Tampere University of Applied Sciences

Evidence of presence of HBCD in the environment and its health effects

Literature review

Mariia Kornei

BACHELOR'S THESIS
November 2021

Energy and Environmental Engineering

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Energy and Environmental Engineering

MARIIA KORNEI:
Evidence of presence of HBCD in the environment and its health effects
Literature review

Bachelor's thesis 22 pages
November 2021

HBCD, or hexabromocyclododecane, is one of many brominated flame retardants, that has been raising concerns as being potentially persistent and toxic. The data is, however, quite scarce and there is no research available on its effects on Finnish ecosystems. This literature review is presenting research from around the world that has been done regarding HBCD and its presence in the environment and in biota.

The evidence shows that HBCD can be found in indoor and outdoor air, soil and sediment, plants, fish, marine mammals and other aquatic organisms, birds and also in humans. Main sources for its leakage into environment are identified to be construction and demolition waste, e-waste, and other types of trash in landfills, as well as polystyrene manufacturing facilities. However, more research on the presence of HBCD in Finnish environment, particularly its toxic effects, would be recommended.

Key words: brominated flame retardants, hexabromocyclododecane

CONTENTS

1 INTRODUCTION 5
1.1 Flame retardants 5
1.1.1 Brominated flame retardants 6
1.1.2 Additive brominated flame retardants 7
1.1.3 Hexabromocyclododecane (HBCD) 7
1.2 Toxicity 9
1.2.1 Environmental and human health risk assessment 9
2 SCOPE 11
3 LITERATURE REVIEW AS A METHOD 12
4 RESULTS AND A DISCUSSION 13
4.1 HBCD levels in the environment and living organisms 13
4.1.1 Indoor and outdoor air and dust 13
4.1.2 Soil and sediment, sewage sludge 15
4.1.3 Plants 17
4.1.4 Marine animals 17
4.1.5 Fish and other aquatic organisms 19
4.1.6 Birds 20
4.2 C&D waste, and insulation materials 21
4.3 Humans 22
4.3.1 Dietary intake of HBCD 24
4.4 Time trends 25
5 CONCLUSIONS 26
REFERENCES 27

ABBREVIATIONS AND TERMS

BPS	brominated polystyrene
BFR	brominated flame retardant
EPS	extended polystyrene
FR	flame retardant
HBCD	hexabromocyclododecane
PUR foam	polyurethane rigid foam
SPM	suspended particulate material
XPS	extruded polystyrene

1 INTRODUCTION

1.1 Flame retardants

Flame retardants (FRs) are used on combustible products to comply with fire safety regulations. The market demand for FRs is worth billions (Eljarrat & Barceló, 2013, p 3.) Figure 1 shows the four phases of the combustion mechanism: pre-heating, volatilization/decomposition, combustion, and dissemination.

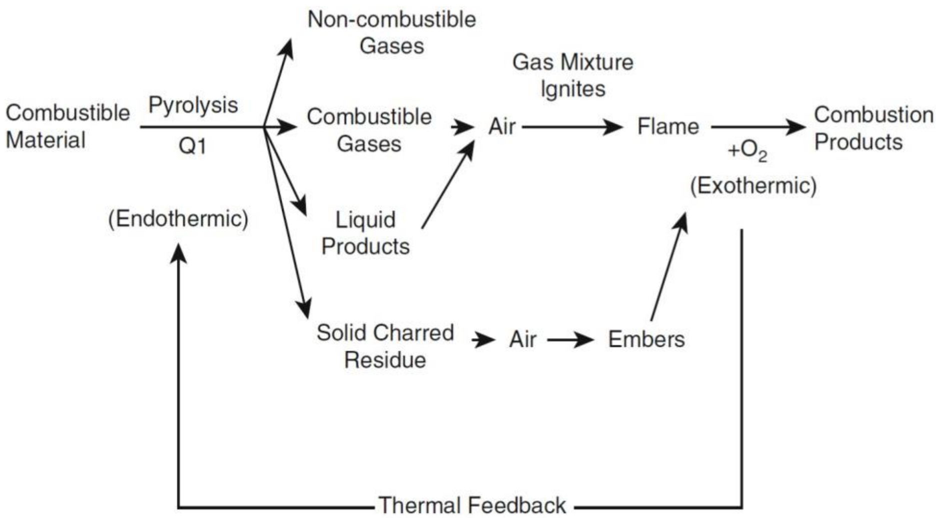

FIGURE 1. The mechanism of combustion (Eljarrat & Barceló, 2013.)

FRs may exist in the solid, liquid, or gas form. A material's flammability is determined by the fire conditions, not by the material itself. Changing the material structure, for example, by adding a FR, would alter the material's response to fire activity. For example, during the combustion phase, free radicals are produced, which allows for the flame to spread. Halogens can capture free radicals, thus reducing the flame's ability to spread. Iodine has the greatest trapping efficiency, followed by bromine, chlorine and then fluorine. For halogen preservation and distribution in polymers, organohalogen compounds play a crucial role. The most common organohalogen that has become more popular over the course of the years due to its optimal ratio of trapping ability and decomposing temperature, is organobromine (Eljarrat & Barceló, 2013, p 4.)

