

Proposal to list “Chlorinated paraffins with carbon chain lengths in the range C₁₄₋₁₇ and chlorination levels ≥45% chlorine by weight” in Annex A, B or C to the Stockholm Convention on Persistent Organic Pollutants

1 Introduction

1. Chlorinated paraffins (CPs) are manufactured substances of “unknown or variable composition, complex reaction products or biological materials” (hereinafter ‘UVCB’). They generally contain linear chloroalkanes, with different degrees of chlorination and chain length distribution depending on the application. This proposal is for C₁₄₋₁₇ chain lengths with a chlorination level at or above 45% chlorine by weight (Cl wt.). These congeners are the principal constituents of substances called “medium chain chlorinated paraffins” (MCCPs) in Europe, North America and Australia, and major constituents of several products manufactured in Asia (e.g. CP-52). Due to the possible confusion regarding different product names, the proposal for listing is based on specific chain lengths and degrees of chlorination. Nevertheless, most of the available hazard and monitoring information is available from assessments on the substance called MCCPs, and so the term “MCCPs” is used in these instances.

2 Regulatory status

2. The substance “MCCPs” (Alkanes, C₁₄₋₁₇, chloro, CAS no. 85535-85-9) was assessed in Europe under the Existing Substances Regulation (EC) No. 793/93 (EC, 2005; EC, 2007), and via a transitional Annex XV dossier once the EU Registration, Evaluation and Authorisation of Chemicals (REACH) Regulation (EC) No. 1907/2006 was introduced (HSE, 2008). “MCCPs” was subsequently included in the first Community Rolling Action Plan under the EU REACH Regulation, and the published Substance Evaluation report prepared by the UK (ECHA, 2019) concludes that it meets the REACH Annex XIII criteria for Persistent, Bioaccumulative and Toxic (PBT) properties. According to the European Chemicals Agency (ECHA) registry of intentions, an Annex XV dossier proposing the substance as a Substance of Very High Concern (SVHC) due to PBT properties will be submitted in January 2021. This proposal is principally based on the Substance Evaluation report, which focused on the assessment of environmental endpoints.
3. “MCCPs” was a priority substance under the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) (OSPAR, 2000).
4. The Australian Department of Health published a hazard assessment of the substance “MCCPs” on their website¹ in June 2019. The review concluded that “MCCPs” meets the domestic PBT criteria, and that some congener groups may meet the Annex D screening criteria for Persistent Organic Pollutants under the Stockholm Convention. The assessment recommended further work to assess environmental exposure and the case for proposing to list as a POP, including adding “MCCPs” to environmental monitoring programmes.
5. Environment and Climate Change Canada reviewed the CPs group in 2008². The review concluded that “MCCPs” is “toxic” as defined in paragraphs 64 (a) and (c) of the Canadian Environmental Protection Act, 1999, on the basis that “MCCPs” is entering, or may enter, the environment in quantities or concentrations or under conditions that: have or may have an

¹ <https://www.nicnas.gov.au/chemical-information/imap-assessments/imap-assessments/tier-ii-environmental-assessments/MCCPs#RiskCharacterisation>

² <https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/chlorinated-paraffins.html>

immediate or long-term harmful effect on the environment or its biological diversity, or constitute or may constitute a danger in Canada to human life or health.

3 Chemical identity

3.1 CAS number, chain length and chlorination

6. Key information for CPs with C₁₄₋₁₇ chain lengths is provided in Table 1, which is based on the EU substance evaluation of “MCCPs” (ECHA, 2019). A non-exhaustive list of relevant CAS numbers is provided in Appendix 3, together with further information (such as additives).

