

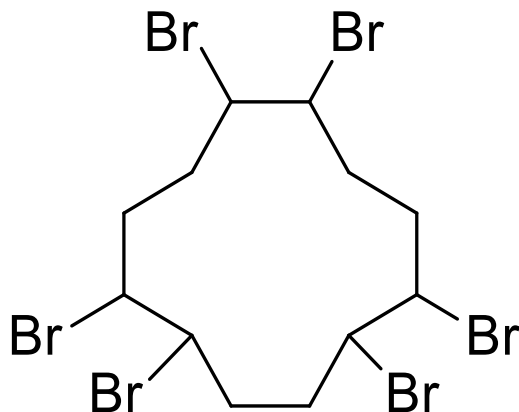


United States
Environmental Protection Agency

Office of Chemical Safety and
Pollution Prevention

Draft Risk Evaluation for Cyclic Aliphatic Bromides Cluster (HBCD)

Supplemental Information on General Population, Environmental and Consumer Exposures



CASRN	NAME
25637-99-4	Hexabromocyclododecane
3194-55-6	1,2,5,6,9,10-Hexabromocyclododecane
3194-57-8	1,2,5,6-Tetrabromocyclooctane

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ABBREVIATIONS

$\mu\text{g}/\text{kg}$	microgram per kilogram
μm	micrometer
AMEM	Arthur D. Little Migration Estimation Model
APCI	Atmospheric Pressure Chemical Ionization
BFR	Brominated Flame Retardants
BEED	Breast milk, Environment, Early-life, and Development
bw/day	body weight per day
CHirP	Chemicals Health and Pregnancy
CHMS	Canadian Health Measures Survey
cm	centimeter
cm/year	centimeters per year
CMI-CWF	Clean Michigan Initiative-Clean Water Fund
dw	dry weight
EC	European Commission
ECNI	electron capture negative ionization
EDI	Estimated Dietary Intake
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
EPS	expanded polystyrene
ESB	German Environmental Specimen Bank
ESI	electrospray ionization mode
GC/ECD	gas chromatography with electron capture detection
GC-MS	gas chromatography-mass spectrometry
GFF	glass fiber filters
GLHGMP	Great Lakes Herring Gull Monitoring Program
h_a	gas-phase mass transfer coefficient
HBCD	hexabromocyclododecane

HPLC	high performance liquid chromatography
HPLC-MS/MS	high performance liquid chromatography with triple quadrupole mass spectrometry
hr/day	hours per day
IIOAC	Integrated Indoor-Outdoor Air Calculation
K _d	linear sorption coefficient
kg/m ³	kilograms per cube meter
km	kilometer
K _{oc}	organic carbon partitioning linear coefficient
LC-ESI-MS/MS	liquid chromatography-electrospray ionization-tandem mass spectrometry
LC-MS/MS	liquid chromatography-tandem mass spectrometry
LOD	limit of detection
LOQ	limit of quantification
lw	lipid weight
m	meter
mg/m ² /hr	milligram per meter squared per hour
mL/day	milliliter per day
m	meter
mg/m ² /hr	milligrams per square meter per hour
mL/day	milliliter per day
MLOD	method limit of detection
MLOQ	method limit of quantification
NAAQS	National Ambient Air Quality Standards
ND	non-detect
NESI	negative electrospray ionization mode
ng/g	nanogram per gram
ng/L	nanogram per liter
ng/m ³	nanogram per cube meter
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NSSS	National Sewage Sludge Survey

OPPT	Office of Pollution Prevention and Toxics
PBT	persistent bioaccumulative toxic
pg	picogram
PM	particulate matter
POP	persistent organic pollutants
POPUP	Persistent Organic Pollutants in Uppsala Primiparas
PSC	point source calculator
PUF	polyurethane foam
SIM	selected ion monitoring
SVOC	semi-volatile organic compounds
TOC	total organic carbon
TS _{overall}	overall time spent
UPLC-APPI-MS/MS	ultra-performance liquid chromatography with tandem mass spectrometry detection using atmospheric pressure photoionization
UPLC-ESI-MS	ultra-performance liquid chromatography coupled to electrospray ionization and mass spectrometry
UPLC-MS/MS	ultra-performance liquid chromatography with tandem mass spectrometry
VVWM	variable volume water module
ww	wet weight
WWTP	wastewater treatment plant
XPS	extruded polystyrene

1 Overview of the Systematic Review Process

EPA completed a comprehensive literature search for hexabromocyclododecane (HBCD) along with the first 10 chemicals. EPA also completed supplemental searches that incorporated additional articles from the following sources: references cited in public comments, references identified as part of earlier efforts to assess exposure to HBCD and other flame retardants, and references identified in EPA's Exposure and Use Assessment for Persistent Bioaccumulative Toxic (PBT) chemicals. Many of the articles that reported information for DecaBDE (one of the PBT5 chemicals) also reported information for HBCD.

After all references from all sources were cross-walked and screened, remaining articles were evaluated and extracted. For an article to pass screening, it had to cover any part of the conceptual model describing potential exposures across the lifecycle of HBCD. It is also worth noting, that additional non-chemical specific sources such as model user guides, guidance documents, or articles that generally discuss exposure pathways of interest for chemicals like HBCD (semi-volatile organic compounds) are also referenced in this exposure assessment and supplemental file but are not part of the "count" of the universe of articles that went through EPA/OPPT's systematic review process.

1.1 Data Extraction Methods and Approach

Studies that were determined to be of sufficient data quality at the data quality evaluation stage that also contained primary quantitative monitoring data, modeled media data, or modeled intake or dose data were selected for extraction.

For environmental monitoring and biomonitoring studies values describing the overall range of data (minimum, maximum, mean, median, and frequency of detection) were extracted for each media presented in the study. Extracted data were further annotated with salient details such as population characteristics, species, location by country, sampling dates, sample media phase (e.g. gas versus particulate phase in air), weight fraction (e.g. lipid, wet or dry weight), tissue type, and location type (e.g. residential, commercial or vehicle for indoor environments and background or near facility for outdoor environments).

For studies that contained modeled estimates of intake or dose a similar approach was taken to capture the range of data; however, model estimates tended to either be point estimates or present a central tendency and high end. In all cases, the study data were extracted along with receptor characteristics, country, and pathways considered.

1.2 Data Integration Methods and Approach

Extracted study data required further processing to allow for the standardization and integration of HBCD data across all studies.

Where studies reported isomers of HBCD (alpha, beta, gamma) separately, these values were summed and total HBCD was recorded. For studies that reported a frequency of detection of less than 100%, that is, that HBCD was not detected in all samples, a value of one-half the limit of detection was imputed as the minimum value for each study and media combination. Reported intakes were converted into average daily doses based on exposure factors describing media intake rates by receptor (cite exposure factors.)

All data were converted to a common unit and aggregated to determine the overall range (lowest reported value to highest reported value) and the range of central tendencies (means and medians) reported for

each study, media, and location type. The plots in sections 3-5 of this supplement contain a data summary plot for each media presenting all studies containing relevant data. These are presented first by location type and then, where applicable, by sample media phase or weight fraction. Within each location type, monitoring data from the US are presented first, followed by data from other countries in alphabetical order by country code, followed by modeled data where available. For each country, data are presented from newest to oldest, based on latest year of sampling. Differentiation by species and tissue type are not shown in these summary plots. The lighter region of each bar represents the overall range of data and the darker region represents the range of central tendency reported in each study. For dose data estimated from modeled intake, each bar represents the mean and high-end central tendency estimates based on the assumptions of the exposure factor.

2 Overview of Key Studies and Data Quality Ratings

Table 2-1 provides the key studies and their overall data quality evaluation score for various media. Summaries are also provided in subsequent sections of this supplemental file. Additional details about the data quality evaluation of each study in Table 2-1 are provided in the *Systematic Review Supplemental File for the TSCA Risk Evaluation: Data Quality Evaluation for Data Sources on Consumer, General Population and Environmental Exposure*.

Figure 2-1. Key studies for the Evaluation of Environmental and Human Exposures

Media	HERO ID	Short Citation	Data Quality Rating
Fish	1927627	Chen <i>et al.</i> (2011)	High
	2343698	Poma <i>et al.</i> (2014)	High
	1927762	Jenssen <i>et al.</i> (2007)	High
Avian	1851195	Chen <i>et al.</i> (2012)	Medium
	999339	Sellstrom <i>et al.</i> (2003)	High
	1927650	Esslinger <i>et al.</i> (2011)	High
Vegetation/Diet	1401050	Schechter <i>et al.</i> (2012)	High
	787666	Gosciny <i>et al.</i> (2011)	High
	3350483	Barghi <i>et al.</i> (2016)	High
Surface Water	2695212	Venier <i>et al.</i> (2014)	High
	1927694	Harrad <i>et al.</i> (2009)	High
	2343678	Ichihara <i>et al.</i> (2014)	High
	1927551	He <i>et al.</i> (2013)	High
	2343704	Oh <i>et al.</i> (2014)	High
Sediment	1927601	La Guardia <i>et al.</i> (2012)	High
	1927611	Yang <i>et al.</i> (2012)	High

Media	HERO ID	Short Citation	Data Quality Rating
	3350544	Drage <i>et al.</i> (2015)	High
Soil	1927826	Remberger <i>et al.</i> (2004)	Medium
	1927586	Wang <i>et al.</i> (2013)	Medium
	1927688	Wang <i>et al.</i> (2009)	High
	3546008	Li <i>et al.</i> (2016)	High
Ambient Air	999242	Hoh and Hites (2005)	Medium
	3019586	Shoeib <i>et al.</i> (2014)	Medium
	3355687	Li <i>et al.</i> (2016)	Medium
Indoor Dust	2343712	Stapleton <i>et al.</i> (2014)	Medium
	3455810	Allgood <i>et al.</i> (2016)	High
	1578505	D'Hollander <i>et al.</i> (2010)	High
	3012178	Sahlström <i>et al.</i> (2015)	High
	2528328	Qi <i>et al.</i> (2014)	High
Indoor Air	1079114	Abdallah <i>et al.</i> (2008)	High
	3227425	Hong <i>et al.</i> (2016)	High
Human Milk	1927577	Carignan <i>et al.</i> (2012)	High
	3862906	Tao <i>et al.</i> (2017)	High
	3449916	Antignac <i>et al.</i> (2016)	High
Human Serum	1927656	Kalantzi <i>et al.</i> (2011)	Medium
	3809262	Peters (2004)	High

2.1 Fish

2.1.1 North America

2.1.1.1 Chen *et al.* (2011)

Chen *et al.* (2011) sampled fish in southeastern Virginia and northeastern North Carolina, a region known historically as a center for textile production. Sample collection of 189 individual adult fish via electrofishing from sites in the Hyco, Dan and Roanoke Rivers occurred from May to October 1999-2002 and 2006-2007. The five species sampled were common carp (*Cyprinus carpio*), flathead catfish (*Pylodictus olivaris*), channel catfish (*Ictalurus punctatus*), redhorse sucker (*Moxostoma sp.*), and gizzard shad (*Dorosoma cepedianum*). Fish were filleted and both individual fish fillets and single species composites of fillets from multiple individuals were analyzed by ultra-performance liquid chromatography coupled to electrospray ionization and mass spectrometry (UPLC-ESI-MS).

Concentrations varied between rivers, but mean total HBCD concentrations increased at all rivers between the 1999-2002 sampling interval (ND-22 ng/g lw) and 2006-2007 sampling interval (13 to 4,640 ng/g lw). The Hyco River generally had the highest concentrations of HBCD. The Hyco watershed is predominately agricultural and forested, but three of the Hyco samplings sites are located downstream of a known BFR-using site (textile related) and a receiving wastewater treatment plant (WWTP). The Dan and Roanoke are large rivers with multiple small towns located within their watersheds, with historical textile and furniture operations. In addition, Chen et al. (2011) conducted a meta-analysis of their present study and seventeen other studies to see if near facility concentrations in fish differed from fish samples collected further away from facilities. The authors report that concentrations in fish sampled near point sources were generally 1 to 2 orders of magnitude higher than fish located further away from sources. For fish located near points sources, Chen et al. (2011) reported concentrations in fish from near point sources ranging from 38 to 6,660 ng/g lw and concentrations in fish from more remote areas ranging from 0.1 to 51.5 ng/g lw.

2.1.2 Europe

2.1.2.1 Poma et al. (2014)

Poma et al. (2014) studied whether HBCD can bioaccumulate in a pelagic food web of a large and deep subalpine lake (Lake Maggiore, Northern Italy), whose catchment is a highly populated area with many manufacturing plants. Zooplankton, shad (*Alosa agone*) and whitefish (*Coregonus lavaretus*) were sampled from Lake Maggiore from May 2011 to January 2012 in four different seasons and at different locations and depths within the pelagic lake. Fish muscle and liver samples and zooplankton were analyzed by gas chromatography-mass spectroscopy (GC-MS) for total HBCD. Levels of detection (LODs) were estimated for each compound as 0.1 ng/g dry weight in biological samples. For zooplankton, minimum = 29 ng/g lw; maximum = 167 ng/g lw. For fish muscle (n=16), minimum = 13 ng/g lw; maximum = 792 ng/g lw. For fish liver (n=16), minimum = 27 ng/g lw; maximum = 1,232 ng/g lw. Results confirmed that HBCD can biomagnify within food webs. The study discusses the variability in lipid content of fish across seasons, isotope analysis differences, and uncertainty regarding human use of HBCDs.

2.1.2.2 Jenssen et al. (2007)

Jenssen et al. (2007) studied HBCD in fish in North-East Atlantic coastal marine ecosystems along a latitudinal gradient from southern Norway to Spitsbergen, Svalbard, in the Arctic. Atlantic cod (*Gadus morhua*) from Oslofjord and Froan and polar cod (*Boreogadus saida*) from Bear Island and Spitsbergen were collected in 2003. Homogenized whole fish samples were analyzed using GC-MS. Detection limits were set to about 3 times the noise level. For Oslofjord, Atlantic cod (n=21): mean = 25.6 ng/g lw; st.dev. = 13.4 ng/g lw. For Froan, Atlantic cod (n=18): mean = 18.7 ng/g lw; st.dev. = 10.5 ng/g lw. For Bear Island, polar cod (n=6): mean = 11.7 ng/g lw; st.dev. = 7.2 ng/g lw. For Spitzbergen, polar cod (n=7): mean = 1.8 ng/g lw; st.dev. = 0.58 ng/g lw. When comparing levels of HBCD in the two cod species from all four locations, levels of HBCD were Oslofjord \approx Froan > Bear Island >> Spitsbergen, i.e. levels of HBCD generally decreased as a function of increasing latitude, reflecting distance from release sources. The use and leakage of brominated flame retardants (BFRs) into the environment is higher in urbanized areas along the Norwegian coast than in the almost unpopulated Spitsbergen. High levels of BFRs have been reported in sewage and because of their semi volatile properties, HBCD are subject to long-range atmospheric transport likely the origin of the BFRs detected in endemic Arctic biota.

2.2 Avian

2.2.1 North America

2.2.1.1 Chen et al. (2012)

Chen et al. (2012) studied eggs of four gull species (Laridae) from Canadian marine and freshwater ecosystems collected from a total of 26 colonies spanning Pacific to Atlantic Canada, including the Great Lakes basin. Gulls are top predators in their respective ecosystems and ideal for monitoring halogenated contaminants. Herring gull eggs from fifteen Great Lakes colony sites were collected from late-April to early-May of 2008. For each colony site, 10 to 13 individual eggs from different nests were pooled on an equal wet-weight basis. In addition, individual eggs (n=10) from different nests of glaucous-winged (*Larus glaucescens*), California (*Larus californicus*), ring-billed (*Larus delawarensis*) or herring gulls were also collected in early-May to early-July of 2008 from each of 11 additional colonies spanning the Pacific to the Atlantic coast of Canada. The pooled and individual eggs were homogenized and stored at 40 C at Environment Canada's National Wildlife Specimen Bank prior to chemical analysis. HBCD was analyzed for using GC-MS-in electron capture negative ionization (ECNI). Method blanks were processed to monitor interferences and contamination and method limit of quantification (MLOQ) = 1.1 ng/g and MLOD (method limit of detection) = 0.28 ng/g. In the marine ecosystem (n=6 pooled samples): minimum median = 0.5 ng/g ww; maximum median = 4.5 ng/g ww; minimum arithmetic mean = 2.2 ng/g ww; maximum arithmetic mean = 9 ng/g ww. For the non-Great Lakes freshwater ecosystem (n=5 pooled samples): minimum median = 4.4 ng/g ww; maximum median = 11.7 ng/g ww; minimum arithmetic mean = 6.7 ng/g ww; maximum arithmetic mean = 16.6 ng/g ww. For the Great Lakes ecosystem (n = 15 pooled samples): minimum of pooled samples = 2.0 ng/g ww; maximum of pooled samples = 12 ng/g ww. Gulls breeding in regions with higher human population densities likely incurred greater flame retardant exposure. This study also contains an analysis of stable isotopes as dietary tracers in relation to flame retardants.

2.2.2 Europe

2.2.2.1 Sellstrom et al. (2003)

Sellstrom et al. (2003) conducted a temporal trend study of HBCD concentrations in individual and/or pooled Guillemot bird eggs collected between 1969 and 2001 from Stora Karlsö, an island off Sweden's west coast in the Baltic Sea. The study is partly based on the analysis of eggs archived and stored in the Swedish Environmental Specimen Bank. Guillemot eggs have previously been shown to be a very important matrix for studies of persistent environmental contaminants, as Guillemots are stationary within the Baltic the entire year, they nest far away from local sources in the central part of the Baltic Proper, and they feed exclusively on pelagic fish that migrate within the Baltic. In this investigation, egg sampling was constrained to early laid eggs to avoid an important source of within-year variation. Samples were analyzed using GC-MS run in the chemical ionization mode, measuring the negative ions formed (ECNI). Quality control measures taken included analysis of duplicate or triplicate calibration curves, laboratory blanks, recovery samples, and the use of laboratory reference material (herring homogenate) extracted and analyzed in parallel with the guillemot eggs. Specifically, one pooled sample of 10 archived eggs was analyzed per study year between 1969 and 1992 (no eggs from 1970, 1974, 1979, 1984, and 1991 were studied) and 10 eggs were analyzed individually per study year between 1993 and 2001. Additionally, the uncertainty of the results obtained from the pooled samples was investigated by analyzing individual eggs from 1976 and 1992; the pooled egg concentrations were within the range of the individual egg concentrations. For HBCD, the analysis indicates a steady and significant ($p < 0.001$) increase in concentrations over time up to recent periods, although there are indications of a minor peak during the mid-1970s or a decrease in concentrations during 1978-1985. The concentrations of HBCD

have approximately doubled during the study period, but this increase seems to have leveled out since the mid-1990s. For 1969-1992 samples (n=18 pooled samples): minimum = 34 ng/g lw; maximum = 140 ng/g lw. For 1993-2001 samples (n=119 individual samples): minimum = 54 ng/g lw; maximum = 300 ng/g lw; minimum annual arithmetic mean = 110 ng/g lw; maximum annual arithmetic mean = 170 ng/g lw. Verreault et al. reported four studies over four years that reported concentrations of HBCD in various tissues of glaucous gulls.

2.2.2.2 Esslinger et al. (2011)

Esslinger et al. (2011) sampled herring gull eggs from the islands Mellum and Trischen in the German Wadden Sea and from the island Heuwiese at the German Baltic Sea coast from 1998 to 2008. Between 35 and 140 eggs were collected annually and the whole content of all eggs from a given site and year were pooled and archived by the German Environmental Specimen Bank (ESB). Egg powders as received from the ESB were homogenized and stored at -20 C until further processing. The 26 egg pool samples were analyzed by high performance liquid chromatography with triple quadrupole mass spectrometry (HPLC-MS/MS) where the LOD for the six stereoisomers ranged between 0.13 and 0.26 pg/g and limit of quantification (LOQ) between 0.48 and 0.93 pg/g. Herring gull eggs are excellent indicators of contaminant exposure in the environment, herrings maintain stable population dynamics, and their feeding habits are well known. Results are reported as six stereoisomers for α -, β -, γ -HBCD, where α -HBCD was detected as the dominant diastereoisomer. Results for total HBCD: Mellum island, 1988-2008, (n=10 pooled samples): minimum = 4.17 ng/g lw; maximum = 107 ng/g lw; Trischen island, 1988-2008, (n=10 pooled samples): minimum = 13.8 ng/g lw; maximum = 74.8 ng/g lw. Heuwiese island, 1998-2008, (n=6 pooled samples): minimum = 25.1 ng/g lw; maximum = 98.7 ng/g lw. The average contamination levels at the three locations are relatively close but nevertheless significantly different from each other. The increase in concentration of HBCD in eggs between 1994 and 2000 might reflect the steady rise in demand of HBCD during this period. Esslinger et al. (2011) also examined temporal trend data on HBCD from bird eggs from other locations from 1970 to 2004. The concentrations in the current study were in the middle range and similar to gull and guillemot eggs elsewhere in Europe. The trends in the reported secondary data varied, including increases in bird eggs from 1983-2003 in Northern Norway, no increases from guillemot eggs from a Swedish Baltic Sea between 1991 and 2001, and slight decreases in peregrine falcon eggs from Greenland between 1986 and 2003 and tawny owl eggs from Central Norway between 1986 and 2004.

2.3 Vegetation/Diet

2.3.1 North America

2.3.1.1 Schechter et al. (2012)

Schechter et al. (2012) measured HBCD stereoisomers (α -, β -, γ -HBCD) in a variety of common, lipid-rich U.S. foods purchased from supermarkets in Dallas, TX in 2010. Thirty-six individual food samples, generally consisting of fish, poultry, pork, beef and peanut butter, were analyzed by liquid chromatography-tandem mass spectrometry (LC-MS/MS). QA/QC measures included multipoint calibration curves, blanks, duplicates, and reference samples. Total HBCD in the individual food samples ranged from 0.010-1.366 ng/g ww, after setting values <LOD set to LOD/2. The median and mean of total HBCD for all the samples were 0.012 and 0.114 ng/g ww, respectively. Detectable levels of HBCD were measured in only 15 individual food samples (detection frequency of 42%). HBCD was not detected in fresh deli meats and fish, chili with beans, and bacon. The highest level of HBCD was in canned sardines, with next highest level in turkey sausage. α -HBCD was detected most often and at the highest concentrations. Although results were not presented, Schechter et al. (2012) stated that in the

present study an association between higher lipid levels and higher HBCD levels were noted. In addition, ten pooled samples collected and analyzed in 2009 by GC-MS for total HBCD (from previous study, Schecter et al., 2009) were reanalyzed for stereoisomers by LC-MS/MS in 2010 as part of the current study, Schecter et al. (2012). These previously analyzed samples were known to contain detectable levels of HBCD. The median concentration of total HBCD in reanalyzed pooled samples (reported as sum of stereoisomers) was 0.116 ng/g ww. Schecter et al. (2012) also compared the total HBCD concentrations to levels from other studies. Reported concentrations from studies in Scotland, Japan and the Netherlands were higher, whereas reported concentrations from Romania, Sweden, UK, Norway were lower. Schecter et al. (2012) discussed various possible reasons for differences, such as the lipid content of food, dust contamination during food preparation, transfer of HBCD from soil to vegetables, livestock raising and husbandry practices, and differences in sources, handling, ingredients, and packaging.

2.3.2 Europe

2.3.2.1 Gosciny et al. (2011)

Gosciny et al. (2011) assessed dietary exposure of the adult Belgian population by measuring HBCD diastereoisomers (α -, β -, and γ -HBCD) by ultra-performance liquid chromatography with tandem mass spectrometry (UPLC-MS/MS) in foods common to the Belgian diet. Food samples from 5 major food groups (dairy, meat, eggs, fish and other food products such as breads, oils and pastries) were purchased in autumn 2008 from supermarkets, fish and butcher shops in Brussels (n=549 individual food samples, combined into 43 composite samples). QA/QC measures were consistent with ISO 17025 and included in-house method validation, method blanks and spiked fish oil samples. HBCDs were detected in 80% of the composite food samples (35 out of 43 samples). HBCD diastereoisomer concentrations were summed and reported in the study as total HBCD, which for the lower, medium and upper bound concentrations ranged from 0-14.652, 0.150-14.652, and 0.550-14.652 ng/g lw, respectively. [For samples in which HBCD was not detected, concentration levels for the diastereoisomers were assigned as follows: lower bound=0, medium bound=1/2 LOD, upper bound=LOD. For samples with HBCD levels between LOD and LOQ, concentration levels for the diastereoisomers were assigned as follows: lower bound=LOD, medium bound=(LOD + LOQ)/2 and upper bound=LOQ.] α -, β -, and γ -HBCD were detected in all food groups; α -HBCD was predominant in fish, while γ -HBCD was predominant in dairy products and meat. Estimated dietary intake (EDI) was based on medium bound total HBCD concentrations from this study and consumption data from the Belgian national food consumption survey of 2004. The total average dietary intake (medium bound) = 0.991 ng/kg bw/day, with SD=0.374 ng/kg bw/day. Total average EDI's for adults in other countries (UK, China, Sweden, the Netherlands, Japan) determined in other studies were also provided, and except for China, were greater than the Belgian values.

2.3.3 Asia

2.3.3.1 Barghi et al. (2016)

Barghi et al. (2016) monitored HBCD concentrations in foods common to the Korean diet and determined dietary exposure to the Korean population. Food samples of 57 food items from 8 major food groups (fish, shellfish, meat, egg, dairy products, vegetables, fruit and cereal/rice) were purchased from supermarkets and local markets in five Korean cities from 2012-2014 (n=521 individual food samples). HBCD diastereoisomers (α -, β -, and γ -HBCD) were measured by LC-MS/MS. QA/QC measures included multipoint calibration curves, method blanks, recovery standards and certified reference materials. HBCDs were detected in >80% of all study samples; total HBCD concentrations ranged from ND (non-detect) (<0.006 ng/g ww)-7.91 ng/g ww in the 521 individual samples. HBCD levels were highest in the fish and shellfish groups (mean of 1.66 ng/g ww and 0.268 ng/g ww, respectively; median of 0.248 ng/g ww and 0.090 ng/g ww, respectively). Of the fish species, herring, halibut, and chub

mackerel contained the highest mean HBCD concentrations: 4.91 ng/g ww (range ND (<0.006 ng/g ww)-7.91 ng/g ww), 2.43 ng/g ww (range 0.762-4.84 ng/g ww), and 1.66 ng/g ww (range 0.405-3.09 ng/g ww), respectively. Diastereoisomer profiles were provided for the various food groups; alpha-HBCD was predominant in animal-based foods, and gamma-HBCD was predominant in plant-based foods. The EDI of total HBCD for the general Korean population and specific subgroups was calculated based on the HBCD concentration data from this study and food consumption rates from nationwide surveys and statistics for Korea (KHIDI, 2013 and KNHANES, 2011). The average dietary intake of HBCD was estimated to be 0.82 ng/kg bw/day in the general population and 2.89 ng/kg bw/day in children up to 5 years of age. Comparison with studies of dietary exposure for other countries showed adult EDI's within the same order of magnitude for China, Norway, Sweden, the UK, the Netherlands, and Belgium. Using the European Food Safety Authority (EFSA) method for risk assessment, it was determined that there is no health concern for the Korean population from the current dietary exposure.

2.4 Surface Water

2.4.1 North America

2.4.1.1 Venier et al. (2014)

Venier et al. (2014) measured background concentrations of HBCD in a large group of organic chemicals, including flame retardants, in surface water samples collected from 18 stations distributed throughout the five Great Lakes (Erie, Huron, Michigan, Ontario, and Superior) in 2011 and 2012 using XAD-2 resin absorption. Surface water samples were collected using the PopCart, a sampling technique customized by Environment Canada, and were analyzed for the flame retardants including total HBCD using GC-MS with ECNI. The method detection limit was not reported. Total HBCD was detected in approximately 61% of the samples (14 of 23). Mean concentrations of total HBCD in surface water ranged from 0.00026 ng/L (SD = 0.00025 ng/L) to 0.00208 ng/L (SD = 0.00228 ng/L) for the five Great Lakes (n=23), with the highest concentrations observed in Lake Ontario.

2.4.2 Europe

2.4.2.1 Harrad et al. (2009)

Harrad et al. (2009) measured background concentrations of HBCD in surface water from nine English freshwater lakes during spring and autumn 2008 and winter 2009. The nine lakes included: Wake Valley Pond, Holt Hall Lake, Chapman's Pond, Crag Lough, Marton Mere, Slapton Ley, Fleet Pond, Edgbaston Pool, and Thoresby Lake. The authors were not aware of any major point source inputs (e.g., wastewater treatment plants) to any of the nine lakes monitored. At each lake three grab samples were collected from 50 cm below the surface (at the deepest point of each lake) during spring and autumn 2008 and winter 2009. Samples were analyzed for individual isomers (alpha-, beta-, and gamma-HBCD) and total HBCD using LC-MS/MS detection operating in the electrospray ionization mode (ESI). The limit of detections (LODs) were not provided. Total HBCD (sum of particulate and dissolved phases) was detected in 100% of the surface water samples ranging from a minimum average concentration of 0.08 ng/L (SD = 0.0073 ng/L) from Thoresby Lake to a maximum average concentration of 0.270 ng/L (SD = 0.031 ng/L from the Edgbaston Pool and SD = 0.018 ng/L from Slapton Ley). According to Harrad et al. (2009) the low standard deviations for the three samples at each site is indicative of no obvious seasonal variability.

2.4.3 Asia

2.4.3.1 Ichihara et al. (2014)

Ichihara et al. (2014) measured HBCD in surface water samples from 19 sampling locations in the Yodo River Basin in western Japan during 2012 and 2013. The upper reach of the basin consists of forests, paddy fields, and city areas whereas the watershed of the lower reach is highly urbanized and industrialized. Water flow in the study area is dominated by tidal action. Multiple samples were collected per sampling location at ebb tide and were analyzed by UPLC-MS/MS detection operating in the negative electrospray ionization mode (NESI) to determine the HBCD stereoisomers (alpha-, beta-, gamma-, delta-, and epsilon-HBCD) and total HBCD. The method limit of quantification for alpha-, beta-, gamma-, delta-, and epsilon-HBCD were 10, 10, 10, 20, and 10 pg, respectively. The annual mean values were reported by sampling location and by river. Across all 19 sampling locations, annual mean surface water concentrations of total HBCD ranged from 0.19 ng/L (SD = 0.2 ng/L) to 14 ng/L (SD = 12 ng/L). Delta- and epsilon-HBCD were not detected in any of the river samples. Average concentrations in the Kanzaki River, Yodo River, and Yamato River were 0.91, 0.76, and 6.7 ng/L. The authors also reported flow rates and estimated pollutant loads. It is noteworthy, that the lowest flow river, the Yamato River, had the highest HBCD concentration.

2.4.3.2 He et al. (2013)

He et al. (2013) measured background concentrations of HBCD in surface water from a river running through a highly industrialized area in the Pearl River Delta of South China during 2010. Five surface water samples were collected from the Dongjiang River catchment with a grabber 50 cm below the surface of the water and were analyzed for individual isomers (alpha-, beta-, and gamma-HBCD) and total HBCD using LC-MS/MS detection operating in the NESI. The reported LODs for individual HBCD isomers were 1.7 pg for alpha-HBCD, 0.5 pg for beta-HBCD, and 1.4 pg for gamma-HBCD. In the dissolved phase, total HBCD was detected in 100% of the surface water samples (n=5) ranging from 0.0095 ng/L to 0.0825 ng/L ww (mean = 0.0397 ng/L). In the particulate phase, total HBCD ranged from ND (0.0036 ng) to 0.0113 ng/g dw (mean = 0.008 ng/g dw). According to He et al. (2013) little information is available for the partition of HBCD between the dissolved and particulate phases. In this study the average proportion of dissolve phase HBCDs were reported as 27% and may be controlled by various factors (e.g., suspended particle content, dissolved organic matter content, and particle organic matter).

2.4.3.3 Oh et al. (2014)

Oh et al. (2014) measured background concentrations of HBCD in surface water from three Japanese rivers (Tsurumi River, Yodo River, and Kuzuryu River) with different HBCD emission sources during 2011. Tsurumi River flows through the two most highly populated areas in Japan (Tokyo and Kanagawa prefecture) with seven municipal wastewater treatment plants located in the river basin; it is ranked as one of the worst in Japan because of the rapid urbanization in the basin. Yodo River flows out of the largest lake in Japan (Lake Biwa), flows through three prefectures (Shiga, Kyoto, and Osaka), and has the most tributaries in Japan. The flow of Yodo River consists of mainly of effluents from industries including expanded polystyrene (EPS) and extruded polystyrene (XPS) production, and household wastewater. Kuzuryu River flows through Fukui prefecture where many dyeing and textile processing factories are located. Surface water samples were collected at 17 sampling sites from the 3 rivers (Tsurumi River; n=4 sites, Yodo River; n=6 sites, and Kuzuryu River; n=7 sites) using a grab sampler and were analyzed for individual isomers (alpha-, beta-, and gamma-HBCD) and total HBCD using HPLC-MS/MS detection operating in the NESI. The LODs were not provided. Total HBCD was detected in 100% of the surface water samples ranging from 6.6 ng/L to 57 ng/L (mean = 21.2 ng/L) for the Tsurumi River (n = 4), 2.5

ng/L to 19 ng/L (mean = 9.3 ng/L) for the Yodo River (n = 6), and 180 ng/L to 2100 ng/L (mean = 642.9 ng/L) for the Kuzuryu River (n = 7). The highest concentrations of total HBCD were observed at the Kuzuryu River followed by the Yodo and Tsurumi Rivers. According to Oh et al. (2014) the different emission sources have direct influence on the behavior of HBCDs for each basin.

2.5 Sediment

2.5.1 North America

2.5.1.1 La Guardia et al. (2012)

La Guardia et al. (2012) studied sediment samples collected at a WWTP outfall along the Yadkin River in North Carolina. The WWTP is owned and operated by a local textile and treats up to 16 million liters per day (~92% industrial process wastewater and ~8% domestic sewage). Treatment includes bar and fine screening, aeration, dual clarifiers, aerobic digesters, and sludge drying beds. Sediment was sampled 16.8 km, 25.2 km and 44.6 km downstream of the outfall, at the outfall, and 0.2 km upstream from the WWTP in July 2009. Samples were collected in precleaned 1 L glass jars with Teflon lids and stored at <4 °C. For total HBCD (α -, β - and γ -HBCD) samples were analyzed by UPLC-MS/MS. In the outfall sediment, total HBCD was the most abundant brominated flame retardant at 390,000 ng/g total organic carbon (TOC). Total HBCD was also detected at every collection site downstream from the outfall, ranging from 88,300 to 12,200 ng/g TOC. However, HBCD was not detected (LOD=1 ng/g, dry weight) at the upstream site. The biota sampled in these same areas had total HBCD concentrations among the highest reported to date worldwide.

2.5.1.2 Yang et al. (2012)

Yang et al. (2012) studied 16 sediment cores from all five Great Lakes. Most of the sites are in depositional zones where chemical input is likely to be dominated by atmospheric deposition. Sediment sampling was conducted from August 1 to 25, 2007 on Lake Superior (4 cores), Lake Michigan (4 cores), Lake Huron (3 cores), Lake Erie (2 cores), and Lake Ontario (3 cores). A total of 223 segments were collected from 16 cores. Samples were analyzed by GC-MS ECNI. The detection frequency for total HBCD was 82% for samples dated 1950 or later. The surface sediment concentration of total HBCD was in the range of 0.04 to 3.1 ng/g dw. According to the author, this is within the concentration range (<10 ng/g dw) worldwide at locations dominated by diffuse sources, but orders of magnitude lower than those near point sources. Chronologically, HBCD appeared in the sediment around the mid-1980s, and increased in nonmonotonic patterns in subsequent years. At most locations, a decrease in input flux was observed in the top sediment segments. Specifically, concentrations ranged from 0.04 to 1.2 ng/g dw for Lake Superior (n=4 pooled samples); 0.09 ng/g dw to 1.0 ng/g dw for Lake Michigan (n=4 pooled samples); 0.27 to 1.4 ng/g dw for Lake Huron (n=3 pooled samples); 0.77 to 1.0 ng/g dw for Lake Erie (n=2 pooled samples); and 0.84 ng/g to 3.1 ng/g dw for Lake Ontario (n=3 pooled samples).

2.5.2 Australia

2.5.2.1 Drage et al. (2015)

Drage et al. (2015) studied surficial sediment samples and sediment cores from four locations within the Sydney estuary, Australia. Sediment cores were taken in 1998/99 in shallow-water areas in locations close to storm water drains which have been previously identified as sources of storm water contaminants (Iron Cove, Burns Bay, and North Harbor). Each core was subsampled at 2 cm intervals to 10 cm depth, and thereafter subsampled at intervals of 10 cm. Sediment age was determined using dating techniques and sedimentation rates (cm/year) were calculated from sediment thickness and age. In May 2014, the investigators collected four surficial sediment samples, extracted the top 5 cm, and pooled the material.

Samples were analyzed by HPLC-MS/MS. HBCD was detected in low levels in sediments deposited as early as 1950–1960s, average = 0.59 ng/g dry wt. Large increases in concentrations were observed for total HBCD between 1980 and 2014. HBCD peaked in sediment representative of 1997 (4.5 ng/g dry wt) and declined to 2.6 ng/g dry wt in surficial sediment from 2014. After a sharp increase in the 1990s, HBCD concentrations peaked at an average of 3.5 ng/g dry wt (1.8–5.3 ng/g dry wt) in surficial samples. These patterns are consistent with commercial use of HBCD in Australia - importation of HBCDs and its containing products into Australia peaked in 2006–07 (90 tons) but decreased to approximately 60 tons in 2010.

2.6 Soil

2.6.1 Europe

2.6.1.1 Remberger et al. (2004)

Remberger et al. (2004) investigated the possible emission pathways and determined the environmental occurrence of HBCD in soil collected near a potential point source (XPS producing facility) in Sweden during 2000. The factory was located southwest of Aspvreten and manufactures flame retarded XPS plastics treated with HBCD during a period of two weeks per year. Soil samples were collected from the upper 3 cm of low moraine ridges from three different directions at a distance of 300, 500, and 700 m from the factory. All samples were analyzed by gas chromatography with electron capture detection (GC/ECD). The limit of detection was not reported for this media. Concentrations of total HBCD ranged from 140 ng/g dw (ridge approximately 700 m NW of factory) to 1300 ng/g dw (ridge 300 m S of factory). According to Remberger et al. (2004) concentrations decreased with increasing distance from the facility.

2.6.2 Asia

2.6.2.1 Wang et al. (2013)

Wang et al. (2013) investigated the presence and distribution of HBCD in farm soils in the Tongzhou region in southeast Beijing, China during 2010 and 2011. The region was predominantly mixed semi-rural and farm lands with increasing urbanization due to the rapid expansion of urban Beijing towards the outskirts. Surface soil sampling was conducted at three types of sites based on the irrigation source. Soil samples were collected from farms adjacent to the Liangshui River (7 sites) which receives treated waste water from WWTPs and effluents from various local industries. Each sample consisted of five subsamples. Additional samples were collected from farmlands (3 sites) that were further away from the river and utilized both wastewater and groundwater as an irrigation source. At two sites farmland that used only groundwater as a source of irrigation were chosen as controls. All samples were analyzed by HPLC-MS/MS detection operating in the atmospheric pressure chemical ionization (APCI) negative ion mode. The reported LODs for individual HBCD isomers were 8 pg for alpha-HBCD, 4 pg for beta-HBCD, and 2 pg for gamma-HBCD. Total HBCD was detected in 100% of the soil samples (n=120) ranging from 0.17 ng/g dw to 34.5 ng/g dw (median = 2.97 ng/g dw). According to Wang et al. (2013) there were no significant differences of HBCD levels among the different irrigation sources; however, the levels of HBCD were significantly higher in samples collected in 2011 than those collected in 2010.

2.6.2.2 Wang et al. (2009)

Wang et al. (2009) reported the presence of HBCD in topsoil in northeastern China during 2006 covering spatial variation between a range of urban and background locations. Soil samples were collected at 17 sites in and around Harbin City which included urban sites (9), suburban sites (4), rural sites (3), and background (1 site). At each site five topsoil subsamples were taken to a depth of 20 cm and combined

into one sample. All samples were analyzed by GC-MS detection operating in the ECNI. The alpha-HBCD concentrations representing the total HBCD were detected HBCD, because beta-HBCD and gamma-HBCD residues in the samples were most likely thermally isomerized to alpha-HBCD and/or degraded in the GC injection port. The reported LOD for total HBCD was 0.340 ng/g. The detection frequency was not reported. Concentrations of total HBCD in topsoil samples ranged from ND (0.340 ng/g dw) to 7.66 ng/g dw (median = 0.534 ng/g dw; mean = 1.750 ng/g dw). The highest concentrations of HBCD were found at suburban sites (school playground and new residential area). Although suburban sites, the source of the high levels may be due to emission from polyurethane foam (PUF)-containing furniture. According to Wang et al. (2009) HBCD was a dominant congener which was consistent with its high production volume in China. HBCD was not detected in background soils indicating urban areas as the source.

2.6.2.3 Li et al. (2016)

Li et al. (2016) investigated the levels, spatial distributions, and mass inventories of HBCD in paddy soils from the Liaohe River Basin in northeast China during 2010. Paddy soil samples were collected at 17 sampling sites using a stainless-steel scooper. All samples were analyzed by HPLC-MS/MS detection operating in the electrospray negative ionization mode. The reported LOQs for individual HBCD isomers were 0.07, 0.03, and 0.08 ng/g dw for alpha-HBCD, beta-HBCD, and gamma-HBCD, respectively. Concentrations of total HBCD ranged from ND (<0.08 ng/g dw) to 3.40 ng/g dw. According to Li et al. (2016) the spatial distributions of HBCD in paddy soils indicate that the local point-input was the major source. In addition, it was found that irrigation with river water was not the major transportation pathway of HBCD in paddy soils.