Bromine is a crucial component in the development of BFRs. Bromine production reached 556,000 metric tons in 2007. The Dead Sea is the world's main source of bromine, with concentrations up to 12 g/L (Eljarrat & Barceló, 2013, p 5.)

Jordan has emerged as the world's third-largest bromine manufacturer. China also has a lot of bromine, particularly in Laizhou Bay in Shangong province. Bromine and brominated compounds prices rose in 2008, reflecting expanding bromine markets and significant rises in energy costs, raw materials, regulatory enforcement, and transportation. BFRs in developed countries continue to use more advanced materials and develop more rigorous flammability requirements. Global demand for bromine is expected to rise, and because of its toxicity and high reactivity, it needs to be regulated. Albemarle Corporation, Chemtura, ICL Consumer Products, and Tosoh Corporation are the major global manufacturers of BFRs, according to the Bromine Research and Environmental Forum (BSEF).

In the EU the use of some BFRs is either banned or restricted, and regulated by The European Food Safety Authority (EFSA) (EFSA, accessed on 26.10.2021.) HBCD, which is a BFR, was listed under Annex A (POPRC8.3, 2013) of the Stockholm Convention on persistent organic pollutants but have not been banned yet (Sun et al, 2018.) However, under the EU's Registration, Evaluation, Authorization, and Registration of Chemicals (REACH) structure, HBCD is classified as a high-volume production chemical (Eljarrat & Barceló, 2013, p 11.) and was listed in annex XIV as a substance subject to authorization (Fromme et al, 2016.)

1.1.1 Brominated flame retardants

Brominated flame retardants (BFRs) are added to a large variety of products in order to make them less flammable (Barghi et al, 2018.)

Bromine is present in around a fourth of all FRs (by volume). BFRs are classified into three categories based on how they are incorporated into polymers:

additive, reactive, and polymeric. Additive BFRs are simply blended with other polymers. Reactive BFR's are a category of compounds that are chemically bound to plastics, like TBBPA. Covalent bonds form between reactive BFRS and the polymer, which can only be a concern if properly bonded (Eljarrat & Barceló, 2013, p 7.)

BFRs were found in the environment for the first time in Sweden around 1980 and since then researchers have been trying to find out about their source, fate, behaviour, and effects (Law et al, 2014.)

1.1.2 Additive brominated flame retardants

PBBs, PBDEs, and HBCD are the most studied additive BFRs (see figure 2) (Eljarrat & Barceló, 2013, p 7.)

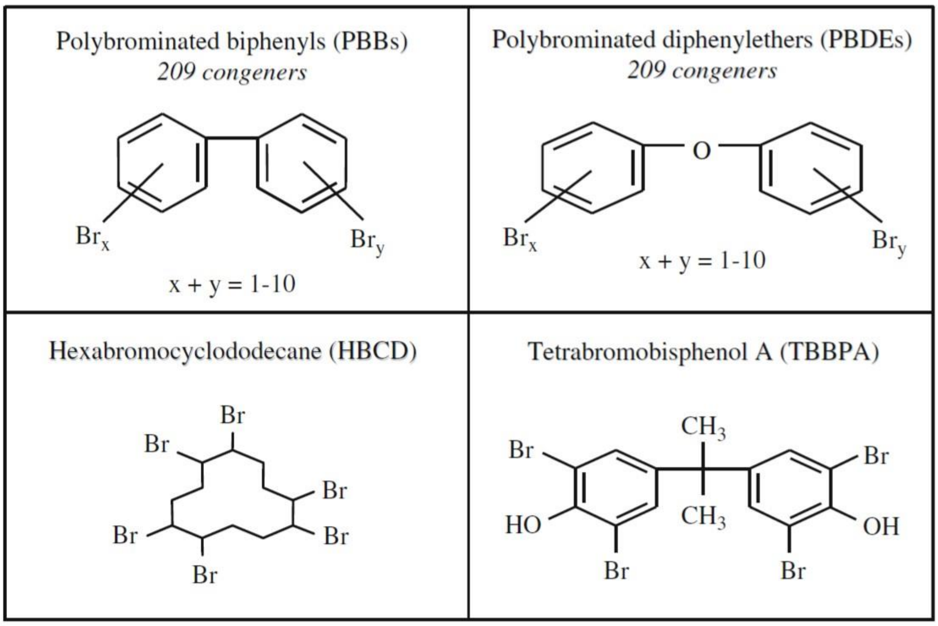

FIGURE 2. Chemical structures of the main BFRs (Eljarrat & Barceló, 2013.)

1.1.3 Hexabromocyclododecane (HBCD)

In 1999 and 2003, the most used aliphatic cyclic additive BFR was HBCD, which had a combined global market share of 15,900 and 21,951 metric tons, respectively (Eljarrat & Barceló, 2013, p 10.) 8900 tons of HBCD were consumed in the European Union in 1999 (Morris et al, 2004.) In 2011, the annual production of HBCD was about 23,000 tons (Barghi et al, 2018.)

