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Contaminant levels in Norwegian farmed Atlantic salmon (*Salmo salar*) in the 13-year period from 1999 to 2011

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ABSTRACT

Background: Environmental pollutants such as dioxins and PCBs, heavy metals, and organochlorine pesticides are a global threat to food safety. In particular, the aquatic biota can bioaccumulate many of these contaminants potentially making seafood of concern for chronic exposure to humans.
Objectives: The main objective was to evaluate trends of contaminant levels in Norwegian farmed Atlantic salmon in light of the derived tolerable intakes.
Methods: Through an EU-instigated surveillance programme, the Norwegian Food Safety Authority (NFSA) has between 1999 and 2011 collected more than 2300 samples of Norwegian farmed Atlantic salmon (*Salmo salar*) for contaminant analyses. The fillets of these fish were homogenised and analysed for dioxins, PCBs, heavy metals and organochlorine pesticides.
Results: The levels of the contaminants mercury, arsenic, dioxins, dioxin-like PCBs and DDT in Norwegian farmed salmon fillet have decreased during our period of analyses. The levels of cadmium, lead and several organochlorine pesticides were too close to the limit of quantification to calculate time trends. For PCB_6 and quantifiable amounts of pesticides, except DDT, stable levels were observed.
Conclusion: The contaminant levels in Norwegian farmed salmon have generally decreased between 1999 and 2011. Excluding other dietary sources, the levels of dioxins and dioxin-like PCBs in 2011 allowed consumption of up to 1.3 kg salmon per week to reach the tolerable weekly intake. The group of contaminants which was the limiting factor for safe consumption of Norwegian farmed salmon, based on currently established TWI values, is the sum of dioxins and dioxin-like PCBs.

1. Introduction

As stated in the report "The State of World Fisheries and Aquaculture" from the Food and Agriculture Organization of the United Nations (FAO, 2012), the global aquaculture production has grown substantially during the last decades. Farmed fish are an increasingly important source of seafood, accounting for almost fifty percent of the world seafood intake in 2010. As the world population is continuously growing, the demand for fish products is expected to increase in the coming decades. The output from capture fisheries has reached a plateau. Accordingly, if seafood is to remain a part of the diet in the future, it needs to be derived from aquaculture. Crustaceans and freshwater fish dominate in terms of production volume, but Atlantic salmon (*Salmo salar*) is one of the leading intensively farmed marine species with a 10 year mean increase of 11.2% in tonnage, and 23.6% in value during the first decade of the new millennia (Bostock et al., 2010). Due to its content of important nutrients such as marine omega-3 fatty acids, proteins and vitamins, Atlantic salmon represents a valuable part of a healthy diet. However, concern regarding the presence of contaminants in seafood has arisen during the last decades (Cohen et al., 2005; Foran et al., 2006; Hites et al., 2004; Ibrahim et al., 2011; Mozaffarian and Rimm, 2006; Usydus et al., 2009; Willett, 2005). In order to evaluate the risk to consumers, there is a continuous need for data on contaminant levels such as mercury in fish as highlighted by the European Food Safety Authority (EFSA, 2012a).

The EU has initiated extensive food surveillance programmes in Europe in order to control the presence of pharmaceutical residues and contaminants in the products of animal origin. The measures to monitor such substances are specified in the EU council directive 96/23 (EU, 1996). By using data collected over several years in these EU-initiated food surveillance programmes, it is possible to evaluate a large sample material of Norwegian farmed salmon, for the presence and mass fraction of a range of selected contaminants. This study has evaluated the presence of dioxins, PCBs, pesticides and heavy metals

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in fillets of Norwegian farmed Atlantic salmon in the period between 1999 and 2011. By examining these results in view of tolerable weekly intakes (TWI), we aimed to estimate safe consumption limits for humans, as well as trends in contaminant levels in Norwegian farmed Atlantic salmon in the period between 1999 and 2011.

2. Materials and methods

2.1. Sample material

The data in the current study comprise in excess of 2300 samples collected between 1999 and 2011. Sampling locations representing all regions along the Norwegian coast with aquaculture activity accounting for at least 10% of the total number of farm sites each year, have been included in the sampling. Sampling was randomised with regards to season and region, and sample identification was withheld from the analysts. Following analyses of all relevant contaminant, the origin of the samples was identified and sampling location and seasonal variation were investigated as influencing factors, however, no effects on contaminant mass fractions were apparent (results not shown). The samples consisted of market-size fish (3–5 kg) collected from processing plants. Farmed fish are kept in net pens containing large populations, and fish from the same net pen are therefore subjected to the same environmental factors and feed, which affect the contaminants levels in the fillets. Data from 1999 to 2003 are based on samples from individual fish, whereas data from 2004 to 2011 are from pooled fillet samples of five Atlantic salmon from the same cage/farm. Sample collection was performed by the Norwegian Food Safety Authority (NFSA), and whole fish were sent to NIFES where sample preparation was performed. A standardised muscle sample Norwegian Quality Cut (NQC) as described by Johnsen et al. (2011) was taken from each fish, and skin was excluded from the sample to reduce the variability of analyses. Subcutaneous fat was retrieved from the skin and added to the sample. Equal amounts of fish muscle samples were pooled and homogenised. The number of fish (N), and type of contaminants analysed varies annually based on priorities set by the NFSA.

