United States
Environmental Protection Agency

Office of Chemical Safety
and Pollution Prevention

Final Risk Evaluation for Cyclic Aliphatic Bromides Cluster (HBCD)

Systematic Review Supplemental File:

Supplemental Information on General Population, Environmental and Consumer Exposures

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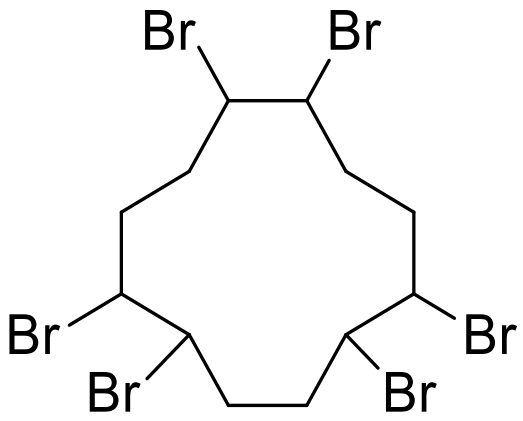

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1. Overview of the Systematic Review Process

EPA completed a comprehensive literature search for hexabromocyclododecane (HBCD) along with the first 10 chemicals, details on search strategy are documented in U.S. EPA (2017). 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, and brominated flame retardant) 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, as defined in Appendix E of U.S. EPA (2018), 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. Data were extracted in litstream™ web-based data extraction forms designed to accommodate measured concentrations and modeled media concentrations reported in both environmental and biomonitoring mediums, as well as modeled estimates of intake and dose. The extraction forms were piloted and refined from previous use in the PBT5 exposure assessment. For environmental monitoring and biomonitoring studies values were extracted describing the overall range of data (minimum, maximum, mean, median, variation 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.

Quality Control

Extractors were provided group training and instruction for data extraction. Following training extractors were assigned a study for extraction. A senior reviewer verified completed extractions for accuracy and advised extractors on any errors from incorrect application of the instructions. If over 90% of the extracted fields were accurate then a screener passed the training review, otherwise extractors had to extract another study for review prior to proceeding with further assignments. Following the initial extraction phase, a targeted quality control phase was performed where studies missing critical fields (such as fractions or location types) required for aggregation were assigned to another extractor for review. Following data visualization another targeted quality control phase was employed for outlier studies identified in media plots. Given the nature of the statistical analysis, studies that carried forward to risk were revisited to verify reported statistics and ensure a complete extraction.

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 in litstream™. For studies that reported a frequency of detection of less than 100%, meaning that HBCD was not detected in all samples, a value of one-half the highest reported limit of detection or limit of quantitation 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 U.S. EPA (2011).

Data were first aggregated by like media and sampling phase or weight fraction type. Further aggregation was performed to group data by location type. Finally, data from countries classified by the World Bank (June 2019) as high-income (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups) were grouped together. Data from high-income countries were used to augment the U.S. datasets due the limited amount of U.S. data available. High-income countries were selected as surrogate U.S. countries based on the assumption that these countries have manufacturing, processing, and use characteristics that are most likely to resemble those in the U.S.

All data and statistical analyses were performed on litstream™ reports of quality control reviewed data using scripts in Python 3.7 using the pandas, scipy and xlrd libraries. All concentrations were converted to a common unit by media and the overall range (lowest reported value to highest reported value) and the range of central tendencies (means and medians) was determined for each study and each aggregated group. The plots in Section 2 of this supplement contain a data summary plot for each media by weight fraction or sampling phase. Each plot presents statistics for each individual study as well as summary statistics for the studies aggregated by location type (i.e., near facility or background) for the high-income countries. Within each location type, monitoring data from North America 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, but

are described in the tables accompanying each plot. 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. In media that carried forward to risk, central tendency and 90th percentile estimates were plotted over the bars for studies that reported enough stats to reconstruct a lognormal or normal distribution. For the summary bar, the overall central tendency and high-end estimates are presented. The following statistical methods were used to calculate the central and high-end estimates.

1.3 Statistical approach of exposure estimates derived from measured concentrations

Studies were aggregated by media, unit, fraction, location type, and high income classification, then means were calculated based on each reported stat type. Based on this aggregation and reported statistics, normal and lognormal distributions were estimated based on available data. In cases where measures of variability were provided, no fitting was required to build a distribution. If geometric means and geometric standard deviations (GSDs) were provided they were used directly to construct a lognormal distribution by using the mean of geometric means (μ) and mean of GSD (σ). Using this distribution, the central tendency was estimated by calculating the arithmetic mean and 90th percentile using the equations below.

Equation for arithmetic mean estimates from lognormal distribution: $e^{(\mu+\frac{\sigma^2}{2})}$
Equation for estimating 90th percentile from lognormal distribution: $e^{(\mu+\sigma*Norminv(0.90))}$
If (arithmetic) means and standard deviations (SDs) or variance were provided, then a normal distribution was also derived and the average of means and the 90th percentile was calculated for the high-end exposure estimate. The following table describes the preferred distributions used in each case. In some cases, the preferred distribution was not used, see the quality control section for this justification.

Table 1-1. Distributions Preferred Depending on Available Reported Statistics

Case type	Description of available statistics per study aggregate	Distribution type preferred
Case 0A	Geometric mean and GSD	lognormal
Case 0B	Median and GSD	lognormal
Case 1A	(Mean == Median) and SD	normal
Case 1B	Mean and SD (no Median)	normal
Case 2A	Median and (min or max or percentile)	lognormal
Case 2B	Median and (FOD<1 and LOD/LOQ)	lognormal
Case 3A	Mean only and (min or max or percentile)	lognormal
Case 3B	Mean only and (FOD<1 and LOD/LOQ)	lognormal
Case 4	Median and mean only	lognormal
All other cases	Not enough data to build distribution	n/a

GSD = geometric standard deviation
SD = standard deviation
FOD = frequency of detection

LOD = limit of detection
LOQ = limit of quantitation

1.3.1 Fitting lognormal distributions

In cases where medians were provided the average median was substituted for geometric mean and the remaining statistics were used to estimate the GSD by minimizing the sum of squared errors for all provided statistical estimates. Sum of squared errors were calculated by comparing the mean of the statistic to the estimated value produced by the fitted distribution based on the following table of assumptions defining the percentiles assumed for each stat type.

Table 1-2. Assumed Percentile for Calculating Error by Statistical Estimate Type

Mean of statistical estimate by type	Assumed percentile for calculating error
Maximum	0.99
Minimum	0.01
nth percentile (eg. 25^{th} percentile)	n/100 (eg. 0.25)
Half limit of quantitation substituted minimum	0.005
Half limit of detection substituted minimum	0.0025

This methodology requires that we begin with an estimate of central tendency and at least one point along the distribution. The lognormal distribution was fitted for studies that provided an arithmetic mean and at least one point along the curve. In this case both the geometric mean and the GSD was solved for by minimizing the sum of the squared errors for all estimates.

1.3.2 Fitting normal distributions

Normal distributions were also constructed for all study aggregates by using a similar approach. Study reported means were assumed to be medians and standard deviation was solved for by minimizing the sum squared error of all available estimates.

1.3.3 Quality control of derived exposure estimates

Initially estimated medians and arithmetic means were verified to fall within the range of the data reported. If estimates fell outside of the range of data, then estimates were not used. When derived GSDs exceeded 10 for lognormal distributions, mean estimates were not used if they exceeded 100% relative percent difference from actual means. In these cases, the estimates from the normal distributions were used when available.

1.3.4 Final risk estimates by media and location type

Central tendencies that carried forward to risk were summarized for each media aggregate by location type for high income countries by taking the mean of the arithmetic mean estimates from the selected distribution (lognormal or normal) that passed the QC process. Similarly, the

90th percentile was calculated by the mean of 90th percentile estimates. Table 1-3 below shows the data available by country. Table 1-4 shows the results and number of studies for each media, location and fraction.

Table 1-3. Availability of Monitoring and Modeled Data by Country Using World Bank Income Classification[1]

Region	Economy	Extracted Monitoring or Modeled Data Available[2]	Data Used in Risk Estimates[3]									
			Diet	Dust	Indoor Air	Ambient Air	Dermal	Mouthing	Surface	Sediment	Soil	Biosolids
High Income Countries (all)												
North America	Bermuda											
	Canada (CA)	✓		●		●			●			
	United States (US)	✓	●	●		●		●	●	●		●
East Asia & Pacific	Australia (AU)	✓								●		
	Brunei Darussalam											
	French Polynesia											
	Guam											
	Hong Kong SAR, China (HK)	✓										
	Japan (JP)	✓	●	●	●				●	●		
	Korea, Rep. (KR)	✓	●					●		●		
	Macao SAR, China											
	New Caledonia											
	New Zealand (NZ)	✓		●								
	Northern Mariana Islands											
	Palau											
	Singapore (SG)	✓										
	Taiwan, China											
Europe & Central Asia	Andorra											
	Austria											
	Belgium (BE)	✓		●						●	●	
	Channel Islands											
	Croatia											
	Cyprus											
	Czech Republic (CZ)	✓						●		●		
	Denmark (DK)	✓										
	Estonia											
	Faroe Islands											
	Finland (FI)	✓										
	France (FR)	✓										
	Germany (DE)	✓		●								
	Gibraltar											
	Greece (GR)	✓										
	Greenland (GL)	✓				●						

Region	Economy	Extracted Monitoring or Modeled Data Available[2]	Data Used in Risk Estimates[3]									
			Diet	Dust	Indoor Air	Ambient Air	Dermal	Mouthing	Surface	Sediment	Soil	Biosolids
	Hungary											
	Iceland (IS)	✓										
	Ireland											
	Isle of Man											
	Italy (IT)	✓								●		
	Latvia (LV)	✓										
	Liechtenstein											
	Lithuania											
	Luxembourg											
	Monaco											
	Netherlands (NL)	✓								●		
	Norway (NO)	✓				●	●			●		
	Poland (PL)	✓							●			
	Portugal (PT)	✓		●								
	San Marino											
	Slovak Republic											
	Slovenia											
	Spain (ES)	✓	●									
	Sweden (SE)	✓		●	●	●				●	●	
	Switzerland (CH)	✓		●						●		
	United Kingdom (GB)	✓	●	●	●	●		●	●	●		
Latin America & Caribbean	Antigua and Barbuda											
	Aruba											
	Bahamas, The											
	Barbados											
	British Virgin Islands											
	Cayman Islands											
	Chile (CL)	✓										
	Curaçao											
	Panama											
	Puerto Rico											
	Sint Maarten (Dutch part)											
	St. Kitts and Nevis											
	St. Martin (French part)											
	Trinidad and Tobago											
	Turks and Caicos Islands											
	Uruguay											
	Virgin Islands (U.S.)											
Middle East & North Africa	Bahrain											
	Israel											
	Kuwait (KW)	✓								●		
	Malta											

Region	Economy	Extracted Monitoring or Modeled Data Available[2]	Data Used in Risk Estimates[3]									
			Diet	Dust	Indoor Air	Ambient Air	Dermal	Mouthing	Surface	Sediment	Soil	Biosolids
	Oman											
	Qatar											
	Saudi Arabia											
	United Arab Emirates											
Sub-Saharan Africa	Seychelles											
Low Income, Lower Middle Income, and Upper Middle Income Countries (only with Extracted Data)												
East Asia & Pacific	Cambodia (KH)	✓										
	China (CN)	✓										
	Indonesia (ID)	✓										
	Lao PDR (LA)	✓										
	Malaysia (MY)	✓										
	Philippines (PH)	✓										
	Vietnam (VN)	✓										
Europe & Central Asia	Romania (RO)	✓										
	Russian Federation (RU)	✓										
Latin America & Caribbean	Mexico (MX)	✓										
Middle East & North Africa	Egypt, Arab Rep. (EG)	✓										
South Asia	India (IN)	✓										
	Nepal (NP)	✓										
Sub-Saharan Africa	Ghana (GH)	✓										
	South Africa (ZA)	✓										
	Tanzania (TZ)	✓										
	Uganda (UG)	✓										
Other	Antarctica (AQ)	✓										

[1] Countries are classified by income level based on the June 2019 World Bank list of economies. https://blogs.worldbank.org/opendata/new-country-classifications-income-level-2018-2019

[2] A checkmark indicates the presence of monitoring or modeled data for the country.

[3] A bullet indicates that data from the country was used in the final risk estimation dataset following application of the statistical cleansing protocol.

Table 1-4. Summary of Exposure Estimates Derived from Available Measured Concentrations from High Income Countries

Matrices	Location type	Count of estimates from high income countries	Unit	Fraction	Average of arithmetic mean estimates	Average of 90th percentile estimates
Fruits, grains, and veggies	n/a	5	mg/g	wet	9.0E-08	1.2E-07
Fruits	n/a	1	mg/g	wet	2.6E-08	5.5E-08
Grains	n/a	2	mg/g	wet	8.2E-08	1.1E-07
Veggies	n/a	2	mg/g	wet	1.6E-07	1.9E-07
Seafood	n/a	8	mg/g	wet	2.0E-06	4.1E-06
Meats, dairy, and fats	n/a	8	mg/g	wet	1.5E-07	2.2E-07
Meats	n/a	3	mg/g	wet	1.1E-07	1.8E-07
Dairy	n/a	3	mg/g	wet	1.6E-07	2.4E-07
Fats	n/a	2	mg/g	wet	1.7E-07	2.3E-07
Breast milk	general	17	mg/g	lipid	4.4E-06	8.7E-06
Indoor air	residential	3	µg/m^3	any	1.0E-03	2.3E-03
	commercial, school, mixed use	4	µg/m^3	any	9.1E-04	1.9E-03
	vehicle	2	µg/m^3	any	2.4E-04	3.3E-04
Ambient air	background	7	µg/m^3	any	2.0E-05	3.0E-05
Indoor dust	residential	24	µg/mg	dry	1.5E-03	2.9E-03
	commercial, school, mixed use	16	µg/mg	dry	1.5E-03	2.9E-03
	vehicle	5	µg/mg	dry	1.7E-02	3.2E-02
Soil	near facility	1	µg/mg	dry	1.0E-03	1.3E-03
	background	2	µg/mg	dry	1.4E-06	3.0E-06
Surface Water	near facility	3	µg/L	wet	8.4E-01	9.9E-01
	background	4	µg/L	wet	4.1E-04	8.0E-04
Sediment	near facility	6	µg/kg	dry	3.4E+03	5.1E+03
	background	14	µg/kg	dry	6.2E+00	2.0E+01

2. Environmental Monitoring Media

2.1. Ambient Air

2.1.1. Ambient Air (ng/g) – Particulate Fraction

Measured concentrations of HBCD in Ambient Air with unit of ng/g, extracted from 1 source, are summarized in Figure 2-1 and supplemental information is provided in Table 2-1. Overall, concentrations ranged from not-detected to 2.90E-04 ng/g from over 36 samples collected between 2010 and 2011 in 1 country, CN. Location types were categorized as Background. Reported detection frequency was 0.56.

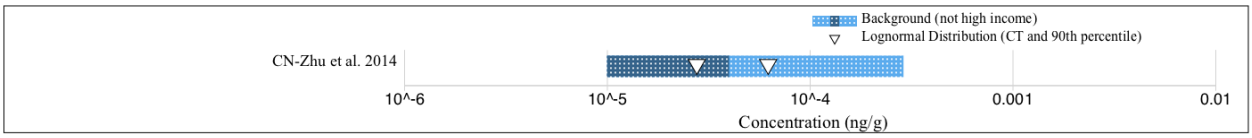


Figure 2-1. Concentration of HBCD (ng/g) in the Particulate Fraction of Ambient Air in Background Locations from 2010-2011

Table 2-1. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Particulate Fraction of Ambient Air

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Zhu et al. (2014a)	CN	Background	2010-2011	36	0.56	N/R	1.3	High

Abbreviations: N/R, Not reported

2.1.2. Ambient Air (ng/m^3) – Gas and/or Particulate Fraction

Measured concentrations of HBCD in Ambient Air with unit of ng/m3, extracted from 6 studies with particulate and gas phase samples and 15 studies with particulate only samples, are summarized in Figure 2-2 and 2-3, respectively. Supplemental information is provided in Table 2-2. Overall, concentrations ranged from not-detected to 1,070 ng/m^3 collected between 2000 and 2012 in at least 10 countries, including US, SE, CA, GL, CZ, GB, NO, CN, JP, and UG. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.25 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.02 and 0.03 ng/m^3 for Background (n = 7 studies).

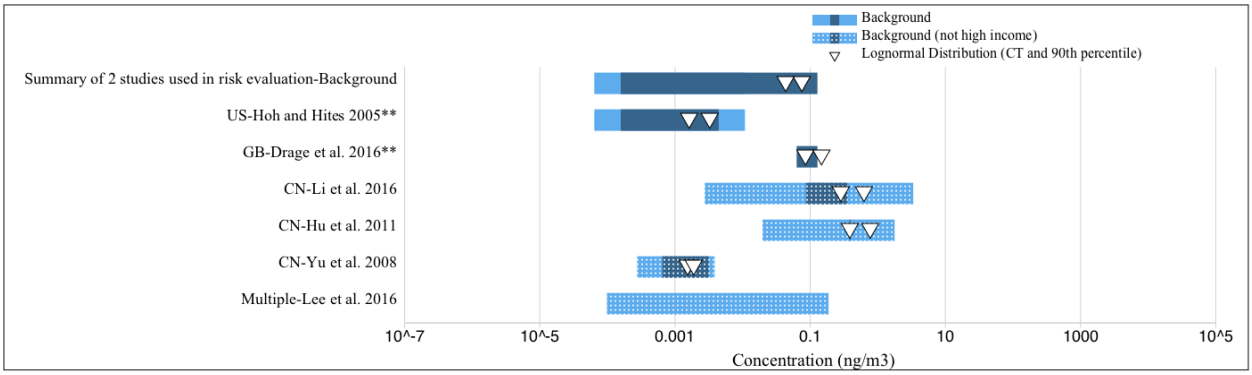


Figure 2-2. Concentration of HBCD (ng/m3) in the Gas and Particulate Fraction of Ambient Air in Background Locations from 2002 to 2013

**High-income country

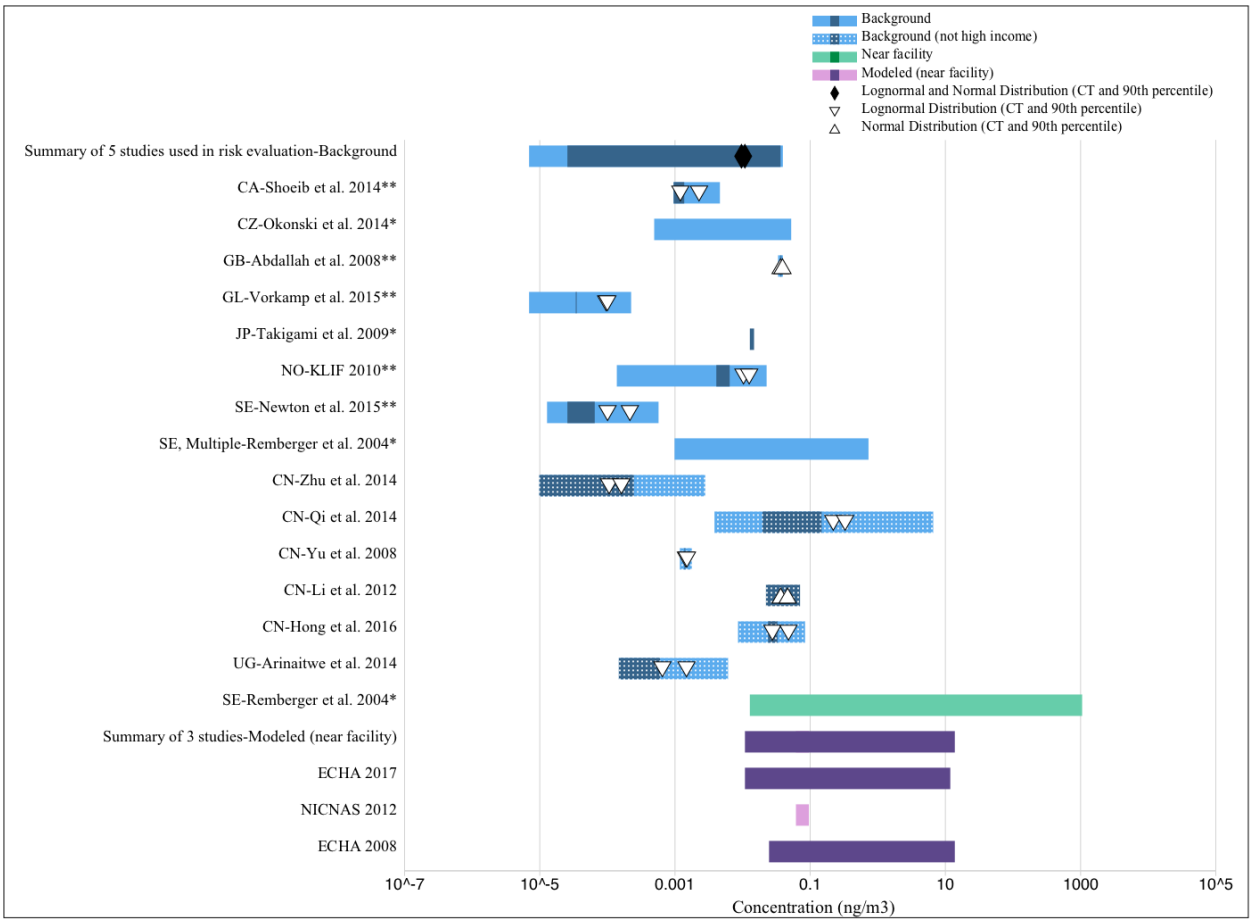


Figure 2-3. Concentration of HBCD (ng/m3) in the Particulate Fraction of Ambient Air in Background and Near Facility Locations and for Modeled Data from 2000 to 2012

* Study conducted in a country/countries classified as “High Income” by the World Bank;
** Study conducted in a country/countries classified as “High Income” by the World Bank and used in risk evaluation final dataset

Table 2-2. Summary of Peer-Reviewed Literature that Measured HBCD (ng/m3) Levels in the of Ambient Air

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/m3)	Quality Score	Overall Quality Level
Gas and Particulate Fraction								
Hoh and Hites (2005)	US**	Background	2002-2004	120	0.82	0.00013	2.0	Medium
Drage et al. (2016)	GB**	Background	2012-2013	384	0.92	0.022	1.3	High
Li et al. (2016c)	CN	Background	2008-2013	222	0.94	0.0056	1.8	Medium
Hu et al. (2011a)	CN	Background	2008-2009	28	1.0	N/R	1.2	High
Yu et al. (2008a)	CN	Background	2004	64	0.95	N/R	1.8	Medium
Lee et al. (2016)	Multiple	Background	2005-2006	160	0.56	0.0001	1.8	Medium
Particulate Fraction								
Shoeib et al. (2014)	CA**	Background	2010-2011	70	0.67	N/R	2.0	Medium
Okonski et al. (2014)	CZ*	Background	2009-2010	24	0.75	0.0005	1.2	High
Abdallah et al. (2008a)	GB**	Background	2007	5	1.0	0.0033	1.3	High
Vorkamp et al. (2015)	GL**	Background	2012	12	0.92	1.4e-05	1.2	High
Takigami et al. (2009b)	JP*	Background	2006	2	N/R	N/R	1.9	Medium
Climate and Pollution (2010)	NO**	Background	2007	26	N/R	N/R	1.4	High
Newton et al. (2015)	SE**	Background	2012	12	0.25	2.6e-05	2.0	Medium
Remberger et al. (2004)	SE, Multiple*	Background	2000-2001	10	1.0	0.001	1.8	Medium
Zhu et al. (2014a)	CN	Background	2010-2011	36	0.56	N/R	1.3	High
Qi et al. (2014a)	CN	Background	2007-2008	57	N/R	0.0029	2.1	Medium
Yu et al. (2008b)	CN	Background	2006	4	1.0	N/R	2.1	Low

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/m3)	Quality Score	Overall Quality Level
Li et al. (2012a)	CN	Background	2006	25	N/R	N/R	1.8	Medium
Hong et al. (2016)	CN	Background	2004-2005	9	N/R	N/R	1.6	High
Arinaitwe et al. (2014)	UG	Background	2008-2010	56	0.29	0.0003	1.4	High
Remberger et al. (2004)	SE*	Near facility	2000-2001	3	1.0	0.001	1.8	Medium
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.0	Medium
NICNAS (2012)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.2. Biosolids

2.2.1. Biosolids (ng/g) – Dry Fraction

Measured concentrations of HBCD in Biosolids with unit of ng/g, extracted from 17 sources, are summarized in Figure 2-4 and supplemental information is provided in Table 2-3. Overall, concentrations ranged from not-detected to 434,740 ng/g from over 343 samples collected between 2000 and 2016 in 12 countries, SE, CA, CZ, ES, NL, ID, US, CH, GB, AU, KR, and CN. Location types were categorized as Near Facility. Reported detection frequencies ranged from 0.29 to 1.0.

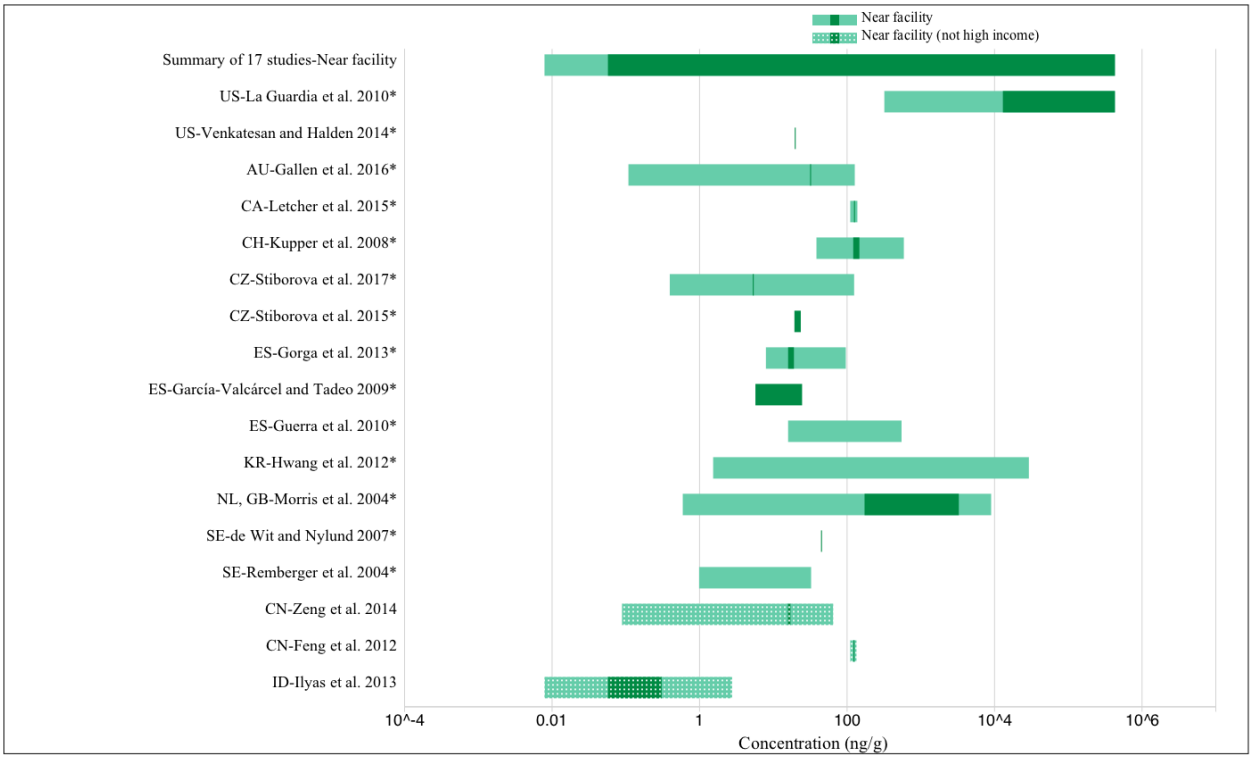


Figure 2-4. Concentration of HBCD (ng/g) in the Dry Fraction of Biosolids in Near Facility Locations from 2000 to 2016

* Study conducted in a country/countries classified as "High Income" by the World Bank

Table 2-3. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Biosolids

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
La Guardia et al. (2010)	US*	2002-2008	8	1.0	N/R	2.0	Medium
Venkatesan and Halden (2014)	US*	2001	1	1.0	0.39	2.1	Medium
Gallen et al. (2016)	AU*	2014	16	1.0	0.26	1.8	Medium
Letcher et al. (2015)	CA*	2004	2	1.0	0.2	1.7	Medium
Kupper et al. (2008)	CH*	2003-2005	16	1.0	6.4	1.8	Medium
Stiborova et al. (2017)	CZ*	2016	15	0.87	0.8	1.7	Medium
Stiborova et al. (2015)	CZ*	2007	6	1.0	1.2	2.1	Medium
Gorga et al. (2013)	ES*	2009	34	0.47	16.0	1.7	Medium

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
García-Valcárcel and Tadeo (2009)	ES*	2008	76	1.0	0.8	1.3	High
Guerra et al. (2010)	ES*	2008	7	0.29	16.0	1.6	High
Hwang et al. (2012)	KR*	2010	11	N/R	4.2	1.8	Medium
Morris et al. (2004)	NL, GB*	2002	19	N/R	1.2	2.3	Low
de Wit et al. (2007)	SE*	2000	50	1.0	N/R	2.3	Low
Remberger et al. (2004)	SE*	2000	6	1.0	1.0	1.8	Medium
Zeng et al. (2014a)	CN	2010-2013	62	1.0	N/R	1.3	High
Feng et al. (2012)	CN	2009-2010	2	1.0	0.061	1.8	Medium
Ilyas et al. (2013)	ID	2008	12	0.92	N/R	1.4	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

2.3. Consumer Products

2.3.1. Consumer Products (ng) – Bulk Fraction

Measured concentrations of HBCD in Consumer Product with unit of ng, extracted from 1 source, are summarized in Figure 2-5 and supplemental information is provided in Table 2-4. Overall, concentrations ranged from not-detected to 230 ng from over 137 samples collected during 2012 in 1 country, AU. Location types were categorized as General. Reported detection frequency was 0.13.

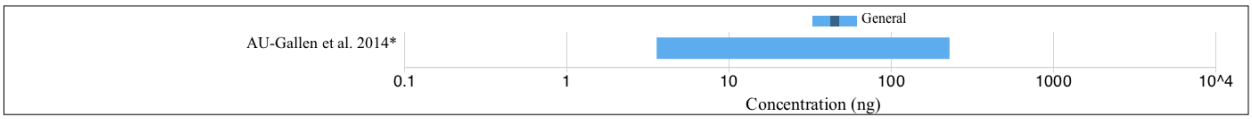


Figure 2-5. Concentration of HBCD (ng) in the Bulk Fraction of Consumer Products in General Locations in 2012

* Study conducted in a country/countries classified as “High Income” by the World Bank;

Table 2-4. Summary of Peer-Reviewed Literature that Measured HBCD (ng) Levels in the Bulk Fraction of Consumer Products

Citation	Country	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng)	Quality Score	Overall Quality Level
Gallen et al. (2014)	AU*	Electronics, plastics, components	2012	137	0.13	N/R	2.0	Low

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.3.2. Consumer Products (ng/g) – Bulk Fraction

Measured concentrations of HBCD in Consumer Product with unit of ng/g, extracted from 8 sources, are summarized in Figure 2-6 and supplemental information is provided in Table 2-4. Overall, concentrations ranged from not-detected to 51,000,000 ng/g from over 950 samples collected between 2013 and 2017 in 5 countries, CZ, CH, GB, KR, and CN. Location types were categorized as General. Reported detection frequencies ranged from 0.89 to 1.0.

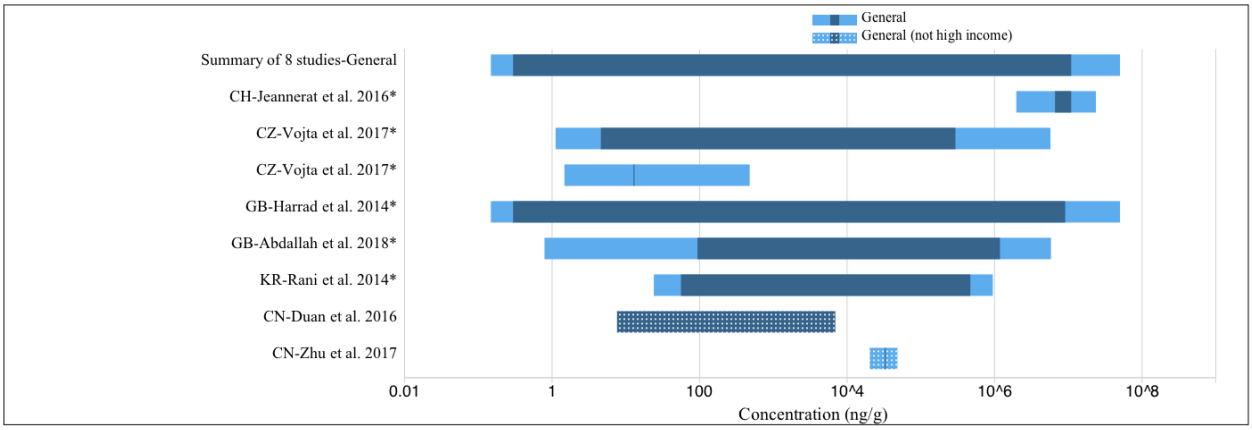


Figure 2-6. Concentration of HBCD (ng/g) in the Bulk Fraction of Consumer Products in General Locations from 2013 to 2017

* Study conducted in a country/countries classified as "High Income" by the World Bank

Table 2-5. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Bulk Fraction of Consumer Products

Citation	Country	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Jeannerat et al. (2016)	CH*	N/R	2013-2014	86	N/R	300000.0	2.2	Medium
Vojta et al. (2017)	CZ*	N/R	2017	130	0.89	2.3	1.5	High

Citation	Country	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Vojta et al. (2017)	CZ*	N/R	2017	8	1.0	2.3	1.5	High
Harrad et al. (2019)	GB*	Construction and demolition waste samples, waste electronic and electrical equipment (weee), automotive waste samples, soft furnishings waste samples	2015-2016	538	N/R	0.3	1.8	Medium
Abdallah et al. (2018)	GB*	Eps packaging, xps packaging, eps and xps packaging	2015-2016	140	N/R	0.8	1.2	High
Rani et al. (2014)	KR*	Expanded polystyrene , extruded polystyrene foam, extruded polystyrene	2014	34	1.0	N/R	1.5	High
Duan et al. (2016)	CN	Construction and demolition waste: furniture, construction and demolition waste: pur foam floor mat, construction and demolition waste: pur foam insulating layer, construction and demolition waste: pur foam and sponge, construction and demolition waste: all other organic c&d waste	2015	9	N/R	0.005	1.9	Medium
Zhu et al. (2017b)	CN	Eps (extended polystyrene foam) waste	2014	5	1.0	0.022	1.7	Medium

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

2.3.3. Consumer Products (ng/cm^2) – Dry Fraction

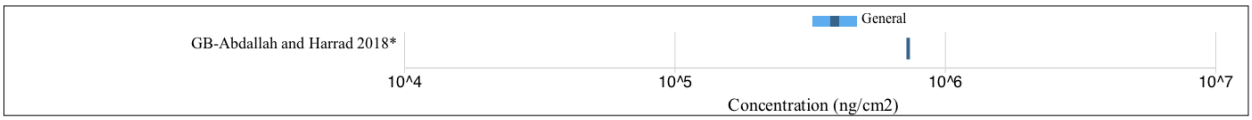


Figure 2-7. Concentration of HBCD (ng/cm2) in the Dry Fraction of Consumer Products in General Locations in 2008

* Study conducted in a country/countries classified as "High Income" by the World Bank

Table 2-6. Summary of Peer-Reviewed Literature that Measured HBCD (ng/cm2) Levels in the Dry Fraction of Consumer Products

Citation	Country	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/cm2)	Quality Score	Overall Quality Level
Abdallah and Harrad (2018)	GB*	Fabric	2008	1	1.0	N/R	1.7	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.4. Diet – Dairy

2.4.1. Dairy (ng/g) – Dry Fraction

Measured concentrations of HBCD in Dairy with unit of ng/g, extracted from 1 source, are summarized in Figure 2-8 and supplemental information is provided in Table 2-7. Overall, concentrations ranged from not-detected to 0.56 ng/g from 1 sample collected during 2004 in 1 country, GB. Location types were categorized as Background. Reported detection frequency was 0.00.