2.7 Ambient Air

2.7.1 North America

2.7.1.1 Hoh and Hites (2005)

Hoh and Hites (2005) studied spatial trends of total HBCD in outdoor air through the analysis of samples collected at five US sites for two years (2002 to 2003). The sites included an urban site in Chicago, Illinois, a semi-urban site in Indiana, an agricultural site in Arkansas, and remote sites in Michigan and Louisiana. Air samples were collected for 24-hours every 12 days. Gas- and particle-phase samples were collected using high-volume samplers fitted with either XAD-2 resin and a quartz fiber filter (Chicago site only) or with a PUF adsorbent and glass fiber filter (other four sites). All samples were analyzed using GC-MS operated in the ECNI mode. Total HBCD was detected in approximately 76% of the samples (120 of 156), in only in the particle phase. Total HBCD concentrations in outdoor air ranged from ND (<0.00007 ng/m³) to 0.011 ng/m³ (mean = 0.0012 ng/m³; median = 0.0005 ng/m³) at the remote Michigan site, from ND (<0.00013 ng/m³) to 0.0096 ng/m³ (mean = 0.0045 ng/m³; median = 0.0042 ng/m³) at the urban Chicago site, from ND (<0.00007 ng/m³) to 0.0036 ng/m³ (mean = 0.001 ng/m³; median = 0.00075 ng/m³) at the semi-urban Indiana site, from ND (<0.00013 ng/m³) to 0.011 ng/m³ (mean = 0.0016 ng/m³; median = 0.0004 ng/m³) at the agricultural Arkansas site, and from ND (<0.00013 ng/m³) to 0.0062 ng/m³ (mean = 0.0006 ng/m³; median = ND) at the remote Louisiana site. The highest mean and median values were from the Chicago site, suggesting that urban areas are the source of this compound. The highest individual concentration of total HBCD occurred at the Arkansas site, which could be attributed to manufacturing areas in southern Arkansas, as investigated using four-day backward air trajectories. The percent HBCD isomer composition of seven samples was variable.

2.7.1.2 Shoeib et al. (2014)

Shoeib et al. (2014) measured flame retardants in air samples collected from a semi-urban location (Environment Canada field site) located in Toronto, Canada, between 2010 and 2011. A total of 70 outdoor air samples (gas and particle phases) were collected using PS-1 type sampler and the sampling train consisted of a glass-fiber filter for collecting the particulate phase. Air samples were collected over a 24-hour sampling period and were analyzed for total HBCD using GC-MS using negative ion chemical ionization mode. Total HBCD was detected only in the particulate phase in 67% of the samples ($n = 70$) with concentrations that ranged ND (<0.00144 ng/m³) to 0.00469 ng/m³ (mean = 0.00139 ng/m³; median = 0.00097 ng/m³). According to Shoeib et al. (2014) these results were similar to mean observed in the east-central United States in 2002-2003 (Hoh and Hites, 2005).

2.7.2 Asia

2.7.2.1 Li et al. (2016)

Li et al. (2016) studied the occurrence and temporal trends of total HBCD in outdoor air for six consecutive years (2008 to 2013) through the analysis of samples collected in a typical urban atmosphere, Harbin, the capital city of Heilongjiang Province in the Northeastern China. During the multi-year sampling period construction of a subway system was ongoing. Air samples were collected nearly every week using high-volume air samplers with PUF applied to collect gas-phase samples and glass fiber filters (GFFs) applied to collect particle-phase samples. A total of 222 pair of gas-phase and particle-phase samples were collected. All samples were analyzed using GC-MS operated in the ECNI mode. The method detection limits ranged from 0.0027 to 0.0056 ng/m³. Total HBCD was detected in approximately 94% of the samples, in the gas-phase plus particle phase. Total HBCD concentrations in outdoor air ranged from ND to 3.4 ng/m³ (mean = 0.36 ng/m³; SD = 0.630 ng/m³; median = 0.088 ng/m³). The doubling times for HBCD increased rapidly in gas-phase (1.5 ± 0.63 years) and particle-phase (0.89 ± 0.05 years). According to Li et al. (2016) this increasing trend might be attributed to the increasing local usage of HBCD since the phase out of commercial PBDEs and/or because of long range atmospheric transport. Another explanation for the rapid increasing trend was the construction of the subway system which coincided with the sampling period. During the construction of the subway system thermal insulation building materials and electronics containing HBCDs may have been used.

2.8 Indoor Dust

2.8.1 North America

2.8.1.1 Stapleton et al. (2014)

Stapleton et al. (2014) measured flame retardants in hand wipe and house dust samples collected from 30 homes located in North Carolina during the spring of 2012. Dust samples were collected on both hardwood and carpeted floors by using a vacuum cleaner with a cellulose thimble inserted in the hose attachment. Samples were analyzed for flame retardants using GC-MS. Total HBCD was detected in all samples ($n = 30$), with concentrations ranging from 77.6 to 2,658 $\mu\text{g}/\text{kg}$ (geometric mean = 338 $\mu\text{g}/\text{kg}$). The results for hand wipes are provided in the Hand Wipe section in this Appendix.

2.8.1.2 Allgood et al. (2016)

Allgood et al. (2016) measured flame retardants in dust samples collected from elevated surfaces and floors at various locations on the campus of the University of California, Irvine during 2013. The microenvironments sampled included a bus, scientific laboratory, computer laboratory, gymnasium, and two each of domestic apartments, classrooms, and offices. The dust samples were collected by vacuum

cleaner using a crevice tool equipped with a cellulose thimble from elevated surfaces (i.e., sofas, book cases, desks, tables, chairs, and counter tops which were approximately 2 feet or higher from the floor) and strictly the floor. All samples were analyzed by ultra-performance liquid chromatography with tandem mass spectrometry detection using atmospheric pressure photoionization (UPLC-APPI-MS/MS). The reported detection limit was 1 ng/g. Total HBCD was detected in 100% of the elevated surface dust samples (n=10) and floor dust samples (n=10). Total HBCD concentrations ranged from 89 ng/g dw to 799 ng/g dw (median = 393 ng/g dw) in elevated surface dust and from 104 ng/g dw to 636 ng/g dw (median = 326 ng/g dw) in floor dust. Allgood et al. (2016) compared median concentrations of total HBCD in elevated surface dust and floor dust and reported a median ratio of 1.02 indicating similar elevated surface and floor dust concentrations. These findings were a notable exception to other flame retardant chemicals where median elevated surface dust concentrations were higher than floor dust concentrations. The authors indicated that these results should be interpreted cautiously because of the small sample size.

2.8.2 Europe

2.8.2.1 D'Hollander et al. (2010)

D'Hollander et al. (2010) measured flame retardants in dust samples collected from 43 homes (living room, bedroom, kitchen, and work area) and ten offices in Flanders, Belgium during 2008. The dust samples were collected from the bare floor or carpet by vacuum cleaner using a nylon sock mounted in the furniture attachment of the vacuum. All samples were analyzed by LC-MS/MS in the electrospray negative ionization mode. The reported LOQ was 5 ng/g for individual HBCD isomers. Total HBCD was detected in 100% of the house dust samples (n=43) and office dust samples (n=10). Total HBCD concentrations ranged from 5 ng/g dw to 42,692 ng/g dw (median = 130 ng/g dw; mean = 1,735 ng/g dw) in house dust and from 256 ng/g dw to 1153 ng/g dw (median = 367 ng/g dw; mean = 592 ng/g dw) in office dust. The 95th percentile HBCD concentration was reported as 4,447 ng/g dw in house dust and 1,092 ng/g dw in office dust. The HBCD pattern in both house and office dust is characterized by alpha-HBCD as the major isomer (59-72%), followed by gamma-HBCD (15-29%) and beta-HBCD (12-13%).

2.8.2.2 Sahlström et al. (2015)

Sahlström et al. (2015) measured flame retardants in dust samples collected from Swedish homes of first-time mothers that had participated in the Persistent Organic Pollutants in Uppsala Primiparas (POPUP) study during 2009-2010. The mothers were re-contacted when their children were about 11 months old and asked to participate in a follow-up study. House dust samples were collected on surfaces at least 1 meter above the floor in the living room, bedroom, kitchen, and/or hallway by vacuum cleaner using cellulose filters in styrene-acrylonitrile holders installed in the nozzle. All samples were analyzed by UPLC-MS/MS to determine the three major HBCD stereoisomers (alpha-, beta-, and gamma-HBCD). The method detection and quantification limit for HBCD were not reported. The individual HBCD isomers (alpha-, beta-, and gamma-HBCD) were each detected in 100% of the house dust samples (n=27). Total HBCD concentrations ranged from 20 ng/g dw to 6,000 ng/g dw (median = 110 ng/g dw; geometric mean = 161 ng/g dw) in house dust.

2.8.3 Asia

2.8.3.1 Qi et al. (2014)

Qi et al. (2014) measured flame retardants in 81 indoor dust samples collected from 45 residential homes (combination of living rooms, bedrooms, and kitchens) and 36 public places (libraries, offices, classrooms, supermarkets, and laboratories) in 23 provinces across China during the winter of 2010. Sample locations were considered urban (n=55) or rural (n=26). The dust samples were collected by

sweeping the floor with pre-cleaned brushes under desks, shelves, and beds, avoiding the influences of resident activities and sunlight. All samples were analyzed using GC-MS operated in the ECNI mode. The reported method detection limit was 2.7 ng/g. Total HBCD was detected in 98.8% of the indoor dust samples (n=81). Total HBCD concentrations ranged from ND (2.7 ng/g dw) to 6,100 ng/g dw (median = 120 ng/g dw; mean = 410 ng/g dw; SD = 830 ng/g dw) in indoor dust. The 5th and 95th percentile HBCD concentrations were reported as 9.6 ng/g dw and 1,600 ng/g dw, respectively. The three highest concentrations were found in an office in Beijing (6,100 ng/g dw), a warehouse in Jilin (3100 ng/g dw), and a school office in Harbin (2,100 ng/g dw). According to Qi et al. (2014) a relatively higher concentration of HBCD was found in public indoor dust samples than in residential indoor dust samples ($p < 0.05$). In addition, Qi et al. (2014) estimated the indoor dust ingestion dose, dermal absorption dose, and total daily exposure dose of total HBCD in indoor dust in China for five age groups (infants, toddlers, children, teenagers, and adults).

2.9 Indoor Air

2.9.1 Europe

2.9.1.1 Abdallah et al. (2008)

Abdallah et al. (2008) measured HBCD diastereoisomer and total HBCD concentrations in indoor air from homes, offices, and public microenvironments in Birmingham U.K from February 2007 to December 2007. Passive air samplers (i.e., PUF disks) were employed to provide a time-integrated sample over a 30 day sampling period. Samples were analyzed for HBCD isomers using LC-MS/MS and summed to provide total HBCD. Quality control measures taken included replicate analysis, field blanks, and procedural blanks. Total HBCD concentrations in indoor air ranged from 0.067 ng/m³ to 1.30 ng/m³ (mean = 0.250 ng/m³; st dev.=0.240 ng/m³, median = 0.180 ng/m³) for homes (n=33; taken from living rooms), 0.070 ng/m³ to 0.460 ng/m³ (mean = 0.180 ng/m³; st dev.=0.090 ng/m³, median = 0.170 ng/m³) for offices (n=25), and 0.820 ng/m³ to 0.960 ng/m³ (mean = 0.900 ng/m³; st dev.=0.060 ng/m³, median = 0.900 ng/m³) for public microenvironments (n=4; three pubs and one restaurant). Estimated human exposure to HBCDs via air inhalation based on concentrations reported in this study are based on the assumption that inhalation occurs pro-rata to typical activity patterns, i.e., for adults 63.8% home, 22.3% office, and 5.1% public microenvironments; for toddlers (6-24 months) 86.1% home and 5.1% public microenvironments. In the absence of data, 100% absorption of intake of HBCDs was assumed. For adult intake from air: 5th percentile=2.3 ng/day; average=5.0 ng/day; median=3.9 ng/day; 95th percentile=10.4 ng/day. For toddler intake from air: 5th percentile=0.5 ng/day; average=1.0 ng/day; median=0.8 ng/day; 95th percentile=2.1 ng/day.

2.9.2 Asia

2.9.2.1 Hong et al. (2016)

Hong et al. (2016) measured HBCD diastereoisomer and total HBCD concentrations in indoor and outdoor air samples collected from different locations within two industrialized cities (Guangzhou and Foshan) in Southern China. According to Hong et al. (2016), the HBCD production capacity in China was 7500 tonnes in 2007. A total of 37 indoor air samples (gas and particle phases) were collected from homes (n=12), offices (n=5), and other workplaces (n=10) between October 2004 and April 2005. Gas-phase samples were collected using a high-volume sampler and particle-phase samples were collected using PUF plugs. Indoor air samplers were placed at floor level. HBCD diastereoisomer determination was made using LC-MS/MS in electrospray ionization negative ion mode with multiple reaction monitoring. Quality control measures taken included duplicate sample collection, field blanks, procedural

blanks, and recovery experiments at multiple concentration levels. The gas- and particle-phase concentrations for alpha-, beta-, and gamma-HBCD and total HBCD in indoor air were calculated using a six-point calibration standard curve. Total HBCD mean concentrations (including gas- and particle-phase) were 0.00543 ng/m³ (0.00089-0.00847 ng/m³) and 0.00821 ng/m³ (0.00405-0.0160 ng/m³) for homes and offices, respectively. The total HBCD mean concentration for other workplaces (workplace type not specified) was significantly higher at 0.0482 ng/m³ (0.010-0.125 ng/m³). According to Hong et al. (2016), these total HBCD mean concentrations were slightly higher than or comparable with levels reported in remote or urban sites within the United States and are significantly lower than those reported in the European atmosphere. Further examination of the diastereoisomer profiles indicated that alpha-HBCD was the dominant isomer with a relative abundance ranging from 56.3% to 83.0% (mean value 73.6%) and that airborne HBCDs were predominantly present in the particulate phase. The study noted that the variation in HBCD distribution in the gas and particulate phases was greater in indoor air samples than outdoor samples. The study concluded with estimating average daily human exposure to HBCDs via inhalation of indoor and outdoor air using the measured indoor and outdoor total HBCD concentrations from this study.

2.10 Human Milk

2.10.1 North America

2.10.1.1 Carignan et al. (2012)

Carignan et al. (2012) studied the levels of HBCD in human milk samples collected from 43 first-time mothers, 18 years or older, who had lived in the Greater Boston, Massachusetts area for at least 3 years at the time of delivery. Each participant provided a single human milk sample 2 to 8 weeks postpartum between April 2004 and January 2005. Most of the women used an electric or manual milk pump to collect the sample. Once the samples were collected, they were stored at -20 °C until they were shipped to the University of Birmingham in 2010 and subsequently analyzed by liquid chromatography-electrospray ionization-tandem mass spectrometry (LC-ESI-MS/MS) for HBCDs (the α , β , and γ diastereomers). Concentrations detected in milk were lipid-adjusted and Σ HBCD was calculated as the sum of α -, β -, and γ -HBCD. Levels of Σ HBCDs ranged from 0.360 to 8.10 μ g/kg lw (geometric mean = 1.02 μ g/kg lw) where α -HBCD was the dominant diastereomer. The participants filled out a questionnaire that was used to identify possible predictors of exposure to HBCD. The number of stereo and video electronics (e.g., TVs, CD player, DVD player, stereos, etc.) in the home was positively associated with body burdens of Σ HBCDs. The HBCDs levels detected in the milk of first-time mothers in this study were comparable to those measured in several other countries. The results suggest that the estimated body burdens are related to lifestyle factors, potentially including diet and domestic electronics.

2.10.2 Europe

2.10.2.1 Tao et al. (2017)

Tao et al. (2017) studied the levels of HBCD in human milk samples collected from two groups of women. The first group of samples (n=25) were collected in 2010 and later obtained from an archived milk bank at Birmingham Women's Hospital. The milk came from primiparous mothers during their first three months of lactation. The second group of samples (n = 10) were collected between August 2014 and May 2015 from mothers during their first three months of lactation and living in Southampton, UK. The second group of mothers were participating in the Breast milk, Environment, Early-life, and Development (BEED) study. Each sample from both groups comprised of approximately 50 mL of milk, was freeze dried, and remained in frozen storage (-20°C) until prepped for analysis by GC-MS operated in ECNI

mode. Measured concentrations of Σ HBCD in human milk ranged from 1.04 to 22.4 $\mu\text{g}/\text{kg}$ lw (mean = 5.95 $\mu\text{g}/\text{kg}$ lw, median = 3.83 $\mu\text{g}/\text{kg}$ lw) and 0.69 to 7.1 $\mu\text{g}/\text{kg}$ lw (mean = 3.2 $\mu\text{g}/\text{kg}$ lw; median = 2.9 $\mu\text{g}/\text{kg}$ lw) for groups 1 and 2, respectively. The study authors indicated that levels of HBCD found in the human milk samples exhibited a similar downward trend to UK indoor air and dust samples collected between 2006 and 2007 (similar period for group 1) and samples collected between 2013 and 2015 (similar period for group 2). The authors estimated the dietary intake for a 1 month old infant using the group 2 milk samples and compared those results to the previously reported dietary intake of nursing infants from the first group. The comparison resulted in no substantial differences between the two intake values.

2.10.2.2 Antignac et al. (2016)

Antignac et al. (2016) studied the presence of a number of persistent organic pollutants (POPs) in human milk collected from French (n= 96), Danish (n= 438), and Finnish women (n= 22). The French women participating in a study from 2011 to 2014, provided milk samples collected between 1 and 2 months postnatally. The Danish and Finnish women participating in two separate cohort studies from 1997 and 2002, provided milk samples collected 1 to 3 months postnatally. The Danish and Finnish milk samples were collected as several small aliquots. All of the samples were stored frozen at -20 °C until analyzed for HBCD isomers by LC-MS/MS. French women were found to have higher levels (approximately 2-fold) of α -HBCD (from 0.22 to 4.21 $\mu\text{g}/\text{kg}$ lw; median = 0.56 $\mu\text{g}/\text{kg}$ lw) compared to Danish women (from 0.02 to 28.7 $\mu\text{g}/\text{kg}$ lw; median = 0.31 $\mu\text{g}/\text{kg}$ lw) or Finnish women (from 0.03 to 2.19; median = 0.31 $\mu\text{g}/\text{kg}$ lw). Although the women had a similar age at the time of sampling, due to differing sampling periods, on average, the French women were born approximately 10 years later than the other women.

2.11 Human Serum

2.11.1 Europe

2.11.1.1 Kalantzi et al. (2011)

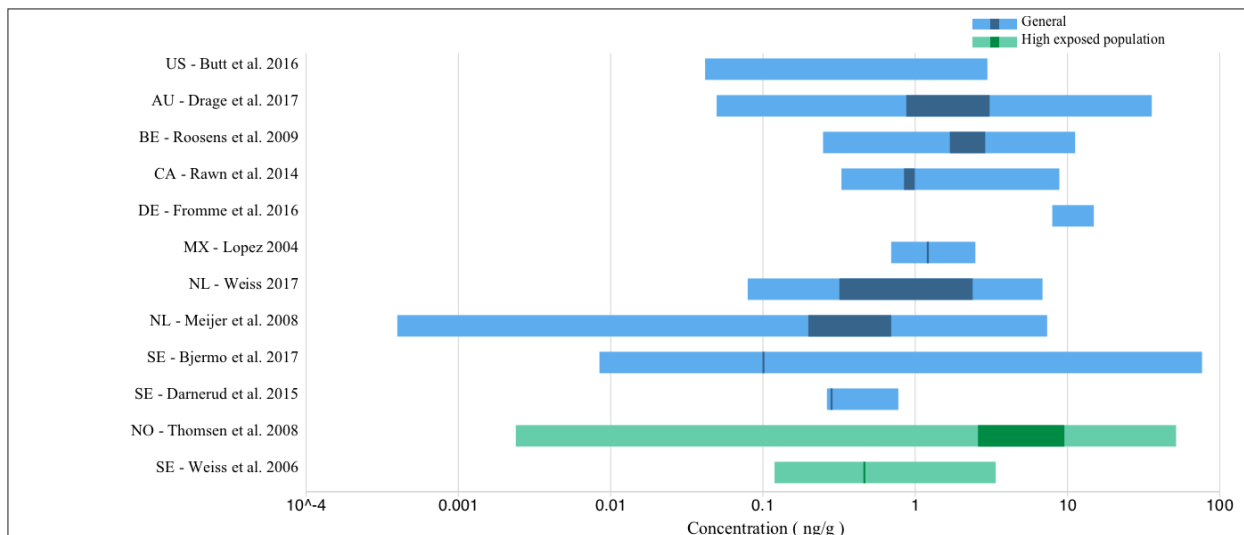
Kalantzi et al. (2011) investigated the levels of HBCD in human serum of 61 individuals (27 females and 34 males, 20-65 years old) residing in the Attika region of Greece between June and October 2007. Serum samples were collected from full-time computer clerks of a large computer company (n=30) and from a separate population (n=31) with no computer use. All samples were analyzed using GC-MS operated in the ECNI mode. The reported limit of quantification was 1.0 ng/g lw. Quality control measures taken included duplicate sample collection, field blanks, procedural blanks, and recovery experiments at multiple concentration levels. HBCD was detected in 70% of the samples (43 of 61). HBCD concentrations in human serum ranged from 0.49 $\mu\text{g}/\text{kg}$ lw to 38.8 ng/g lw (mean = 3.39 $\mu\text{g}/\text{kg}$ lw; median = 1.32 $\mu\text{g}/\text{kg}$ lw; SD=6.85 $\mu\text{g}/\text{kg}$ lw). There was a significant difference between males and females with regards to HBCD (p=0.044) but females from both groups had lower HBCD concentrations than males (median of 0.71 $\mu\text{g}/\text{kg}$ lw, compared to 1.44 $\mu\text{g}/\text{kg}$ lw for males).

3 Overview of Human Biomonitoring

EPA/OPPT summarized data from human biomonitoring in various matrices. HBCD has been reported in many matrices in many countries over time.

3.1 Blood

3.1.1 Blood ng/g chart



3.1.2 Blood (ng/g) Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
3350486	{Butt, 2016, 3350486}	0.042	3		
3545935	{Drage, 2017, 3545935}	0.05	36	0.88	3.1
787720	{Roosens, 2009, 787720}	0.25	11.3	1.7	2.9
2238553	{Rawn, 2014, 2238553}	0.33	8.9	0.85	1
3127742	{Fromme, 2016, 3127742}	8	15		
3986475	{Lopez, 2004, 3986475}	0.7	2.5	1.2	1.2
3969313	{Weiss, 2017, 3969313}	0.08	6.9	0.32	2.4
787696	{Meijer, 2008, 787696}	0.0004	7.4	0.2	0.7
3545919	{Bjermo, 2017, 3545919}	0.0085	77	0.1	0.1
2936564	{Darnerud, 2015, 2936564}	0.265	0.78	0.28	0.28
1927761	{Thomsen, 2008, 1927761}	0.0024	52	2.6	9.6
787751	{Weiss, 2006, 787751}	0.12	3.4	0.46	0.46

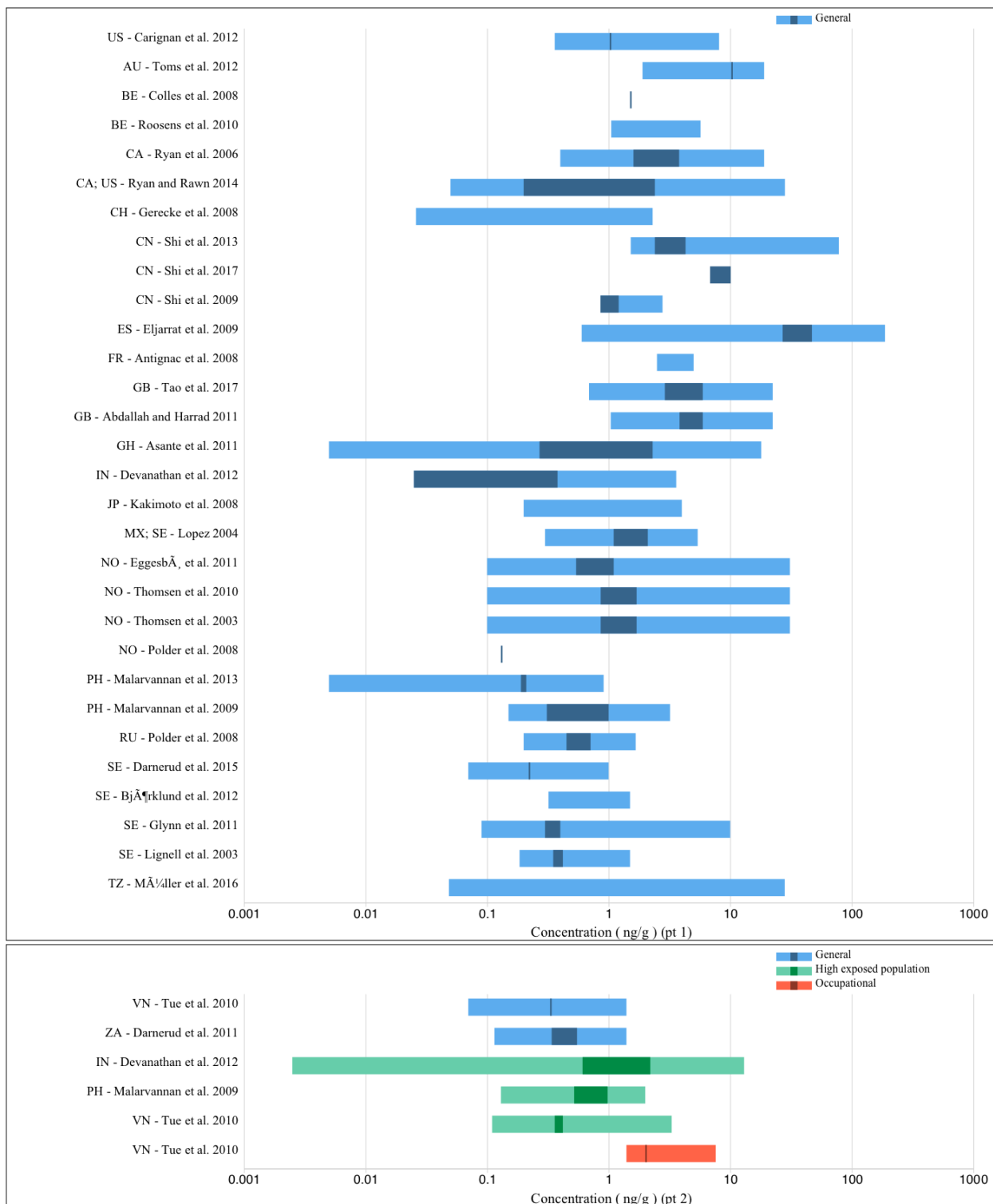
3.1.3 Human Blood (ng/g): Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid								
{Butt, 2016, 3350486}	US	General	2008 - 2010	43	0.07	0.084	1.9	Medium
{Drage, 2017, 3545935}	AU	General	2002 - 2015	63	0.73	N/R	1.4	High
{Roosens, 2009, 787720}	BE	General	2007	9	0.56	0.5	1.4	High
{Rawn, 2014, 2238553}	CA	General	2007 - 2009	57	1	0.004	1.3	High
{Fromme, 2016, 3127742}	DE	General	2013	42	0.09	16	1.8	Medium
{Lopez, 2004, 3986475}	MX	General	2003	5	N/R	N/R	2.1	Medium
{Weiss, 2017, 3969313}	NL	General	2004	90	N/R	0.16	1.6	High
{Meijer, 2008, 787696}	NL	General	2001 - 2002	81	0.89	0.0016	1.8	Medium
{Bjermo, 2017, 3545919}	SE	General	2010 - 2011	170	0.61	0.5	1.6	High
{Darnerud, 2015, 2936564}	SE	General	1996 - 2010	36	0.11	0.48	1.8	Medium
{Thomsen, 2008, 1927761}	NO	High exposed population	2004 - 2005	49	0.75	0.0048	1.5	High
{Weiss, 2006, 787751}	SE	High exposed population	2000	50	N/R	0.24	1.4	High

[Rawn et al. \(2014b\)](#) used surplus blood serum samples originally collected as part of the Canadian Health Measures Survey (CHMS) to prepare composite pooled serum samples to increase the number of samples with detectable levels of a number of classes of POPs, including flame retardants. Approximately 5,000 individual serum samples collected between 2007 and 2009 were used to form 59 composite pooled samples. The pooled samples were categorized by sex and five age groups ranging from 6 to 79 years. Overall, total HBCD concentrations ranged 0.33-8.9 $\mu\text{g}/\text{kg}$ lw (mean = 1.0 $\mu\text{g}/\text{kg}$ lw; geometric mean = 0.85 $\mu\text{g}/\text{kg}$ lw). Study authors reported that there were no differences in total HBCD concentration associated with age or sex.

3.2 Breast Milk

3.2.1 Breast milk Chart



3.2.2 Breast Milk Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1927577	{Carignan, 2012, 1927577}	0.36	8.1	1.02	1.02
1927589	{Toms, 2012, 1927589}	1.9	19	10.2	10.2
1061439	{Colles, 2008, 1061439}			1.5	1.5
1927679	{Roosens, 2010, 1927679}	1.05	5.7		
3445832	{Ryan, 2006, 3445832}	0.4	19	1.6	3.8
2343679	{Ryan, 2014, 2343679}	0.05	28.2	0.2	2.4
1927965	{Gerecke, 2008, 1927965}	0.026	2.3		
1927559	{Shi, 2013, 1927559}	1.52	78.28	2.4	4.29
3828886	{Shi, 2017, 3828886}			6.83	10.1
1927708	{Shi, 2009, 1927708}	0.857	2.776	0.857	1.209
1927715	{Eljarrat, 2009, 1927715}	0.6	188	27	47
787643	{Antignac, 2008, 787643}	2.5	5		
3862906	{Tao, 2017, 3862906}	0.69	22.37	2.9	5.95
787631	{Abdallah, 2011, 787631}	1.04	22.37	3.83	5.95
1927640	{Asante, 2011, 1927640}	0.005	18	0.27	2.3
1927618	{Devanathan, 2012, 1927618}	0.025	3.6	0.025	0.38
787682	{Kakimoto, 2008, 787682}	0.2	4		
3986475	{Lopez, 2004, 3986475}	0.3	5.4	1.1	2.1
787656	{EggesbÃ¶, 2011, 787656}	0.1	31	0.54	1.1
1927695	{Thomsen, 2010, 1927695}	0.1	31	0.86	1.7
3809230	{Thomsen, 2003, 3809230}	0.1	31	0.86	1.7
786310	{Polder, 2008, 786310}			0.13	0.13
1927568	{Malarvannan, 2013, 1927568}	0.005	0.91	0.19	0.21
116881	{Malarvannan, 2009, 116881}	0.15	3.2	0.31	1
1061432	{Polder, 2008, 1061432}	0.2	1.67	0.45	0.71
2936564	{Darnerud, 2015, 2936564}	0.07	1	0.22	0.22
1927616	{BjÃ¶rklund, 2012, 1927616}	0.32	1.5		
1061450	{Glynn, 2011, 1061450}	0.09	10	0.3	0.4
3809248	{Lignell, 2003, 3809248}	0.185	1.5	0.35	0.42
3350490	{MÃ¼ller, 2016, 3350490}	0.0485	28.1		
1927687	{Tue, 2010, 1927687}	0.07	1.4	0.33	0.33
787654	{Darnerud, 2011, 787654}	0.115	1.4	0.34	0.55
1927618	{Devanathan, 2012, 1927618}	0.0025	13	0.61	2.2

116881	{Malarvannan, 2009, 116881}	0.13	2	0.52	0.98
1927687	{Tue, 2010, 1927687}	0.11	3.3	0.36	0.42
1927687	{Tue, 2010, 1927687}	1.4	7.6	2	2

3.2.3 Breast Milk: Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid								
{Carignan, 2012, 1927577}	US	General	2004 - 2005	43	1	0.036	1.2	High
{Toms, 2012, 1927589}	AU	General	1993 - 2009	13	0.69	3.8	1.8	Medium
{Colles, 2008, 1061439}	BE	General	2008	1	1	N/R	2.6	Low
{Roosens, 2010, 1927679}	BE	General	2006	22	0.27	2.1	1.8	Medium
{Ryan, 2006, 3445832}	CA	General	2002 - 2003	8	N/R	N/R	2.1	Medium
{Ryan, 2014, 2343679}	CA; US	General	1989 - 2005	109	0.78	0.1	1.8	Medium
{Gerecke, 2008, 1927965}	CH	General	2003 - 2007	36	N/R	N/R	1.8	Medium
{Shi, 2013, 1927559}	CN	General	2011	103	N/R	N/R	1.6	High
{Shi, 2017, 3828886}	CN	General	2011	29	1	0.01	1.8	Medium
{Shi, 2009, 1927708}	CN	General	2007	24	0.92	N/R	1.6	High
{Eljarrat, 2009, 1927715}	ES	General	2006 - 2007	33	0.91	3.8	1.3	High
{Antignac, 2008, 787643}	FR	General	2004 - 2005	23	0.3	N/R	1.6	High

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid								
{Tao, 2017, 3862906}	GB	General	2010 - 2015	35	N/R	N/R	1.1	High
{Abdallah, 2011, 787631}	GB	General	2010	34	1	N/R	1.6	High
{Asante, 2011, 1927640}	GH	General	2004 - 2009	67	N/R	0.01	1.8	Medium
{Devanathan, 2012, 1927618}	IN	General	2009	17	N/R	0.05	1.9	Medium
{Kakimoto, 2008, 787682}	JP	General	1973 - 2006	18	0.83	0.4	1.3	High
{Lopez, 2004, 3986475}	MX; SE	General	2003	12	N/R	N/R	2.1	Medium
{EggesbÃfÃ., 2011, 787656}	NO	General	2003 - 2006	193	0.68	N/R	2.0	Medium
{Thomsen, 2010, 1927695}	NO	General	2003 - 2005	310	0.57	0.2	1.4	High
{Thomsen, 2003, 3809230}	NO	General	2003 - 2005	310	0.57	0.2	1.9	Medium
{Polder, 2008, 786310}	NO	General	2000 - 2002	10	0.1	0.05	1.7	Medium
{Malarvannan, 2013, 1927568}	PH	General	2008	30	N/R	0.01	1.8	Medium
{Malarvannan, 2009, 116881}	PH	General	2004	11	1	N/R	1.3	High
{Polder, 2008, 1061432}	RU	General	2000	37	0.3	N/R	1.8	Medium
{Darnerud, 2015, 2936564}	SE	General	2010	30	0.97	N/R	1.8	Medium
{BjÃfÃ¶rklund, 2012, 1927616}	SE	General	2008 - 2009	18	0.17	N/R	1.9	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid								
{Glynn, 2011, 1061450}	SE	General	2000 - 2004	295	0.77	N/R	1.7	Medium
{Lignell, 2003, 3809248}	SE	General	2002 - 2003	30	0.8	0.37	2.1	Medium
{Müller, 2016, 3350490}	TZ	General	2012	1	0.4	N/R	1.9	Medium
{Tue, 2010, 1927687}	VN	General	2007	9	N/R	N/R	1.8	Medium
{Darnerud, 2011, 787654}	ZA	General	2004	14	0.93	0.006	1.6	High
{Devanathan, 2012, 1927618}	IN	High exposed population	2009	8	1	0.05	1.9	Medium
{Malarvannan, 2009, 116881}	PH	High exposed population	2004	22	1	N/R	1.3	High
{Tue, 2010, 1927687}	VN	High exposed population	2007	24	N/R	N/R	1.8	Medium
{Tue, 2010, 1927687}	VN	Occupational	2007	9	N/R	N/R	1.8	Medium

3.2.4 North America

As reported in [NICNAS \(2012\)](#) and [EC \(2008\)](#), [López et al. \(2004\)](#) measured HBCD in human milk samples from seven indigenous women in Mexico (date of sampling not specified). Total HBCD concentrations ranged from 0.8 to 5.4 µg/kg lw (mean = 2.1 µg/kg lw).

HBCD was measured in human milk samples collected 2004-2005 from 43 first-time mothers in the Greater Boston, Massachusetts area ([Carignan et al., 2012](#)). The participants were 18 years of age or older, lived in the Greater Boston area for at least 3 years, spoke Spanish or English, and had pregnancies that were healthy and singlet. One sample was collected from each participant 2-8 weeks postpartum. Samples were analyzed for HBCD using HPLC-MS/MS with ESI in the negative mode. In human milk, total HBCD was detected in all analyzed samples in concentrations ranging from 0.360 to 8.10 µg/kg lw (geometric mean = 1.02 µg/kg lw).

[Ryan and Rawn \(2014\)](#) measured flame retardants in human milk samples collected from individuals residing in various regions across Canada, between 1992 and 2005. In addition, comparative milk samples were collected in the United States from residents of Austin, TX in 2002 and 2004. The U.S. samples were collected in 2002 (n = 10) and 2004 (n = 25) from the mother's milk bank at Austin, TX. The milk samples (n = 18) from Ontario, obtained in 2002 as well as samples in 2005 (n = 34), all originated from the hospital clinic at McMaster University, Hamilton, Ontario. Samples were analyzed for the flame retardants using either isotope dilution GC-MS or LC-MS/MS with ESI in the negative mode. Total HBCD ranged from ND to 2.2 µg/kg lw in 2002 and 2004 samples (n = 35) from the United States and from ND to 28.2 µg/kg lw in 2002 and 2005 samples (n = 52) from Canada.

3.2.5 Europe

The Australian risk assessment ([NICNAS, 2012](#)) provided a relatively comprehensive compilation of HBCD concentrations in human milk samples collected in Europe, as reported from fourteen studies ([Eggesbo et al., 2011](#); [Glynn et al., 2011](#); [Abdallah and Harrad, 2010](#); [Thomsen et al., 2010](#); [Eljarrat et al., 2009](#); [Polder et al., 2008b](#); [Polder et al., 2008a](#); [Colles et al., 2008](#); [Fangstrom et al., 2008](#); [Lignell et al., 2005](#); [López et al., 2004](#); [Lignell et al., 2003](#); [Thomsen et al., 2003](#); [Aune et al., 2001](#)). The studies encompass six countries (Belgium, Norway, Russia, Spain, Sweden, and the United Kingdom) with sampling dates ranging from 1980 to 2009. Some of these studies are also summarized in the other international risk assessments. One of the European studies [Fangstrom et al. \(2008\)](#), examined HBCD concentrations over time in human milk pooled from 15-116 Swedish subjects. The results show mean concentrations of total HBCD ranging from 0.084 µg/kg lw in 1980 to 0.39 µg/kg lw in 2004. The peak HBCD concentration of 0.60 µg/kg lw was observed in 2002. The study generally shows that HBCD levels have increased since HBCD began to be widely used as a brominated flame retardant in the 1980s. The highest concentrations were observed in the study by [Eljarrat et al. \(2009\)](#), in which HBCD was measured in milk samples collected from women in Spain (Catalonia) in 2006 to 2007 (ND to 188 µg/kg lw, mean = 47 µg/kg lw; median = 27 µg/kg lw). High concentrations were also observed in the United Kingdom from the [Abdallah and Harrad \(2010\)](#) study (1.04 to 22.37 µg/kg lw; mean = 5.95 µg/kg lw; median = 3.83 µg/kg lw). [NICNAS \(2012\)](#) selected the 75th percentile (6.9 µg/kg lw) and 95th percentile (16.0 µg/kg lw) from the [Abdallah and Harrad \(2010\)](#) data to represent typical and worst-case values, respectively. In Russia ([Polder et al., 2008b](#)), HBCD was detected in human milk samples collected in 2000 and 2002 from 37 subjects at 0.20 to 1.67 µg/g (means = 0.47-0.71 µg/g; medians = 0.45-0.62 µg/g). For the remaining studies, HBCD concentrations in human milk collected since the year 2000 ranged from ND to 31 µg/kg lw (means/medians = ND-1.5 µg/kg lw).

Additionally, [Law et al. \(2014\)](#) reported the results of the [Roosens et al. \(2010\)](#) study, which measured HBCD in 22 pooled human milk samples collected from mothers in Belgium in 2006. Total HBCD ranged from ND to 5.7 µg/kg lw.

HBCD was measured in human milk samples collected 2010-2011 from 10 first-time mothers from Birmingham, United Kingdom ([Harrad and Abdallah, 2015](#)). The participants were between 18 and 35 years of age. One sample was collected from each participant per month for the 12-month duration of the study. Samples were analyzed for HBCD using LC-MS/MS with ESI in the negative mode. In human milk, total HBCD was detected in all analyzed samples (n = 120) in concentrations ranging from 1.46 to 20.65 µg/kg lw.

3.2.6 Asia

[Kakimoto et al. \(2008\)](#), as cited in [NICNAS \(2012\)](#), examined the level of total HBCD in pooled breast milk from 13 to 35 Japanese subjects aged 25-29 years and/or 30+ years per year between 1973 and 2006. HBCD was not detected in samples from 1973, 1978 or 1983. Mean HBCD concentrations ranged from 0.43 to 4.0 $\mu\text{g}/\text{kg}$ lw between 1988 and 2006. The results did not show a consistent pattern of increase or decrease of HBCD concentration with maternal age. As cited in [NICNAS \(2012\)](#), levels of HBCD were measured in 33 mother's milk samples collected in 2004 in the Philippines ([Malarvannan et al., 2009](#)). Total HBCD concentrations ranged from 0.13 to 3.2 $\mu\text{g}/\text{kg}$ lw (mean = 0.86 $\mu\text{g}/\text{kg}$ lw; median = 0.62 $\mu\text{g}/\text{kg}$ lw). [NICNAS \(2012\)](#) also reported HBCD levels from samples collected near e-waste recycling and dismantling sites in Vietnam ([Tue et al., 2010](#)). Reference site samples showed HBCD concentrations of 0.070 to 1.4 $\mu\text{g}/\text{kg}$ lw (median = 0.33 $\mu\text{g}/\text{kg}$ lw) in nine samples. Concentrations from workers and non-workers at e-waste sites ranged from 0.11 to 7.6 $\mu\text{g}/\text{kg}$ lw (median = 0.36 to 2.0 $\mu\text{g}/\text{kg}$ lw) in 24 samples.

As cited in [Law et al. \(2014\)](#), the median HBCD concentration from 30 mother's milk samples collected in 2008 the Philippines was 0.19 $\mu\text{g}/\text{kg}$ lw ([Malarvannan et al., 2013](#)).