2.2. Analyses

The fish samples were collected over a period of more than a decade. All amendments to the analytical methods during the years have been verified for analytical correctness through a comparison with the previous analytical procedure, and by analysis of certified reference materials (CRM). The CRMs given for each method in this paper were the ones in current use in 2011. Heavy metal determination of arsenic (As), cadmium (Cd), mercury (Hg) and lead (Pb) was done at NIFES by inductively coupled plasma mass spectrometry (ICPMS) on an Agilent 7500c as described by Julshamn et al. (2007). For quality control, CRM 1566b (oyster tissue) from the National Institute of Standards and Technology (Gaithersburg, USA) and Tort-2 from National Research Council (Ottawa, Canada) were included in each sample run. The method was accredited according to NS-EN ISO/IEC 17025 in 1999. Fish samples from 1999 were analysed for dioxins and dioxin-like PCBs (dl-PCB) by the Norwegian Institute for Air Research (NILU) using GC/MS. This analysis was accredited according to EN-45001, a European standard preceding the ISO/IEC 17025. The rest of the analyses were performed in-house. From 2002 until 2010, dioxins and dl-PCBs were analysed using GC/MS as described by Berntssen et al. (2005). For quality control, an in-house control sample was run with each sample series whilst the CRM WMF-01 from Wellington Laboratories (Ontario, Canada) is run for periodical validation of the method. Each sample was analysed for: polychlorinated dibenzo-p-dioxins (PCDD) which includes 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD and OCDD, polychlorinated dibenzofurans (PCDF) which includes 2,3,7,8-TCDF, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 2,3,4,6,7,8-HxCDF, 1,2,3,4,6,7,8-HpCDF, 1,2,3,4,7,8,9-HpCDF and OCDF. In this paper, the term "dioxin" will include all dioxins and furans mentioned above, unless otherwise specified. The non-ortho polychlorinated biphenyls (noPCB) analysed were PCB 77, 81, 126, and 169, and the mono-ortho polychlorinated biphenyls (moPCB) PCB 105, 114, 118, 123, 156, 157, 167 and 189. For dioxins and dl-PCBs, the mass fraction of each congener was converted to toxicity equivalents (TEQ), ng TE kg^{-1} wet weight (Van den Berg et al., 2006). When the sum of dioxins and dl-PCBs are calculated, mass fractions that are lower than the limit of quantification (LOQ) are set equal to the LOQ (upperbound LOQ) to avoid underestimation of the risk. For analyses before 2004, mono-ortho PCBs were not included in the sum of dioxins and dl-PCBs. In order to compare data, the average stipulated contribution of the sum of mono-ortho PCBs (4.9%) throughout the years 2004–2011 is calculated and added to the sum dioxins and dl-PCBs for the years 1999–2002.

PCB_6 represents six congeners of non-dioxin like PCBs (NDL-PCBs), which are used as indicators for the entire group of NDL-PCBs, because they represent about 50% of total NDL-PCBs in food (EFSA, 2005). From 2010 PCB_6 (PCB 28, 52, 101, 138, 153, and 180) was included in the dioxin and dl-PCB-method at NIFES, which led to small changes in sample preparation without any changes in the analytical principle. The method was accredited according to NS-EN ISO/IEC 17025 in 2002. PCB_6 were prior to inclusion with dioxins and dl-PCBs, analysed using GC/MS as described by Berntssen et al. (2011a). In-house control sample was used in each sample run for quality control, and the CRM SRM-1974b from the National Institute of Standards and Technology (Gaithersburg, USA) was analysed at least once a year. The method was accredited according to NS-EN ISO/IEC 17025 in 2002 to 2009 and ran without accreditation from 2009 until 2011. DDT and its metabolites were analysed from 2002 to 2011 using the same method as described for PCB_6. From 2006 several other organochlorine pesticides were also analysed using GC/MS as described by Berntssen et al. (2011b). For quality control, an in-house control sample was analysed with each run, and the CRM SRM-1946 from the National Institute of Standards and Technology (Gaithersburg, USA) was analysed at least once a year. The pesticides analysed were: aldrin, dieldrin, alpha-endosulfan, beta-endosulfan, endosulfan-sulphate, alpha-hexachlorocyclohexane, beta-hexachlorocyclohexane, gamma- hexachlorocyclohexane, cis-chlordane, trans-chlordane, oxy-chlordane, cis-nonachlor, trans-nonachlor heptachlor A, hexachlorocyclobenzene, isodrin, mirex and toxaphene (40 + 41, 26, 32, 42a, 50, 62). Not all pesticides were measured in each sample; the number of replicates for each pesticide is given in Appendix 1. This method was accredited in 2005, and remained accredited to and including 2011.

