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Contaminant analyses of harbour porpoises

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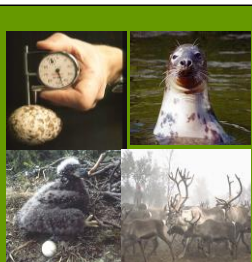

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Report author Anna Roos Naturhistoriska Riksmuseet Enheten för Miljöforskning och Övervakning, MFÖ Naturhistoriska riksmuseet Box 50007 104 05 Stockholm	**Responsible publisher** Naturhistoriska Riksmuseet Enheten för Miljöforskning och Övervakning, MFÖ Naturhistoriska riksmuseet Box 50007 104 05 Stockholm **Telephone** +46(0)8-519 540 00
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Sammanfattning

Altogether, 22 porpoises were analyzed for organochlorines (PCBs DDTs, HCHs, HCB), PBDEs, HBCDD and CPs in blubber, and 23 porpoises for PFAS and OTCs in liver, and metals and Se in muscle and liver, and SI (d13C and d15N) in muscle. The animals were divided into four groups: animals originating from the North Sea Population area (juveniles and adults) and animals from the Belt Sea Population area (juveniles and adults). Generally, no difference in concentrations or SI signatures were seen between the two areas, only few exceptions. Juveniles had a higher SI signature compared to adults, probably at least partly due to fact that they still carry the signature from the lactation period. Generally, concentrations of metals were higher in liver compared to muscle. Strong correlation between Hg and Se was seen in liver but not muscle. Concentrations of Hg *vs* Se on a molar weight basis showed that a majority of the porpoises had an excess of Se. One porpoise had concentrations of Hg in liver above the level of observed negative effects that have been seen in dolphins.

Concentrations of OTCs were generally low, but one specimen had concentrations at levels of concern. It was a 16-year-old male that had elevated concentrations of ∑OTCs (TBT+MBT+DBT), higher than has been suggested cytotoxic level for marine mammals.

Seven porpoises had concentrations of ∑7PCB above a suggested threshold for adverse effects on health (one juvenile and six adults) – even though the suggested threashold levels include more than only 7 PCBs. One lactating five-year-old female had very low concentrations of organochlorines. Two adult porpoises had extremely low concentrations of PFAS.

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1. Background

The harbour porpoise (*Phocaena phocaena*) is the only cetacean that is found all year round in Swedish waters. It is a common species on the west coast but in the Baltic, it is extremely rare. There are three populations in Sweden: the North Sea population (usually found in the North Sea, the Skagerrak and northern Kattegat), the Belt population (usually found in southern Kattegat, the Strait and Southwestern Baltic) and the Baltic Sea population (in Baltic Proper). The Baltic porpoise population is classified as critically endangered on the IUCN Red List. The porpoise was protected in Sweden in 1973.

The harbor porpoise (from now on called porpoise) used to be common also in the Baltic. It is a top predator along with seals, sea eagles and otters, and can be used as an indicator of the status of the environment. A porpoise can live up to 20 years but rarely lives longer than half that age. Mortality is highest during the first year of its life, and less than 5% of them seems to live beyond 12 years [1]. Since they do not get very old, a change in the habitat that affects the porpoise negatively can quickly result in decreases at population level, and therefore it is important to monitor the porpoise's health condition, identify threats and monitor population size and contaminant burden. The porpoise's often coastal habitat makes it particularly vulnerable to anthropogenic activities, such as environmental contaminants, marine traffic, wind turbines, noise and unintentional bycatch in fishing activities [2].

PCBs as well as other contaminants can affect reproduction and health negatively among marine mammals. Few data on contaminants in porpoise are available from Swedish waters in recent years. In this study, we have analyzed 22-23 individuals for a number of chlorinated, brominated, fluorinated (PFAS) and organotin (OTCs) compounds, metals and selenium and stable isotopes (SI, dC13 and dN15).

2. Material and methods

Altogether 22 porpoises were analyzed within this study for all elements and one additional porpoise was analyzed for metals, OTCs and PFAS only. The porpoises originate from the Skagerrak (n=9), the Kattegat (n=3), Öresund (n=8) and the Baltic (n=2, see Table 1 for more details), representing most likely two populations: the North Sea population (in the Skagerrak and northern Kattegat) and the Belt population (in southern Kattegat, Öresund and western parts of the Baltic) [3]. Naturally, the boarders are not exact and two of the porpoises were found in the Baltic, and could originate from the Belt Sea population or the Baltic population. Also it is possible that Belt Sea population have been mixed in the North Sea population and vise versa, in this study as well as the fact that individuals from the North Sea population can be found in the Baltic. Genetic analyses can indicate which individuals belong to which population. In this report, approximate borders have been used to divide the two populations. Eleven of the porpoises in this study were immature and eleven adults (5-16 years old).

ACES, Stockholm University has analyzed chlorinated and brominated substances in blubber, and perfluorinated chemicals in liver. ALS Analytica has analyzed metals and selenium in muscle and liver and organotin compounds in liver. Christina Lockyer, Age Dynamics, has performed the age determination. Igor Eulaers, Arhus University, has analyzed stable isotopes (SI) in muscle tissue.

Table 1. Biological information on the individual porpoises analyzed in this study.