3.2.7 Australia

[Toms et al. \(2012\)](#) measured levels of HBCD in 12 pooled mother's milk samples collected 1993-2009 for time trends in Australia. As cited in [Law et al. \(2014\)](#), total HBCD residues ranged from ND to 19.0 $\mu\text{g}/\text{kg}$ lw. HBCD concentrations in human milk showed no temporal trend.

3.2.8 Africa

[Asante et al. \(2011\)](#) and [Darnerud et al. \(2011\)](#) measured levels of total HBCD in mother's milk samples from Ghana and South Africa in 2004-2009. As cited in [Law et al. \(2014\)](#), median levels of total HBCD were 0.62-1.0 and 0.3 $\mu\text{g}/\text{kg}$ lw, respectively. No significant increases of HBCD concentrations were observed from 2004-2009 in human milk samples from Ghana.

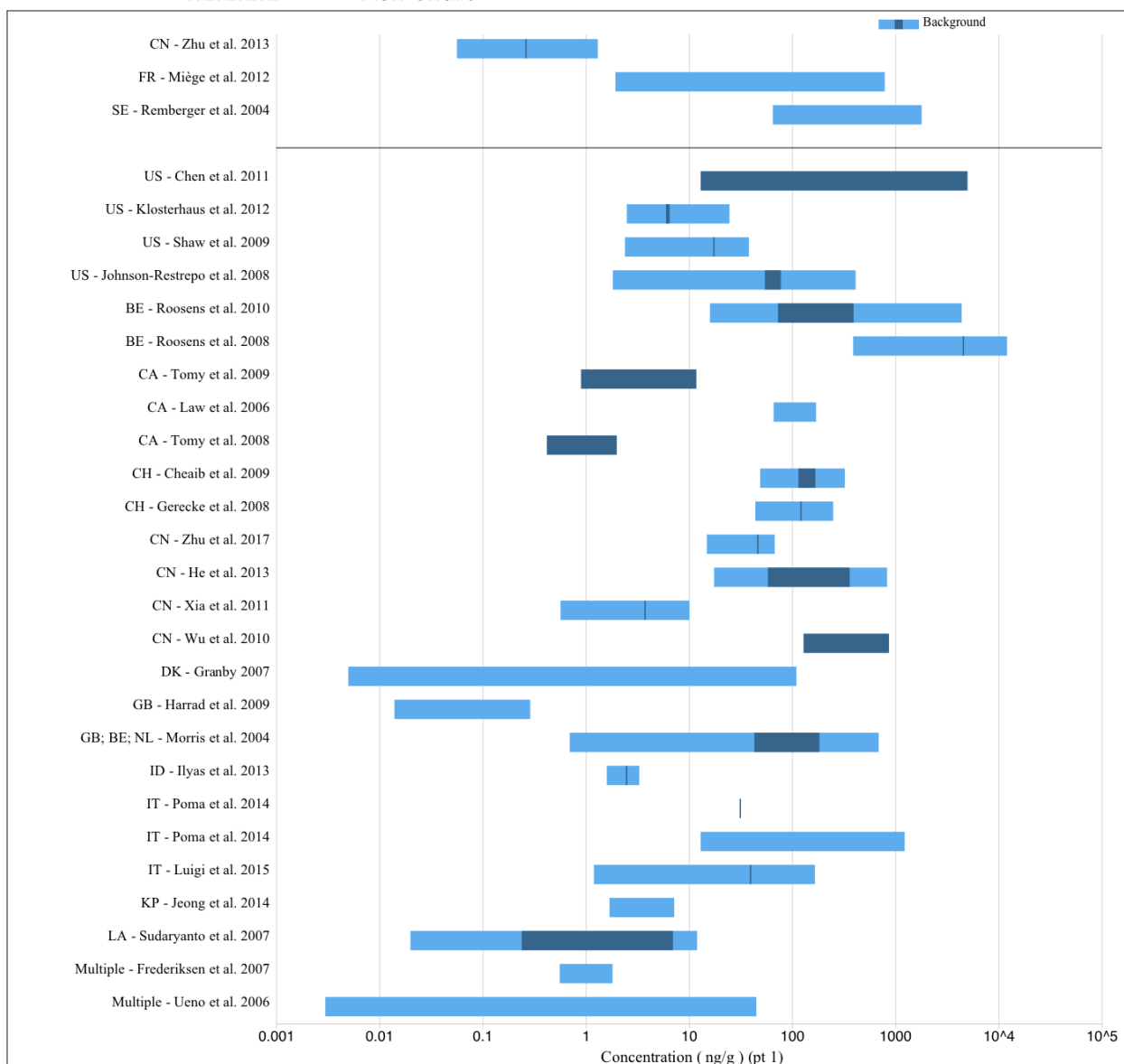
4 Overview of Wildlife Biota Summary

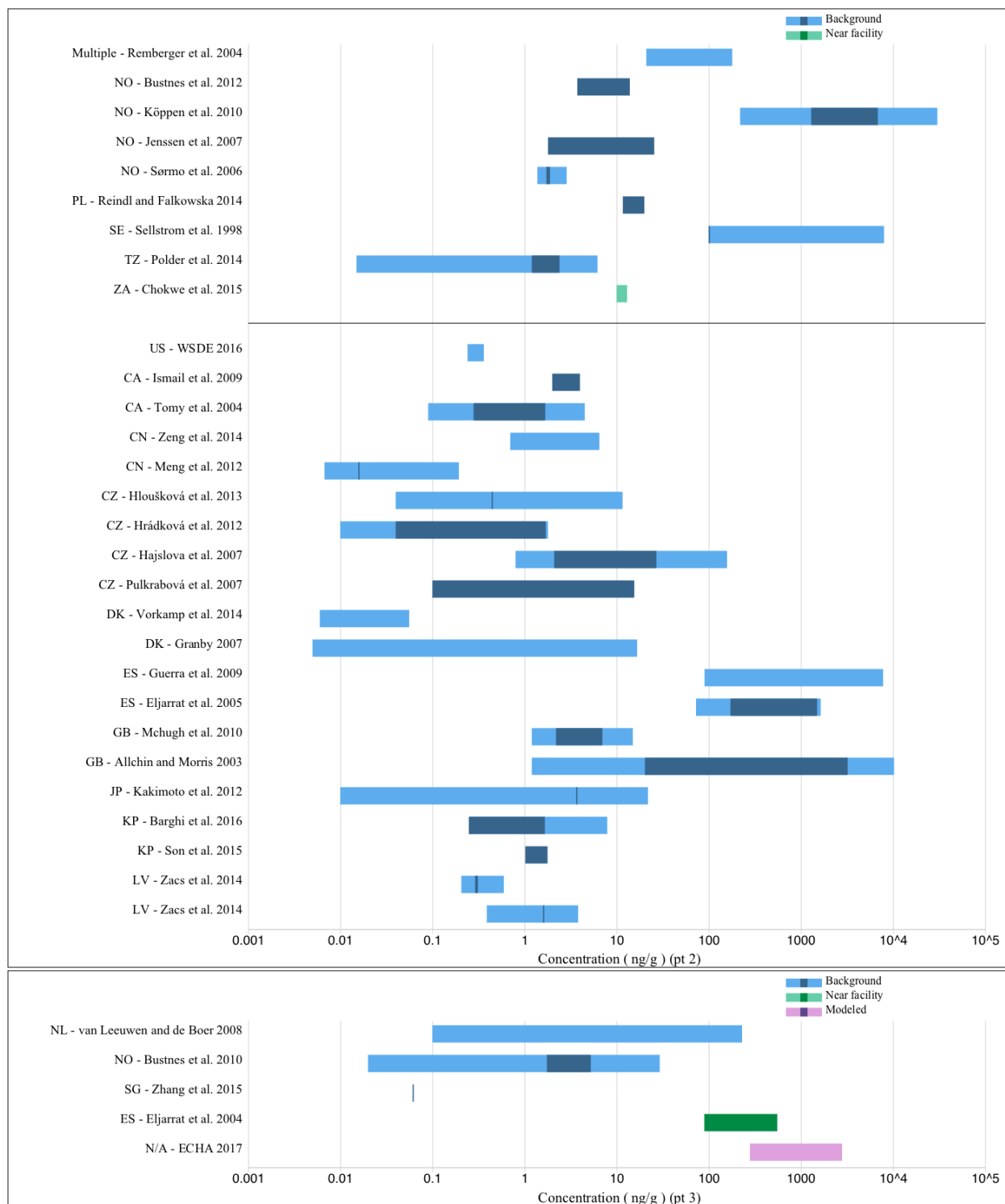
Over 100 studies have reported HBCD concentrations in wildlife biota. In this section concentrations are reported in terms of lipid weight (lw) when provided. Dry weight (dw) or wet weight (ww) units may also be reported available for some studies but are not provided below.

4.1 Fish

4.1.1 Wildlife Biota

4.1.1.1.1 Fish Chart





4.1.1.1.2 Fish Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1927543	{Zhu, 2013, 1927543}	0.0565	1.31	0.26	0.26
1441147	{MiÄ“ge, 2012, 1441147}	1.94	790.6		
1927826	{Remberger, 2004, 1927826}	65	1800		
1927627	{Chen, 2011, 1927627}			13	5010
1443796	{Klosterhaus, 2012, 1443796}	2.5	24.7	6	6.5
1443830	{Shaw, 2009, 1443830}	2.4	38.1	17.2	17.2
1927767	{Johnson-Restrepo, 2008, 1927767}	1.83	413	54.5	77.7
1927683	{Roosens, 2010, 1927683}	16	4397	73	394
1927747	{Roosens, 2008, 1927747}	390	12100	4500	4500
1279130	{Tomy, 2009, 1279130}			0.9	11.8
999306	{Law, 2006, 999306}	66.18	170.61		
1443836	{Tomy, 2008, 1443836}			0.42	2
1927722	{Cheaib, 2009, 1927722}	49	324	115	168
1927965	{Gerecke, 2008, 1927965}	44	250	120	120
3546047	{Zhu, 2017, 3546047}	14.9	67.8	45.9	45.9
1927551	{He, 2013, 1927551}	17.5	832	58.3	361
1927654	{Xia, 2011, 1927654}	0.57	10.1	3.7	3.7
1927678	{Wu, 2010, 1927678}			129	868
3986479	{Granby, 2007, 3986479}	0.005	110		
1927694	{Harrad, 2009, 1927694}	0.014	0.29		
1927817	{Morris, 2004, 1927817}	0.7	690	43	184
2149566	{Ilyas, 2013, 2149566}	1.6	3.3	2.45	2.45
2343685	{Poma, 2014, 2343685}			31	31
2343698	{Poma, 2014, 2343698}	13	1232		
2919854	{Luigi, 2015, 2919854}	1.2	166.3	38.94	38.94
2343722	{Jeong, 2014, 2343722}	1.7	7.2		
4158939	{Sudaryanto, 2007, 4158939}	0.02	12	0.24	7
3575380	{Frederiksen, 2007, 3575380}	0.56	1.82		
1927796	{Ueno, 2006, 1927796}	0.003	45		
1927826	{Remberger, 2004, 1927826}	21	180		
1927591	{Bustnes, 2012, 1927591}			3.74	13.9
1927674	{KÄ“ppen, 2010, 1927674}	218.9	30316.8	1295.9	6845.9
1927762	{Jenssen, 2007, 1927762}			1.8	25.6
1927787	{SÄ“rmo, 2006, 1927787}	1.38	2.87	1.73	1.89
2528326	{Reindl, 2014, 2528326}			11.68	20
1715539	{Sellstrom, 1998, 1715539}	100	8000	100	100
2343683	{Polder, 2014, 2343683}	0.015	6.2	1.2	2.4

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3350535	{Chokwe, 2015, 3350535}	10	13		
3982306	{WSDE, 2016, 3982306}	0.242	0.362	0.242	0.243
1443833	{Ismail, 2009, 1443833}			2	4
1927822	{Tomy, 2004, 1927822}	0.09	4.51	0.28	1.68
2343681	{Zeng, 2014, 2343681}	0.7	6.5		
1927604	{Meng, 2012, 1927604}	0.00675	0.194	0.0157	0.0157
1927549	{HlouÅ;kovÅ;, 2013, 1927549}	0.04	11.6	0.44	0.44
1927635	{HrÅ;dkovÅ;, 2012, 1927635}	0.01	1.8	0.04	1.7
1927955	{Hajslova, 2007, 1927955}	0.8	158	2.1	27
1927763	{PulkrabovÅ;, 2007, 1927763}			0.1	15.55
2343732	{Vorkamp, 2014, 2343732}	0.006	0.056		
3986479	{Granby, 2007, 3986479}	0.005	16.7		
3575325	{Guerra, 2009, 3575325}	90	7813		
1927819	{Eljarrat, 2005, 1927819}	72.8	1643	172	1501
1927686	{Mchugh, 2010, 1927686}	1.2	15	2.2	7
3809206	{Allchin, 2003, 3809206}	1.2	10275	20.3	3216
1927593	{Kakimoto, 2012, 1927593}	0.01	21.9	3.64	3.64
3350483	{Barghi, 2016, 3350483}	0.24883	7.91491	0.24883	1.66372
3350528	{Son, 2015, 3350528}			1.02	1.78
2528323	{Zacs, 2014, 2528323}	0.206	0.597	0.291	0.312
2343713	{Zacs, 2014, 2343713}	0.39	3.82	1.59	1.59
1927756	{van, 2008, 1927756}	0.1	230		
1274407	{Bustnes, 2010, 1274407}	0.02	29.4	1.75	5.24
3350497	{Zhang, 2015, 3350497}			0.061	0.061
999290	{Eljarrat, 2004, 999290}			89.5	554.4
3970753	{ECHA, 2017, 3970753}	280	2800		

4.1.1.1.3 Fish: Supporting Data

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry									
{Zhu, 2013, 1927543}	CN	Background	(Oxygymnocypris stewartii, Schizopygopsis younghusbandi, Schizothorax macropogon, Schizothorax o'connori, Schizothorax waltoni, Gymoncypris waddellii, Gymoncypris przewalskii and Racoma tibetanus	2007 - 2011	52	0.65	0.11	1.3	High
{Miège, 2012, 1441147}	FR	Background	Barbel, common bream, white bream and chub (whole specimen)	2008 - 2009	32	1	0.36	1.7	Medium
{Remberger, 2004, 1927826}	SE	Background	Pike (muscle)	2000	4	1	N/R	1.8	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Chen, 2011, 1927627}	US	Background	Common carp (fish fillet)	1999 - 2007	9	N/R	0.2	1.4	High
{Klosterhaus, 2012, 1443796}	US	Background	White croaker (whole specimen); Shiner surfperch (whole specimen)	2006	14	N/R	N/R	1.7	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Shaw, 2009, 1443830}	US	Background	Silver hake, white hake, Atlantic herring, American plaice, alewife, winter flounder, Atlantic mackerel	2006	12	0.87	N/R	1.1	High
{Johnson-Restrepo, 2008, 1927767}	US	Background	Bull shark (muscle); Atlantic sharpnose shark (muscle)	1993 - 2004	16	1	0.0013	1.9	Medium
{Roosens, 2010, 1927683}	BE	Background	European eel	2000 - 2006	50	1	2	1.5	High
{Roosens, 2008, 1927747}	BE	Background	Multiple fish species and Eel (whole fish/eel)	2006	35	1	2	2.0	Medium
{Tomy, 2009, 1279130}	CA	Background	Arctic cod; Pacific herring; Arctic cisco	2004 - 2005	29	N/R	N/R	2.4	Low
{Law, 2006, 999306}	CA	Background	Walleye, whitefish, emerald shiner, burbot, white sucker, and goldeye (muscle)	2000 - 2002	28	1	0.08	1.2	High
{Tomy, 2008, 1443836}	CA	Background	Redfish; Arctic cod	2000 - 2001	10	N/R	0.0036	1.7	Medium
{Cheaib, 2009, 1927722}	CH	Background	Lake trout	2004	9	1	N/R	1.6	High
{Gerecke, 2008, 1927965}	CH	Background	Trout	2003	25	1	N/R	1.8	Medium
{Zhu, 2017, 3546047}	CN	Background	Grass carp	2012 - 2013	5	1	N/R	3.0	Low ^a
{He, 2013, 1927551}	CN	Background	Mud carp; Nile Tilapia; Suckermouth catfish	2009	34	N/R	N/R	1.3	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
1927654	CN	Background	Yellow croaker and silver pomfret (fillet)	2008	46	1	0.3	1.7	Medium
1927678	CN	Background	Carp; Crucian carp; Snakehead; Water snake	2006	23	0.7	3	2.0	Medium
3986479	DK	Background	Salmon, trout, herring, eel	2002 - 2006	59	0.94	0.01	3	Low ^a
{Harrad, 2009, 1927694}	GB	Background	Multiple species (muscle)	2008	30	1	0.25	1.7	Medium
{Morris, 2004, 1927817}	GB; BE; NL	Background	Cod; Eels	1999 - 2000	32	N/R	1.2	2.3	Low
{Ilyas, 2013, 2149566}	ID	Background	Nile tilapia	2008	2	1	N/R	1.4	High
{Poma, 2014, 2343685}	IT	Background	Rutilus rutilus	2011 - 2012	5	1	0.01	1.9	Medium
{Poma, 2014, 2343698}	IT	Background	Shad, whitefish (muscle); Shad, whitefish (liver)	2011 - 2012	26	1	0.1	1.2	High
{Luigi, 2015, 2919854}	IT	Background	Common carp, bream, sander, and sheatfish (liver)	2010	10	1	0.011	1.9	Medium
{Jeong, 2014, 2343722}	KP	Background	Crucian carp (muscle); Crucian carp (eggs)	2010	15	1	0.02	1.3	High
{Sudaryanto, 2007, 4158939}	LA	Background	Snakehead (muscle); Tilapia (muscle); Carp (muscle)	2005	30	N/R	0.02	1.9	Medium
{Frederiksen, 2007, 3575380}	Multiple	Background	Shorthorn sculpin (Liver)	2006	2	0.5	1.1	2.1	Medium
{Ueno, 2006, 1927796}	Multiple	Background	Skipjack tuna (muscle)	1997 - 2001	62	0.95	0.001	1.5	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Remberger, 2004, 1927826}	Multiple	Background	Herring (muscle)	1999 - 2000	6	1	N/R	1.8	Medium
{Bustnes, 2012, 1927591}	NO	Background	Saithe; Cod	2007	80	1	0.01	1.2	High
{K�ppen, 2010, 1927674}	NO	Background	Multiple species	2006	5	1	0.006	1.9	Medium
{Jenssen, 2007, 1927762}	NO	Background	Atlantic Cod (whole body); Atlantic cod (whole body); Polar cod (whole body)	2003	52	N/R	N/R	1.6	High
{S�rmo, 2006, 1927787}	NO	Background	Polar cod	2003	7	N/R	0.3	2.2	Medium
{Reindl, 2014, 2528326}	PL	Background	Herring (Whole Fish); Herring (Herring Muscle); Herring (Herring Liver)	2009 - 2010	24	1	1.4	2.2	Medium
{Sellstrom, 1998, 1715539}	SE	Background	Pike (muscle)	1995	15	0.33	N/R	2.0	Medium
{Polder, 2014, 2343683}	TZ	Background	Tilapia (muscle)	2011	13	0.78	0.03	1.8	Medium
{Chokwe, 2015, 3350535}	ZA	Near facility	Carp (muscle)	2013	12	1	0.48	1.6	High
^a Study evaluation score was downgraded from medium to low based on professional judgement.									

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HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{WSDE, 2016, 3982306}	US	Background	Multiple species	2014	44	0.27	100	1.1	High
{Ismail, 2009, 1443833}	CA	Background	Lake trout (whole specimen)	1979 - 2004	29	1	N/R	1.8	Medium
{Tomy, 2004, 1927822}	CA	Background	Lake trout; Forage fish	2002	85	1	N/R	2.0	Medium
{Zeng, 2014, 2343681}	CN	Background	Carp, snakehead (serum)	2010	6	1	0.004	1.8	Medium
{Meng, 2012, 1927604}	CN	Background	Tilapia, bighead carp, bluntnout bream, grass carp, northern snakehead, largemouth bass, and mandarin fish; snubnose pompano, crimson snapper, red drum, hairtail and gold thread (muscle)	2004 - 2005	60	0.7	0.003	1.3	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{HlouÅ;kovÃ;j, 2013, 1927549}	CZ	Background	Freshwater river fish: common breams, European chubs, roaches, crucian carp, European perch, gudgeon, grayling, common carp, rainbow trout and rudd (muscle)	2010	48	0.79	0.08	1.7	Medium
{HrÃ;dkovÃ;j, 2012, 1927635}	CZ	Background	Chub (fillet); Common bream (fillet); Roaches (fillet)	2008 - 2009	38	0.82	0.02	1.2	High
{Hajslova, 2007, 1927955}	CZ	Background	Bream; Chub; Perch	2005	80	1	0.02	2.0	Medium
{PulkrabovÃ;j, 2007, 1927763}	CZ	Background	Chub, barbel, bream, perch (muscle); Trout (whole body)	2001 - 2003	136	0.87	0.1	2.0	Medium
{Vorkamp, 2014, 2343732}	DK	Background	Multiple freshwater and seawater fish	2012	11	0.9	0.012	2.0	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Granby, 2007, 3986479}	DK	Background	Salmon, trout, herring, eel	2002 - 2006	59	0.94	0.01	3	Low ^a
{Guerra, 2009, 3575325}	ES	Background	Barbels, Bleaks, and Southwestern Nases (whole fish (bleaks and nases); muscle and liver (barbels))	2002 - 2004	73	N/R	7	2.0	Medium
{Eljarrat, 2005, 1927819}	ES	Background	Bleak	2002	15	1	N/R	1.7	Medium
{Mchugh, 2010, 1927686}	GB	Background	European eel	2005	5	1	N/R	2.2	Medium
{Allchin, 2003, 3809206}	GB	Background	Brown trout and eel (muscle)	2003	10	1	1.2	2.1	Medium
{Kakimoto, 2012, 1927593}	JP	Background	Multiple species	2011	18	0.9	0.02	1.6	High
{Barghi, 2016, 3350483}	KP	Background	Multiple species	2012 - 2014	40	1	0.0029	1.3	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Son, 2015, 3350528}	KP	Background	Mackerel, cod, halibut, pacific saury, herring, anchovy, gray mullet (whole organism, entrails removed); Catfish (whole organism, entrails removed)	2012 - 2013	39	N/R	0.0029	1.6	High
{Zacs, 2014, 2528323}	LV	Background	Eel (Muscle)	2013	24	1	0.045	3	Low
{Zacs, 2014, 2343713}	LV	Background	Salmon (fillets)	2012	25	1	0.006	1.2	High
{van, 2008, 1927756}	NL	Background	Multiple freshwater fish, marine fish, and shellfish species	2003	44	N/R	N/R	1.5	High
{Bustnes, 2010, 1274407}	NO	Background	Saithe; Cod	2007	155	N/R	0.01	1.7	Medium
{Zhang, 2015, 3350497}	SG	Background	Marine catfish (tissue)	2014	11	0.36	0.0054	1.7	Medium
{Eljarrat, 2004, 999290}	ES	Near facility	Barbel fish (muscle); Barbel fish (liver)	2002	22	1	N/R	1.8	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{ECHA, 2017, 3970753}	N/A	Modeled	N/A	N/A	N/A	N/A	N/A	2	Medium
^a Study evaluation score was downgraded from medium to low based on professional judgement.									
^b Study evaluation score was downgraded from high to medium based on professional judgement.									

4.1.1.1.4 North America

Four studies were identified which report HBCD concentrations in fish from the United States. [Johnson-Restrepo et al. \(2008\)](#) reported total HBCD concentrations of 1.83 to 413 µg/kg lw (n = 16) in bull shark and Atlantic sharpnose shark muscle from samples collected in the coastal waters of Florida from 1991 to 2004 [as cited in [EC/HC \(2011\)](#)]. [Larsen et al. \(2005\)](#) reported total HBCD concentrations ranging from ND to 73.9 µg/kg lw in various fish species collected in 2003 from the Chesapeake Bay (detection in 50 of 52 samples) and [Shaw et al. \(2009\)](#) reported total HBCD concentrations ranging from 7.6 to 23 µg/kg lw (means) from various fish species collected off the Maine coast [as cited in [EC/HC \(2011\)](#)]. [Chen et al. \(2011\)](#) reported a rise in total HBCD concentrations from 13 to 4,640 µg/kg lw (means) in carp collected from the Hyco River in Virginia between 1999 and 2007 [as cited in [Law et al. \(2014\)](#)].

Other studies reported HBCD concentrations in fish from Canada, including from lakes and the arctic region. Total HBCD concentrations were observed at levels up to 92 µg/kg lw. One study ([Ismail et al., 2009](#)), reported total HBCD concentrations of 16 to 33 µg/kg lw in archived trout from Lake Ontario, with total HBCD decreasing significantly over the 25 years between 1979 and 2004 [as cited in [NICNAS \(2012\)](#) and [EC/HC \(2011\)](#)].

[Tomy et al. \(2009\)](#) measured the three major isomers of HBCD across eight species in a Canadian Arctic food web. Isomer specific distribution across trophic levels was noted by the authors. Total HBCD levels were derived by using method detection limits and dividing those by two when values were not reported. The β-isomer was not detected across any species. Sample size was five for each species with the exception of arctic cod with eight. Levels of total HBCD in red fish ranged from 0.51 to 4.4 ug/kg lw with geometric mean of 2.0 ug/kg lw and in Arctic cod ranged from 0.002 to 1.45 lw with geometric mean of 0.42.

4.1.1.1.5 Europe

Numerous European studies have examined HBCD concentrations in fish. HBCD concentrations in fish collected in Europe appear to be higher than those collected in North America. For example, [Allchin and Morris \(2003\)](#), as reported in [EC/HC \(2011\)](#), report total HBCD concentrations ranging from ND to 10,275 µg/kg ww in eel and trout of rivers in the United Kingdom (sampling year and number of samples not reported). The highest concentration reported was 160,905 µg/kg

lw, which was found in trout samples collected in 2002 downstream of a HBCD manufacturing plant. The plant is no longer producing HBCD [Gems *et al.*, 2006, as cited in [EC \(2008\)](#)].

Total HBCD has been detected in fish collected in remote arctic areas. As noted by [ECHA \(2008\)](#), two studies report detection in polar cod (whole fish) collected in 2003 from the Norwegian arctic, with central tendency values of 1.73 and 11.7 µg/kg lw. [ECHA \(2008\)](#) also provided statistical summaries of fish data presented in [EC \(2008\)](#). For freshwater muscle, they report total HBCD concentrations ranging from 0.52 to 160,095 µg/kg lw, with a median of 120 µg/kg lw and a mean of 5,223 µg/kg lw (n = 151). They note that concentrations in whole fish can be higher. For marine fish muscle, [EC \(2008\)](#) reported median concentrations of 13 µg/kg lw (n = 100) in Western Europe, 11.5 µg/kg lw (n = 38) in the Baltic Sea, 107 µg/kg lw (n = 16) in the Western Scheldt, and 63 µg/kg lw (n = 300) in the UK.

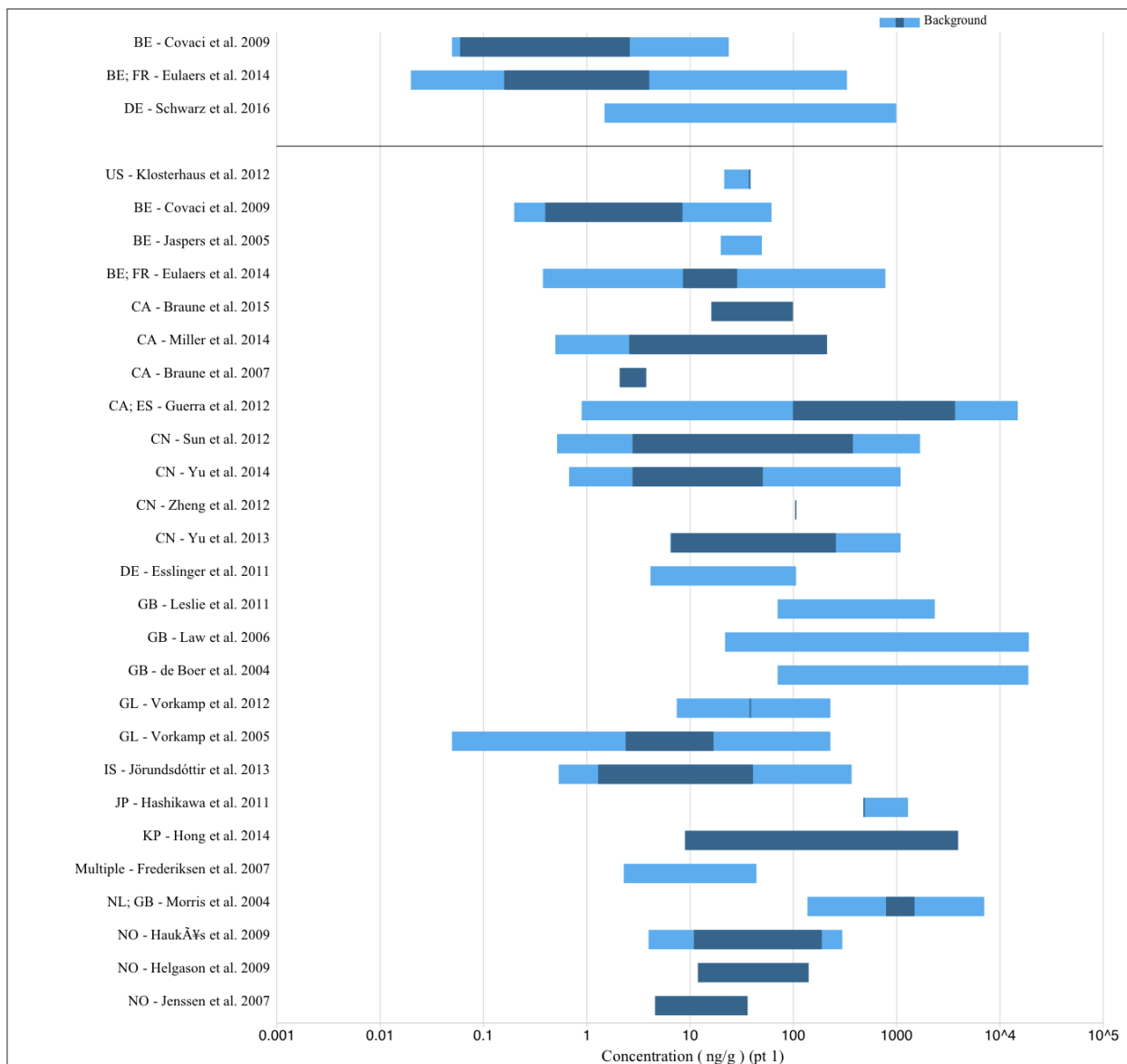
4.1.1.1.6 Asia

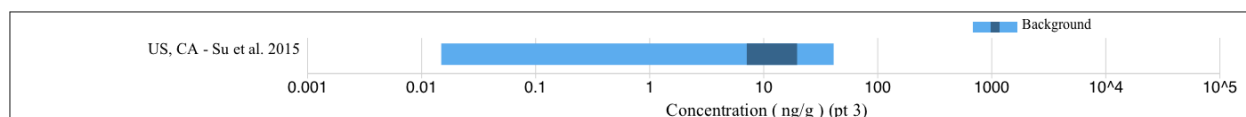
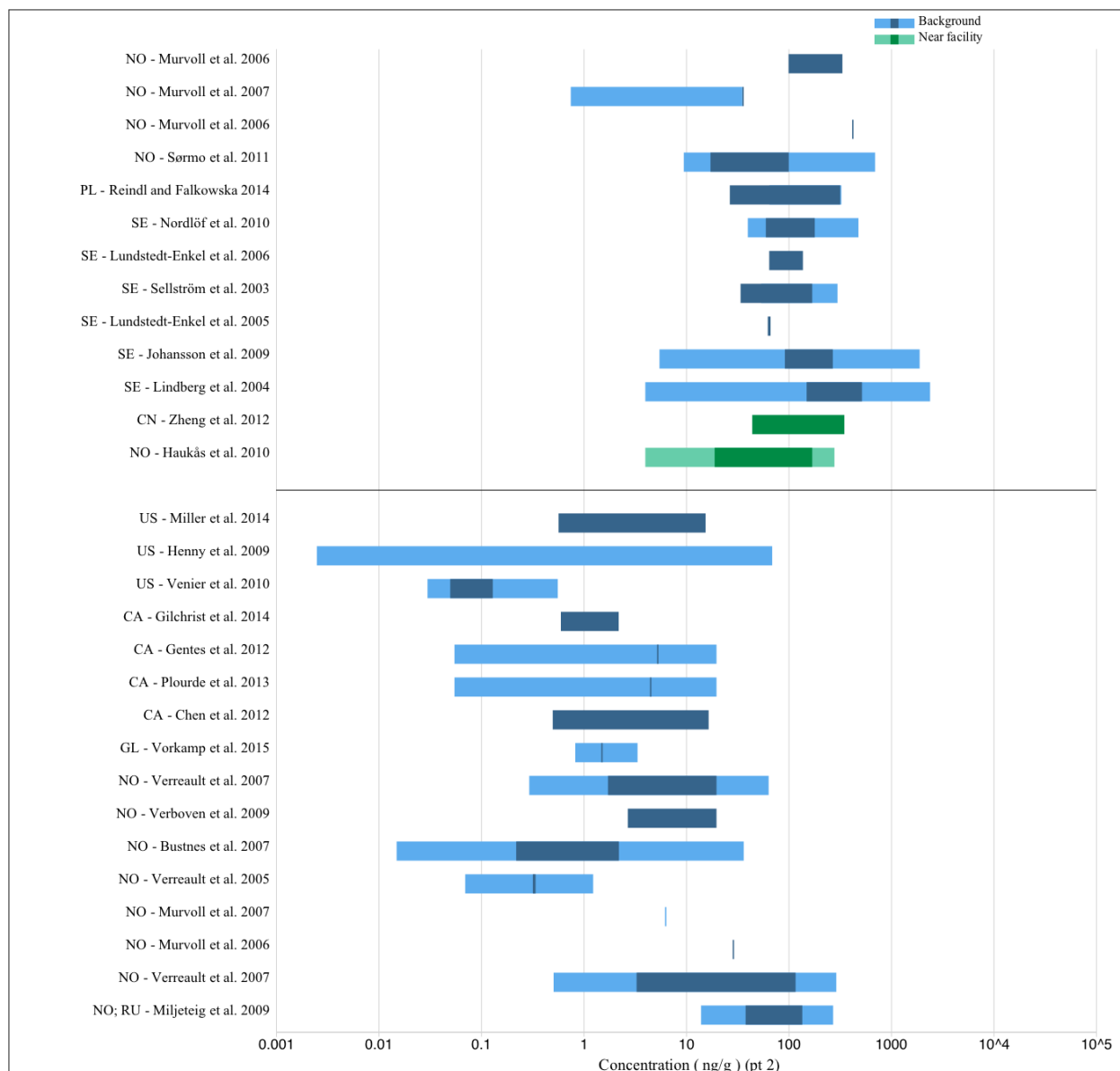
In Asia, only a limited number of studies have investigated HBCD levels in fish, including [Ueno et al. \(2006\)](#) and [Xian et al. \(2008\)](#), as reported in [EC/HC \(2011\)](#). These studies reported concentrations ranging from ND to 160 µg/kg lw in samples collected between 1997 and 2006. [Law et al. \(2014\)](#) reported results from an additional two studies conducted in China and Japan (sampling dates not reported). In [Xia et al. \(2011\)](#), the average total HBCD concentration was 3.7 µg/kg lw in marine fish and in [Nakagawa et al. \(2010\)](#) the median total HBCD concentrations ranged from 0.12 to 2.1 µg/kg lw in wild and farmed fish.

A more recent study, [Son et al. \(2015\)](#), analyzed various fish and marine invertebrate species purchased from conventional fish markets in South Korea in 2012 (five locations) and in 2013 (six locations). Eight fish species consisting of seven marine species (mackerel, halibut, pacific saury, herring, anchovy, gray mullet) and one freshwater species (catfish) were monitored for total HBCD in samples of muscle (fillet) with the exception of anchovy. Samples were analyzed for total HBCD using LC-MS/MS with ESI in the negative mode. Total HBCD (sum of α - and γ -HBCD) concentrations varied between the different species, but mean concentrations in marine and freshwater fish were 1.78 and 1.02 µg/kg ww, respectively.