Table 1: Substance identity

IUPAC name	Alkanes, C ₁₄₋₁₇ , chloro
CAS number:	85535-85-9
EC number:	287-477-0
Molecular formula:	C _x H _(2x - y+2) Cl _y , where x = 14 - 17 and y = 1 - 17
Molecular weight range:	300 - 600 g/mole (approximately)
Synonyms:	Medium-chain chlorinated paraffins (MCCPs); Chlorinated paraffins, C ₁₄₋₁₇ (used in Annex VI of the CLP Regulation)

7. The identity of “MCCPs” is governed by chain length distribution and degree of chlorination of the paraffin feedstock which then defines the composition of the substance. It is a UVCB substance containing linear chloroalkanes predominantly in the range C₁₄₋₁₇. The chain length distribution reflects the hydrocarbon feedstocks used in its manufacture within Europe, North America and Australia.
8. In contrast to “MCCPs”, CPs produced in Asian countries such as India and China are differentiated based on their chlorine content (or viscosity) rather than by the carbon chain lengths of their constituent congeners. An example is the product CP-52, which accounts for 80% of the total commercial CP production in China (Wei *et al.*, 2016). This contains C₉₋₃₀ chain lengths with a significant fraction in the range C₁₄₋₁₇.
9. The chlorination process is random, and so all of these products (e.g. “MCCPs” and CP-52) contain many thousands of constituents³. A UVCB substance technically does not contain impurities but some constituents outside of the C₁₄₋₁₇ range are present in small amounts. The chain lengths below C₁₄ are structurally analogous to short-chain chlorinated paraffins (SCCPs – see paragraph 13). Information presented in ECHA (2019) indicates that commercially supplied “MCCP” products are likely to include a significant proportion of the chlorinated C₁₄ carbon chain lengths. For example, analytical data for one product indicated that it contained 60% C₁₄. The chlorine content of the commercially available product types is generally within the range 40% to 63% by weight, with the majority of product types having a chlorine content between 45% and 52% by weight. The chlorine content varies according to the applications the products are used for. Table 2 indicates the structural formulae of possible constituents of the different product types (adapted from information originally presented in EC (2000) and EC (2005)). As described above, the “blocks” in the table will still contain large numbers of individual isomers.

³ Tomy *et al.* (1997) includes a formula for the calculation of the number of isomers.

Table 2: Theoretical chlorine content of constituents for C₁₄₋₁₇ chain lengths

Chlorine content, % w/w	Carbon chain length			
	C ₁₄	C ₁₅	C ₁₆	C ₁₇
<40	C ₁₄ H ₂₉ Cl to C ₁₄ H ₂₇ Cl ₃	C ₁₅ H ₃₁ Cl to C ₁₅ H ₂₉ Cl ₃	C ₁₆ H ₃₃ Cl to C ₁₆ H ₃₀ Cl ₄	C ₁₇ H ₃₅ Cl to C ₁₇ H ₃₂ Cl ₄
40 - 45	C ₁₄ H ₂₆ Cl ₄	C ₁₅ H ₂₆ Cl ₄	C ₁₆ H ₂₉ Cl ₅	C ₁₇ H ₃₁ Cl ₅
45 - 50	C₁₄H₂₅Cl₅	C₁₅H₂₇Cl₅	C₁₆H₂₈Cl₆	C₁₇H₃₀Cl₆
50 - 55	C₁₄H₂₄Cl₆	C₁₅H₂₆Cl₆ & C₁₅H₂₅Cl₇	C₁₆H₂₇Cl₇	C₁₇H₂₉Cl₇
55 - 65	C₁₄H₂₃Cl₇ to C₁₄H₂₁Cl₉	C₁₅H₂₄Cl₈ to C₁₅H₂₂Cl₁₀	C₁₆H₂₆Cl₈ to C₁₆H₂₃Cl₁₁	C₁₇H₂₈Cl₈ to C₁₇H₂₅Cl₁₁
>65	C₁₄H₂₀Cl₁₀ and higher no. of Cl atoms	C₁₅H₂₁Cl₁₁ and higher no. of Cl atoms	C₁₆H₂₂Cl₁₂ and higher no. of Cl atoms	C₁₇H₂₄Cl₁₂ and higher no. of Cl atoms

(bold text indicates those blocks within scope of the proposal)

10. The main constituents in the majority of product types have between five and seven chlorine atoms per molecule. Nevertheless, it should be noted that percentage chlorine content only represents an average level of chlorination, and so a wider range of constituents may be present in any particular product.

11. Around forty CAS numbers are known to have been used to describe the whole chlorinated paraffin family, and these are further detailed in Appendix 3. It is possible that some may contain chlorinated alkanes in the C₁₄₋₁₇ range.

3.2 Structural formula

12. Two example structures (hydrogen atoms removed for simplicity) of CPs with C₁₄ and C₁₇ chain lengths are shown in Figure 1.