Number	Date	Sea	Area	Probable population	Sex	Body length (cm)	Body weight (kg)	Age group	Age (year)	Cause of death
C2015/05287	2015-04-18	The Kattegat	Lilla Amundön, Göteborg	North Sea	Female	132	32	Immature		Not determined
A2016/05525	2016-09-10	The Skagerrak	Tjörn	North Sea	Male	108	25	Immature	0,5	Bycaught
A2016/05527	2015-12-11	The Skagerrak	Kämpersvik, Fjällbacka	North Sea	Male	120	29	Immature	1	peridontitis, trauma
A2016/05522	2016-02-01	The Skagerrak	Pinnevik, Lysekil	North Sea	Male	117	22	Immature	1,5	Pneumea
A2018/05709	2018-08-28	The Skagerrak	Tjörn	North Sea	Male	152	52	Adult	5	Bycaught
C2015/05285	2015-01-13	The Skagerrak	Lysekil Ålevik	North Sea	Male	142	54	Adult	7	Not determined
A2018/05711	2018-09-05	The Skagerrak	Tjörn	North Sea	Male		43	Adult	8	Bycaught
A2016/05524	2016-06-16	The Skagerrak	Munkevik, Skaftö	North Sea	Male	143	41	Adult	9	Probably bycaught
A2018/05710	2018-09-01	The Skagerrak	Tjörn	North Sea	Male	146	49	Adult	9	Bycaught
A2017/05593	2017-06-19	The Skagerrak	Hällevik, Orust	North Sea	Male	144	56	Adult	12	Not determined
A2019/05586	2019-10-10	The Kattegat	Nidingen	North Sea	Male	104	19	Immature	0,5	Not determined
A2019/05295	2019-03-11	The Kattegat	Vejbystrand	Belt	Male	121	31	Immature	3	Perdation, possible bycaught?
A2017/05217	2017-03-23	Öresund	Öresund	Belt	Female	123	27	Immature	1	Not determined
A2019/05573	2019-05-21	Öresund	Öresund	Belt	Female	120	30	Immature	1	Bycaught
A2017/05214	2016-11-30	Öresund	Helsingborg	Belt	Female	133	42	Immature	1,5	Probably bycaught
A2019/05578	2019-08-16	Öresund	Rydebäck	Belt	Female	133	36	Immature	2	Not determined
A2017/05594	2017-06-26	Öresund	Helsingborg	Belt	Female	159	68	Adult	5	Bycaught
A2016/05637	2016-10-27	Öresund	Helsingborg	Belt	Male	142	43	Adult	12	
A2018/05283	2017-11-20	Öresund	Lomma, Limhamn	Belt	Male	160	60	Adult	14	Purulent pneumonia, Cholangitis, Unspecified dermatitis
A2019/05585	2019-10-30	Öresund	Lomma hanm	Belt	Male	145	45	Adult	15-16	Not determined
A2018/05712	2018-09-05	The Baltic	Trelleborg	Belt/The Baltic	Male	133	33	Immature	2	Blunt trauma
A2019/05584	2019-09-12	The Baltic	Trelleborg	Belt/The Baltic	Male		(38 kg)	Adult	5	Not determined

Analyses of metals: Digestion was performed in closed Teflon vessels in a microwave with HNO3 / H2O2 without sample drying. The ICP-SFMS analyses were carried out according to SS EN ISO 17294- 2: 2016 and US EPA Method 200.8: 1994. Analytical methods for chlorinated paraffins is described previously [4], as well as PFAS [5] and organochlorines and PBDEs [6]. The analyses of stable isotopes is described in for example Lippold et al [7] and age determination was performed by counting growth layer groups (GLGs) in porpoise teeth [8].

2.1. Statistics

Pearson product-moment correlation was applied to test interrelationships among metals, POPs and stable isotopes. Analysis of variance (ANOVA) was applied to test of difference between age groups and populations and in case of POPs also between sex. Compound concentrations was $\log_e$transformed prior analyses in order to approach assumptions of normality and variance homogeneity. The tests of the explanatory variables were based on Type III Sum of Squares, where every term in the model is tested in light of every other term in the model (“partial”).

3. Results

3.1. Stable isotopes

Juveniles had higher values compared to adults for both C and N (See Figure 1). No difference was seen between populations for d15N ($p=0.51$), only for d13C ($p<0.05$).

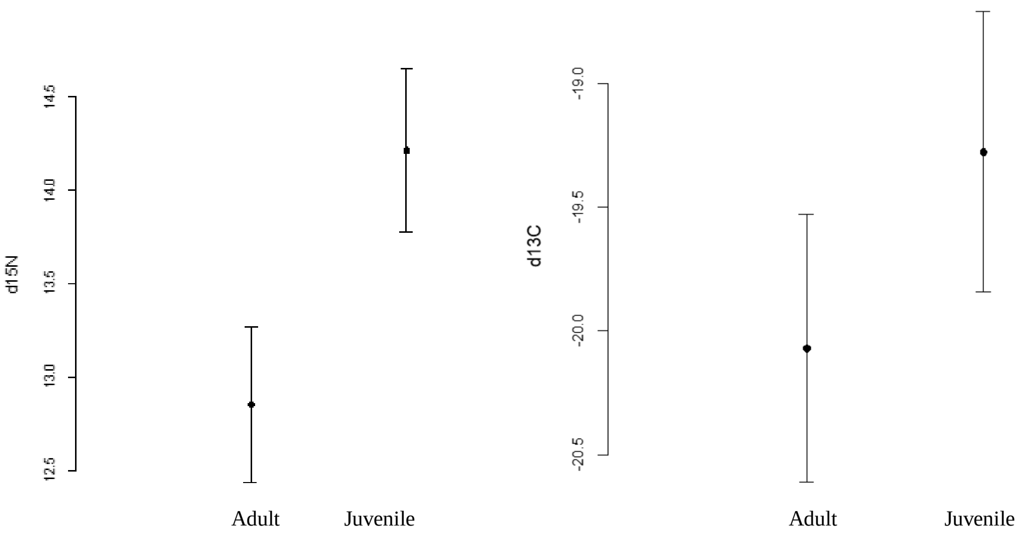

Figure 1. d13C (left) and d15N (right) in muscle from adult and juvenile harbor porpoises.

3.2. Heavy metals and trace metals

Arsenic (As), Cadmium (Cd), Cobolt (Co), Crome (Cr), Copper (Cu), Total Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), Selenium (Se), Vanadium (V) and Zinc (Zn) were analyzed in muscle and liver from 23 porpoises. The results are presented in µg/g wet weight (ww) and in Table 2.