2.3. Statistics

The median was chosen as the descriptor of the population mean due to the lack of normality of the data, and a large number of measurements below the LOQ. Median is presented with interquartile ranges to illustrate variability. When more than 50% of the results were below the LOQ the median was not calculated. Since the uncertainty increases when one approaches the LOQ, regression analyses were excluded when more than 50% of the analyses were below 1.5× LOQ. Regression was used for evaluating time trends for the different contaminants. Differences between years were also determined using the non-parametric Kruskal–Wallis with post hoc paired comparisons. Differences were regarded as significant when $p < 0.05$. Statistical analyses were performed using Statistica 9 (StatSoft Inc., Tulsa, USA), and Graphpad Prism 5.04 (Graphpad software Inc., San Diego, CA, USA).

3. Results

3.1. Heavy metals

A total of 1025 samples from 2005 to 2011 were analysed for elemental mass fraction of Hg, As, Pb and Cd. For Cd, the measured levels

in 933 of the total 1025 samples were < LOQ (0.01 mg kg^{-1} w.w.), whilst 994 measurements of Pb were < LOQ (0.04 mg kg^{-1} w.w.). In contrast, the measured levels of Hg were < LOQ (0.03 mg kg^{-1}) in only seven samples, and As was detectable > LOQ in all samples. Since most of Cd and Pb data were < LOQ, statistical analyses of time trends were not feasible. A linear regression showed a decline during the 6 years of sampling for As and Hg mass fraction in fillet (Fig. 1). This time trend was verified using the non-parametric Kruskal–Wallis test. The median elemental mass fractions of As and Hg in fillets for the time period were 1.07 and 0.029 mg kg^{-1} w.w. respectively.

3.2. Dioxins and dl-PCBs

A total of 432 samples were analysed for dioxins and dl-PCBs from 1999 to 2011. For data from 2005 and earlier, only 1998 WHO TEQ was available. Thus a conversion regression described by Bhavsar et al. (2008) was used to convert data to WHO-TEQ 2005. The regression analyses performed by Bhavsar et al. (2008) were performed for fish data, and it is therefore assumed that the congener profile will be similar to that in Atlantic salmon and that the regression constants are valid for our study.

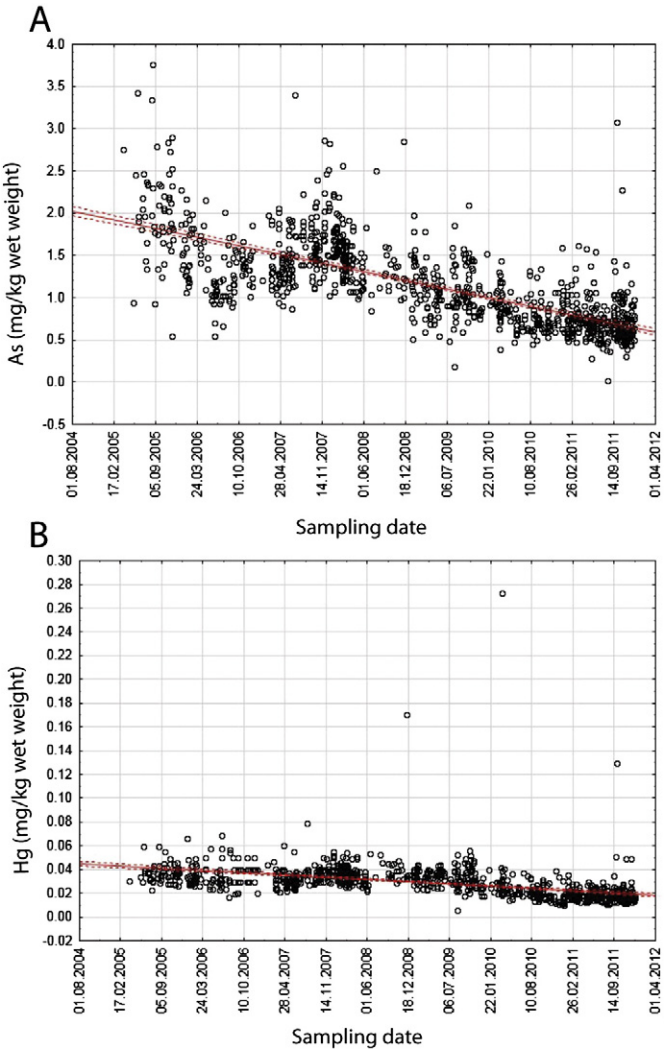

Fig. 1. Heavy metals in Norwegian farmed salmon from 2005 to 2011. Linear regression of As and Hg against year where the dotted line represents the confidence band. For As (A) the slope was −0.72 with r^2 of 0.52 ($p < 0.0001$). For Hg (B) the slope was −0.48 with an r^2 of 0.23 ($p < 0.0001$).