HBCD is primarily used in extended polystyrene (EPS) and extruded polystyrene (XPS), which are widely used in building products like thermal insulation and moulded foam packaging, as well as textiles like furniture and appliances. In 2001, the demand for HBCD in the European market was 9,500 metric tons, accounting for 57% of the global demand, which surpassed the market demand for PBDEs in 1999 and 2001, making HBCD the second most used BFR. Bromine is applied to cis–trans–trans-1,5,9-cyclododecatriene to generate technical 1, 2, 5, 6, 9, 10-HBCD. Theoretically, this process produces 16 stereoisomers, but consumer products usually contain three diastereoisomers: α-, β-, and γ-isomer (see figure 3) (Morris et al, 2004.)

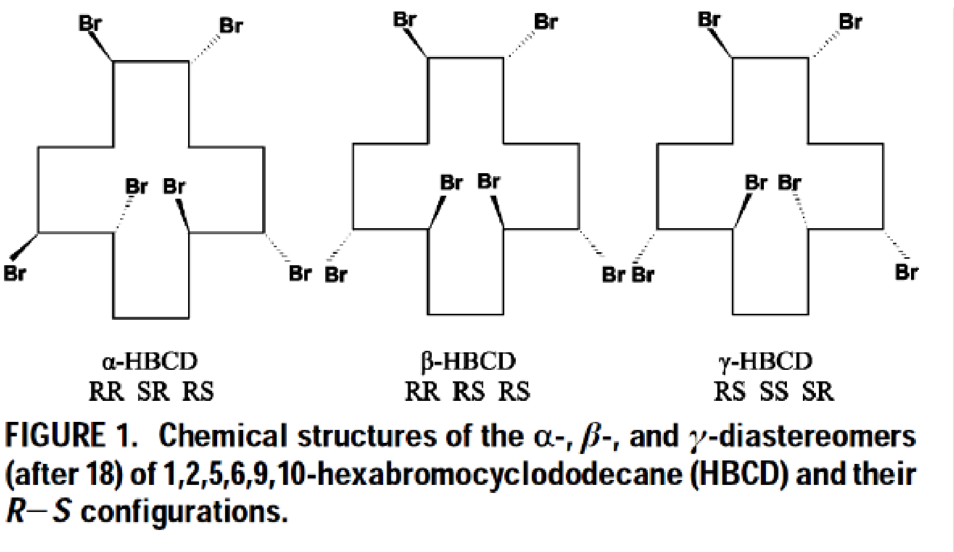

FIGURE 3. Chemical structures of α-, β-, and γ-isomers (Morris et al, 2004.)

In most industrial mixtures, γ-isomer is the most prevalent (ranging from 75 to 89%), followed by the α- and then β-isomer (10–13 percent and 1–12 percent, respectively). HBCD shares physical and chemical properties with certain PBDEs and other POPs. Since HBCD is not covalently bound to polymers, they are susceptible to migration during use and disposal. As a result, this substance has a high tendency for absorption into soil and sediments. As a result of differences in the composition, α-, β-, and γ-isomers have different polarities, dipole moments, and solubilities in water. As a result, the variations in their environmental behaviour can be explained by these distinct properties. It was discovered that the distribution of HBCD isomers in sediments was close to that of industrial mixtures, with γ-HBCD being the most abundant isomer, whereas in biota α-isomer is the most present one, and β-isomer is barely even there (Eljarrat & Barceló, 2013, p 11.)

1.2 Toxicity

There have been multiple studies about HBCD being a persistent, bio-accumulative chemical that is globally distributed in different environmental media and in biota (Fromme et al, 2016.) The toxicological database for HBCD is, however, quite limited, and further research is needed. So far results from experiments on rats show that HBCD have low acute toxic effects, but there are indications of several effects that HBCD may have on a living organism: induce cancer by a non-mutagenic mechanism; disrupt the thyroid hormone system; alter the normal uptake of neurotransmitters in rat brain; and have developmental neurotoxic effects, such as aberrations in spontaneous behaviour, learning, and memory function (Covaci et al, 2006.)

A 2016 study from China found that HBCD had high bioaccumulation potential on the marine copepod *Tigriopus japonicus* and caused significant developmental delay (Shi et al, 2017.)

A 2019 study on rats showed that the house dust equivalent mixture of brominated flame retardants, that also contained HBCD, can have effects on ovarian function and bone formation (Hales & Robaire, 2020.)

1.2.1 Environmental and human health risk assessment

The European Union began its risk assessment for HBCD in 1997, and still more information is needed. The United Kingdom Chemical Stakeholders Forum named HBCD a persistent, bio-accumulative, and toxic type of chemical and included them in the OSPAR list of chemicals for priority action. In the meanwhile, the BFR industry in Europe is taking voluntary measures to reduce the emission of HBCD from production and handling sites, whereas there are no specific regulations for it being implemented in the United States, and it has been only identified for risk assessment in countries like Canada, Australia and Japan (Covaci et al, 2006.)

Because HBCD has been estimated to have a half-life from 23 to 219 days for its technical mixture, the European Food Safety Authority suggested using the upper value of 219 days as a half-life of HBCD in the human body for margin of exposure (MOE) calculations (Barghi et al, 2017.) The 2015 study from China assessed the overall occupational risk posed by HBCD exposure and concluded that 72% of all workers in HBCD-related industries were potentially exposed to increased health risks. The most significant potential health risk was found to be the risk of reduced bone mineral density in female offspring (Yi et al, 2016.)