Concentrations of Co, Cr, Ni and Pb were very low and most often below detection limit in both muscle and liver, hence no statistical analyses were performed on these.

Table 2. Concentrations of metals and elements in muscle and liver from 23 porpoises (µg/g wet weight).

		Min	Max	Mean	Median	Number under limit of detection
Muscle (µg/g ww)	As	0.078	1.08	0.26	0.20	0
	Cd	<0.002	0.01		<0.002	15
	Co	<0.004	<0.004			23
	Cr	<0.02	1.04			14
	Cu	0.675	2.42	1.73	1.75	0
	Hg	0.13	1.52	0.71	0.67	0
	Mn	0.13	0.38	0.25	0.25	0
	Ni	<0.02	<0.02			23
	Pb	<0.01	0.02			22
	Se	0.17	0.72	0.41	0.39	0
	V	<0.004	0.03			17
	Zn	9.43	25.3	14.39	12.8	0
Liver (µg/g ww)	As	0.143	0.80	0.37	0.31	0
	Cd	<0.002	0.64	0.13	0.08	1
	Co	<0.005	0.02		0.01	8
	Cr	<0.02	0.06			22
	Cu	3.75	19.6	9.15	8.58	0
	Hg	0.37	64.7	14.4	7.15	0
	Mn	3.07	6.4	4.67	4.56	0
	Ni	<0.02	0.17			21
	Pb	<0.01	0.03			17
	Se	0.494	27.5	7.1	3.86	0
	V	<0.005	0.11	0.04	0.03	3
	Zn	24.7	99.3	48.6	41	0

3.2.1. Muscle vs liver

Concentrations of metals and selenium were generally higher in liver compared to muscle (Figure 2). In muscle, concentrations of Cd, Co, Cr, Ni, Pb and V were below detection limit in a majority of the porpoises, hence they are not included in statistical analysis. Furthermore, in liver samples, Cr, Ni and Pb were below detection limit in a majority of the porpoises, hence they are not included in statistical analysis either.

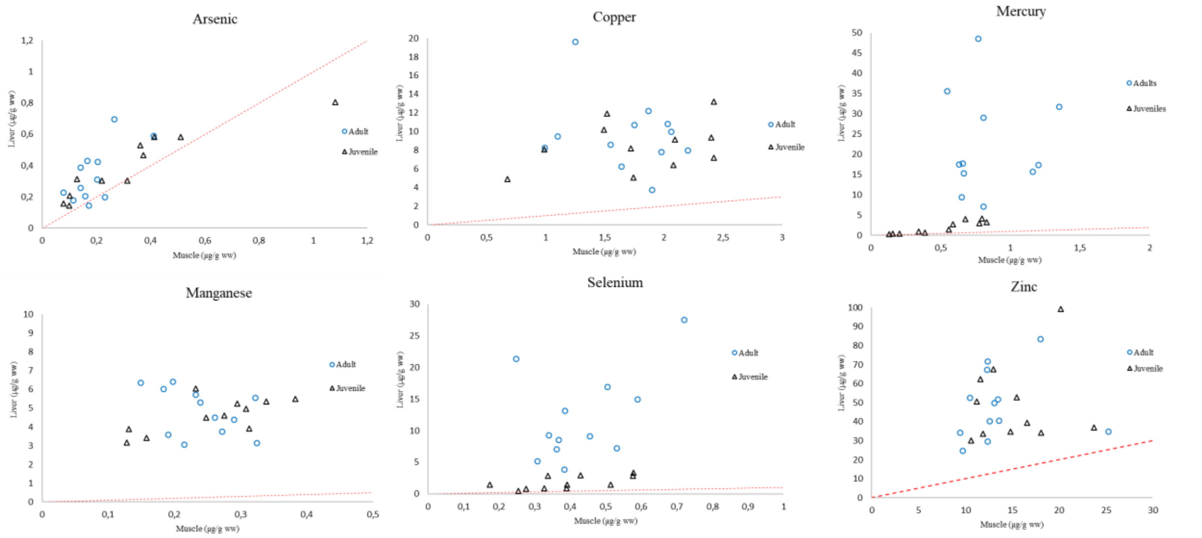

Figure 2. Concentrations of arsenic, copper, mercury, manganese, selenium and zinc in liver vs muscle. The red dotted line represents a 1:1 relationship. In almost all samples, concentrations were higher in liver compared to muscle.

A test for correlations between concentrations in muscle and liver, and SI show several correlations between the elements. Concentrations of Hg in muscle was significantly positively correlated with concentrations of Cu and Se in muscle and Cd, Hg, Se, and V in liver. Concentrations of Cd in liver was positively correlated with liver concentrations of As, Hg, Mn, Se and V. Zn did not correlate with any elements.

As for stable isotopes, d13C was vaguely correlated with As in muscle and Se and Cd in liver. Furthermore d15N was vaguely correlated with As in muscle and As, Cd, Hg, Mn, Se and V in liver.

3.2.2. Metals and trace elements: Geographic differences, age and Hg vs Se

The pattern of the elements was similar in both populations, *i.e.* no differences were found between the two populations.

Concentrations of Hg and Se depended on age of the animal, with higher concentrations in older animals (Figure 3).