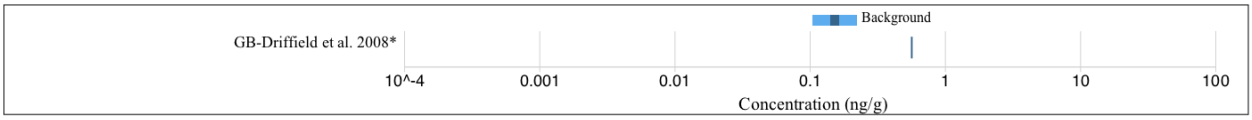


Figure 2-8. Concentration of HBCD (ng/g) in the Dry Fraction of Dairy in Background Locations in 2004

* Study conducted in a country/countries classified as "High Income" by the World Bank

Table 2-7. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Dairy

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Driffield et al. (2008)	GB*	Background	Milk	2004	1	0.0	N/R	1.4	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.4.2. Dairy (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Dairy with unit of ng/g, extracted from 6 sources, are summarized in Figure 2-9 and supplemental information is provided in Table 2-8. Overall, concentrations ranged from not-detected to 5.29 ng/g from over 174 samples collected between 1999 and 2015 in 5 countries, SE, ES, BE, GB, and CN. Location types were categorized as Background. Reported detection frequencies ranged from 0.25 to 1.0.

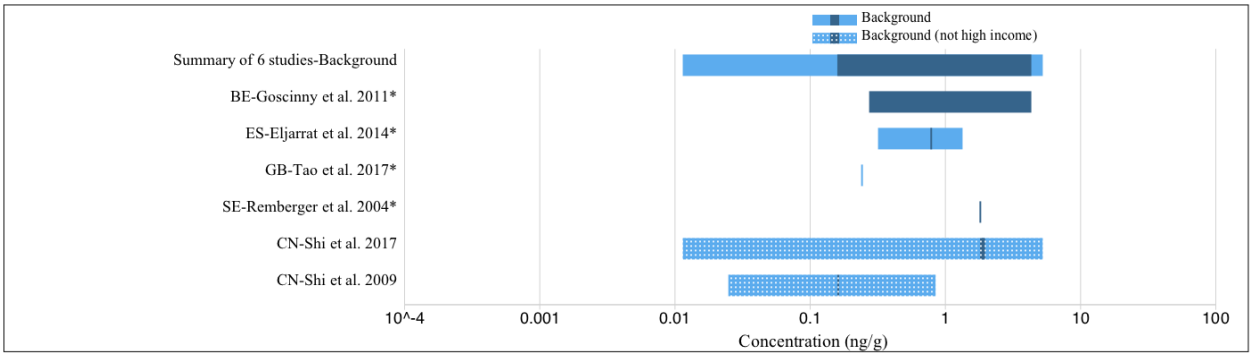


Figure 2-9. Concentration of HBCD (ng/g) in the Lipid Fraction of Dairy in Background Locations from 1999 to 2015

* Study conducted in a country/countries classified as "High Income" by the World Bank

Table 2-8. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Dairy

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Goscinny et al. (2011)	BE*	Background	Milk, cheese, butter, pizza	2008	132	N/R	0.55	1.6	High
Eljarrat et al. (2014)	ES*	Background	Dairy products	2009	7	1.0	0.14	1.8	Medium
Tao et al. (2017)	GB*	Background	Cheese	2015	2	N/R	0.24	1.1	High
Remberger et al. (2004)	SE*	Background	Milk	1999	1	N/R	1.0	1.8	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Shi et al. (2017a)	CN	Background	Milk	2011	20	0.95	0.023	2.0	Medium
Shi et al. (2009)	CN	Background	Milk	2007	12	0.25	0.05	1.6	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.4.3. Dairy (ng/g) – Wet Fraction

Measured concentrations of HBCD in Dairy with unit of ng/g, extracted from 8 sources, are summarized in Figure 2-10 and supplemental information is provided in Table 2-9. Overall, concentrations ranged from not-detected to 0.56 ng/g from over 404 samples collected between 2004 and 2014 in 6 countries, SE, US, FR, GB, KR, and RO. Location types were categorized as Background. Reported detection frequencies ranged from 0.00 to 0.89. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.16 and 0.24 ng/g for Background (n = 3 studies).

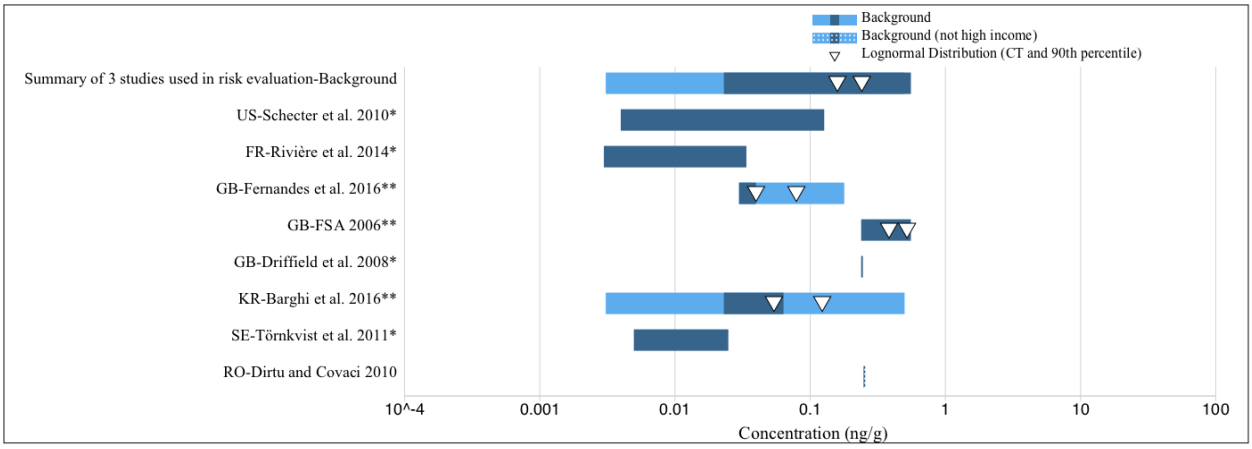


Figure 2-10. Concentration of HBCD (ng/g) in the Wet Fraction of Dairy in Background Locations from 2004 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-9. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Dairy

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Whole milk yogurt, cream cheese, frozen yogurt, ice cream, whole milk, other cheese, american cheese, butter	2009	N/R	N/R	0.13	2.0	Medium
Rivière et al. (2014)	FR*	Background	Milk, dairy products, cheese, butter, dairy-based desserts	2007-2009	170	N/R	N/R	1.7	Medium
Fernandes et al. (2016)	GB**	Background	Milk, dairy products	2013	16	N/R	0.03	1.3	High
Fsa (2006)	GB**	Background	Dairy products, milk	2004	2	0.0	0.56	2.0	Medium
Driffield et al. (2008)	GB*	Background	Dairy products	2004	1	0.0	N/R	1.4	High
Barghi et al. (2016)	KR**	Background	Dairy products	2012-2014	36	0.89	0.0062	1.3	High
Törnkvist et al. (2011)	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	0.05	1.8	Medium
Dirtu and Covaci (2010)	RO	Background	Dairy products (cheese, butter, milk, cream)	2007	37	0.0	N/R	2.6	Low

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.5. Diet – Fats

2.5.1. Fats (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Fats with unit of ng/g, extracted from 3 sources, are summarized in Figure 2-11 and supplemental information is provided in Table 2-10. Overall, concentrations ranged from 0.15 to 6.5 ng/g from over 49 samples collected between 1999 and 2009 in 3 countries, SE, BE, and ES. Location types were categorized as Background. Reported detection frequency was 1.0.

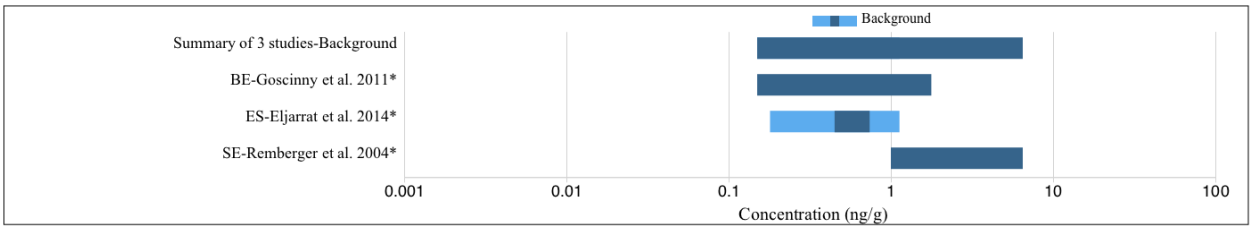


Figure 2-11. Concentration of HBCD (ng/g) in the Lipid Fraction of Fats in Background Locations from 1999 to 2009

* Study conducted in a country/countries classified as "High Income" by the World Bank

Table 2-10. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Fats

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Goscinny et al. (2011)	BE*	Background	Animal deep frying fat, vegetable oil, olive oil, arachide oil, sunflower oil, salad oil, choco spread	2008	38	N/R	0.55	1.6	High
Eljarrat et al. (2014)	ES*	Background	Animal fat, olive oil	2009	6	1.0	0.14	1.8	Medium
Remberger et al. (2004)	SE*	Background	Lamb fat, pork fat, beef fat, veal fat, chicken fat	1999	5	N/R	1.0	1.8	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.5.2. Fats (ng/g) – Wet Fraction

Measured concentrations of HBCD in Fats with unit of ng/g, extracted from 6 sources, are summarized in Figure 2-12 and supplemental information is provided in Table 2-11. Overall, concentrations ranged from not-detected to 0.39 ng/g from over 18 samples collected between 2004 and 2009 in 4 countries, RO, FR, US, and GB. Location types were categorized as Background. Reported detection frequencies ranged from 0.00 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.17 and 0.23 ng/g for Background (n = 2 studies).

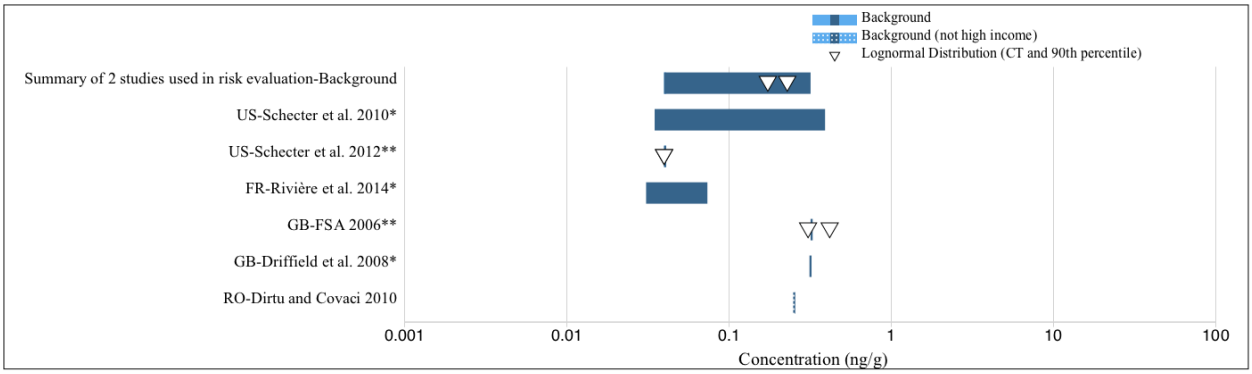


Figure 2-12. Concentration of HBCD (ng/g) in the Wet Fraction of Fats in Background Locations from 2004 to 2009

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-11. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Fats

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Peanut butter, margarine, canola oil, olive oil	2009	N/R	N/R	0.39	2.0	Medium
Schecter et al. (2012)	US**	Background	Peanut butter	2009	3	1.0	0.02	1.2	High
Rivière et al. (2014)	FR*	Background	Oils, margarine, pizzas, quiches, and savory pastries	2007-2009	11	N/R	N/R	1.7	Medium
Fsa (2006)	GB**	Background	Oils and fats	2004	1	0.0	0.32	2.0	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Driffield et al. (2008)	GB*	Background	Oils and fats	2004	1	0.0	N/R	1.4	High
Dirtu and Covaci (2010)	RO	Background	Vegetable oil	2007	2	0.0	N/R	2.6	Low

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.6. Diet – Fruit

2.6.1. Fruit (ng/g) – Dry Fraction

Measured concentrations of HBCD in Fruit with unit of ng/g, extracted from 1 source, are summarized in Figure 2-13 and supplemental information is provided in Table 2- 12. Overall, concentrations ranged from 0.27 to 0.75 ng/g from over 2 samples collected during 2004 in 1 country, GB. Location types were categorized as Background. Reported detection frequency was 1.0.

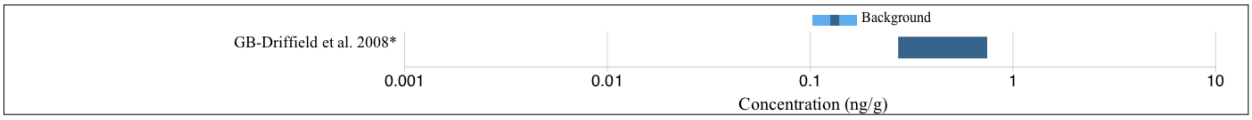


Figure 2-13. Concentration of HBCD (ng/g) in the Dry Fraction of Fruit in Background Locations in 2004

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 2-12. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Fruit

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Driffield et al. (2008)	GB*	Background	Fruit, fruit products	2004	2	1.0	N/R	1.4	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

2.6.2. Fruit (ng/g) – Wet Fraction

Measured concentrations of HBCD in Fruit with unit of ng/g, extracted from 4 sources, are summarized in Figure 2-14 and supplemental information is provided in Table 2-13. Overall, concentrations ranged from 0.01 to 0.75 ng/g from over 15 samples collected between 2004 and 2014 in 3 countries, GB, US, and KR. Location types were categorized as Background. Reported

detection frequency was 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.03 and 0.05 ng/g for Background (n = 1 study).

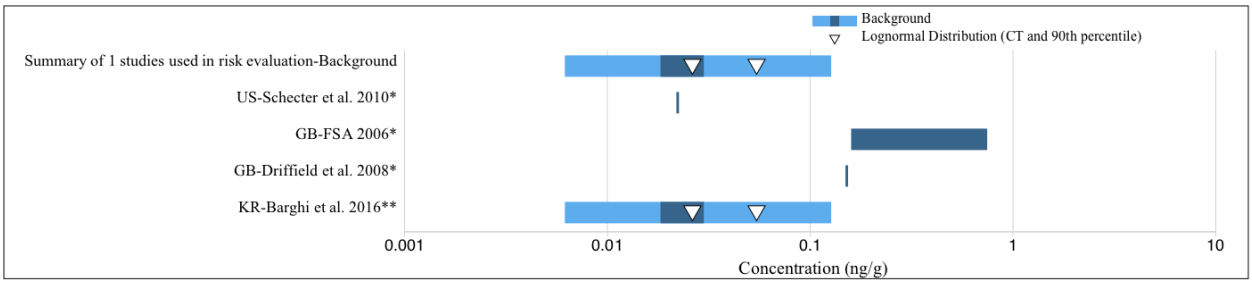


Figure 2-14. Concentration of HBCD (ng/g) in the Wet Fraction of Fruit in Background Locations from 2004 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-13. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Fruit

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Apples	2009	N/R	N/R	0.022	2.0	Medium
Fsa (2006)	GB*	Background	Fresh fruit, fruit products, sugars and preserves	2004	3	1.0	N/R	2.0	Medium
Driffield et al. (2008)	GB*	Background	Sugars and preserves	2004	1	1.0	N/R	1.4	High
Barghi et al. (2016)	KR**	Background	Fruit	2012-2014	11	N/R	0.0062	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
**Study conducted in a country/countries classified as "High Income" by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.7. Diet – Grain

2.7.1. Grain (ng/g) – Dry Fraction

Measured concentrations of HBCD in Grain with unit of ng/g, extracted from 1 source, are summarized in Figure 2-15 and supplemental information is provided in Table 2-14. Overall, concentrations were around 0.02 ng/g from over 3 samples collected between 2005 and 2008 in 1 country, CN. Location types were categorized as Background. Reported detection frequency was 1.0.

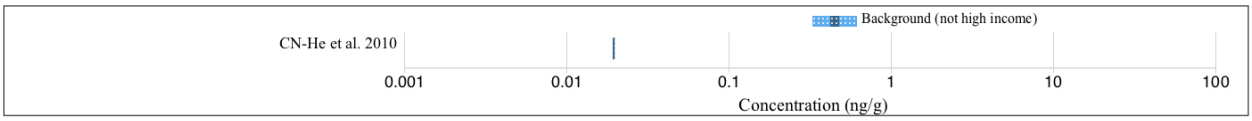


Figure 2-15. Concentration of HBCD (ng/g) in the Dry Fraction of Grain in Background Locations from 2005 to 2008

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 2-14. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Grain

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
He et al. (2010)	CN	Background	Grain/rice	2005-2008	3	1.0	3.0	1.2	High

2.7.2. Grain (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Grain with unit of ng/g, extracted from 1 source, are summarized in Figure 2-16 and supplemental information is provided in Table 2-15. Overall, concentrations ranged from 0.91 to 2.44 ng/g from over 80 samples collected during 2008 in 1 country, BE. Location types were categorized as Background. No detection frequencies were reported.

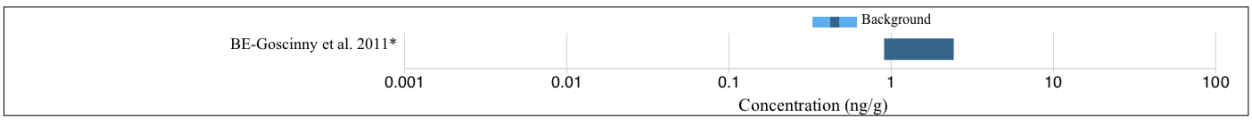


Figure 2-16. Concentration of HBCD (ng/g) in the Lipid Fraction of Grain in Background Locations in 2008

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 2-15. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Grain

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Goscinny et al. (2011)	BE*	Background	Croissant, cakes, pies, pastry, cookies/biscuits	2008	80	N/R	0.55	1.6	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.7.3. Grain (ng/g) – Wet Fraction

Measured concentrations of HBCD in Grain with unit of ng/g, extracted from 5 sources, are summarized in Figure 2-17 and supplemental information is provided in Table 2-16. Overall, concentrations ranged from not-detected to 0.18 ng/g from over 32 samples collected between 2004 and 2014 in 4 countries, FR, US, GB, and KR. Location types were categorized as Background. Reported detection frequency was 0.00. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.08 and 0.11 ng/g for Background (n = 2 studies).

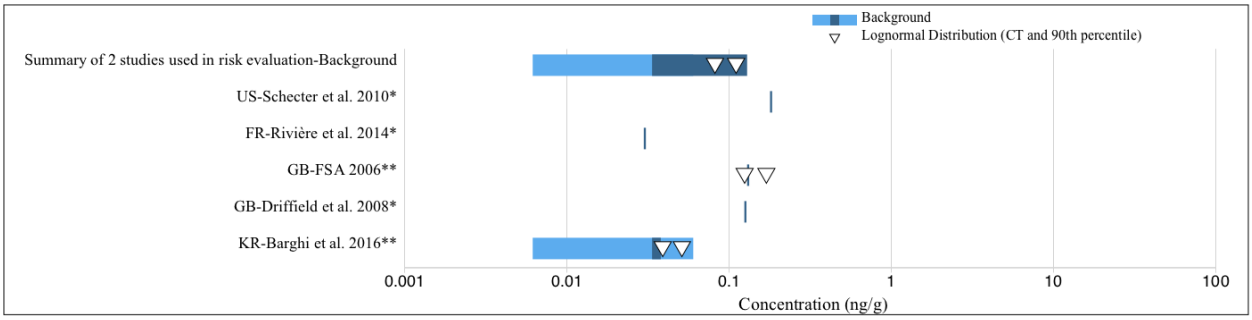


Figure 2-17. Concentration of HBCD (ng/g) in the Wet Fraction of Grain in Background Locations from 2004 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-16. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Grain

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Cereals	2009	N/R	N/R	0.18	2.0	Medium
Rivière et al. (2014)	FR*	Background	Sandwiches and snacks	2007-2009	18	N/R	N/R	1.7	Medium
Fsa (2006)	GB**	Background	Bread, cereal	2004	2	0.0	0.13	2.0	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Driffield et al. (2008)	GB*	Background	Bread, cereals	2004	2	0.0	N/R	1.4	High
Barghi et al. (2016)	KR**	Background	White rice	2012-2014	10	N/R	0.0062	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
**Study conducted in a country/countries classified as "High Income" by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.8. Diet – Meat

2.8.1. Meat (ng/g) – Dry Fraction

Measured concentrations of HBCD in Meat with unit of ng/g, extracted from 1 source, are summarized in Figure 2-18 and supplemental information is provided in Table 2-17. Overall, concentrations were around 0.31 ng/g from over 5 samples collected during 2014 in 1 country, VN. Location types were categorized as Background. Reported detection frequency was 1.0.

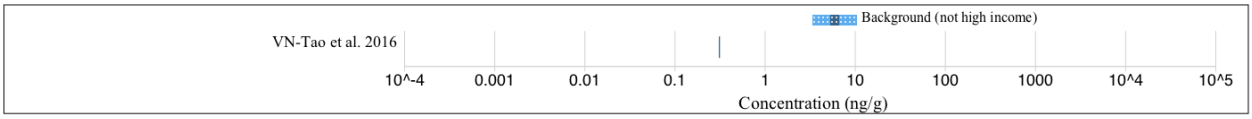


Figure 2-18. Concentration of HBCD (ng/g) in the Dry Fraction of Meat in Background Locations in 2014

Table 2-17. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Meat

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Tao et al. (2016)	VN	Background	Pork	2014	5	1.0	0.05	2.0	Medium

2.8.2. Meat (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Meat with unit of ng/g, extracted from 10 sources, are summarized in Figure 2-19 and supplemental information is provided in Table 2-18. Overall, concentrations ranged from not-detected to 2000.0 ng/g from over 477 samples collected between 1999 and 2022 in at least 8 countries, including SE, CA, ES, TZ, BE, GB, CN, and DE. Location types were categorized as Background. Reported detection frequencies ranged from 0.54 to 1.0.

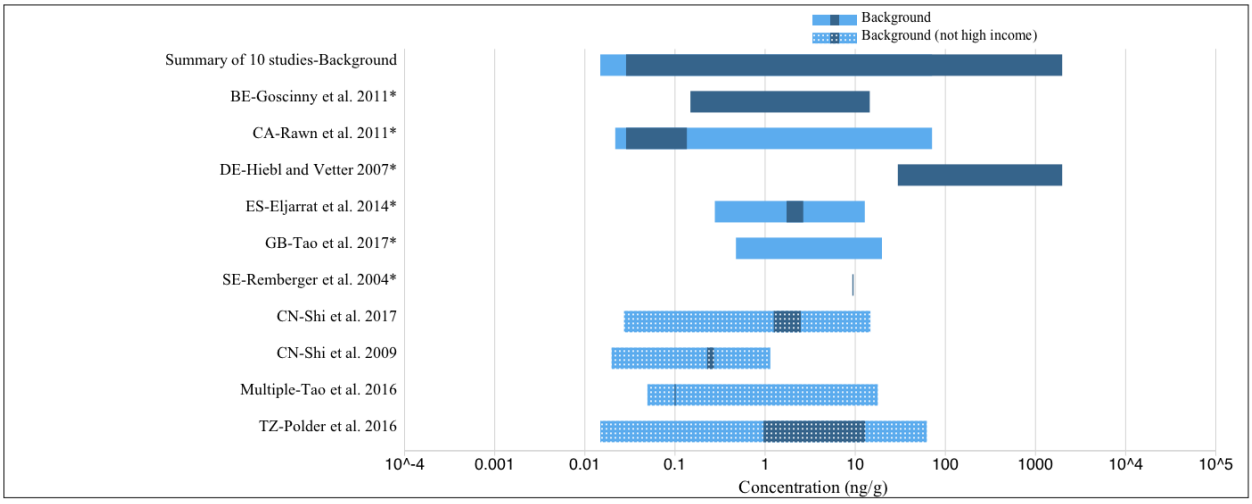


Figure 2-19. Concentration of HBCD (ng/g) in the Lipid Fraction of Meat in Background Locations from 1999 to 2015

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-18. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Meat

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Goscinny et al. (2011)	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	0.55	1.6	High
Rawn et al. (2011)	CA*	Background	Egg yolks	2005-2006	162	1.0	0.022	2.0	Medium
Hiebl and Vetter (2007)	DE*	Background	Eggs	2007	3	N/R	20.0	2.1	Medium
Eljarrat et al. (2014)	ES*	Background	Meat, eggs	2009	12	1.0	0.14	1.8	Medium
Tao et al. (2017)	GB*	Background	Meat, egg	2015	19	N/R	0.48	1.1	High
Remberger et al. (2004)	SE*	Background	Egg yolk	1999	1	N/R	1.0	1.8	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Shi et al. (2017a)	CN	Background	Eggs, meat	2011	40	0.95	0.055	2.0	Medium
Shi et al. (2009)	CN	Background	Meat, eggs	2007	24	0.54	0.04	1.6	High
Tao et al. (2016)	Multiple	Background	Chicken (eggs), chicken (muscle, liver, and skin)	2014	8	N/R	0.05	2.0	Medium
Polder et al. (2016)	TZ	Background	Eggs	2012	27	0.63	0.03	1.9	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.8.3. Meat (ng/g) – Wet Fraction

Measured concentrations of HBCD in Meat with unit of ng/g, extracted from 10 sources, are summarized in Figure 2-20 and supplemental information is provided in Table 2-19. Overall, concentrations ranged from not-detected to 0.74 ng/g from over 649 samples collected between 2004 and 2014 in 7 countries, SE, US, FR, GB, KR, CN, and RO. Location types were categorized as Background. Reported detection frequencies ranged from 0.00 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.11 and 0.18 ng/g for Background (n = 3 studies).

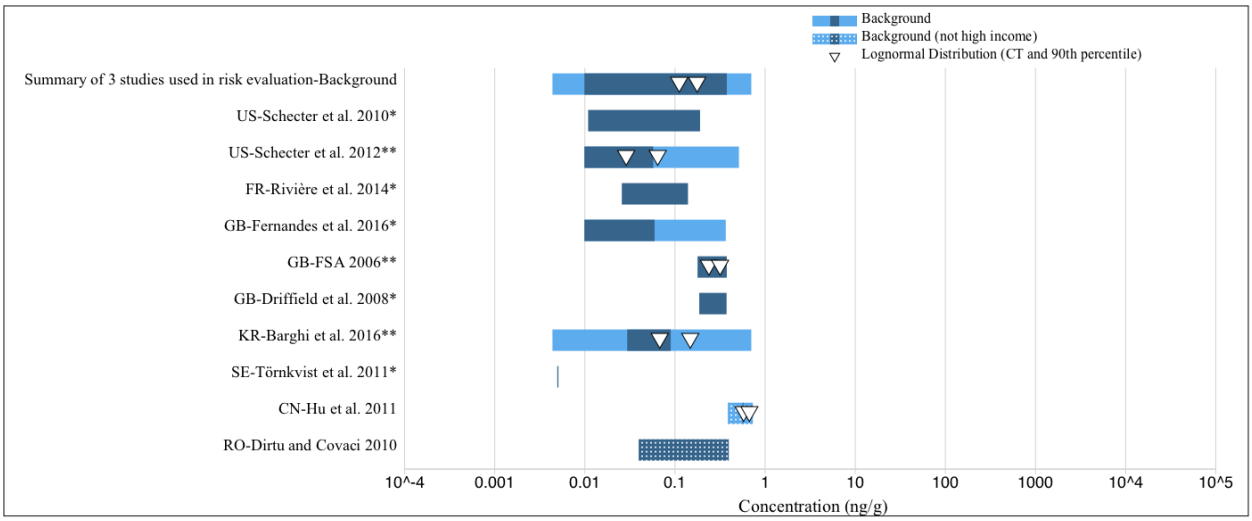


Figure 2-20. Concentration of HBCD (ng/g) in the Wet Fraction of Meat in Background Locations from 2004 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-19. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Meat

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Canned chili, roast beef, sliced chicken breast, ham, sausages, sliced turkey, bacon, hamburger, eggs	2009	N/R	N/R	0.06	2.0	Medium
Schecter et al. (2012)	US**	Background	Chili with beans, meat	2009	18	0.28	0.02	1.2	High
Rivière et al. (2014)	FR*	Background	Eggs, meats, poultry and game, offal	2007-2009	228	N/R	N/R	1.7	Medium
Fernandes et al. (2016)	GB*	Background	Offal, meat, processed meat, eggs	2013	72	N/R	0.03	1.3	High
Fsa (2006)	GB**	Background	Meat, eggs, meat products, offal, poultry	2004	5	0.4	0.38	2.0	Medium
Driffield et al. (2008)	GB*	Background	Meat, offal, poultry, eggs	2004	5	0.4	N/R	1.4	High
Barghi et al. (2016)	KR**	Background	Meat, eggs	2012-2014	142	N/R	0.0062	1.3	High
Törnkvist et al. (2011)	SE*	Background	Beef (24%), pork (23%), lamb (1%), chicken (12%), game (2%), processed meats except pizza (38%), eggs	2005	136	N/R	0.01	1.8	Medium
Hu et al. (2011b)	CN	Background	Eggs	2011	3	1.0	0.2	2.3	Low
Dirtu and Covaci (2010)	RO	Background	Meat (pork, beef, and chicken steak, salami and pork sausages), eggs	2007	40	0.0	N/R	2.6	Low

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.9. Diet – Other Food

2.9.1. Other Food (ng/g) – Dry Fraction

Measured concentrations of HBCD in Other Food with unit of ng/g, extracted from 2 sources, are summarized in Figure 2-21 and supplemental information is provided in Table 2-20. Overall, concentrations ranged from not-detected to 0.29 ng/g from over 8 samples collected between 2005 and 2008 in 2 countries, BE and CN. Location types were categorized as Background. Reported detection frequencies ranged from 0.2 to 1.0.

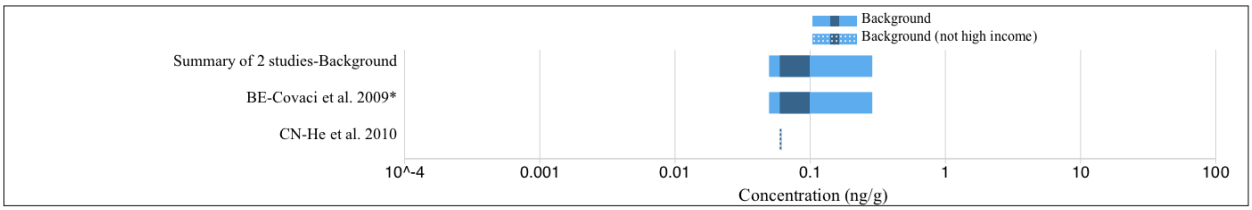


Figure 2-21. Concentration of HBCD (ng/g) in the Dry Fraction of Other Food in Background Locations from 2005 to 2008

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-20. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Other Food

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Covaci et al. (2009)	BE*	Background	Other - kitchen waste	2007	5	0.2	0.1	1.8	Medium
He et al. (2010)	CN	Background	Eucalyptus plant	2005-2008	3	1.0	3.0	1.2	High

*Study conducted in a country/countries classified as "High Income" by the World Bank

2.9.2. Other Food (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Other Food with unit of ng/g, extracted from 1 source, are summarized in Figure 2-22 and supplemental information is provided in Table 2-21. Overall, concentrations ranged from not-detected to 2.22 ng/g from over 12 samples collected during 2007 in 1 country, CN. Location types were categorized as Background. Reported detection frequency was 0.92.

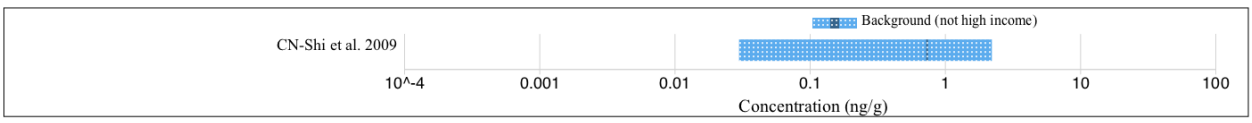


Figure 2-22. Concentration of HBCD (ng/g) in the Lipid Fraction of Other Food in Background Locations in 2007

Table 2-21. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Other Food

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Shi et al. (2009)	CN	Background	Various	2007	12	0.92	0.06	1.6	High

2.9.3. Other Food (ng/g) – Wet Fraction

Measured concentrations of HBCD in Other Food with unit of ng/g, extracted from 6 sources, are summarized in Figure 2-23 and supplemental information is provided in Table 2-21. Overall, concentrations ranged from not-detected to 6.62 ng/g from over 231 samples collected between 2002 and 2016 in 6 countries, PT, US, FR, BE, NO, and GB. Location types were categorized as Background. Reported detection frequencies ranged from 0.08 to 1.0.

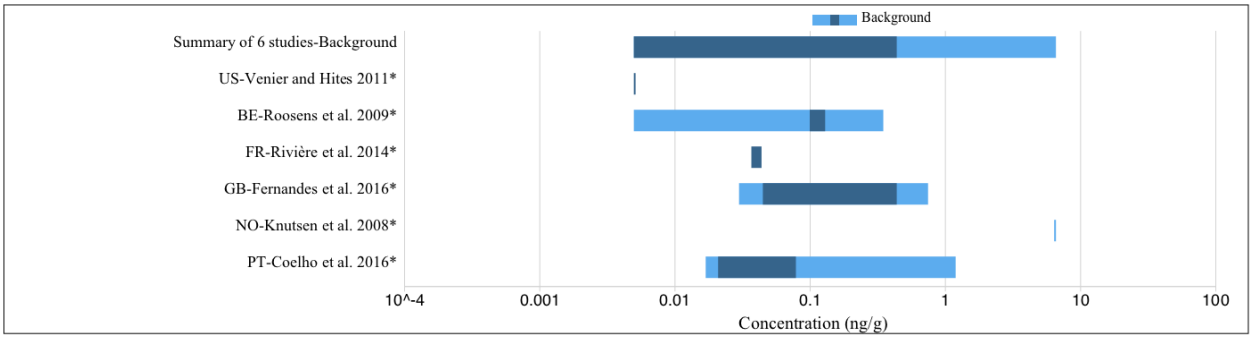


Figure 2-23. Concentration of HBCD (ng/g) in the Wet Fraction of Other Food in Background Locations from 2002 to 2016

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 2-22. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Other Food

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Venier and Hites (2011)	US*	Background	Dog food	2010	16	1.0	N/R	1.9	Medium
Roosens et al. (2009)	BE*	Background	Duplicate diet for each participant on each day	2007	13	0.077	0.01	1.4	High

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Rivière et al. (2014)	FR*	Background	Mixed dishes, seasonings and sauces	2007-2009	64	N/R	N/R	1.7	Medium
Fernandes et al. (2016)	GB*	Background	Other foods, processed foods, animal feed: composite feeds, animal feed: fish feeds, animal feed: oilseeds and cereals, animal feed: grasses	2013	63	N/R	0.13	1.3	High
Knutsen et al. (2008)	NO*	Background	Meat, dairy products, eggs, various foods (including vegetable oil, ice cream, biscuit, and banana).	2002-2006	54	N/R	N/R	1.8	Medium
Coelho et al. (2016b)	PT*	Background	Multiple food types	2016	21	N/R	N/R	1.4	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

2.10. Diet – Seafood

2.10.1. Seafood (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Seafood with unit of ng/g, extracted from 7 sources, are summarized in Figure 2-24 and supplemental information is provided in Table 2-22. Overall, concentrations ranged from not-detected to 70 ng/g from over 72 samples collected between 1996 and 2015 in at least 5 countries, including SE, ES, GB, CN, and DE. Location types were categorized as Background. Reported detection frequencies ranged from 0.95 to 1.0.