Same study found HBCD in environmental samples, however, it concluded that there were no significant environmental risks to nearby soil and marine environments. But the high amount of γ-HBCD in those samples may indicate a potential threat to the marine environment, which in turn can also affect human (Yi et al, 2016.)

2 SCOPE

The intent of this study is to investigate the potential effects of HBCD with respect to Finnish ecosystems. However, there is no knowledge available on that topic specifically, so this study will try to compensate that by conducting a literature review in search of evidence of HBCD presence in various ecosystems from around the world as well as its impacts on living organisms. Naturally, the source of presence and leakage of HBCD in the environment also needs to be identified.

3 LITERATURE REVIEW AS A METHOD

Literature review is a systematic way of collecting and synthesizing previous research, thus combining the knowledge from multiple studies into one paper. There are three main types of literature review: a systematic literature review, semi-systematic, and integrative. Systematic reviews are essentially a golden standard for reviews and are meant to synthesize research findings in a systematic, transparent, and reproducible way and to answer a pre-existing research question. A semi-systematic review (i.e., narrative review) is intended for issues that have been studied by academics from different fields, making a complete systematic review difficult to conduct. Similar to this, integrative or critical review approach has a purpose of assessing, critiquing and synthesizing research on mature or new, emerging topics, enabling new perspectives and theoretical frameworks to appear (Snyder, 2019.)

For this work specifically, a systematic approach was applied. The research question was identified as: “Does construction and demolition waste contribute to HBCD levels in the environment and what are its potential effects on it?” The search criteria for scientific literature included only HBCD and excluded other BFRs, also focus was on total HBCD found in various environments, indoors and outdoors, and not necessarily fate of its diastereoisomers. The year of each article was not of great significance, most studies are dated late 90s – early 2000s. There is plenty of studies available on other BFRs, not as many on HBCD specifically. Nevertheless, when the first few research articles were reviewed, it became clear that all information about HBCD was related to human health, HBCD presence in various outdoor and indoor environments, in animals, in landfills and waste. Many of the articles were literature reviews on their own. All that data was extracted, synthesized, and presented in this thesis.

4 RESULTS AND A DISCUSSION

The Nordic Council of Ministers in 2011 released a white paper report that stated that BFRs were found in the air, different biota, sediment, and sludge samples from various corners of the Nordic environment, certain types of BFRs were more prevalent in certain locations (Norden, 2011.)

Regarding air samples, higher BFR concentrations were more typical for urban areas than rural areas, both outdoor and indoor, and several of those BFRs were also found in moss samples, in fish, mussels and bird eggs. As for sediment samples, most of them were collected in urban areas and showed appearance of BFRs most likely due to the presence of wastewater treatment plants. Higher BFR concentrations were also found in sediment samples taken near harbours and marinas. BFRs were also found in wastewater treatment plant sludge, stormwater sludge and sludge from landfills (Norden, 2011.)

The ecotoxicological data for BFRs is rather incomplete and makes the ecotoxicological risk assessment nearly impossible to do, and further research is needed (Norden, 2011.) There is, however, research available on the presence of BFRs in ecosystems from various parts of the world. This chapter contains a collection of studies between the year 1967 and 2019 that makes a case for HBCD being globally present in various environments and biota. Some data from these studies is presented in table forms, showing total HBCD levels, meaning the sum of all three α-, β-, and γ-HBCD diastereoisomers. Those levels are either median values or ranges of total HBCD.

4.1 HBCD levels in the environment and living organisms

4.1.1 Indoor and outdoor air and dust

HBCD evidence in air samples is scarce. The bulk of the airborne fraction is sorbed to particulate matter due to the high lipophilicities and low vapor pressures. Only statistics on HBCD context concentrations are available come from Scandinavian countries and the United States (Covaci et al, 2006.)

Air samples from Sweden and remote locations in northern Sweden, Finland, the United States and China were found to contain HBCD (Covaci et al, 2006; Fromme et al, 2016.) In air from working environments at plants manufacturing extruded polystyrene foam flame retarded with HBCD higher levels were measured (see table 1.) There has been no research on the bioavailability of HBCD in humans following pulmonary (air and soil inhalation) or gastro-intestinal (dust ingestion) contact (Covaci et al, 2006.)

Studies from Korea reported quite high concentrations of HBCD in dust samples from offices, schools, kindergartens, and public indoor environments, as well as high concentrations of HBCD in products for children, thus suggesting that exposure risk to BFRs is of special concern for children. HBCD was also found in dust samples from homes in Romania, the Netherlands, Canada, the US, and the UK (Barghi et al, 2017), see table 2.

TABLE 1. Total HBCD levels in urban and rural air (Covaci et al, 2006; Fromme et al, 2016.)

Location	Year	Total HBCD
Urban and rural areas in Sweden	1990 - 2001	2 - 610 pg/m^3
Urban and rural areas in China	2016	0.28 - 1800 pg/m^3
Urban and rural areas in the US	2002 - 2004	< 0.1 - 4.2 pg/m^3
Plants producing XPS foam with HBCD	2000	280 - 28 500 ng/ m^3

TABLE 2. Total HBCD levels in indoor environments (Covaci et al, 2006; Barghi et al, 2017.)