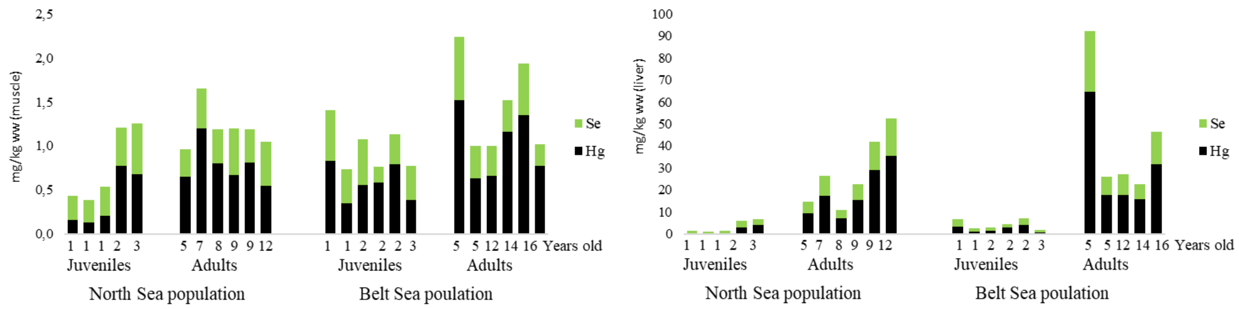

Figure 3. Mercury and selenium in muscle (left) and liver (right) in harbor porpoises (mg/kg ww).

Four animals had higher concentrations of Hg compared to Se in muscle on molar weight basis, but in liver all animals had lower concentrations of Hg compared to Se (Figure 4).

Concentrations of Hg and Se on molar weight basis was strongly correlated to each other in liver, but not as strong in muscle. In four cases (18%) the concentrations of Hg was above a 1:1 Hg/Se ratio on molar weight basis in muscle: one juvenile female from Öresund, a 16-year-old male also from Öresund, a 12 year old male from Helsingborg (all probably Belt Sea population) and a 7 year old male from Lysekil (probably North Sea population). In liver, all samples were below this 1:1 ratio, i.e. having a surplus of Se, although all of them were very close to 1:1. The ratio Hg/Se in liver was 0.22-0.73 (mean 0.39) for juveniles and 0.73-0.93 (mean 0.84) for adults.

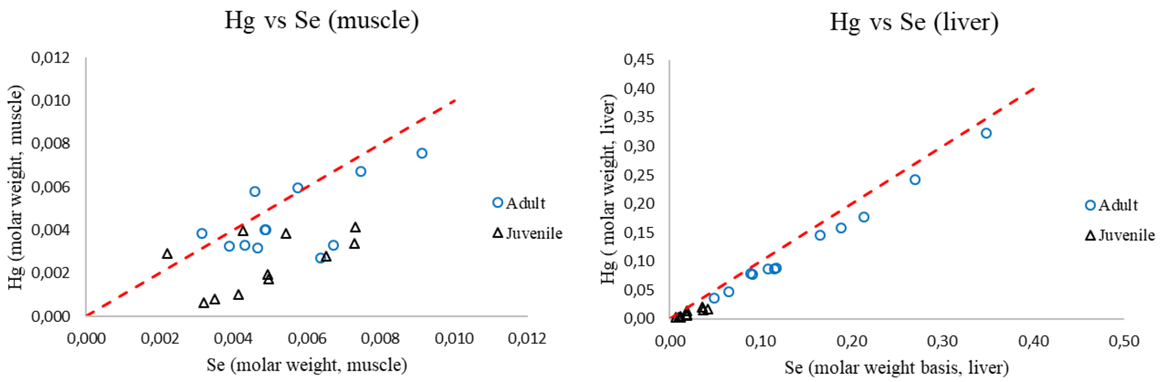

Figure 4. Hg vs Se on molar weight basis in muscle (left) and liver (right). Red dotted line indicates a 1:1 relationship. Four of the porpoises had concentrations above 1:1 in muscle but in liver, all porpoises were below the dotted line.

3.3 Organotin compounds

Twenty three porpoises were analyzed for tributyltin **(**TBT), monobutyltin (MBT), dibutyltin (DBT), tetrabutyltin (TTBT), monooktyltin (MOT), dioktyltin (DOT), trifenyltin (TPhT), tricyklohexyltin (TCHT), monophenyltin (MPhT) and diphenyltin (DPhT). Results are presented in ng/g ww, in liver. Concentrations of TBT, MOT, DOT, TPhT, THCT, MPhT and DPhT were mostly below level of detection (<1,0 ng/g ww) and hence not included in statistical analysis. See Table 3.

An Annova based on ∑TBT (TBT+MBT+DBT) showed no difference between populations, but higher concentrations in adults compared to immatures ($p<0.002$).

Table 3. OTCs in 23 porpoises (ng/g ww, liver). Range, mean, median and number of samples below detection limit (Nr ud).

	Min	Max	Mean	Median	Nr ud
TBT	1,5	21	9,9	8,8	0
DBT	5,6	100	34	27	0
MBT	<1,0	13	4,3	4,0	3
TTBT	<1,0	<1,0			23
MOT	<1,0	<1,0			23
DOT	<1,0	<1,0			23
TPhT	<1,0	2		<1,0	14
TCHT	<1,0	<1,0			23
MPhT	<1,0	<2,0			23
DPhT	<1,0	1,00			22

The highest concentrations were found for DPT, ranging up to 100 ng/g ww in a 16-year-old male from Öresund (Belt Sea population), see Figure 5. Lower concentrations were generally seen in the North Sea population, most obvious among juveniles. One exception was a three-year-old male from Vejbystrand, Skåne (probably from the Belt Sea population) who had much lower concentrations compared to other juveniles from the Belt Sea population and more in line with juveniles from the North Sea population. Similarly, one juvenile from the North Sea population had elevated concentrations and more in line with the Belt Sea juvenile porpoises.

Concentrations of all three TBTs increased with increasing age.

The ratio TBT/∑TBT+MBT+DBT were between 0.11 and 0.38 (mean 0.23) with the older porpoises having the lowest ratio.