Linear regression, median, interquartile range and range of the sum of dioxins and dl-PCBs are shown in Fig. 2A. Total dioxins and dl-PCBs decreased from 1999 to 2011. Fig. 2B illustrates the contribution of the dioxins fraction and the dl-PCBs fraction to the total TEQ. The median for all years of sum of dioxins and dl-PCBs were 0,9 pg TEQ-WHO 05 g^{-1}, whilst the median for 2011 specifically was 0.6 pg TEQ-WHO 05 g^{-1}.

3.3. Non-dioxin like polychlorinated biphenyls (PCB_6)

From 2002 to 2011, 475 samples were analysed for PCB_6. Although some statistical differences were observed, no clear trend in the sum of PCB_6 was found as shown in Fig. 3. The median mass fraction of sum of PCB_6 through the years was 5.94 μg/kg w.w.

3.4. Pesticides

In the period from 2006 to 2011, 324 samples were analysed for various pesticides. The sum of DDT is presented as box and whisker plots per year, as well as linear regression in Fig. 4A. The sum of DDT declined from 2002 to 2011, and the median over the years was 9.40 μg/kg w.w. The levels of the other pesticides were too close to the LOQ for trend analyses. Thus, pesticide data was pooled (except DTT) and statistics were performed on all years combined (Fig. 4B).

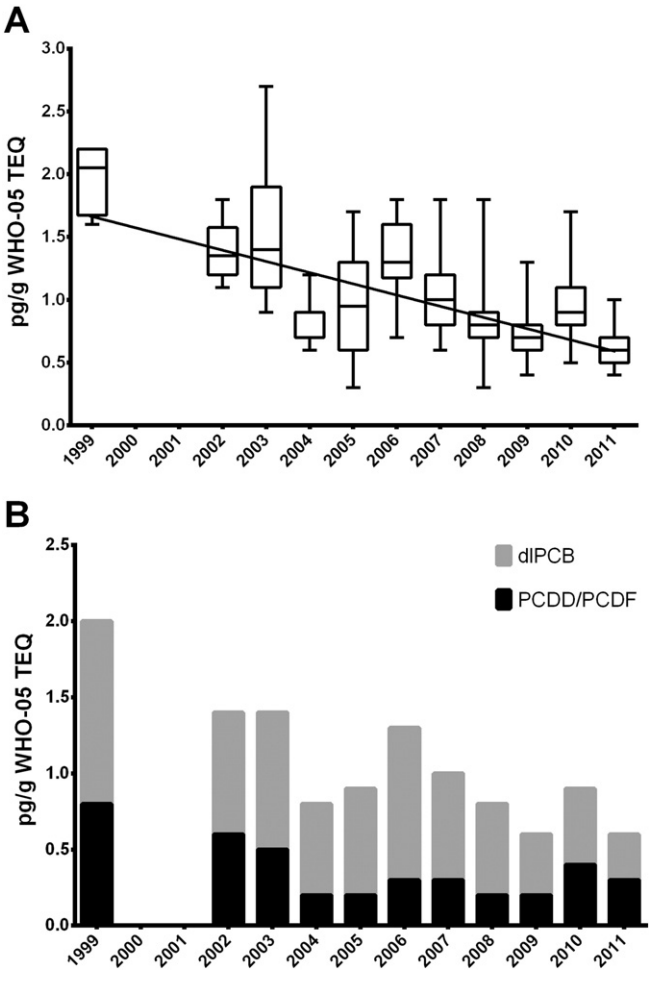

Fig. 2. Dioxins and dl-PCBs in Norwegian farmed salmon from 1999 to 2011. (A) Box and whiskers plot for each year of the sum of dioxins and dl-PCBs, where the flat line is median, boxes are interquartile ranges and whiskers are depicting ranges. The linear regression of the sum of dioxins and dl-PCBs against year is shown as a line across the figure, where the slope was −0.66 and r^2 was 0.43 ($p < 0.0001$). (B) Bar graph showing the impact of dioxins and dl-PCBs on the sums of TEQ.