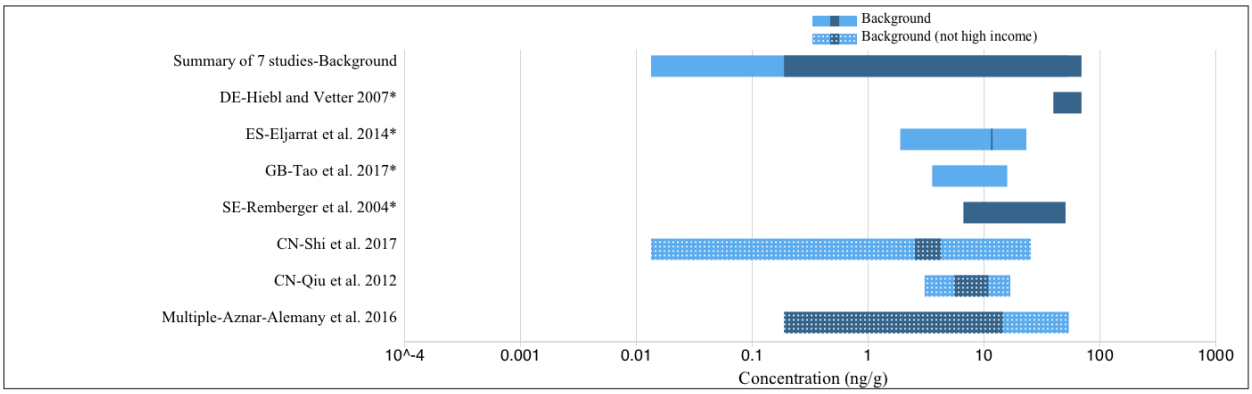


Figure 2-24. Concentration of HBCD (ng/g) in the Lipid Fraction of Seafood in Background Locations from 1996 to 2015

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-23. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Seafood

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Hiebl and Vetter (2007)	DE*	Background	Whole, fillets, fillet	2007	3	N/R	20.0	2.1	Medium
Eljarrat et al. (2014)	ES*	Background	Seafood	2009	22	1.0	0.14	1.8	Medium
Tao et al. (2017)	GB*	Background	Salmon, mackerel, tuna, trout	2015	9	N/R	N/R	1.1	High
Remberger et al. (2004)	SE*	Background	Seafood, salmon	1996-1999	3	N/R	1.0	1.8	Medium
Shi et al. (2017a)	CN	Background	Fish	2011	20	0.95	0.027	2.0	Medium
Qiu et al. (2012)	CN	Background	Fish - mandarin fish (muscle)	2007-2008	15	1.0	N/R	2.0	Medium
Aznar-Alemany et al. (2016)	Multiple	Background	Seafood	2014-2015	N/R	N/R	2.0	1.7	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.10.2. Seafood (ng/g) – Wet Fraction

Measured concentrations of HBCD in Seafood with unit of ng/g, extracted from 15 sources, are summarized in Figure 2-25 and supplemental information is provided in Table 2-24. Overall, concentrations ranged from not-detected to 77.3 ng/g from over 898 samples collected between 2002 and 2014 in 10 countries, SE, ES, US, FR, BE, GB, KR, NO, CN, and JP. Location types were categorized as Background. Reported detection frequencies ranged from 0.67 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 2.0 and 4.1 ng/g for Background (n = 8 studies).

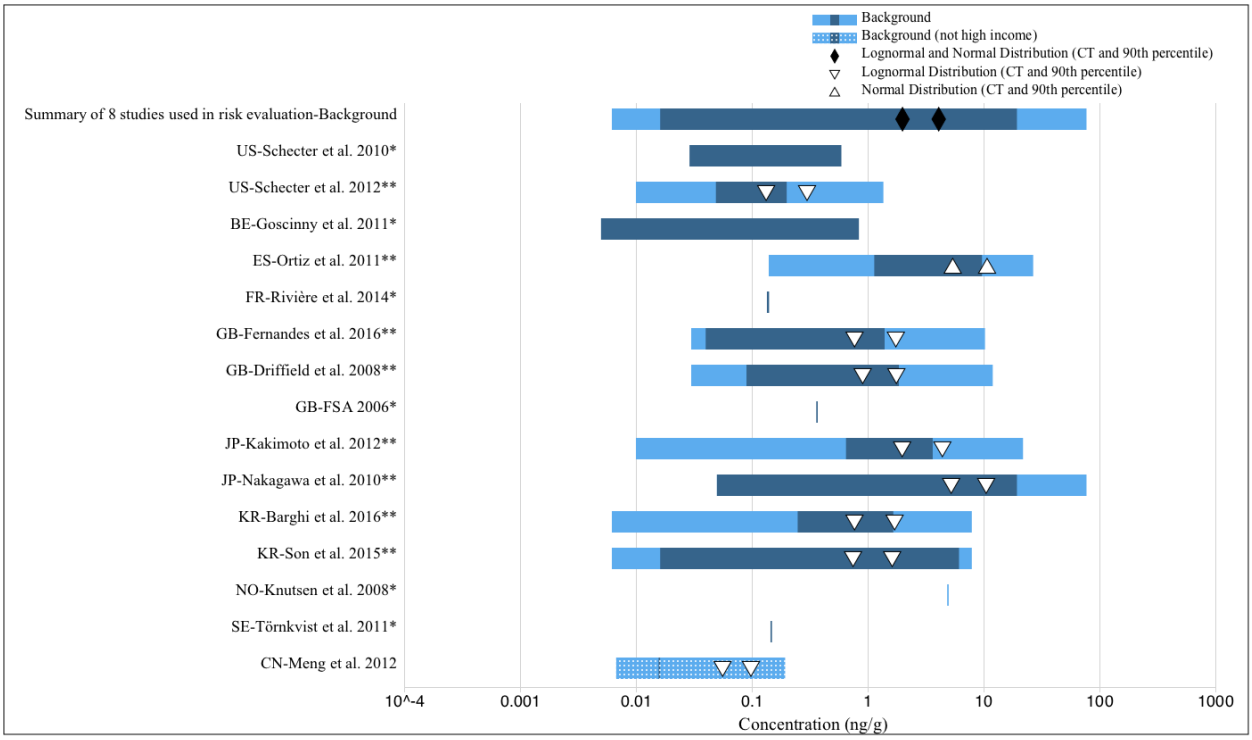


Figure 2-25. Concentration of HBCD (ng/g) in the Wet Fraction of Seafood in Background Locations from 2002 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-24. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Seafood

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Frozen fish sticks, canned sardines, cod, tilapia, catfish fillet, canned tuna, salmon	2009	N/R	N/R	0.059	2.0	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2012)	US**	Background	Seafood	2009	15	0.67	0.02	1.2	High
Goscinny et al. (2011)	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	0.55	1.6	High
Ortiz et al. (2011)	ES**	Background	Fish oil	2011	22	1.0	0.14	1.4	High
Rivière et al. (2014)	FR*	Background	Fish, crustaceans and mollusks	2007-2009	82	N/R	N/R	1.7	Medium
Fernandes et al. (2016)	GB**	Background	Fish, shellfish	2013	56	N/R	0.03	1.3	High
Driffield et al. (2008)	GB**	Background	Fish, oysters, mussels, scallops	2004-2006	36	0.83	N/R	1.4	High
Fsa (2006)	GB*	Background	Fish	2004	1	1.0	N/R	2.0	Medium
Kakimoto et al. (2012)	JP**	Background	Fish	2011	18	0.89	0.02	1.6	High
Nakagawa et al. (2010)	JP**	Background	Seafood: marine fish and invertebrates	2004-2008	64	N/R	0.05	1.4	High
Barghi et al. (2016)	KR**	Background	Fish	2012-2014	40	N/R	0.0062	1.3	High

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Son et al. (2015)	KR**	Background	Fish - mackerel, cod, halibut, pacific saury, herring, anchovy, gray mullet (whole organism, entrails removed), fish - catfish (whole organism, entrails removed), marine invertebrates - snow crab, blue crab, king prawn, lobster, tiger prawn, sea urchin, jellyfish, sea cucumber, spoon worm, sea squirt, warty sea squirt, whelk, conch, pen shell, abalone, river snail, east asian white clam, cockle, white clam, scallop, mussel, oyster, octopus, mitra squid, squid, cuttlefish, beka squid, webfoot octopus, and long-legged octopus (whole organisms (some with entrails included))	2012-2013	227	N/R	0.0062	1.6	High
Knutsen et al. (2008)	NO*	Background	Seafood	2002-2006	55	N/R	N/R	1.8	Medium
Törnkvist et al. (2011)	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
Meng et al. (2012)	CN	Background	Tilapia, bighead carp, bluntsnout 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	0.013	1.3	High

*Study conducted in a country/countries classified as “High Income” by the World Bank

**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation

Abbreviations: N/R, Not reported

2.11. Diet – Vegetable

2.11.1. Vegetable (ng/g) – Dry Fraction

Measured concentrations of HBCD in Vegetable with unit of ng/g, extracted from 1 source, are summarized in Figure 2-26 and supplemental information is provided in Table 2-25. Overall, concentrations ranged from not-detected to 0.51 ng/g from over 4 samples collected during 2004 in 1 country, GB. Location types were categorized as Background. Reported detection frequency was 0.75.

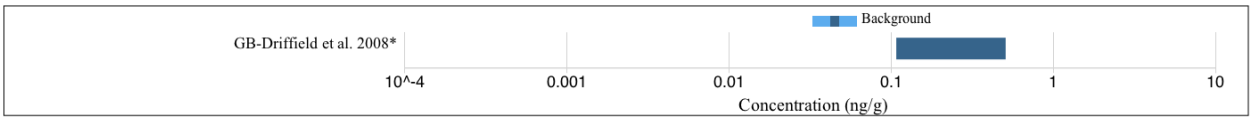


Figure 2-26. Concentration of HBCD (ng/g) in the Dry Fraction of Vegetable in Background Locations in 2004

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-25. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Vegetable

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Driffield et al. (2008)	GB*	Background	Green vegetables, potatoes, other vegetables, canned vegetables	2004	4	0.75	N/R	1.4	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.11.2. Vegetable (ng/g) – Wet Fraction

Measured concentrations of HBCD in Vegetable with unit of ng/g, extracted from 5 sources, are summarized in Figure 2-27 and supplemental information is provided in Table 2-26. Overall, concentrations ranged from not-detected to 0.51 ng/g from over 34 samples collected between 2004 and 2014 in 4 countries, FR, US, GB, and KR. Location types were categorized as Background. Reported detection frequencies ranged from 0.8 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.16 and 0.19 ng/g for Background (n = 2 studies).

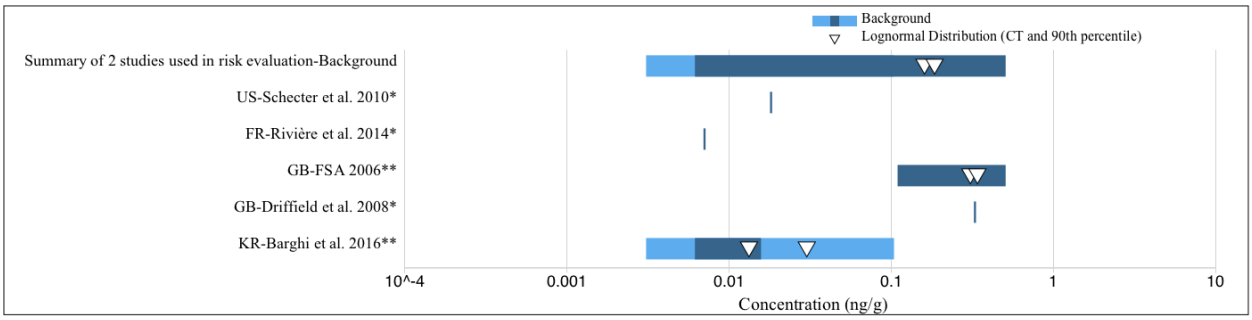


Figure 2-27. Concentration of HBCD (ng/g) in the Wet Fraction of Vegetable in Background Locations from 2004 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-26. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Vegetable

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schecter et al. (2010)	US*	Background	Potatoes	2009	N/R	N/R	0.018	2.0	Medium
Rivière et al. (2014)	FR*	Background	Vegetables	2007-2009	3	N/R	N/R	1.7	Medium
Fsa (2006)	GB**	Background	Canned vegetables, green vegetables, nuts, other vegetables, potatoes	2004	5	0.8	0.51	2.0	Medium
Driffield et al. (2008)	GB*	Background	Nuts	2004	1	1.0	N/R	1.4	High
Barghi et al. (2016)	KR**	Background	Vegetables	2012-2014	25	0.88	0.0062	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
**Study conducted in a country/countries classified as "High Income" by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.12. Indoor Air

2.12.1. Indoor Air (ng/m^3)

Measured concentrations of HBCD in Indoor Air with unit of ng/m3, extracted from 16 sources with particulate and/or gas fractions are summarized in Figure 2-28 and supplemental

information is provided in Table 2-27. Overall, concentrations ranged from not-detected to 29.5 ng/m3 between 2001 and 2012 in 5 countries, SE, VN, GB, CN, and JP. Location types were categorized as Residential, Mixed Use, Commercial, and Vehicle. Reported detection frequencies ranged from 0.15 to 1.0. Following the statistical procedures described above to obtain a final data set, central tendency and high-end estimates, respectively, were 1.0 and 2.3 ng/m^3 for Residential (n = 3 studies), 0.91 and 1.9 ng/m^3 for Commercial/Mixed Use/Schools (n = 4 studies), 0.24 and 0.33 ng/m^3 Vehicle (n = 2 studies).

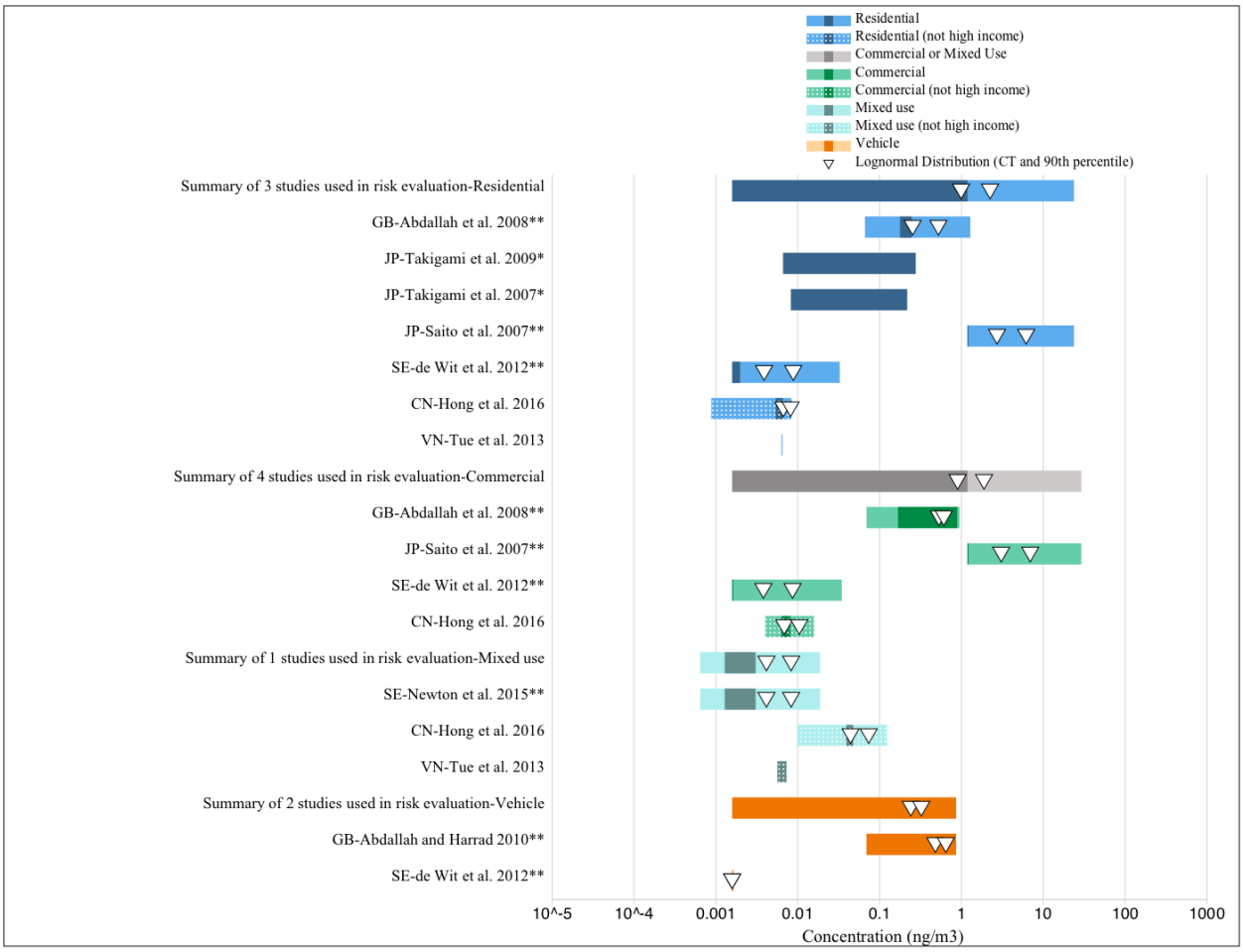


Figure 2-28. Concentration of HBCD (ng/m3) in Indoor Air in Residential, Commercial, and Mixed Use Locations from 2001 to 2012

* Study conducted in a country/countries classified as “High Income” by the World Bank;
** Study conducted in a country/countries classified as “High Income” by the World Bank and used in risk evaluation final dataset

Table 2-27. Summary of Peer-Reviewed Literature that Measured HBCD (ng/m3) Levels in Indoor Air

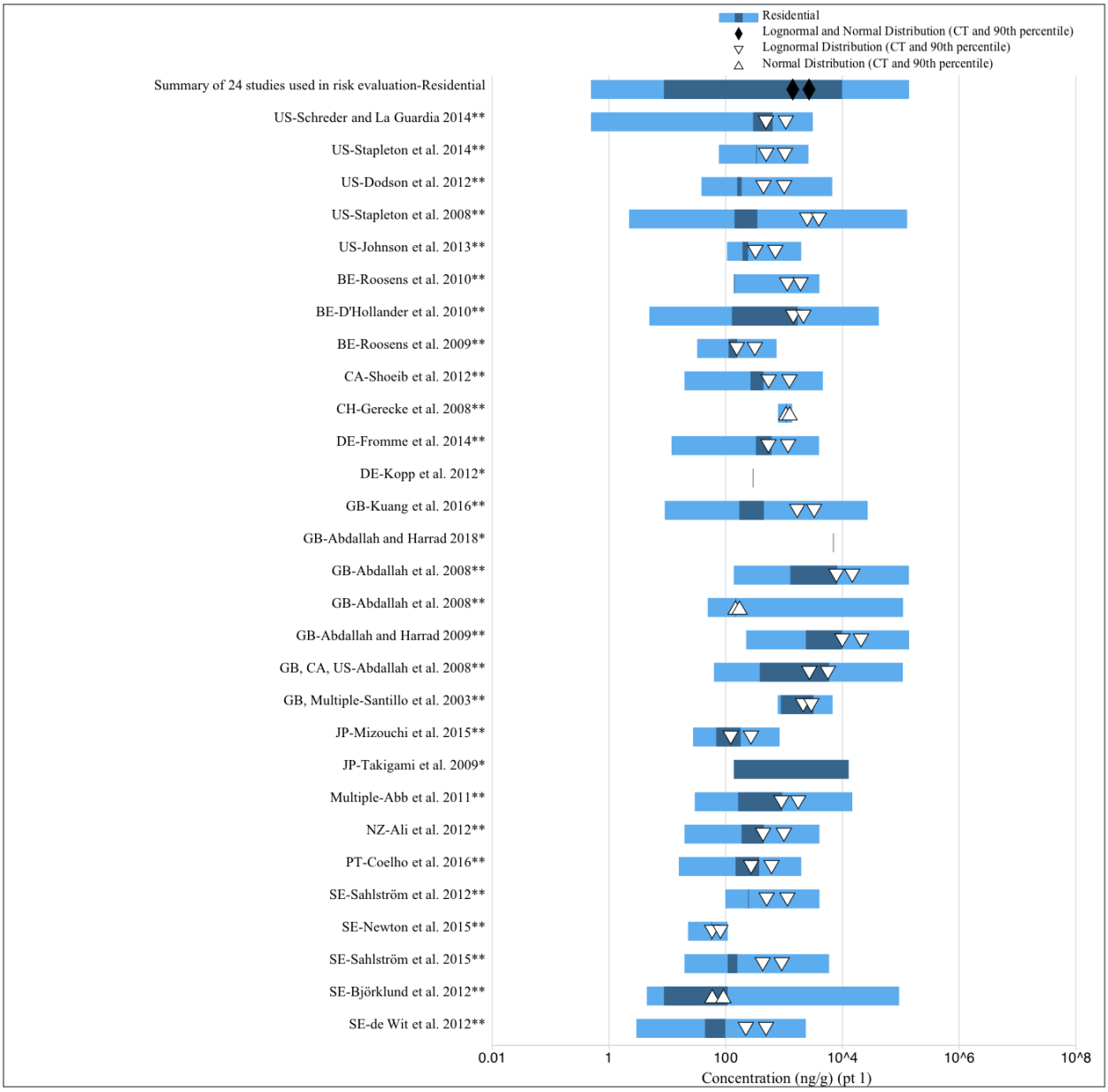
Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/m3)	Quality Score	Overall Quality Level
Particulate Fraction								
Abdallah et al. (2008a)	GB**	Residential	2007	33	1.0	0.0033	1.3	High
Takigami et al. (2009b)	JP*	Residential	2006	4	N/R	N/R	1.9	Medium
Takigami et al. (2007)	JP*	Residential	2006	4	1.0	N/R	2.2	Medium
Saito et al. (2007)	JP**	Residential	2001	18	N/R	1.2	1.9	Medium
Hong et al. (2016)	CN	Residential	2004-2005	12	N/R	N/R	1.6	High
Tue et al. (2013)	VN	Residential	2008	N/R	N/R	N/R	1.9	Medium
Abdallah et al. (2008a)	GB**	Commercial	2007	29	1.0	0.0033	1.3	High
Saito et al. (2007)	JP**	Commercial	2001	14	N/R	1.2	1.9	Medium
Hong et al. (2016)	CN	Commercial	2004-2005	5	N/R	N/R	1.6	High
Newton et al. (2015)	SE**	Mixed use	2012	13	0.15	0.0013	2.0	Medium
Hong et al. (2016)	CN	Mixed use	2004-2005	10	N/R	N/R	1.6	High
Tue et al. (2013)	VN	Mixed use	2008	N/R	N/R	N/R	1.9	Medium
Gas and Particulate Fraction								
de Wit et al. (2012)	SE**	Residential	2006	54	N/R	0.0016	1.1	High
de Wit et al. (2012)	SE**	Commercial	2006	20	N/R	0.0016	1.1	High
Abdallah and Harrad (2010)	GB**	Vehicle	2008-2009	39	1.0	N/R	1.4	High
de Wit et al. (2012)	SE**	Vehicle	2006	24	N/R	0.0016	1.1	High

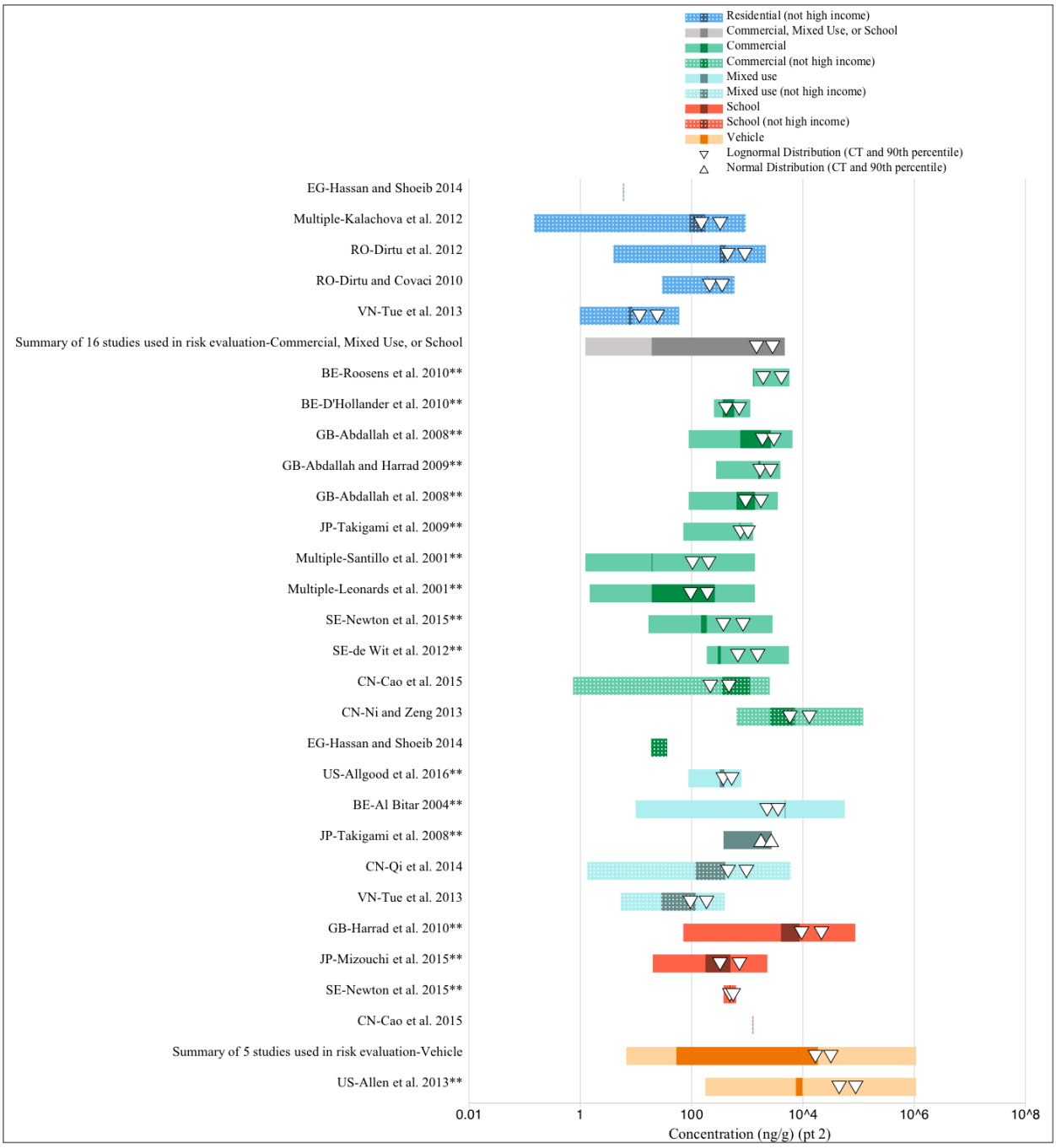
*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.13. Indoor Dust

2.13.1. Indoor Dust (ng/g) – Dry Fraction

Measured concentrations of HBCD in Indoor Dust with unit of ng/g, extracted from 63 sources, are summarized in Figure 2-29 and supplemental information is provided in Table 2-28. Overall, concentrations ranged from not-detected to 1100000.0 ng/g from over 1711 samples collected between 2000 and 2015 in at least 14 countries, including SE, CA, PT, NZ, RO, US, CH, EG, BE, GB, VN, CN, JP, and DE. Location types were categorized as Vehicle, School, Residential, Industrial, Commercial, and Mixed Use. Reported detection frequencies ranged from 0.2 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 1431.95 and 2721.92 ng/g for Residential (n = 26 studies), 900.97 and 1627.54 ng/g for Commercial (n = 10 studies), 1492.96 and 2303.79 ng/g for Mixed Use (n = 3 studies), 3479.34 and 7718.1 ng/g for School (n = 3 studies), and 17014.78 and 32326.8 ng/g for Vehicle (n = 5 studies).


Residential
Lognormal and Normal Distribution (CT and 90th percentile)
Lognormal Distribution (CT and 90th percentile)
Normal Distribution (CT and 90th percentile)
Summary of 24 studies used in risk evaluation-Residential
US-Schreder and La Guardia 2014**
US-Stapleton et al. 2014**
US-Dodson et al. 2012**
US-Stapleton et al. 2008**
US-Johnson et al. 2013**
BE-Roosens et al. 2010**
BE-D'Hollander et al. 2010**
BE-Roosens et al. 2009**
CA-Shoeib et al. 2012**
CH-Gerecke et al. 2008**
DE-Fromme et al. 2014**
DE-Kopp et al. 2012*
GB-Kuang et al. 2016**
GB-Abdallah and Harrad 2018*
GB-Abdallah et al. 2008**
GB-Abdallah et al. 2008**
GB-Abdallah and Harrad 2009**
GB, CA, US-Abdallah et al. 2008**
GB, Multiple-Santillo et al. 2003**
JP-Mizouchi et al. 2015**
JP-Takigami et al. 2009*
Multiple-Abb et al. 2011**
NZ-Ali et al. 2012**
PT-Coelho et al. 2016**
SE-Sahlström et al. 2012**
SE-Newton et al. 2015**
SE-Sahlström et al. 2015**
SE-Björklund et al. 2012**
SE-de Wit et al. 2012**
0.01
1
100
10^4
10^6
10^8
Concentration (ng/g) (pt 1)


Residential (not high income)
Commercial, Mixed Use, or School
Commercial
Commercial (not high income)
Mixed use
Mixed use (not high income)
School
School (not high income)
Vehicle
Lognormal Distribution (CT and 90th percentile)
Normal Distribution (CT and 90th percentile)
EG-Hassan and Shoeib 2014
Multiple-Kalachova et al. 2012
RO-Dirtu et al. 2012
RO-Dirtu and Covaci 2010
VN-Tue et al. 2013
Summary of 16 studies used in risk evaluation-Commercial, Mixed Use, or School
BE-Roosens et al. 2010**
BE-D'Hollander et al. 2010**
GB-Abdallah et al. 2008**
GB-Abdallah and Harrad 2009**
GB-Abdallah et al. 2008**
JP-Takigami et al. 2009**
Multiple-Santillo et al. 2001**
Multiple-Leonards et al. 2001**
SE-Newton et al. 2015**
SE-de Wit et al. 2012**
CN-Cao et al. 2015
CN-Ni and Zeng 2013
EG-Hassan and Shoeib 2014
US-Allgood et al. 2016**
BE-Al Bitar 2004**
JP-Takigami et al. 2008**
CN-Qi et al. 2014
VN-Tue et al. 2013
GB-Harrad et al. 2010**
JP-Mizouchi et al. 2015**
SE-Newton et al. 2015**
CN-Cao et al. 2015
Summary of 5 studies used in risk evaluation-Vehicle
US-Allen et al. 2013**
0.01
1
100
10^4
10^6
10^8
Concentration (ng/g) (pt 2)

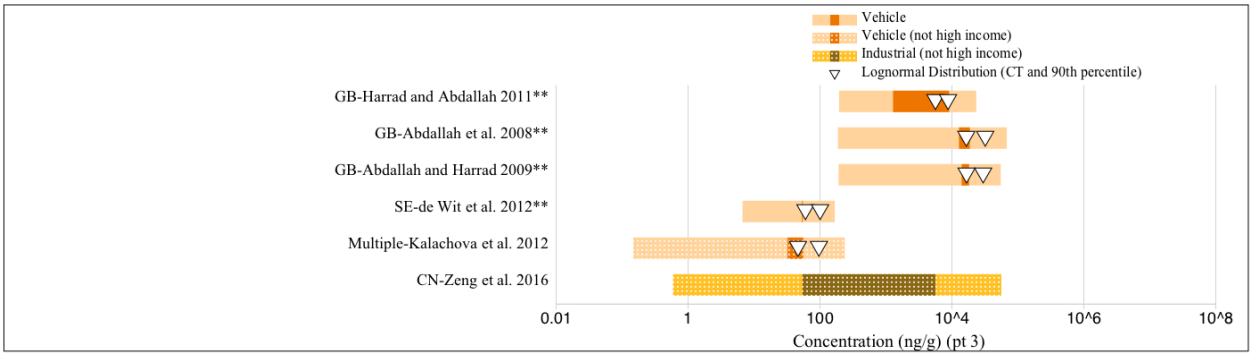

Vehicle
Vehicle (not high income)
Industrial (not high income)
Lognormal Distribution (CT and 90th percentile)
GB-Harrad and Abdallah 2011**
GB-Abdallah et al. 2008**
GB-Abdallah and Harrad 2009**
SE-de Wit et al. 2012**
Multiple-Kalachova et al. 2012
CN-Zeng et al. 2016
0.01
1
100
10^4
10^6
10^8
Concentration (ng/g) (pt 3)

Figure 2-29. Concentration of HBCD (ng/g) in the Dry Fraction of Indoor Dust in Residential, Commercial, Mixed Use, School, Vehicle, and Industrial Locations from 2000 to 2015

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-28. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Indoor Dust

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Schreder and La Guardia (2014)	US**	Residential	2011-2012	20	0.95	1.0	1.6	Medium
Stapleton et al. (2014)	US**	Residential	2012	30	1.0	N/R	1.8	Medium
Dodson et al. (2012)	US**	Residential	2006-2011	32	1.0	5.0	1.4	High
Stapleton et al. (2008)	US**	Residential	2006	35	0.94	4.5	2.1	Medium
Johnson et al. (2013)	US**	Residential	2002-2003	38	0.97	N/R	2.1	Medium
Roosens et al. (2010a)	BE**	Residential	2008	43	1.0	N/R	1.7	Medium
D'Hollander et al. (2010)	BE**	Residential	2008	43	1.0	N/R	1.6	High
Roosens et al. (2009)	BE**	Residential	2007	16	1.0	N/R	1.4	High
Shoeib et al. (2012)	CA**	Residential	2007-2008	116	1.0	N/R	2.0	Medium
Gerecke et al. (2008)	CH**	Residential	2003-2007	3	1.0	N/R	1.8	Medium
Fromme et al. (2014)	DE**	Residential	2013	40	1.0	1.0	2.0	Medium
Kopp et al. (2012)	DE*	Residential	2012	5	1.0	3.0	1.8	Medium
Kuang et al. (2016)	GB**	Residential	2015	60	1.0	0.56	1.4	High
Abdallah and Harrad (2018)	GB*	Residential	2008	1	1.0	N/R	1.7	Medium
Abdallah et al. (2008a)	GB**	Residential	2006-2007	45	1.0	0.1	1.3	High
Abdallah et al. (2008b)	GB**	Residential	2007	37	1.0	0.2	1.7	Medium
Abdallah and Harrad (2009)	GB**	Residential	2007	21	1.0	0.3	1.2	High
Abdallah et al. (2008c)	GB, CA, US**	Residential	2006	52	1.0	N/R	1.8	Medium
Santillo et al. (2003)	GB, Multiple**	Residential	2002	12	1.0	2.5	1.6	High