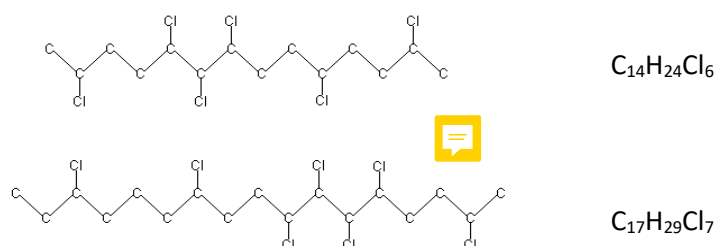


Figure 1: Structures of two representative constituents of CPs with C₁₄ and C₁₇ chain lengths

3.3 Analogues

13. Short chain chlorinated paraffins (SCCPs, containing C₁₀₋₁₃ carbon chain lengths) and long chain chlorinated paraffins (LCCPs, containing C₁₈₋₃₀ carbon chain lengths) are structural analogues registered under EU REACH. SCCPs was listed as a Persistent Organic Pollutant (POP) in 2017. Commercial “MCCPs” contains C₁₀₋₁₃ constituents that may be analogous to SCCPs, at levels typically below 1% by weight (often much lower), although the identity and actual concentration of the individual constituents is not known.

14. The REACH transition Annex XV dossier (HSE, 2008) indicated that LCCPs based on a C₁₈₋₂₀ carbon chain length may contain up to 20% C₁₇ CPs. An earlier report on LCCPs (EA, 2010) is currently being updated by the UK following the substance evaluation of “MCCPs” in the EU. As pointed out in paragraph 8, some Asian products (e.g. CP-52) contain LCCP chain lengths together with MCCP and SCCP chain lengths in a single product (and C_{<10} constituents).

15. Further details of the analogues are provided in Appendix 3.

4 Physico-chemical properties

16. Key data relevant to this proposal are summarised in Table 3. The complexity and variability of the substance in commercial products means that many of the values represent averages. For example, the log K_{OW} of a commercial product will have a range covering several orders of magnitude, reflecting the wide variety of congeners present. This value may change for products with different degrees of chlorination. A standardised set of measurements covering all major constituent blocks at differing degrees of chlorination is not available, although some attempts have been made to look for patterns using predictive software (e.g. Glüge *et al.*, 2013).

Table 3: Physicochemical properties for CPs with C₁₄₋₁₇ chain lengths

Property	Value	Source of information/remarks
Physical state at 20 °C and 101.3 kPa	Liquid	EC, 2005
Melting / freezing point	The pour point varies between -50 °C and +25 °C, depending on degree of chlorination	EC, 2005
Boiling point	Decomposition occurs at around 200 °C before boiling	EC, 2005
Vapour pressure	1.3 x 10 ⁻⁴ to 2.7 x 10 ⁻⁴ Pa at 20 °C for C ₁₄₋₁₇ chlorinated n-alkane, 52% Cl wt. 1.07 x 10 ⁻³ Pa at 45 °C, 6 x 10 ⁻³ Pa at 60 °C and 0.051 Pa at 80 °C for C ₁₄₋₁₇ chlorinated n-alkane, 52% Cl wt.; 2.27 x 10 ⁻³ Pa at 40 °C and 0.16 Pa at 80 °C for C ₁₄₋₁₇ chlorinated n-alkane, 45% Cl wt.	Campbell and McConnell, 1980 BUA, 1992 as cited in EC, 2005
Water solubility	0.0061 mg/L at 20 °C for C ₁₄ chlorinated n-alkane, 50% Cl wt. 0.005 - 0.027 mg/L at 20 °C for C ₁₅ chlorinated n-alkane, 51% Cl wt. 0.01 mg/L in freshwater and 0.004 mg/L in seawater at 16-20 °C for C ₁₆ chlorinated n-alkane, 52% Cl wt.	Unpublished, 2019a; non-GLP OECD Test Guideline (TG) 105. Analytical method: APCI-ToF-HRMS. Study considered to be reliable without restriction. Madeley, <i>et al.</i> , 1983; non-standard method. Analytical method: thin-layer chromatography and radioactivity measurements. Key study used in EC (2005) and considered to be a realistic upper limit for this substance. Campbell and McConnell, 1980; method unknown. Analytical method: radioactivity measurements
Partition coefficient n-octanol/water (log K _{OW})	6.58 ± 0.09 for C ₁₄ chlorinated n-alkane, 50% Cl wt.	Unpublished, 2019b; non-GLP OECD TG 123 (slow stir). Analytical method: APCI-ToF-HRMS. Very little variability