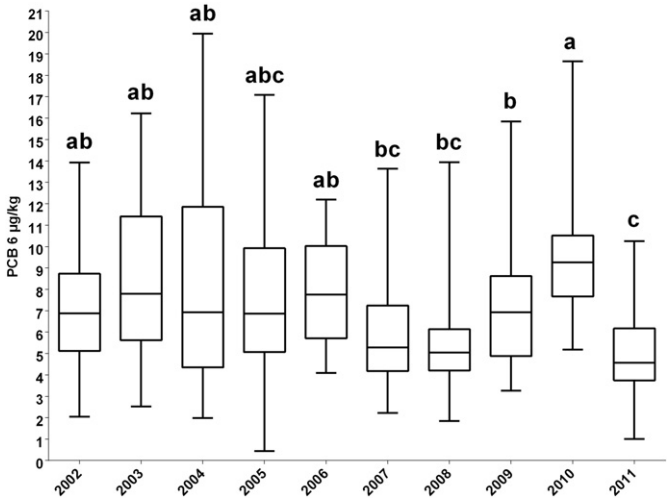

Fig. 3. PCB_6 in Norwegian farmed salmon between 2002 and 2011. Median (line), interquartile range (box), and range (whiskers) of PCB_6 are presented. Significant changes ($p < 0.05$) are indicated through lettering.

3.5. Food safety of Norwegian salmon

Hg and dioxins and dl-PCBs were evaluated according to current TWIs. To calculate safe consumption limits, all dioxins and dl-PCBs data were converted to 98 WHO TEQ. The maximum tolerable consumption of Norwegian farmed salmon without reaching the TWI increased over the years and reached 1.3 kg in 2011 (Fig. 5). From 1999 to 2011, dioxins and dl-PCBs represent the limiting factors in terms of safe consumption of Norwegian farmed salmon.

4. Discussion

In this study, contaminants were examined in more than 2300 samples, and since most samples were pooled, the total number of fish analysed exceeds 10,000 individual Norwegian farmed salmon. The fish were sampled over a period of 13 years from all regions with aquaculture activity, thereby providing a representative overview of the contaminant levels in Norwegian farmed salmon over the last decade. The amount and types of contaminants investigated were based on EU Council Directive 96/23/EC (EU, 1996). The contaminants chosen were also the same as previously reported in salmonids, both farmed and wild (Hites et al., 2004; Jacobs et al., 2002; Kelly et al., 2011), as well as in salmon feed (Sissener et al., 2013).

4.1. Elements

In this study, the heavy metals Pb, Cd, Hg and the metalloid As have been measured in fillets from Norwegian farmed Atlantic salmon. The levels of heavy metals described in this paper are comparable to other studies of farmed Atlantic salmon (Foran et al., 2004), as well as for farmed Atlantic-, Coho- and Chinook salmon from British Columbia (Kelly et al., 2008). These elements are well known for their toxicological effects in humans, which have been well described elsewhere (Bernhoft, 2013; Clarkson and Magos, 2006; Watanabe and Hirano, 2013; Zhang et al., 2013). Although the Cd levels in salmon feed increased from 2000 until 2010, with mean values ranging from 0.2 to 0.4 mg kg^{-1} dry feed (Sissener et al., 2013), their levels were usually below the LOQ in salmon fillets. This in line with earlier observations that, Cd together with Pb and inorganic As, have limited ability to accumulate in the muscle of Atlantic salmon (Berntssen et al., 2010).

Our data show a clear decline in the content of total As and total Hg in Norwegian farmed Atlantic salmon over the last 5 to 6 years. The