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Mizouchi et al. (2015)	JP**	Residential	2009-2010	10	1.0	20.0	1.9	Medium
Takigami et al. (2009b)	JP*	Residential	2006	2	N/R	N/R	1.9	Medium
Abb et al. (2011)	Multiple**	Residential	2011	26	1.0	N/R	1.9	Medium
Ali et al. (2012)	NZ**	Residential	2008	50	1.0	N/R	1.9	Medium
Coelho et al. (2016a)	PT**	Residential	2010-2011	56	1.0	0.23	2.0	Medium
Sahlström et al. (2012)	SE**	Residential	2012	6	1.0	N/R	1.9	Medium
Newton et al. (2015)	SE**	Residential	2012	4	1.0	N/R	2.0	Medium
Sahlström et al. (2015a)	SE**	Residential	2009-2010	27	1.0	N/R	1.7	Medium
Björklund et al. (2012)	SE**	Residential	2008-2009	37	0.86	9.1	1.9	Medium
de Wit et al. (2012)	SE**	Residential	2006	44	N/R	3.0	1.1	High
Hassan and Shoeib (2014)	EG	Residential	2013	17	N/R	N/R	1.6	Medium
Kalachova et al. (2012)	Multiple	Residential	2008	24	0.88	0.3	1.7	Medium
Dirtu et al. (2012)	RO	Residential	2010	47	1.0	6.0	1.3	High
Dirtu and Covaci (2010)	RO	Residential	2007	18	1.0	N/R	2.6	Low
Tue et al. (2013)	VN	Residential	2008	13	1.0	N/R	1.9	Medium
Roosens et al. (2010a)	BE**	Commercial	2008	10	1.0	N/R	1.7	Medium
D'Hollander et al. (2010)	BE**	Commercial	2008	10	1.0	N/R	1.6	High
Abdallah et al. (2008a)	GB**	Commercial	2006-2007	32	1.0	0.1	1.3	High
Abdallah and Harrad (2009)	GB**	Commercial	2007	21	1.0	0.3	1.2	High
Abdallah et al. (2008c)	GB**	Commercial	2006	6	1.0	N/R	1.8	Medium
Takigami et al. (2009a)	JP**	Commercial	2006	8	1.0	20.0	1.7	Medium
Santillo et al. (2001)	Multiple**	Commercial	2000-2001	7	0.71	2.5	2.0	Medium
Leonards et al. (2001)	Multiple**	Commercial	2000	10	0.7	3.0	1.8	Medium
Newton et al. (2015)	SE**	Commercial	2012	27	1.0	N/R	2.0	Medium

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
de Wit et al. (2012)	SE**	Commercial	2006	20	N/R	3.0	1.1	High
Cao et al. (2015)	CN	Commercial	2012	65	N/R	1.5	1.8	Medium
Ni and Zeng (2013)	CN	Commercial	2009	56	1.0	N/R	1.4	High
Hassan and Shoeib (2014)	EG	Commercial	2013	14	N/R	N/R	1.6	Medium
Allgood et al. (2016)	US**	Mixed use	2013	20	1.0	1.0	1.3	High
Al Bitar (2004)	BE**	Mixed use	2003	23	0.26	20.0	1.4	Low
Takigami et al. (2008)	JP**	Mixed use	2005	15	0.2	400.0	1.8	Medium
Qi et al. (2014b)	CN	Mixed use	2010-2011	81	0.99	2.7	1.4	High
Tue et al. (2013)	VN	Mixed use	2008	20	1.0	N/R	1.9	Medium
Harrad et al. (2010)	GB**	School	2007-2008	36	0.83	N/R	2.0	Medium
Mizouchi et al. (2015)	JP**	School	2009-2010	18	1.0	20.0	1.9	Medium
Newton et al. (2015)	SE**	School	2012	2	1.0	N/R	2.0	Medium
Cao et al. (2015)	CN	School	2012	2	N/R	1.5	1.8	Medium
Allen et al. (2013)	US**	Vehicle	2010	40	1.0	0.12	2.1	Medium
Harrad and Abdallah (2011)	GB**	Vehicle	2009	28	1.0	N/R	2.0	Medium
Abdallah et al. (2008a)	GB**	Vehicle	2006-2007	20	1.0	0.1	1.3	High
Abdallah and Harrad (2009)	GB**	Vehicle	2007	12	1.0	0.3	1.2	High
de Wit et al. (2012)	SE**	Vehicle	2006	4	N/R	3.0	1.1	High
Kalachova et al. (2012)	Multiple	Vehicle	2008	26	0.96	0.3	1.7	Medium
Zeng et al. (2016)	CN	Industrial	2013	48	0.92	1.2	1.2	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.14. Landfill Leachate

2.14.1. Landfill Leachate (ng/g) – Dry Fraction

Measured concentrations of HBCD in Landfill Leachate with unit of ng/g, extracted from 1 source, are summarized in Figure 2-30 and supplemental information is provided in Table 2-29. Overall, concentrations ranged from 2.5 to 36000 ng/g from over 11 samples collected during 2002 in 1 country, NL. Location types were categorized as Near Facility. Reported detection frequency was 1.0.

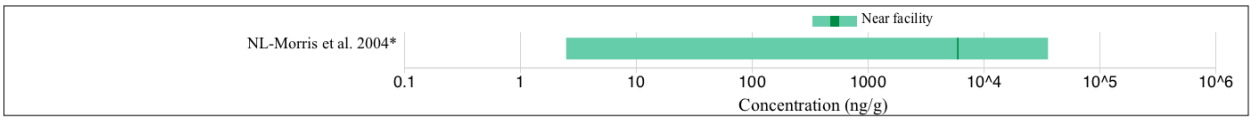


Figure 2-30. Concentration of HBCD (ng/g) in the Dry Fraction of Landfill Leachate in Near Facility Locations in 2002

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-29. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Landfill Leachate

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Morris et al. (2004)	NL*	2002	11	1.0	1.2	2.3	Low

*Study conducted in a country/countries classified as "High Income" by the World Bank

2.14.2. Landfill Leachate (ng/g) – Wet Fraction

Measured concentrations of HBCD in Landfill Leachate with unit of ng/g, extracted from 1 source, are summarized in Figure 2-31 and supplemental information is provided in Table 2-30. Overall, concentrations ranged from 390 to 4100 ng/g from over 2 samples collected during 2006 in 1 country, JP. Location types were categorized as Background. Reported detection frequency was 1.0.

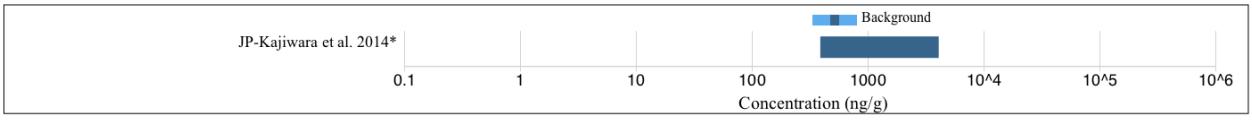


Figure 2-31. Concentration of HBCD (ng/g) in the Wet Fraction of Landfill Leachate in Background Locations in 2006

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-30. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Landfill Leachate

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Kajiwara et al. (2014)	JP*	2006	2	1.0	N/R	2.0	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.14.3. Landfill Leachate (ng/L) – Wet Fraction

Measured concentrations of HBCD in Landfill Leachate with unit of ng/l, extracted from 3 sources, are summarized in Figure 2-32 and supplemental information is provided in Table 2-31. Overall, concentrations ranged from 4.80E-03 to 9.0 ng/l from over 33 samples collected between 2000 and 2014 in 3 countries, SE, ZA, and AU. Location types were categorized as Near Facility. Reported detection frequency was 1.0.

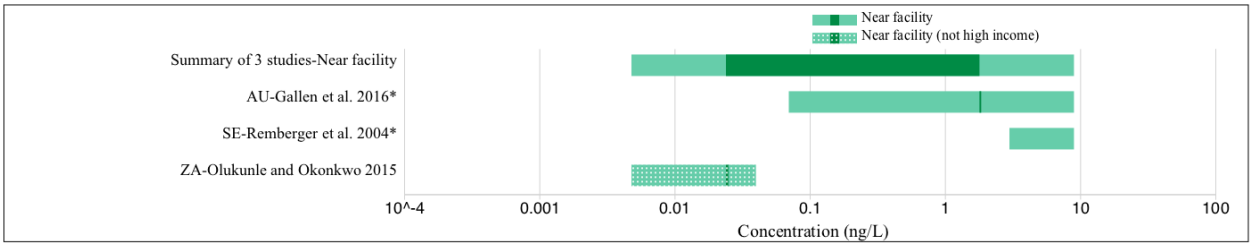


Figure 2-32. Concentration of HBCD (ng/L) in the Wet Fraction of Landfill Leachate in Near Facility Locations from 2000 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-31. Summary of Peer-Reviewed Literature that Measured HBCD (ng/L) Levels in the Wet Fraction of Landfill Leachate

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Gallen et al. (2016)	AU*	2014	13	N/R	0.3	1.8	Medium
Remberger et al. (2004)	SE*	2000	2	1.0	N/R	1.8	Medium
Olukunle and Okonkwo (2015)	ZA	2013	18	N/R	25000.0	1.8	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.15. Precipitation

2.15.1. Precipitation (ng/L) – Wet Fraction

Measured concentrations of HBCD in Precipitation with unit of ng/l, extracted from 3 sources, are summarized in Figure 2-33 and supplemental information is provided in Table 2-32. Overall, concentrations ranged from not-detected to 1835 ng/l from over 494 samples collected between 2003 and 2010 in 2 countries, NL and CA. Location types were categorized as Background. Reported detection frequencies ranged from 0.00 to 0.02.

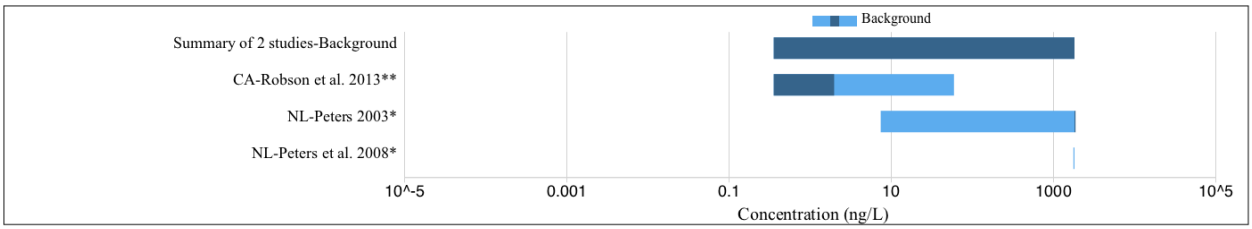


Figure 2-33. Concentration of HBCD (ng/L) in the Wet Fraction of Precipitation in Background Locations from 2003 to 2010

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-32. Summary of Peer-Reviewed Literature that Measured HBCD (ng/L) Levels in the Wet Fraction of Precipitation

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Robson et al. (2013)	CA*	Background	Rain, snow	2004-2010	443	N/R	N/R	1.4	High
Peters (2003)	NL*	Background	Precipitation	2003	50	0.02	15.0	1.7	Medium
Peters et al. (2008)	NL*	Background	Rainwater	2003	1	0.0	15.0	2.0	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank

2.16. Seawater

2.16.1. Seawater (ng/L) – Wet Fraction

Measured concentrations of HBCD in Seawater with unit of ng/l, extracted from 2 sources, are summarized in Figure 2-34 and supplemental information is provided in Table 2-33. Overall, concentrations ranged from 0.05 to 1.58 ng/l from over 15 samples collected between 2012 and 2014 in 2 countries, AQ and DK. Location types were categorized as Background. Reported detection frequency was 1.0.

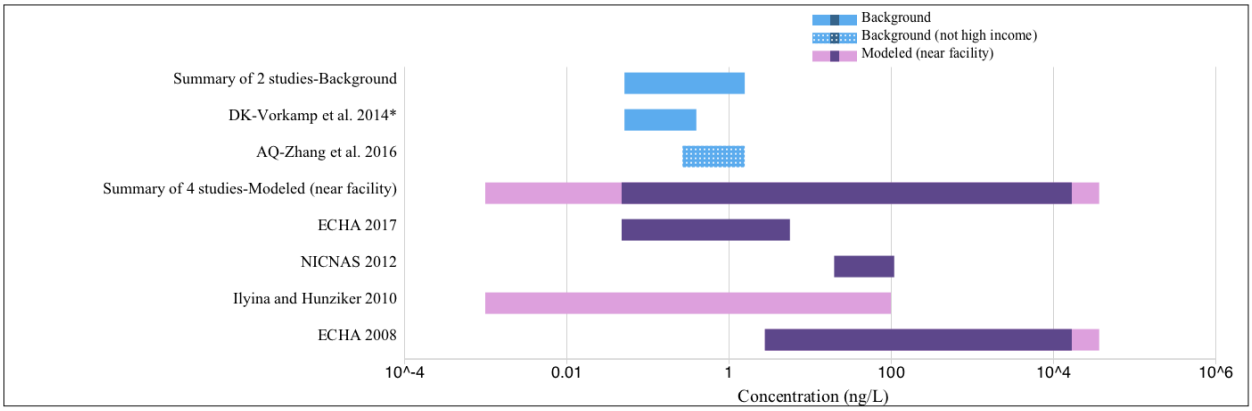


Figure 2-34. Concentration of HBCD (ng/L) in the Wet Fraction of Seawater in Background Locations and for Modeled Data from 2012 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-33. Summary of Peer-Reviewed Literature that Measured HBCD (ng/L) Levels in the Wet Fraction of Seawater

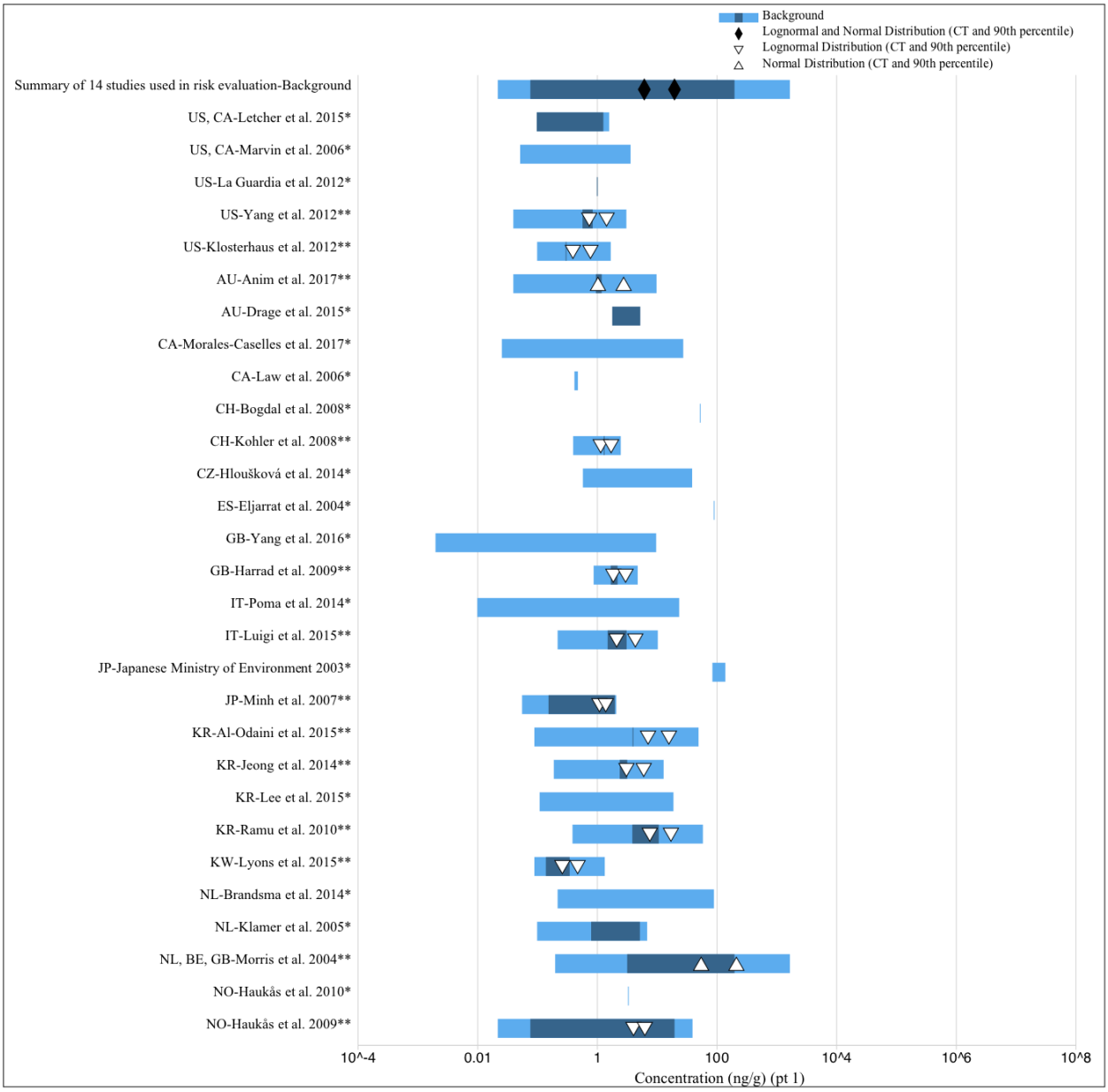
Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Vorkamp et al. (2014)	DK*	Background	2012	5	1.0	0.012	2.0	Medium
Zhang et al. (2016a)	AQ	Background	2013-2014	10	1.0	0.004	1.8	Medium
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.0	Medium
NICNAS (2012)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
Ilyina and Hunziker (2010)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.2	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.17. Sediment

2.17.1. Sediment (ng/g) – Dry Fraction

Measured concentrations of HBCD in Sediment with unit of ng/g, extracted from 60 sources, are summarized in Figure 2-35 and supplemental information is provided in Table 2-34. Overall, concentrations ranged from not-detected to 85000 ng/g from over 1244 samples collected between 1974 and 2016 in 19 countries, CA, CZ, ES, KW, AU, NO, CN, ZA, NL, CH, SE, SG, ID, US, KR, JP, IT, BE, and GB. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 6.19 and 19.78 ng/g for Background (n = 14 studies) and 3442.64 and 5072.51 ng/g for Near Facility (n = 6 studies).


Background
Lognormal and Normal Distribution (CT and 90th percentile)
Lognormal Distribution (CT and 90th percentile)
Normal Distribution (CT and 90th percentile)
Summary of 14 studies used in risk evaluation-Background
US, CA-Letcher et al. 2015*
US, CA-Marvin et al. 2006*
US-La Guardia et al. 2012*
US-Yang et al. 2012**
US-Klosterhaus et al. 2012**
AU-Anim et al. 2017**
AU-Drage et al. 2015*
CA-Morales-Caselles et al. 2017*
CA-Law et al. 2006*
CH-Bogdal et al. 2008*
CH-Kohler et al. 2008**
CZ-Hloušková et al. 2014*
ES-Eljarrat et al. 2004*
GB-Yang et al. 2016*
GB-Harrad et al. 2009**
IT-Poma et al. 2014*
IT-Luigi et al. 2015**
JP-Japanese Ministry of Environment 2003*
JP-Minh et al. 2007**
KR-Al-Odaini et al. 2015**
KR-Jeong et al. 2014**
KR-Lee et al. 2015*
KR-Ramu et al. 2010**
KW-Lyons et al. 2015**
NL-Brandsma et al. 2014*
NL-Klamer et al. 2005*
NL, BE, GB-Morris et al. 2004**
NO-Haukås et al. 2010*
NO-Haukås et al. 2009**
10^-4
0.01
1
100
10^4
10^6
10^8
Concentration (ng/g) (pt 1)

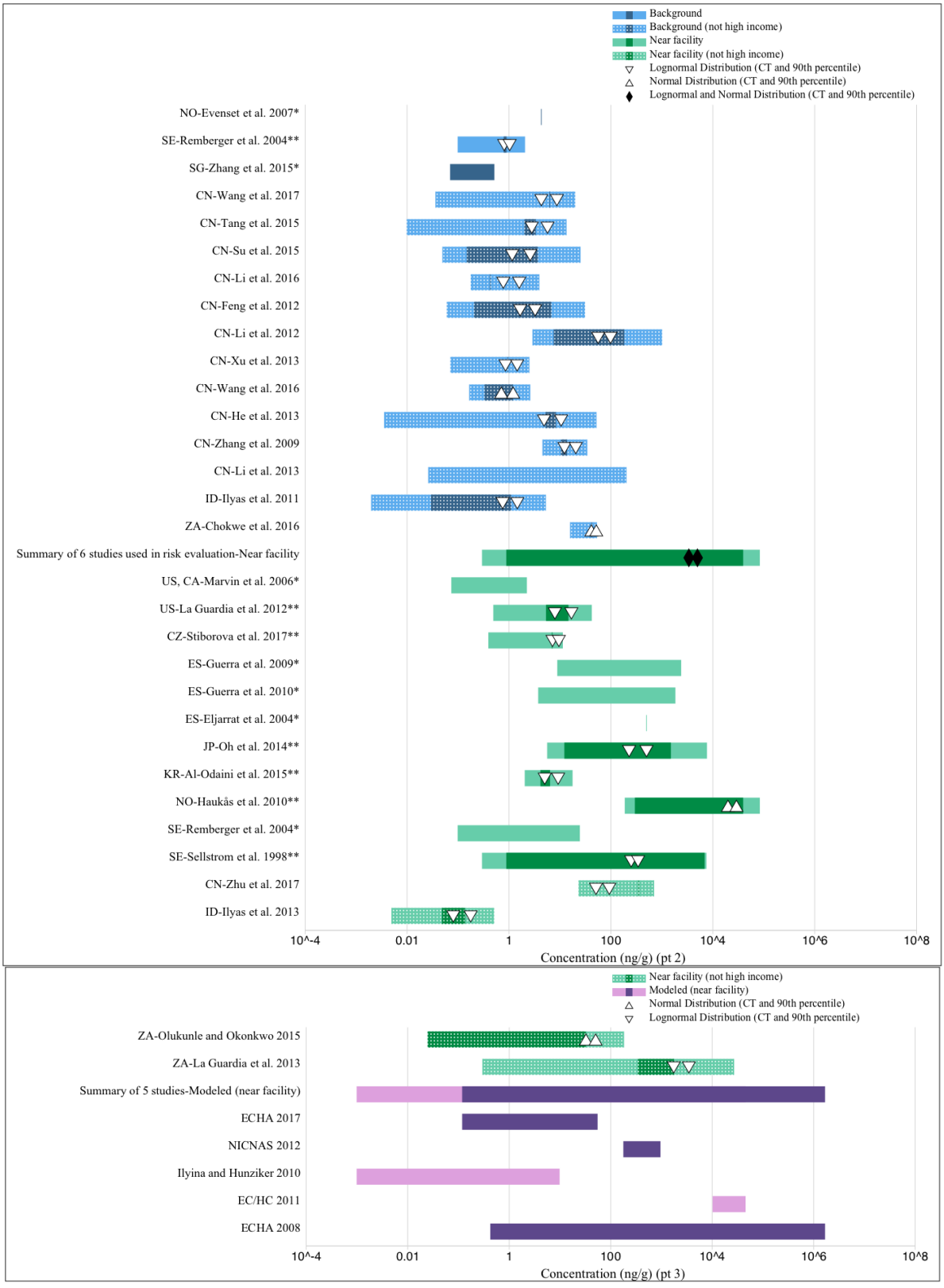


Figure 2-35. Concentration of HBCD (ng/g) in the Dry Fraction of Sediment in Background and Near Facility Locations and for Modeled Data from 1974 to 2016

* Study conducted in a country/countries classified as “High Income” by the World Bank;
** Study conducted in a country/countries classified as “High Income” by the World Bank and used in risk evaluation final dataset

Table 2-34. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Sediment

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Letcher et al. (2015)	US, CA*	Background	2004	37	0.35	0.2	1.7	Medium
Marvin et al. (2006)	US, CA*	Background	2001	49	0.65	0.075	1.8	Medium
La Guardia et al. (2012)	US*	Background	2009	1	N/R	1.0	1.7	Medium
Yang et al. (2012)	US**	Background	2007	16	N/R	N/R	1.6	High
Klosterhaus et al. (2012)	US**	Background	2007	10	1.0	N/R	1.7	Medium
Anim et al. (2017)	AU**	Background	2014-2015	48	N/R	N/R	1.3	High
Drage et al. (2015)	AU*	Background	2014	4	1.0	N/R	1.7	Medium
Morales-Caselles et al. (2017)	CA*	Background	2011	7	0.57	0.0	1.8	Medium
Law et al. (2006a)	CA*	Background	2003	4	N/R	0.16	1.2	High
Bogdal et al. (2008)	CH*	Background	2005	34	N/R	N/R	1.9	Medium
Kohler et al. (2008)	CH**	Background	1974-2001	5	1.0	N/R	1.9	Medium
Hloušková et al. (2014)	CZ*	Background	2010	31	0.97	0.9	1.7	Medium
Eljarrat et al. (2004)	ES*	Background	2002	1	1.0	N/R	1.8	Medium
Yang et al. (2016)	GB*	Background	2011-2012	74	0.76	0.01	1.9	Medium
Harrad et al. (2009)	GB**	Background	2008-2009	9	1.0	N/R	1.7	Medium
Poma et al. (2014b)	IT*	Background	2011-2012	17	0.88	0.01	1.6	High
Luigi et al. (2015)	IT**	Background	2010	5	1.0	0.011	1.9	Medium
Japanese Ministry of (2003)	JP*	Background	2003	1	0.0	23.0	2.6	Low
Minh et al. (2007)	JP**	Background	2002	9	1.0	0.03	2.1	Medium
Al-Odaini et al. (2015)	KR**	Background	2010	19	1.0	N/R	1.9	Medium
Jeong et al. (2014)	KR**	Background	2010	12	1.0	0.02	1.3	High
Lee et al. (2015)	KR*	Background	2009	24	1.0	0.006	1.6	High
Ramu et al. (2010)	KR**	Background	2005	29	1.0	N/R	1.4	High
Lyons et al. (2015)	KW**	Background	2013-2014	29	1.0	0.18	1.4	High

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Brandsma et al. (2014b)	NL*	Background	2008	6	1.0	0.5	2.0	Medium
Klamer et al. (2005)	NL*	Background	2000	10	0.9	0.2	2.1	Medium
Morris et al. (2004)	NL, BE, GB**	Background	1999-2002	78	N/R	1.2	2.3	Low
Haukås et al. (2010b)	NO*	Background	2007	4	0.0	3.3	1.9	Medium
Haukås et al. (2009)	NO**	Background	2006-2007	25	1.0	0.005	1.9	Medium
Evenset et al. (2007)	NO*	Background	2001	1	1.0	0.06	2.2	Medium
Remberger et al. (2004)	SE**	Background	1996-2000	11	1.0	0.1	1.8	Medium
Zhang et al. (2015)	SG*	Background	2014	12	1.0	0.007	1.7	Medium
Wang et al. (2017)	CN	Background	2016	23	0.96	0.073	1.9	Medium
Tang et al. (2015)	CN	Background	2012	40	1.0	N/R	1.4	High
Su et al. (2015b)	CN	Background	2010	40	N/R	0.011	1.9	Medium
Li et al. (2016a)	CN	Background	2010	17	N/R	0.18	1.4	High
Feng et al. (2012)	CN	Background	2009-2010	121	N/R	0.061	1.8	Medium
Li et al. (2012b)	CN	Background	2010	6	1.0	N/R	1.1	High
Xu et al. (2013)	CN	Background	2010	12	0.83	0.14	1.8	Medium
Wang et al. (2016)	CN	Background	2009	26	N/R	0.011	1.9	Medium
He et al. (2013)	CN	Background	2009	85	N/R	N/R	1.3	High
Zhang et al. (2009)	CN	Background	2006	7	1.0	N/R	1.8	Medium
Li et al. (2013)	CN	Background	2003-2004	34	0.59	0.4	1.4	High
Ilyas et al. (2011b)	ID	Background	2008	33	0.94	N/R	2.0	Medium
Chokwe et al. (2016)	ZA	Background	2013	6	1.0	N/R	1.7	Medium
Marvin et al. (2006)	US, CA*	Near facility	2001	14	0.71	0.075	1.8	Medium
La Guardia et al. (2012)	US**	Near facility	2009	4	1.0	1.0	1.7	Medium
Stiborova et al. (2017)	CZ**	Near facility	2016	12	0.58	0.8	1.7	Medium
Guerra et al. (2009)	ES*	Near facility	2002-2006	12	N/R	9.0	2.0	Medium
Guerra et al. (2010)	ES*	Near facility	2006	7	0.86	3.8	1.6	High

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Eljarrat et al. (2004)	ES*	Near facility	2002	1	1.0	N/R	1.8	Medium
Oh et al. (2014)	JP**	Near facility	2011	17	1.0	N/R	1.4	High
Al-Odaini et al. (2015)	KR**	Near facility	2010	10	1.0	N/R	1.9	Medium
Haukås et al. (2010b)	NO**	Near facility	2007	8	1.0	270.0	1.9	Medium
Remberger et al. (2004)	SE*	Near facility	2000	6	1.0	0.1	1.8	Medium
Sellstrom et al. (1998)	SE**	Near facility	1995	9	0.78	0.6	2.0	Medium
Zhu et al. (2017b)	CN	Near facility	2015	4	1.0	0.022	1.7	Medium
Ilyas et al. (2013)	ID	Near facility	2008	5	0.8	N/R	1.4	High
Olukunle and Okonkwo (2015)	ZA	Near facility	2013	18	N/R	N/R	1.8	Medium
La Guardia et al. (2013)	ZA	Near facility	2011	45	0.69	0.6	1.9	Medium
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.0	Medium
NICNAS (2012)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
Ilyina and Hunziker (2010)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.2	Medium
Environment Canada and Health Canada (2011)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.17.2. Sediment (ng/g) – Wet Fraction

Measured concentrations of HBCD in Sediment with unit of ng/g, extracted from 2 sources, are summarized in Figure 2-36 and supplemental information is provided in Table 2-35. Overall, concentrations ranged from not-detected to 169 ng/g from over 15 samples collected between 2006 and 2013 in 2 countries, ZA and CN. Location types were categorized as Near Facility. Reported detection frequencies ranged from 0.67 to 1.0.

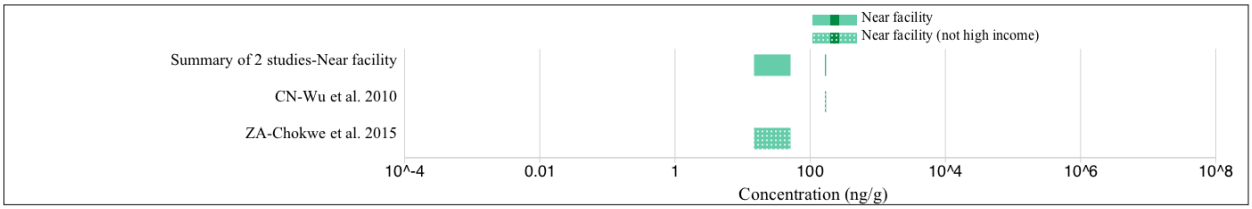


Figure 2-36. Concentration of HBCD (ng/g) in the Wet Fraction of Sediment in Near Facility Locations from 2006 to 2013

Table 2-35. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Sediment

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Wu et al. (2010)	CN	Near facility	2006	3	0.67	N/R	2.0	Medium
Chokwe et al. (2015)	ZA	Near facility	2013	12	1.0	0.48	1.6	High

Abbreviations: N/R, Not reported

2.18. Soil

2.18.1. Soil (ng/g) – Dry Fraction

Measured concentrations of HBCD in Soil with unit of ng/g, extracted from 26 sources, are summarized in Figure 2-37 and supplemental information is provided in Table 2-36. Overall, concentrations ranged from not-detected to 317,52 ng/g from over 706 samples collected between 1999 and 2015 in 9 countries, SE, ID, CH, BE, IN, CN, VN, MY, and KH. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.75 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 1.44 and 3.01 ng/g for Background (n = 2 studies) and 1015.69 and 1253.76 ng/g for Near Facility (n = 1 study).