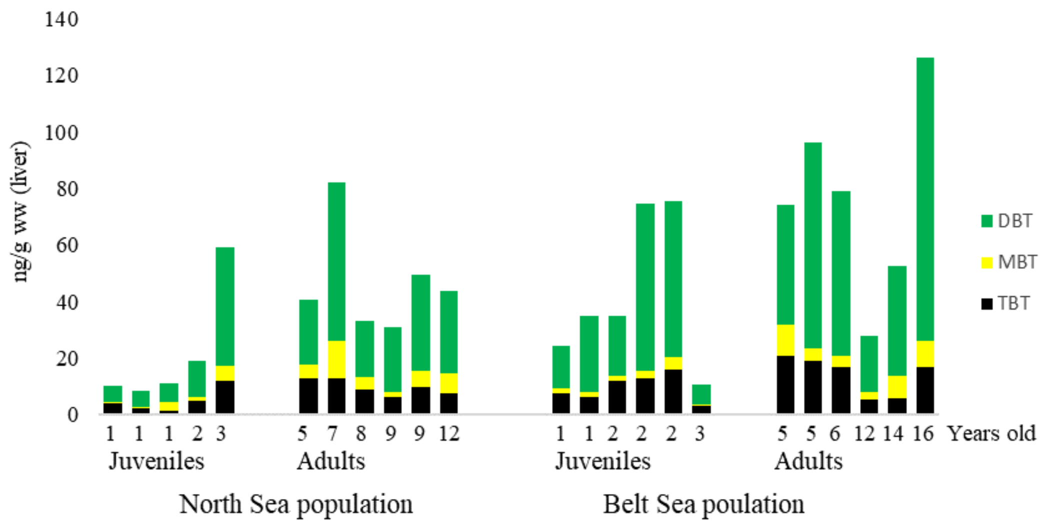

Figure 5. Proportion of TBT, MBT and DBT (ng/g ww, liver) in porpoises from (probably) the North Sea population and the Belt Sea population, divided between juveniles (0-3 years old) and adults (4-16 years old).

3.4. Chlorinated and brominated substances

Blubber from 22 porpoises were analyzed for PCBs (seven congeners: CB-28, -52, -101, -118, -153, -138+163 and -180), *p,p'*-DDT and the metabolites *p,p'*-DDD och *p,p'*-DDE, HCB, a-HCH, b-HCH and lindane. Also, short, medium and long chained chlorinated paraffins (SCCPs, MCCPs and LCCPs) were analyzed, as well as six brominated flame retardants: BDE-47, -99, -100, -153, -154 and HBCDD (Table 4).

sPCB (*i.e.* sum of CB-101+118+153+138+163+180) was the most dominant compound in porpoises, followed by DDTs (Figure 6). The concentrations of sPCB ranged between 1241-24219 ng/g lw. A five-year-old female from Öresund had the lowest concentrations of sPCB. She was pregnant and lactating. The highest concentration was found in a 16-year-old male from Öresund. CB-153 was the most dominant CB congener, followed by CB 138+163. Seven of the 22 porpoises had higher concentrations of sPCB than 9000 ng/g, a suggested thresh hold level for adverse health effects [9]. This threshold is based on total PCB or 25PCBs, and in this study, only 7PCB congeners were analyzed, so probably more porpoises exceed this level.

sDDT was found in concentrations between 904-12 279 ng/g lw, *i.e.* approximately half the concentrations compared with PCB. Between 5 and 12% of sDDT consisted of *p,p'*-DDT. Highest concentration was found in a five-year-old male from Öresund. Lowest concentration was found in a lactating five-year-old female from Öresund and a juvenile male from the Skagerrak. There was a difference in concentrations of sDDT between the populations, Belt Sea porpoises had slightly higher concentrations ($p<0.04$).

HCB was found in low concentrations in all porpoises, between 99 and 726 ng/g ww. A-HCH and lindane were found below level of detection in all porpoises. B-HCH was found below level of detection in all but six porpoises, therefore HCHs were not included in statistical analyses. Only adults had concentrations above level of detection, between 77 and 212 ng/g lw. There was no difference in concentrations between the two populations, nor between age groups or sex.

Table 4. Concentrations of contaminants in blubber from harbor porpoise (ng/g lw, n=22).

	Min	Max	Mean	Median
Fat %	70	88	80	79
sPBDE	44	323	134	120
HBCD	35	525	182	141
HCB	99	726	337	315
sDDT	904	12 279	3 741	2 878
s7PCB	1 241	24 219	6 592	4 013
SCCPs	7.45	145	55	41
MCCPs	1.11	56	17	14
LCCPs	0.43	70	6.4	0.5

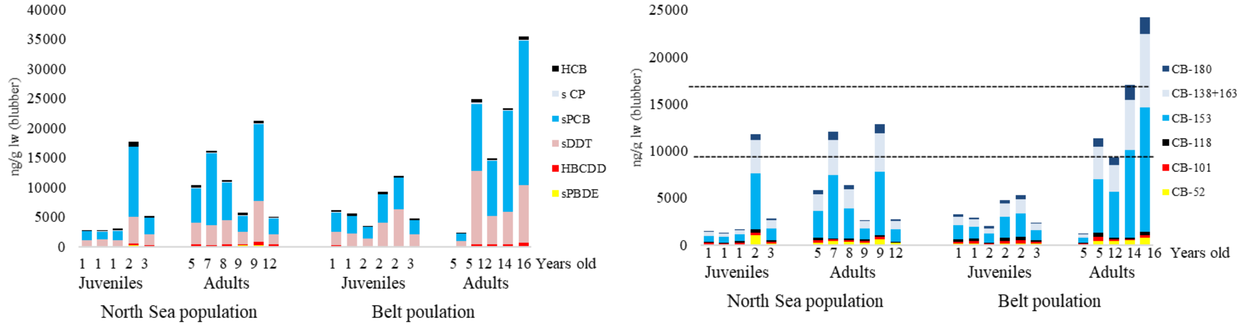

Figure 6. Left: concentrations of sPBDE, HBCD, sDDT, sPCB, CPs and HBCD in porpoise blubber, where PCB and sDDT contribute most. Right: Six PCB congeners in porpoise blubber. The black dotted line indicate represent the suggested threashold level (9000 ng/g Σ25CBs) for adverse health effects among marine mammals [9].