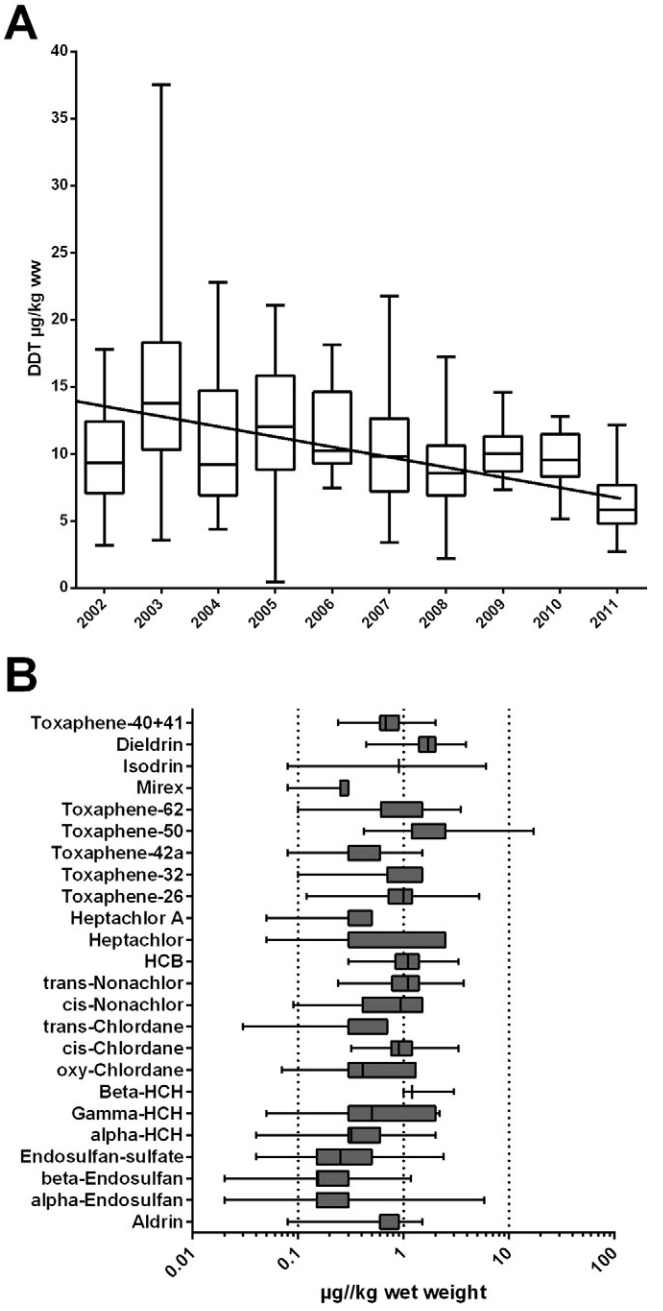

Fig. 4. Presence of pesticides in Norwegian farmed salmon between 2002 and 2011. (A) The sum of DDT presented as median (line), interquartile range (box) and range (whiskers). Linear regression of the sum of DDT based on sampling year and mass fraction are shown as line. Slope of the curve was −0.34 and r^2 was 0.11 ($p < 0.0001$). (B) All pesticide data (except DDTs) are gathered over the last 5 years, but due to no clear time trends the data were analysed together. Data are presented as median (line), interquartile range (box) and range (whiskers).

decreasing level of As is likely due to the concurrent decline in the use of fish meal and fish oil in commercial fish feed. Furthermore, the As mass fraction in farmed salmon fillet is related to the fisheries of wild fish such as blue whiting (*Micromesistius poutassou*) and their subsequent inclusion in the feed (Sissener et al., 2013). Seafood is considered to be the largest contributor of total As to human exposure, but the levels are not considered toxic because it is mainly present in fish as arsenobetaine (Borak and Hosgood, 2007; Kaise and Fukui, 1992). The organic form of Hg, methylmercury ($MeHg^+$), is the most toxic, and it is estimated that 70 to 100% of the Hg in fish is present as $MeHg^+$ (Amlund et al., 2007). EFSA has established a TWI for $MeHg^+$, and the

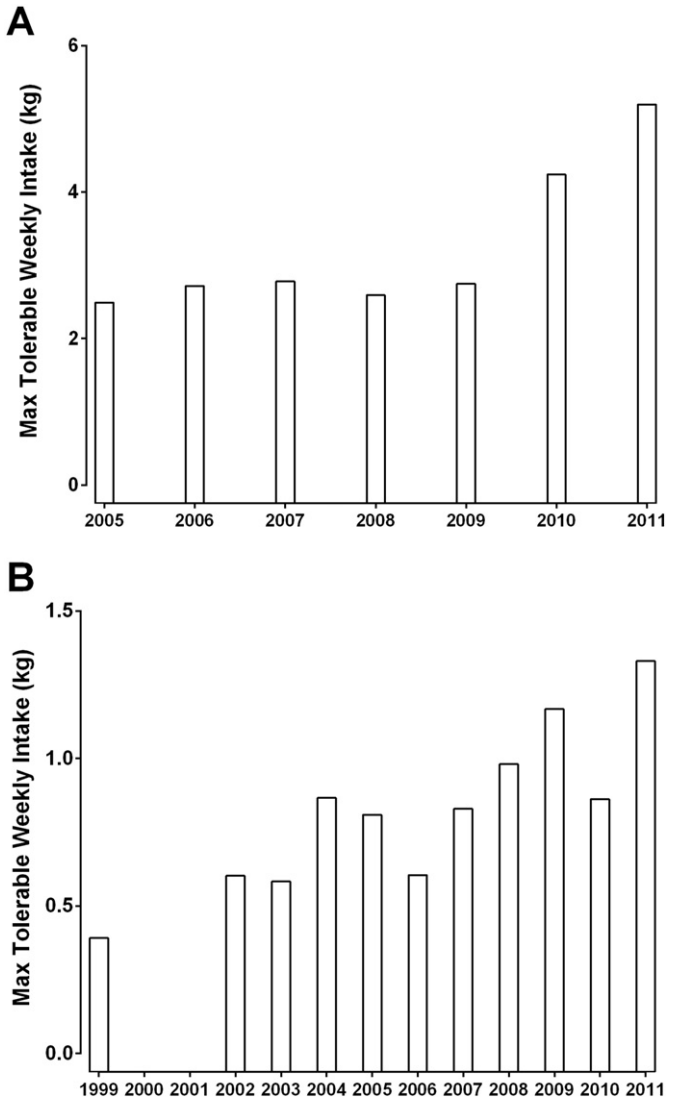

Fig. 5. TWI of Norwegian farmed salmon calculated for each year (given a person of 70 kg) of A: Methylmercury and B: dioxins and dioxin-like PCBs. Both graphs display maximum tolerable intake (in kg) per week. The calculations are based on the latest PTWI for $MeHg^+$ and dioxins and dl-PCBs from EFSA and SCF respectively. These values are given without consideration to other sources of these contaminants.

food safety issues related to the levels shown here in Norwegian farmed Atlantic salmon are discussed below.