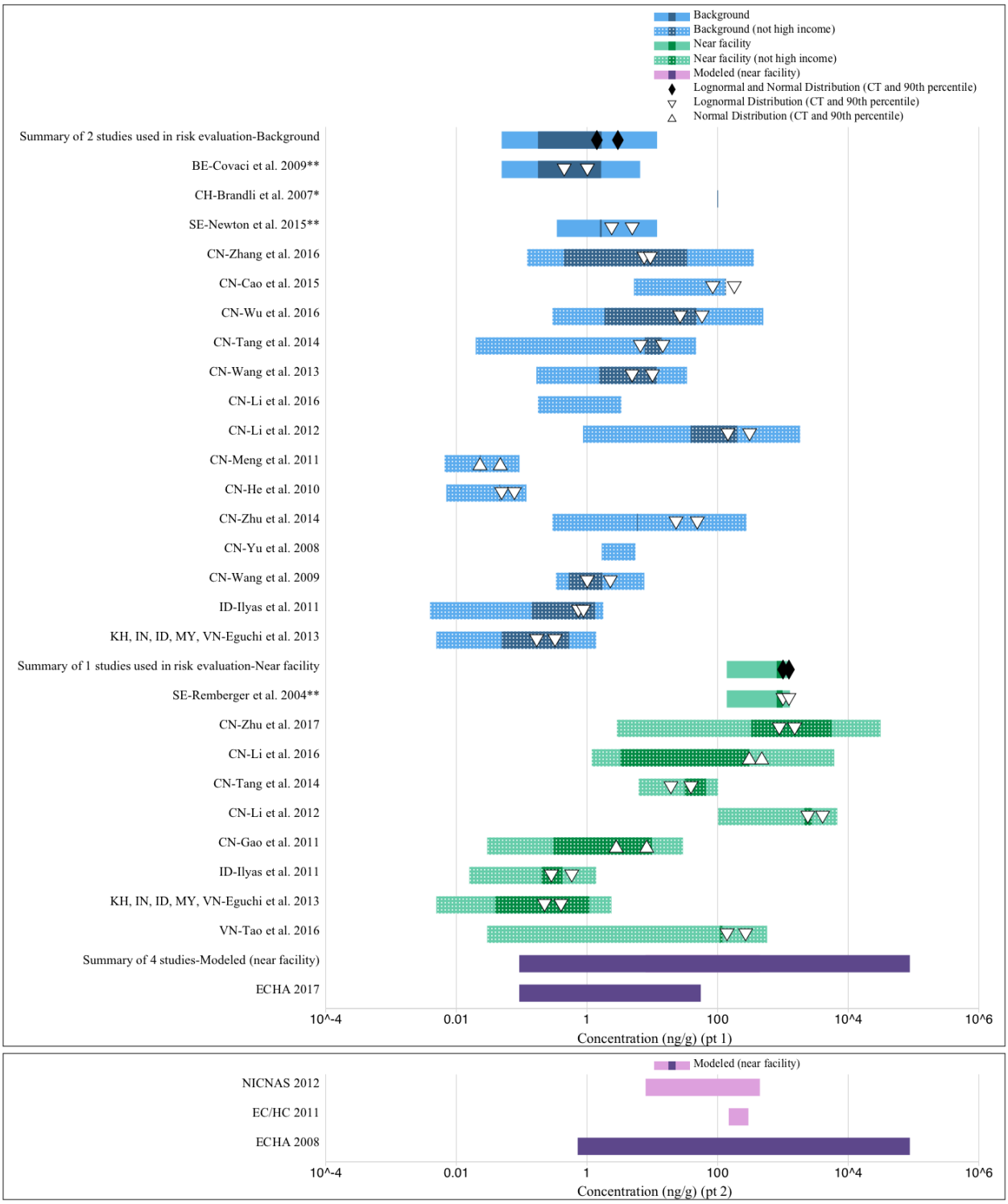


Figure 2-37. Concentration of HBCD (ng/g) in the Dry Fraction of Soil in Background and Near Facility Locations and for Modeled Data from 1999 to 2015

* Study conducted in a country/countries classified as “High Income” by the World Bank;
** Study conducted in a country/countries classified as “High Income” by the World Bank and used in risk evaluation final dataset

Table 2-36. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Soil

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Covaci et al. (2009)	BE**	Background	2006-2007	20	0.75	0.1	1.8	Medium
Brandli et al. (2007)	CH*	Background	2006	18	N/R	N/R	2.0	Medium
Newton et al. (2015)	SE**	Background	2012	8	1.0	N/R	2.0	Medium
Zhang et al. (2016b)	CN	Background	2013	188	1.0	0.017	1.3	High
Cao et al. (2015)	CN	Background	2012	10	N/R	1.5	1.8	Medium
Wu et al. (2016)	CN	Background	2012	74	1.0	0.03	1.6	High
Tang et al. (2014)	CN	Background	2012	53	1.0	0.02	1.6	High
Wang et al. (2013)	CN	Background	2010-2011	24	1.0	N/R	1.9	Medium
Li et al. (2016a)	CN	Background	2010	17	N/R	0.18	1.4	High
Li et al. (2012b)	CN	Background	2010	11	1.0	N/R	1.1	High
Meng et al. (2011)	CN	Background	2009	22	0.86	0.013	1.3	High
He et al. (2010)	CN	Background	2005-2008	4	1.0	3.0	1.2	High
Zhu et al. (2014b)	CN	Background	2008	38	N/R	0.003	1.8	Medium
Yu et al. (2008b)	CN	Background	2006	3	1.0	N/R	2.1	Low
Wang et al. (2009)	CN	Background	2006	17	N/R	0.34	1.4	High
Ilyas et al. (2011a)	ID	Background	2008	17	0.88	N/R	1.7	Medium
Eguchi et al. (2013)	KH, IN, ID, MY, VN	Background	1999-2007	N/R	N/R	0.005	1.4	High
Remberger et al. (2004)	SE**	Near facility	2000	3	1.0	N/R	1.8	Medium
Zhu et al. (2017b)	CN	Near facility	2015	14	1.0	0.022	1.7	Medium
Li et al. (2016b)	CN	Near facility	2014	81	N/R	1.2	1.8	Medium
Tang et al. (2014)	CN	Near facility	2012	37	1.0	0.02	1.6	High
Li et al. (2012b)	CN	Near facility	2010	4	1.0	N/R	1.1	High
Gao et al. (2011)	CN	Near facility	2006-2008	32	1.0	0.011	1.4	High
Ilyas et al. (2011a)	ID	Near facility	2008	6	1.0	N/R	1.7	Medium

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Eguchi et al. (2013)	KH, IN, ID, MY, VN	Near facility	1999-2007	N/R	N/R	0.005	1.4	High
Tao et al. (2016)	VN	Near facility	2014	5	1.0	0.05	2.0	Medium
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.0	Medium
NICNAS (2012)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
Environment Canada and Health Canada (2011)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.19. Surface Water

2.19.1. Surface Water (ng/L) – Wet Fraction

Measured concentrations of HBCD in Surface/Ground Water with unit of ng/l, extracted from 14 sources, are summarized in Figure 2-38 and supplemental information is provided in Table 2-37. Overall, concentrations ranged from not-detected to 3100 ng/l from over 157 samples collected between 2004 and 2014 in 10 countries, AQ, PL, CA, ZA, US, DK, GB, KR, CN, and JP. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.61 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 0.41 and 0.8 ng/L for Background (n = 4 studies) and 840.91 and 992.93 ng/L for Near Facility (n = 3 studies).

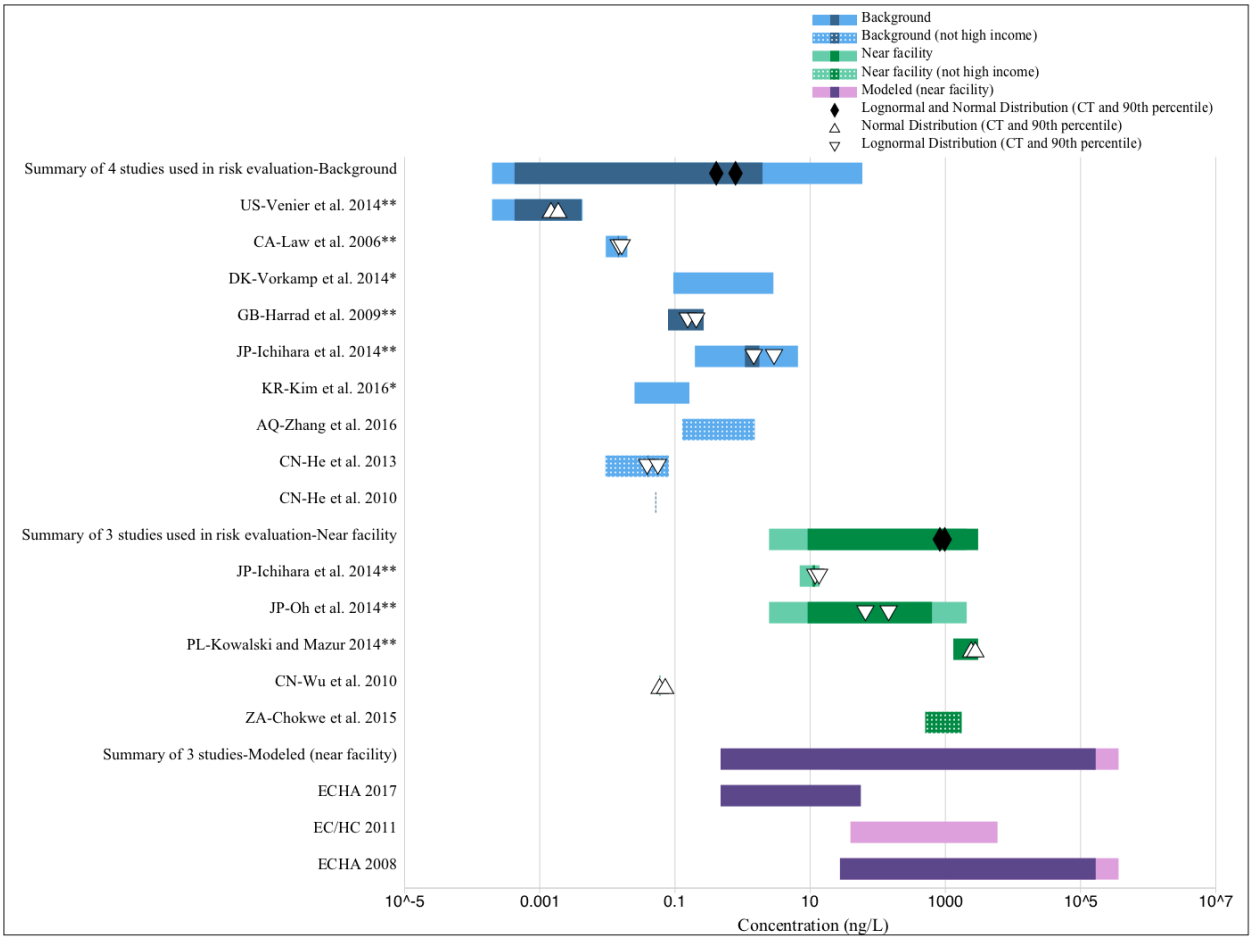


Figure 2-38. Concentration of HBCD (ng/L) in the Wet Fraction of Surface Water in Background and Near Facility Locations and for Modeled Data from 2004 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank;
** Study conducted in a country/countries classified as "High Income" by the World Bank and used in risk evaluation final dataset

Table 2-37. Summary of Peer-Reviewed Literature that Measured HBCD (ng/L) Levels in the Wet Fraction of Surface Groundwater

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Venier et al. (2014)	US**	Background	2011-2012	23	0.61	N/R	1.7	Medium
Law et al. (2006a)	CA**	Background	2004	3	1.0	0.013	1.2	High
Vorkamp et al. (2014)	DK*	Background	2012	5	1.0	0.012	2.0	Medium
Harrad et al. (2009)	GB**	Background	2008-2009	27	1.0	N/R	1.7	Medium
Ichihara et al. (2014)	JP**	Background	2012-2013	16	1.0	N/R	1.4	High

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Kim et al. (2016)	KR*	Background	2010	13	1.0	N/R	1.4	High
Zhang et al. (2016a)	AQ	Background	2013-2014	12	1.0	N/R	1.8	Medium
He et al. (2013)	CN	Background	2009	5	N/R	N/R	1.3	High
He et al. (2010)	CN	Background	2005-2008	3	1.0	N/R	1.2	High
Ichihara et al. (2014)	JP**	Near facility	2012-2013	3	1.0	N/R	1.4	High
Oh et al. (2014)	JP**	Near facility	2011	17	1.0	N/R	1.4	High
Kowalski and Mazur (2014)	PL**	Near facility	2014	15	N/R	320.0	2.3	Low
Wu et al. (2010)	CN	Near facility	2006	3	0.67	N/R	2.0	Medium
Chokwe et al. (2015)	ZA	Near facility	2013	12	1.0	200.0	1.6	High
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	2.0	Medium
Environment Canada and Health Canada (2011)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
**Study conducted in a country/countries classified as “High Income” by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

2.19.2. Surface Water (ng/m^2) – Wet Fraction

Measured concentrations of HBCD in Surface/Ground Water with unit of ng/m2, extracted from 1 source, are summarized in Figure 2-39 and supplemental information is provided in Table 2-38. Overall, concentrations ranged from 0.58 to 4.56 ng/m^2 from over 12 samples collected between 2008 and 2010 in 1 country, UG. Location types were categorized as Background. Reported detection frequency was 1.0.

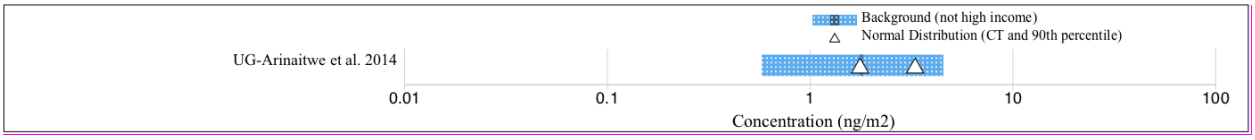


Figure 2-39. Concentration of HBCD (ng/m2) in the Wet Fraction of Surface Water in Background Locations from 2008 to 2010

Table 2-38. Summary of Peer-Reviewed Literature that Measured HBCD (ng/m2) Levels in the Wet Fraction of Surface Groundwater

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/m2)	Quality Score	Overall Quality Level
Arinaitwe et al. (2014)	UG	Background	2008-2010	12	1.0	N/R	1.4	High

Abbreviations: N/R, Not reported

2.20. Vegetation

2.20.1. Vegetation (ng/g) – Dry Fraction

Measured concentrations of HBCD in Vegetation with unit of ng/g, extracted from 3 sources, are summarized in Figure 2-40 and supplemental information is provided in Table 2-39. Overall, concentrations ranged from 3.45 to 160,241 ng/g from over 90 samples collected between 2010 and 2015 in 1 country, CN. Location types were categorized as Background and Near Facility. Reported detection frequency was 1.0.

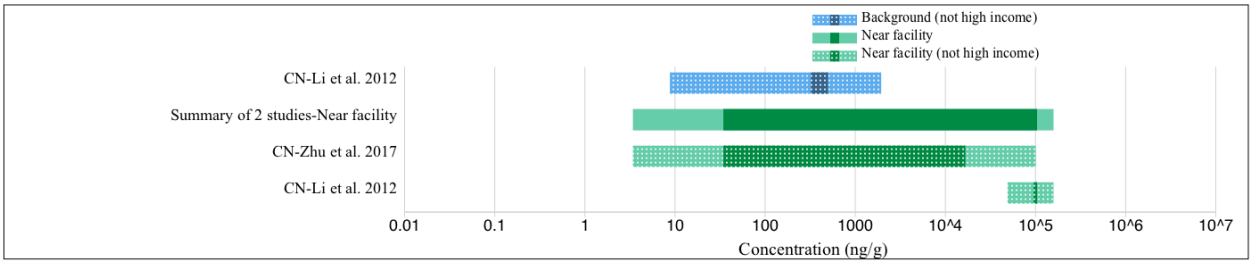


Figure 2-40. Concentration of HBCD (ng/g) in the Dry Fraction of Vegetation in Background and Near Facility Locations from 2010 to 2015

Table 2-39. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Vegetation

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Li et al. (2012b)	CN	Background	Reed, cyprus, seepweed	2010	14	1.0	N/R	1.1	High
Zhu et al. (2017b)	CN	Near facility	Holly, cyprus, pine (includes wax, inner leaf, branch, and bark samples for each)	2015	70	1.0	0.022	1.7	Medium
Li et al. (2012b)	CN	Near facility	Reed, cyprus, seepweed	2010	6	1.0	N/R	1.1	High

Abbreviations: N/R, Not reported

2.20.2. Vegetation (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Vegetation with unit of ng/g, extracted from 3 sources, are summarized in Figure 2-41 and supplemental information is provided in Table 2-40. Overall, concentrations ranged from 0.27 to 3400 ng/g from over 59 samples collected between 2009 and 2012 in 10 countries, CA, ZA, IS, CZ, ID, US, NO, AU, CN, and NP. Location types were categorized as Background. Reported detection frequency was 1.0.

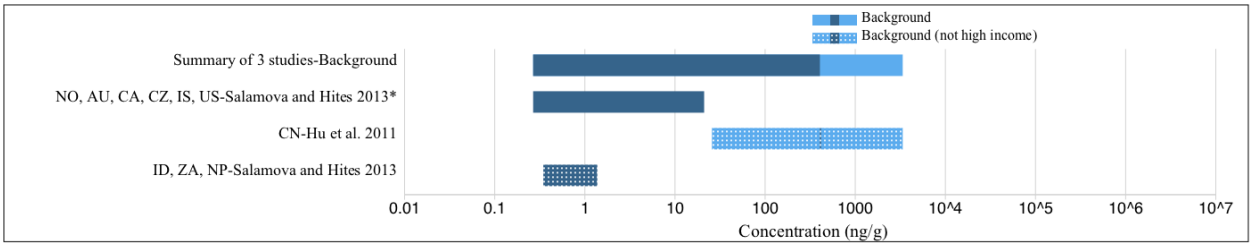


Figure 2-41. Concentration of HBCD (ng/g) in the Lipid Fraction of Vegetation in Background Locations from 2009 to 2012

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-40. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Vegetation

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Salamova and Hites (2013)	NO, AU, CA, CZ, IS, US*	Background	Tree bark from full-grown hardwood and coniferous trees with coarse bark such as, pine, fir, and spruce	2009-2012	32	1.0	N/R	2.0	Medium
Hu et al. (2011a)	CN	Background	N/R	2009-2010	15	1.0	N/R	1.2	High
Salamova and Hites (2013)	ID, ZA, NP	Background	Tree bark from full-grown hardwood and coniferous trees with coarse bark such as, pine, fir, and spruce	2009-2012	12	1.0	N/R	2.0	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.21. Wastewater (Influent; Effluent)

2.21.1. Wastewater (ng/g) – Dry Fraction

Measured concentrations of HBCD in Wastewater (Influent; Effluent) with unit of ng/g, extracted from 1 source, are summarized in Figure 2-42 and supplemental information is provided in Table 2-41. Overall, concentrations ranged from 0.4 to 3800 ng/g from over 15 samples collected during 2002 in 2 countries, NL and GB. Location types were categorized as Near Facility. No detection frequencies were reported.

Figure 2-42. Concentration of HBCD (ng/g) in the Dry Fraction of Wastewater in Near Facility Locations in 2002

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-41. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Wastewater

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Morris et al. (2004)	NL, GB*	Near facility	2002	15	N/R	1.2	2.3	Low

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

2.21.2. Wastewater (ng/L) – Wet Fraction

Measured concentrations of HBCD in Wastewater (Influent; Effluent) with unit of ng/l, extracted from 5 sources, are summarized in Figure 2-43 and supplemental information is provided in Table 2-42. Overall, concentrations ranged from not-detected to 1270 ng/l from over 80 samples collected between 2000 and 2012 in 4 countries, SE, JP, US, and KR. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.00 to 1.0.

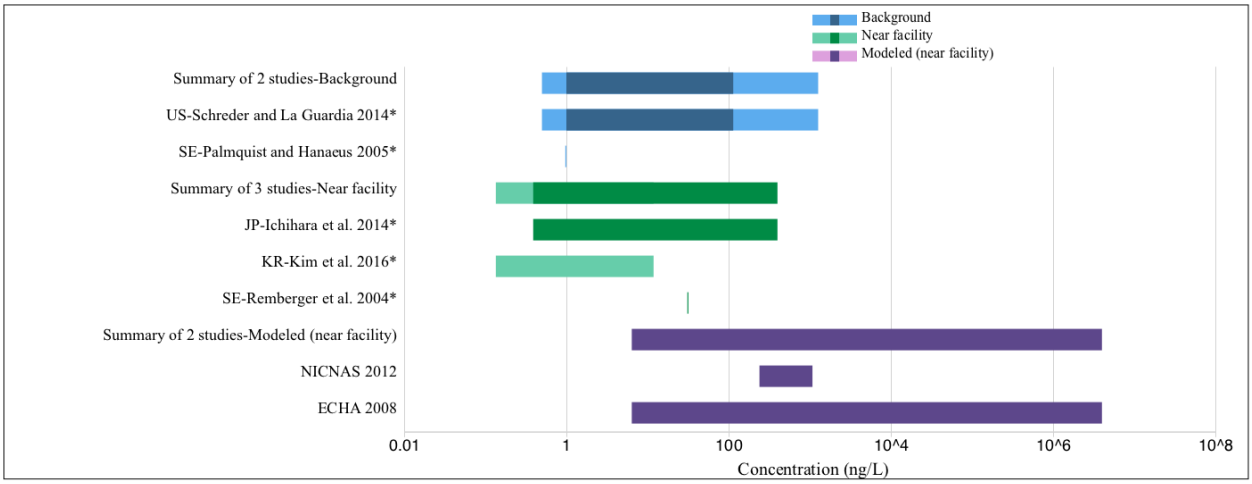


Figure 2-43. Concentration of HBCD (ng/L) in the Wet Fraction of Wastewater in Background and Near Facility Locations and for Modeled Data from 2000 to 2012

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 2-42. Summary of Peer-Reviewed Literature that Measured HBCD (ng/L) Levels in the Wet Fraction of Wastewater

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Schreder and La Guardia (2014)	US*	Background	2011-2012	19	0.26	1.0	1.6	Medium
Palmquist and Hanaeus (2005)	SE*	Background	2004	7	0.0	1.0	2.1	Medium
Ichihara et al. (2014)	JP*	Near facility	2012	30	1.0	N/R	1.4	High
Kim et al. (2016)	KR*	Near facility	2010	23	1.0	N/R	1.4	High
Remberger et al. (2004)	SE*	Near facility	2000	1	1.0	N/R	1.8	Medium
NICNAS (2012)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.8	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3. Ecomonitoring Media

3.1. Amphibians

3.1.1. Amphibians (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Amphibian with unit of ng/g, extracted from 2 sources, are summarized in Figure 3-1 and supplemental information is provided in Table 3-1. Overall, concentrations ranged from 4.22 to 96.24 ng/g from over 14 samples collected between 2011 and 2013 in 1 country, CN. Location types were categorized as Background. Reported detection frequency was 1.0.

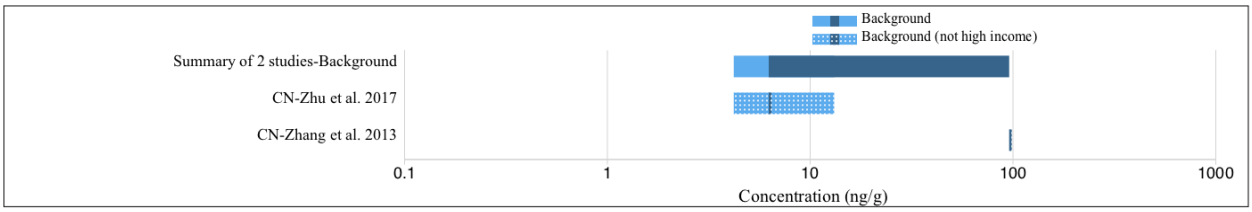


Figure 3-1. Concentration of HBCD (ng/g) in the Lipid Fraction of Amphibians in Background Locations from 2011 to 2013

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-1. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Amphibians

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Zhu et al. (2017a)	CN	Background	Frog	2012-2013	11	1.0	N/R	2.0	Low
Zhang et al. (2013)	CN	Background	Pond green frog	2011	3	1.0	0.022	1.7	Medium

Abbreviations: N/R, Not reported

3.2. Aquatic Invertebrates

3.2.1. Aquatic Invertebrates (ng/g) – Dry Fraction

Measured concentrations of HBCD in Aquatic Invertebrates with unit of ng/g, extracted from 3 sources, are summarized in Figure 3-2 and supplemental information is provided in Table 3-2. Overall, concentrations ranged from 0.09 to 28.8 ng/g from over 187 samples collected between 2006 and 2014 in 2 countries, GB and CN. Location types were categorized as Background and Near Facility. Reported detection frequency was 1.0.

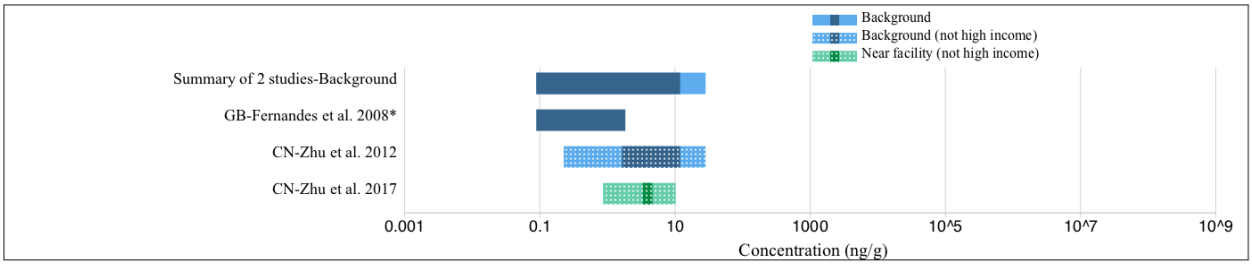


Figure 3-2. Concentration of HBCD (ng/g) in the Dry Fraction of Aquatic Invertebrates in Background and Near Facility Locations from 2008 to 2017

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-2. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Aquatic Invertebrates

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Fernandes et al. (2008)	GB*	Background	Oysters , mussels , scallops (gonad tissue), scallop (adductor tissue)	2006	40	N/R	N/R	1.7	Medium
Zhu et al. (2012)	CN	Background	Amusium veneriformis , chinese scallop , chinese venus , surf clam , asiatic hard clam , soft-shell clam , blue mussel , bladder moon snail , crassostrea talienwhanensis , veined rapa whelk , ark clam	2009-2010	131	1.0	0.2	1.9	Medium
Zhu et al. (2017b)	CN	Near facility	Mantis shrimp, helice crab	2014	16	1.0	0.022	1.7	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3.2.2. Aquatic Invertebrates (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Aquatic Invertebrates with unit of ng/g, extracted from 24 sources, are summarized in Figure 3-3 and supplemental information is provided in Table 3-3. Overall, concentrations ranged from not-detected to 362,900 ng/g from over 741 samples collected between 1999 and 2013 in at least 10 countries, including CA, NL, US, IT, FR, GB, KR, NO, CN, and JP. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.17 to 1.0.

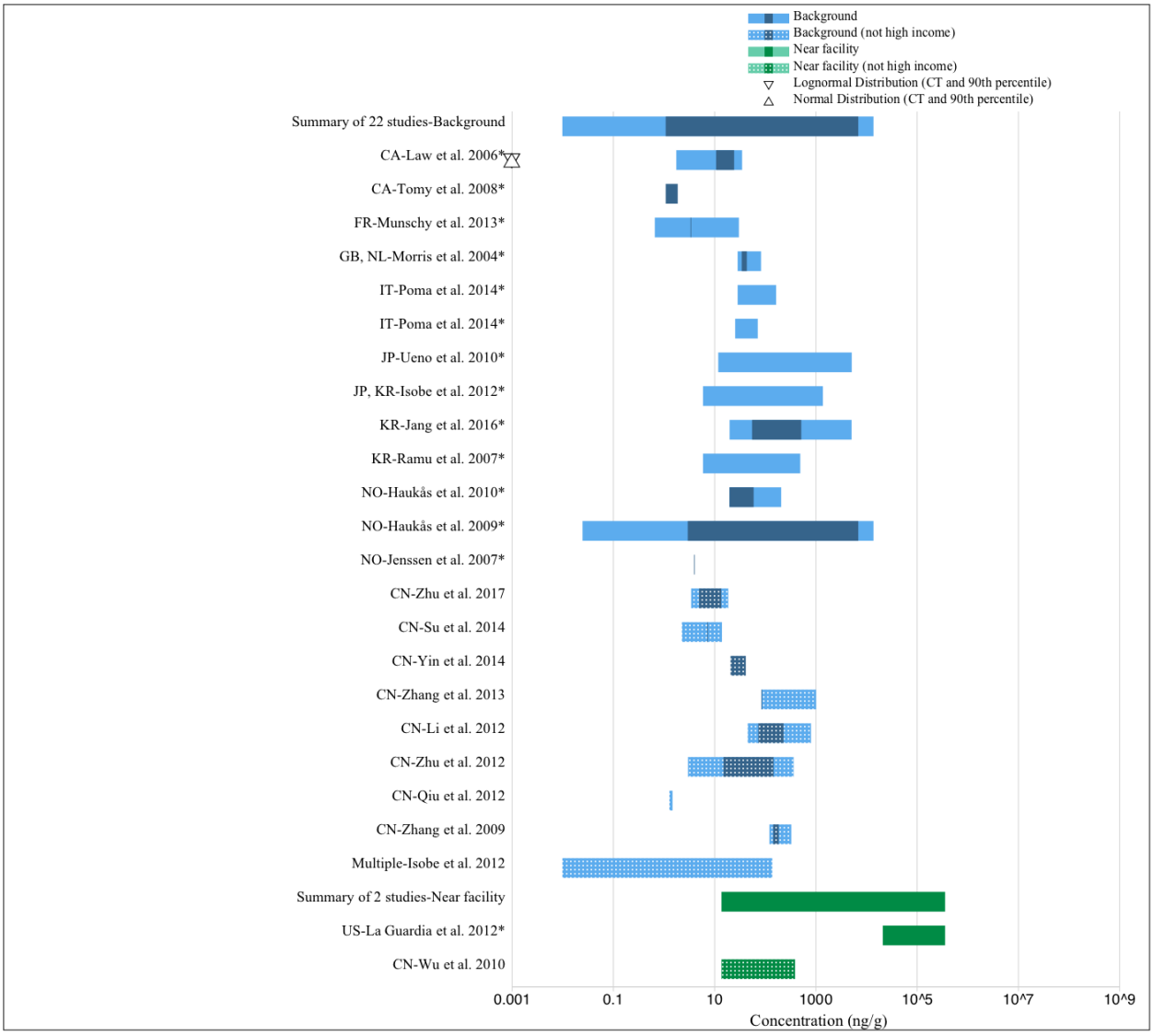


Figure 3-3. Concentration of HBCD (ng/g) in the Lipid Fraction of Aquatic Invertebrates in Background and Near Facility Locations from 2003 to 2011

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-3. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Aquatic Invertebrates

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Law et al. (2006a)	CA*	Background	Mussels (muscle), zooplankton, phytoplankton, and small fish	2002	10	1.0	0.16	1.2	High
Tomy et al. (2008)	CA*	Background	Copepods , shrimp , clams	2000-2002	15	N/R	0.0042	1.7	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Munschy et al. (2013)	FR*	Background	Filter-feeding molluscs	2008-2010	17	1.0	0.006	2.2	Low
Morris et al. (2004)	GB, NL*	Background	Whelk , sea star (digestive system)	1999	6	N/R	1.2	2.3	Low
Poma et al. (2014c)	IT*	Background	Zooplankton	2011-2012	4	1.0	0.1	1.2	High
Poma et al. (2014a)	IT*	Background	Dreissena polymorpha	2011-2012	32	1.0	0.01	1.9	Medium
Ueno et al. (2010)	JP*	Background	Oysters , blue mussels	2005	26	1.0	0.3	1.8	Medium
Isobe et al. (2012)	JP, KR*	Background	Green and blue mussels	2003-2008	41	1.0	0.01	2.4	Low
Jang et al. (2016)	KR*	Background	Mussels	2013	63	N/R	N/R	1.7	Medium
Ramu et al. (2007)	KR*	Background	Blue mussels	2005	17	1.0	0.015	2.0	Medium
Haukås et al. (2010a)	NO*	Background	Blue mussels (whole specimen), shorecrab (whole specimen with exoskeleton), lugworm (whole specimen)	2006-2007	34	0.79	N/R	1.9	Medium
Haukås et al. (2009)	NO*	Background	Lugworm, blue mussel , shore crab	2006-2007	65	0.88	0.05	1.9	Medium
Jenssen et al. (2007)	NO*	Background	Zooplankton	2003	3	N/R	N/R	1.6	High
Zhu et al. (2017a)	CN	Background	Apple snail , stone snail	2012-2013	8	1.0	N/R	2.0	Low
Su et al. (2014)	CN	Background	Shrimp (whole organism)	2009-2012	N/R	N/R	N/R	2.2	Medium
Yin et al. (2014)	CN	Background	Blue mussel (whole tissue), clam (whole tissue)	2010-2011	18	1.0	N/R	1.8	Medium
Zhang et al. (2013)	CN	Background	Chinese mystery snail, chinese mitten crab, mantis shrimp, veinadrapa whelk, helice crab, octopus	2011	28	1.0	0.022	1.7	Medium
Li et al. (2012b)	CN	Background	Crab (spermary, ovary, gill), freshwater shrimp (whole body)	2011	171	1.0	N/R	1.1	High

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Zhu et al. (2012)	CN	Background	Amusium veneriformis, Chinese scallop, Chinese venus, surf clam, asiatic hard clam, soft-shell clam, blue mussel, bladder moon snail, crassostrea talienwhanensis, veined rapa whelk, ark clam	2009-2010	131	1.0	0.2	1.9	Medium
Qiu et al. (2012)	CN	Background	Crawfish (butter-like gland)	2007	1	1.0	N/R	2.0	Medium
Zhang et al. (2009)	CN	Background	Winkle	2006	9	1.0	N/R	1.8	Medium
Isobe et al. (2012)	Multiple	Background	Green and blue mussels	2003-2008	29	0.97	0.01	2.4	Low
La Guardia et al. (2012)	US*	Near facility	Filter feeding bivalve, filter-feeding bivalve, grazing gastropod,	2009	7	1.0	1.0	1.7	Medium
Wu et al. (2010)	CN	Near facility	Snail, prawn	2006	6	0.17	3.0	2.0	Medium

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

3.2.3. Aquatic Invertebrates (ng/g) – Wet Fraction

Measured concentrations of HBCD in Aquatic Invertebrates with unit of ng/g, extracted from 6 sources, are summarized in Figure 3-4 and supplemental information is provided in Table 3-4. Overall, concentrations ranged from not-detected to 7.0 ng/g from over 347 samples collected between 2002 and 2014 in 6 countries, Int. Waters, SG, CA, NL, NO, and KR. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.97 to 1.0.

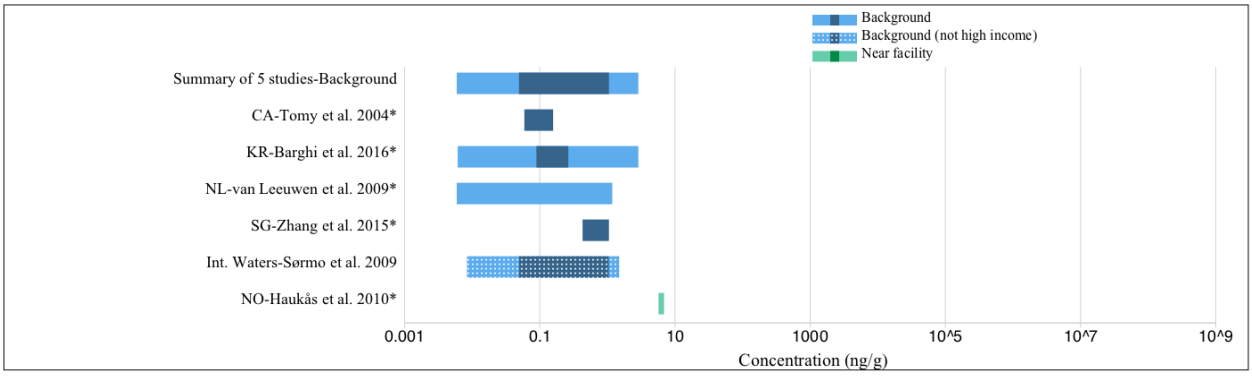


Figure 3-4. Concentration of HBCD (ng/g) in the Wet Fraction of Aquatic Invertebrates in Background and Near Facility Locations from 2002 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-4. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Aquatic Invertebrates

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Tomy et al. (2004)	CA*	Background	Mysis (shrimp), diporeia (shrimp), plankton	2002	6	1.0	N/R	2.0	Medium
Barghi et al. (2016)	KR*	Background	Multiple species	2012-2014	248	N/R	0.0062	1.3	High
van Leeuwen et al. (2009)	NL*	Background	Shrimp (shrimp)	2007-2008	6	1.0	N/R	2.1	Medium
Zhang et al. (2015)	SG*	Background	Polychaete (tissue), clam (tissue)	2014	11	N/R	0.0054	1.7	Medium
Sørmo et al. (2009)	Int. Waters	Background	Calanoid copepods (whole specimen), whiting (whole specimen), sand goby (whole specimen), black goby (whole specimen), northern shrimp (whole specimen), shore shrimp (whole specimen), saithe (whole specimen), sandeels (whole specimen)	2003-2004	34	0.97	0.017	2.1	Medium
Haukås et al. (2010b)	NO*	Near facility	Mussels (soft tissue)	2007	42	1.0	N/R	1.9	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3.3. Aquatic Mammals

3.3.1. Aquatic Mammals (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Aquatic Mammals with unit of ng/g, extracted from 27 sources, are summarized in Figure 3-5 and supplemental information is provided in Table 3-5. Overall, concentrations ranged from not-detected to 9590.0 ng/g from over 1590 samples collected between 1972 and 2013 in at least 10 countries, including HK, CA, ES, GL, US, FR, GB, NO, CN, and JP. Location types were categorized as Background. Reported detection frequencies ranged from 0.94 to 1.0.