Among the chlorinated paraffins, the short-chain paraffines (SCCPs) were most dominant, followed by the medium-chained chlorinated paraffins (MCCPs, see Figure 7). There were no differences between the two populations, or between sexes, and juveniles had lower concentrations compared to adults (p-values below 0,03).

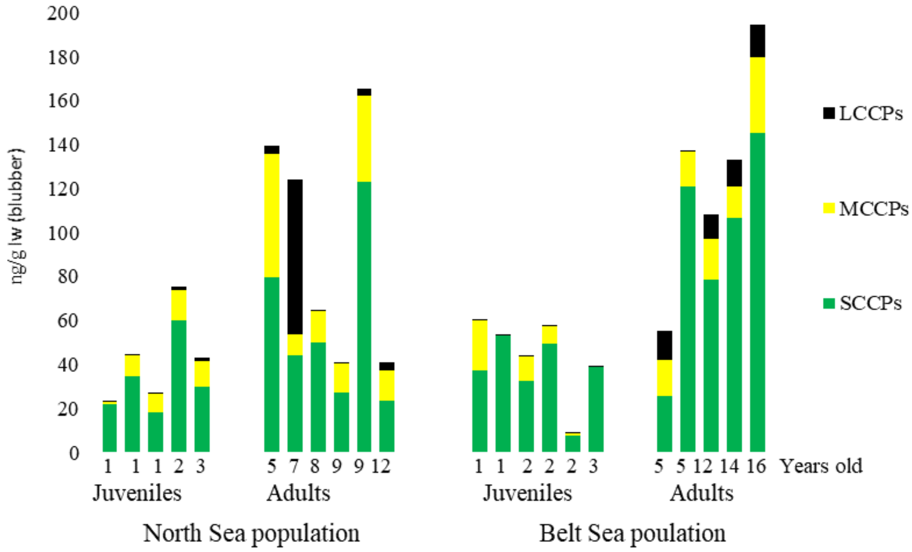

Figure 7. Short-chained, medium-chained and long-chained chlorinated paraffins (SCCPs, MCCPs, LCCPs) in porpoise blubber (ng/g lw)

As for PBDE, there were no differences between the two populations, and no age or sex differences (all p>0.11). BDE-47 accounted for 50% of sPBDE. A lactating five-year old female from Öresund and two juveniles from Skagerrak had the lowest concentrations of sPBDE (44-45 ng/g lw). Highest concentrations of sPBDE was found in a juvenile male from the Skagerrak (323 ng/g lw)

As for, HBCDD, adults had higher concentrations compared to juveniles but no difference in concentrations between the two populations, and sexes was seen. Among juveniles, concentrations of HBCDD were approximately the same as for sPBDE, but in adults HBCDD were found in higher concentrations (See Figure 8). Highest concentrations of HBCDD was found in two males, one 9-year-old from the Skagerrak and one 16-year-old from Öresund.

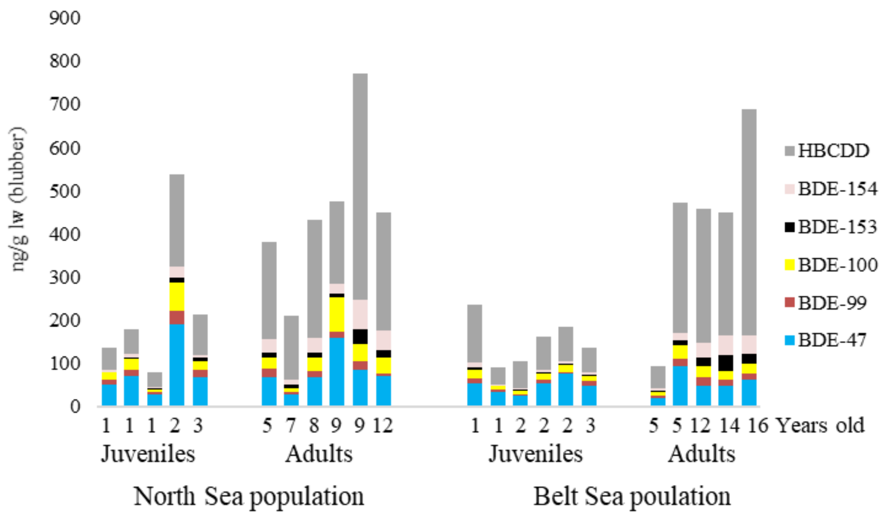

Figure 8. Major PBDEs and HBCDD in porpoises from Swedish waters. HBCDD was usually the predominating compound.

3.5 PFAS

There were no statistically significant differences between populations, age or sex (ANNOVA). PFOS was the most predominating PFAS (Figure 9). Two adult males from the Belt Sea population had very low concentrations of all PFAS. These were reanalyzed and the second analysis confirmed the low concentrations. The reason for the extremely low concentrations is not known.