4.2. Dioxins and dl-PCBs

Dioxins and dl-PCBs are persistent organic pollutants which bioaccumulate in the marine food chain. Dioxins and dl-PCBs are also well known for their toxic effects in humans, which are described elsewhere (Larsen, 2006). The levels of both total dioxins and dl-PCBs declined from 1999 to 2011, which was mainly related to the substitution of fish oils by vegetable oils in the feed (Berntssen et al., 2005; Turchini et al., 2009). In particular, the decline in the sum of dioxins from 2003 to 2004 was considerable. This may be due to the geographical origin and species used for producing the fish oil, thereby altering the ratio of dioxins versus dl-PCBs in the sum dioxins and dl-PCBs. This ratio has previously been shown to vary considerably both between, and within, food items (EFSA, 2010), and the dioxins and dl-PCBs in feed based on different fish oil and fish meal have also been shown to affect the congener profile in Atlantic Salmon (Isosaari et al., 2004).

The levels of dioxins and dl-PCBs presented in this study are generally lower than those found in other reports (Hites et al., 2004; Jacobs et al., 2002; Shaw et al., 2006). However, as dioxins and dl-PCBs are lipophilic, their accumulation in Atlantic salmon muscle may be directly related to the fat content in the fillets. Excluding the skin from the analyses may impact the fat content of each sample. Shaw and co-workers showed that by comparing Norwegian salmon fillets skin-on samples to skin-off samples, gave a 2–3 fold decrease in dl-PCBs in the latter (Shaw et al., 2006). However, if our results from the beginning of the decade are compared to results shown by Hites et al. (2004), where fish were sampled with skin in 2002, results are quite similar. During our sampling, the skin of the fish was carefully scraped to include the subcutaneous fat in the samples. Subcutaneous fat was excluded in skin-off samples reported by Shaw et al. (2006). A TWI for dioxins and dl-PCBs was established in 2001 by the Scientific Committee of Food (SCF, 2001), and the food safety of these compounds in salmon is discussed below.

4.3. PCB_6

PCB_6, also called indicator PCBs, represents about 50% of the sum of non-dioxin-like (ndl)-PCBs in food and are used by EFSA as indicator of the content of ndl-PCBs in food (EFSA, 2005). Our PCB_6 results revealed certain differences amongst the years, which may be due to different geographical origins of the fish oil used in the feed. However, no long term trend was observed. There was no correlation between dioxins and dl-PCBs with PCB_6 in our samples (results not shown). This may also be due to differences amongst the fish oils used in commercial fish feed. Furthermore, it supports the EFSA conclusion that the ratios between PCB_6 and dioxins and/or dl-PCBs varies greatly amongst different foods and countries (EFSA, 2005).

4.4. Pesticides

Most Western countries have banned the use of the pesticides included in this study. However, these contaminants are still present in our environment due to their persistence. Moreover, DDT is currently still used in certain parts of the world to limit the spread of vector borne diseases, such as malaria (WHO, 2011). Our results show a decline in the levels of DDT and its metabolites in Norwegian farmed salmon from 2002 to 2011, which is consistent with the decline of DDT in fish feed in the same period (Sissener et al., 2013). The other pesticides presented in this paper do not exhibit any time trends since most of the data are below, or close to, the LOQ. Therefore all pesticides analysed in the course of the years were compiled and presented as medians (Fig. 4B).

In the report by Hites et al. (2004), the pesticides showing the highest abundance in farmed salmon, apart from the sum of DDT, were dieldrin and toxaphene. In our study, however, these two pesticides were found in considerably lower amounts. This may be due to a decrease through the years which are not reflected in our historical data since pesticides have only been analysed since 2006.

4.5. Food safety

The EU has established maximum levels in commercial foodstuff for several of the contaminants discussed in this paper. None of the samples in our study had contaminant levels which exceeded the maximum limits set, so we focused on TWI which is a measure of acceptable risk during a lifetime of exposure. We have not included contributions from other food sources to the total exposure of contaminants. A report from EFSA estimated that the daily human exposure in Europe of the sum of dioxins and dl-PCBs is between 0.57 and 2.54 pg WHO 2005 TEQ/kg body weight (b.w)., and identified seafood, dairy products and meat products as the main sources (EFSA, 2012b). The data presented in this paper can be used in risk calculations where contributions from other sources are known. As an example: 660 g salmon per week

would contribute to 50% of the TWI based on our data from 2011. However, predicting the contribution from other food sources on a global scale is beyond the scope of this paper. Therefore the maximum tolerable intake limits proposed here consider only salmon as the exposure source.