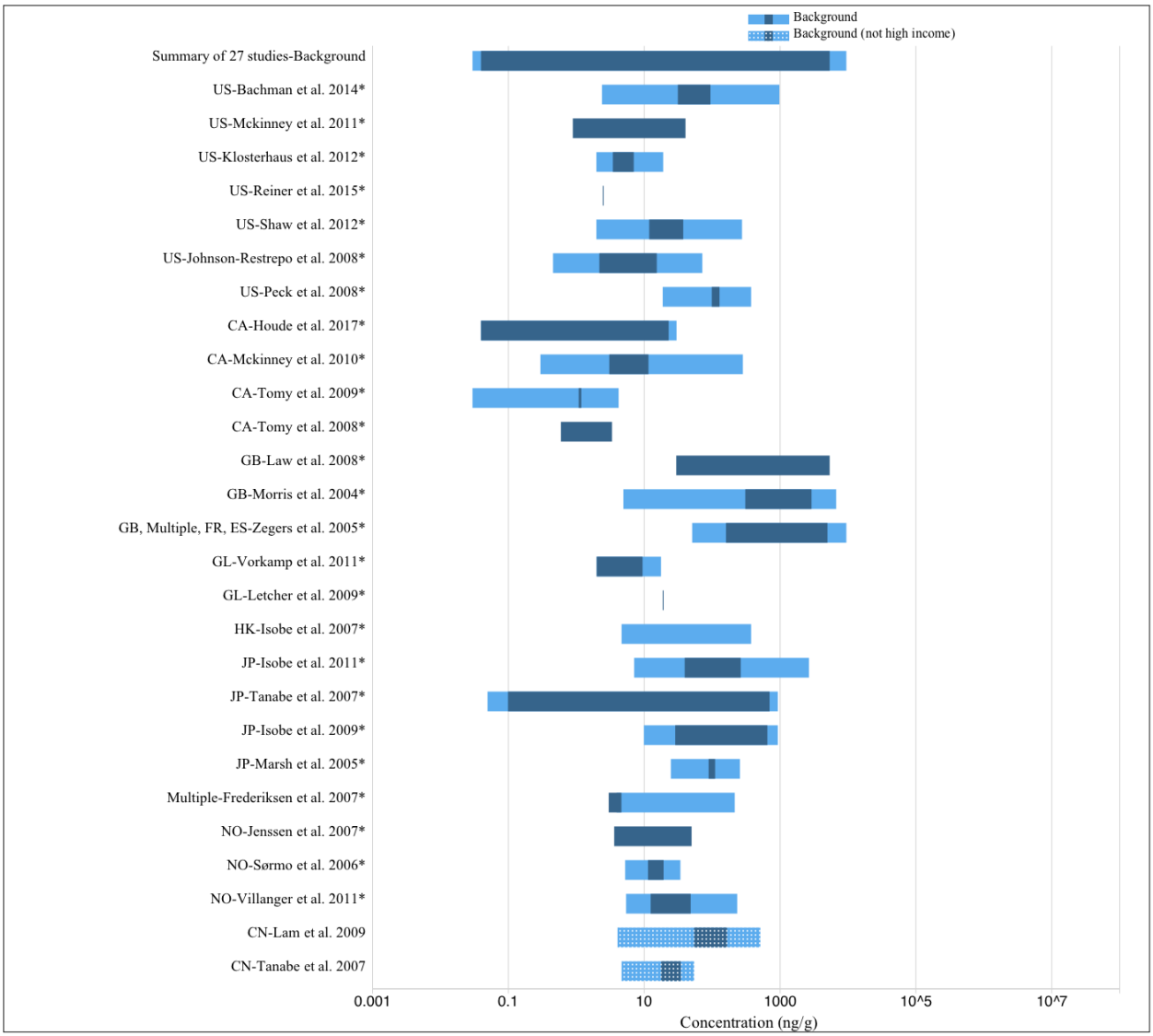


Figure 3-5. Concentration of HBCD (ng/g) in the Lipid Fraction of Aquatic Mammals in Background Locations from 1972 to 2013

*** Study conducted in a country/countries classified as "High Income" by the World Bank.**

Table 3-5. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Aquatic Mammals

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Bachman et al. (2014)	US*	Background	Pygmy killer whale, longman's beaked whale, pygmy sperm whale, dwarf sperm whale, humpback whale, blainville's beaked whale, killer whale, melon-headed whale, sperm whale, false killer whale, spotted dolphin, striped dolphin, spinner dolphin, rough-toothed dolphin, bottlenose dolphin, and cuvier's beaked whale (blubber)	1997-2011	42	N/R	2.4	1.9	Medium
McKinney et al. (2011)	US*	Background	Polar bear (adipose tissue)	2006-2008	144	N/R	0.3	1.9	Medium
Klosterhaus et al. (2012)	US*	Background	Adult harbor seals (blubber), harbor seal (blubber)	2007-2008	17	1.0	N/R	1.7	Medium
Reiner et al. (2015)	US*	Background	Northern fur seal (blubber)	1987-2007	50	0.96	N/R	1.8	Medium
Shaw et al. (2012)	US*	Background	Harbor seals (seal liver), harbor seals (seal blubber)	2001-2006	65	1.0	5.5	1.8	Medium
Johnson-Restrepo et al. (2008)	US*	Background	Bottlenose dolphin (blubber)	1991-2004	15	1.0	0.0013	1.9	Medium
Peck et al. (2008)	US*	Background	White-sided dolphins (blubber)	1993-2004	57	1.0	0.4	1.8	Medium
Houde et al. (2017)	CA*	Background	Ringed seals (blubber)	1998-2013	370	N/R	N/R	2.0	Medium
McKinney et al. (2010)	CA*	Background	Polar bear	1991-2008	92	N/R	0.3	2.0	Medium
Tomy et al. (2009)	CA*	Background	Beluga (blubber and liver), ringed seal	2004-2007	18	N/R	N/R	2.4	Low
Tomy et al. (2008)	CA*	Background	Walrus , beluga , narwhal	1996-2000	15	N/R	0.023	1.7	Medium
Law et al. (2008)	GB*	Background	Porpoises (blubber)	1995-2006	222	1.0	N/R	2.0	Medium
Morris et al. (2004)	GB*	Background	Porpoise (blubber), harbor seal (blubber), harbor porpoise (blubber)	1998-1999	11	N/R	1.2	2.3	Low
Zegers et al. (2005)	GB, Multiple, FR, ES*	Background	Harbor porpoises (blubber), common dolphins (blubber)	2005	104	1.0	N/R	2.0	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Vorkamp et al. (2011)	GL*	Background	Ringed seal (blubber)	1986-2008	50	N/R	2.5	2.0	Medium
Letcher et al. (2009)	GL*	Background	Ringed seals (blubber)	2001-2002	15	1.0	N/R	2.1	Medium
Isobe et al. (2007)	HK*	Background	Finless porpoises (blubber), indo-pacific humpback dolphins (blubber)	1990-2001	19	1.0	N/R	2.4	Low
Isobe et al. (2011)	JP*	Background	Finless porpoises (blubber)	1999-2007	51	0.96	N/R	1.9	Medium
Tanabe et al. (2007)	JP*	Background	Fur seal (blubber), striped dolphin (blubber), melon-headed whale (blubber)	1972-2006	70	0.96	0.1	2.0	Medium
Isobe et al. (2009a)	JP*	Background	Striped dolphins (blubber)	1978-2003	21	1.0	N/R	1.9	Medium
Marsh et al. (2005)	JP*	Background	Striped dolphin (fresh blubber and cooked liver), bottlenose dolphin (sliced bacon), minke whale (fresh blubber), baird's beaked whale (shredded bacon)	1999	5	1.0	N/R	2.2	Medium
Frederiksen et al. (2007)	Multiple *	Background	Minke whale (blubber), pilot whale (blubber), pilot whale (liver), polar bear (adipose), polar bear (liver), ringed seal (blubber), ringed seal (liver), minke whale (liver), ringed seal (blubber) w greenland	2006	32	0.94	7.9	2.1	Medium
Jenssen et al. (2007)	NO*	Background	Harbor seals (blubber), ringed seals (blubber)	1998-2003	25	N/R	N/R	1.6	High
Sørmo et al. (2006)	NO*	Background	Polar bear (adipose tissue), ringed seal (blubber)	2003	10	N/R	N/R	2.2	Medium
Villanger et al. (2011)	NO*	Background	White whale (blubber)	1996-2001	9	1.0	2.5	2.0	Medium
Lam et al. (2009)	CN	Background	Dolphins , porpoises	2002-2008	49	1.0	0.9	1.9	Medium
Tanabe et al. (2007)	CN	Background	Finless porpoise (blubber)	1990-2001	12	1.0	N/R	2.0	Medium

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

3.3.2. Aquatic Mammals (ng/g) – Wet Fraction

Measured concentrations of HBCD in Aquatic Mammals with unit of ng/g, extracted from 5 sources, are summarized in Figure 3-6 and supplemental information is provided in Table 3-6.

Overall, concentrations ranged from not-detected to 19208.0 ng/g from over 142 samples collected between 1993 and 2012 in 4 countries, GB, NO, US, and GL. Location types were categorized as Background. Reported detection frequencies ranged from 0.13 to 1.0.

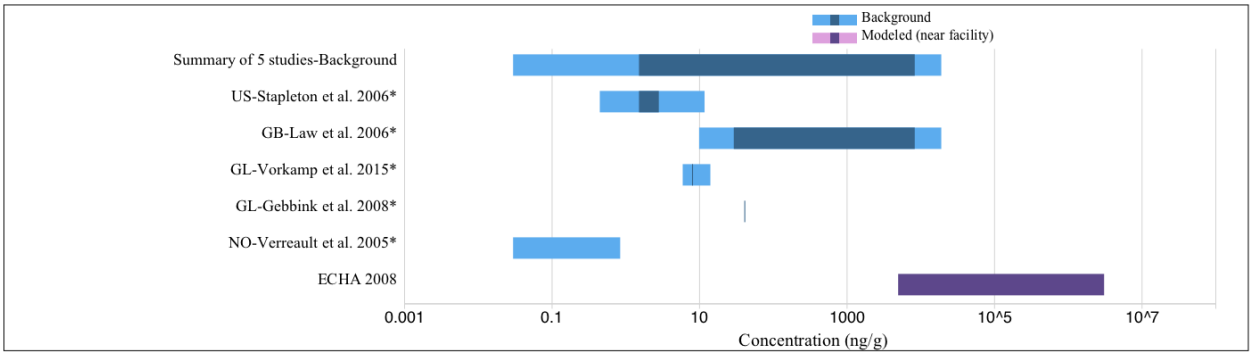


Figure 3-6. Concentration of HBCD (ng/g) in the Wet Fraction of Aquatic Mammals in Background Locations and for Modeled Data from 1993 to 2012

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-6. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Aquatic Mammals

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Stapleton et al. (2006)	US*	Background	California sea lions	1993-2003	25	0.8	0.9	1.3	High
Law et al. (2006c)	GB*	Background	Harbor porpoises (blubber)	1994-2003	84	1.0	N/R	1.9	Medium
Vorkamp et al. (2015)	GL*	Background	Ringed seal (blubber)	2012	5	1.0	N/R	1.2	High
Gebbink et al. (2008)	GL*	Background	Polar bear (tissue)	1999-2001	13	0.62	N/R	2.0	Medium
Verreault et al. (2005)	NO*	Background	Polar bears	2002	15	0.13	0.03	1.4	High
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3.4. Birds

3.4.1. Birds (ng/g) – Dry Fraction

Measured concentrations of HBCD in Birds with unit of ng/g, extracted from 3 sources, are summarized in Figure 3-7 and supplemental information is provided in Table 3-7. Overall, concentrations ranged from not-detected to 1000.0 ng/g from over 143 samples collected between 2006 and 2011 in 3 countries, FR, BE, and DE. Location types were categorized as Background. Reported detection frequencies ranged from 0.5 to 1.0.

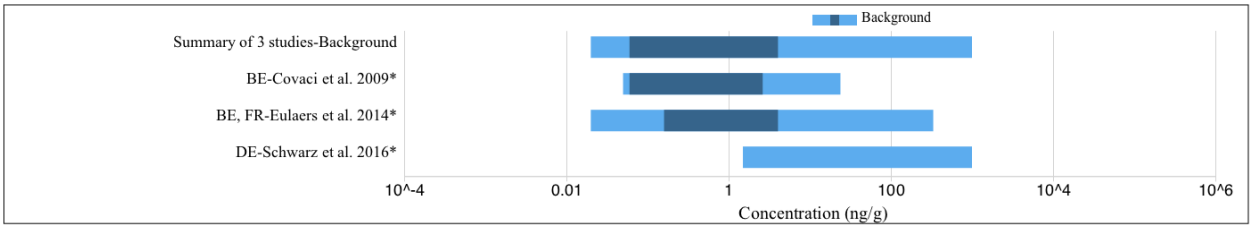


Figure 3-7. Concentration of HBCD (ng/g) in the Dry Fraction of Birds in Background Locations from 2006 to 2011

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-7. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Birds

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Covaci et al. (2009)	BE*	Background	Chickens (feces)	2006-2007	20	0.6	0.1	1.8	Medium
Eulaers et al. (2014)	BE, FR*	Background	Barn owl (feathers)	2008-2009	73	1.0	N/R	2.0	Medium
Schwarz et al. (2016)	DE*	Background	Peregrine falcon (egg contents)	2006-2011	50	0.5	3.0	2.2	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3.4.2. Birds (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Birds with unit of ng/g, extracted from 51 sources, are summarized in Figure 3-8 and supplemental information is provided in Table 3-8. Overall, concentrations ranged from not-detected to 19200.0 ng/g from over 2253 samples collected between 1969 and 2014 in at least 18 countries, including CA, ES, GL, FR, NO, CN, DE, ZA, IS, NL, PL, SE, US, VN, KR, JP, BE, and GB. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.05 to 1.0.

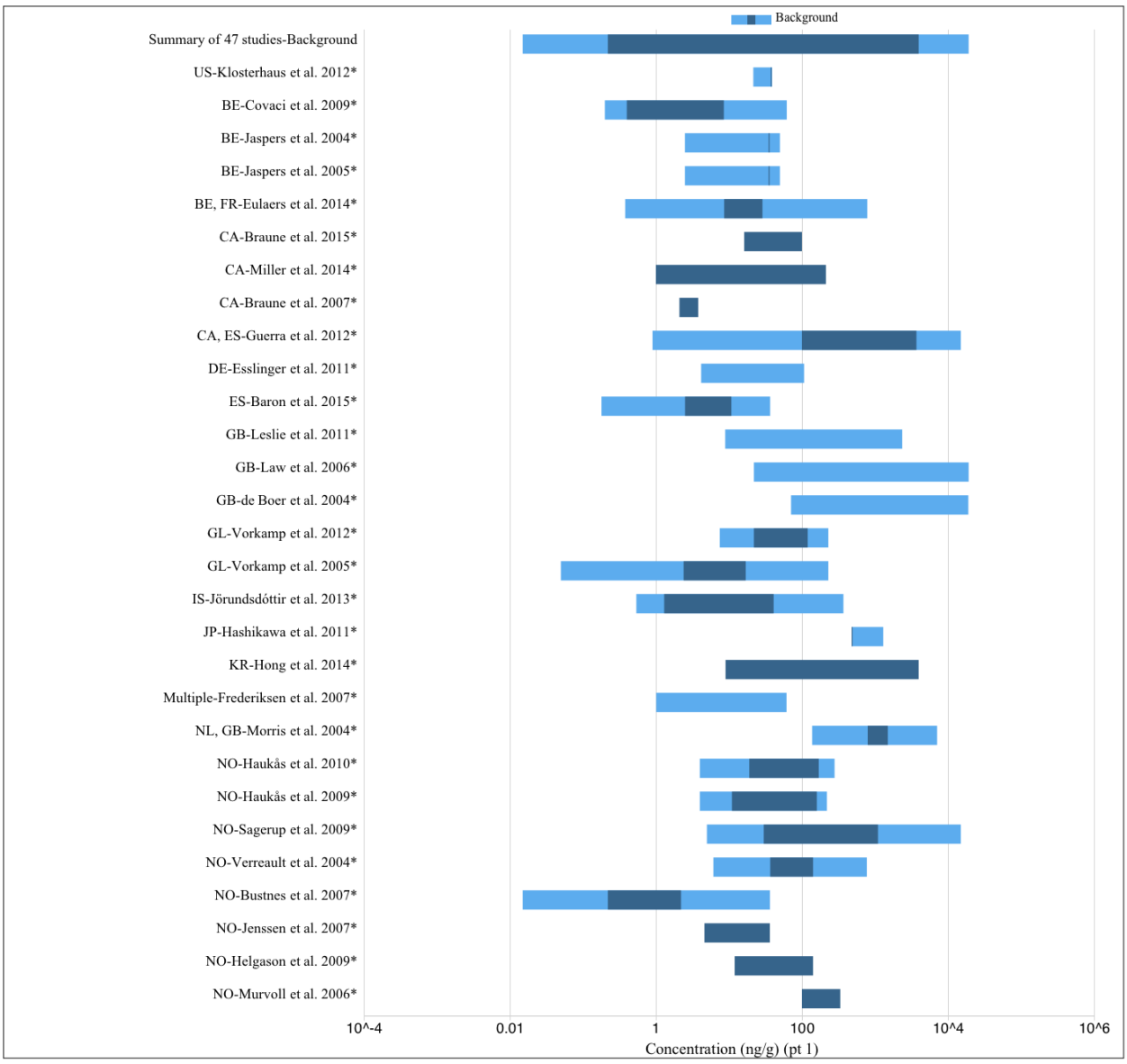


Figure 3-8. Concentration of HBCD (ng/g) in the Lipid Fraction of Birds in Background and Near Facility Locations from 1969 to 2014

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 3-8. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Birds

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Klosterhaus et al. (2012)	US*	Background	Double-crested cormorant (eggs)	2008	3	1.0	N/R	1.7	Medium
Covaci et al. (2009)	BE*	Background	Chicken (eggs), chickens (eggs)	2006-2007	20	0.55	0.4	1.8	Medium
Jaspers et al. (2004)	BE*	Background	Little owl (eggs)	1998-2000	40	0.05	5.0	2.2	Medium
Jaspers et al. (2005)	BE*	Background	Little owls	1998-2000	40	0.05	5.0	2.2	Medium
Eulaers et al. (2014)	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	1.0	N/R	2.0	Medium
Braune et al. (2015)	CA*	Background	Glaucous gull (eggs), black-legged kitiwake (eggs)	2008-2013	51	N/R	1.0	1.9	Medium
Miller et al. (2014b)	CA*	Background	Rhinoceros auklets (eggs), leach's storm-petrel (eggs), ancient murrelet (eggs)	1990-2011	25	0.68	1.0	1.9	Medium
Braune et al. (2007)	CA*	Background	Ivory gull (eggs)	1976-2004	24	1.0	0.3	2.0	Medium
Guerra et al. (2012)	CA, ES*	Background	Peregrine falcon (eggs)	2003-2009	25	0.8	N/R	1.8	Medium
Esslinger et al. (2011)	DE*	Background	Herring gulls (eggs)	1988-2008	26	N/R	0.00025	1.7	Medium
Baron et al. (2015)	ES*	Background	Black kite, white stork, greater flamingo	1999-2013	108	N/R	0.7	1.4	High
Leslie et al. (2011)	GB*	Background	Peregrine falcon (eggs), sparrow hawk (muscle)	1973-2002	127	0.17	N/R	1.7	Medium
Law et al. (2006b)	GB*	Background	Falcon (eggs), sparrowhawk (muscle)	1973-2002	21	0.19	N/R	1.8	Medium
de Boer et al. (2004)	GB*	Background	Falcon (eggs), sparrowhawk (muscle)	1973-2002	116	0.18	N/R	1.9	Medium
Vorkamp et al. (2012)	GL*	Background	Gulls (liver)	1994-2010	44	1.0	0.76	2.1	Medium
Vorkamp et al. (2005)	GL*	Background	Falcon (eggs)	1986-2003	33	0.88	0.1	2.0	Medium
Jörundsdóttir et al. (2013)	IS*	Background	Guillemot (eggs), fulmar (eggs), arctic tern (eggs), common eider (eggs), gulls (eggs), great skua (eggs)	2002-2004	63	N/R	4.7	2.0	Medium
Hashikawa et al. (2011)	JP*	Background	Common cormorants (muscle)	1993-2007	41	N/R	N/R	2.3	Low

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Hong et al. (2014)	KR*	Background	Gull (muscle), pigeon (muscle), loon (muscle), heron, egrets (muscle)	2009	15	1.0	N/R	1.9	Medium
Frederiksen et al. (2007)	Multiple*	Background	Black guillemot (egg), black guillemot (liver), fulmar (liver), fulmar (subcutaneous fat)	2006	20	0.9	4.6	2.1	Medium
Morris et al. (2004)	NL, GB*	Background	Tern (eggs), cormorant (liver)	1999-2001	15	1.0	1.2	2.3	Low
Haukås et al. (2010a)	NO*	Background	Great blackbeaked gull (whole seabird eggs without shell), common eider (whole seabird eggs without shell)	2006-2007	55	1.0	N/R	1.9	Medium
Haukås et al. (2009)	NO*	Background	Common eider	2006-2007	32	1.0	0.05	1.9	Medium
Sagerup et al. (2009)	NO*	Background	Gulls (liver), gulls (brain)	2003-2005	42	1.0	0.3	2.0	Medium
Verreault et al. (2004)	NO*	Background	Glaucous gulls	2002-2004	30	1.0	N/R	1.2	High
Bustnes et al. (2007)	NO*	Background	Owl (eggs)	1986-2004	139	0.24	0.03	1.8	Medium
Jenssen et al. (2007)	NO*	Background	Common terns (eggs), arctic terns (eggs)	2003	30	N/R	N/R	1.6	High
Helgason et al. (2009)	NO*	Background	Herring (eggs), kittiwake (eggs), puffin (eggs)	1983-2003	89	1.0	N/R	1.7	Medium
Murvoll et al. (2006b)	NO*	Background	North atlantic kittiwake (yolk sac)	2002	37	N/R	1.5	2.1	Medium
Murvoll et al. (2007)	NO*	Background	Brunnich's guillemot (yolk sac), common eider (yolk sac)	2002	23	0.43	1.5	2.1	Medium
Murvoll et al. (2006a)	NO*	Background	European shag (yolk sac)	2002	30	1.0	1.5	2.1	Medium
Sørmo et al. (2011)	NO*	Background	Herring gulls (liver)	1998	16	1.0	N/R	1.8	Medium
Reindl and Falkowska (2014)	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	1.0	1.4	2.2	Medium
Johansson et al. (2011)	SE*	Background	Peregrine falcons (eggs)	1974-2007	25	0.72	20.0	1.6	High
Nordlöf et al. (2010)	SE*	Background	Sea eagle (eggs)	1992-2005	44	1.0	13.0	1.9	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Lundstedt-Enkel et al. (2006)	SE*	Background	Baltic sea guillemot (eggs), baltic sea guillemot (muscle)	2000-2002	50	N/R	N/R	2.0	Medium
Sellström et al. (2003)	SE*	Background	Guillemot (eggs)	1969-2001	137	1.0	N/R	1.8	Medium
Lundstedt-Enkel et al. (2005)	SE*	Background	Guillemot	2000	30	N/R	N/R	2.0	Medium
Lindberg et al. (2004)	SE*	Background	Falcon	1987-1999	21	0.81	N/R	2.0	Medium
Johansson et al. (2009)	SE*	Background	Peregrine falcons (eggs)	1991-1999	34	0.94	11.0	1.7	Medium
Sun et al. (2012)	CN	Background	Bulbul (muscle), shrike (muscle), oriental magpie-robin (muscle)	2009-2011	39	N/R	1.0	1.9	Medium
Zhang et al. (2013)	CN	Background	Herring gull	2011	3	1.0	0.022	1.7	Medium
Yu et al. (2014)	CN	Background	Tree sparrow (muscle), common magpie (muscle)	2009-2011	68	1.0	1.6	1.9	Medium
Zheng et al. (2012)	CN	Background	Hens	2010	8	1.0	4.7	1.9	Medium
He et al. (2010)	CN	Background	Pond heron (muscle), white-breasted waterhen (muscle), common snipe (muscle), slaty-breasted rail (muscle), spotted dove (muscle), chinese francolin (muscle)	2005-2008	40	N/R	3.0	1.2	High
Yu et al. (2013)	CN	Background	Common kestrel , eagle owl , eurasian tree sparrow	2005-2007	87	1.0	0.3	2.0	Medium
Polder et al. (2008c)	ZA	Background	African darter, reed cormorant, cattle egret, african sacred ibis, crowned plover, little grebe, white-fronted plover, kelp gull (eggs)	2004-2005	43	N/R	0.2	1.9	Medium
Haukås et al. (2009)	NO*	Near facility	Great black backed gull	2006-2007	42	1.0	0.05	1.9	Medium
Sun et al. (2012)	CN	Near facility	Bulbul (muscle), shrike (muscle), oriental magpie-robin (muscle)	2009-2011	30	N/R	1.0	1.9	Medium
Zheng et al. (2012)	CN	Near facility	Hens	2010	33	1.0	4.7	1.9	Medium
Tao et al. (2016)	VN	Near facility	Chicken (eggs), chicken muscle, liver, and skin	2014	30	1.0	0.05	2.0	Medium

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

3.4.3. Birds (ng/g) – Wet Fraction

Measured concentrations of HBCD in Birds with unit of ng/g, extracted from 18 sources, are summarized in Figure 3-9 and supplemental information is provided in Table 3-9. Overall, concentrations ranged from not-detected to 292 ng/g from over 825 samples collected between 2001 and 2013 in 5 countries, CA, GL, US, RU, and NO. Location types were categorized as Background. Reported detection frequencies ranged from 0.00 to 1.0.

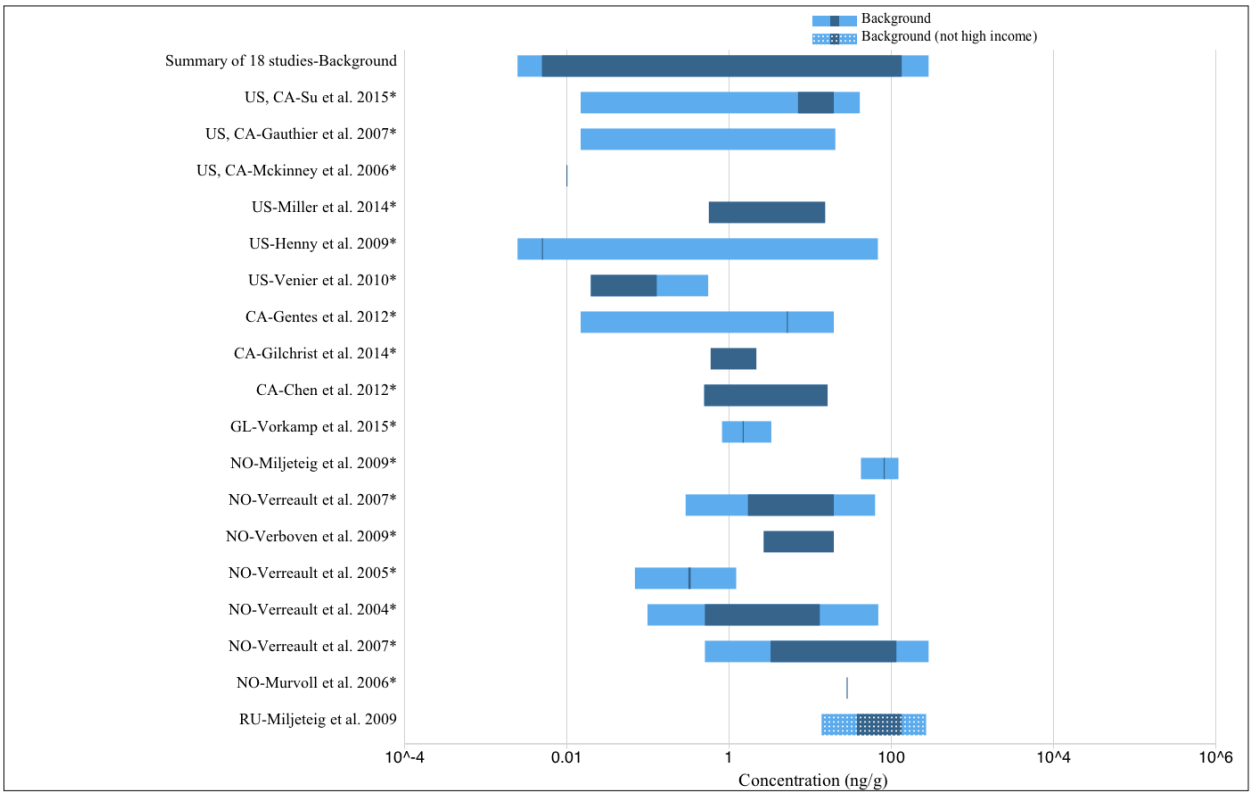


Figure 3-9. Concentration of HBCD (ng/g) in the Wet Fraction of Birds in Background Locations from 2001 to 2013

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-9. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Birds

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Su et al. (2015a)	US, CA*	Background	Herring gull (eggs)	2012-2013	130	0.98	0.03	1.3	High
Gauthier et al. (2007)	US, CA*	Background	Herring gulls (eggs)	2004	6	0.83	0.03	1.9	Medium
McKinney et al. (2006)	US, CA*	Background	Bald eagle (plasma)	2001-2003	29	0.0	0.01	2.0	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Miller et al. (2014a)	US*	Background	Double-crested cormorant (egg), great blue heron (egg)	2003-2012	50	N/R	1.0	2.2	Medium
Henny et al. (2009)	US*	Background	Osprey (eggs), cormorant (eggs)	2002-2007	119	0.11	0.005	2.0	Medium
Venier et al. (2010)	US*	Background	Bald eagle	2005	15	0.47	N/R	1.7	Medium
Gentes et al. (2012)	CA*	Background	Ring-billed gull (plasma), ring-billed gull (liver)	2010	58	0.43	0.03	1.4	High
Gilchrist et al. (2014)	CA*	Background	Tree swallows (eggs)	2007-2010	87	N/R	N/R	1.9	Medium
Chen et al. (2012)	CA*	Background	Gulls: glaucous-winged, california, ring-billed, herring	2008	26	N/R	0.28	1.9	Medium
Vorkamp et al. (2015)	GL*	Background	Glaucous gull (liver)	2012	4	1.0	N/R	1.2	High
Miljeteig et al. (2009)	NO*	Background	Ivory gull (eggs)	2007	10	N/R	N/R	1.4	High
Verreault et al. (2007a)	NO*	Background	Glaucous gulls (blood plasma), glaucaus gull (blood plasma), glaucaus gull (egg yolk)	2006	80	0.76	0.59	1.6	High
Verboven et al. (2009)	NO*	Background	Gulls (eggs), gulls (plasma)	2006	42	N/R	N/R	1.9	Medium
Verreault et al. (2005)	NO*	Background	Gulls	2004	27	1.0	0.03	1.4	High
Verreault et al. (2004)	NO*	Background	Glaucous gulls	2002-2004	30	1.0	N/R	1.2	High
Verreault et al. (2007b)	NO*	Background	Glaucous gulls (blood), glaucous gulls (liver), glaucous gulls (whole body homogenate with feathers), glaucous gulls (whole body homogenate without feathers)	2002	57	1.0	N/R	1.6	High
Murvoll et al. (2006a)	NO*	Background	European shag (yolk sac)	2002	30	1.0	1.5	2.1	Medium
Miljeteig et al. (2009)	RU	Background	Ivory gull (eggs)	2006	25	N/R	N/R	1.4	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

3.5. Fish

3.5.1. Fish (ng/g) – Dry Fraction

Measured concentrations of HBCD in Fish with unit of ng/g, extracted from 5 sources, are summarized in Figure 3-10 and supplemental information is provided in Table 3-10. Overall, concentrations ranged from not-detected to 1,800 ng/g from over 100 samples collected between 2000 and 2014 in 3 countries, FR, SE, and CN. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.65 to 1.0.

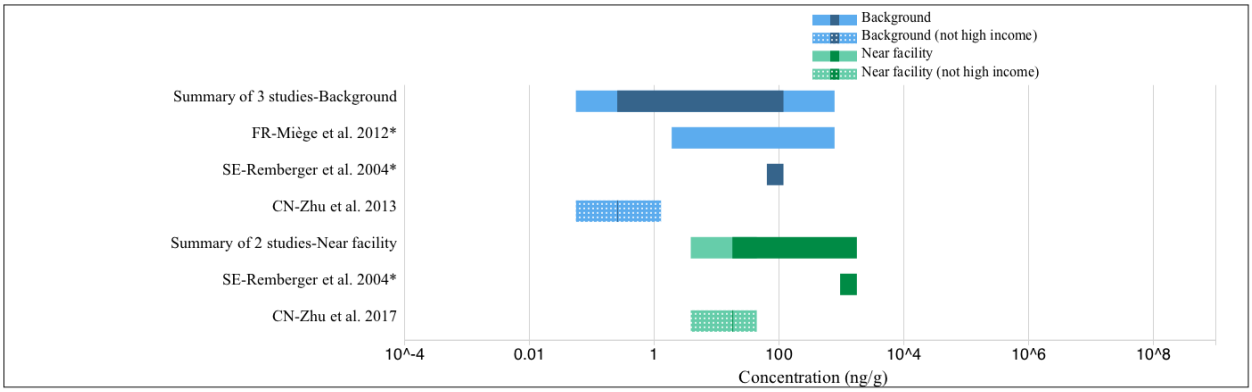


Figure 3-10. Concentration of HBCD (ng/g) in the Dry Fraction of Fish in Background and Near Facility Locations from 2000 to 2014

*Study conducted in a country/countries classified as "High Income" by the World Bank

Table 3-10. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Dry Fraction of Fish

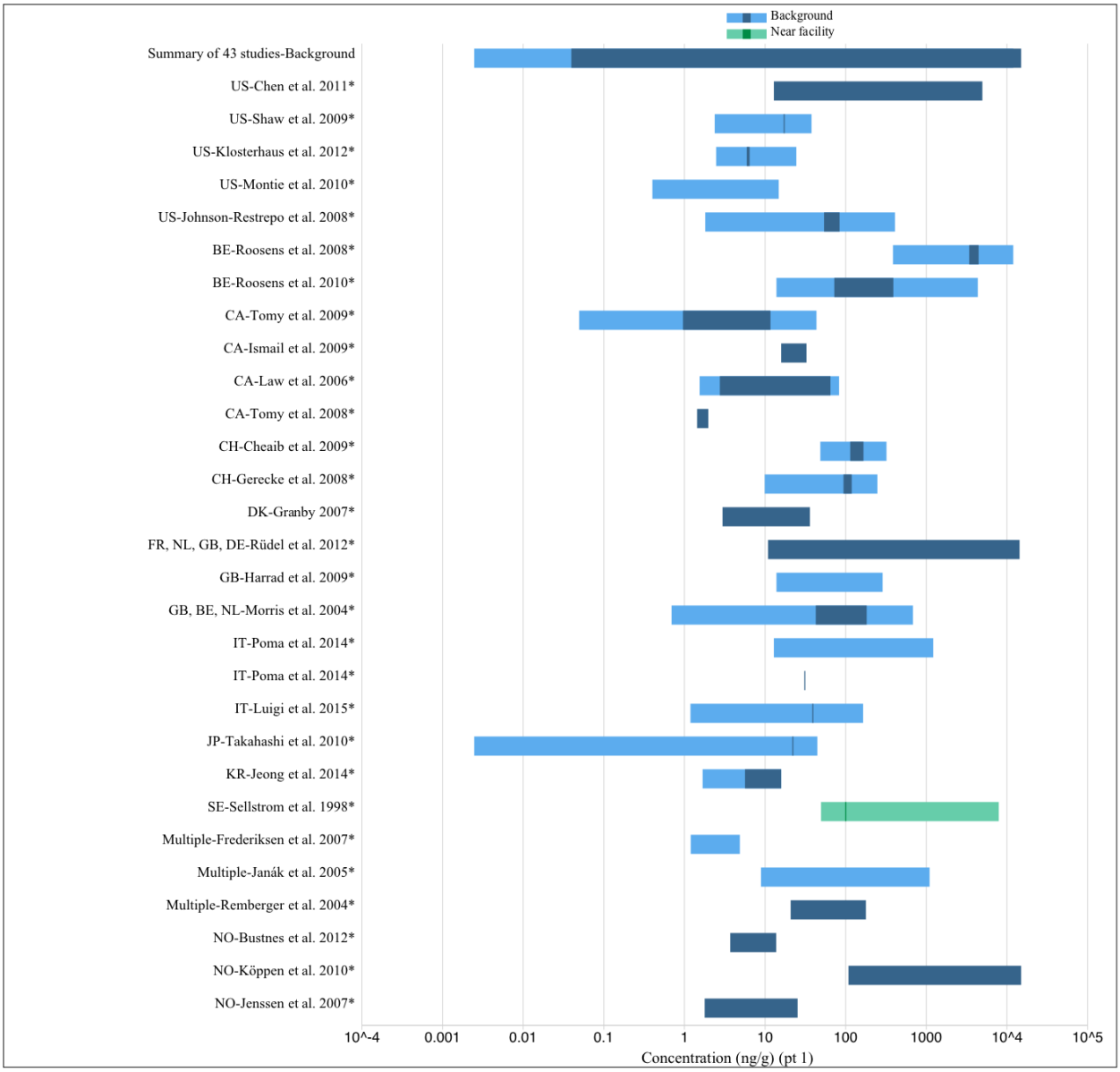
Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Miège et al. (2012)	FR*	Background	Barbel, common bream, white bream and chub (whole specimen)	2008-2009	32	1.0	0.36	1.7	Medium
Remberger et al. (2004)	SE*	Background	Pike (muscle) and eel	2000	4	1.0	N/R	1.8	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Zhu et al. (2013)	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
Remberger et al. (2004)	SE*	Near facility	Pike (muscle) and eel	2000	4	1.0	N/R	1.8	Medium
Zhu et al. (2017b)	CN	Near facility	Bartial flathead	2014	8	1.0	0.022	1.7	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3.5.2. Fish (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Fish with unit of ng/g, extracted from 48 sources, are summarized in Figure 3-11 and supplemental information is provided in Table 3-11. Overall, concentrations ranged from not-detected to 15,158.39 ng/g from over 1602 samples collected between 1979 and 2014 in at least 22 countries, including CA, FR, NO, CN, LA, DE, ZA, NL, CH, PL, SE, ID, US, TZ, VN, KR, JP, DK, IT, BE, GB, and GH. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.33 to 1.0.