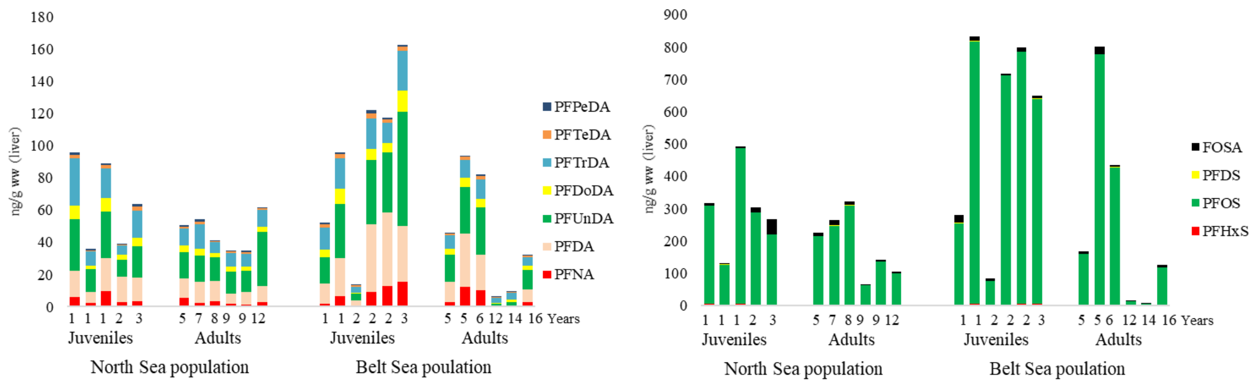

Figure 9. PFSA and PFAS distribution in harbor porpoises from Swedish waters (ng/g ww, liver).

4. Discussion

4.1. Stable isotopes

Juveniles had a higher ratio of N and C compared to adults. This is to be expected since the signature in the juveniles probably still reflect the lactation period.

Also, no significant difference in d15N ratios between the two populations was observed. This could be due to the low number of porpoises analyzed in this study, or that the division into populations is not correct. d13C showed a significant difference between populations, probably indicating a less saline influence in the Belt Sea population. However, it is very possible that porpoises feed on similar trophic levels within the two populations in Swedish waters.

4.2 Metals and selenium

It is difficult to evaluate what contaminants are of concerns for wild animals. Often measured concentrations in wild animals are compared to established threashold levels from laboratory experiments. However, these laboratory experiments are usually performed under optimal conditions (except for the toxin they are exposed to) unlike in the wild where there are many stressors like food shortage at some periods, climate differences, competition, parasites, diseases etc. Also, laboratory animals are usually exposed only to one single contaminant in high doses during a short period of time, whereas in the wild, animals are exposed to a large number of contaminants during their whole lifetime. Also, there can be large differences in species sensitivities for different contaminants. However, laboratory experiments can give some indications and highlights what are extremely high concentrations. Studies on concentrations in wild animals vs health also give indications to what levels are of concern, but again, wild animals are exposed to a cocktail of contaminants and it is difficult to evaluate which contaminants are of highest concerns.

The main form of mercury in fish muscle is methyl mercury (MeHg). In the body, MeHg will be demethylated in the liver, and form a strong bond with Se. Therefore, there is a strong correlation between Hg and Se on a molar weight basis in the liver, in contrast to what is seen in the muscle. In porpoises, we can assume that the main form of Hg in muscle is the more toxic MeHg, however it has not been analyzed.

Elevated concentrations of persistent organic pollutants as well as Hg and Zn has been correlated with poor health status [10].

The range of Hg concentrations found in liver in this study varied between 0.37-4.1 µg/g ww among juveniles and 7.2-65 µg/g ww among adults, which is in the range of other studies. There are a few suggested threshold levels for negative effect of mercury in marine mammals. Ronald et al. exposed harp seals to mercury and suggested a few threshold levels in liver of marine mammals [11]: No risk <16 µg/g ww, low risk at 16-64 µg/g ww, moderate risk 64-83 µg/g ww, high risk 83-123 µg/g ww and severe risk >123 µg/g ww. All juvenile harbor porpoises in this study had levels of Hg in the "no risk"-category and seven of the adults were in the "low-risk" category. One porpoise had 64 µg/g ww, *i.e.* in the moderate-high risk category. It was a female, only five years old and probably from the Belt Sea population. However, these threshold categories were suggested after laboratory experiments on harp seals and might not be applicable for harbor porpoises. Rawson et al studied mercury in liver of bottlenose dolphins and found liver abnormalities in dolphins with Hg concentrations of 61 µg/g ww or more [12]. The five-year-old female shows that mercury can be of concern for adult porpoises.

In contrast to the terrestrial environment, the marine environment usually contain high levels of Se which binds to Hg, and acts like an antioxidant. Hg and Se binds 1:1 on a molar weight basis. Ratios above 1 imply excessive Hg compared to Se. In this study, four of the porpoises had ratios above 1 in muscle, and all were below 1 in liver, where the binding of Hg ad Se take place. However, Se is an essential element that is needed for many processes in the body, and it is possible that if almost all Se is bound to Hg, the porpoise has a deficiency of Se.

Several studies have shown a correlation between elevated concentrations of metals and higher incidences of diseases such as pneumonia as well as parasites [10, 13]. However, in this study, only a few animals in each age group and population, making it difficult to draw any conclusions.

The ratio Hg:Se were studied in 102 porpoises from different parts of the North Sea and 93% of them had a surplus of Se. The ratio was found to be between 0.08-1.27, i.e. similar to this study [14].

Concentrations of Cd and Pb were very low, under suggested threshold levels for negative effects among marine mammals, and lower compared to what is seen in porpoises from higher altitudes, probably because of diet differences [14].

Elevated concentrations of Hg and Zn as well as other metals and chemicals have been correlated with poor health status [10]. Zink is important element for the immune system, and elevated concentrations have been associated with poor health and pneumonia [15]. Concentrations above 100 mg/kg ww in liver have been suggested to be elevated [16]. In this study, all animals had concentrations below 100 mg/kg ww.

4.3 Chlorinated and brominated substances

It is well documented that PCB can cause a range of adverse health effects among mammals, including marine mammals [17-22]. Experimental studies have confirmed that PCB causes adverse effects on health and reproduction among aquatic mammals [23-27]. Several threshold levels for PCB has been suggested, varying between 9000-40000 ng/g lw [9, 20, 23, 25-28]. The most commonly used for cetaceans is 9000 ng/g lw [28]. However, these studies are often based on more PCB congeners than the present study. Seven porpoises in this study had concentrations of sPCB exceeding 9000 ng/g. Six of those porpoises were adults, and one was a juvenile. One adult female had very low concentrations, because she was lactating, and thus had been transferring fat-soluble contaminants to the offspring.