Type of environment	Country	Year	Total HBCD
Office	Different countries in EU	2000	< 3 - 3 700 ng/g
Office	The UK	2002	940 - 6 900 ng/g
Office	Belgium	2004	< 20 - 58 000) ng/g
Private home	The US	2004	< 3 - 925 ng/g
School	Korea	2017	72.84 – 9748.27 ng/g
Private home	Korea	2017	18.92 - 2645.49 ng/g
Car	Korea	2017	57.47 - 4171.80 ng/g
Office	Korea	2017	116.84 - 2519.38 ng/g
Kindergarten	Korea	2017	184.56 - 1159.98 ng/g
Private home	The Netherlands	2010	140.33 ng/g
Private home	Romania	2010	190 ng/g
Private home	Canada	2018	640 ng/g
Private home	The US	2018	390 ng/g
Private home	The UK	2018	730 ng/g

4.1.2 Soil and sediment, sewage sludge

HBCD is closely attached to solid particles such as mud, sediment, and waste sludge due to their hydrophobic nature. Low concentrations of HBCD were found at sites with no known HBCD sources. In sediments and suspended particulates downstream of urban centres and manufacturing zones, HBCD has been detected at slightly higher concentrations than PBDEs (Covaci et al, 2006.)

HBCD in sewage sludge is due to diffuse leaching and abrasion from flame-retarded materials into drainage streams. As with PBDEs, spreading these sludges on agricultural or other land can redistribute the stored HBCD into the soil/sediment compartment, and then into aquatic or terrestrial food chains. HBCD concentrations in wastewater treatment system influent is much higher than those in the effluent (Covaci et al, 2006.) HBCD residues was found in sewage sludges from the U.K., Ireland and in The Netherlands (Morris et al, 2004), see table 3.

Significant concentrations of HBCD were observed in sediments from Tianjin municipality in China, Korea, and Indonesia (Law et al, 2014.) HBCD was also detected in river and estuarine sediment samples from the U.K., Belgium, and The Netherlands, as well as in the particulate phase of Dutch landfill leachates (Morris et al, 2004), see table 4.

TABLE 3. Total HBCD in sewage sludges (Morris et al, 2004.)

Country	**Year**	**Total HBCD**
UK	2004	<0.4 - 2683 µg/kg dry weight
Ireland	2004	153 - 9120 µg/kg dry weight
The Netherlands	2004	<0.6 - 3800 µg/kg dry weight

TABLE 4. Total HBCD levels in sediment samples from rivers and lakes (Covaci et al, 2006; Morris et al, 2004.)

Location	**Year**	**Total HBCD**
The Netherlands	1999 - 2001	<0.2 - 950 ng/g dry weight
UK	1999 - 2001	<2.4 - 1680 ng/g dry weight
Norway	2002 - 2003	<0.1 - 84 ng/g dry weight
Sweden	1995 - 2000	<0.2 - 1590 ng/g dry weight
Canada/the US	2003	<0.1 - 3.7 ng/g dry weight
Belgium	2004	<0.2 - 950 µg/kg dry weight

4.1.3 Plants

Isomer-specific HBCD accumulation in maize has been demonstrated, as well as consequent oxidative stress and DNA damage. The uptake of HBCD into plants, and so into the human diet, has been showed to be limited by adsorption to the soil matrix (Law et al, 2014.) 2012 study from China reported finding HBCD in environmental plant samples (Li et al, 2012), see table 5.

TABLE 5. Total HBCD in plant samples from manufacturing facilities in Lai-zhou Bay area, East China (Li et al, 2012.)

Plant species	Total HBCD
Reed	8.88 - 160241 ng/g dry weight
Cypress	84.2 - 148957 ng/g dry weight
Seepweed	110 - 710 ng/g dry weight

4.1.4 Marine animals

To date, only a few studies have assessed HBCD in marine mammals. In one study, HBCD were found in 131 of 133 marine mammal samples. Porpoises stranded on the Irish and Scottish coasts of the Irish Sea and the northwest coast of Scotland had the largest HBCD concentrations. Only a few stereoisomer-specific experiments on marine mammals have been conducted to date, and α-HBCD has been shown to be the dominant stereoisomer (Covaci et al, 2006.)

Several papers have reported on the bioaccumulation and occurrence of HBCD in various species of marine mammals, such as harp seals (*Pagophilus groenlandicus*) and Steller sea lions (*Eumetopias jubatus*) from Canada, pinniped species from Antarctica, humpback whales (*Megaptera novaeangliae*) from the North Pacific and Atlantic, minke whales, finless porpoises and common dolphins from Korea, and harbor seals (*Phoca vitulina*) from the eastern USA. Another study reported an annual increase of HBCD levels in the blubber of juvenile ringed seals from East Greenland sampled between 1986 and 2008 at around 6% per year. In adipose tissue of polar bears from western Hudson Bay, sampled in 2000s, HBCD was detected at quite low concentrations (Law et al, 2014.) HBCD was found in samples of liver and blubber of lung breathing, top marine predator mammals of the North Sea (Morris et al, 2004), see table 5.

TABLE 5. Total HBCD levels in marine mammals (Covaci et al, 2006.)