Background
Near facility
Summary of 43 studies-Background
US-Chen et al. 2011*
US-Shaw et al. 2009*
US-Klosterhaus et al. 2012*
US-Montie et al. 2010*
US-Johnson-Restrepo et al. 2008*
BE-Roosens et al. 2008*
BE-Roosens et al. 2010*
CA-Tomy et al. 2009*
CA-Ismail et al. 2009*
CA-Law et al. 2006*
CA-Tomy et al. 2008*
CH-Cheaib et al. 2009*
CH-Gerecke et al. 2008*
DK-Granby 2007*
FR, NL, GB, DE-Rüdel et al. 2012*
GB-Harrad et al. 2009*
GB, BE, NL-Morris et al. 2004*
IT-Poma et al. 2014*
IT-Poma et al. 2014*
IT-Luigi et al. 2015*
JP-Takahashi et al. 2010*
KR-Jeong et al. 2014*
SE-Sellstrom et al. 1998*
Multiple-Frederiksen et al. 2007*
Multiple-Janák et al. 2005*
Multiple-Remberger et al. 2004*
NO-Bustnes et al. 2012*
NO-Köppen et al. 2010*
NO-Jenssen et al. 2007*
10^-4
0.001
0.01
0.1
1
10
100
1000
10^4
10^5
Concentration (ng/g) (pt 1)

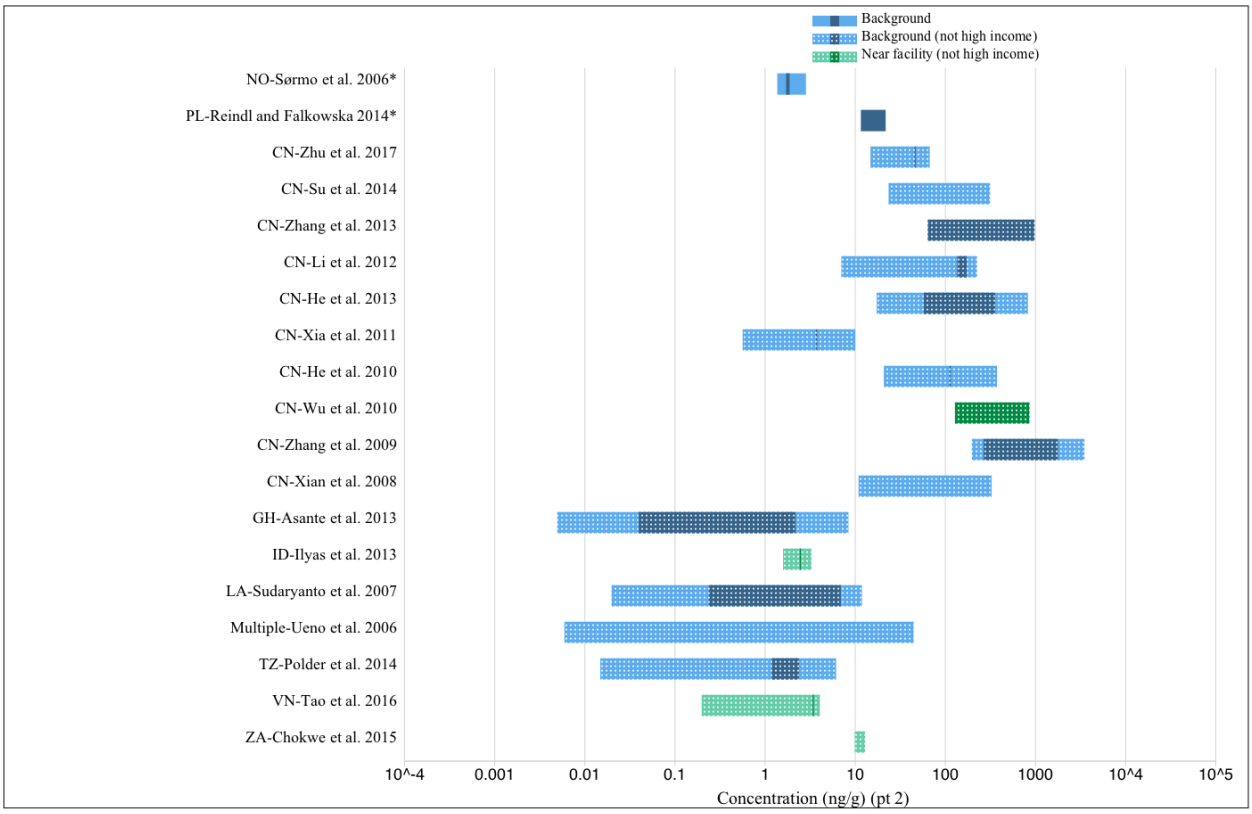


Figure 3-11. Concentration of HBCD (ng/g) in the Lipid Fraction of Fish in Background and Near Facility Locations from 1979 to 2014

*Study conducted in a country/countries classified as "High Income" by the World Bank

Table 3-11. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Fish

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Chen et al. (2011)	US*	Background	Common carp (fish fillet)	1999-2007	9	N/R	0.2	1.4	High
Shaw et al. (2009)	US*	Background	Silver hake, white hake, atlantic herring, american plaice, alewife, winter flounder, atlantic mackerel	2006	12	0.83	N/R	1.1	High
Klosterhaus et al. (2012)	US*	Background	White croaker (whole specimen), shiner surfperch (whole specimen)	2006	14	N/R	N/R	1.7	Medium
Montie et al. (2010)	US*	Background	Flounder	2004	6	0.17	0.81	2.1	Medium
Johnson-Restrepo et al. (2008)	US*	Background	Bull shark (muscle), atlantic sharpnose shark (muscle)	1993-2004	16	1.0	0.0013	1.9	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Roosens et al. (2008)	BE*	Background	Multiple fish species and eel (whole fish/eel)	2006	35	1.0	2.0	1.7	Medium
Roosens et al. (2010c)	BE*	Background	European eel	2000-2006	50	1.0	5.0	1.9	Medium
Tomy et al. (2009)	CA*	Background	Arctic cod , pacific herring , arctic cisco	2004-2005	29	N/R	N/R	2.4	Low
Ismail et al. (2009)	CA*	Background	Lake trout (whole specimen)	1979-2004	29	1.0	N/R	1.8	Medium
Law et al. (2006a)	CA*	Background	Walleye, whitefish, emerald shiner, burbot, white sucker, and goldeye (muscle)	2000-2002	28	1.0	0.16	1.2	High
Tomy et al. (2008)	CA*	Background	Redfish , arctic cod	2000-2001	10	N/R	0.0036	1.7	Medium
Cheaib et al. (2009)	CH*	Background	Lake trout	2004	9	1.0	N/R	1.6	High
Gerecke et al. (2008)	CH*	Background	Brown trout , whitefish, multiple	2003	75	1.0	N/R	1.8	Medium
Granby and Cederberg (2007)	DK*	Background	Cod - north sea, cod liver , farmed eels, herring, mackerel, plaice, salmon - baltic sea, salmon - farmed, trout - farmed	2002-2006	63	N/R	0.01	2.1	Low
Rüdel et al. (2012)	FR, NL, GB, DE*	Background	Bream (muscle), sole (muscle)	2007-2010	270	1.0	13.0	1.6	High
Harrad et al. (2009)	GB*	Background	Multiple species (muscle)	2008	30	1.0	N/R	1.7	Medium
Morris et al. (2004)	GB, BE, NL*	Background	Cod (liver), yellow eels , yellow eels	1999-2000	32	N/R	1.2	2.3	Low
Poma et al. (2014c)	IT*	Background	Shad, whitefish (muscle), shad, whitefish (liver)	2011-2012	26	1.0	0.1	1.2	High
Poma et al. (2014a)	IT*	Background	Rutilus rutilus	2011-2012	5	1.0	0.01	1.9	Medium
Luigi et al. (2015)	IT*	Background	Common carp, bream, sander, and sheatfish (liver)	2010	10	1.0	0.011	1.9	Medium
Takahashi et al. (2010)	JP*	Background	Deep sea fishes	2005	20	0.9	0.005	1.2	High
Jeong et al. (2014)	KR*	Background	Crucian carp (muscle), crucian carp (eggs)	2010	15	1.0	0.02	1.3	High
Frederiksen et al. (2007)	Multiple*	Background	Shorthorn sculpin (liver)	2006	5	0.6	1.1	2.1	Medium
Janák et al. (2005)	Multiple*	Background	Eel, sole, plaice, bib, whiting	2005	10	N/R	0.11	2.2	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Remberger et al. (2004)	Multiple*	Background	Fish - herring (muscle)	1999-2000	6	1.0	N/R	1.8	Medium
Bustnes et al. (2012)	NO*	Background	Saithe , cod	2007	80	1.0	0.01	1.2	High
Köppen et al. (2010)	NO*	Background	Mackerel, codfish, thorny skate, pollack, flounder	2006	25	1.0	0.006	1.9	Medium
Jenssen et al. (2007)	NO*	Background	Atlantic cod (whole body), atlantic cod (whole body), polar cod (whole body)	2003	52	N/R	N/R	1.6	High
Sørmo et al. (2006)	NO*	Background	Polar cod	2003	7	N/R	N/R	2.2	Medium
Reindl and Falkowska (2014)	PL*	Background	Herring (whole fish), herring (herring muscle), herring (herring liver)	2009-2010	24	1.0	1.4	2.2	Medium
Zhu et al. (2017a)	CN	Background	Grass carp	2012-2013	5	1.0	N/R	2.0	Low
Su et al. (2014)	CN	Background	Common carp (whole organism), yellow catfish (whole organism)	2009-2012	62	1.0	N/R	2.2	Medium
Zhang et al. (2013)	CN	Background	Mud fish, topmouth gudgeon, crucian carp, ricefield eel, snakehead, anchovy, weever, bartial flathead, sea catfish, hairtail	2011	42	1.0	0.022	1.7	Medium
Li et al. (2012b)	CN	Background	Loach, silver carp, goby, crucian carp, stone moroko (eggs, muscle, roe, body, etc)	2011	153	1.0	N/R	1.1	High
He et al. (2013)	CN	Background	Mud carp , nile tilapia , suckermouth catfish	2009	34	N/R	N/R	1.3	High
Xia et al. (2011)	CN	Background	Yellow croaker and silver pomfret (fillet)	2008	46	1.0	0.3	1.7	Medium
He et al. (2010)	CN	Background	Crucian carp (muscle)	2005-2008	7	1.0	3.0	1.2	High
Zhang et al. (2009)	CN	Background	Crucian carp, loach	2006	19	1.0	N/R	1.8	Medium
Xian et al. (2008)	CN	Background	Multiple species (9 different species) (muscle, liver, whole, egg)	2006	24	1.0	0.005	1.1	High
Asante et al. (2013)	GH	Background	Tilapia	2010	40	N/R	0.01	1.2	High
Sudaryanto et al. (2007)	LA	Background	Snakehead (muscle), tilapia (muscle), carp (muscle)	2005	30	N/R	0.02	1.9	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Ueno et al. (2006)	Multiple	Background	Skipjack tuna (muscle)	1997-2001	62	0.95	0.006	1.5	High
Polder et al. (2014)	TZ	Background	Tilapia (muscle)	2011	13	0.77	0.03	1.8	Medium
Montie et al. (2010)	US*	Near facility	Flounder	2004	6	0.5	0.81	2.1	Medium
Sellstrom et al. (1998)	SE*	Near facility	Pike (muscle)	1995	15	0.33	100.0	2.0	Medium
Wu et al. (2010)	CN	Near facility	Carp , crucian carp , snakehead , water snake	2006	23	0.7	3.0	2.0	Medium
Ilyas et al. (2013)	ID	Near facility	Nile tilapia	2008	2	1.0	N/R	1.4	High
Tao et al. (2016)	VN	Near facility	Tilapia (oreochromis mossambicus)	2014	5	1.0	0.05	2.0	Medium
Chokwe et al. (2015)	ZA	Near facility	Carp (muscle)	2013	12	1.0	0.48	1.6	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

3.5.3. Fish (ng/g) – Wet Fraction

Measured concentrations of HBCD in Fish with unit of ng/g, extracted from 21 sources, are summarized in Figure 3-12 and supplemental information is provided in Table 3-12. Overall, concentrations ranged from not-detected to 10275.0 ng/g from over 936 samples collected between 2001 and 2014 in 13 countries, SG, CA, ES, CZ, NL, US, DK, FR, GB, LV, NO, CN, and DE. Location types were categorized as Background and Near Facility. Reported detection frequencies ranged from 0.27 to 1.0.

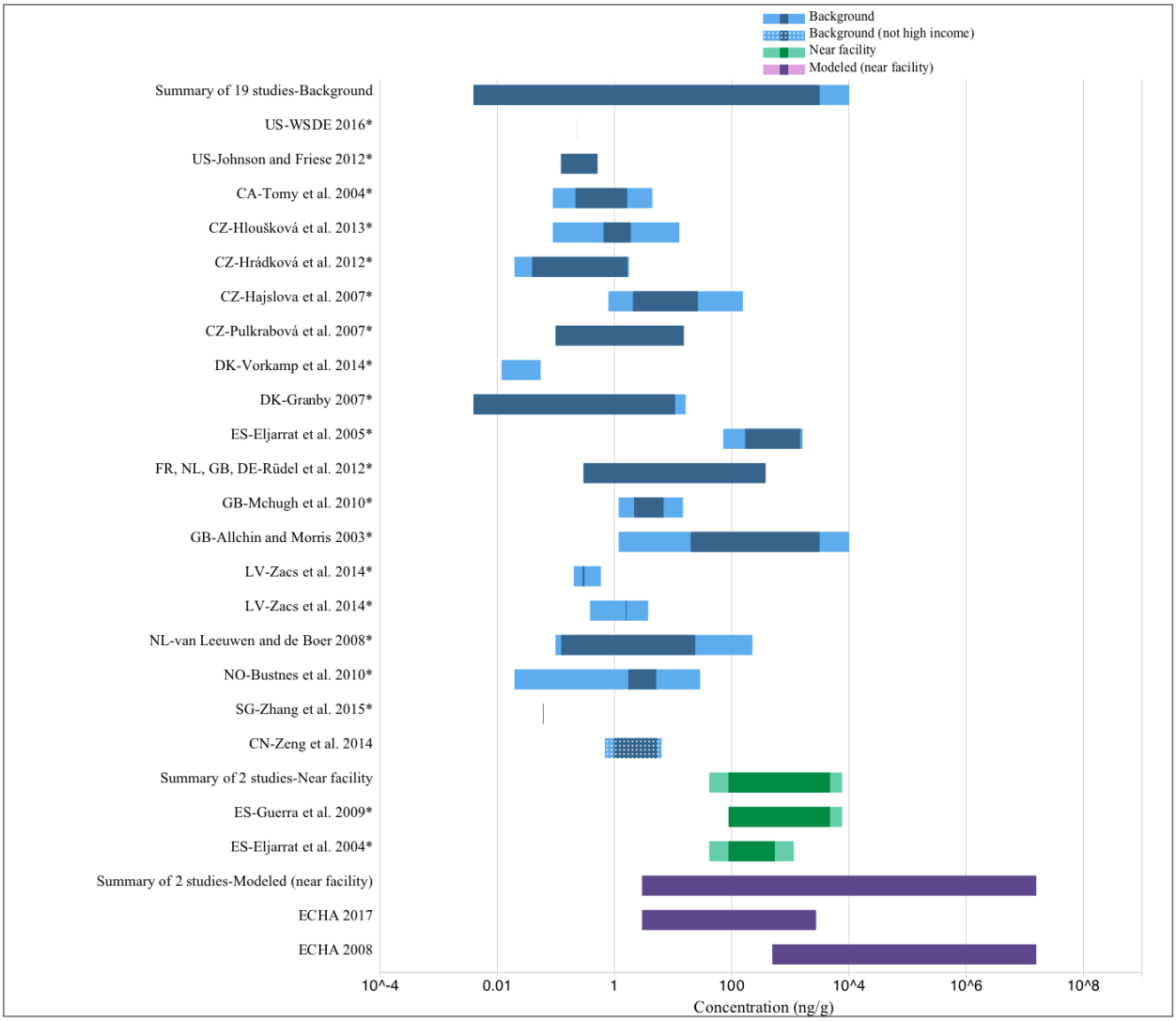


Figure 3-12. Concentration of HBCD (ng/g) in the Wet Fraction of Fish in Background and Near Facility Locations and for Modeled Data from 2001 to 2014

*Study conducted in a country/countries classified as "High Income" by the World Bank

Table 3-12. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Fish

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Wsde (2016)	US*	Background	Multiple species	2014	44	0.27	100.0	1.1	High
Johnson and Friese ()	US*	Background	Common carp (muscle), large scale sucker (whole fish)	2011	8	N/R	100.0	1.4	High
Tomy et al. (2004)	CA*	Background	Lake trout, alewife, rainbow smelt, and slimy sculpin	2002	14	1.0	N/R	2.0	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Hloušková et al. (2013)	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	N/R	1.7	Medium
Hrádková et al. (2012)	CZ*	Background	Chub (fillet), common bream (fillet), roaches (fillet)	2008-2009	38	0.82	N/R	1.2	High
Hajslova et al. (2007)	CZ*	Background	Bream, chub, perch	2005	80	1.0	N/R	1.4	Medium
Pulkrabová et al. (2007)	CZ*	Background	Perch, chub, bream, barbel	2001-2003	N/R	N/R	0.1	2.0	Medium
Vorkamp et al. (2014)	DK*	Background	Multiple freshwater and seawater fish	2012	11	0.91	0.012	2.0	Medium
Granby and Cederberg (2007)	DK*	Background	Cod - north sea, cod liver , farmed eels, herring, mackerel, plaice, salmon - baltic sea, salmon - farmed, trout - farmed	2002-2006	63	N/R	0.01	2.1	Low
Eljarrat et al. (2005)	ES*	Background	Bleak	2002	15	1.0	N/R	1.7	Medium
Rüdel et al. (2012)	FR, NL, GB, DE*	Background	Bream (muscle)	2007-2010	240	1.0	13.0	1.6	High
McHugh et al. (2010)	GB*	Background	European eel	2005	5	1.0	N/R	2.2	Medium
Allchin and Morris (2003)	GB*	Background	Brown trout and eel (muscle)	2003	10	1.0	1.2	2.1	Medium
Zacs et al. (2014b)	LV*	Background	Eel (muscle)	2013	24	1.0	0.045	2.1	Low
Zacs et al. (2014a)	LV*	Background	Salmon (fillets)	2012	25	1.0	0.006	1.2	High
van Leeuwen and de Boer (2008)	NL*	Background	Multiple freshwater fish, marine fish, and shellfish species	2003	44	N/R	0.1	1.5	High
Bustnes et al. (2010)	NO*	Background	Saithe , cod	2007	155	N/R	0.01	1.7	Medium
Zhang et al. (2015)	SG*	Background	Marine catfish (tissue)	2014	11	0.36	0.0054	1.7	Medium

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Zeng et al. (2014b)	CN	Background	Mud carp (serum), northern snakehead (serum)	2010	6	1.0	0.004	1.8	Medium
Guerra et al. (2009)	ES*	Near facility	Barbels, bleaks, and southwestern nases (whole fish (bleaks and nases); muscle and liver (barbels))	2002-2004	73	N/R	7.0	2.0	Medium
Eljarrat et al. (2004)	ES*	Near facility	Barbel fish (muscle), barbel fish (liver)	2002	22	1.0	N/R	1.8	Medium
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	N/R	2.0	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	N/R	1.3	High

*Study conducted in a country/countries classified as “High Income” by the World Bank
Abbreviations: N/R, Not reported

3.6. Terrestrial Invertebrates

3.6.1. Terrestrial Invertebrates (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Terrestrial Invertebrates with unit of ng/g, extracted from 1 source, are summarized in Figure 3-13 and supplemental information is provided in Table 3-13. Overall, concentrations ranged from 0.16 to 30.34 ng/g from over 10 samples collected between 2012 and 2013 in 1 country, CN. Location types were categorized as Background. Reported detection frequency was 1.0.

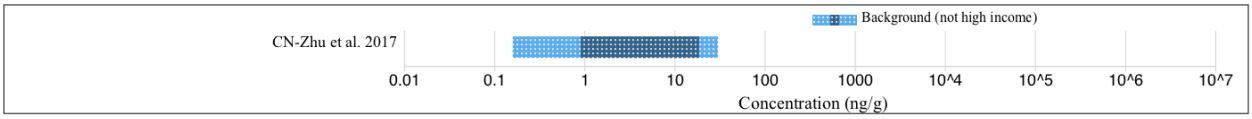


Figure 3-13. Concentration of HBCD (ng/g) in the Lipid Fraction of Terrestrial Invertebrates in Background Locations from 2012 to 2013

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 3-13. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Terrestrial Invertebrates

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Zhu et al. (2017a)	CN	Background	Butterfly, dragonfly, grasshopper	2012-2013	10	1.0	N/R	2.0	Low

Abbreviations: N/R, Not reported

3.6.2. Terrestrial Invertebrates (ng/g) – Wet Fraction

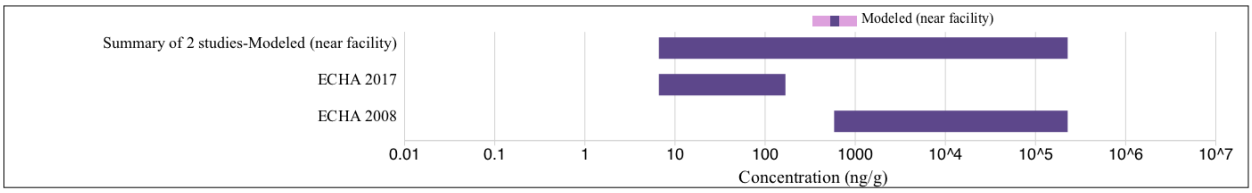


Figure 3-14. Concentration of HBCD (ng/g) in the Wet Fraction of Terrestrial Invertebrates in Modeled Data from 2008 to 2017

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-14. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Terrestrial Invertebrates

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
ECHA (2017)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	N/R	2.0	Medium
KemI (2008)	N/R	Modeled (near facility)	N/R	N/R	N/R	N/R	N/R	1.3	High

Abbreviations: N/R, Not reported

3.7. Terrestrial Mammals

3.7.1. Terrestrial Mammals (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Terrestrial Mammals with unit of ng/g, extracted from 5 sources, are summarized in Figure 3-15 and supplemental information is provided in Table 3-15. Overall, concentrations ranged from not-detected to 180.0 ng/g from over 243 samples collected between 1997 and 2014 in 4 countries, NO, JP, US, and CN. Location types were categorized as Background. Reported detection frequencies ranged from 0.01 to 1.0.

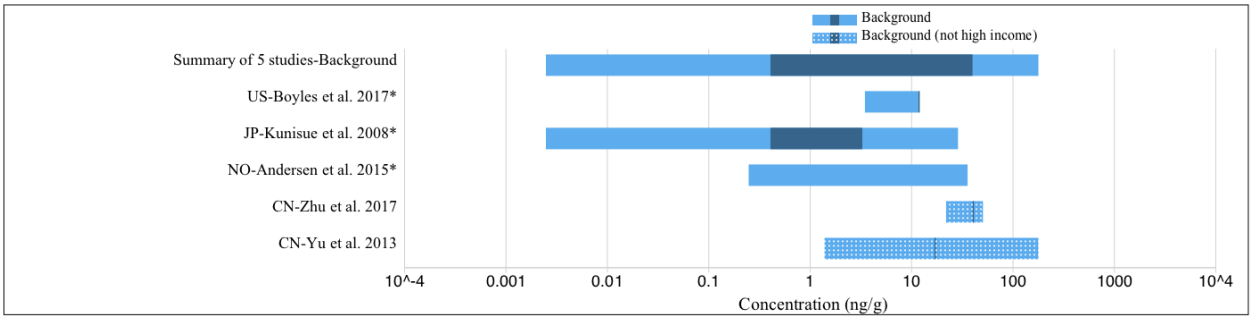


Figure 3-15. Concentration of HBCD (ng/g) in the Lipid Fraction of Terrestrial Mammals in Background Locations from 1997 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-15. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Terrestrial Mammals

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Boyles et al. (2017)	US*	Background	Bobcat (liver)	2013-2014	44	N/R	3.5	1.7	Medium
Kunisue et al. (2008)	JP*	Background	Raccoon dogs (liver tissue), raccoon dogs (adipose tissue)	2001-2006	47	0.77	0.005	1.9	Medium
Andersen et al. (2015)	NO*	Background	Arctic fox (liver)	1997-2013	141	0.014	0.5	1.8	Medium
Zhu et al. (2017a)	CN	Background	Rat	2012-2013	3	1.0	N/R	2.0	Low
Yu et al. (2013)	CN	Background	Brown rat	2005-2007	8	1.0	0.3	2.0	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

3.7.2. Terrestrial Mammals (ng/g) – Wet Fraction

Measured concentrations of HBCD in Terrestrial Mammals with unit of ng/g, extracted from 1 source, are summarized in Figure 3-16 and supplemental information is provided in Table 3-16. Overall, concentrations ranged from not-detected to 0.18 ng/g from over 17 samples collected during 2010 in 1 country, US. Location types were categorized as Background. Reported detection frequency was 0.94.

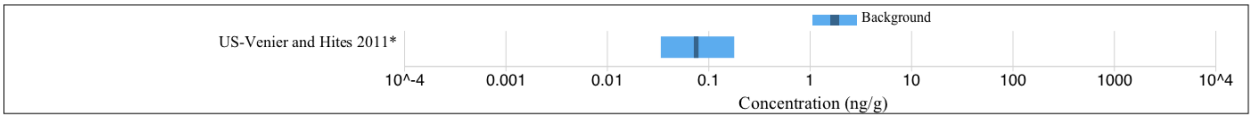


Figure 3-16. Concentration of HBCD (ng/g) in the Wet Fraction of Terrestrial Mammals in Background Locations in 2010

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 3-16. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Terrestrial Mammals

Citation	Country	Location Type	Species	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Venier and Hites (2011)	US*	Background	Dogs (serum)	2010	17	0.94	N/R	1.9	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

4. Biomonitoring Media

4.1. Dermal Wipes

4.1.1. Dermal Wipes (ng) – Dry Fraction

Measured concentrations of HBCD in Dermal Wipes with unit of ng, extracted from 2 sources, are summarized in Figure 4-1 and supplemental information is provided in Table 4-1. Overall, concentrations ranged from not-detected to 8,900 ng from over 83 samples collected between 2012 and 2014 in 2 countries, NO and US. Location types were categorized as General. Reported detection frequencies ranged from 0.52 to 1.0.

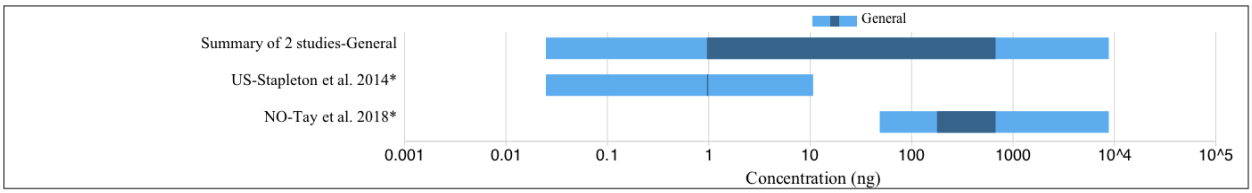


Figure 4-1. Concentration of HBCD (ng) in the Dry Fraction of Dermal Wipes in the General Population from 2012 to 2014

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 4-1. Summary of Peer-Reviewed Literature that Measured HBCD (ng) Levels in the Dry Fraction of Dermal Wipes

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng)	Quality Score	Overall Quality Level
Stapleton et al. (2014)	US*	2012	23	0.52	0.05	1.8	Medium
Tay et al. (2018)	NO*	2013-2014	60	1.0	68.0	1.1	High

*Study conducted in a country/countries classified as "High Income" by the World Bank

4.1.2. Dermal Wipes (ng/cm^2) – Dry Fraction

Measured concentrations of HBCD in Dermal Wipes with unit of ng/cm2, extracted from 1 source, are summarized in Figure 4-2 and supplemental information is provided in Table 4-2. Overall, concentrations ranged from 0.03 to 11.0 ng/cm^2 from over 60 samples collected between 2013 and 2014 in 1 country, NO. Location types were categorized as General. Reported detection frequency was 1.0.

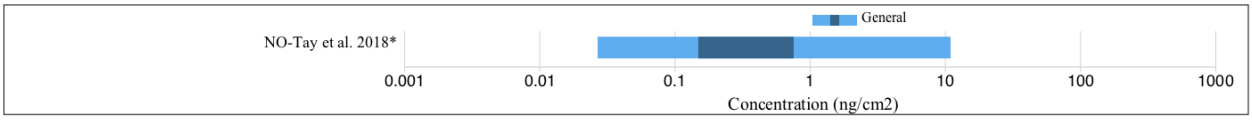


Figure 4-2. Concentration of HBCD (ng/cm^2) in the Dry Fraction of Dermal Wipes in the General Population from 2013 to 2014

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-2. Summary of Peer-Reviewed Literature that Measured HBCD (ng/cm^2) Levels in the Dry Fraction of Dermal Wipes

Citation	Country	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/cm2)	Quality Score	Overall Quality Level
Tay et al. (2018)	NO*	2013-2014	60	1.0	N/R	1.1	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

4.2. Human Adipose Tissue

4.2.1. Human Adipose Tissue (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Adipose Tissue with unit of ng/g, extracted from 4 sources, are summarized in Figure 4-3 and supplemental information is provided in Table 4-3. Overall, concentrations ranged from not-detected to 39 ng/g from over 214 samples collected between 2003 and 2008 in 4 countries, FR, JP, US, and CZ. Location types were categorized as General. Reported detection frequencies ranged from 0.5 to 0.85.

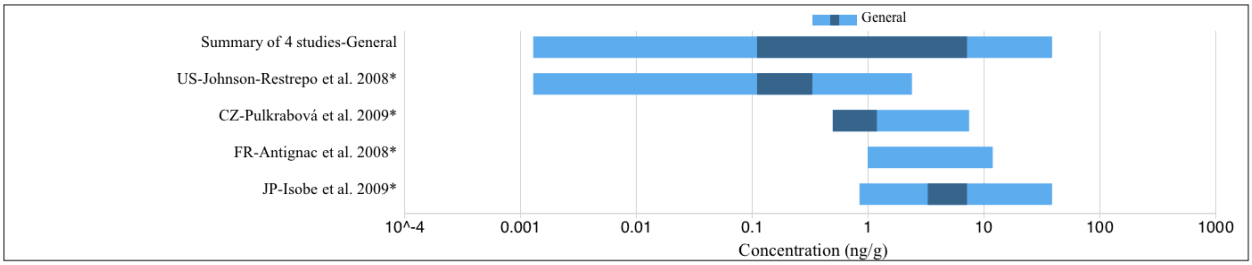


Figure 4-3. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Adipose Tissue in the General Population from 2003 to 2008

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-3. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Adipose Tissue

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Johnson-Restrepo et al. (2008)	US*	General	2003-2004	20	0.85	0.0026	1.9	Medium
Pulkrabová et al. (2009)	CZ*	General	2008	98	N/R	0.5	1.8	Medium
Antignac et al. (2008)	FR*	General	2004-2005	26	0.5	N/R	1.6	High
Isobe et al. (2009b)	JP*	General	2003-2004	70	N/R	0.05	1.7	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

4.3. Human Blood

4.3.1. Human Blood (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Blood with unit of ng/g, extracted from 12 sources, are summarized in Figure 4-4 and supplemental information is provided in Table 4-4. Overall, concentrations ranged from not-detected to 77 ng/g from over 695 samples collected between 1996 and 2015 in 9 countries, SE, CA, NL, US, BE, NO, AU, MX, and DE. Location types were categorized as High Exposed Population and General. Reported detection frequencies ranged from 0.07 to 1.0.