An earlier study of porpoises from Swedish waters showed higher concentrations of PCBs, DDTs and dioxins in animals from the Baltic [29] compared to porpoises from the Swedish west coast, but this was not confirmed in the present study. However, the present study was based on a low number of porpoises, and probably none of them originate from the Baltic population.

Chlorinated paraffins are industrial chemicals that have been produced in large amounts in the world for many years, and has gotten increased attention the last few years. According to the carbon chain length, CPs are subdivided into short-chain chlorinated paraffins (SCCPs, C10−13), medium-chain chlorinated paraffins (MCCPs, C14−17), and long-chain chlorinated paraffins (LCCPs, C>17). Strong increasing concentrations of CPs were seen in cetaceans in the South China Sea [30]. The Swedish Chemicals Agency has recently submitted a proposal to the European Commission for a restriction on MCCPs (www.kemi.se) and an evaluation of an EU-wide restriction of MCCPs is currently ongoing since they are persistent, bioaccumulative and toxic (ECHA, 2019). SCCPs were listed under the Stockholm Convention in 2017.

In the present study, SCCPs were found in the highest concentrations, followed by MCCPs and LCCPs, in contrast to porpoises and dolphins in the South China Sea where MCCPs were found in highest concentrations. The concentrations of CPs in South China Sea cetaceans were much higher compared to porpoises in the present study which is not surprising since China is the largest producer, exporter as well as consumer of CPs in the world [30]. Recent studies on emerging contaminants of concern in the Baltic sea, both blubber and liver from harbor porpoises were analyzed, and concentrations were higher in liver compared to blubber [6], and generally twice as high concentrations in harbor porpoise compared to grey seal (*Halichoerus grypus*) and harbor seal (*Phoca vitulina*) [4, 6]. Furthermore, it seemed like SCCPs have the highest biomagnification potential compared to MCCPs and LCCPs [6].

4.4. Organotin compounds

Nakata and coworkers suggested that concentrations of 100 ng/g of DBT+TBT is a cytotoxic level for marine mammals [31]. The concentrations of DBT+TBT in the present study was 7.8-117 ng/g ww. The highest concentration was found in a 16-year-old male from the Belt Sea population area. Other porpoises had concentrations below 100 ng/g ww.

4.5. PFAS

As in many other studies, no significant differences were seen between concentrations of PFAS vs age or sex. This is in accordance with several other studies [5, 32-37]. Also, PFOS was the most predominating PFAS, also in according to previous mentioned studies.

Two adult males from the Belt Sea population had very low concentrations of all PFAS. The concentrations were so low that the porpoises were reanalyzed, to make sure the low concentrations were correct and the second analysis confirmed the first very low results.

PFOS accounted for the by far the largest portion of the PFAS analyzed in this study, similar to for example grey seals in the Baltic [38] and porpoises from Danish waters [39].

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Supplementary Information

Porpoises analysed within this study

Number	Year	Sea	Area	Sex	Body length (cm)	Body weight (kg)	Age group	Age (years)	Cause of death
A2016/05525	2016	The Skagerrak	Tjörn	Male	108	25,00	immature	0,5	Bycaught
A2016/05527	2015	The Skagerrak	mpersvik, Fjällbac	Male	119,5	29,00	immature	1	peridontitis, trauma
A2016/05522	2016	The Skagerrak	Pinnevik, Lysekil	Male	117	21,8	immature	1,5	Pneumea
A2018/05709	2018	The Skagerrak	Tjörn	Male	151,5	52,0	Adult	5	Bycaught
C2015/05285	2015	The Skagerrak	Lysekil Ålevik	Male	142	54,0	Adult	7	Not determined
A2018/05711	2018	The Skagerrak	Tjörn	Male		43,0	Adult	8	Bycaught
A2016/05524	2016	The Skagerrak	Munkevik, Skaftö	Male	143	41,0	Adult	9	Probably bycaught
A2018/05710	2018	The Skagerrak	Tjörn	Male	146	49,0	Adult	9	Bycaught
A2017/05593	2017	The Skagerrak	Hällevik, Orust	Male	144	56,0	Adult	12	Not determined
A2019/05586	2019	The Kattegat	Nidingen	Male	103,5	18,80	immature		Not determined
A2019/05295	2019	The Kattegat	Vejbystrand	Male	121	31,0	immature	3	Perdation, possible bycaught?
C2015/05287	2015	The Kattegat	Lilla Amundön, Göteborg	Female	132	32,0	immature		Not determined
A2017/05217	2017	Öresund	Öresund	Female	123	27,20	immature	1	Not determined
A2019/05573	2019	Öresund	Öresund	Female	120	30,00	immature	1	Bycaught
A2017/05214	2016	Öresund	Helsingborg	Female	133	42,0	immature	1,5	Probably bycaught
A2019/05578	2019	Öresund	Rydebäck	Female	132,5	36,0	immature	2	Not determined
A2017/05594	2017	Öresund	Helsingborg	Female	158,6	68,0	Adult	5	Bycaught
A2016/05637	2016	Öresund	Helsingborg	Male	141,5	43,0	Adult	12	
A2018/05283	2017	Öresund	Lomma, Limhamn	Male	159,5	60,0	Adult	14	Purulent pneumonia, Cholangitis, Unspecified dermatitis
A2019/05585	2019	Öresund	Lomma hanm	Male	144,5	45,0	Adult	15-16	Not determined
A2018/05712	2018	The Baltic	Trelleborg	Male	132,5	33,0	immature	2	Blunt trauma
A2019/05584	2019	The Baltic	Trelleborg	Male		(38 kg)	Adult	5	Not determined