4.2 Birds

4.2.1 Birds Chart





4.2.2 Birds Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
787649	{Covaci, 2009, 787649}	0.05	23.9	0.06	2.63
2343720	{Eulaers, 2014, 2343720}	0.02	333	0.16	4.06

3449771	{Schwarz, 2016, 3449771}	1.5	1000		
1443796	{Klosterhaus, 2012, 1443796}	21.6	39	37.4	37.4
787649	{Covaci, 2009, 787649}	0.2	62	0.4	8.52
1927816	{Jaspers, 2005, 1927816}	20	50		
2343720	{Eulaers, 2014, 2343720}	0.38	785	8.61	28.8
3350522	{Braune, 2015, 3350522}			16.2	100
2528327	{Miller, 2014, 2528327}	0.5	213.3	2.6	213.3
1412405	{Braune, 2007, 1412405}			2.1	3.8
1927628	{Guerra, 2012, 1927628}	0.9	15000	100	3700
1927580	{Sun, 2012, 1927580}	0.52	1700	2.8	380
2343702	{Yu, 2014, 2343702}	0.68	1100	2.8	51
1927597	{Zheng, 2012, 1927597}			105	105
1927541	{Yu, 2013, 1927541}	6.5	1100	6.6	260
1927650	{Esslinger, 2011, 1927650}	4.17	107		
1927659	{Leslie, 2011, 1927659}	71	2360		
3969307	{Law, 2006, 3969307}	22	19200		
3986474	{de Boer, 2004, 3986474}	71	19000		
1927578	{Vorkamp, 2012, 1927578}	7.5	230	38	38
1927805	{Vorkamp, 2005, 1927805}	0.05	230	2.4	17
2149610	{JÃ¶rundsÃ¶ttir, 2013, 2149610}	0.54	370	1.3	41
3809208	{Hashikawa, 2011, 3809208}	480	1300	480	480
2149601	{Hong, 2014, 2149601}			9	3970
3575380	{Frederiksen, 2007, 3575380}	2.3	44.33		
1927817	{Morris, 2004, 1927817}	138	7100	796	1501
1927703	{HaukÃ¶s, 2009, 1927703}	4	300	11	190
1927723	{Helgason, 2009, 1927723}			12	142
1927762	{Jenssen, 2007, 1927762}			4.62	36.4

1414571	{Murvoll, 2006, 1414571}			100	335
1927774	{Murvoll, 2007, 1927774}	0.75	35.4	35.4	35.4
1927797	{Murvoll, 2006, 1927797}			417	417
1927631	{SÄ_rmo, 2011, 1927631}	9.5	698	17.3	100.32
2528326	{Reindl, 2014, 2528326}	65.02	326.91	26.72	319.17
1927660	{NordlÄ_f, 2010, 1927660}	40	480	60	180
1927794	{Lundstedt-Enkel, 2006, 1927794}			64.7	138
999339	{SellstrÄ_m, 2003, 999339}	54	300	34	170
1927804	{Lundstedt-Enkel, 2005, 1927804}			62.7	66.7
1927734	{Johansson, 2009, 1927734}	5.5	1900	92	270
1927824	{Lindberg, 2004, 1927824}	4	2400	150	520
1927597	{Zheng, 2012, 1927597}			44.2	350
1927667	{HaukÄ_s, 2010, 1927667}	4	280	19	170
2528324	{Miller, 2014, 2528324}			0.57	15.5
1927712	{Henny, 2009, 1927712}	0.0025	69.2		
1927677	{Venier, 2010, 1927677}	0.03	0.56	0.05	0.13
2149396	{Gilchrist, 2014, 2149396}			0.6	2.2
3283561	{Gentes, 2012, 3283561}	0.055	19.8	5.22	5.22
4160319	{Plourde, 2013, 4160319}	0.055	19.8	4.45	4.45
1851195	{Chen, 2012, 1851195}			0.5	16.6
3015562	{Vorkamp, 2015, 3015562}	0.83	3.36	1.49	1.49
1927771	{Verreault, 2007, 1927771}	0.295	63.9	1.73	19.8
1927975	{Verboven, 2009, 1927975}			2.7	19.8
1927758	{Bustnes, 2007, 1927758}	0.015	36.5	0.22	2.21
1927809	{Verreault, 2005, 1927809}	0.07	1.24	0.32	0.34

1927774	{Murvoll, 2007, 1927774}	6.23	6.23		
1927797	{Murvoll, 2006, 1927797}			28.5	28.5
531779	{Verreault, 2007, 531779}	0.51	292	3.29	117
1274420	{Miljeteig, 2009, 1274420}	14	272	38.1	136
3345569	{Su, 2015, 3345569}	0.015	41.4	7.17	19.8

4.2.3 Birds: Supporting Data

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry									
{Covaci, 2009, 787649}	BE	Background	Chickens (feces)	2006 - 2007	20	0.6	N/R	1.8	Medium
{Eulaers, 2014, 2343720}	BE; FR	Background	Barn owl (feathers)	2008 - 2009	73	1	N/R	2.0	Medium
{Schwarz, 2016, 3449771}	DE	Background	Peregrine falcon (Egg contents)	2006 - 2011	50	0.5	3	2.2	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Klosterhaus, 2012, 1443796}	US	Background	Double-crested cormorant (eggs)	2008	3	1	N/R	1.7	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Covaci, 2009, 787649}	BE	Background	Chicken (eggs); Chickens (eggs)	2006 - 2007	20	0.55	0.4	1.8	Medium
{Jaspers, 2005, 1927816}	BE	Background	Little owls	1998 - 2000	40	0.05	5	2.2	Medium
{Eulaers, 2014, 2343720}	BE; FR	Background	Barn Owl (muscle); Barn Owl (liver tissue); Barn Owl (gland tissue); Barn owl (adipose tissue); Barn owl (muscle); Barn owl (liver tissue); Barn owl (gland tissue)	2008 - 2009	88	1	N/R	2.0	Medium
{Braune, 2015, 3350522}	CA	Background	Glaucous gull (eggs); Black-legged kitiwake (eggs)	2008 - 2013	51	N/R	1	1.9	Medium
{Miller, 2014, 2528327}	CA	Background	Rhinoceros auklets (eggs); Leach's storm-petrel (eggs); Ancient murrelet (eggs)	1990 - 2011	26	0.69	1	1.9	Medium
{Braune, 2007, 1412405}	CA	Background	Ivory gull (eggs)	1976 - 2004	24	1	0.3	2.0	Medium
{Guerra, 2012, 1927628}	CA; ES	Background	Peregrine falcon (eggs)	2003 - 2009	25	0.8	N/R	1.8	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Sun, 2012, 1927580}	CN	Background	Bulbul (muscle); Shrike (muscle); Oriental magpie-robin (muscle)	2009 - 2011	69	0.99	1	1.9	Medium
{Yu, 2014, 2343702}	CN	Background	Tree sparrow (muscle); Common magpie (muscle)	2009 - 2011	68	1	1.6	1.9	Medium
{Zheng, 2012, 1927597}	CN	Background	Hens	2010	8	1	4.7	1.9	Medium
{Yu, 2013, 1927541}	CN	Background	Common kestrel; Eagle owl; Eurasian tree sparrow	2005 - 2007	87	1	0.67	2.0	Medium
{Esslinger, 2011, 1927650}	DE	Background	Herring gulls (eggs)	1988 - 2008	26	N/R	0.00092	1.7	Medium
{Leslie, 2011, 1927659}	GB	Background	Peregrine falcon (eggs); Sparrow hawk (muscle)	1973 - 2002	127	0.16	N/R	1.7	Medium
{Law, 2006, 3969307}	GB	Background	Falcon (eggs); Sparrowhawk (muscle)	1973 - 2002	21	0.2	N/R	1.8	Medium
{de Boer, 2004, 3986474}	GB	Background	Falcon (eggs); Sparrowhawk (muscle)	1973 - 2002	116	0.18	N/R	1.9	Medium
{Vorkamp, 2012, 1927578}	GL	Background	Gulls	1994 - 2010	8	1	0.76	2.1	Medium
{Vorkamp, 2005, 1927805}	GL	Background	Falcon (eggs)	1986 - 2003	33	0.88	0.1	2.0	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{JÃ¶rundsÃ¶ttir, 2013, 2149610}	IS	Background	Guillemot (eggs); Fulmar (eggs); Arctic tern (eggs); Common eider (eggs); Gulls (eggs); Great skua (eggs)	2002 - 2004	63	0.89	4.7	2.0	Medium
{Hashikawa, 2011, 3809208}	JP	Background	Common Cormorants (muscle)	1993 - 2077	41	N/R	N/R	3.0	Low
{Hong, 2014, 2149601}	KP	Background	Gull (muscle); Pigeon (muscle); Loon (muscle); Heron, egrets (muscle)	2009	15	1	N/R	1.9	Medium
{Frederiksen, 2007, 3575380}	Multiple	Background	Black Guillemot (Egg); Black Guillemot (Liver); Fulmar (Liver); Fulmar (Subcutaneous fat)	2006	8	0.75	4.6	2.1	Medium
{Morris, 2004, 1927817}	NL; GB	Background	Tern (eggs); Cormorant (liver)	1999 - 2001	15	1	1.2	2.3	Low
{HaukÃ¶fÃ¶ys, 2009, 1927703}	NO	Background	Common eider; Great black backed gull	2006 - 2007	74	1	0.05	1.9	Medium
{Helgason, 2009, 1927723}	NO	Background	Herring (eggs); Kittiwake (eggs); Puffin (eggs)	1983 - 2003	89	1	N/R	1.7	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Jenssen, 2007, 1927762}	NO	Background	Common terns (eggs); Arctic terns (eggs)	2003	30	N/R	N/R	1.6	Medium
{Murvoll, 2006, 1414571}	NO	Background	North Atlantic kittiwake (yolk sac)	2002	37	N/R	1.5	2.1	Medium
{Murvoll, 2007, 1927774}	NO	Background	Brunnich's guillemot (yolk sac); Common eider (yolk sac)	2002	23	0.43	1.5	2.1	Medium
{Murvoll, 2006, 1927797}	NO	Background	European shag (yolk sac)	2002	30	1	1.5	2.1	Medium
{Sørmo, 2011, 1927631}	NO	Background	Herring gulls (liver)	1998	16	1	N/R	1.8	Medium
{Reindl, 2014, 2528326}	PL	Background	African penguin (Whole Egg); African penguin (Egg Yolk); African penguin (Egg Albumen); African penguin (Muscle); African penguin (brain); African penguin (Liver); African penguin (Adipose)	2008 - 2010	21	1	1.4	2.2	Medium
{Nordliff, 2010, 1927660}	SE	Background	Sea eagle (eggs)	1992 - 2005	44	1	13	1.9	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Lundstedt-Enkel, 2006, 1927794}	SE	Background	Baltic Sea guillemot (eggs); Baltic Sea guillemot (muscle)	2000 - 2002	50	N/R	N/R	2	Medium
{Sellström, 2003, 999339}	SE	Background	Guillemot (eggs)	1969 - 2001	137	1	N/R	1.8	Medium
{Lundstedt-Enkel, 2005, 1927804}	SE	Background	Guillemot	2000	10	N/R	N/R	2	Medium
{Johansson, 2009, 1927734}	SE	Background	Peregrine falcons (eggs)	1991 - 1999	34	0.95	11	1.7	Medium
{Lindberg, 2004, 1927824}	SE	Background	Falcon	1987 - 1999	21	0.81	N/R	2	Medium
{Zheng, 2012, 1927597}	CN	Near facility	Hens	2010	33	1	4.7	1.9	Medium
{Haukeas, 2010, 1927667}	NO	Near facility	Great blackbeaked gull (whole seabird eggs without shell); Common eider (whole seabird eggs without shell)	2006 - 2007	55	1	N/R	1.9	Medium

Hero ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Rounded Evaluation Score
wet									
{Miller, 2014, 2528324 }	US	Background	Double-crested cormorant (egg); Great blue heron (egg)	2003 - 2012	50	N/R	1	2.2	Medium
{Henny, 2009, 1927712 }	US	Background	Osprey (eggs); Cormorant (eggs)	2002 - 2007	119	0.11	0.005	2.0	Medium
{Venier, 2010, 1927677 }	US	Background	Bald eagle	2005	15	0.47	N/R	1.7	Medium
{Gilchrist, 2014, 2149396 }	CA	Background	Tree swallows (eggs)	2007 - 2010	87	N/R	N/R	1.9	Medium
{Gentes, 2012, 3283561 }	CA	Background	Ring-billed gull (plasma); Ring-billed gull (liver)	2010	58	0.43	0.11	1.4	High
{Plourde, 2013, 4160319 }	CA	Background	Gulls (liver)	2010	21	0.9	0.11	1.8	Medium
{Chen, 2012, 1851195 }	CA	Background	Gulls: glaucous-winged, California, ring-billed, herring	2008	26	N/R	1.1	1.9	Medium

PEER REVIEW DRAFT - DO NOT CITE OR QUOTE

PEER REVIEW DRAFT – DO NOT CITE OR QUOTE.

Hero ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Rounded Evaluation Score
wet									
{Vorkamp, 2015, 3015562 }	GL	Background	Glaucous gull (liver)	2012	4	1	N/R	1.2	High
{Verreault, 2007, 1927771 }	NO	Background	Glaucous gulls (blood plasma); Glaucous gull (blood plasma); Glaucous gull (egg yolk)	2006	80	0.76	0.59	1.6	High
{Verboven, 2009, 1927975 }	NO	Background	Gulls (eggs); Gulls (plasma)	2006	42	N/R	N/R	1.9	Medium
{Bustnes, 2007, 1927758 }	NO	Background	Owl (eggs)	1986 - 2004	139	0.24	0.03	1.8	Medium
{Verreault, 2005, 1927809 }	NO	Background	Gulls	2004	27	1	0.03	1.4	High
{Murvoll, 2007, 1927774 }	NO	Background	Common eider (yolk sac)	2002	14	0.07	1.5	2.1	Medium
{Murvoll, 2006, 1927797 }	NO	Background	European shag (yolk sac)	2002	30	1	1.5	2.1	Medium

Hero ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Rounded Evaluation Score
wet									
{Verreault, 2007, 531779}	NO	Background	Glaucous gulls (blood); Glaucous gulls (liver); Glaucous gulls (whole body homogenate with feathers); Glaucous gulls (whole body homogenate without feathers)	2002	57	1	N/R	1.6	High
{Miljeteig, 2009, 1274420}	NO; RU	Background	Ivory gull (eggs)	2006 - 2007	35	N/R	N/R	1.4	High
{Su, 2015, 3345569}	US, CA	Background	Herring gull (eggs)	2012 - 2013	130	0.97	0.03	1.3	High

4.2.4 North America

[Law et al. \(2014\)](#) reported total HBCD concentrations in avian samples collected in Montreal, Canada, including liver samples from ring-billed gulls ([Gentes et al., 2012](#)), unknown tissue samples from peregrine falcons ([Fernie and Letcher, 2010](#)), and unhatched eggs from peregrine falcons ([Guerra et al., 2012](#)). Total HBCD concentrations were 5.22 µg/kg wet weight (mean) in

avian liver, ND to 0.03 µg/kg wet weight in an unknown avian tissue, and ND- 14,600 µg/kg lipid weight (mean of 3,700 µg/kg lipid weight) in unhatched eggs.

[Gilchrist et al. \(2014\)](#) studied the reproduction of tree swallows (*Tachycineta bicolor*) nesting near WWTPs in Canada between 2007 and 2010. The breeding colonies were located near two WWTPs and near a reservoir for a wildlife conservation area that was selected as a reference area. One of the first three eggs in each clutch was collected, and a subset of 30 eggs from approximately 10 nests per site was used for chemical analysis. The eggs were analyzed for PCBs, organochlorine pesticides, and flame retardant chemicals including total HBCD. Analysis consisted of an accelerated solvent extraction method followed by GC-MS with ECNI. The mean total HBCD concentrations were 2.2 µg/kg ww (n = 71) for eggs collected near both WWTPs and 0.6 µg/kg ww (n = 16) for eggs collected near the reservoir.

[Braune et al. \(2015\)](#) analyzed samples of eggs of two seabird species (thick-billed murre (*Uria lomvia*) and northern fulmer (*Fulmarus glacialis*) collected annually from Prince Leopold Island Migratory Bird Sanctuary in Lancaster Sound, Nunavut, Canada from 2003 and 2005-2014. Eggs were analyzed for total HBCD by GC-MS with ECNI using a method in which the β- and γ-isomers are converted to α-HBCD in the injection port. Egg samples were analyzed as pooled (composite) samples, with each pool consisting of three individual egg samples (2005-2014) or five individual egg samples (2003). The mean concentrations of total HBCD in eggs (n = 330 eggs; 106 pools) ranged from ND to 27.9 µg/kg lw.

[Braune et al. \(2007\)](#) also analyzed ivory gull eggs to examine temporal trends. From 1976 to 2004, 24 samples were collected. Concentrations of HBCD in 1976 were 3.8 ng/g lw, 3.0 ng/g lw in 1987, and 2.1 ng/g lw in 2004. Overall, pooled samples had a mean concentration ranging from 2.1 to 3.8 ng/g lw.

[Su et al. \(2015\)](#) analyzed samples of herring gull (*Larus argentatus*) eggs collected from 20 colonies within both US and Canada waters of the Laurentian Great Lakes basin from 2012 to 2013. Eggs were collected in 2012 from 15 colonies under Canada's Laurentian Great Lakes Herring Gull Monitoring Program (GLHGMP) and in 2012-2013 from 5 colonies under Clean Michigan Initiative-Clean Water Fund (CMI-CWF). For the GLHGMP sites, 1 pooled sample (comprised of 13 individual eggs) was analyzed for each colony, and for the US CMI-CWF sites, 20 individual eggs were analyzed for each colony. Samples were analyzed for total HBCD by GC-MS using a method in which the β- and γ-isomers are converted to α-HBCD in the injection port. The mean concentrations of total HBCD residues in 15 egg pools collected 2012 from the GLHGMP colonies ranged from 86.5 to 225 µg/kg lw. Concentrations of total HBCD residues in eggs (n = 100 eggs) collected in 2012 and 2013 from the 5 CMI-CWF colonies ranged from ND to 557 µg/kg lw (90.5 to 197 µg/kg lw mean); the limit of detection was reported as 0.03 µg/kg ww.

[Gauthier et al. \(2007\)](#) analyzed samples of herring gull egg pools from six locations in the Great Lakes. Alpha-HBCD was detected in 5 of 6 sites, Gamma-HBCD was detected in 2 sites, and beta HBCD was not detected. Overall HBCD levels across isomers and sites ranged from ND to 20 ug/kg wet weight.

Chen *et al.* (2012) studied eggs of four gull species (Laridae) from Canadian marine and freshwater ecosystems collected from a total of 26 colonies spanning Pacific to Atlantic Canada, including the Great

Lakes basin. Gulls are top predators in their respective ecosystems and ideal for monitoring halogenated contaminants. Herring gull eggs from fifteen Great Lakes colony sites were collected from late-April to early-May of 2008. For each colony site, 10 to 13 individual eggs from different nests were pooled on an equal wet-weight basis. In addition, individual eggs (n=10) from different nests of glaucous-winged (*Larus glaucescens*), California (*Larus californicus*), ring-billed (*Larus delawarensis*) or herring gulls were also collected in early-May to early-July of 2008 from each of 11 additional colonies spanning the Pacific to the Atlantic coast of Canada. The pooled and individual eggs were homogenized and stored at -40 C at Environment Canada's National Wildlife Specimen Bank prior to chemical analysis. HBCD was analyzed for using GC-MS-in ECNI. Method blanks were processed to monitor interferences and contamination and MLOQ = 1.1 ng/g and MLOD = 0.28 ng/g. In the marine ecosystem (n=6 pooled samples): minimum median = 0.5 ng/g ww; maximum median = 4.5 ng/g ww; minimum arithmetic mean = 2.2 ng/g ww; maximum arithmetic mean = 9 ng/g ww. For the non-Great Lakes freshwater ecosystem (n=5 pooled samples): minimum median = 4.4 ng/g ww; maximum median = 11.7 ng/g ww; minimum arithmetic mean = 6.7 ng/g ww; maximum arithmetic mean = 16.6 ng/g ww. For the Great Lakes ecosystem (n = 15 pooled samples): minimum of pooled samples = 2.0 ng/g ww; maximum of pooled samples = 12 ng/g ww. Gulls breeding in regions with higher human population densities likely incurred greater flame retardant exposure. This study also contains an analysis of stable isotopes as dietary tracers in relation to flame retardants.

4.2.5 Europe

As cited in [Law et al. \(2014\)](#), liver samples from herring gulls from Norway [Sormo et al., 2011](#), eggs from white-tailed sea eagles and peregrine falcons from Sweden, the Netherlands, and the UK ([Leslie et al., 2011](#); [Nordlof et al., 2010](#)), and muscle samples from sparrowhawk from Sweden, the Netherlands, and the UK were analyzed ([Leslie et al., 2011](#)). Overall, total HBCD residues ranged from 10-698 µg/kg lipid weight in avian liver and 84-19,000 µg/kg lipid weight in avian muscle. In avian eggs, reported total HBCD concentrations ranged from 71-1,200 µg/kg lipid weight in the [Leslie et al. \(2011\)](#) study and reported means of total HBCD concentrations ranged from 60-150 µg/kg lipid weight in the [Nordlof et al. \(2010\)](#) study.

[Bustnes et al. \(2007\)](#) reported HBCD concentrations in the eggs of tawny owls from 1986 to 2004. HBCD was detected in 34 of 139 samples with concentrations reported from 0.04 to 36.5 µg/kg lw and mean concentration of 2.21 µg/kg lw.

Three studies of HBCD in birds were reported in Stockholm Conventions Persistent Organic Pollutants Review Committee's risk profile of HBCD. [KLIF \(2010\)](#) reported HBCD in glaucous gulls (*Larus hyperboreus*) and great black-backed gulls (*Larus marinus*) found dead in the Norwegian Arctic between 2003-2005. The α-HBCD concentrations in the brain samples of glaucous gulls ranged from 5.1 ng/g lw to 475 ng/g lw and from 195 ng/g lw to 15,027 ng/g lw in the liver. HBCD levels in two great black-backed gulls were 44.7-44.8 ng/g lw in the brain and 1,881 - 3,699 ng/g lw in the liver. A similar study, ([KLIF, 2005](#)) reported HBCD levels in egg samples from three bird species in 1983, 1993, and 2003, and found that median levels increased from 7.9-110 ng/g lw in herring gulls, 8.4-72.3 ng/g lw in Atlantic puffins and 15.9 – 161.3 ng/g lw in black-legged kittiwakes, and 25.3-81.4 ng/g lw in glaucous gulls ([KLIF, 2005](#)).

[Miljeteig et al. \(2009\)](#) reported HBCD levels ranging from 14 to 272 ng/g lw in ivory sea gull eggs at four Arctic sites in Norway and Russia.

Esslinger *et al.* (2011) sampled herring gull eggs from the islands Mellum and Trischen in the German Wadden Sea and from the island Heuwiese at the German Baltic Sea coast from 1998 to 2008. Between 35 and 140 eggs were collected annually and the whole content of all eggs from a given site and year were pooled and archived by the German Environmental Specimen Bank (ESB). Egg powders as received from the ESB were homogenized and stored at -20 C until further processing. The 26 egg pool samples were analyzed by HPLC-MS/MS where the LOD for the six stereoisomers ranged between 0.13 and 0.26 pg/g and LOQ between 0.48 and 0.93 pg/g. Herring gull eggs are excellent indicators of contaminant exposure in the environment, herrings maintain stable population dynamics, and their feeding habits are well known. Results are reported as six stereoisomers for α -, β -, γ -HBCD, where α -HBCD was detected as the dominant diastereoisomer. Results for total HBCD: Mellum island, 1988-2008, (n=10 pooled samples): minimum = 4.17 ng/g lw; maximum = 107 ng/g lw; Trischen island, 1988-2008, (n=10 pooled samples): minimum = 13.8 ng/g lw; maximum = 74.8 ng/g lw. Heuwiese island, 1998-2008, (n=6 pooled samples): minimum = 25.1 ng/g lw; maximum = 98.7 ng/g lw. The average contamination levels at the three locations are relatively close but nevertheless significantly different from each other. The increase in concentration of HBCD in eggs between 1994 and 2000 might reflect the steady rise in demand of HBCD during this period. Esslinger *et al.* (2011) also examined temporal trend data on HBCD from bird eggs from other locations from 1970 to 2004. The concentrations in the current study were in the middle range and similar to gull and guillemot eggs elsewhere in Europe. The trends in the reported secondary data varied, including increases in bird eggs from 1983-2003 in Northern Norway, no increases from guillemot eggs from a Swedish Baltic Sea between 1991 and 2001, and slight decreases in peregrine falcon eggs from Greenland between 1986 and 2003 and tawny owl eggs from Central Norway between 1986 and 2004.

Sellstrom *et al.* (2003) conducted a temporal trend study of HBCD concentrations in individual and/or pooled Guillemot bird eggs collected between 1969 and 2001 from Stora Karlso, an island off Sweden's west coast in the Baltic Sea. The study is partly based on the analysis of eggs archived and stored in the Swedish Environmental Specimen Bank. Guillemot eggs have previously been shown to be a very important matrix for studies of persistent environmental contaminants, as Guillemots are stationary within the Baltic the entire year, they nest far away from local sources in the central part of the Baltic Proper, and they feed exclusively on pelagic fish that migrate within the Baltic. In this investigation, egg sampling was constrained to early laid eggs to avoid an important source of within-year variation. Samples were analyzed using GC-MS run in the chemical ionization mode, measuring the negative ions formed (ECNI). Quality control measures taken included analysis of duplicate or triplicate calibration curves, laboratory blanks, recovery samples, and the use of laboratory reference material (herring homogenate) extracted and analyzed in parallel with the guillemot eggs. Specifically, one pooled sample of 10 archived eggs was analyzed per study year between 1969 and 1992 (no eggs from 1970, 1974, 1979, 1984, and 1991 were studied) and 10 eggs were analyzed individually per study year between 1993 and 2001. Additionally, the uncertainty of the results obtained from the pooled samples was investigated by analyzing individual eggs from 1976 and 1992; the pooled egg concentrations were within the range of the individual egg concentrations. For HBCD, the analysis indicates a steady and significant ($p < 0.001$) increase in concentrations over time up to recent periods, although there are indications of a minor peak during the mid-1970s or a decrease in concentrations during 1978-1985. The concentrations of HBCD have approximately doubled during the study period, but this increase seems to have leveled out since the mid-1990s. For 1969-1992 samples (n=18 pooled samples): minimum = 34 ng/g lw; maximum = 140 ng/g lw. For 1993-2001 samples (n=119 individual samples): minimum = 54 ng/g lw; maximum = 300 ng/g lw; minimum annual arithmetic

mean = 110 ng/g lw; maximum annual arithmetic mean = 170 ng/g lw. Verreault et al. reported four studies over four years that reported concentrations of HBCD in various tissues of glaucous gulls. Verreault et al. (2004) reported a range of 20-774 ug/kg lw (142 mean) in glaucous gull eggs, 6.13 to 108 ug/kg lw (37 mean) in the plasma of male glaucous gulls, and 19-122 ug/kg lw (52 mean) in the plasma of female glaucous gulls. [Verreault et al. \(2005\)](#) reported 0.07-1.24 ug/kg ww in the blood plasma of glaucous gulls. [Verreault et al. \(2007a\)](#) reported 7.23- 63.9 ug/kg HBCD in glaucous gull eggs and 1.73-2.07 ug/kg ww in plasma. Finally, [Verreault et al. \(2007b\)](#) reported an average of 3.29 ug/kg ww in glaucous gull blood, an average of 75.6 ug/kg ww in glaucous gull liver, and a range of 38.4 to 194 ug/kg ww in whole body (no feathers) HBCD concentrations (mean 91).

4.2.6 Asia

Eggs and unspecified muscle samples from cormorant chicks and adults from Lake Biwa, Japan were analyzed in [Hashikawa et al. \(2011\)](#). As cited in [Law et al. \(2014\)](#), the average concentration of total HBCD residues in muscle of adults was 480 µg/kg lipid weight.

4.2.7 Africa

Eggs of eight bird species were analyzed and HBCD was detected in three of them. The sample size varied across species with 43 samples collected overall. Across 14 African darter egg samples HBCD levels ranged from ND to 11 ug/kg lw. In two sacred ibis egg samples HBCD levels were 4.8 and 71 ug/kg lw. In one crowned plover egg sample, HBCD was detected at 1.6 ug/kg lw. HBCD was not detected in reed cormorant, cattle egret, little grebe, white-fronted plover, kelp gull eggs.

5 Overview of Environmental Monitoring Data

5.1 Surface Water

5.1.1 Environmental Media

5.1.1.1.1 Surface Water (ng/g) Chart



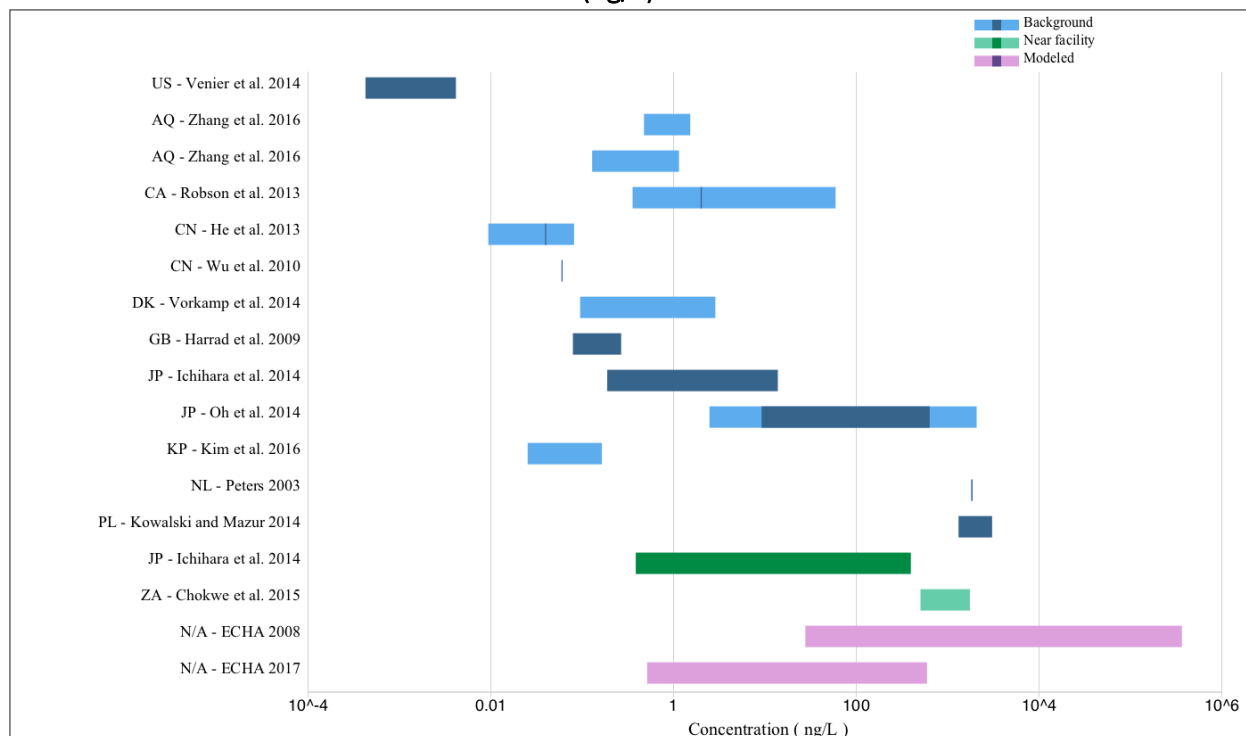
5.1.1.1.2 Surface Water (ng/g) Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1927551	{He, 2013, 1927551}	8	11.3	8	8

5.1.1.1.3 Surface Water (ng/g): Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
{He, 2013, 1927551}	CN	Background	2009	5	N/R	N/R	1.3	High

5.1.1.1.4 Surface Water (ng/L) Chart



5.1.1.1.5 Surface Water (ng/L) Summary Statistics

HERO ID	Study name	Min	Max	Central Tendency (low)	Central Tendency (high)
2695212	{Venier, 2014, 2695212}			0.00043	0.0042
3350551	{Zhang, 2016, 3350551}	0.48	1.54		
3350551	{Zhang, 2016, 3350551}	0.13	1.16		
2182416	{Robson, 2013, 2182416}	0.36	60	2	2
1927551	{He, 2013, 1927551}	0.0095	0.0824	0.0397	0.0397
1927678	{Wu, 2010, 1927678}			0.06	0.06
2343732	{Vorkamp, 2014, 2343732}	0.096	2.9		
1927694	{Harrad, 2009, 1927694}			0.08	0.27
2343678	{Ichihara, 2014, 2343678}			0.19	14
2343704	{Oh, 2014, 2343704}	2.5	2100	9.3	642.9

HERO ID	Study name	Min	Max	Central Tendency (low)	Central Tendency (high)
3545985	{Kim, 2016, 3545985}	0.0256	0.166		
3809261	{Peters, 2003, 3809261}	1835	1835	1835	1835
2343691	{Kowalski, 2014, 2343691}			1330	3100
2343678	{Ichihara, 2014, 2343678}			0.39	400
3350535	{Chokwe, 2015, 3350535}	510	1770		
3970747	{ECHA, 2008, 3970747}	28	370000		
3970753	{ECHA, 2017, 3970753}	0.52	600		

5.1.1.1.6 Surface Water (ng/L): Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/L)	Data Quality Evaluation Score	Overall Quality Level
{Venier, 2014, 2695212}	US	Background	2011 - 2012	23	0.61	N/R	1.7	Medium
{Zhang, 2016, 3350551}	AQ	Background	2013 - 2014	8	1	N/R	1.8	Medium
{Zhang, 2016, 3350551}	AQ	Background	2013 - 2014	4	1	N/R	1.8	Medium
{Robson, 2013, 2182416}	CA	Background	2004 - 2010	443	0.73	N/R	1.4	High
{He, 2013, 1927551}	CN	Background	2009	5	N/R	N/R	1.3	High
{Wu, 2010, 1927678}	CN	Background	2006	3	0.5	N/R	2.0	Medium
{Vorkamp, 2014, 2343732}	DK	Background	2012	5	1	0.012	2.0	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/L)	Data Quality Evaluation Score	Overall Quality Level
{Harrad, 2009, 1927694}	GB	Background	2008 - 2009	27	1	N/R	1.7	Medium
{Ichihara, 2014, 2343678}	JP	Background	2012 - 2013	19	1	N/R	1.4	High
{Oh, 2014, 2343704}	JP	Background	2011	17	1	N/R	1.4	High
{Kim, 2016, 3545985}	KP	Background	2010	16	1	N/R	1.4	High
{Peters, 2003, 3809261}	NL	Background	2003	50	0.02	15	1.7	Medium
{Kowalski, 2014, 2343691}	PL	Background	2014	15	N/R	950	3.0	Low
{Ichihara, 2014, 2343678}	JP	Near facility	2012	30	1	N/R	1.4	High
{Chokwe, 2015, 3350535}	ZA	Near facility	2013	12	1	200	1.6	High
{ECHA, 2008, 3970747}	N/A	Modeled	N/A	N/A	N/A	N/A	1.3	High
{ECHA, 2017, 3970753}	N/A	Modeled	N/A	N/A	N/A	N/A	2	Medium

5.1.1.1.7 Surface Water Summary

North America

[Venier et al. \(2014\)](#) measured a large group of organic chemicals, including flame retardants, in surface water samples collected from 18 stations distributed throughout the five Great Lakes (Erie, Huron, Michigan, Ontario, and Superior) in 2011 and 2012 using XAD-2 resin absorption. Surface water samples were collected using the PopCart, a sampling technique customized by Environment Canada, and were analyzed for the flame retardants including total HBCD using GC-MS with ECNI. Mean concentrations of total HBCD in surface water ranged from 2.0e-7 to 4.4e-6 µg/L for the five Great Lakes (n=24), with the highest concentrations observed in Lake Ontario.

[Robson et al. \(2013\)](#) investigated the temporal and spatial trends of brominated flame retardants including total HBCD in wet deposition in the Great Lakes Basin. Precipitation samples were collected at 9 sites (Burlington, Rock Point, St. Clair, Point Pelee, Grand Bend, Point Petre, Sibley,

Turkey Lakes, and Burnt Island) in the Canadian Great Lakes between 2004 and 2010. One sample was collected from each site every month using an automated wet deposition sampler. HBCD was detected in 63-86% of 443 samples. Total HBCD concentrations ranged from ND to 0.06 µg/L (mean = 0.002 µg/L; median = 0.00036 µg/L). Mean concentrations of total HBCD ranged from 0.0004 to 0.0048 µg/L.

The Canadian risk assessment ([EC/HC, 2011](#)) includes one study performed by [Law et al. \(2006b\)](#) of dissolved phase water in the south basin of Lake Winnipeg in 2004. For α-HBCD only, concentrations ranged from 0.000006 to 0.000013 µg/L (mean = 0.000011 µg/L). The researchers commented that detection of only α-HBCD in the samples was consistent with its much greater aqueous solubility.

[Backus et al. \(2005\)](#) investigated HBCD levels in precipitation samples from the Great Lakes Basin. As cited in [EC/HC \(2011\)](#), total HBCD concentrations ranged from ND to 0.035 µg/L. The average distribution of α-, β- and γ-HBCD, respectively, was 77%, 15% and 8%. The number of samples and sampling year was not reported.

Europe

There are very limited surface water monitoring data reported in available assessments of HBCD. The few measurements reported in freshwater environment are associated with measurements within and/or in the vicinity (upstream & downstream) of a production facility in the United Kingdom as reported in both the Canadian risk assessment ([EC/HC, 2011](#)) and the EU RAR ([EC, 2008](#)). The primary source for these reports is the same, [Deuchar \(2002\)](#). Surface water concentrations as high as 1.52 µg/L were reported at a tributary which receives surface water from an industrial estate before combining with STP effluent and fugitive releases to surface water.

The Australian Priority Existing Chemical Assessment Report states that no Australian monitoring data for HBCD in water are available ([NICNAS, 2012](#)).

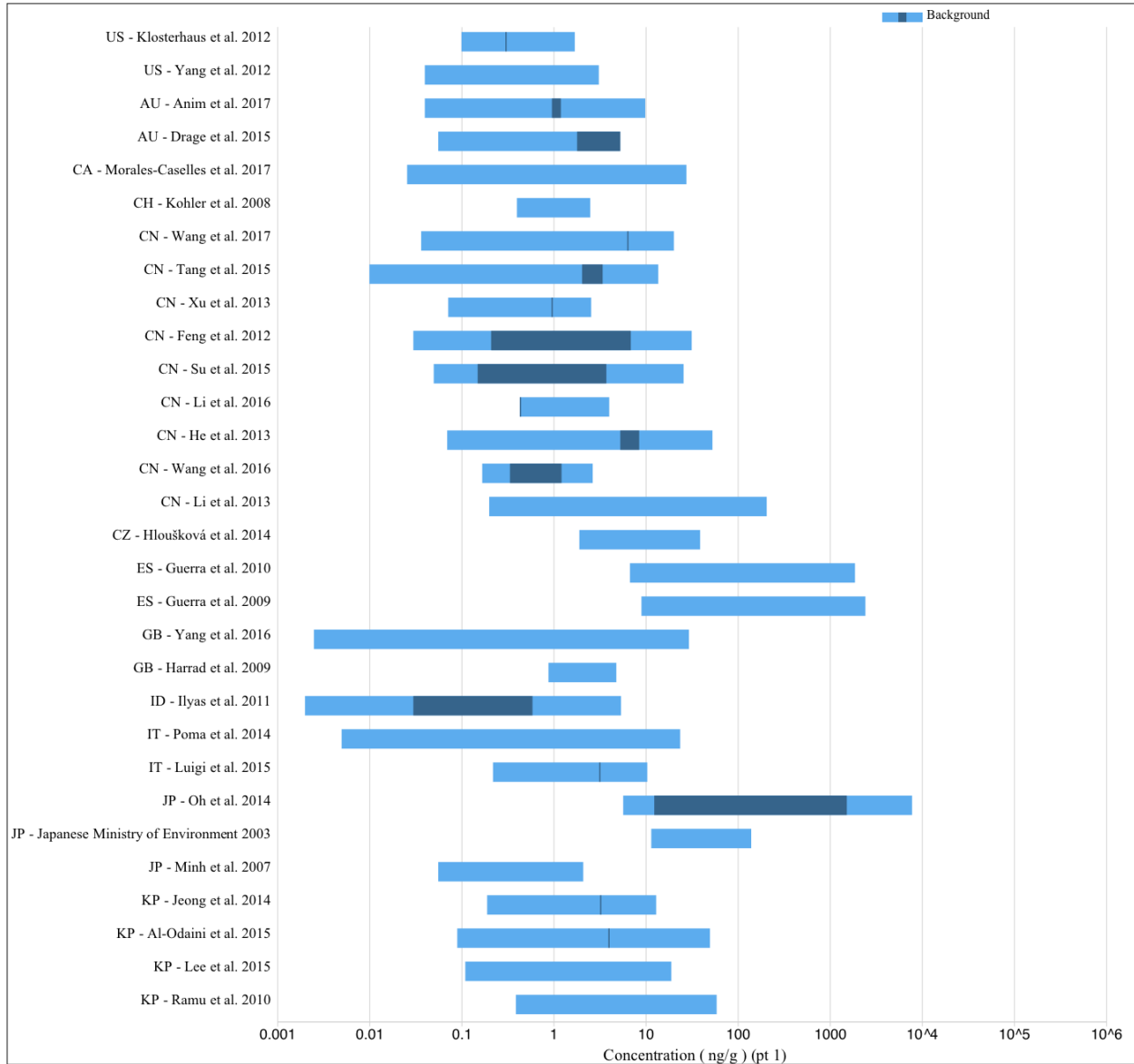
Two European studies measured HBCD levels in precipitation, as cited in [EC/HC \(2011\)](#). In the [Peters \(2003\)](#) study conducted in the Netherlands in 2003, total HBCD was detected in one of 50 samples at 1.835 µg/L. In the [Remberger et al. \(2004\)](#) study, also cited as [Sternbeck et al. \(2001\)](#) in [EC \(2008\)](#), total HBCD in deposition ranged from 0.00002 µg/m³ in a remote area of Sweden to 0.366 µg/m³ in an urban area of Sweden (n = 4). In Finland, total HBCD in deposition ranged from 0.0051 and 0.013 µg/m³ (n = 2).

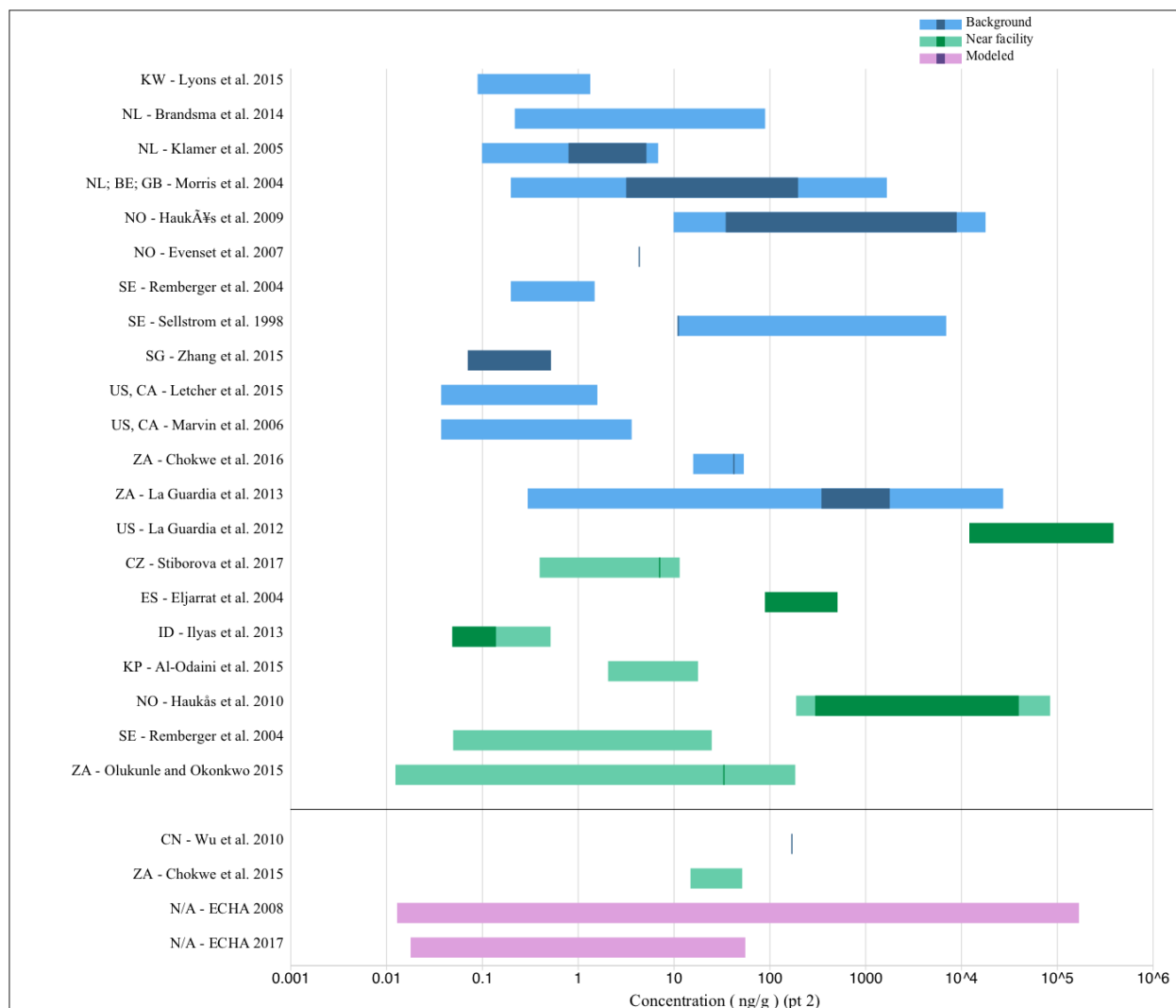
Asia

[Ichihara et al. \(2014\)](#) measured HBCD in surface water samples from 19 sampling locations in the Yodo River basin in Japan. Multiple samples were collected per sampling location and the mean values were reported by sampling location and by river. Across all 19 sampling locations, surface water concentrations ranged from 1.9e-4 ug/L to 1.4e-2 ug/L with an average concentration of 3.3e-3 ug/L. Average concentrations in the Kanzaki River, Yodo River, and Yamato River were 9.1e-4, 7.6e-4, and 6.7e-3 ug/L, respectively. The authors also reported flow rates and estimated pollutant loads. It is noteworthy, that the lowest flow river, the Yamato River, had the highest HBCD concentration.