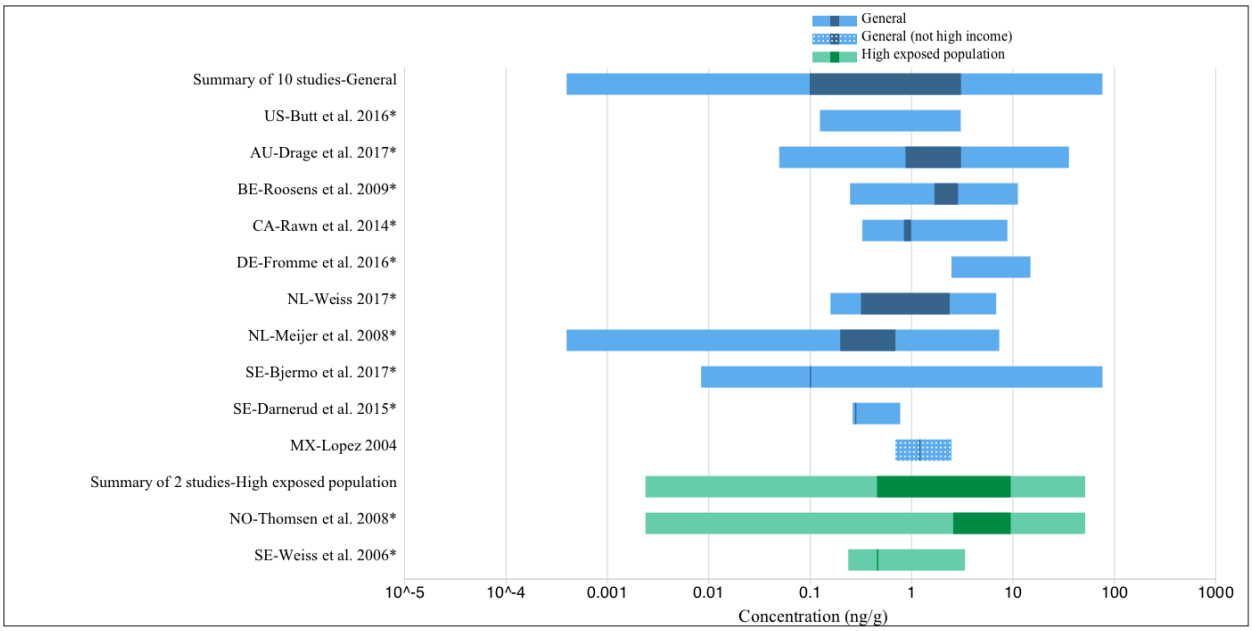


Figure 4-4. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Blood in General and High Exposed Populations from 1996 to 2015

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-4. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Blood

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Butt et al. (2016)	US*	General	2008-2010	43	0.07	0.084	1.9	Medium
Drage et al. (2017)	AU*	General	2002-2015	63	0.73	0.1	1.4	High
Roosens et al. (2009)	BE*	General	2007	9	0.56	0.5	1.4	High
Rawn et al. (2014b)	CA*	General	2007-2009	57	1.0	0.004	1.3	High
Fromme et al. (2016)	DE*	General	2013	42	0.095	5.0	1.8	Medium
Weiss et al. (2017)	NL*	General	2004	90	N/R	0.16	1.6	High
Meijer et al. (2008)	NL*	General	2001-2002	81	0.89	0.0008	1.8	Medium
Bjermo et al. (2017)	SE*	General	2010-2011	170	0.61	0.017	1.6	High
Darnerud et al. (2015)	SE*	General	1996-2010	36	0.11	0.53	1.8	Medium

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
López et al. (2004)	MX	General	2003	5	N/R	N/R	2.1	Medium
Thomsen et al. (2008)	NO*	High exposed population	2004-2005	49	0.76	0.0048	1.5	High
Weiss et al. (2006)	SE*	High exposed population	2000	50	N/R	0.24	1.4	High

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

4.3.2. Human Blood (ng/L) – Serum Fraction

Measured concentrations of HBCD in Human Blood with unit of ng/l, extracted from 1 source, are summarized in Figure 4-5 and supplemental information is provided in Table 4-5. Overall, concentrations ranged from 30 to 234 ng/l from over 515 samples collected between 2008 and 2011 in 1 country, BE. Location types were categorized as General. No detection frequencies were reported.

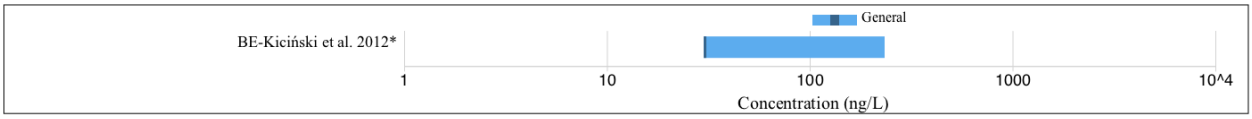


Figure 4-5. Concentration of HBCD (ng/L) in the Serum Fraction of Human Blood in the General Population from 2008 to 2011

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-5. Summary of Peer-Reviewed Literature that Measured HBCD (ng/L) Levels in the Serum Fraction of Human Blood

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/L)	Quality Score	Overall Quality Level
Kiciński et al. (2012)	BE*	General	2008-2011	515	N/R	30.0	1.9	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

4.3.3. Human Blood (ng/g) – Wet Fraction

Measured concentrations of HBCD in Human Blood with unit of ng/g, extracted from 1 source, are summarized in Figure 4-6 and supplemental information is provided in Table 4-6. Overall, concentrations ranged from not-detected to 0.06 ng/g from over 40 samples collected during 2003 in an unknown number of countries. Location types were categorized as General. Reported detection frequency was 0.02.

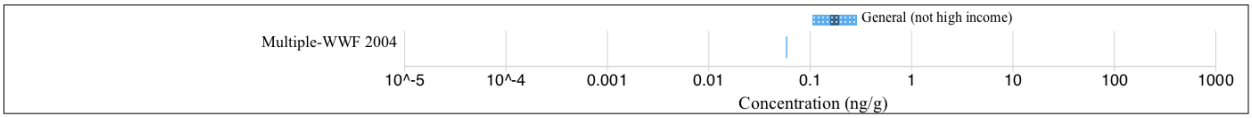


Figure 4-6. Concentration of HBCD (ng/g) in the Wet Fraction of Human Blood in the General Population in 2003

Table 4-6. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Human Blood

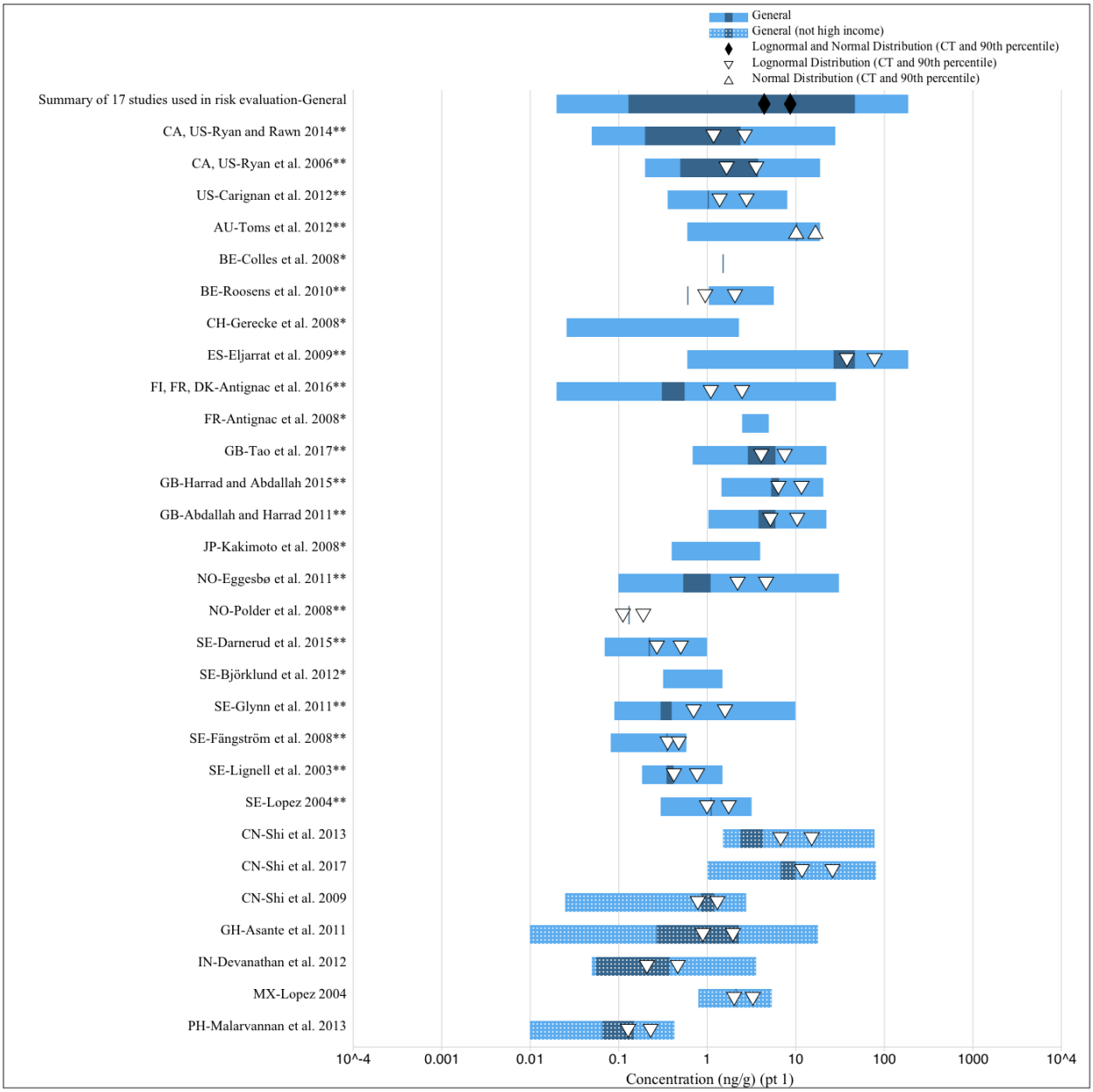
Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Wwf (2004)	Multiple	General	2003	40	0.025	N/R	2.4	Low

Abbreviations: N/R, Not reported

4.4. Human Breast Milk

4.4.1. Human Breast Milk (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Breast Milk with unit of ng/g, extracted from 39 sources, are summarized in Figure 4-7 and supplemental information is provided in Table 4-7. Overall, concentrations ranged from not-detected to 188 ng/g from over 2115 samples collected between 1973 and 2015 in 22 countries, CA, GH, ES, FR, NO, AU, CN, ZA, CH, RU, IN, SE, US, TZ, FI, VN, MX, JP, DK, BE, GB, and PH. Location types were categorized as High Exposed Population, Occupational, and General. Reported detection frequencies ranged from 0.00 to 1.0. Following the statistical procedures described above to obtain a final dataset, central tendency and high-end estimates, respectively, were 4.44 and 8.74 ng/g for General (n = 17 studies).


General
General (not high income)
Lognormal and Normal Distribution (CT and 90th percentile)
Lognormal Distribution (CT and 90th percentile)
Normal Distribution (CT and 90th percentile)
Summary of 17 studies used in risk evaluation-General
CA, US-Ryan and Rawn 2014**
CA, US-Ryan et al. 2006**
US-Carignan et al. 2012**
AU-Toms et al. 2012**
BE-Colles et al. 2008*
BE-Roosens et al. 2010**
CH-Gerecke et al. 2008*
ES-Eljarrat et al. 2009**
FI, FR, DK-Antignac et al. 2016**
FR-Antignac et al. 2008*
GB-Tao et al. 2017**
GB-Harrad and Abdallah 2015**
GB-Abdallah and Harrad 2011**
JP-Kakimoto et al. 2008*
NO-Eggesbø et al. 2011**
NO-Polder et al. 2008**
SE-Darnerud et al. 2015**
SE-Björklund et al. 2012*
SE-Glynn et al. 2011**
SE-Fängström et al. 2008**
SE-Lignell et al. 2003**
SE-Lopez 2004**
CN-Shi et al. 2013
CN-Shi et al. 2017
CN-Shi et al. 2009
GH-Asante et al. 2011
IN-Devanathan et al. 2012
MX-Lopez 2004
PH-Malarvannan et al. 2013
10^-4
0.001
0.01
0.1
1
10
100
1000
10^4
Concentration (ng/g) (pt 1)

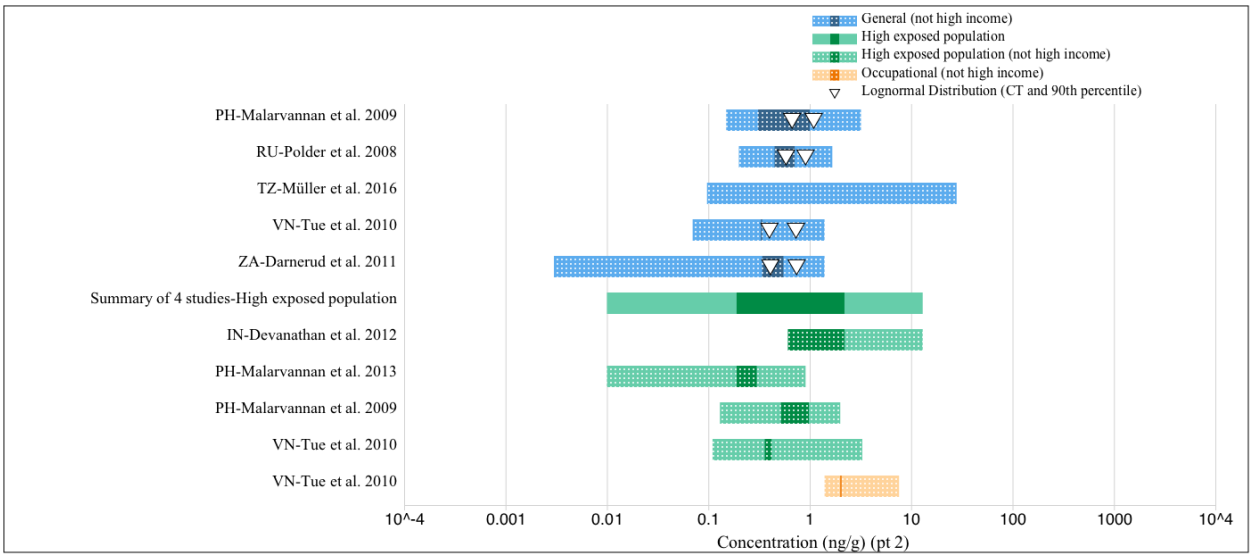


Figure 4-7. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Breast Milk in General, High Exposed, and Occupational Populations from 1989 to 2015

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-7. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Breast Milk

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Ryan and Rawn (2014)	CA, US**	General	1989-2005	109	0.78	0.1	1.8	Medium
Ryan et al. (2006)	CA, US**	General	2002-2003	17	N/R	N/R	2.1	Medium
Carignan et al. (2012)	US**	General	2004-2005	43	1.0	0.036	1.2	High
Toms et al. (2012)	AU**	General	1993-2009	13	0.69	1.2	1.8	Medium
Colles et al. (2008)	BE*	General	2008	1	1.0	0.8	2.6	Low
Roosens et al. (2010b)	BE**	General	2006	22	0.27	2.1	1.8	Medium
Gerecke et al. (2008)	CH*	General	2003-2007	36	N/R	N/R	1.8	Medium
Eljarrat et al. (2009)	ES**	General	2006-2007	33	0.91	1.2	1.3	High
Antignac et al. (2016)	FI, FR, DK**	General	1997-2014	498	0.98	N/R	1.4	High
Antignac et al. (2008)	FR*	General	2004-2005	23	0.3	N/R	1.6	High
Tao et al. (2017)	GB**	General	2010-2015	35	N/R	N/R	1.1	High

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Harrad and Abdallah (2015)	GB**	General	2010-2011	120	1.0	0.036	1.9	Medium
Abdallah and Harrad (2011)	GB**	General	2010	34	1.0	N/R	1.6	High
Kakimoto et al. (2008)	JP*	General	1973-2006	18	0.83	0.4	1.3	High
Eggesbø et al. (2011)	NO**	General	2003-2006	193	0.68	N/R	2.0	Medium
Polder et al. (2008b)	NO**	General	2000-2002	10	0.1	0.05	1.7	Medium
Darnerud et al. (2015)	SE**	General	2010	30	0.97	N/R	1.8	Medium
Björklund et al. (2012)	SE*	General	2008-2009	18	0.17	N/R	1.9	Medium
Glynn et al. (2011)	SE**	General	2000-2004	387	0.77	N/R	1.7	Medium
Fängström et al. (2008)	SE**	General	1980-2004	28	1.0	N/R	2.0	Medium
Lignell et al. (2003)	SE**	General	2002-2003	30	0.8	0.37	2.1	Medium
López et al. (2004)	SE**	General	2003	5	N/R	N/R	2.1	Medium
Shi et al. (2013)	CN	General	2011	103	N/R	N/R	1.6	High
Shi et al. (2017b)	CN	General	2011	29	1.0	0.28	1.8	Medium
Shi et al. (2009)	CN	General	2007	24	0.92	0.05	1.6	High
Asante et al. (2011)	GH	General	2004-2009	67	N/R	0.01	1.7	Medium
Devanathan et al. (2012)	IN	General	2009	17	N/R	0.05	1.9	Medium
López et al. (2004)	MX	General	2003	7	N/R	N/R	2.1	Medium
Malarvannan et al. (2013)	PH	General	2008	10	N/R	0.01	1.8	Medium
Malarvannan et al. (2009)	PH	General	2004	11	1.0	N/R	1.3	High
Polder et al. (2008a)	RU	General	2000	37	0.3	N/R	1.8	Medium
Müller et al. (2016)	TZ	General	2012	1	0.0	0.097	1.9	Medium
Tue et al. (2010)	VN	General	2007	9	N/R	N/R	1.8	Medium
Darnerud et al. (2011)	ZA	General	2004	14	0.93	0.006	1.6	High

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Devanathan et al. (2012)	IN	High exposed population	2009	8	1.0	0.05	1.9	Medium
Malarvannan et al. (2013)	PH	High exposed population	2008	20	N/R	0.01	1.8	Medium
Malarvannan et al. (2009)	PH	High exposed population	2004	22	1.0	N/R	1.3	High
Tue et al. (2010)	VN	High exposed population	2007	24	N/R	N/R	1.8	Medium
Tue et al. (2010)	VN	Occupational	2007	9	N/R	N/R	1.8	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
**Study conducted in a country/countries classified as "High Income" by the World Bank and included in risk evaluation
Abbreviations: N/R, Not reported

4.5. Human Feces

4.5.1. Human Feces (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Feces with unit of ng/g, extracted from 1 source, are summarized in Figure 4-8 and supplemental information is provided in Table 4-8. Overall, concentrations ranged from 0.21 to 59 ng/g from over 22 samples collected between 2009 and 2011 in 1 country, SE. Location types were categorized as General. No detection frequencies were reported.

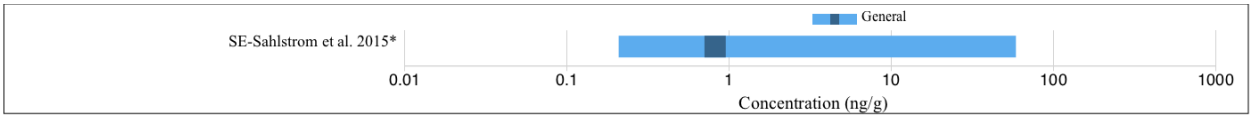


Figure 4-8. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Feces in the General Population from 2009 to 2011

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-8. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Feces

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Sahlström et al. (2015b)	SE*	General	2009-2011	22	N/R	N/R	1.8	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank
Abbreviations: N/R, Not reported

4.6. Human Fetal Tissue

4.6.1. Human Fetal Tissue (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Fetal Tissue with unit of ng/g, extracted from 1 source, are summarized in Figure 4-9 and supplemental information is provided in Table 4-9. Overall, concentrations ranged from not-detected to 4,500 ng/g from over 51 samples collected between 1998 and 2010 in 1 country, CA. Location types were categorized as General. Reported detection frequency was 0.9.

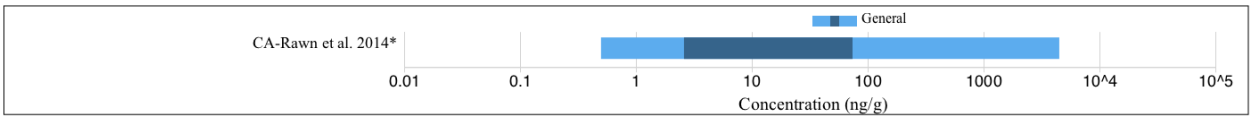


Figure 4-9. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Fetal Tissue in the General Population from 1998 to 2010

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-9. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Fetal Tissue

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Rawn et al. (2014a)	CA*	General	1998-2010	51	0.9	1.0	1.4	High

*Study conducted in a country/countries classified as "High Income" by the World Bank

4.7. Human Hair

4.7.1. Human Hair (ng/g) – Wet Fraction

Measured concentrations of HBCD in Human Hair with unit of ng/g, extracted from 2 sources, are summarized in Figure 4-10 and supplemental information is provided in Table 4-10. Overall, concentrations ranged from 0.3 to 5.4 ng/g from over 30 samples collected during 2008 in 1 country, PH. Location types were categorized as High Exposed Population and General. No detection frequencies were reported.

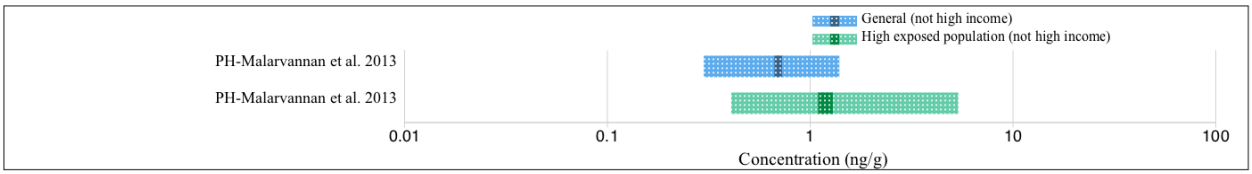


Figure 4-10. Concentration of HBCD (ng/g) in the Wet Fraction of Human Hair in General and High Exposed Populations in 2008

Table 4-10. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Human Hair

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Malarvannan et al. (2013)	PH	General	2008	10	N/R	0.01	1.8	Medium
Malarvannan et al. (2013)	PH	High exposed population	2008	20	N/R	0.01	1.8	Medium

Abbreviations: N/R, Not reported

4.8. Human Placental Tissue

4.8.1. Human Placental Tissue (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Placental Tissue with unit of ng/g, extracted from 1 source, are summarized in Figure 4-11 and supplemental information is provided in Table 4-11. Overall, concentrations ranged from not-detected to 5,600 ng/g from over 142 samples collected between 1998 and 2010 in 1 country, CA. Location types were categorized as General. Reported detection frequency was 0.97.

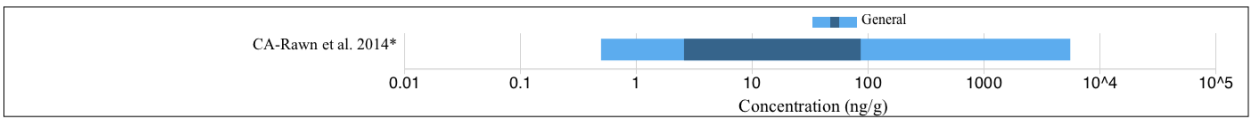


Figure 4-11. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Placental Tissue in the General Population from 1998 to 2010

* Study conducted in a country/countries classified as “High Income” by the World Bank.

Table 4-11. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Placental Tissue

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Rawn et al. (2014a)	CA*	General	1998-2010	142	0.97	1.0	1.4	High

*Study conducted in a country/countries classified as “High Income” by the World Bank

4.9. Human Serum

4.9.1. Human Serum (ng/g) – Lipid Fraction

Measured concentrations of HBCD in Human Serum with unit of ng/g, extracted from 1 source, are summarized in Figure 4-12 and supplemental information is provided in Table 4-12. Overall, concentrations ranged from not-detected to 38.8 ng/g from over 61 samples collected during 2007 in 1 country, GR. Location types were categorized as General. Reported detection frequency was 0.7.

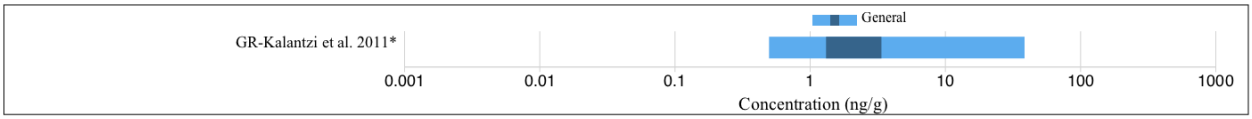


Figure 4-12. Concentration of HBCD (ng/g) in the Lipid Fraction of Human Serum in the General Population in 2007

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-12. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Lipid Fraction of Human Serum

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Kalantzi et al. (2011)	GR*	General	2007	61	0.7	1.0	1.8	Medium

*Study conducted in a country/countries classified as "High Income" by the World Bank

4.9.2. Human Serum (ng/g) – Wet Fraction

Measured concentrations of HBCD in Human Serum with unit of ng/g, extracted from 1 source, are summarized in Figure 4-13 and supplemental information is provided in Table 4-13. Overall, concentrations ranged from not-detected to 0.36 ng/g from over 91 samples collected during 2004 in 1 country, NL. Location types were categorized as General. Reported detection frequency was 0.12.

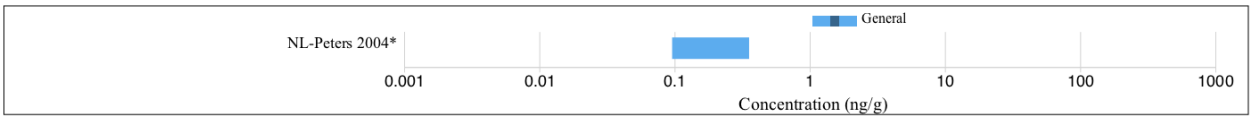


Figure 4-13. Concentration of HBCD (ng/g) in the Wet Fraction of Human Serum in the General Population in 2004

* Study conducted in a country/countries classified as "High Income" by the World Bank.

Table 4-13. Summary of Peer-Reviewed Literature that Measured HBCD (ng/g) Levels in the Wet Fraction of Human Serum

Citation	Country	Location Type	Sampling Year	Number of Samples	Frequency of Detection	Detection Limit (ng/g)	Quality Score	Overall Quality Level
Peters (2004)	NL*	General	2004	91	0.12	0.08	1.3	High

*Study conducted in a country/countries classified as "High Income" by the World Bank

5. Overview of Indoor Semivolatile Organic Compounds 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. (2004); 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. See Figure 5-1. Overview of Indoor Emission, Fate, Transport, and Exposure to SVOCs. Figure 5-1 shows the process flow for SVOC emissions, fate, transport, and ultimately exposure in the indoor environment.

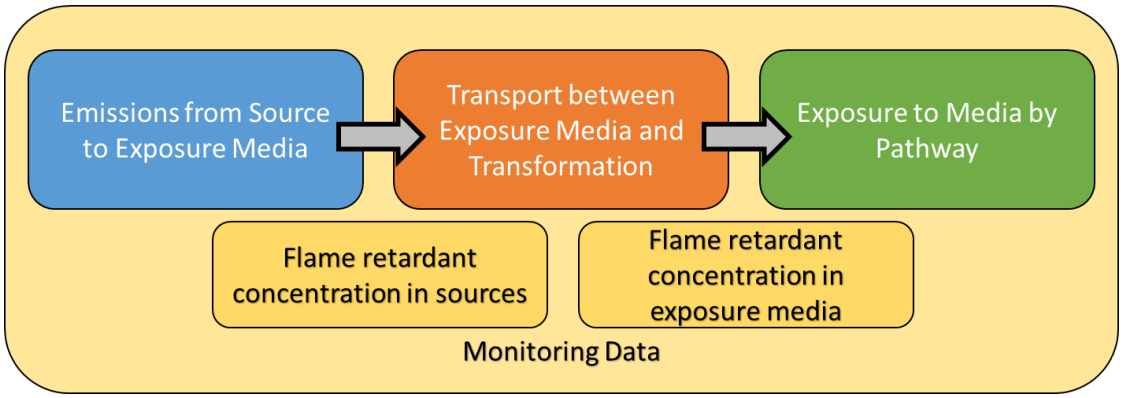


Figure 5-1. Overview of Indoor Emission, Fate, Transport, and Exposure to SVOCs

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 Figure 5-2 and detailed in the following sections.

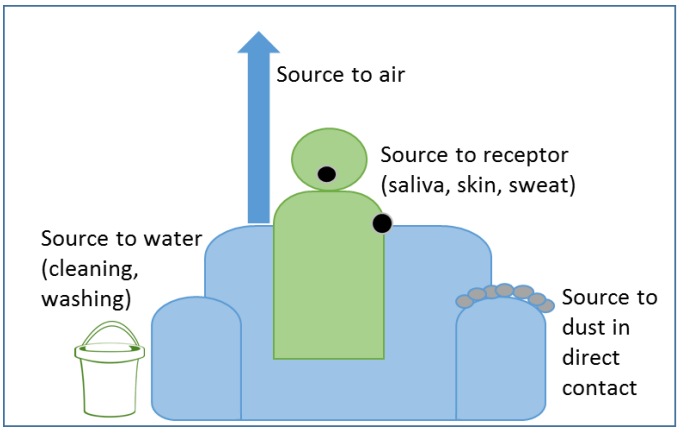


Figure 5-2. Example Emission Pathways for Flame Retardants

Chemical Mass Transfer from Source to Air: Flame retardant additives are SVOCs with low vapor pressures (~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).

Equation 1

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

where:

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

D_s = the SVOC solid-phase diffusion coefficient (m^2/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 in Equation 2.

Equation 2

$$\mathrm{E} = h_a \times (y_o - y)$$

where:

E = Emission factor (mg/m^2/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/m^3)

y = gas-phase SVOC concentration in bulk air (mg/m^3)

This methodology relies upon measurement or estimation of y_0. In the absence of experimental data, y_0 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 5-1. 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); Destaillats 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 5-1. 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	Destaillats et al. (2008)
	PUF / insulation	12-140,000 ng/m^2/hr	Kemmlein et al. (2003)

5.1. 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. (2014a). In the case of HBCD, the surface concentrations greater than 400 ng/m^2 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.

Equation 3

$$\mathrm{K}_{dm} = \frac{C_d}{C_m} = \frac{\mathrm{K}_{da}}{\mathrm{K}_{ma}}$$

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/m3)

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)

5.2. 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 µg/cm^2/hr KemI (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 ng/cm^2/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. Mäkinen 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.

5.3. 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. (2012); Cao et al. (2013); Cao et al. (2014); 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. (2015). This pathway, though not well characterized, can explain the high dust concentrations reported on the surfaces of some objects.

5.4. 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 **Figure 5-3** and discussed in the following sections.

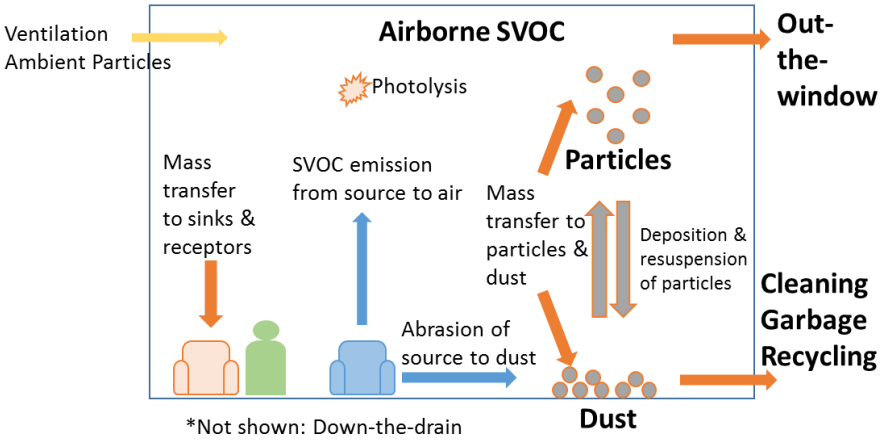


Figure 5-3. Relevant Fate and Transport Processes in the Indoor Environment

5.5. 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. An empirical relationship for partitioning between air and particles is presented in Weschler and Nazaroff (2010) and shown in Equation 4.

Equation 4

$$K_p = f_{om\_part} \times \frac{K_{oa}}{\rho_{part}}$$

where:

K_p = SVOC partition coefficient between air and TSP (KTSP) or dust (KDust) (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 in Equation 5. 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 Lyng et al. (2015); Salthammer and Schripp (2015); Guo (2014); Liu et al. (2014)

Equation 5

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

where:

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

MW = molecular weight (g/mol)

5.6. 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 (2013); Guo (2014; Stapleton et al. (2004). 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.

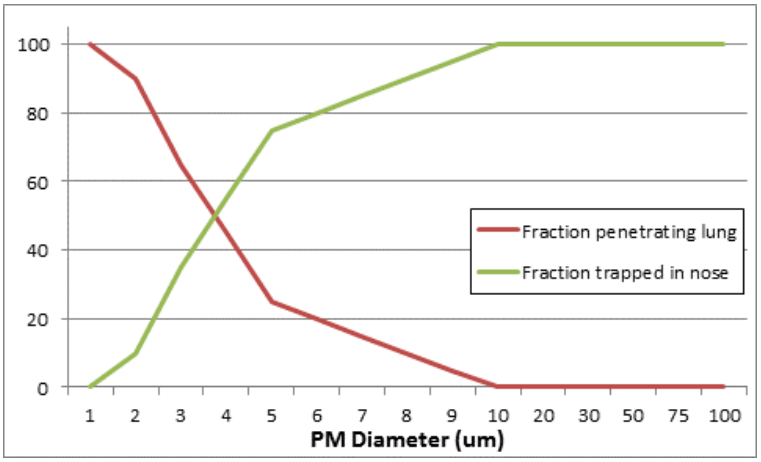
5.7. Relationship between Prevalence in Media and Physical-Chemical Properties

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 KOAs 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 KOA 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.

5.8. Estimating Exposure and Relevant Exposure Pathways for SVOCs

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. Figure 5-4 demonstrates the percentage of inhaled particles that are trapped in the upper or lower airway



depending on particle size (U.S. Bureau of Mines (1987).

Figure 5-4. Percentage of Inhaled Particles that are Trapped in either the Lung or Nose by Particle Diameter

5.9. 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 2.4.4.4 of the main risk evaluation document.

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

5.10. 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.

A summary of the various routes of exposure to SVOCs is presented in **Figure 5-6**.

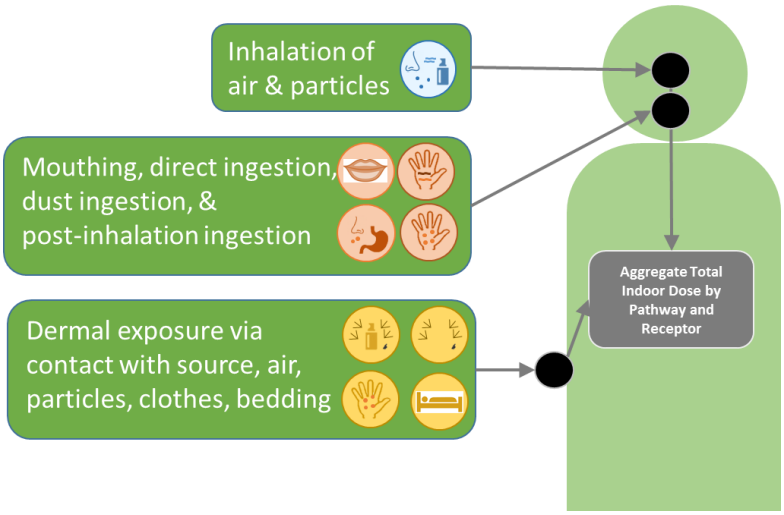


Figure 5-5. Summary of the Various Routes of Exposure to SVOCs

6. References

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