Species	Country	Year	Total HBCD
Common dolphins, blubber	Ireland, France, Spain, Japan, the US	1993 - 2002	184 - 1223 ng/g lipid weight
Harbor porpoise, blubber	Ireland, UK, Netherlands, Belgium, France	1996 - 2003	<3 ng/g wet weight - 4697 ng/g lipid weight
Sea lion, blubber	The US	1993 - 2003	<0.4 - 96 ng/g lipid weight
Whale, blubber	Japan	1999	25 - 57 ng/g lipid weight
Grey seal	Sweden	1980 - 2000	16 - 177 ng/g lipid weight
Ringed seal, blubber	Norway	2002	15 - 35 ng/g lipid weight
Harbor seal, blubber	The Netherlands	1999 - 2001	63 - 2055 ng/g lipid weight
Polar bear, plasma	Norway	2002	<3 - 85 ng/g lipid weight

4.1.5 Fish and other aquatic organisms

A study from 2004 measured residue levels of HBCD in animals representing different trophic levels from the food web of the North Sea and there was no substantial evidence for biomagnification of HBCD in these webs (Morris et al, 2004.)

HBCD has been detected in many studies in both freshwater and marine biota. Fish often exhibit high residues of HBCD. It can accumulate in different tissues depending on the species of the fish. For example, in barbel, bib, and whiting, HBCD concentrations were higher in liver than in muscle, whereas in sole and plaice the concentrations were higher in muscle than in liver. Less data exists for aquatic invertebrates. The highest concentrations were found in starfish, shrimps, and mussels close to current or past production facilities for HBCD. However, concentrations of HBCD in invertebrates were lower than in fish collected from corresponding locations, which suggests biomagnification (Covaci et al, 2006.)

Relatively low levels of HBCD were determined in some fish species from South China. The levels were higher in farmed freshwater and seawater fish than in wild marine fish, suggesting that human activities are most likely a key source of HBCD in aquaculture. The HBCD levels found were lower than seen in many other regions of the world, especially Europe, where HBCD has been used more intensively than elsewhere (Law et al, 2014.) HBCD was found in mud carp (*Cirrhinus molitorella*), tilapia (*Tilapia nilotica*), and plecostomus (*Hypostomus plecostomus*) from rivers and an electronic waste recycling site in Pearl River Delta, South China. The HBCD concentrations in plecostomus were significantly higher than those in the other fish species, indicating that plecostomus can be a “sentinel” regarding the HBCD pollution in the freshwater environment, meaning it accumulates in their tissues without having significant adverse effects. Among all samples, fish from harbour and e-waste locations had the highest HBCD amounts (Sun R. et al., 2018.) In the US, HBCD was reported to be found in bivalves and snails (Law R. J. et al. 2014.) In Japan, quite low levels of HBCD were observed in both wild and farmed fish samples from several regions, such as *Anguilliformes*, *Perciformes*, *Clupeiformes* and farmed *Salmoniformes* (Law et al, 2014), see table 6.

TABLE 6. Total HBCD levels in fish in the beginning of (Covaci et al, 2006; Sun et al, 2018.)

Species	**Location**	**Year**	**Total HBCD**
Trout, muscle	Tees/Skerne rivers, UK	2001	<1.2 - 6758 ng/g lipid weight
Eel, muscle	Tees/Skerne rivers, UK	2001	40 - 10275 ng/g lipid weight
Barbel, liver/muscle	Cinca river, Spain	2002	<0.1 - 495 ng/g lipid weight
Bleak fish, whole body	Cinca river, Spain	2002	<0.1 - 1643 ng/g lipid weight
Mud carp, muscle	The PRD, China	2018	12.8 - 75.2 ng/g lipid weight
Tilapia, muscle	The PRD, China	2018	5.90 - 115 ng/g lipid weight
Plecostomus, muscle	The PRD, China	2018	34.3 - 518 ng/g lipid weight

4.1.6 Birds

The highest concentrations of HBCD have been observed in birds of prey (Law et al, 2014.) HBCD were present in cormorant liver (*Phalacrocorax carbo*) from the Netherlands, peregrine falcon eggs (*Falco pere Grinus*) from Sweden, and guillemot eggs (*Uria aalge*) from Baltic Sea region. HBCD was found in the muscle and liver of peregrine falcons (*Accipiter nisus*) and little owl (*Athene* *noctua*) nests (Covaci A. et al. 2006.) HBCD and other BFRs were also found in ospreys, herring gulls, and other bird species (Law et al, 2014), see table 7.

TABLE 7. Total HBCD levels in birds (Covaci et al, 2006.)

Species	Location	Year	Total HBCD
Peregrine falcon, eggs	Sweden, UK, Greenland	1973 - 2003	<0.1 - 2400 ng/g lipid weight
Little owl, eggs	Belgium	1998 - 2000	<5 - 50 ng/g lipid weight
Guillemot, eggs/muscle	Sweden	1969 - 2003	34 - 300 ng/g lipid weight
Cormorants, liver	UK	1999 - 2000	138 - 1320 ng/g lipid weight

4.2 C&D waste, and insulation materials

Electronic waste, if transported, stored and dismantled improperly, pose a threat to environmental and human health (Sun et al, 2018.)