5.2 Sediment

5.2.1 Sediment Chart





5.2.2 Sediment Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1443796	{Klosterhaus, 2012, 1443796}	0.1	1.7	0.3	0.3
1927611	{Yang, 2012, 1927611}	0.04	3.1		
3828881	{Anim, 2017, 3828881}	0.04	9.9	0.96	1.2
3350544	{Drage, 2015, 3350544}	0.056	5.3	1.8	5.3
3982731	{Morales-Caselles, 2017, 3982731}	0.0257	27.682		
1927729	{Kohler, 2008, 1927729}	0.4	2.5		
3546093	{Wang, 2017, 3546093}	0.0365	20.25	6.31	6.31
3350536	{Tang, 2015, 3350536}	0.01	13.7	2.04	3.41
1927542	{Xu, 2013, 1927542}	0.0718	2.56	0.95	0.95

1927606	{Feng, 2012, 1927606}	0.03	31.6	0.21	6.892
3350531	{Su, 2015, 3350531}	0.05	25.8	0.15	3.74
3546008	{Li, 2016, 3546008}	0.43	4.02	0.43	0.43
1927551	{He, 2013, 1927551}	0.07	53.1	5.3	8.5
3350514	{Wang, 2016, 3350514}	0.168	2.66	0.336	1.22
1927554	{Li, 2013, 1927554}	0.2	206.102		
2343734	{HlouÅ;kovÅ;, 2014, 2343734}	1.905	39		
1040997	{Guerra, 2010, 1040997}	6.75	1873		
3575325	{Guerra, 2009, 3575325}	9	2430		
3350516	{Yang, 2016, 3350516}	0.0025	29.5		
1927694	{Harrad, 2009, 1927694}	0.88	4.8		
1927663	{Ilyas, 2011, 1927663}	0.002	5.4	0.03	0.59
2528332	{Poma, 2014, 2528332}	0.005	23.7		
2919854	{Luigi, 2015, 2919854}	0.22	10.41	3.128	3.128
2343704	{Oh, 2014, 2343704}	5.7	7800	12.4	1526.7
4296220	{Japanese, 2003, 4296220}	11.5	140		
1927778	{Minh, 2007, 1927778}	0.056	2.1		
2343722	{Jeong, 2014, 2343722}	0.19	13	3.2	3.2
3350546	{Al-Odaini, 2015, 3350546}	0.09	49.9	3.94	3.94
3350542	{Lee, 2015, 3350542}	0.11	19		
947611	{Ramu, 2010, 947611}	0.39	59		
3350521	{Lyons, 2015, 3350521}	0.09	1.35		
2528319	{Brandsma, 2014, 2528319}	0.22	90.2		
683627	{Klamer, 2005, 683627}	0.1	6.9	0.8	5.2
1927817	{Morris, 2004, 1927817}	0.2	1680	3.2	199
1927703	{HaukÅ;fÅ;s, 2009, 1927703}	10	18000	35	9000
469357	{Evenset, 2007, 469357}			4.31	4.31
1927826	{Remberger, 2004, 1927826}	0.2	1.5		
1715539	{Sellstrom, 1998, 1715539}	11	7000	11	11
3350497	{Zhang, 2015, 3350497}			0.071	0.525
3350541	{Letcher, 2015, 3350541}	0.0375	1.6		
1927800	{Marvin, 2006, 1927800}	0.0375	3.65		
3545930	{Chokwe, 2016, 3545930}	16	54	42	42
1927534	{La Guardia, 2013, 1927534}	0.3	27500	349	1800
1927601	{La Guardia, 2012, 1927601}			12192	389700
3546060	{Stiborova, 2017, 3546060}	0.4	11.57	7.04	7.04
999290	{Eljarrat, 2004, 999290}			89.7	513.6
2149566	{Ilyas, 2013, 2149566}	0.049	0.52	0.049	0.14
3350546	{Al-Odaini, 2015, 3350546}	2.07	17.98		

1927670	{HaukÅs, 2010, 1927670}	190	85000	300	40000
1927826	{Remberger, 2004, 1927826}	0.05	25		
3016112	{Olukunle, 2015, 3016112}	0.0125	186	33	33
1927678	{Wu, 2010, 1927678}			169	169
3350535	{Chokwe, 2015, 3350535}	15	52		
3970747	{ECHA, 2008, 3970747}	0.013	170000		
3970753	{ECHA, 2017, 3970753}	0.018	56		

5.2.3 Sediment: Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Klosterhaus, 2012, 1443796}	US	Background	2007	10	1	N/R	1.7	Medium
{Yang, 2012, 1927611}	US	Background	2007	16	N/R	N/R	1.6	High
{Anim, 2017, 3828881}	AU	Background	2014 - 2015	48	N/R	N/R	1.3	High
{Drage, 2015, 3350544}	AU	Background	1850 - 2014	30	0.8	N/R	1.7	Medium
{Morales-Caselles, 2017, 3982731}	CA	Background	2011	7	0.58	0	1.8	Medium
{Kohler, 2008, 1927729}	CH	Background	1974 - 2001	5	1	N/R	1.9	Medium
{Wang, 2017, 3546093}	CN	Background	2016	23	0.96	0.073	1.9	Medium
{Tang, 2015, 3350536}	CN	Background	2012	40	1	N/R	1.4	High
{Xu, 2013, 1927542}	CN	Background	2010	12	0.83	0.14	1.8	Medium
{Feng, 2012, 1927606}	CN	Background	2009 - 2010	121	N/R	N/R	1.8	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Su, 2015, 3350531}	CN	Background	2010	40	N/R	0.003	1.7	Medium
{Li, 2016, 3546008}	CN	Background	2010	17	N/R	0.08	1.4	High
{He, 2013, 1927551}	CN	Background	2009	80	N/R	N/R	1.3	High
{Wang, 2016, 3350514}	CN	Background	2009	26	N/R	0.003	1.9	Medium
{Li, 2013, 1927554}	CN	Background	2003 - 2004	34	0.59	0.4	1.4	High
{HlouÅ;kovÅ;, 2014, 2343734}	CZ	Background	2010	31	0.96	3.8	1.7	Medium
{Guerra, 2010, 1040997}	ES	Background	2006	7	0.71	14	1.6	High
{Guerra, 2009, 3575325}	ES	Background	2002 - 2006	12	N/R	9	2	Medium
{Yang, 2016, 3350516}	GB	Background	2011 - 2012	74	0.76	0.005	1.9	Medium
{Harrad, 2009, 1927694}	GB	Background	2008 - 2009	9	1	N/R	1.7	Medium
{Ilyas, 2011, 1927663}	ID	Background	2008	33	0.94	N/R	2.0	Medium
{Poma, 2014, 2528332}	IT	Background	2011 - 2012	17	0.9	0.01	1.6	High
{Luigi, 2015, 2919854}	IT	Background	2010	5	1	0.011	1.9	Medium
{Oh, 2014, 2343704}	JP	Background	2011	17	1	N/R	1.4	High
{Japanese, 2003, 4296220}	JP	Background	2003	1	0.07	23	2.6	Low

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Minh, 2007, 1927778}	JP	Background	2002	9	1	0.01	2.1	Medium
{Jeong, 2014, 2343722}	KP	Background	2010	12	1	0.02	1.3	High
{Al-Odaini, 2015, 3350546}	KP	Background	2010	19	1	N/R	1.9	Medium
{Lee, 2015, 3350542}	KP	Background	2009	24	1	0.006	1.6	High
{Ramu, 2010, 947611}	KP	Background	2005	29	1	N/R	1.4	High
{Lyons, 2015, 3350521}	KW	Background	2013 - 2014	29	1	N/R	1.4	High
{Brandsma, 2014, 2528319}	NL	Background	2008	6	1	0.5	2.0	Medium
{Klamer, 2005, 683627}	NL	Background	2000	10	0.9	0.2	2.1	Medium
{Morris, 2004, 1927817}	NL; BE; GB	Background	1999 - 2002	77	N/R	1.2	2.3	Low
{HaukÃfÃs, 2009, 1927703}	NO	Background	2006 - 2007	25	1	0.005	1.8	Medium
{Evenset, 2007, 469357}	NO	Background	2001	1	1	0.06	2.2	Medium
{Remberger, 2004, 1927826}	SE	Background	1943 - 1997	6	1	0.1	1.8	Medium
{Sellstrom, 1998, 1715539}	SE	Background	1995	9	0.78	N/R	2.0	Medium
{Zhang, 2015, 3350497}	SG	Background	2014	12	1	0.007	1.7	High
{Letcher, 2015, 3350541}	US, CA	Background	2004	37	0.35	0.075	1.7	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Marvin, 2006, 1927800}	US, CA	Background	2001	63	0.67	0.075	1.8	Medium
{Chokwe, 2016, 3545930}	ZA	Background	2013	6	1	N/R	1.7	Medium
{La Guardia, 2013, 1927534}	ZA	Background	2011	45	0.69	0.6	1.9	Medium
{La Guardia, 2012, 1927601}	US	Near facility	2009	5	N/R	1	1.7	Medium
{Stiborova, 2017, 3546060}	CZ	Near facility	2016	12	0.58	0.8	1.7	Medium
{Eljarrat, 2004, 999290}	ES	Near facility	2002	2	N/R	N/R	1.8	Medium
{Ilyas, 2013, 2149566}	ID	Near facility	2008	5	0.8	N/R	1.4	High
{Al-Odaini, 2015, 3350546}	KP	Near facility	2010	10	1	N/R	1.9	Medium
{Haukås, 2010, 1927670}	NO	Near facility	2007	8	1	270	1.9	Medium
{Remberger, 2004, 1927826}	SE	Near facility	2000	8	0.38	0.1	1.8	Medium
{Olukunle, 2015, 3016112}	ZA	Near facility	2013	18	0.2	N/R	1.8	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet								
{Wu, 2010, 1927678}	CN	Background	2006	3	0.5	N/R	2.0	Medium
{Chokwe, 2015, 3350535}	ZA	Near facility	2013	12	1	0.48	1.6	High
{ECHA, 2008, 3970747}	N/A	Modeled	N/A	N/A	N/A	N/A	1.3	High
{ECHA, 2017, 3970753}	N/A	Modeled	N/A	N/A	N/A	N/A	2	Medium

5.2.3.1.1 North America

The Canadian and Australian risk assessments ([NICNAS, 2012](#); [EC/HC, 2011](#)) summarized sediment data from two studies conducted in North America. [Law et al. \(2014\)](#) reported sediment concentrations of 0.05 µg/kg dw from four sites in Lake Winnipeg. In this study, γ-HBCD was detected ([Law et al., 2006b](#)). [Marvin et al. \(2006\)](#) measured HBCD in suspended sediments from nine locations in the Detroit River, noting an association between magnitude of concentration and proximity to urban and industrial areas. HBCD concentrations ranged from ND to 3.7 µg/kg dw, with the highest levels being found downstream of the urban region surrounding the city of Detroit. Mean concentrations ranged from 0.012 to 1.14 µg/kg dw ([Marvin et al., 2006](#)).

[Yang et al. \(2012\)](#) measured brominated flame retardants in 16 sediment core samples collected from the Great Lakes (Superior, Michigan, Huron, Erie, and Ontario) during August 2007. Samples were analyzed for total HBCD using GC-MS. Total HBCD concentrations ranged from 0.04 to 3.1 µg/kg dw in all sediment samples (n = 16). The detection rate for total HBCD was 82% for samples deposited 1950 or later.

[Letcher et al. \(2015\)](#) measured HBCD in bottom sediment samples collected from the Detroit River and Lake Erie (western, central, and eastern basins) and sludge from two Windsor, Ontario WWTPs that feed into the Detroit River, between May and June 2004. Sediment subsamples (n = 37) were obtained from the “top” 10 cm of a 30-cm core sample from Lake Erie (n = 18 sites) and the Detroit River (n = 17 sites) and were analyzed for total HBCD using LC-MS/MS with ESI in the negative mode. Total HBCD concentrations ranged from ND to 1.60 µg/kg dw in all sediment samples (n = 37).

[La Guardia et al. \(2012\)](#) measured HBCD in river sediment, bivalve, and gastropod at the outfall and downstream from a textile facility in North Carolina. Sediment concentrations decreased with distance from the outfall. HBCD concentrations ranged from 389,700 ug/kg at the outfall to 12,192 ug/kg 44 kilometers downstream.

5.2.3.1.2 Europe

The Australian, Canadian, UNEP, and EU risk assessments ([NICNAS, 2012](#); [EC/HC, 2011](#); [UNEP, 2010](#); [EC, 2008](#)) summarized sediment data from sixteen studies conducted in Europe. As discussed in the EU RAR ([EC, 2008](#)), total HBCD concentrations ranged over several orders of magnitude, from ND in unpolluted areas to over 30,000 µg/kg in areas where HBCD is produced and used. The average HBCD concentrations calculated in [EC \(2008\)](#) for areas near point sources was 338 µg/kg, while the average HBCD concentration for areas not impacted by point sources was 31 µg/kg. For areas impacted by point sources, 90th percentile and maximum HBCD sediment concentrations were reported as 270 ug/kg and 33,500 µg/kg, while for areas not impacted by point sources, 90th percentile and maximum HBCD sediment concentrations were reported as 100 µg/kg and 511 µg/kg, respectively. High-end sediment concentrations are likely below the maximum and above the 90th percentile. A 95th percentile value or similar estimate of high-end sediment concentrations was not reported.

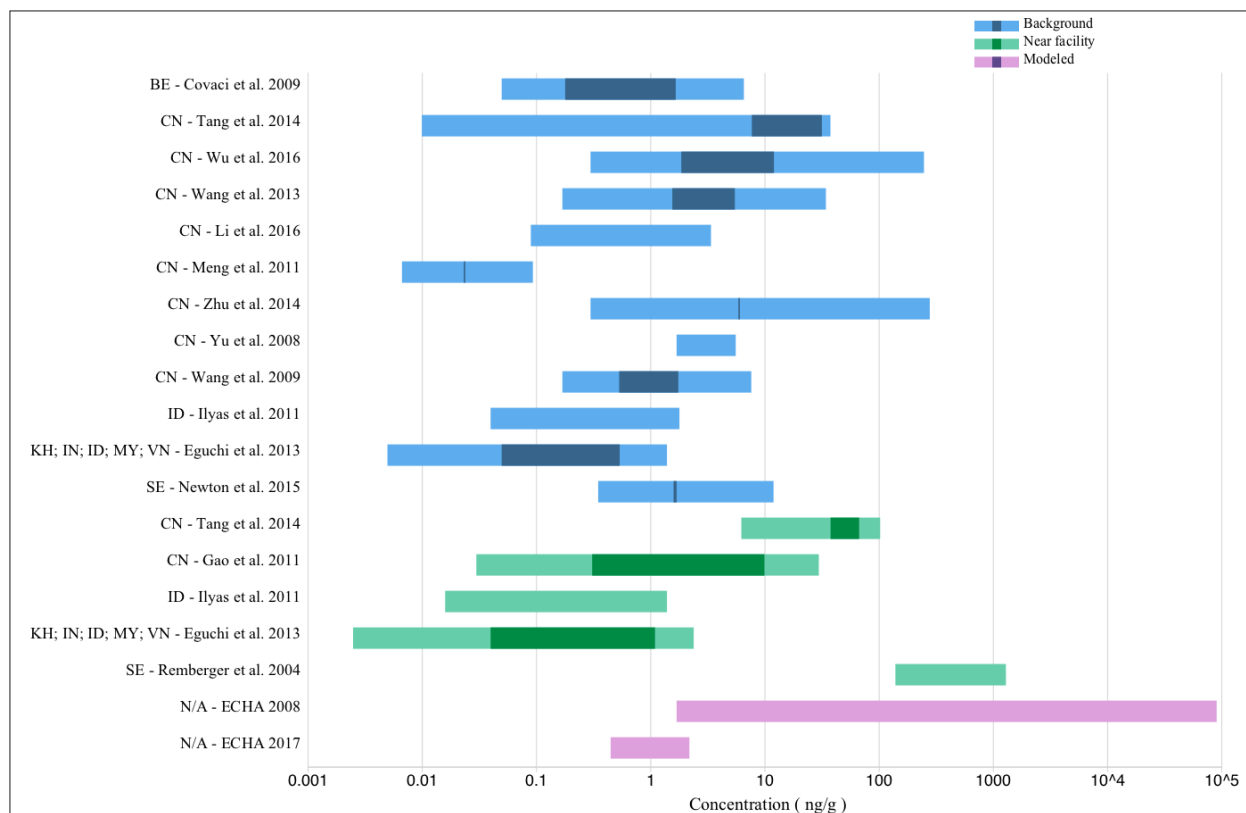
5.2.3.1.3 Asia

The UNEP assessment and [Law et al. \(2014\)](#) summarized Asian sediment data from four studies, shown in the table below. Overall, total HBCD concentrations ranged from ND to 634 µg/kg dw. Studies in Asia and in other locations report a correlation between proximity to sources emitting HBCD and elevated levels in sediment. Sampling locations upstream from or further away from point sources generally reported lower levels of HBCD in sediment ([Law et al., 2014](#)). Sediment dwelling organisms such as mussels, oysters, and other bivalves are additional potential human exposure pathways in addition to fish consumption.

Surface sediment from Jinhae Bay and Masan Bay on the southeastern coast of South Korea was investigated by [Al-Odaini et al. \(2015\)](#) for the presence of HBCD in samples collected in March 2010. Sediment samples were collected from industrialized areas, sewage effluent-receiving areas, urbanized areas, a shipbuilding yard, and aquaculture farms and were analyzed for total HBCD using LC-MS/MS with APCI. Total HBCD surface concentrations ranged from 0.09 to 49.9 µg/kg dw (3.94 µg/kg dw median) in all sediment samples (n = 19). The highest surface sediment concentrations (25.6 to 49.9 µg/kg dw) were measured at sites near the aquaculture farm. In addition, to evaluate whether a WWTP that feeds into Masan Bay could be a point source of HBCD, 10 sediment samples were collected from three transects originating from the plant outfall. Total HBCD surface sediment concentrations ranged from 2.07 to 17.98 µg/kg dw in all sediment samples from the transects (n = 10).

5.2.4 Soil

5.2.4.1.1 Soil Chart



5.2.4.1.2 Soil Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
787649	{Covaci, 2009, 787649}	0.05	6.6	0.18	1.67
2343699	{Tang, 2014, 2343699}	0.01	37.8	7.75	31.8
3223093	{Wu, 2016, 3223093}	0.3	249	1.87	12.1
1927586	{Wang, 2013, 1927586}	0.17	34.5	1.56	5.5
3546008	{Li, 2016, 3546008}	0.09	3.4		
1058212	{Meng, 2011, 1058212}	0.0067	0.0938	0.0233	0.0233
2343705	{Zhu, 2014, 2343705}	0.3	280	5.91	5.91

1049627	{Yu, 2008, 1049627}	1.7	5.6		
1927688	{Wang, 2009, 1927688}	0.17	7.66	0.534	1.76
1927642	{Ilyas, 2011, 1927642}	0.04	1.8		
1927572	{Eguchi, 2013, 1927572}	0.005	1.4	0.05	0.54
2911989	{Newton, 2015, 2911989}	0.35	12	1.6	1.7
2343699	{Tang, 2014, 2343699}	6.27	103	37.9	67.4
1927645	{Gao, 2011, 1927645}	0.03	29.9	0.31	9.99
1927642	{Ilyas, 2011, 1927642}	0.016	1.4		
1927572	{Eguchi, 2013, 1927572}	0.0025	2.4	0.04	1.1
1927826	{Remberger, 2004, 1927826}	140	1300		
3970747	{ECHA, 2008, 3970747}	1.7	91000		
3970753	{ECHA, 2017, 3970753}	0.45	2.2		

5.2.4.1.3 Soil: Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Covaci, 2009, 787649}	BE	Background	2006 - 2007	20	0.75	0.1	1.8	Medium
{Tang, 2014, 2343699}	CN	Background	2012	90	0.92	0.02	1.6	High
{Wu, 2016, 3223093}	CN	Background	2012	37	1	0.03	1.6	High
{Wang, 2013, 1927586}	CN	Background	2010 - 2011	72	1	N/R	1.9	Medium
{Li, 2016, 3546008}	CN	Background	2010	17	N/R	0.08	1.4	High

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Meng, 2011, 1058212}	CN	Background	2009	22	0.86	0.013	1.3	High
{Zhu, 2014, 2343705}	CN	Background	2008	38	N/R	0.003	1.8	Medium
{Yu, 2008, 1049627}	CN	Background	2006	3	N/R	N/R	3	Low ^a
{Wang, 2009, 1927688}	CN	Background	2006	17	N/R	0.34	1.4	High
{Ilyas, 2011, 1927642}	ID	Background	2008	17	0.88	N/R	1.7	Medium
{Eguchi, 2013, 1927572}	KH; IN; ID; MY; VN	Background	1999 - 2007	24	N/R	0.005	1.4	High
{Newton, 2015, 2911989}	SE	Background	2012	8	1	N/R	2.0	Medium
{Tang, 2014, 2343699}	CN	Near facility	2012	90	0.92	0.02	1.6	High
{Gao, 2011, 1927645}	CN	Near facility	2006 - 2008	32	1	0.011	1.4	High
{Ilyas, 2011, 1927642}	ID	Near facility	2008	6	1	N/R	1.7	Medium
{Eguchi, 2013, 1927572}	KH; IN; ID; MY; VN	Near facility	1999 - 2007	42	N/R	0.005	1.4	High
{Remberger, 2004, 1927826}	SE	Near facility	2000	3	1	N/R	1.8	Medium
{ECHA, 2008, 3970747}	N/A	Modeled	N/A	N/A	N/A	N/A	1.3	High
{ECHA, 2017, 3970753}	N/A	Modeled	N/A	N/A	N/A	N/A	2	Medium

^a Study evaluation score was downgraded from medium to low based on professional judgement.

5.2.4.1.4 Europe

As cited in the secondary source international risk assessments ([NICNAS, 2012](#); [EC/HC, 2011](#); [UNEP, 2010](#); [EC, 2008](#)), six studies present HBCD concentrations in soil collected from industrial sites in the United Kingdom and Sweden. Overall, total HBCD concentrations ranged from 10 to 89,600 $\mu\text{g}/\text{kg dw}$. The highest concentration was observed at a flame retardant formulator/compounder plant, followed by a backcoater (up to 61,000 $\mu\text{g}/\text{kg dw}$), under cellular plastic of railway embankments (up to 45,000 $\mu\text{g}/\text{kg dw}$), and at XPS-producing facilities (up to 23,200 $\mu\text{g}/\text{kg dw}$).

5.2.4.1.5 Asia

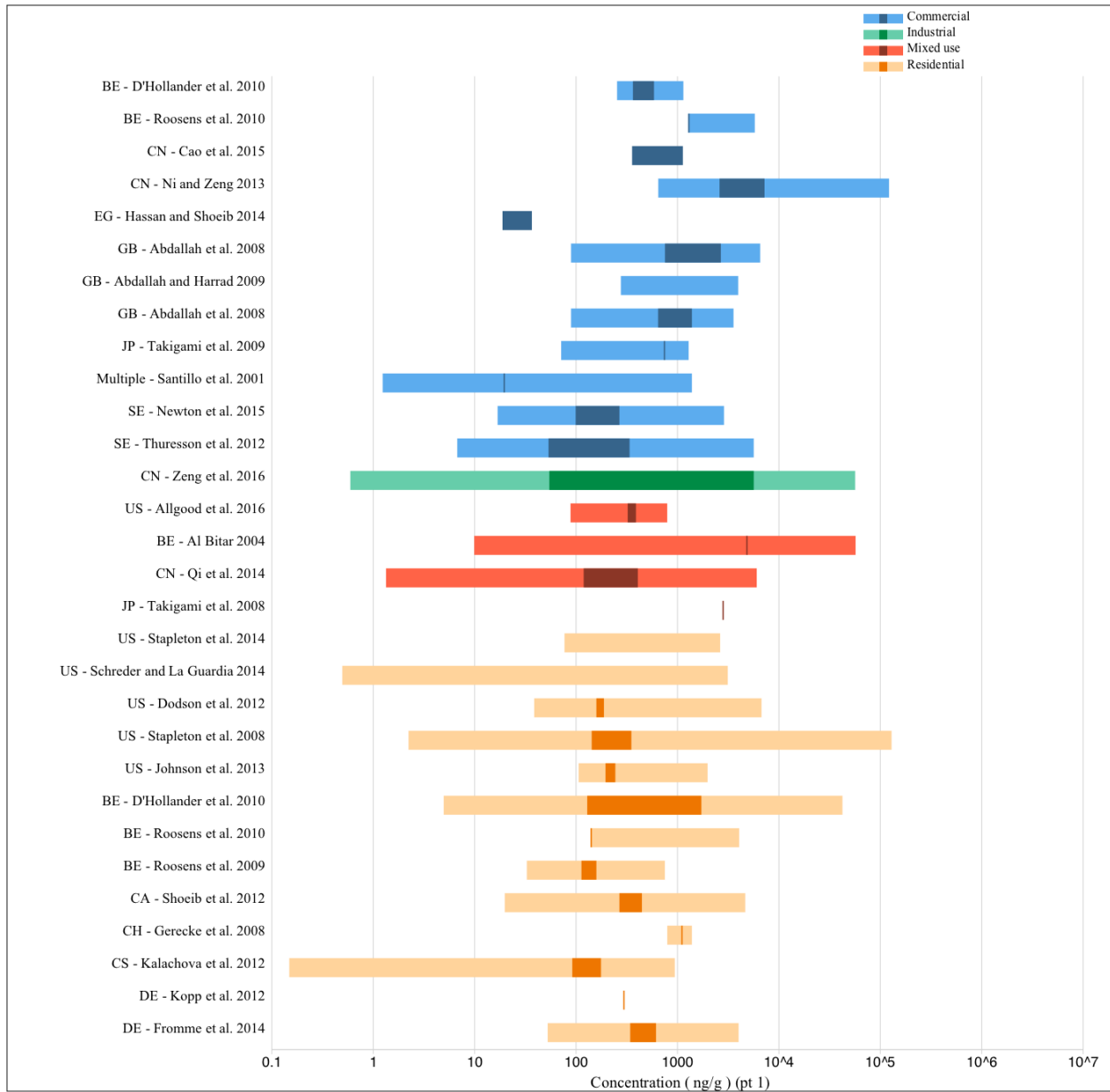
The Canadian risk assessment identified one study ([Yu et al., 2008a](#)) which measured HBCD in soil samples collected in China in 2006. Total HBCD concentrations ranged from 1.7 to 5.6 $\mu\text{g}/\text{kg dw}$ in three samples.

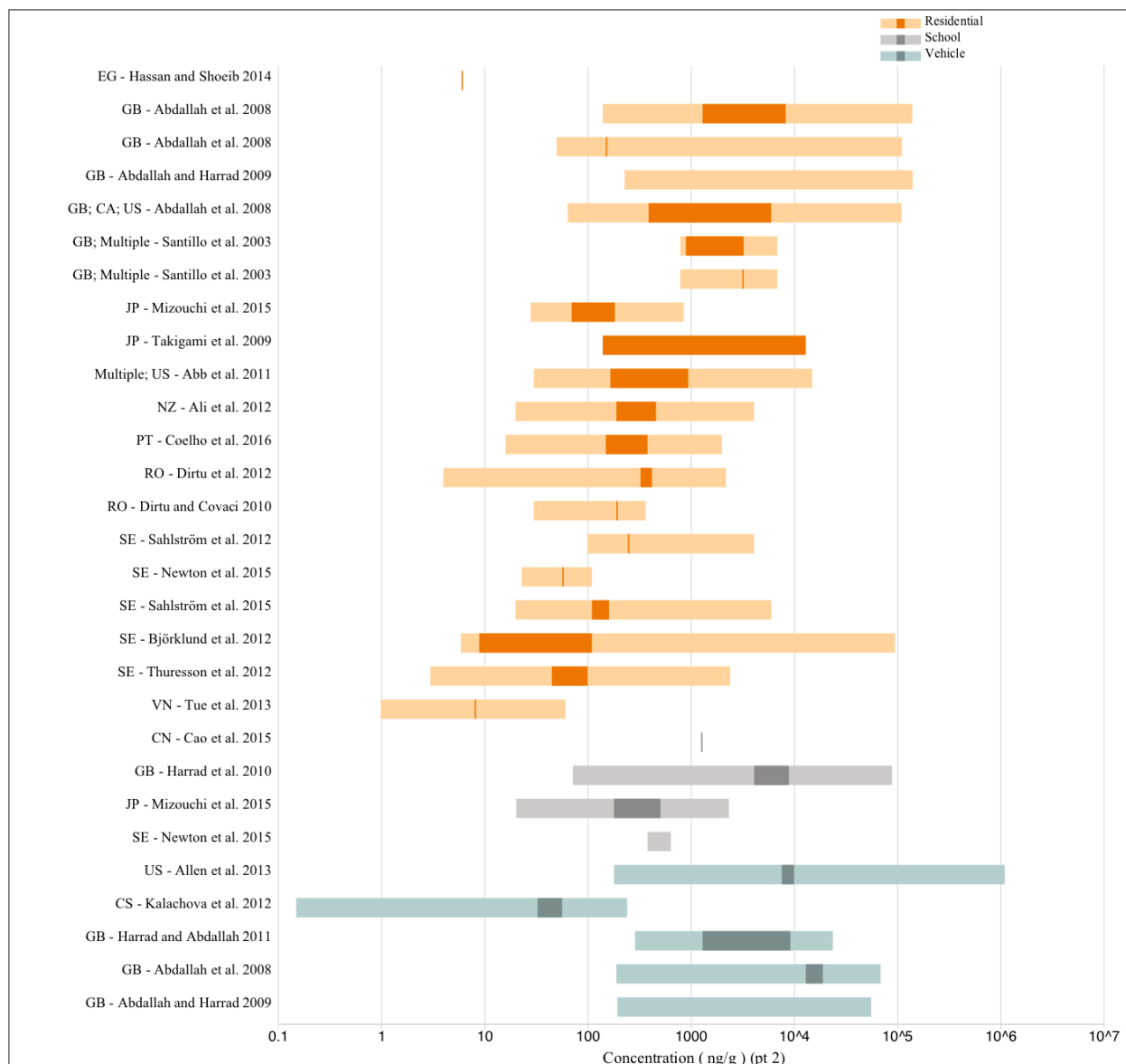
[Law et al. \(2014\)](#) identified four studies conducted in Asia. Total HBCD concentrations from samples collected in rural, urban, agricultural and industrial areas of China and Indonesia ranged from ND to 35 $\mu\text{g}/\text{kg dw}$, with the exception of a maximum value of 284 $\mu\text{g}/\text{kg dw}$ from an e-waste recycling site. Reported central tendency values were 3.0 $\mu\text{g}/\text{kg dw}$ (median) for farms in southeast Beijing, 0.22 to 0.79 $\mu\text{g}/\text{kg dw}$ (means) for industrial areas in south China, and 0.31 to 10 $\mu\text{g}/\text{kg dw}$ (means) in e-waste areas of south China.

[Tang et al. \(2014\)](#) collected 90 samples from the Ningbo Region in China. Land-use was explicitly considered as soil samples were collected from six different land-uses. There are likely differences between countries regarding the overall magnitude of HBCD concentrations in soil. However, the differences across HBCD concentrations by land use categories may be similar across countries. The overall range of soil concentrations reported was ND (farmland areas) to 103 $\mu\text{g}/\text{kg}$ (industrial areas) with land-use highly influencing the overall magnitude of reported soil concentrations.

5.2.5 Indoor Dust

5.2.5.1.1 Indoor Dust Chart





5.2.5.1.2 Indoor Dust Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1578505	{D'Hollander, 2010, 1578505}	256	1153	367	592
1927685	{Roosens, 2010, 1927685}	1288.73	5836.79	1288.73	1288.73
3016880	{Cao, 2015, 3016880}			360	1140
1927552	{Ni, 2013, 1927552}	652	122973	2621	7276
2528318	{Hassan, 2014, 2528318}			19	37
1079114	{Abdallah, 2008, 1079114}	90	6600	760	2700
787630	{Abdallah, 2009, 787630}	279	4004		
1079430	{Abdallah, 2008, 1079430}	90	3600	650	1400
1927720	{Takigami, 2009, 1927720}	72	1300	740	740

1003986	{Santillo, 2001, 1003986}	1.25	1400	19.5	19.5
2911989	{Newton, 2015, 2911989}	17	2900	100	270
1927620	{Thuresson, 2012, 1927620}	6.8	5700	54	340
3350480	{Zeng, 2016, 3350480}	0.6	57000	55	5700
3455810	{Allgood, 2016, 3455810}	89	799	326	393
1007825	{Al Bitar, 2004, 1007825}	10	57554	4805	4805
2528328	{Qi, 2014, 2528328}	1.35	6100	120	410
1927735	{Takigami, 2008, 1927735}			2800	2800
2343712	{Stapleton, 2014, 2343712}	77.6	2658		
2528320	{Schreder, 2014, 2528320}	0.5	3160		
2557649	{Dodson, 2012, 2557649}	39	6800	160	190
697789	{Stapleton, 2008, 697789}	2.25	130200	144	354
1676758	{Johnson, 2013, 1676758}	107	1999	197	246
1578505	{D'Hollander, 2010, 1578505}	5	42692	130	1735
1927685	{Roosens, 2010, 1927685}	140.33	4092.74	140.33	140.33
787720	{Roosens, 2009, 787720}	33	758	114	160
1927609	{Shoeib, 2012, 1927609}	20	4700	270	450
1927965	{Gerecke, 2008, 1927965}	800	1400	1100	1100
1927573	{Kalachova, 2012, 1927573}	0.15	949.5	92.6	177.7
1928011	{Kopp, 2012, 1928011}			295.03	295.03
2343719	{Fromme, 2014, 2343719}	53	4041	345	620
2528318	{Hassan, 2014, 2528318}			6	6
1079114	{Abdallah, 2008, 1079114}	140	140000	1300	8300
1927749	{Abdallah, 2008, 1927749}	50	111000	150	150
787630	{Abdallah, 2009, 787630}	228	140774		
1079430	{Abdallah, 2008, 1079430}	64	110000	390	6000
1006146	{Santillo, 2003, 1006146}	790	6900	895	3250
3809265	{Santillo, 2003, 3809265}	790	6900	3158	3250
3015040	{Mizouchi, 2015, 3015040}	28.033	851.84	70	183.366
198241	{Takigami, 2009, 198241}			140	13000
787629	{Abb, 2011, 787629}	30	15000	166	945
1927602	{Ali, 2012, 1927602}	20	4100	190	460
3350460	{Coelho, 2016, 3350460}	16	2000	150	380
1927581	{Dirtu, 2012, 1927581}	4	2190	325	420
1061566	{Dirtu, 2010, 1061566}	30	365	190	190
1927594	{Sahlstr�m, 2012, 1927594}	100	4100	246	246
2911989	{Newton, 2015, 2911989}	23	110	57	57
3012178	{Sahlstr�m, 2015, 3012178}	20	6000	110	161
1927616	{Bj�rklund, 2012, 1927616}	5.9	95000	8.9	110
1927620	{Thuresson, 2012, 1927620}	3	2400	45	100
1927567	{Tue, 2013, 1927567}	0.99	61	8.05	8.05
3016880	{Cao, 2015, 3016880}			1260	1260
1076646	{Harrad, 2010, 1076646}	72	89000	4100	8900

3015040	{Mizouchi, 2015, 3015040}	20.33	2334.465	180	507.427
2911989	{Newton, 2015, 2911989}	380	640		
1597662	{Allen, 2013, 1597662}	180	1100000	7600	10000
1927573	{Kalachova, 2012, 1927573}	0.15	241.4	32.7	56.6
1082335	{Harrad, 2011, 1082335}	288	23722	1300	9200
1079114	{Abdallah, 2008, 1079114}	190	69000	13000	19000
787630	{Abdallah, 2009, 787630}	194	55822		

5.2.5.1.3 Indoor Dust: Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{D'Hollander, 2010, 1578505}	BE	Commercial	2008	10	1	N/R	1.6	High
{Roosens, 2010, 1927685}	BE	Commercial	2008	10	1	N/R	1.5	High
{Cao, 2015, 3016880}	CN	Commercial	2012	65	N/R	1.5	1.8	Medium
{Ni, 2013, 1927552}	CN	Commercial	2009	56	N/R	N/R	1.4	High
{Hassan, 2014, 2528318}	EG	Commercial	2013	14	N/R	N/R	2.0	Medium
{Abdallah, 2008, 1079114}	GB	Commercial	2006 - 2007	32	1	0.1	1.3	High
{Abdallah, 2009, 787630}	GB	Commercial	2007	21	1	0.3	1.2	High
{Abdallah, 2008, 1079430}	GB	Commercial	2006	6	1	N/R	1.8	Medium
{Takigami, 2009, 1927720}	JP	Commercial	2006	8	1	20	1.7	Medium
{Santillo, 2001, 1003986}	Multiple	Commercial	2000 - 2001	7	0.7	2.5	2	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Newton, 2015, 2911989}	SE	Commercial	2012	21	1	N/R	2.0	Medium
{Thuresson, 2012, 1927620}	SE	Commercial	2006	37	N/R	N/R	1.7	Medium
{Zeng, 2016, 3350480}	CN	Industrial	2013	48	0.92	1.2	1.2	High
{Allgood, 2016, 3455810}	US	Mixed use	2013	20	1	1	1.3	High
{Al Bitar, 2004, 1007825}	BE	Mixed use	2003	23	0.26	20	3.0	Low
{Qi, 2014, 2528328}	CN	Mixed use	2010 - 2011	81	0.99	2.7	1.4	High
{Takigami, 2008, 1927735}	JP	Mixed use	2005	15	0.2	0.4	1.8	Medium
{Stapleton, 2014, 2343712}	US	Residential	2012	30	1	N/R	1.8	Medium
{Schreder, 2014, 2528320}	US	Residential	2011 - 2012	20	0.95	1	2.0	Medium
{Dodson, 2012, 2557649}	US	Residential	2006 - 2011	32	1	5	1.4	High
{Stapleton, 2008, 697789}	US	Residential	2006	35	0.95	4.5	2.1	Medium
{Johnson, 2013, 1676758}	US	Residential	2002 - 2003	38	0.97	N/R	2.1	Medium
{D'Hollander, 2010, 1578505}	BE	Residential	2008	43	1	N/R	1.6	High
{Roosens, 2010, 1927685}	BE	Residential	2008	43	1	N/R	1.5	High
{Roosens, 2009, 787720}	BE	Residential	2007	16	1	N/R	1.4	High

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Shoeib, 2012, 1927609}	CA	Residential	2007 - 2008	116	1	N/R	2.0	Medium
{Gerecke, 2008, 1927965}	CH	Residential	2003 - 2007	3	1	N/R	1.8	Medium
{Kalachova, 2012, 1927573}	CS	Residential	2008	24	0.88	0.3	1.7	Medium
{Kopp, 2012, 1928011}	DE	Residential	N/R	5	1	3	1.8	Medium
{Fromme, 2014, 2343719}	DE	Residential	N/R	20	1	1	2.0	Medium
{Hassan, 2014, 2528318}	EG	Residential	2013	17	N/R	N/R	2.0	Medium
{Abdallah, 2008, 1079114}	GB	Residential	2006 - 2007	45	1	0.1	1.3	High
{Abdallah, 2008, 1927749}	GB	Residential	2007	37	1	0.2	1.7	Medium
{Abdallah, 2009, 787630}	GB	Residential	2007	21	1	0.3	1.2	High
{Abdallah, 2008, 1079430}	GB; CA; US	Residential	2006	52	1	N/R	1.8	Medium
{Santillo, 2003, 1006146}	GB; Multiple	Residential	2002	12	1	2.5	1.6	High
{Santillo, 2003, 3809265}	GB; Multiple	Residential	2002	102	1	13	2.2	Medium
{Mizouchi, 2015, 3015040}	JP	Residential	2009 - 2010	10	1	20	1.9	Medium
{Takigami, 2009, 198241}	JP	Residential	2006	2	N/R	N/R	1.9	Medium
{Abb, 2011, 787629}	Multiple; US	Residential	2011	28	1	N/R	1.9	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Ali, 2012, 1927602}	NZ	Residential	2008	50	1	N/R	1.9	Medium
{Coelho, 2016, 3350460}	PT	Residential	2010 - 2011	28	1	0.23	2.0	Medium
{Dirtu, 2012, 1927581}	RO	Residential	2010	47	1	6	1.3	High
{Dirtu, 2010, 1061566}	RO	Residential	2007	18	1	N/R	2.6	Low
{Sahlstr�m, 2012, 1927594}	SE	Residential	2012	6	1	N/R	1.9	Medium
{Newton, 2015, 2911989}	SE	Residential	2012	4	1	N/R	2	Medium
{Sahlstr�m, 2015, 3012178}	SE	Residential	2009 - 2010	27	1	N/R	1.7	Medium
{Bj�rklund, 2012, 1927616}	SE	Residential	2008 - 2009	37	0.87	9	1.9	Medium
{Thuresson, 2012, 1927620}	SE	Residential	2006	54	N/R	3	1.7	Medium
{Tue, 2013, 1927567}	VN	Residential	2008	13	1	N/R	1.9	Medium
{Cao, 2015, 3016880}	CN	School	2012	2	N/R	1.5	1.8	Medium
{Harrad, 2010, 1076646}	GB	School	2007 - 2008	36	0.83	N/R	2.0	Medium
{Mizouchi, 2015, 3015040}	JP	School	2009 - 2010	18	1	20	1.9	Medium
{Newton, 2015, 2911989}	SE	School	2012	4	1	N/R	2.0	Medium
{Allen, 2013, 1597662}	US	Vehicle	2010	40	1	0.12	2.1	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry								
{Kalachova, 2012, 1927573}	CS	Vehicle	2008	26	0.97	0.3	1.7	Medium
{Harrad, 2011, 1082335}	GB	Vehicle	2009	42	1	N/R	2.0	Medium
{Abdallah, 2008, 1079114}	GB	Vehicle	2006 - 2007	20	1	0.1	1.3	High
{Abdallah, 2009, 787630}	GB	Vehicle	2007	12	1	0.3	1.2	High

5.2.5.1.4 North America

[NICNAS \(2012\)](#) and [EC \(2008\)](#) provided HBCD measurements in home and office dust samples from three studies conducted in the United States and Canada ([Abdallah et al., 2008a](#); [Stapleton et al., 2008](#); [Stapleton et al., 2004](#)). [Stapleton et al. \(2004\)](#) analyzed settled dust particles <1000 μm collected from 17 houses in the United States. Total HBCD concentrations ranged from ND to 925 $\mu\text{g}/\text{kg}$ (median = 140 $\mu\text{g}/\text{kg}$). [Stapleton et al. \(2008\)](#) analyzed dust samples from the living room of homes in the US (n = 16). Total HBCD concentrations ranged from ND to 130,200 $\mu\text{g}/\text{kg}$ (geometric mean = 354 $\mu\text{g}/\text{kg}$, median = 230 $\mu\text{g}/\text{kg}$). Bedrooms and home vacuum bags were also sampled in [Stapleton et al. \(2008\)](#), but results were not reported in the secondary sources. [Abdallah et al. \(2008a\)](#) measured HBCD in the dust vacuumed from 13 US homes and 8 Canadian homes. Total HBCD concentrations in the US homes ranged from 110 to 4,000 $\mu\text{g}/\text{kg}$ (mean = 810 $\mu\text{g}/\text{kg}$; median = 390 $\mu\text{g}/\text{kg}$). In the Canadian homes, total HBCD concentrations ranged from 64 to 1,300 $\mu\text{g}/\text{kg}$ (mean = 670 $\mu\text{g}/\text{kg}$; median = 640 $\mu\text{g}/\text{kg}$).