The EFSA, the Joint FAO/WHO Expert Committee on Food Additives (JECFA), SCF and WHO have derived TWIs for several of the contaminants which have been evaluated in this paper. TWIs have been established for some of the pesticides, some metals, and the sum of dioxins and dl-PCBs. For all compounds except Hg and the sum of dioxins and dl-PCBs, the measured amounts were negligible compared to the current TWIs, therefore calculations were limited to Hg and the sum of dioxins and dl-PCBs. There is a general agreement that 70–100% of the Hg in fish and seafood is present, in its most toxic chemical form, as $MeHg^+$ (Amlund et al., 2007; EFSA, 2012a). Accordingly, the TWI for $MeHg^+$ was used in the risk calculations of the Norwegian farmed Atlantic salmon fillet. TWIs derived in Europe were chosen for the exposure calculation, SCF TWI for dioxins and dl-PCBs (SCF, 2001), and the EFSA TWI for $MeHg^+$ (EFSA, 2012a).

Based on Lowest Observed Adverse Effect Level (LOAEL) observed in the most sensitive rodent studies, the SCF issued a PTWI of 14 pg WHO 1998 TEQ/kg b.w. for dioxins and dl-PCBs (SCF, 2001). This PTWI included an uncertainty factor of 3.2 based on intraspecies toxicokinetic and toxicodynamic differences. Furthermore, the use of the LOAEL instead of the No Observed Adverse Effect Level (NOAEL), added an uncertainty factor of 3, resulting in a total uncertainty factor of 9.6. The interspecies differences were already calculated based on examined data, and were therefore not added again as an uncertainty factor (SCF, 2001). By comparison the Environmental Protection Agency of the United States (US-EPA) issued a PTWI for dioxins and dl-PCBs of 4.9 pg/kg b.w. (EPA, 2012). In 2012 EFSA issued a PTWI for $MeHg^+$ of 1.3 μg/kg b.w (EFSA, 2012a). This TWI was based on results from epidemiological studies performed in the Faroe Islands and the Seychelles, and the confounding effects of nutrients from fish were also taken into account. Based on the these studies, the US-EPA issued a Reference Dose (RfD) of 0.1 μg/kg b.w. per day (EFSA, 2012a). The guidelines used in Europe and the USA appear to diverge substantially.

Previous food safety assessments of farmed Atlantic salmon have shown varying results. In 2004, Hites and co-workers recommended farmed Atlantic salmon meals to be reduced to one per month, based on the levels of PCBs, toxaphene and dieldrin from 12 Norwegian farmed Atlantic salmon (Hites et al., 2004), in addition to their analyses of farmed salmon from other countries. The food safety calculations were based on guidelines from the US-EPA (EPA, 2000). The mean sum of dioxins and dl-PCBs in farmed Atlantic salmon found by Hites and co-workers was approximately 2.3 pg WHO-TEQ 98 g^{-1}/kg b.w. When converted into WHO-TEQ 05, this corresponds to 1.8 pg WHO-TEQ 05 g^{-1}/kg b.w. These fish were collected in the years 2002–2003 and are therefore comparable to our results from that period. Conversely, if the PTWI established by the SCF for dioxins and dl-PCBs is used on the results from Hites et al. (2004), the maximum tolerable consumption of Atlantic farmed salmon is approximately 420 g per week. Shaw and co-workers also evaluated Norwegian farmed salmon in terms of dl-PCB levels (Shaw et al., 2006). However, as no dioxins was analysed the total TEQ reported was based on dl-PCBs. They observed a total dl-PCBs of 2.85 pg WHO TEQ 98 g^{-1} which translates into 2.22 pg WHO TEQ 05 g^{-1}. These results are based on triplicates of three salmon collected between 2003 and 2004. In comparison, our results show lower levels of dioxins and dl-PCBs than earlier studies. However, if the decline in contaminant burden during the last years is taken into account, our results are comparable.

5. Conclusion

In this study, a large number of Norwegian farmed Atlantic salmon have been analysed for a range of contaminants. In general, the levels of contaminants in the fillet of Norwegian farmed Atlantic salmon have decreased from 1999 to 2011. The levels of contaminants measured in Norwegian farmed salmon were compared with the TWIs established by the SCF and EFSA, and the limiting factor for consumption of Norwegian farmed Atlantic salmon was the content of dioxins and dl-PCBs. Due to the decrease of the levels in these contaminants over the years, the amount of Norwegian farmed salmon that can safely be consumed in terms of the TWI has increased from 370 g per week in 1999, to more than 1.3 kg per week in 2011. It should be noted, however, that the contributions of dioxins and dl-PCBs from other food sources are not included in these calculations.

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Appendix A. Supplementary data

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