Monitoring to ensure seafood safety of large fish stocks – A baseline study of Atlantic cod (*Gadus morhua*).

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Summary
This study is one of several baseline studies conducted to provide comprehensive basic information about the content of undesirable substances in important fish species caught in Norwegian waters. More than 2000 Atlantic cod sampled from 83 different positions in the Barents Sea, the North Sea and in coastal areas of Norway, were analyzed for metals and persistent organic pollutants (POPs) in muscle and liver. The levels of undesirable substances in muscle samples were low, well below the maximum levels set by EU and Norway for contaminants in fish muscle for human consumption. In liver samples the levels of POPs were quite high, and 42% of individual fish had concentrations of the sum of dioxins, furans and dioxin-like PCBs (PCDD/Fs+dl-PCBs) above the maximum level. Cod liver is a traditional food product in Norway and a potential source for POPs in the diet. The concentration of undesirable substances varied between different areas. The concentration of mercury in muscle and POPs in liver were higher in the North Sea and coastal areas in the southern part of Norway than in the Barents Sea and coastal areas in the northern part of Norway.

Introduction
Atlantic cod (*Gadus morhua*) is distributed in the North Atlantic Ocean and consists of several different stocks. In addition to the Northeast Arctic cod in the Barents Sea which is the largest cod stock in the world, North Sea cod and Norwegian fjord and coastal cod stocks are important for the European and Norwegian fisheries. The levels of undesirable substances in Atlantic cod in Norway have been regularly monitored by spot checks since 1994. The EU has set maximum levels for the heavy metals mercury (Hg), cadmium (Cd) and lead (Pb) in fish muscle and for the sum of PCDD/Fs+dl-PCBs and the sum of six non-dioxin-like PCBs (PCB_6) in fish muscle and fish liver in order to ensure that seafood products with particularly high levels of these substances are not sold in the European market. To provide more reliable surveillance data on undesirable substances in commercially important species such as cod, comprehensive baseline studies including fish from the entire area of distribution and all seasons of the year, are needed for documentation of seafood safety and as a basis for future risk-based monitoring. Several fish stocks from Norwegian waters (Greenland halibut, Norwegian spring spawning herring, North Sea herring, mackerel, saithe and Atlantic cod) have been subjected to such baseline studies, and this study describes results from the baseline study of Atlantic cod.

Materials and Methods
A total of 2007 cod were collected between February 2009 and December 2011 in the Barents Sea (804 fish, 32 positions), the North Sea (516 fish, 23 positions) and coastal areas of Norway (687 fish, 28 positions) (Figure 1). Weight, length, gender and age were determined for each fish. Heavy metals (Hg, Cd, Pb) and arsenic were determined in muscle and liver of each individual fish by ICP-MS as

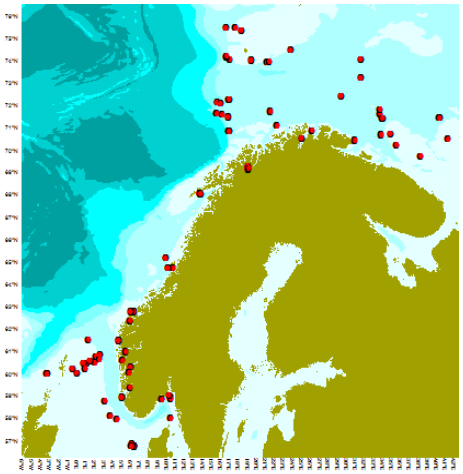

Figure 1. Sampling positions for Atlantic cod (*Gadus morhua*) in the Barents Sea, the North Sea and in coastal areas of Norway sampled from February 2009 to December 2011.

described by Julshamn *et al.* (2013a, 2013b). PCDD/Fs, dl-PCBs, PCB_6 and polybrominated diphenylethers (PBDEs) were determined in liver of each individual fish and in muscle from 30 individual fish by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS), by triple quad GC-MSMS or by GC-MS NCI (negative chemical ionization) as described by Julshamn *et al.* (2013c).

Results and Discussion

In cod muscle, the levels of all undesirable substances determined were quite low, giving no reason for concern for food safety. The concentrations of Cd and Pb were below the limit of quantification for most samples. For Hg, only three (out of 2007) fish had concentrations above the EU maximum level of 0.5 mg/kg w.w. The mean concentration of Hg in cod muscle from the North Sea and the coastal areas of Norway were about three times as high as the mean concentration in the Barents Sea (Table 1). The mean concentrations of Hg were also higher in coastal areas in the southern part of Norway than in coastal areas in the northern part of Norway. The concentrations of POPs in 30 muscle samples were very low.

In cod liver, the levels of POPs were quite high, with 42% of the individual fish showing concentrations of the sum PCDD/Fs+dl-PCB above the EU maximum level of 20 ng TE/kg w.w. Further, 20% of the individual fish had concentrations of PCB_6 in liver above the EU maximum level of 200 μg/kg w.w. The mean concentrations of POPs in liver were higher in the North Sea than in the Barents Sea, and the highest mean concentrations of POPs were found in cod from the coastal areas of Norway (Table 1). Within the coastal areas, the mean concentrations of POPs were higher in the southern part than in the northern part of Norway.

Table 1. Concentrations of Hg in muscle, sum PCDD/Fs+dl-PCBs in liver and sum PCB_6 in liver of Atlantic cod from the Barents Sea, the North Sea and coastal areas of Norway. Mean values with minimum and maximum values in parentheses. Sums are based on upperbound LOQ and values for sum PCDD/Fs+dl-PCBs are expressed as ng TEQ/kg w.w., calculated using WHO TEF 2005. EU maximum levels for Hg in fish muscle and PCDD/Fs+dl-PCBs and PCB_6 in fish liver for human consumption are given.

Area	N	Mercury in muscle (mg/kg w.w.)	N	Sum PCDD/Fs + dl-PCBs in liver (ng TEQ /kg w.w.)	Sum PCB_6 in liver (μg/kg w.w.)
Barents Sea	804	0.036 (0.01-0.16)	784	14.2 (1.0-151)	92 (9.7-510)
North Sea	516	0.11 (0.01-0.54)	495	21.3 (4.9- 59)	138 (11- 428)
Coastal areas	687	0.11 (0.01-0.71)	671	31.0 (5.3-276)	282 (12-5400)
EU max level		0.50		20.0	200

The differences in mean concentrations of Hg in muscle and POPs in liver between different areas may reflect different levels of mercury and POPs contamination and/or different availability of possible prey species for cod in the different areas.

References

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