[Stapleton et al. \(2009\)](#) investigated levels of flame retardants in household dust collected between 2002 and 2007. The dust samples (n = 50) were collected from home vacuum cleaner bags in Boston, Massachusetts. Sieved dust samples were extracted using pressurized fluid extraction and then analyzed for brominated flame retardants using GC-MS in ECNI. Total HBCD was detected in 92% of the samples and ranged from ND to 2,750 $\mu\text{g}/\text{kg}$ (geometric mean = 166 $\mu\text{g}/\text{kg}$).

[Dodson et al. \(2012\)](#) measured flame retardants in dust samples collected in 16 California homes in 2011. This study was a repeat of a previous study that was conducted in 2006 at the same 16 homes. The samples were collected, from surfaces in the living areas, using a vacuum equipped with a cellulose extraction thimble and analyzed by HPLC-MS/MS with ESI. Results were similar across time periods. Total HBCD was detected in 100% of the dust samples and ranged from 82 to 6,800 $\mu\text{g}/\text{kg}$ (median = 190 $\mu\text{g}/\text{kg}$) in 2006 and from 39 to 1,800 $\mu\text{g}/\text{kg}$ (median = 160 $\mu\text{g}/\text{kg}$) in 2011.

[Shoeib et al. \(2012\)](#) measured flame retardants in dust samples collected from homes located in Vancouver, Canada, between 2007 and 2008 as part of the Chemicals Health and Pregnancy (CHirP) study. Dust samples, obtained by sampling either vacuum cleaner bags or canisters from bag-less or central vacuums, were analyzed for the flame retardants using GC-MS with ECNI. Total HBCD was detected in all samples (n = 116) with concentrations that ranged from 20 to 4,700 $\mu\text{g}/\text{kg}$ (mean = 450 $\mu\text{g}/\text{kg}$; median = 270 $\mu\text{g}/\text{kg}$). According to the study authors, HBCD was the second most abundant flame retardant found in the dust samples.

[Allen et al. \(2013\)](#) investigated the potential for exposure to flame retardant chemicals from dust found within airplanes. Because flame retardants are used in the manufacture of materials found on airplanes to slow the propagation of fire within an aircraft, exposure to high levels of flame retardants was expected. A total of 40 dust samples were collected between November and December of 2010 from carpeted floors and low-lying air return vents located on the walls of 19 commercial airplanes that were parked overnight at an unidentified international airport in the United States. The samples were collected using a canister vacuum equipped with a cellulose extraction thimble, extracted using a pressurized solvent extraction method, and analyzed by GC-MS. Samples collected from floor and vent displayed similar range and central tendencies. Total HBCD was detected in 100% of the dust samples and ranged from 180 to 1,100,000 $\mu\text{g}/\text{kg}$ (median = 7,600-10,000 $\mu\text{g}/\text{kg}$).

[Johnson et al. \(2013\)](#) studied the correlation between flame retardants in house dust and men's hormone levels. Serum hormone data used in this study were taken from a separate ongoing study on environmental exposures and male reproductive health. A subset of the men from the study, recruited between 2002 and 2003, provided used vacuum bags from their homes. Dust from these vacuum bags was analyzed for the brominated flame retardants using GC-MS with ECNI. Total HBCD concentrations in the dust samples (n = 38) ranged from ND to 1,999 $\mu\text{g}/\text{kg}$ (mean = 246 $\mu\text{g}/\text{kg}$; geometric mean = 197 $\mu\text{g}/\text{kg}$).

[Schreder and La Guardia \(2014\)](#) measured flame retardants in house dust samples and in domestic sewage (laundry wastewater) collected from homes located in Vancouver and Longview, Washington state in 2011 and 2012. Dust samples were obtained using a vacuum fitted with a cellulose filter held in the crevice tool with a stainless-steel ring. Samples were analyzed for the flame retardants using UPLC-MS/MS with atmospheric pressure photoionization (APPI). Total HBCD was detected in all but one of the samples (n = 20) with concentrations that ranged from ND to 3,160 $\mu\text{g}/\text{kg}$ (mean = 649 $\mu\text{g}/\text{kg}$; median = 300 $\mu\text{g}/\text{kg}$).

[Stapleton et al. \(2014\)](#) measured flame retardants in hand wipe and house dust samples collected from homes located in North Carolina during the spring of 2012. Dust samples were collected on both hardwood and carpeted floors by using a vacuum cleaner with a cellulose thimble inserted in the hose attachment. Samples were analyzed for flame retardants using GC-MS. Total HBCD was detected in all samples (n = 30) with concentrations that ranged from 77.6 to 2,658 $\mu\text{g}/\text{kg}$ (geometric mean = 338 $\mu\text{g}/\text{kg}$). The results for hand wipes are provided in the Hand Wipe section in this Appendix.

5.2.5.1.5 Europe

[NICNAS \(2012\)](#) provided a relatively comprehensive compilation of HBCD concentrations in indoor dust samples collected in Europe, as reported from eight studies ([D'Hollander et al., 2010](#);

[Dirtu and Covaci, 2010](#); [Harrad et al., 2010](#); [Abdallah et al., 2008a](#); [Santillo et al., 2003b](#); [Santillo et al., 2003a](#); [Leonards et al., 2001](#); [Santillo et al., 2001](#)). The results for some of these studies were also reported in [EC/HC \(2011\)](#) and [EC \(2008\)](#). The studies sampled dust from homes, office buildings, schools, and daycare centers from 12 countries (United Kingdom, Belgium, France, Romania, Spain, Germany, Italy, Austria, Denmark, Finland, Sweden and the Netherlands). Samples were generally collected using a vacuum cleaner and were analyzed as individual or pooled samples by HPLC or GC-MS. Particle sizes of the dust samples analyzed varied. Overall, total HBCD concentrations in these dust samples ranged from ND to 110,000 µg/kg (means = 225 to 8,900 µg/kg; medians = 130 to 4,100 µg/kg). HBCD was detected in the majority of the samples. As noted in [NICNAS \(2012\)](#), there is a large variation of measured HBCD levels, with a few extreme residues observed in both UK and US samples (discussed above). [NICNAS \(2012\)](#) combined the UK dust samples from [Abdallah et al. \(2008a\)](#) and [Harrad et al. \(2010\)](#), and determined the data exhibit a log normal distribution. [NICNAS \(2012\)](#) selected the 75th percentile (5,450 µg/kg) and 95th percentile (35,630 µg/kg) to represent typical and worst-case values, respectively.

Two additional studies were conducted in the United Kingdom ([Abdallah et al., 2008b](#)) and Belgium ([Roosens et al., 2009](#)), as reported in [EC/HC \(2011\)](#). The dust samples were collected from homes, offices, cars, and public microenvironments. Results were similar to those presented in [NICNAS \(2012\)](#). Overall, total HBCD concentrations in the 113 dust samples of this dataset ranged from 33 to 140,000 µg/kg (means = 160 to 19,000 µg/kg; medians = 114 to 13,000 µg/kg). HBCD was detected in all samples.

Results from an additional study in Belgium ([Al Bitar, 2004](#)) was also reported in [EC \(2008\)](#). In this study, 23 dust samples (individual and pooled) were analyzed from homes and offices. Concentrations of total HBCD ranged from ND to 58,000 µg/kg, with detection in only 6 samples. The study concluded that homes and offices were equally contaminated.

As cited in [Law et al. \(2014\)](#), HBCD was measured in dust samples collected from homes in Czechoslovakia. Total HBCD residues ranged from ND to 950 µg/kg.

5.2.5.1.6 Asia

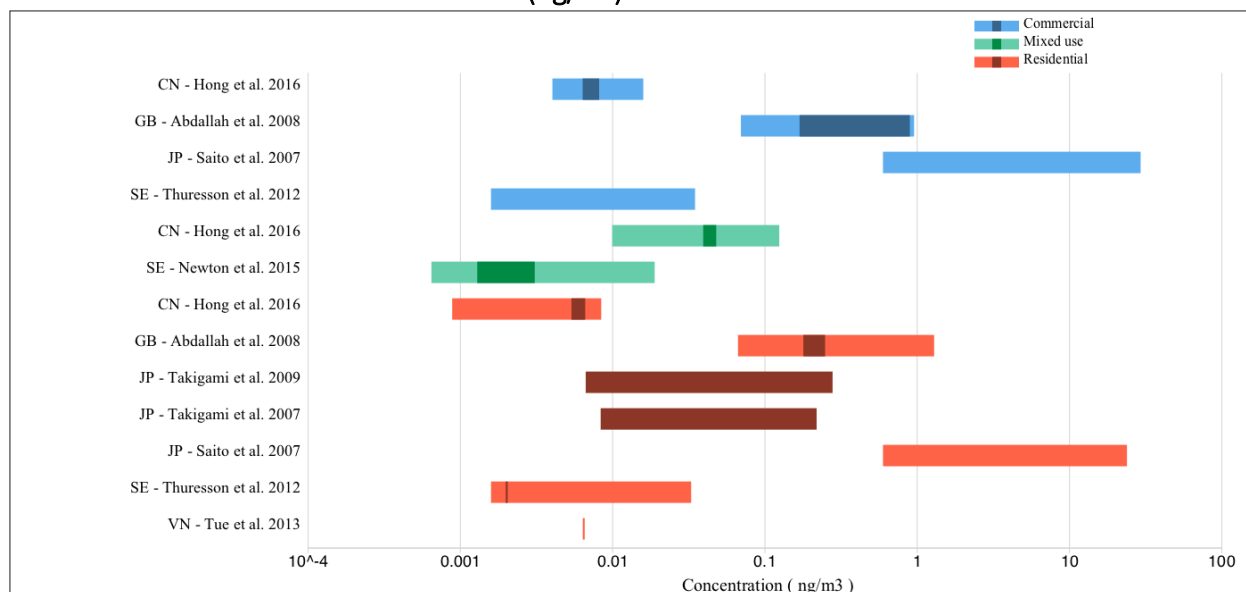
[Ni and Zeng \(2013\)](#) measured total HBCD in air conditioning filter dust samples from an office building in Shenzhen, China in March 2009. The dust samples were collected by brushing the air conditioner fiberglass filters, which trapped particles over 0.3 µm. Total HBCD concentrations in the 56 dust samples, determined by LC-MS with ESI in the negative mode, ranged from 652 to 122,973 µg/kg (mean = 7,276 µg/kg; geometric mean = 3,246 µg/kg; median = 2,621 µg/kg). The study authors noted that since smaller particles may be more likely to blow through the filter or to remain on the filter after brushing, HBCD concentrations observed in the study may be underestimated.

[Cao et al. \(2015\)](#) attempted to determine seasonal and particle size dependent variations of total HBCD in settled dust from five microenvironment categories (offices, hotels, kindergartens, dormitories, and roads) from Beijing, China. Individual dust samples were collected in 2012 from 22 offices, 3 hotels, 2 kindergartens, 40 dormitories, and 10 sites on main roads using a vacuum. Samples from each microenvironment were pooled and homogenized into one composite sample, and each of the five composite samples was fractionated into nine fractions according to particle size. Total HBCD

concentrations in settled floor dust from 45 size-segregated samples ranged from 5.3 (road dust) to 2,580 µg/kg (dormitories). In addition, indoor dust samples from two offices were collected between March 2012 and August 2012 (Office A) at weekly intervals, and March 2012 and December 2012 (Office B) at biweekly intervals, to study seasonality of HBCD in indoor dust. Mean concentrations of total HBCD were 1,310 and 1,210 µg/kg, respectively, for Office A (n = 23) and Office B (n = 17).

5.2.6 Indoor Air

5.2.6.1.1 Indoor Air (ng/m³) Chart



5.2.6.1.2 Indoor Air (ng/m³) Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
3227425	{Hong, 2016, 3227425}	0.00405	0.016	0.0064	0.00821
1079114	{Abdallah, 2008, 1079114}	0.07	0.96	0.17	0.9
1927779	{Saito, 2007, 1927779}	0.6	29.5		
1927620	{Thuresson, 2012, 1927620}	0.0016	0.035		
3227425	{Hong, 2016, 3227425}	0.01	0.125	0.0396	0.0482
2911989	{Newton, 2015, 2911989}	0.00065	0.019	0.0013	0.0031

3227425	{Hong, 2016, 3227425}	0.00089	0.00847	0.0054	0.00665
1079114	{Abdallah, 2008, 1079114}	0.067	1.3	0.18	0.25
198241	{Takigami, 2009, 198241}			0.0067	0.28
4197589	{Takigami, 2007, 4197589}			0.0084	0.22
1927779	{Saito, 2007, 1927779}	0.6	24		
1927620	{Thuresson, 2012, 1927620}	0.0016	0.033	0.002	0.002
1927567	{Tue, 2013, 1927567}		0.0066		

5.2.6.1.3 Indoor Air (ng/m³): Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/m ³)	Data Quality Evaluation Score	Overall Quality Level
particulate								
{Hong, 2016, 3227425}	CN	Commercial	2004 - 2005	5	N/R	N/R	1.6	High
{Abdallah, 2008, 1079114}	GB	Commercial	2007	29	1	0.0033	1.3	High
{Saito, 2007, 1927779}	JP	Commercial	2001	14	N/R	1.2	1.9	Medium
{Thuresson, 2012, 1927620}	SE	Commercial	2006	20	N/R	0.0016	1.7	Medium
{Hong, 2016, 3227425}	CN	Mixed use	2004 - 2005	10	N/R	N/R	1.6	High
{Newton, 2015, 2911989}	SE	Mixed use	2012	13	0.15	0.0013	2.0	Medium
{Hong, 2016, 3227425}	CN	Residential	2004 - 2005	12	N/R	N/R	1.6	High
{Abdallah, 2008, 1079114}	GB	Residential	2007	33	1	0.0033	1.3	High

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/m ³)	Data Quality Evaluation Score	Overall Quality Level
particulate								
{Takigami, 2009, 198241}	JP	Residential	2006	4	N/R	N/R	1.9	Medium
{Takigami, 2007, 4197589}	JP	Residential	2006	4	1	N/R	2.2	Medium
{Saito, 2007, 1927779}	JP	Residential	2001	32	N/R	1.2	1.9	Medium
{Thuresson, 2012, 1927620}	SE	Residential	2006	54	N/R	0.0016	1.7	Medium
{Tue, 2013, 1927567}	VN	Residential	2008	1	0.25	N/R	1.9	Medium

5.2.6.1.4 Europe

[EC/HC \(2011\)](#) reported HBCD measurements in indoor air from one study ([Abdallah et al., 2008b](#)) which was conducted in the United Kingdom. Median HBCD concentrations were 0.000180 $\mu\text{g}/\text{m}^3$ in homes (n = 33), 0.000170 $\mu\text{g}/\text{m}^3$ in offices (n = 25), and 0.000900 $\mu\text{g}/\text{m}^3$ in public microenvironments (n = 4).

5.2.6.1.5 Asia

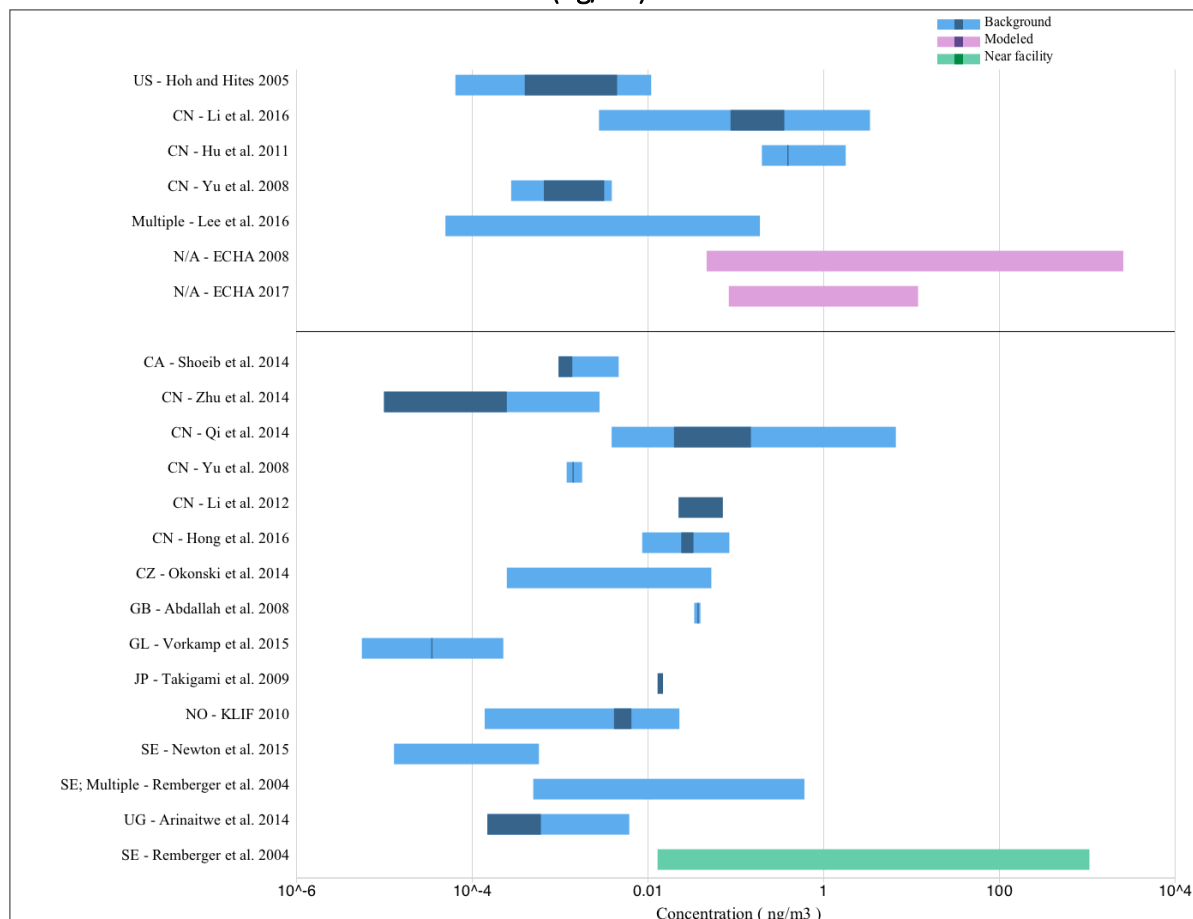
[Hong et al. \(2013\)](#) measured HBCD diastereoisomer and total HBCD concentrations in indoor and outdoor air samples collected from different locations within two industrialized cities (Guangzhou and Foshan) in Southern China. According to [Hong et al. \(2016\)](#), the HBCD production capacity in China was 7500 tonnes in 2007. A total of 37 indoor air samples (gas and particle phases) were collected from homes (n=12), offices (n=5), and other workplaces (n=10) between October 2004 and April 2005. Gas-phase samples were collected using a high-volume sampler and particle-phase samples were collected using PUF plugs. Indoor air samplers were placed at floor level. HBCD diastereoisomer determination was made using LC-MS/MS in electrospray ionization negative ion mode with multiple reaction monitoring. Quality control measures taken included duplicate sample collection, field blanks, procedural blanks, and recovery experiments at multiple concentration levels. The gas- and particle-phase concentrations for alpha-, beta-, and gamma-HBCD and total HBCD in indoor air were calculated using a six-point calibration standard curve. Total HBCD mean concentrations (including gas- and particle-phase) were 0.00543 ng/m^3 (0.00089-0.00847 ng/m^3) and 0.00821 ng/m^3 (0.00405-0.0160 ng/m^3) for homes and offices, respectively. The total HBCD mean concentration for other workplaces (workplace type not specified) was significantly higher at 0.0482 ng/m^3 (0.010-0.125 ng/m^3). According to [Hong et al.](#)

(2016), these total HBCD mean concentrations were slightly higher than or comparable with levels reported in remote or urban sites within the United States and are significantly lower than those reported in the European atmosphere. Further examination of the diastereoisomer profiles indicated that alpha-HBCD was the dominant isomer with a relative abundance ranging from 56.3% to 83.0% (mean value 73.6%) and that airborne HBCDs were predominantly present in the particulate phase. The study noted that the variation in HBCD distribution in the gas and particulate phases was greater in indoor air samples than outdoor samples. The study concluded with estimating average daily human exposure to HBCDs via inhalation of indoor and outdoor air using the measured indoor and outdoor total HBCD concentrations from this study.

Using measured HBCD concentrations in air conditioning filter dust samples collected from an office building in Shenzhen, China, [Ni and Zeng \(2013\)](#) calculated HBCD concentrations in the particulate phase of indoor office air, using an equation described in [Ni and Zeng \(2013\)](#). HBCD concentrations from 56 offices were estimated to range from 13.5 to 1,099 pg/m^3 (505 pg/m^3 mean; 516 pg/m^3 median) in $\text{PM}_{2.5}$ (representing dust with particle diameter of 0.4–2.2 μm) and from 18.4 to 2,274 pg/m^3 (1,001 pg/m^3 mean; 1,091 pg/m^3 median) in PM_{10} (representing dust with particle diameter of 2.5–8.9 μm).

5.2.7 Ambient Air

5.2.7.1.1 Ambient Air (ng/m^3) Chart



5.2.7.1.2 Ambient Air (ng/m³) Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
999242	{Hoh, 2005, 999242}	6.50E-05	0.011	0.0004	0.0045
3355687	{Li, 2016, 3355687}	0.0028	3.4	0.088	0.36
1927637	{Hu, 2011, 1927637}	0.2	1.8	0.39	0.39
1058394	{Yu, 2008, 1058394}	0.00028	0.00392	0.00066	0.00321
3350487	{Lee, 2016, 3350487}	5.00E-05	0.19		
3970747	{ECHA, 2008, 3970747}	0.047	2600		
3970753	{ECHA, 2017, 3970753}	0.084	12		
3019586	{Shoeib, 2014, 3019586}	0.00097	0.00469	0.00097	0.00139
2343682	{Zhu, 2014, 2343682}	1.00E-05	0.00284	1.00E-05	0.00025
2343693	{Qi, 2014, 2343693}	0.0039	6.7	0.02	0.15
1049627	{Yu, 2008, 1049627}	0.0012	0.0018	0.0014	0.0014
1927607	{Li, 2012, 1927607}			0.0225	0.0719
3227425	{Hong, 2016, 3227425}	0.00869	0.0853	0.0242	0.0333
2528316	{Okonski, 2014, 2528316}	0.00025	0.0532		
1079114	{Abdallah, 2008, 1079114}	0.034	0.04	0.037	0.037
3015562	{Vorkamp, 2015, 3015562}	5.60E-06	0.000228	3.46E-05	3.46E-05
198241	{Takigami, 2009, 198241}			0.013	0.015
3809228	{KLIF, 2010, 3809228}	0.00014	0.02302	0.00415	0.00654
2911989	{Newton, 2015, 2911989}	1.30E-05	0.00058		
1927826	{Remberger, 2004, 1927826}	0.0005	0.61		
2343716	{Arinaitwe, 2014, 2343716}	0.00015	0.00619	0.00015	0.00061
1927826	{Remberger, 2004, 1927826}	0.013	1070		

5.2.7.1.3 Ambient Air (ng/m³): Supporting Data

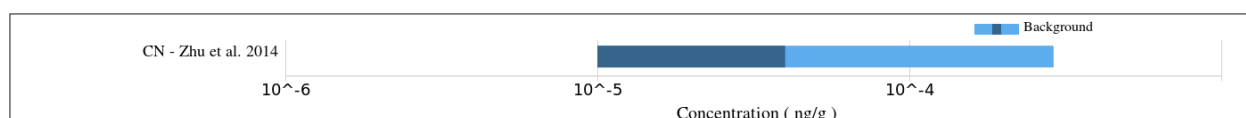
HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/m ³)	Data Quality Evaluation Score	Overall Quality Level
gas and particulate								
{Hoh, 2005, 999242}	US	Background	2002 - 2004	120	0.82	0.00013	2.0	Medium
{Li, 2016, 3355687}	CN	Background	2008 - 2013	222	0.94	0.0056	1.8	Medium
{Hu, 2011, 1927637}	CN	Background	2011	28	1	0.024	1.2	High
{Yu, 2008, 1058394}	CN	Background	2004	64	0.95	N/R	1.8	Medium
{Lee, 2016, 3350487}	Multiple	Background	2005 - 2006	160	0.56	1e-04	1.8	Medium
{ECHA, 2008, 3970747}	N/A	Modeled	N/A	N/A	N/A	N/A	1.3	High
{ECHA, 2017, 3970753}	N/A	Modeled	N/A	N/A	N/A	N/A	2.0	Medium

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/m ³)	Data Quality Evaluation Score	Overall Quality Level
particulate								
{Shoeib, 2014, 3019586}	CA	Background	2010 - 2011	70	0.67	N/R	2.0	Medium
{Zhu, 2014, 2343682}	CN	Background	2010 - 2011	36	0.56	N/R	1.3	High

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/m ³)	Data Quality Evaluation Score	Overall Quality Level
particulate								
{Qi, 2014, 2343693}	CN	Background	2007 - 2008	57	N/R	0.0029	2.1	Medium
{Yu, 2008, 1049627}	CN	Background	2006	4	N/R	N/R	3.0	Low
{Li, 2012, 1927607}	CN	Background	2006	25	N/R	N/R	1.8	Medium
{Hong, 2016, 3227425}	CN	Background	2004 - 2005	9	N/R	N/R	1.6	High
{Okonski, 2014, 2528316}	CZ	Background	2009 - 2010	24	0.75	5e-04	1.2	High
{Abdallah, 2008, 1079114}	GB	Background	2007	5	1	0.0033	1.3	High
{Vorkamp, 2015, 3015562}	GL	Background	2012	36	0.69	1.4e-05	1.2	High
{Takigami, 2009, 198241}	JP	Background	2006	2	N/R	N/R	1.9	Medium
{KLIF, 2010, 3809228}	NO	Background	2007	26	N/R	N/R	1.4	High
{Newton, 2015, 2911989}	SE	Background	2012	12	0.25	2.6e-05	2.0	Medium
{Remberger, 2004, 1927826}	SE; Multiple	Background	2000 - 2001	14	0.86	0.001	1.8	Medium
{Arinaitwe, 2014, 2343716}	UG	Background	2008 - 2010	56	0.29	3e-04	1.4	High

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/m ³)	Data Quality Evaluation Score	Overall Quality Level
particulate								
{Remberger, 2004, 1927826}	SE	Near facility	2000 - 2001	3	1	0.001	1.8	Medium

5.2.7.1.4 Ambient Air (ng/g) Chart



5.2.7.1.5 Ambient Air (ng/g) Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
2343682	{Zhu, 2014, 2343682}	1.00E-05	0.00029	1.00E-05	4.00E-05

5.2.7.1.6 Ambient Air (ng/g): Supporting Data

HERO ID	Country	Location Type	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
particulate								
{Zhu, 2014, 2343682}	CN	Background	2010 - 2011	36	0.56	N/R	1.3	High

5.2.7.1.7 North America

The Canadian and Australian risk assessments ([NICNAS, 2012](#); [EC/HC, 2011](#)) summarized outdoor air data from three studies conducted in North America. In remote arctic areas of Canada, total HBCD levels from samples collected between 1994 and 2007 ranged from ND to 0.000003 µg/m³ ([Xiao et al., 2010](#); [Alaee et al., 2003](#)). The 12 samples from [Alaee et al. \(2003\)](#) were reported as less than 0.0000018 µg/m³. In the United States, total HBCD levels collected in 2002-2003 from 156 samples ranged from ND to 0.000011 µg/m³, with detection in 120 samples ([Hoh and Hites, 2005](#)). The samples were collected in east central states from urban, semi-urban, agricultural, and remote areas.

Hoh and Hites (2005) studied spatial trends of total HBCD in outdoor air through the analysis of samples collected at five US sites for two years (2002 to 2003). The sites included an urban site in Chicago, Illinois, a semi-urban site in Indiana, an agricultural site in Arkansas, and remote sites in Michigan and Louisiana. Air samples were collected for 24-hours every 12 days. Gas- and particle-phase samples were collected using high-volume samplers fitted with either XAD-2 resin and a quartz fiber filter (Chicago site only) or with a PUF adsorbent and glass fiber filter (other four sites). All samples were analyzed using GC-MS operated in the ECNI mode. Total HBCD was detected in approximately 76% of the samples (120 of 156), in only in the particle phase. Total HBCD concentrations in outdoor air ranged from ND ($<0.00007 \text{ ng/m}^3$) to 0.008 ng/m^3 (mean = 0.0012 ng/m^3 ; median = 0.0005 ng/m^3) at the remote Michigan site, from ND ($<0.00013 \text{ ng/m}^3$) to 0.0096 ng/m^3 (mean = 0.0045 ng/m^3 ; median = 0.0042 ng/m^3) at the urban Chicago site, from ND ($<0.00007 \text{ ng/m}^3$) to 0.0036 ng/m^3 (mean = 0.001 ng/m^3 ; median = 0.00075 ng/m^3) at the semi-urban Indiana site, from ND ($<0.00013 \text{ ng/m}^3$) to 0.011 ng/m^3 (mean = 0.0016 ng/m^3 ; median = 0.0004 ng/m^3) at the agricultural Arkansas site, and from ND ($<0.00013 \text{ ng/m}^3$) to 0.0062 ng/m^3 (mean = 0.0006 ng/m^3 ; median = ND) at the remote Louisiana site. The highest mean and median values were from the Chicago site, suggesting that urban areas are the source of this compound. The highest individual concentration of total HBCD occurred at the Arkansas site, which could be attributed to manufacturing areas in southern Arkansas, as investigated using four-day backward air trajectories. The percent HBCD isomer composition of seven samples was variable.

[Shoeib et al. \(2014\)](#) measured flame retardants in air samples collected from a semi-urban location (Environment Canada field site) located in Toronto, Canada, between 2010 and 2011. A total of 70 outdoor air samples (gas and particle phases) were collected using PS-1 type sampler and the sampling train consisted of a glass-fiber filter for collecting the particulate phase. Air samples were collected over a 24-hour sampling period and were analyzed for total HBCD using GC-MS using negative ion chemical ionization mode. Total HBCD was detected only in the particulate phase in 67% of the samples ($n = 70$) with concentrations that ranged ND ($<0.00144 \text{ ng/m}^3$) to 0.00469 ng/m^3 (mean = 0.00139 ng/m^3 ; median = 0.00097 ng/m^3). According to Shoeib *et al.* (2014) these results were similar to mean observed in the east-central United States in 2002-2003 (Hoh and Hites, 2005).

5.2.7.1.8 Europe

The Australian, Canadian, UNEP, and EC risk assessments ([NICNAS, 2012](#); [EC/HC, 2011](#); [UNEP, 2010](#); [EC, 2008](#)) summarized outdoor air data from seven studies conducted in Europe. Overall, total HBCD concentrations in remote areas ranged from ND to $0.00028 \mu\text{g}/\text{m}^3$. In urban and rural areas, total HBCD concentrations ranged from 0.000002 to $0.00061 \mu\text{g}/\text{m}^3$. In industrial areas, total HBCD concentrations ranged from 0.000013 to $1.07 \mu\text{g}/\text{m}^3$. The highest concentrations (0.280 and $1.07 \mu\text{g}/\text{m}^3$) were from the vicinity of XPS production plants in samples collected prior to 2001.

[Okonski et al. \(2014\)](#) collected outdoor air samples from two sites in the Czech Republic (one urban site in central Brno and one rural site near the village of Telnice) between October 2009 and October 2010 using a high-volume air sampler. For flame retardants, 12 samples were analyzed from each site, with weekly samples grouped by season. Particle size and HBCD isomers were differentiated. Samples were analyzed for HBCD (particulate phases) by HPLC-MS/MS with ESI in the negative mode. Concentrations were reported for individual isomers (α , $-\beta$, and γ -HBCD); total HBCD was calculated herein by summing results for the individual isomers across all particle sizes. Overall, concentrations of total HBCD ranged from 0.00000624 to $0.00005333 \mu\text{g}/\text{m}^3$ in ambient outdoor air ($n=24$), with higher concentrations observed in warm seasons at the rural site. The study authors indicate that HBCD in outdoor air is largely particle-bound, even in warm seasons, and thus seasonality in emissions rather than in gas-particle partitioning, governs particle-phase concentrations, as seen for other novel flame retardants.

5.2.7.1.9 Asia

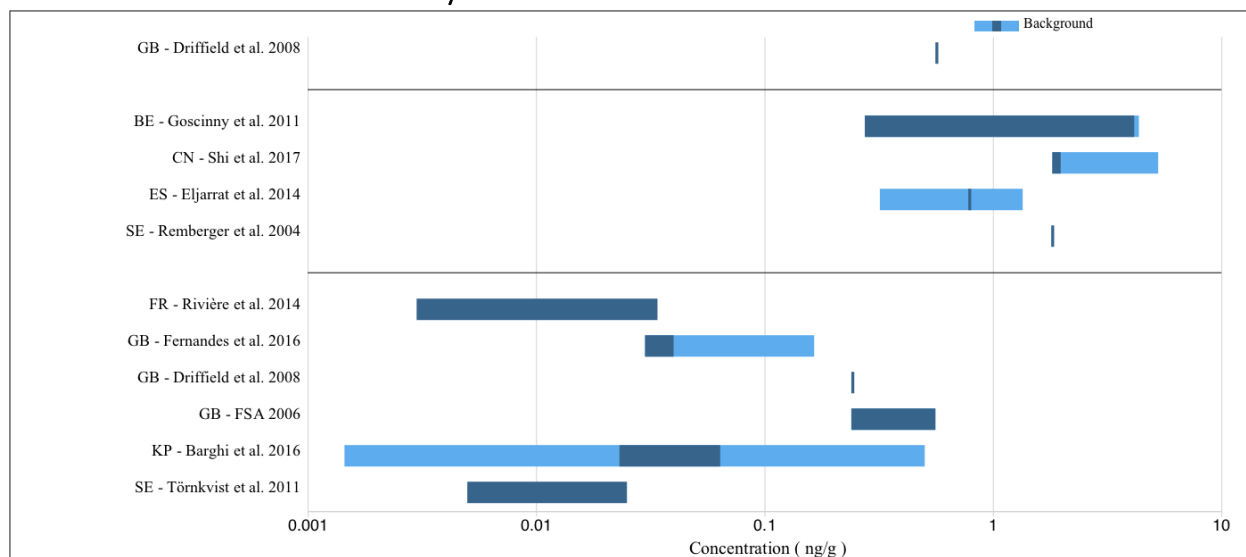
The Canadian and Australian risk assessments ([NICNAS, 2012](#); [EC/HC, 2011](#)) summarized outdoor air data from two studies conducted in China. In a method validation study, total HBCD concentrations in air samples ranged from 0.0000012 to $0.0000018 \mu\text{g}/\text{m}^3$ ([Yu et al., 2008a](#)). In [Yu et al. \(2008b\)](#), total HBCD concentrations were measured in air in 2006 from two industrial sites (means = 0.00000069 and $0.00000089 \mu\text{g}/\text{m}^3$), one urban site (mean = $0.00000309 \mu\text{g}/\text{m}^3$), and one city mountaintop (mean = $0.00000167 \mu\text{g}/\text{m}^3$). Between ~70 and 95% of the residues existed in the particle phase.

As cited in [Law et al. \(2014\)](#), two studies measured levels of HBCD in outdoor air samples collected from industrial and urban locations in China (Shanghai and Beijing). Total HBCD concentrations in outdoor air ranged from 0.00002 to $0.0018 \mu\text{g}/\text{m}^3$ in Beijing ([Hu et al., 2011](#)). According to the [Li et al. \(2012\)](#) study, average total HBCD concentrations in Shanghai ranged from $0.000023 \mu\text{g}/\text{m}^3$ to $0.000072 \mu\text{g}/\text{m}^3$.

[Hong et al. \(2013\)](#) collected outdoor and indoor air samples from two industrialized cities (Guangzhou and Foshan) in Southern China between October 2004 and April 2005. Total HBCD concentrations (vapor and particulate phases) were determined by LC-MS/MS with ESI in the negative ion mode. Concentrations in outdoor air ($n=9$) ranged from 0.00000869 to $0.0000853 \mu\text{g}/\text{m}^3$ (mean = $0.0000333 \pm 0.0000281 \mu\text{g}/\text{m}^3$; median = $0.0000242 \mu\text{g}/\text{m}^3$).