In China, one study found high concentrations of HBCD in the scrap PUR foams and in furniture samples, specifically in rigid polyurethane foam faux wood materials. γ-HBCD was the predominant diastereoisomer in PUR foam materials and thermal insulation plastics, whereas α-HBCD was the predominant diastereoisomer in construction and demolition (C&D) waste consisting mainly of asphalt, textiles, and furniture (Duan et al, 2016.)

A 2018 study from Tampere, Finland found HBCD in some demolition waste insulation materials. Samples were taken from a local construction waste stream, packaging materials of everyday items, furniture, and electronic appliances, from a current local construction and renovation project of an apartment building and included insulation materials as well as packaging materials for home appliances. HBCD was not found in packaging materials in this study but was found in XPS such as insulation pink foam and light blue XPS, and underfloor insulation (Honkala, 2018.)

In 2019, another study from Tampere showed presence of HBCD in waste stream in EPS samples, but not XPS (Yunakovskiy 2019), see table 8.

TABLE 8. Total HBCD levels in C&D waste (Duan et al, 2016; Honkala 2018; Yunakovskiy 2019.)

Material	Location	Year	Total HBCD
PUR foam and sponge	Shenzhen, China	2016	7039 µg/kg
PUR foam insulating layer	Shenzhen, China	2016	166.6 µg/kg
PUR foam floor mat	Shenzhen, China	2016	110.51 µg/kg
Furniture	Shenzhen, China	2016	30.2 µg/kg
Asphalt	Shenzhen, China	2016	10.9 µg/kg
Pink foam, hard	Tampere, Finland	2018	3200 mg/kg
Light blue XPS	Tampere, Finland	2018	min. 15000 mg/kg
Underfloor insulation, grey	Tampere, Finland	2018	min. 150 mg/kg
EPS, XPS C&D materials	Tampere, Finland	2019	485 mg/kg wet weight

4.3 Humans

Human gets exposed to HBCD mainly through diet and dust ingestion. In confirmation of this, few studies have reported finding HBCD in human scalp hair. It results most likely from the endogenous exposure (i.e., bloodstream) rather than from external exposure. One study from Vietnam reported finding HBCD concentrations in the hair of e-waste recycling workers. Naturally the hair of people residing in other places had lower concentrations. In the Philippines, they tested the hair of people living on a dump site and compared it to the hair of people living in other places, and both had some levels of HBCD present in the hair. HBCD was also found in the hair samples from Korea, indicating that Koreans have a high exposure to HBCD. This stems from flammability standards implemented in Korea, resulting in high consumption of BFRs in Korean products (Barghi et al, 2018.)

One study from Sweden of wives and ex-wives of Swedish professional fishermen showed some levels of HBCD present in their blood. HBCD was also found in pregnant women and cord blood samples in the Netherlands, blood of hobby fishermen and women living near a BFR-contaminated lake in Norway, computer clerks and control population blood samples in Greece, as well as in various blood samples in Belgium and Canada (Fromme et al, 2016), see table 9.

TABLE 9. Total HBCD levels in human (Barghi et al, 2018; Fromme et al, 2016.)

Samples	Country	Year	Total HBCD
E-waste recycling workers, scalp hair	Vietnam	2012	3.9 ng/g
Scalp hair samples	The Philip-pines	2013	0.3 - 5.4 ng/g
Scalp hair samples	Korea	2018	0.2 ng/g
Wives and ex-wives of profes-sional fishermen, blood serum	Sweden	2000	<0.24 - 3.4 ng/g lipid weight
Pregnant women, blood serum	The Nether-lands	2000 - 2001	<LOD - 7.4 ng/g lipid weight
Cord blood	The Nether-lands	2000 - 2001	0.2 - 4.3 ng/g lipid weight
Hobby fishermen, blood serum	Norway	2004 - 2005	<1.0 - 52 ng/g lipid weight
Women, blood serum	Norway	2004 - 2005	<1.0 - 18 ng/g lipid weight
Computer clerks, general popula-tion, blood serum	Greece	2007	0.49 - 38.8 ng/g lipid weight
Blood serum samples	Belgium	2007	0.5 - 11.3 ng/g lipid weight
Blood serum samples	Canada	2007 - 2009	0.75 – 1.10 ng/g lipid weight

4.3.1 Dietary intake of HBCD

Dietary intake can be only assessed by combining chemical concentrations in foodstuffs with food consumption factors, which may be determined by conducting food surveys (Fromme et al, 2016.) Regarding HBCD, there are only a few dietary intake estimates reported. A food basket study from Sweden concluded that HBCD mainly came from fish (65%), dairy products (24%) and meat (10%.) (Törnkvist et al, 2011.) HBCD intake estimations also came from Sweden, Norway, Japan, France, Belgium, Spain, the US, and China (Fromme et al, 2016), see table 10.

TABLE 10. HBCD dietary intake estimations (Fromme et al, 2016.)

