS of 200–250 ng/g ww. Results presented here highlight the fact that mercury concentrations in perch in both Sweden and Finland continue to be high. Therefore, there is a need for continued monitoring of key ecological species and continual efforts to reduce anthropogenic mercury emissions throughout both Scandinavia and Europe.

Acknowledgments Many institutes and people contributed to the acquisition of data for this report and in valuable discussions of data treatment, including Susan Londesborough (Finnish Safety and Chemicals Agency, Tukes, Finland), Jaakko Mannio (Finnish Environmental Institute SYKE, Finland), Helene Lager and Mikaela Gönczi (Naturvårdsverket, Sweden) and Kjell Johansson and Staffan Åkerblom (SLU, Sweden). The Swedish Environmental Protection Agency (Naturvårdsverket) is thanked for providing funding to make this research possible (contract number 216 1051).

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