5.2.8 Dietary Monitoring

5.2.8.1.1 Dairy Chart



5.2.8.1.2 Dairy Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1252276	{Driffield, 2008, 1252276}			0.56	0.56
787666	{Gosciny, 2011, 787666}	0.275	4.355	0.275	4.155
3975096	{Shi, 2017, 3975096}	1.82	5.29	1.82	1.98
2343701	{Eljarrat, 2014, 2343701}	0.32	1.35	0.78	0.78
1927826	{Remberger, 2004, 1927826}			1.8	1.8
2343707	{Rivière, 2014, 2343707}			0.003	0.034
3350498	{Fernandes, 2016, 3350498}	0.03	0.165	0.03	0.04
1252276	{Driffield, 2008, 1252276}			0.24	0.24
4159524	{FSA, 2006, 4159524}	0.24	0.56	0.24	0.56
3350483	{Barghi, 2016, 3350483}	0.00145	0.50289	0.02318	0.06398
1927648	{Törnkvist, 2011, 1927648}			0.005	0.025

5.2.8.1.3 Dairy: Supporting Data

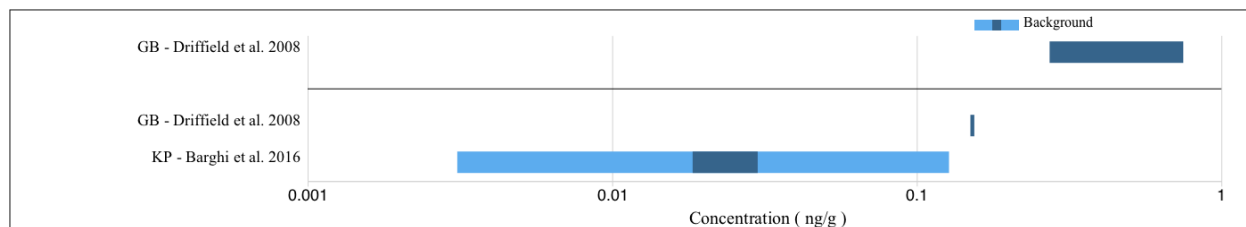
HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry									
{Driffield, 2008, 1252276}	GB	Background	Milk	2004	1	N/R	N/R	1.4	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Gosciny, 2011, 787666}	BE	Background	Milk; Cheese; Butter; Pizza	2008	132	N/R	1.1	1.6	High
{Shi, 2017, 3975096}	CN	Background	Milk	2011	20	0.95	N/R	1.3	High
{Eljarrat, 2014, 2343701}	ES	Background	Dairy products	2009	7	1	0.2	1.8	Medium
{Remberger, 2004, 1927826}	SE	Background	Milk	1999	1	N/R	1	1.8	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Rivière, 2014, 2343707}	FR	Background	Milk; Dairy products; Cheese; Butter; Dairy-based desserts	2007 - 2009	170	N/R	N/R	1.7	Medium
{Fernandes, 2016, 3350498}	GB	Background	Dairy Products	2013	13	N/R	0.01	1.3	High
{Driffield, 2008, 1252276}	GB	Background	Dairy products	2004	1	N/R	N/R	1.4	High
{FSA, 2006, 4159524}	GB	Background	Dairy products; Milk	2004	2	0	0.56	2.0	Medium
{Barghi, 2016, 3350483}	KP	Background	Dairy products	2012 - 2014	36	0.87	0.0029	1.3	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{TÃ¶rnkvist, 2011, 1927648}	SE	Background	Milk (61%), sour milk (16%), yoghurt (8%), cream and sour cream (5%), cheese (8%), cottage cheese (2%); Butter (9%), margarine (46%), low fat margarine (29%), oil (9%), mayonnaise (6%)	2005	142	N/R	N/R	1.8	Medium

5.2.8.1.4 Fruit Chart



5.2.8.1.5 Fruit Summary Statistics

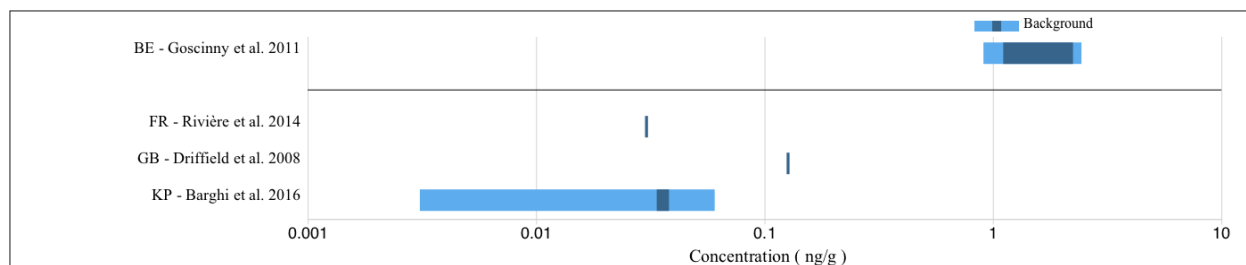
HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1252276	{Driffield, 2008, 1252276}			0.273	0.75
1252276	{Driffield, 2008, 1252276}			0.15	0.15
3350483	{Barghi, 2016, 3350483}	0.0031	0.12758	0.01837	0.03004

5.2.8.1.6 Fruit: Supporting Data

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry									
{Driffield, 2008, 1252276}	GB	Background	Fruit; Fruit products	2004	2	N/R	N/R	1.4	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Driffield, 2008, 1252276}	GB	Background	Sugars and preserves	2004	1	N/R	N/R	1.4	High
{Barghi, 2016, 3350483}	KP	Background	Fruit	2012 - 2014	11	1	0.0029	1.3	High

5.2.8.1.7 Grain Chart



5.2.8.1.8 Grain Summary Statistics

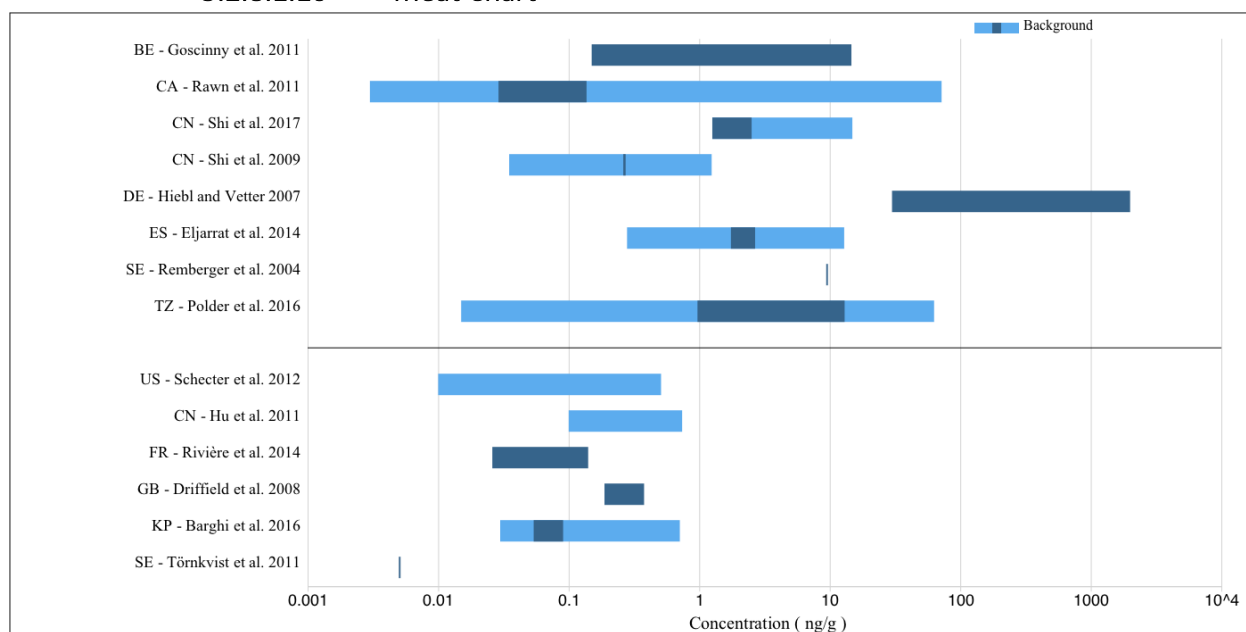
HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
787666	{Gosciny, 2011, 787666}	0.909	2.441	1.11	2.241
2343707	{Rivière, 2014, 2343707}			0.03	0.03
1252276	{Driffield, 2008, 1252276}			0.125	0.125
3350483	{Barghi, 2016, 3350483}	0.0031	0.06053	0.03375	0.03819

5.2.8.1.9 Grain: Supporting Data

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Gosciny, 2011, 787666}	BE	Background	Croissant; Cakes, pies, pastry; Cookies/biscuits	2008	80	N/R	1.1	1.6	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Rivi�re, 2014, 2343707}	FR	Background	Sandwiches and snacks	2007 - 2009	18	N/R	N/R	1.7	Medium
{Driffield, 2008, 1252276}	GB	Background	Bread; Cereals	2004	2	N/R	N/R	1.4	High
{Barghi, 2016, 3350483}	KP	Background	White rice	2012 - 2014	10	1	0.0029	1.3	High

5.2.8.1.10 Meat Chart



5.2.8.1.11 Meat Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
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787666	{Gosciny, 2011, 787666}			0.15	14.652
1927636	{Rawn, 2011, 1927636}	0.003	71.9	0.029	0.137
3975096	{Shi, 2017, 3975096}	1.26	14.9	1.26	2.52
1927708	{Shi, 2009, 1927708}	0.035	1.245	0.262	0.273
1927776	{Hiebl, 2007, 1927776}			30	2000
2343701	{Eljarrat, 2014, 2343701}	0.28	12.9	1.75	2.68
1927826	{Remberger, 2004, 1927826}			9.4	9.4
3347466	{Polder, 2016, 3347466}	0.015	63	0.97	13
1401050	{Schecter, 2012, 1401050}	0.01	0.51		
1224355	{Hu, 2011, 1224355}	0.1	0.74		
2343707	{RiviÅre, 2014, 2343707}			0.026	0.141
1252276	{Driffield, 2008, 1252276}			0.188	0.378
3350483	{Barghi, 2016, 3350483}	0.02987	0.71033	0.05392	0.09064
1927648	{TÅrnkvist, 2011, 1927648}			0.005	0.005

5.2.8.1.12 Meat: Supporting Data

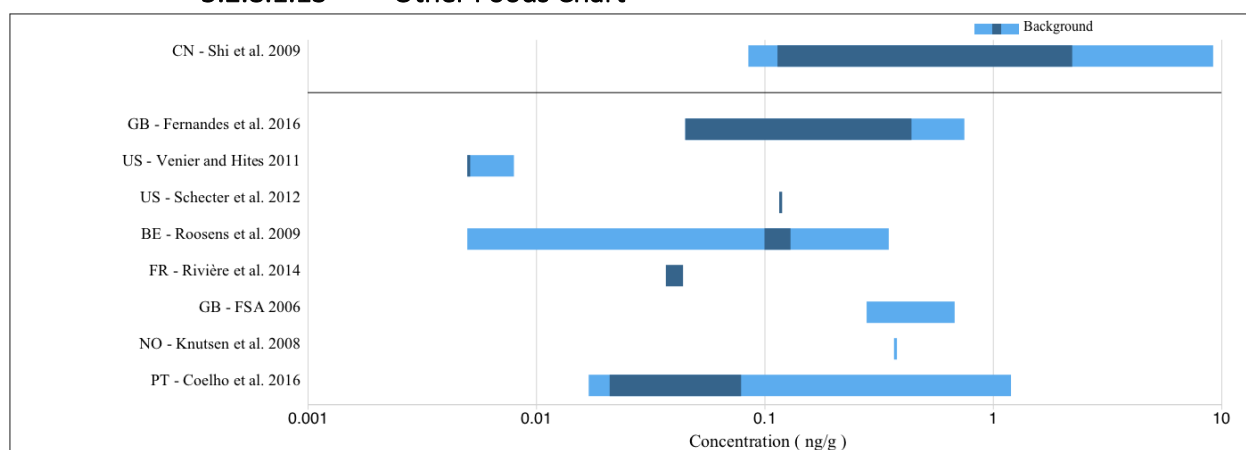
HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Gosciny, 2011, 787666}	BE	Background	Beef; Veal; Pork; Sheep; Turkey; Horse; Chicken; Duck; Rabbit; Hind, pheasant, guinea hen, wild boar, quail, pigeon; Sausages, salami, pie, meatloaf, pudding, horse filet; Liver of veal, pork, rabbit, foie gras; Eggs	2008	181	N/R	1.1	1.6	High
{Rawn, 2011, 1927636}	CA	Background	Egg yolks	2005 - 2006	162	N/R	0.006	2.0	Medium
{Shi, 2017, 3975096}	CN	Background	Eggs; Meat	2011 - 2022	40	0.95	N/R	1.3	High
{Shi, 2009, 1927708}	CN	Background	Meat; Eggs	2007	24	0.54	0.07	1.6	High
{Hiebl, 2007, 1927776}	DE	Background	Eggs	2007	3	N/R	20	2.1	Medium
{Eljarrat, 2014, 2343701}	ES	Background	Meat; Eggs	2009	12	1	0.2	1.8	Medium
{Remberger, 2004, 1927826}	SE	Background	Egg yolk	1999	1	N/R	1	1.8	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Polder, 2016, 3347466}	TZ	Background	Eggs	2012	28	0.61	0.03	1.9	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Schecter, 2012, 1401050}	US	Background	Smoked turkey sausages; Fresh deli sliced turkey; Chili with beans; Fresh deli sliced ham; Smoked turkey sausage; Bacon; Fresh deli sliced beef; Fresh deli sliced chicken; Sausages; Sliced turkey; Sliced chicken breast; Sliced ham; Canned chili	2009 - 2010	24	0.46	0.08	1.2	High
{Hu, 2011, 1224355}	CN	Background	Eggs	2011	3	0.1	0.2	2.3	Low
{Rivi�re, 2014, 2343707}	FR	Background	Eggs; Meats; Poultry and game; Offal	2007 - 2009	228	N/R	N/R	1.7	Medium
{Driffield, 2008, 1252276}	GB	Background	Meat; Offal	2004	2	N/R	N/R	1.4	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Barghi, 2016, 3350483}	KP	Background	Meat; Eggs	2012 - 2014	142	1	0.0029	1.3	High
{TÅ¶rnkvist, 2011, 1927648}	SE	Background	Beef (24%), pork (23%), lamb (1%), chicken (12%), game (2%), processed meats except pizza (38%); Eggs	2005	136	N/R	N/R	1.8	Medium

5.2.8.1.13 Other Foods Chart



5.2.8.1.14 Other Foods Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1927708	{Shi, 2009, 1927708}	0.085	9.208	0.114	2.224
3350498	{Fernandes, 2016, 3350498}	0.045	0.75	0.045	0.44
1927638	{Venier, 2011, 1927638}	0.005	0.008	0.005	0.005

1401050	{Schecter, 2012, 1401050}			0.116	0.116
787720	{Roosens, 2009, 787720}	0.005	0.35	0.1	0.13
2343707	{RiviÃre, 2014, 2343707}			0.037	0.044
4159524	{FSA, 2006, 4159524}	0.28	0.68		
1927755	{Knutsen, 2008, 1927755}		0.38		
3350459	{Coelho, 2016, 3350459}	0.017	1.2	0.021	0.079

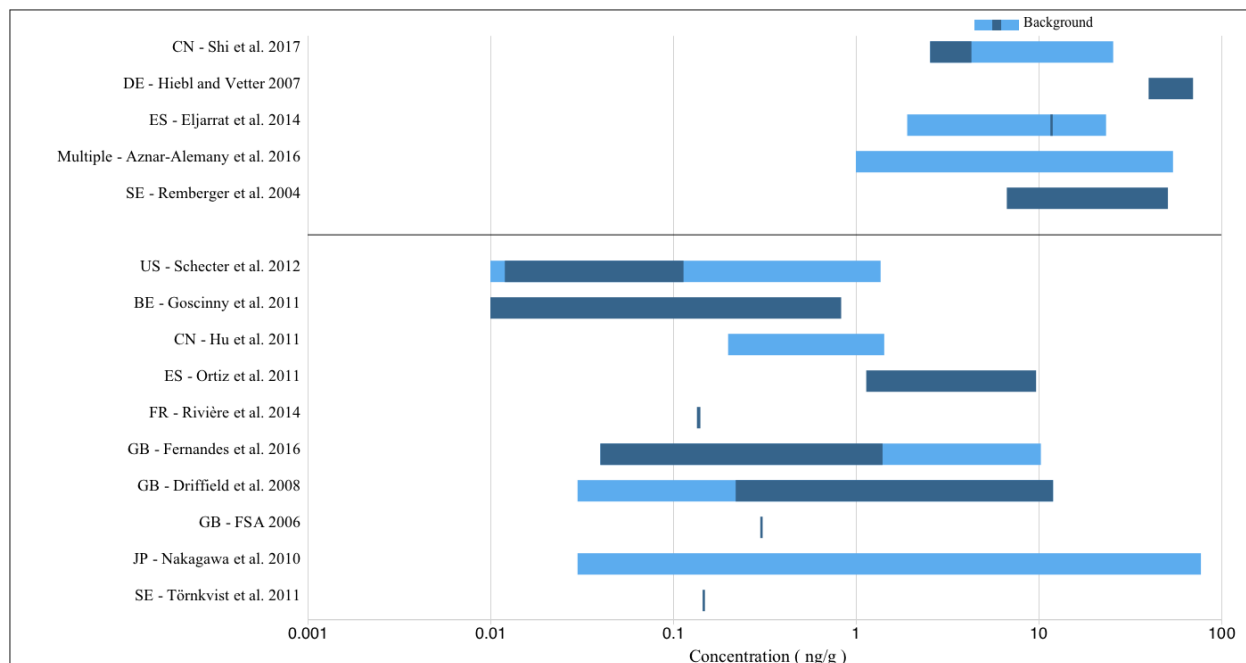
5.2.8.1.15 Other Foods: Supporting Data

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Shi, 2009, 1927708}	CN	Background	Aquatic food	2007	12	0.92	0.13	1.6	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Fernandes, 2016, 3350498}	GB	Background	Other Foods, edible portion; Processed Foods, edible portion; Composite feeds for animals; Animal Feed-Fish Feeds; Animal feed-Oilseeds and cereals	2013	61	N/R	0.01	1.3	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Venier, 2011, 1927638}	US	Background	Dog food	2010	16	1	N/R	1.9	Medium
{Schecter, 2012, 1401050}	US	Background	Processed and fresh foods	2009	10	1	N/R	1.2	High
{Roosens, 2009, 787720}	BE	Background	Duplicate diet for each participant on each day	2007	13	0.08	0.01	1.4	High
{RiviÄre, 2014, 2343707}	FR	Background	Mixed dishes; Seasonings and sauces	2007 - 2009	64	N/R	N/R	1.7	Medium
{FSA, 2006, 4159524}	GB	Background	Combined food groups	2004	19	0.47	0.56	2.0	Medium
{Knutsen, 2008, 1927755}	NO	Background	Various foods (including vegetable oil, ice cream, biscuit, and banana).	2002 - 2006	12	N/R	N/R	1.8	Medium
{Coelho, 2016, 3350459}	PT	Background	Multiple food types	2016	21	N/R	N/R	1.4	High

5.2.8.1.16 Seafood Chart



5.2.8.1.17 Seafood Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
3975096	{Shi, 2017, 3975096}	2.55	25.6	2.55	4.29
1927776	{Hiebl, 2007, 1927776}			40	70
2343701	{Eljarrat, 2014, 2343701}	1.91	23.4	11.6	11.6
3454553	{Aznar-Alemany, 2016, 3454553}	1	54.4		
1927826	{Remberger, 2004, 1927826}			6.7	51
1401050	{Schechter, 2012, 1401050}	0.01	1.366	0.012	0.114
787666	{Gosciny, 2011, 787666}			0.01	0.831
1224355	{Hu, 2011, 1224355}	0.2	1.43		
1927653	{Ortiz, 2011, 1927653}			1.14	9.69
2343707	{Rivière, 2014, 2343707}			0.135	0.141
3350498	{Fernandes, 2016, 3350498}	0.04	10.29	0.04	1.4

1252276	{Driffield, 2008, 1252276}	0.03	12	0.22	12
4159524	{FSA, 2006, 4159524}			0.3	0.3
1927668	{Nakagawa, 2010, 1927668}	0.03	77.3		
1927648	{TÅ¶rnkvist, 2011, 1927648}			0.145	0.145

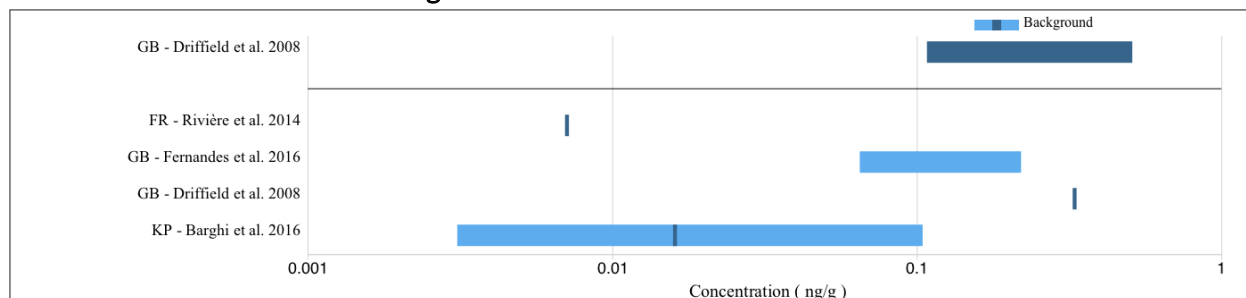
5.2.8.1.18 Seafood: Supporting Data

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
lipid									
{Shi, 2017, 3975096}	CN	Background	Fish	2011	20	0.95	N/R	1.3	High
{Hiebl, 2007, 1927776}	DE	Background	Whole; Fillets; Fillet	2007	3	N/R	20	2.1	Medium
{Eljarrat, 2014, 2343701}	ES	Background	Seafood	2009	22	1	0.2	1.8	Medium
{Aznar-Alemany, 2016, 3454553}	Multiple	Background	Seafood	2014 - 2015	42	0.48	2	1.7	Medium
{Remberger, 2004, 1927826}	SE	Background	Seafood; Salmon	1996 - 1999	3	N/R	1	1.8	Medium

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Schecter, 2012, 1401050}	US	Background	Sardines in water; Fresh salmon; Sardines in olive oil; Fresh catfish; Fresh tilapia; Fish sticks; Processed foods and fresh fish; Canned sardines	2009 - 2010	90	0.48	0.08	1.2	High
{Gosciny, 2011, 787666}	BE	Background	Salmon; Tuna; Cod; Herring; Sardine; Mackerel; Trout, halibut, sole, monkfish, saithe, hake; Crustaceans; Molluscs; Tuna salad, crab salad, fish salad, surimi salad; Fish stick, surimi	2008	118	N/R	N/R	1.6	High
{Hu, 2011, 1224355}	CN	Background	Fish feed	2011	4	0.13	0.4	2.3	Low
{Ortiz, 2011, 1927653}	ES	Background	Fish oil	2011	22	1	0.03	1.4	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{Rivière, 2014, 2343707}	FR	Background	Fish; Crustaceans and mollusks	2007 - 2009	82	N/R	N/A	1.7	Medium
{Fernandes, 2016, 3350498}	GB	Background	Fish, edible portion; Shellfish, edible portion	2013	56	N/R	0.01	1.3	High
{Driffield, 2008, 1252276}	GB	Background	Fish; Oysters; Mussels; Scallops	2004	36	N/R	N/R	1.4	High
{FSA, 2006, 4159524}	GB	Background	Fish	2004	1	1	N/R	2.0	Medium
{Nakagawa, 2010, 1927668}	JP	Background	Seafood: marine fish and invertebrates	2004 - 2008	64	N/R	0.02	1.4	High
{Tärnkvist, 2011, 1927648}	SE	Background	Fresh and frozen lean fish (26%), fresh and frozen fatty fish (15%), canned/processed products (47%), prawns (12%)	2005	104	N/R	N/R	1.8	Medium

5.2.8.1.19 Vegetable Chart



5.2.8.1.20 Vegetable Summary Statistics

HERO ID	Study Name	Min	Max	Central Tendency (low)	Central Tendency (high)
1252276	{Driffield, 2008, 1252276}			0.108	0.51
2343707	{Rivière, 2014, 2343707}			0.007	0.007
3350498	{Fernandes, 2016, 3350498}	0.065	0.22		
1252276	{Driffield, 2008, 1252276}			0.325	0.325
3350483	{Barghi, 2016, 3350483}	0.0031	0.10455	0.01584	0.01584

5.2.8.1.21 Vegetable: Supporting Data

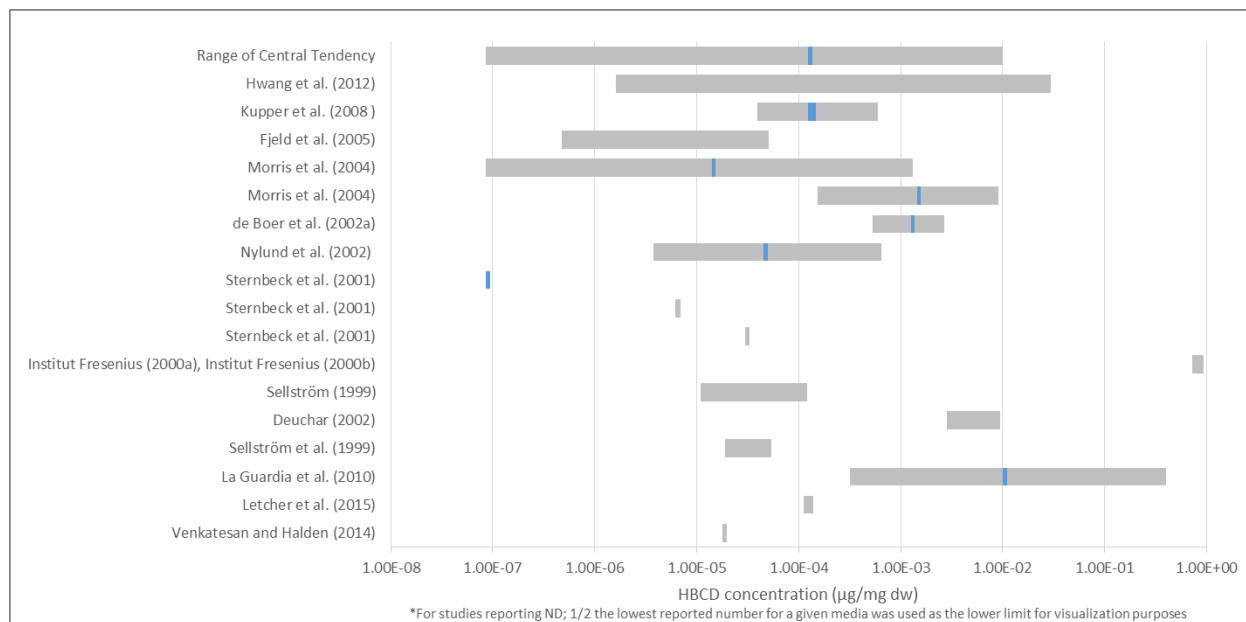
HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
dry									
{Driffield, 2008, 1252276}	GB	Background	Green vegetables; Potatoes; Other vegetables; Canned vegetables	2004	4	N/R	N/R	1.4	High

HERO ID	Country	Location Type	Species	Sampling Year	No. of Samples	FoD	DL (ng/g)	Data Quality Evaluation Score	Overall Quality Level
wet									
{RiviÃrre, 2014, 2343707}	FR	Background	Vegetables	2007 - 2009	3	N/R	N/R	1.7	Medium
{Fernandes, 2016, 3350498}	GB	Background	Grasses	2013	2	N/R	N/R	1.3	High
{Driffield, 2008, 1252276}	GB	Background	Nuts	2004	1	N/R	N/R	1.4	High
{Barghi, 2016, 3350483}	KP	Background	Vegetables	2012 - 2014	12	0.41	0.0029	1.3	High

5.2.9 Sewage Sludge

5.2.9.1.1 Sewage Sludge and Biosolids Summary

Figure 5-1. HBCD Concentration in Sewage Sludge and Biosolids ($\mu\text{g}/\text{mg dw}$)



5.2.9.1.2 North America

[Venkatesan and Halden \(2014\)](#) determined national baseline levels and release inventories of 77 traditional and novel BFRs including HBCD in biosolid composite samples (prepared from 110 samples) originally collected by the US EPA as part of the 2001 National Sewage Sludge Survey (NSSS). Representative biosolid samples, reflecting processed sewage sludge intended for disposal, were collected between February and March 2001 from 94 WWTPs in 32 US States and the District of Columbia. Of the 94 WWTPs, 89 had a single system (either aerobic or anaerobic digestion) and 5 had two systems for sludge treatment (both aerobic and anaerobic digestion). Remaining samples were collected as duplicate samples from 14 facilities, amounting to 110 biosolid samples. Aliquots from each sample were pooled to obtain five composites, each containing solids from between 21 and 24 individual samples. A mega-composite sample (mixture of composites 1 through 5) was analyzed for total HBCD using LC-MS/MS. The mega-composite sample contained 19.8 $\mu\text{g}/\text{kg dw}$ total HBCD.

[Letcher et al. \(2015\)](#) measured HCBd in sludge, from two Windsor Ontario WWTPs that feed into the Detroit River, and sediment samples collected from the Detroit River and Lake Erie, between May and June 2004. Sewage sludge samples ($n = 2$) were analyzed for total HBCD using LC-MS/MS with ESI in the negative mode. Total HBCD concentrations were 112 and 140 $\mu\text{g}/\text{kg dw}$ in sewage sludge samples ($n = 2$). The results for sediment are provided in the Sediment section.

The Canadian risk assessment ([EC/HC, 2011](#)) reported the results from one study conducted in the mid-Atlantic region of the United States ([La Guardia et al., 2010](#)). In this study secondary sewage sludge samples were collected in 2002, 2005, 2007, and 2008 from one WWTP which treated

domestic and industrial waste. Total HBCD concentrations in the sewage sludge samples (n = 4) ranged from 320 to 400,000 µg/kg dw (geometric mean = 10,040 µg/kg dw).

5.2.9.1.3 Europe

The EU RAR ([EC, 2008](#)) provides a relatively comprehensive summary of sewage sludge sampling results from seven studies conducted in Europe. The Canadian risk assessment ([EC/HC, 2011](#)) provides results for an additional two studies not covered in the EU RAR. Overall, the studies represent six countries (United Kingdom, Ireland, the Netherlands, Norway, Sweden, and Switzerland) and sampling dates between 1997 and 2005. Total HBCD concentrations in the sewage sludge samples ranged from ND to 942,000 µg/kg dw, with means that ranged from 45 to 149 µg/kg dw and medians that ranged from 14 to 1,439 µg/kg dw (central tendency values were not reported for all studies). The highest concentrations of 728,000 to 942,000 µg/kg dw were reported from a sewage treatment plant in the Netherlands which was located close to a production plant ([Institut Fresenius, 2000a](#)). The next highest concentration was 9,120 µg/kg dw from a sewage treatment plant in Ireland ([de Boer et al., 2002](#)). In one of the larger studies ([Law et al., 2006a](#)), the analysis of sewage sludge from 50 sewage treatment plants in Sweden in 2000 showed that there was little variation between sewage treatment plants, with the exception of higher concentrations (2 to 8 times) in samples with known or suspected point sources connected to them.

5.2.9.1.4 Asia

As cited in [Law et al. \(2014\)](#), concentrations of total HBCD ranged from 1.6 to 29,600 µg/kg in sewage sludge samples collected from both municipal and industrial sources in Ulsan city, Korea ([Hwang et al., 2012](#)).

Table 5.1: Sewage Sludge and Biosolids Concentrations

Location ^a	Site	Sludge Type	Year	N (# ND) ^b	Total HBCD Concentration (µg/kg dw)		Reference
					Range ^c	Central Tendency ^d	
<i>North America</i>							
US, 32 states and the District of Columbia	94 WWTPs	Biosolids from processed sewage sludge intended for disposal	2001	1 mega-composite (0)	19.8	--	Venkatesan and Halden (2014)
CA; Windsor, Ontario	Two WWTPs along the Detroit River	Sewage sludge	2004	2 (0)	112-140	NR	Letcher et al. (2015)
US, mid-Atlantic	One WWTP (domestic/industrial)	Secondary sludge	2002-2008	4	320-400,000	10,040 (geometric mean)	La Guardia <i>et al.</i> (2010) [as cited in EC/HC (2011)]
<i>Europe</i>							
SE	3 STPs	Sewage sludge	NR	3 (0)	19-54	NR	Sellström <i>et al.</i> (1999) [as cited in EC (2008)]

Location ^a	Site	Sludge Type	Year	N (# ND) ^b	Total HBCD Concentration (µg/kg dw)		Reference
					Range ^c	Central Tendency ^d	
UK	1 STP	Sewage sludge cake	NR	1 (0)	9,547	--	Deuchar (2002) [as cited in EC (2008)]
SE	STPs	Sewage sludge	1997-1998	4 (0)	11-120	NR	Sellström (1999) [as cited in EC/HC (2011)]
NL	1 STP (close to production plant)	Sewage sludge	1999-2000	3 (0)	728,000-942,000	NR	Institut Fresenius (2000a), Institut Fresenius (2000b) [as cited in as cited in EC (2008) and EC/HC (2011)]
SE	1 STP (receives input from textile industry)	Sewage sludge	2000	2 (0)	30, 33	NR	Sternbeck <i>et al.</i> (2001) [as cited in EC (2008)] and Remberger <i>et al.</i> (2004) [as cited in EC/HC (2011)]
	1 STP (urban environment)	Primary sewage sludge	2000	1 (0)	6.9	--	
	3 STPs (urban environment)	Digested sewage sludge	2000	3 (3)	ND	ND	
SE	50 STPs	Sewage sludge	2000	50 (0)	3.8-650	45 (mean)	Nylund <i>et al.</i> (2002) [as cited in EC (2008)] Law <i>et al.</i> (2006a) [as cited in EC/HC (2011) and NICNAS (2012)]
UK	5 STPs	Sewage sludge	2002	5 (0)	531-2,683	1,256 (median)	de Boer <i>et al.</i> (2002a) [as cited in EC (2008) and NICNAS (2012)] Morris <i>et al.</i> (2004) [as cited in EC/HC (2011)]
IR	6 STPs		2002	6 (0)	153-9,120	1,439 (median)	
NL	10 STPs		2002	9 (5)	ND-1,320	14 (median)	
NO	4 STPs (urban)	Sewage sludge	2004	6 (5)	0.48-51	NR	Fjeld <i>et al.</i> (2005) [as cited in EC (2008)]
CH	STPs	Sewage sludge	2003 and 2005	19 (0)	39-597	149 (mean) 123 (median)	Kupper <i>et al.</i> (2008) [as cited in EC/HC (2011)]
<i>Asia</i>							
KR	Municipal and Industrial Sources	Sewage sludge	NR	NR (NR)	1.6-29,600	NR	Hwang <i>et al.</i> (2012) [as cited in Law et al. (2014)]

NR = Not reported; ND = Non-detect values

^a CA = Canada; CH = Switzerland; IR = Ireland; KR = Korea; NL = the Netherlands; NO = Norway; SE = Sweden; UK = United Kingdom

^b N refers to the number of samples, unless otherwise noted. The number of non-detect values is reported in parenthesis.

^c The range is the minimum and maximum values reported.

^d The central tendency values sh ce.

6 Overview of Doses Estimated by Others and Comparison with EPA doses

6.1 Overview of Modeling Approaches Used

EPA/OPPT compiled monitoring data to derive exposure estimates for ecological and general population exposure. However, modeled estimates were also used to inform weight of evidence, assess site specific conditions, and derive environmental concentrations and doses given available information, if measured data was less robust.

EPA/OPPT used the following modeling approaches to estimate environmental concentrations and doses.

- Estimation of ambient air concentrations
- Estimation of indoor air concentrations
- Estimation of indoor dust concentrations
- Estimation of surface water concentrations
- Estimation of sediment concentrations

6.1.1 IECCU

6.1.1.1.1 Typical residential home

A three-zone configuration described by Bevington et al. (2017) was used to represent a generic residential building, where the insulation is applied to both the attic and crawlspace. The baseline ventilation and interzonal air flows are shown in Figure 1. The ventilation rates for the three zones are shown in Table 1. In this work, EPA used the ventilation rates for the “vented” attic and crawlspace.

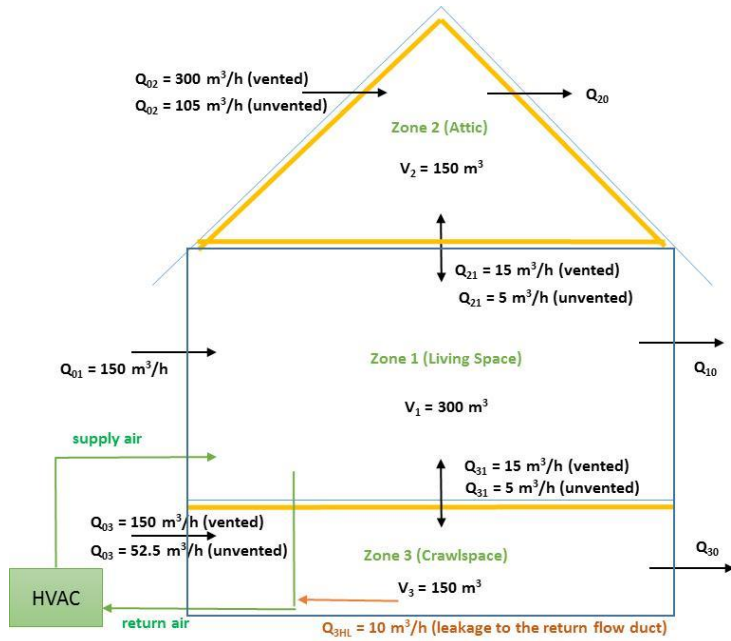


Figure 1. The three-zone configuration for a generic residential setting and baseline ventilation and interzonal air flows.

Table 1. Zone names, volumes, and baseline ventilation rates.

Zone name	Zone volume (m ³)	Ventilation rate (h ⁻¹)
Living space	300	0.5
Attic	150	2.0 (vented) 0.7 (unvented)
Crawlspace	150	1.0 (vented) 0.35 (unvented)

6.1.1.1.2 “Typical” passenger vehicle

EPA used 3.4 m³ as the typical interior volume of a small SUV (passenger volume plus cargo volume).

The in-vehicle ventilation rate can be drastically different depending on factors such as whether the vehicle is moving, how the AC operates, and vehicle type and age. A study by Ott et al. (2007) shows that, with a vehicle moving, windows closed, and the ventilation system off (or the air conditioner set to AC Max), the air change rate was less than 6.6 h⁻¹ for speeds ranging from 20 to 72 mph (32 to 116 km/h).

In this work EPA assume the air change rate is 5 h⁻¹ for a moving vehicle with windows closed, and 0.5 h⁻¹ for a stationary vehicle with windows closed.

6.1.1.1.3 Temperature in the vehicle

For a moving vehicle with the AC on, EPA assume the temperature inside the cabin is constant and at 21 °C.

For a stationary vehicle, EPA assume its temperature is subject to diurnal fluctuation, as defined by the following parameters:

Daily average	20 °C
Daily fluctuation	±15 °C
Peak temperature occurrence	2:00 pm

6.1.1.1.4 HBCD source

The parameters EPA used to represent the HBCD sources in passenger vehicles are the same as those in Table 2 except that the source area is 0.5 m² and that the HBCD content in the polymer is 2.5%.

6.1.1.1.5 Settled dust

The parameters EPA used to represent the settled dust in passenger vehicles are the same as those in the simulations for homes (Table 4).

6.1.1.1.6 Estimation of key parameters

- Material/air partition coefficient (K)

EPA have been unable to find experimentally determined material/air partition coefficients for HBCD in insulation boards. In this evaluation, EPA estimated K from Equation 7 (Guo, 2002):

$$\ln K = 9.76 - 0.785 \ln P \quad (7)$$

where P is the vapor pressure, mm Hg.

The K values obtained from Equation 7 was then adjusted by the density of the foam material (Equation 8):

$$K' = K \frac{\rho}{\rho_0} \quad (8)$$

where

K' is the partition coefficient for the foam board, dimensionless,

K is the partition coefficient for the neat polymer, dimensionless,

ρ is the density of the foam, g/cm³,

ρ_0 is the density of the neat polymer, g/cm³; $\rho_0 = 1.05$ for polystyrene polymer.

The temperature dependence of the partition coefficient was estimated by the method proposed by Tian et al. (2017):

$$\ln \frac{K_2}{K_1} = a \frac{\Delta H_v}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \quad (9)$$

where

K_1 , K_2 are partition coefficients at temperatures T_1 and T_2 (dimensionless),

a is the absolute value of the slope for the $\ln(K)$ - $\ln(P)$ relationship, where P is vapor pressure.

ΔH_v = vaporization enthalpy (J/mol),

T_1, T_2 = absolute temperature corresponding to K_1 and K_2 (K),

R = gas constant (J/mol/K).

Parameter a is reported to be between 0.753 and 1.05 for open-cell PU foam. In this work, EPA used $a = 0.9$ and $\Delta H_v = 8.14 \times 10^4$ J/mol (Tian et al., 2017).

- Solid-phase diffusion coefficient (D)

A QSAR model developed by Huang et al. (2017) was used to estimate the solid-phase diffusion coefficient for the foam materials (Equation 10):

$$\log D = 6.39 - 2.49 \log m + b + \frac{\tau - 3486}{T} \quad (10)$$

where

m is the molecular weight of the chemical, g/mol,

b is an empirical constant that reflects the material type,

τ is an empirical constant that reflects the temperature effect,

T is temperature (K).

The values of b and τ for polystyrene foams — including both XPS and EPS — are -8.323 and 1676, respectively. The difference between XPS and EPS is discussed in Section 1.2.6 of the main risk evaluation document.

- Aerosol/air partition coefficient (K_p)

The aerosol/air partition coefficient was calculated from Equation 11 (Finizio et al., 1997):

$$\log K_p = m \log K_{OA} + b \quad (11)$$

where

m and b are constant for a given chemical,

K_{OA} is the octanol-air partition coefficient (dimensionless).

In this work, EPA used $K_{OA} = 2.92 \times 10^{10}$ for HBCD (from EPA's EPI Suite (<https://www.epa.gov/tsca-screening-tools/epi-suite-estimation-program-interface>)). The m and b values for generic organic compounds are $m = 0.55$, and $b = 8.23$ (Finizio et al., 1997). The resulting K_p is 3.36×10^9 for HBCD.

- Dust/air partition coefficient (K_d)

The dimensionless dust/air partition coefficient was estimated with the empirical model developed by Shoeib et al. (2005):

$$K_d = 0.411 \rho f_{oc} K_{OA} \quad (12)$$

where

ρ is the density of the dust, g/cm³,

f_{oc} is the organic carbon content in the dust, fraction,

K_{OA} is the octanol/air partition coefficient, dimensionless.

6.1.1.1.7 Model parameters

- HBCD sources – polystyrene foam boards

EPA assume that the source areas are 180 m² in the attic and 120 m² in the crawlspace (Bevington et al., 2017). Other parameters are summarized in Table 1.

Table 2. Parameters for the HBCD sources.

Parameter	Value	Data source/method
Board thickness (cm)	10	FOAMULAR 400 specs
HBCD content	0.50%	EPA report (2014)
Board density (kg/m ³)	28.9	FOAMULAR 400 specs
Partition coef. (K) at 21 °C	1.70×10^7	Guo (2002); adjusted by foam density
K as a function of temperature	Equation 9	Tian et al. (2017)
Diffusion coef. (D) at 21 °C (m ² /h)	3.20×10^{-12}	Huang et al. (2017)
D as a function of temperature	Equation 10	Huang et al. (2017)

- HBCD sinks – gypsum board walls

The indoor sinks in the living space are represented by the gypsum board walls. Parameters used are shown in Table 3.

Table 3. Parameters for the HBCD sinks.

Parameter	Value	Data source/method
Surface area (m ²)	800	Bevington et al. (2017)
Thickness (m)	0.01 (~3/8 inch)	Product specs
Partition coefficient (dimensionless)	5.88×10^8	Guo (2002)

Diffusion coefficient (m ² /h)	1.08×10^{-9}	Huang et al. (2017)
---	-----------------------	---------------------

- Airborne PM

For airborne particulate matter, EPA used the following parameters:

- Particle size 2.5 μm
- Mass concentration in ambient air 30 $\mu\text{g}/\text{m}^3$
- Infiltration factor 0.8
- Aerosol/air partition coefficient 3.36×10^9 (by the Finizio et al. (1997) method)
- Deposition rate constant 0.68 h^{-1} for the living area
- 0.60 for attic and crawlspace
- Settled dust

The parameters EPA used to model settled dust are presented in Table 4.

Table 4. Parameters for settled dust.

Parameter	Value	Data source/method
Average diameter (μm)	50	Bevington et al. (2017)
Dust loading (g/m^2)	10	Bevington et al. (2017)
Partition coefficient	2.90×10^9	Shoeib et al. (2005)
Diffusion coefficient (m ² /h)	1.0×10^{-13}	Estimated ^[1]

^[1] The reported diffusion coefficient values for aerosol particles vary significantly. The value EPA used is in the middle.

6.1.2 IIOAC

EPA/OPPT's Integrated Indoor-Outdoor Air Calculation (IIOAC) was used to estimate ambient air concentrations for highly exposed groups living near facilities. IIOAC is based on a set of pre-run AERMOD dispersion scenarios at a variety of meteorological and land-use settings. For the source types of interest in HBCD modeling, users are required to enter: (1) emission parameters – emission source type, number of emission scenarios, number of releases per scenario, mass released per day, release duration, number of release days, and release pattern; (2) system parameters – applicable only for fugitive sources where an area must be specified; and (3) location parameters – urban or rural setting, particle size/vapor, and climate region. IIOAC outputs of daily-averaged air concentration, annual-averaged air concentration, and doses are provided as central tendency and high-end estimates at two distances: fenceline (100 m from source) and community (averaged across 100 to 1,000 m from the source).

IIOAC calculates ambient air concentration based on the release duration and number of days of release per year entered by the user (e.g., release occurs 4 hrs/day for 52 days in a year). An adjusted emission rate is first calculated, as shown in Equation 1, to take into account the release duration and convert the user-defined mass released per day into g/s.

$$ER_{adj} = \frac{ER}{h} \cdot 0.2778 \quad (1)$$

where ER_{adj} = adjusted emission rate [g/s]
 ER = user-defined mass released per day [kg/day]
 h = emission duration [hrs/day]
0.2778 = conversion factor from kg/hr to g/s

Air concentrations are calculated in Equation 2 by scaling the post-processed AERMOD result, obtained based on an emission of 1 g/s, by the adjusted emission rate. For fugitive sources, scaling by just the adjusted emission rate gives an air concentration corresponding to an area size of 100 m², the same as that used in the AERMOD runs. To account for a different area size, an area size scaling factor, SF_j , is applied.

$$C_{outdoor} = \frac{ER_{adj}}{1 \text{ g/s}} \cdot SF_j \cdot \text{Postprocessed AERMOD result} \quad (2)$$

where $C_{outdoor}$ = outdoor air concentration [$\mu\text{g}/\text{m}^3$]
 ER_{adj} = adjusted emission rate [g/s]
 SF_j = scaling factor for fugitive area size j [-]; set to 1 for point sources

For point and fugitive sources, three particle size scenarios are available:

- Fine particles (with a mass-mean aerodynamic diameter of 2.5 μm),
- Coarse particles (with a mass-mean aerodynamic diameter of 10 μm), and
- Vapor (no particles).