Country	Year	Total HBCD
Sweden	1998 - 1999	1.83 - 2.33 ng/kg body weight
Norway	2008	0.27 ng/kg body weight
The Netherlands	2008	0.12 ng/kg body weight
Japan	2010	1.3 - 3.7 ng/kg body weight
France	2014	0.21 – 0.32 ng/kg body weight
Sweden	2011	0.14 ng/kg body weight
Belgium	2011	0.99 ng/kg body weight
The UK	2004	5.9 ng/kg body weight
Spain	2009	2.6 ng/kg body weight
The US	2010	0.22 ng/kg body weight
Japan	2007	2.4 ng/kg body weight
China	2009	0.43 ng/kg body weight

4.4 Time trends

There have been studies conducted that investigated the time trends of various BFRs in the environment. However, the data are insufficient to show consistent trends, but enough to find indications of a continuing increase in HBCD levels. One of those studies indicated a sharp increase in HBCD concentrations found in the blubber of harbour porpoises in Europe from about 2001 onward. Another study from Japan indicates that environmental levels of HBCD and other BFRs have risen significantly during the last 30 years and continue to rise. This is caused by the continuing and increasing usage of HBCD in Japan. There is also evidence of environmental contamination by HBCD in Chinese coastal waters (Law et al, 2008.)

5 CONCLUSIONS

The evidence is sufficient to conclude that HBCD pose a real problem as it was found in the indoor and outdoor environment, in various ecosystems and living organisms: indoor air, soil and sediment, plants, fish, marine animals, birds and lastly, in humans. There are two probable pathways for human HBCD ingestion – through indoor air (dust) and through food. The source of leakage in the first pathway is more likely to be home furniture. As for the second one, the evidence from studies suggests altogether that HBCD leaks into the environment possibly from C&D, electronic and other types of waste in landfills, as well as insulation material manufacturing facilities. Subsequently, it gets into soil, water, fish, animals, and birds, and inevitably it ends up in humans, potentially making it a very persistent contaminant.

There are no actual studies conducted on the potential harmful effects of HBCD on Finnish ecosystems. However, there is some research available on the evidence of the presence of HBCD in C&D waste. That and all the other evidence is enough to deduce what the impacts can be. The suggestion would be to conduct more research specifically on Finnish biota, more toxicological data would be especially useful.

REFERENCES

Barghi M. et al. 2017. Human exposure to HBCD and TBBPA via indoor dust in Korea: Estimation of external exposure and body burden. The Science of the Total Environment. 593-594, 779-786.

Barghi M. et al. 2018. HBCD and TBBPA in human scalp hair: Evidence of internal exposure. Chemosphere. 207, 70-77.

Covaci A. et al. 2006. Hexabromocyclododecanes (HBCDs) in the Environment and Humans: A Review. Environmental Science & Technology. 40(12), 3679–3688.

Duan H. et al. 2016. Characterization of brominated flame retardants in construction and demolition waste components: HBCD and PBDEs. The Science of the Total Environment. 572, 77-85.

EFSA. Brominated flame retardants. Read 26.10.2021. https://www.efsa.europa.eu/en/topics/topic/brominated-flame-retardants

Eljarrat E. & Barceló D. 2013. Brominated Flame Retardants. The Handbook of Environmental Chemistry. 2011th ed. Springer.

Fromme H. et al. 2016. Brominated flame retardants – Exposure and risk assessment for the general population. International Journal of Hygiene and Environmental Health. 219, 1–23.

Hales B. F. & Robaire B. 2020. Effects of brominated and organophosphate ester flame retardants on male reproduction. Andrology. Wiley. 8(4), 915-923.

Honkala I. 2018. HBCD in Insulation Materials: XRF in Preliminary Detection. Tampereen ammattikorkeakoulu.

Law R. J. et al. 2008. Levels and trends of HBCD and BDEs in the European and Asian environments, with some information for other BFRs. Chemosphere. 73, 223-241.

Law R. J. et al. 2014. Levels and trends of PBDEs and HBCDs in the global environment: Status at the end of 2012. Environment International. 65, 147-158.

Li H. et al. 2012. Levels and distribution of hexabromocyclododecane (HBCD) in environmental samples near manufacturing facilities in Laizhou Bay area, East China. Journal of Environmental Monitoring. 14, 2591.

Morris S. et al. 2004. Distribution and Fate of HBCD and TBBPA Brominated Flame Retardants in North Sea Estuaries and Aquatic Food Webs. Environmental Science Technology. 38, 5497-5504.

Schlabach M. et al. 2011. Brominated Flame Retardants (BFR) in the Nordic Environment. Norden.

Shi D. et al. 2017. Accumulation and developmental toxicity of hexabromocyclododecanes (HBCDs) on the marine copepod Tigriopus japonicus. Chemosphere. 167, 155-162.

Snyder H. 2019. Literature review as a research methodology: An overview and guidelines. Journal of Business Research. 104, 333–339.

Sun R. et al. 2018. Hexbromocyclododecanes (HBCDs) in fish: Evidence of recent HBCD input into the coastal environment. Marine Pollution Bulletin. 126, 357-362.

Törnkvist A. et al. 2011. PCDD/F, PCB, PBDE, HBCD and chlorinated pesticides in a Swedish maket basket from 2005 – Levels and dietary intake estimations. Chemosphere. 83(2), 193-199.

Yi S. et al. 2016. Assessment of the occupational and environmental risks of hexabromocyclododecane (HBCD) in China. Chemosphere. 150, 431-437.

Yunakovskiy A. 2019. HBCD in waste stream. Tarastenjärvi waste site. Tampereen ammattikorkeakoulu.