All calculated air concentrations of fine and coarse particles are capped by an upper limit equal to the National Ambient Air Quality Standards (NAAQS) for particulate matter (PM) (US EPA 2016b). These limits are 35 and 150 $\mu\text{g}/\text{m}^3$ for fine and coarse particles (i.e., the NAAQS for PM_{2.5} and PM₁₀), respectively. For vapors, the chemical is released in gaseous form and therefore there is no transfer from one phase to another. IIOAC currently does not set an upper limit for point and fugitive sources in vapor form. air concentrations are then calculated by multiplying the ambient air concentration by an indoor-outdoor ratio.

In modeling ambient air concentration for highly exposed groups living near facilities, twelve emission scenarios were considered, based on the conditions of use defined in the engineering assessment (EPA, 2019). For scenarios with site-specific information, this information was used in the IIOAC model runs. When site-specific information was not unknown, the following default parameters were used:

- Emission parameters:
 - Source type: Both stack and fugitive.
 - Emission duration: 24 hours.
 - Release pattern: Conservative pattern of release was used for all runs.
- System parameters:
 - Fugitive source area: 100 m²
- Location parameters:
 - Population setting: Rural
 - Particle size: Coarse - In the United States, standard grade HBCD powder is defined as a mean particle size of 20 to 150 µm; therefore, coarse particles was selected for use in the IIOAC runs.
 - Climate region default: Three regions were used:
 - West north central to obtain central tendency estimates for both air concentration and particle deposition.
 - South (coastal) to obtain high-end estimates when considering only air concentration.
 - East north central to obtain high-end estimates when considering both air concentration and particle deposition.

6.1.3 VVWM-PSC

The Point Source Calculator (PSC) is variation of the Variable Volume Water Model (VVWM) used by the USEPA for chemical exposure in surface waters. Details of the VVWM are given in the model user guide (EPA 2019). The PSC is similar to the SWCC and PFAM in that employs a user-friendly interface that generates a VVWM input file, runs the VVWM, and processes the data. The differences in PSC, SWCC, and PFAM are essentially in the user interface and in the post processing output. In the case of the PSC, the user interface and post processing are intended to assess chemicals that flow directly into a water body and to compare the chemical concentrations to levels of concern.

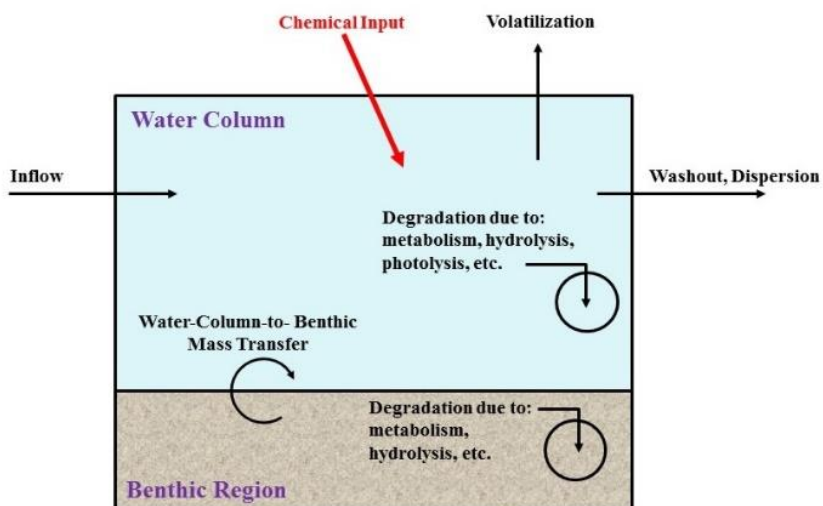


Figure 1. Depiction of the chemical processes in the Point

The conceptualization of the processes in the PSC is given by Figure 1. In this conceptualization, the VVWM is used to represent a segment of a water body which receives a direct application of a chemical. The chemical immediately mixes with the water column of the segment. The water column is coupled to a sediment layer and chemical can move into the sediment by a first-order mass transfer process. Chemical can degrade in the water column by user-supplied inputs of hydrolysis, photolysis, and general degradation. Water column chemical can also volatilize according to chemical properties supplied by the user. In the benthic region, the chemical can degrade by hydrolysis and a general benthic degradation rate as supplied by the user. Partitioning to suspended sediment as well as benthic solids occurs according to input values for either an organic carbon partitioning linear coefficient (K_{oc}) or a linear sorption coefficient (K_d).

In all cases, the waterbody is modeled as a single segment (comprised of a water column and a benthic region), with the appropriate segment being the one that receives the direct application of the chemical.

6.2 Overview of Indoor SVOC Exposure, Fate, and Transport

The indoor environment is complex. Research on emissions from sources and assessment of human exposure to indoor pollutants is of increasing interest ([Guo, 2014](#); [Liagkouridis et al., 2014](#); [Guo, 2013](#); [Salthammer and Bahadir, 2009](#)). A detailed understanding of most relevant chemical substances, including their physical-chemical properties, sources, distribution among indoor media (such as the gas phase, airborne particles and settled dust), and contact with receptors is needed to more accurately estimate exposure. Sources may include building products, furnishings and other indoor materials that often contain semi-volatile organic compounds (SVOCs) such as flame retardants and plasticizers. Many studies have shown that the types of sources in residential and commercial indoor environments, the range of emitted compounds and the duration of emission can vary widely [see for example ([Stapleton et al., 2005](#); [Singer et al., 2004](#); [Zhao et al., 2004](#))].

SVOCs including flame retardants and plasticizers are commonly found in many products used in homes or other indoor environments and have been detected in a wide variety of indoor air and dust samples [see for example ([Weschler and Nazaroff, 2010](#); [Allen et al., 2008](#))]. Exposure may occur via inhalation, dermal or oral pathways from several sources including indoor and ambient air, drinking water, soil, food, indoor surfaces, and household dust. However, the relative contributions from various chemicals in these media are not well characterized. Because products containing these chemicals are often retained in the indoor environment for several years over their lifecycle, there is the potential for chronic exposures. **Error! Reference source not found.** shows the process flow for SVOC emissions, fate, transport, and ultimately exposure in the indoor environment.

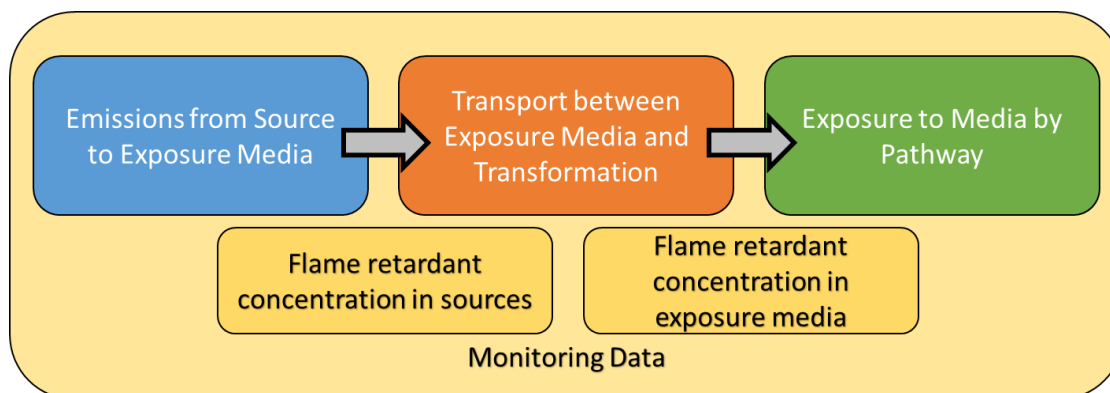


Figure 6-1. Overview of indoor emission, fate, transport, and exposure to SVOCs.

Flame retardants or other SVOCs can enter indoor air by volatilization from the consumer articles; the airborne SVOCs can be adsorbed or absorbed by settled dust, suspended particles and interior surfaces. The dust may absorb SVOCs by direct contact with the article; and the article itself can be abraded such that small pieces of the article become constituents of indoor dust. Human receptors in the indoor environment can interact with the article via dermal contact (touching) or mouthing of the article itself. Flame retardant additives can also be emitted/extracted from the article during cleaning, such as washing textiles. These processes are presented graphically in **Error! Reference source not found.** and detailed in the following sections.

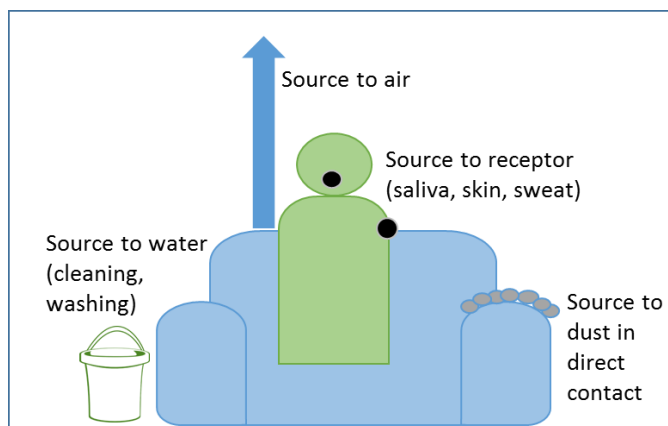


Figure 6-2. Example emission pathways for flame retardants.

Chemical Mass Transfer from Source to Air: Flame retardant additives are SVOCs with low vapor pressures ($\sim 10^{-14}$ to 10^{-4} atm). Because SVOCs have a strong affinity to indoor surfaces and particles, measuring their emission rates has been challenging. Given the low concentrations in air, methods with detection limits in the pg/m^3 range are required. Furthermore, SVOCs are often adsorbed to the sampling apparatus itself, hindering the measurement (Liang and Xu, 2014; Liu et al., 2013; Katsumata et al., 2008). It is important to note that, while the SVOC emissions are relatively slow the emissions can be

nearly constant over time and last for years or even decades. Besides, indoor SVOC sources often cover large surface areas.

Emission of flame retardants via volatilization can be described by the two-phase mass transfer theory and depends on the chemical-polymer specific diffusion, partitioning, and mass transfer coefficients, as shown in Equation 1. In the first phase of mass transfer the chemical diffuses through the article to the surface. The chemical flux is described by the solid phase mass transfer coefficient ($2D_s/L$) and the concentration gradient in the solid. In the second phase, at the surface of the article, the gas-phase mass transfer coefficient (h_a), along with gas-phase concentration gradient, is used to describe the rate of chemical movement from the surface to the air. By combining the two resistances in series, the overall gas-phase mass transfer coefficient (H_{source}) can be estimated. (Guo, 2013)

$$\frac{1}{H_{source}} = \frac{1}{\frac{2D_s}{L}K_{source}} + \frac{1}{h_a} \quad (1)$$

where:

H_{source} = Overall gas-phase mass transfer coefficient for interior source (m/hr)

D_s = the SVOC solid-phase diffusion coefficient (m²/hr)

L = the thickness of the solid layer (m)

K_{source} = the SVOC material-air partition coefficient (unitless)

h_a = the SVOC gas-phase mass transfer coefficient (m/hr)

A simpler approach that may be used in a screening model is to assume a constant concentration of flame retardant in the article (i.e., the flame retardant levels are not appreciably reduced by emissions). With this approach, diffusion in solid phase can be ignored, and the emission factor is described as

$$E = h_a \times (y_o - y) \quad (2)$$

where:

E = Emission factor (mg/m²/hr)

h_a = the SVOC gas-phase mass transfer coefficient (m/hr)

y_o = the SVOC concentration in the air immediately adjacent to the article (mg/m³)

y = gas-phase SVOC concentration in bulk air (mg/m³)

This methodology relies upon measurement or estimation of y_o . In the absence of experimental data, y_o can be estimated by either the saturation concentration or the ratio of the SVOC concentration in the article to the material-air partition coefficient. These methodologies will result in the upper-bound estimates of the emission rates. (Xu et al., 2012; Xu et al., 2009; Xu and Little, 2006)

Emission rates have been measured for flame retardant article combinations, as shown in Table Error! No text of specified style in document..1. In general, emission rates are on the order of micrograms per hour, with whole house emission rates of various brominated flame retardants calculated on the order of hundreds of milligrams per year (Batterman et al., 2010). While changes in relative humidity do not appear to affect emissions appreciably (Clausen et al., 2004), increased temperatures are shown to

increase emissions (Kajiwara et al., 2013; Destailats et al., 2008; Carlsson et al., 2000). This is of importance as flame retardants are added to electronics, foam insulation, automobile interiors, and other materials that could be exposed to heat while in use.

Table Error! No text of specified style in document..1. Measured emission rates of flame retardants from articles

Flame Retardant	Article	Emission Factor	Source
HBCD	computer casing	0.4 ng/m ² /hr	Kemmlein et al. (2003)
HBCD	textile	0-8,000 ng/m ² /hr	Kajiwara et al. (2013)
	insulation	0.1-30 ng/m ² /hr	Kemmlein et al. (2003)
TCPP	computer casing	24 ng/unit/hr	Destailats et al. (2008)
	PUF / insulation	12-140,000 ng/m ² /hr	Kemmlein et al. (2003)

6.2.1 Chemical Mass Transfer from Source to Particles

The transfer rates of flame retardants from the article surface directly to the dust in contact with the article are difficult to measure and more research is needed (Liagkouridis et al., 2015). Currently, no models exist to predict dynamic transfer rates directly to dust. Elevated levels of flame retardants have been measured in dust found near or on flame retardant sources as compared to the whole house dust (Brandsma et al., 2014). In the case of HBCD, the surface concentrations greater than 400 ng/m² have been measured on the surface of electronics (Di Napoli-Davis and Owens, 2013). HBCD has been measured in the dust inside television casings at levels of 240 ng/g and 2.5 ng/g, respectively (Takigami et al., 2008). In one study, the presence of dust on the surface of sources was shown to increase emission rates for SVOCs by increasing the external concentration gradient above the surface of the substrate (Clausen et al., 2004).

If the dust-air and source-air partition coefficients are known for the chemical of interest, the maximum SVOC concentration that would be found in dust in direct contact with the surface of an article can be described by the material-dust partitioning coefficient as shown in Equation 3.

$$K_{dm} = \frac{c_d}{c_m} = \frac{K_{da}}{K_{ma}} \quad (3)$$

where:

K_{dm} = the SVOC solid-solid partition coefficient between dust and source (unitless)

c_d = equilibrium SVOC concentration in dust (mg/m³)

C_m	=	equilibrium SVOC concentration in source material (mg/m ³)
K_{da}	=	the SVOC solid-air partition coefficient between dust and air (unitless)
K_{ma}	=	the SVOC solid-air partition coefficient between source and air (unitless)

6.2.2 Chemical Mass Transfer from Source to Skin

Dermal exposure to flame retardants can occur via direct skin contact with the source article. While flame retardants can partition into skin surface lipids and be subsequently absorbed, skin functions as a barrier to xenobiotic chemicals. However, sweat on the surface of the skin can mediate this process. Migration rates for TCPP from foam to simulated sweat have been measured upwards of 130 $\mu\text{g}/\text{cm}^2/\text{hr}$ (European Commission, 2008).

In general, dermal absorption is described as a flux through the skin that is based on a chemical-specific skin permeability coefficient (Weschler and Nazaroff, 2012). For more volatile compounds, a competing evaporative flux away from the skin must also be considered. In general, the permeability is the rate-limiting step rather than the mass of flame retardant available on the skin, which makes comparisons of published data based on fraction absorbed challenging. Absorption rates of 2-20% have been reported for HBCD (Abdallah et al., 2015a). Associated permeability coefficients for HBCD have been shown to be on the order of 10^{-3} cm/hr; permeability coefficients for HBCD have been measured on the order of 10^{-4} cm/hr with associated fluxes ranging from approximately 0.5 to 1.5 $\text{ng}/\text{cm}^2/\text{hr}$ (Abdallah et al., 2015b).

Although measuring the flux through the skin is challenging, measurement of flame retardants on the skin can provide evidence of transfer to the skin, making the chemical available for subsequent absorption. Makinen et al. (2009) measured TCEP, TCPP, TDCPP, and HBCD residues on hands via wipe sampling in occupational settings as a surrogate for dermal exposure and found the average levels ranging from 2 to 70 ng/2 hands. Keller et al. (2014) showed that touching tent fabrics resulted in a transfer of TDCPP to the hands; less evidence of transfer of HBCD was presented.

6.2.3 Transfer to Dust by source fragmentation and direct source-dust contact

In addition to volatilization, the article itself can be abraded to the extent that small pieces of the article are ground into dust. This portion of the dust would have elevated additive levels, equal to that of the original source article. This pathway, though not well characterized, is believed to be a possible explanation for underpredictions of flame retardant concentrations in dust from exposure models used to characterize emissions. Rauert et al. (2014) mimicked physical abrasion of HBCD-treated textiles and saw an increase of HBCD in deposited dust from 110 ng/g to 4,020-52,500 ng/g. Additionally, the dust fibers were analyzed via microscopy and determined to be consistent with fragments of the source article. These results are supported by (Cao et al., 2014; Cao et al., 2013; Cao et al., 2012; Suzuki et al., 2009), who analyzed flame retardant levels in dust by particle size. Flame retardant concentrations were highest in the finest particle range. This is hypothesized to be due to gas-phase partitioning. A second peak of flame retardant concentration was found in dust particles in the mid-size range. These findings suggest that the abrasion of materials such as upholstery that contain flame retardants plays an important role in determining the levels of flame retardant in dust.

If dust is present on the surface of an article, a chemical can directly transfer from the source to the dust. This process has been reported for HBCD-treated textiles in modified chambers (Rauert et al., 2016), and for PCB treated primer and caulk in modified chambers (Liu et al., 2016). This pathway, though not well characterized, can explain the high dust concentrations reported on the surfaces of some objects.

6.2.4 Fate and Transport of Chemical Substances within Indoor Environments

Once emitted to the indoor environment, flame retardants undergo a variety of fate and transport processes. Vapor-phase flame retardants can be transferred via diffusion and partitioning to particles or other sinks, such as furnishings, building materials, or clothing. Sinks can also become secondary sources of SVOCs. Airborne chemicals, either in the vapor phase or particle-bound, can then be removed from the indoor environment (and released to the outdoor environment) via ventilation. Flame retardants in settled dust can be removed via surface cleaning. Articles containing flame retardants can be disposed of via trash or recycling, and flame retardants can be removed from articles via washing. These processes are shown in **Error! Reference source not found.** and discussed in the following sections.

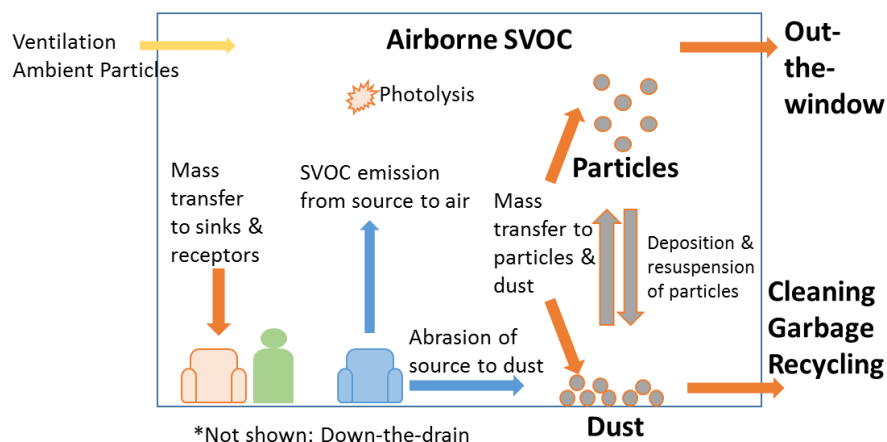


Figure 6-3. Relevant fate and transport processes in the indoor environment.

6.2.5 Chemical Mass Transfer between Air and Particles

Gas-phase SVOCs, including flame retardants, will partition between the gas-phase and airborne and settled particles. The equilibrium concentration between the gas and particle phases is described by the gas-particle partition coefficient. This is a function of the flame retardant itself, the composition of the particles, and temperature. Particle-air partition coefficients are difficult to measure and data is rare. Measured partition coefficients in the literature are summarized in **Table X**. An empirical relationship for partitioning between air and particles is presented in Weschler and Nazaroff (2010) and shown in Equation 12.

$$K_p = f_{om_part} \times \frac{K_{oa}}{\rho_{part}} \quad (12)$$

where:

K_p = SVOC partition coefficient between air and TSP (K_{TSP}) or dust (K_{Dust}) (m^3/mg)

f_{om_part} = volume fraction of organic matter in airborne particles (unitless)

K_{oa} = octanol-air partition coefficient (unitless)

ρ_{part} = density of airborne particles (mg/m^3)

However, the gas and particle phases do not reach instantaneous equilibrium. The rate of transfer between the air and gas phase is described by the gas-phase mass transfer coefficient. Available measured mass transfer coefficients are presented. An empirical relationship between the molecular weight and the gas phase mass transfer coefficient is presented in the Arthur D Little Migration Estimation Model (AMEM) and is shown below. Recent research (U.S. EPA, 2007) has shown that partitioning is dependent on the vapor pressure, temperature, particle size, indoor air velocities, and can be described to varying degrees in relation to other partitioning coefficients, including Henry's Law constant and the octanol-water partition coefficient (Liu et al., 2015; Salthammer and Schripp, 2015; Guo, 2014; Liu et al., 2014)

$$h_a = 46.8 \times \frac{3.3}{(2.5+MW^{1/3})^2} \quad (12)$$

where:

h_a = gas phase mass transfer coefficient for SVOC between bulk air and surface (m/hr)

MW = molecular weight (g/mol)

6.2.6 Chemical Mass Transfer between Air and Sinks

The behavior that describes SVOC release from a source to the air can also be used to describe the SVOC transfer between the air and the sink. In reality, SVOC transfer to particles is a special case of transfer to a sink. The equilibrium concentrations are described by the material-air partition coefficient, and the rate of transfer is described by the mass-transfer coefficient and fugacity difference between the two phases. Common indoor sinks, such as furnishings and building materials, have a much larger mass and volume than indoor particles, meaning that much more SVOC mass can be absorbed by the sink before equilibrium is reached. In addition to the concentration gradient, the rate of transfer will be determined by the room temperature and properties of the sink itself (Bi et al., 2015; Guo, 2014, 2013; Stapleton et al., 2005). It is important to note that after a primary source has been removed, lowering the air concentration of the SVOC and reversing the concentration gradient, the sink can become a secondary source (Zhao et al., 2004). A particular sink of emerging interest is clothing and bedding, which can absorb SVOCs between washings and then, when used in close contact with a receptor, serve as a secondary source of both inhalation and dermal exposures (Morrison et al., 2015)

Few data are available to describe the partitioning and mass transfer between the air and specific sinks. The equations from Section 3.1.1.1 and 3.1.2.1 can be applied to sinks.

6.2.7 Relationship between prevalence in media and physical-chemical properties

The physical-chemical properties of HBCD can be found in Section 1.1 of the main risk evaluation document.

The physical-chemical properties of chemical substances inform the exposure media a chemical is likely to be found in and, therefore, affect indoor exposures. SVOC chemicals generally have higher molecular weights, lower vapor pressures, higher boiling points, and higher log K_{OAS} than VOCs. Therefore, SVOCs are more likely to be found sorbed to indoor particles or sinks than in the gas-phase compared to VOCs. HBCD has a relatively low vapor pressure as an SVOC. In

addition, the log K_{OA} for HBCD is relatively high compared to other SVOCs, indicating its strong affinity to bind to particles in the indoor environment (Weschler and Nazaroff, 2010). Measurements of physical-chemical properties can vary for a given chemical and estimates can be uncertain (Salthammer and Schripp, 2015). However, measurement of physical-chemical properties is important to accurately assess the fate, transport, and potential exposures to chemicals in indoor environments.

6.2.8 Estimating Exposure and Relevant Exposure Pathways for SVOCs

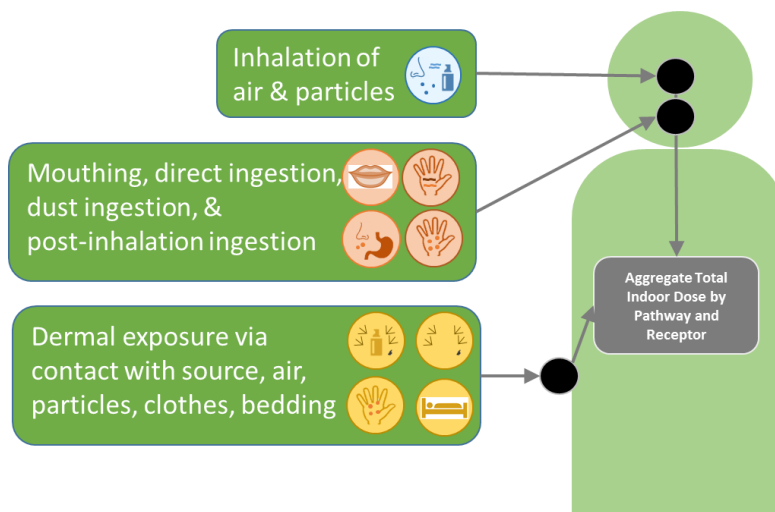


Figure X. Inhalation of Vapor-Phase Air and Suspended Particles

Gas-phase SVOCs and SVOCs sorbed to suspended particles can be inhaled via indoor air. Physiology, including age, gender, and body mass index, and activity level impact breathing rates and directly impact exposure. Gas-phase SVOCs can result in higher exposures because they are more readily absorbed by the body. SVOCs sorbed to particles, as HBCD is expected to be, can have a longer residence time in the lung particularly for small particles that penetrate deep into the lung. SVOCs sorbed to larger particles can be trapped in the upper airway and subsequently coughed out or swallowed, resulting in ingestion exposures.

6.2.9 Ingestion of Suspended Particles, Settled Dust, and Mouthing

In addition to the ingestion of previously inhaled particles, as discussed in the previous section, settled particles can also be ingested either due to hand-to-mouth or object-to-mouth transfer of dust. This exposure is driven by the frequency and duration of hand-to-mouth and object-to-mouth events, which is likely to be higher in young children. Small children also spend more time in closer proximity to the floor which may explain their higher exposure through this pathway. Reported dust ingestion rates are highly variable and expected to vary by person due to the age and behaviors of the individual, such as handwashing, and the environmental conditions, such as the dusty level of the environment.

Because SVOCs like HBCD may be found in consumer articles in which children come into contact, mouthing, or directly licking or sucking, the HBCD-containing article can also contribute

to exposures. As with dust ingestion, mouthing exposure increases with the duration and frequency of mouthing behavior, and is expected to be more relevant to children than adults. Mouthing exposure is also highly dependent on the transfer of the SVOC, like HBCD, from the source to the saliva, termed the migration rate. This is expected to be dependent on both the additive (HBCD) and the polymer. Although migration rates can be determined experimentally through in-vitro and/or in-vivo approaches, data have been scarce in the literature. Mouthing is discussed in detail in Section 6.2.9.

Regardless of the pathway of ingestion, ingestion exposure depends on the ability of the chemical to be absorbed into the gastrointestinal tract after ingestion.

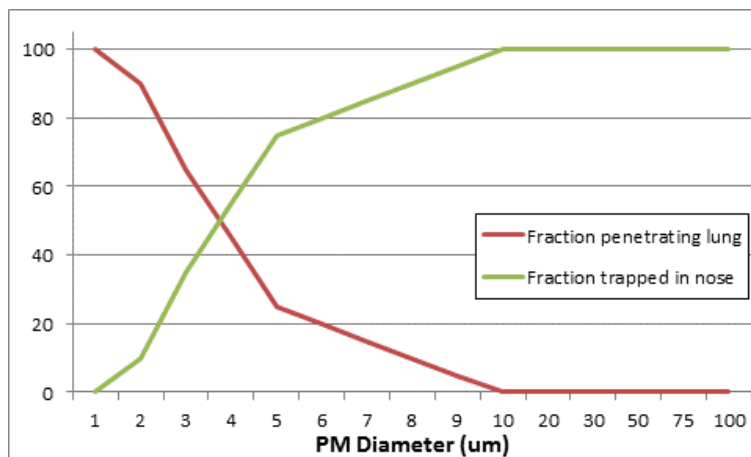


Figure 6-4. Percentage of inhaled particles that are trapped in either the lung or nose by particle diameter.

U.S. Bureau of Mines (1987)

6.2.10 Dermal Contact with Source, Airborne SVOCs, and Sinks

Chemicals can contact the skin by direct contact with sources, contact with dust on surfaces of floors or objects, air deposition to the skin, or direct contact with secondary sources (sinks) with or without adhered dust. Hand wipe samples and other methods that measure chemical loadings on skin surface show that chemicals can remain on the skin. Additionally, it has been shown that low vapor pressure compounds such as HBCD are more likely to be absorbed by the skin than higher vapor pressure chemicals (Weschler and Nazaroff, 2014). Therefore, in addition to ingestion exposure resulting from hand-to-mouth contact, dermal absorption should be considered.

The amount of chemical that is absorbed into the skin depends on the competing processes of a chemical flux to and through the skin and chemical flux away from the skin, either by volatilization or washing. Clothing, bedding, and other physical barriers may prevent or reduce chemical contact with the skin or serve as vectors that increase exposure (Nazaroff and Goldstein, 2015).

Generally, dermal absorption rates tend to be lower than inhalation and ingestion rates and an individual may need to spend more time in a microenvironment (on the order of hours) for dermal exposure whereas inhalation and ingestion exposures occur more quickly. However, this pathway may contribute to overall exposure even though it is not as well characterized.

6.3 Age-Specific Exposure Factors and Activity Patterns Used in this Assessment

Table Error! No text of specified style in document..2: Body Weights

Age Grouping	Males & Females		
	N	Mean	10th
Birth to <1 month	158	4.8	3.9
1 to<3 months	284	5.9	4.7
3 to<6 months	489	7.4	6.1
6 to<12 months	927	9.2	7.5
1 to <2 years	1,176	11.4	9.3
2 to <3 years	1,144	13.8	11.5
3 to<6 years	2,318	18.6	14.4
6 to <11 years	3,593	31.8	21.3
11 to <16 years	5,297	56.8	37.2
16 to <21 years	4,851	71.6	52
21 to <30 years	3,232	78.4	54.7
30 to <40 years	3,176	80.8	57
40 to <50 years	3,121	83.6	58.8
50 to <60 years	2,387	83.4	59
60 to <70 years	2,782	82.6	59.8

[U.S. EPA \(2011\)](#), Chapter 8.

Table Error! No text of specified style in document..3: Body Weights Used in the Assessment

Age Grouping	Body weight Used (kg)	
	CT	HE
Infant (<1 year)	7.7	6.3
Young Toddler (1-<2 years)	11.1	9.1
Toddler (2-<3 years)	13.5	11.0
Small Child (3-<6 years)	18.3	14.3
Child (6-<11 years)	31.7	20.9
Teen (11-<16 years)	55.9	38.6
Adult (16-<70 years)	73.1	52.9

[U.S. EPA \(2011\)](#), Chapter 8.

Table Error! No text of specified style in document..4: Dust and Soil Ingestion Rates by Age

Age Grouping	Dust Ingestion Rate (mg/day)		Soil Ingestion Rate (mg/day)	
	CT (mean)	HE (95th)	CT (mean)	HE (95th)
Infant (<1 year)	30.0	80.0	25.0	70.0
Young Toddler (1-<2 years)	50.0	100.0	40.0	90.0
Small Child (2-6 years)	30.0	100.0	30.0	90.0
Child (6-<11 years)	30.0	100.0	30.0	90.0
Teen (12-<16 years)	20.0	100.0	30.0	90.0
Adult (16-<78 years)	20.0	60.0	10.0	50.0

[U.S. EPA \(2017\)](#), for central tendency values, and high-end values

Table Error! No text of specified style in document..5: Inhalation Rates by Age Group

Age Grouping	Inhalation rate (m ³ /day)	
	CT (mean)	HE (95th)
Infant (<1 year)	5.4	9.2
Young Toddler (1-<2 years)	8.0	12.8
Toddler (2-<3 years)	8.9	13.7
Small Child (3-<6 years)	10.1	13.8
Child (6-<11 years)	12.0	16.6
Teen (11-<16 years)	15.2	21.9
Adult (16-<70 years)	15.7	21.3

[U.S. EPA \(2011\)](#), Chapter 6. Recommended Values from Table 6-1. Note that Inhalation Rates were averaged across age groups >16

Table Error! No text of specified style in document..6: Generic Activity Patterns for Time Spent Awake

Microenvironment	Time Awake Spent (hr/day) ¹			Fraction Awake Time Spent (unitless)		
	SAH Adult / Child	Part-Time School / COF / Work	Full-Time School / COF / Work	SAH Adult / Child	Part-Time School / COF / Work	Full-Time School / COF / Work
Comm/ Public/ Gov / School / COF	1	3	6	0.07	0.23	0.46
Outside	2	2	2	n/a	n/a	n/a
Automobile	1	2	2	0.07	0.15	0.15
Residences	11	8	5	0.84	0.62	0.38

[U.S. EPA \(2009\)](#). Informs Dust and Soil Ingestion as these activities only occur when awake. Assumed Sleep time is 9 hours per day based on weighted average across age groups, and 15 hours are spent awake. Assume that all soil ingestion that would occur, occurs while outdoors-no fraction of day is applied to soil ingestion exposure equation.

Table Error! No text of specified style in document..7: Generic Activity Patterns for Total Time Spent

Microenvironment	Time Spent Total (hr/day) ¹			Fraction Time Spent Total (unitless)		
	SAH Adult / Child	Part-Time School / COF / Work	Full-Time School / COF / Work	SAH Adult / Child	Part-Time School / COF / Work	Full-Time School / COF / Work
Comm/ Public/ Gov / School / COF	1	3	6	0.04	0.125	0.25
Outside	2	2	2	0.08	0.08	0.08
Automobile	1	2	2	0.04	0.08	0.08
Residences	20	17	14	0.83	0.71	0.583

[U.S. EPA \(2009\)](#). Informs Inhalation pathway as breathing occurs 24 hours per day.

These generic activity patterns were informed by an analysis of the CHAD database. The amount of time that children and adults spend in different microenvironments is highly variable. It influences both the magnitude of the concentration and the duration of exposure over which people are exposed. CHAD contains the most robust human activity data available and contains activity-pattern information from survey respondents who logged their location for one or multiple days. The database contains this information for individuals on different days and for people ranging from young children to adults.

The database contains information from different surveys, and all data were used in the analysis. As a first step, an initial quality control step was performed. The number of unique entries in the database was determined to be 1,901,301. The number of unique entries in the database after removing entries where field QCmiss > 60 (either activity or location is unknown for more than 1 hr/day) and field qcsleep is missing (no sleep time entered) was 1,633,914. The corresponding unique number of activity days captured in the database is 42,090. From here, percentile estimates of time spent by age group, weekday/weekend, season, and overall microenvironment type were calculated. The following equation was used to take a weighted average across seasons and weekends/weekdays for the overall time spent ($TS_{overall}$).

$$TS_{overall} = 0.25 \times \left(\frac{5}{7} \times TS_{summer-weekday} + \frac{2}{7} \times TS_{summer-weekend} \right) + 0.75 \times \left(\frac{5}{7} \times TS_{non-summer-weekday} + \frac{2}{7} \times TS_{non-summer-weekend} \right)$$

The interquartile range, from the 25th to the 75th percentile, was used to inform the generic activity patterns selected for the analysis. All the estimates in **Table Error! No text of specified style in document..6** and [U.S. EPA \(2009\)](#). Informs Dust and Soil Ingestion as these activities only occur when awake. Assumed Sleep time is 9 hours per day based on weighted average across age groups, and 15

hours are spent awake. Assume that all soil ingestion that would occur, occurs while outdoors-no fraction of day is applied to soil ingestion exposure equation.

Table Error! No text of specified style in document..7 are generally within the interquartile ranges identified below. While there is some variation across age groups, three generic activity patterns were applied across all age groups.

Table Error! No text of specified style in document..8: Interquartile Range of Hours/Per day in Microenvironments from CHAD

Age Group	Residences			Schools			P&CB			Outside			Automobile		
	25t h	50t h	75t h	25t h	50t h	75t h	25t h	50t h	75t h	25t h	50t h	75t h	25t h	50t h	75t h
1: 1 & under	19.5	21.6	23.2	3.0	6.5	8.5	0.7	1.3	2.3	0.6	1.2	2.3	0.5	1.0	1.6
2: 1 to 2	17.3	20.2	22.5	2.8	5.7	7.1	0.6	1.3	2.2	0.9	1.8	3.1	0.5	1.0	1.5
3: 3 to 5	16.1	18.6	21.3	2.9	5.0	6.7	0.6	1.2	2.3	0.9	1.9	3.3	0.5	1.0	1.5
4: 6 to 10	15.1	16.8	18.7	4.7	5.4	6.0	0.6	1.4	2.5	1.2	2.1	3.6	0.5	1.0	1.5
5: 11 to 15	14.9	16.9	19.3	4.2	5.6	6.5	0.7	1.8	3.0	0.8	1.9	3.3	0.5	1.0	1.6
6: 16 to 20	14.1	16.7	20.3	3.9	5.4	6.2	1.0	2.7	5.1	0.6	1.5	2.9	0.5	1.0	2.0
7: 21 & above	13.8	16.4	20.6	0.7	2.4	5.9	1.4	4.2	7.6	0.6	1.3	3.1	0.9	1.4	2.1

[U.S. EPA \(2009\)](#)

Table Error! No text of specified style in document..9: Fish Ingestion Rates for General Population

Age Grouping	Fish Ingestion Rate (g/day)	
	CT (mean)	HE (95th)
Infant (<1 year)	0.0	0.0
Young Toddler (1-<2 years)	0.6	4.7
Toddler (2-<3 years)	0.6	4.7
Small Child (3-<6 years)	0.7	5.8
Child (6-<11 years)	1.1	7.7
Teen (11-<16 years)	1.1	8.3
Adult (16-<70 years)	5.0	22.0

[U.S. EPA \(2014\)](#) Tables 9a and 20a

Table Error! No text of specified style in document..10: Fish Ingestion Rates for Tribal Populations

Age Grouping	Fish Ingestion Rate (g/day)
Infant (<1 year)	0.0

Young Toddler (1-<2 years)	70
Toddler (2-<3 years)	70
Small Child (3-<6 years)	70
Child (6-<11 years)	70
Teen (11-<16 years)	70
Adult (16-<70 years)	142.5

[U.S. EPA \(2011\)](#) Table 10-6

Table Error! No text of specified style in document..11: Drinking Water Ingestion Rates

Age Grouping	Drinking Water Ingestion Rate (mL/day)	
	CT (mean)	HE (95th)
Infant (<1 year)	283.3	961.5
Young Toddler (1-<2 years)	271.0	837
Toddler (2-<3 years)	317	877
Small Child (3-<6 years)	327	959
Child (6-<11 years)	414	1316
Teen (11-<16 years)	520	1821
Adult (16-<70 years)	765.7	2369.7

Table Error! No text of specified style in document..12: Breast Milk Ingestion Rates

Age Grouping	Breast Milk Ingestion Rate (mL/day)		Breast Milk Ingestion Rate (mL/day)	
	CT (mean)	HE (95th)		
Birth to 1 month	510	950	20	38
1 to < 3 months	690	980	27	40
3 to < 6 months	770	1000	30	42
6 to < 12 months	620	1000	25	42
Birth to 1 year	654	994	26	41.5

[U.S. EPA \(2011\)](#), Chapter 15.

Table 3.14. Grain Ingestion Rates

Age Grouping	Grain Ingestion Rate (g/kg day)	
	CT (mean)	HE (95th)
Infant (<1 year)	3.9	8.7
Young Toddler (1-<2 years)	6.4	12.7
Toddler (2-<3 years)	6.4	11.7
Small Child (3-<6 years)	6	10.5
Child (6-<11 years)	4.6	8.7

Teen (11-<16 years)	2.7	5.7
Adult (16-<21 years)	2.3	5
Adult (21-50 years)	2.1	4.6
Adult (50+)	1.7	3.6

Table 3.14. Fruit Ingestion Rates

Age Grouping	Fruit Ingestion Rate (g/kg day)	
	CT (mean)	HE (95th)
Infant (<1 year)	9.9	27.2
Young Toddler (1-<2 years)	9.8	24
Toddler (2-<3 years)	7.7	20.5
Small Child (3-<6 years)	5.8	16.4
Child (6-<11 years)	3.2	10
Teen (11-<16 years)	1.6	5.2
Adult (16-<21 years)	1.1	4
Adult (21-50 years)	1.3	4.3
Adult (50+)	1.6	4.5

Table 3.14. Vegetable Ingestion Rates

Age Grouping	Vegetable Ingestion Rate (g/kg day)	
	CT (mean)	HE (95th)
Infant (<1 year)	6.7	18.7
Young Toddler (1-<2 years)	6.7	16.3
Toddler (2-<3 years)	6	14
Small Child (3-<6 years)	5.3	13.3
Child (6-<11 years)	3.8	9.9
Teen (11-<16 years)	2.4	6.3
Adult (16-<21 years)	2.3	5.3
Adult (21-50 years)	2.5	6.1
Adult (50+)	2.6	6

Table 3.14. Meat Ingestion Rates

Age Grouping	Meat Ingestion Rate (g/kg day)	
	CT (mean)	HE (95th)
Infant (<1 year)	3	8.9
Young Toddler (1-<2 years)	4.1	9.6
Toddler (2-<3 years)	4.3	9.6
Small Child (3-<6 years)	4	9

Child (6-<11 years)	3	6.7
Teen (11-<16 years)	2.2	4.9
Adult (16-<21 years)	2	4.6
Adult (21-50 years)	1.8	4.1
Adult (50+)	1.5	3.2