Property	Value	Source of information/remarks
	7.2 (4.7-8.3) for C ₁₆ chlorinated n-alkane, 35% Cl wt.	in K _{ow} was observed between differently chlorinated congener groups. Study considered to be reliable without restriction. Fisk <i>et al.</i> , 1998b; key study used in EC (2005). Analytical method: high performance liquid chromatography (HPLC). Study considered to provide indicative information only.
	5.52 to 8.21 for C ₁₄₋₁₇ chlorinated n-alkane, 45% Cl wt.; 5.47 to 8.01 for C ₁₄₋₁₇ chlorinated n-alkane, 52% Cl wt.	Renberg <i>et al.</i> (1980); non-GLP non-guideline study. Analytical method: reversed-phase high performance thin layer chromatography (RP-HPTLC). Study considered to provide indicative information only

5 Information in relation to the Persistent Organic Pollutant screening criteria

5.1 Chemical analytical challenges

17. The highly complex nature of CPs means that there are considerable analytical challenges associated with detection and quantification. Only limited information is available on the actual carbon chain length distribution and chlorine contents of the CPs detected in environmental samples, although advances in analytical methodologies have meant that more detail has been possible in some of the more recent studies. The current recommended analytical method is APCI-QToF-HRMS⁴. In an inter-laboratory comparison by van Mourik *et al.* (2018), the most commonly used analytical technique for SCCPs analysis – GC-ECNI-LRMS⁵ – showed the largest variation, and the same is likely to be true for longer chains. High Resolution Mass Spectrometry (HRMS) was recommended to be used in future. The degree of chlorination can also be important, especially if the substance in a sample differs from the analytical standards used. Furthermore some commonly used low resolution mass spectrometry methods may be subject to interferences from both the matrix and other contaminants (such as chlordanes, polychlorobiphenyls and toxaphenes) unless highly efficient sample clean-up procedures are used. A large proportion of measured values reported in the academic literature may therefore be unreliable. In general, detections of “MCCPs” in biota and the environment are considered to be qualitative indicators only in the following discussion.

5.2 Persistence

5.2.1 Abiotic data

18. No measured atmospheric half-lives are available for CPs with C₁₄₋₁₇ chain lengths. AOPWIN v1.92 (part of the EPI Suite™ platform (US EPA, 2020)) has been used to make predictions of

⁴ APCI-QToF-HRMS: Atmospheric-Pressure Chemical Ionization Quantitative Time of Flight High Resolution Mass Spectrometry

⁵ GC-ECNI-LRMS: Gas Chromatography Electron Capture Negative Ionisation Low Resolution Mass Spectrometry

atmospheric half-life based on estimated values for the second order rate constant for reaction with atmospheric hydroxyl radicals. These predictions estimate the rate of reaction of the C-H bond in the substance. The rate constant is influenced by the number of C-H bonds and their relative position in the chemical structure. The model is based on a training set of experimentally determined gas-phase hydroxyl radical rate constants for 667 organic chemicals taken at room temperature. Within the training set, 1-chlorohexane is the closest analogue to the chlorinated C₁₄₋₁₇ structures. The AOPWIN model uses a hydroxyl radical concentration of 1.5E+06 OH/cm³, but the ECHA R16 recommends a value of 5E+05 OH/cm³ (equation R.16-12). This lower concentration also appears to have been preferred in previous POPs proposals, and is used here: AOPWIN predicts the atmospheric half-lives of two representative constituents – a C₁₄ (52.6% Cl wt.) and a C₁₇ (51.6% Cl wt.) substance – as 49.2 h and 40.2 h, respectively (i.e. between 1.7 and 2.1 days).

19. For a given chain length, increasing the chlorination level decreases the rate constant as fewer C-H bonds exist for reaction with the hydroxyl radicals. For example, a C₁₄ chain length with higher levels than 52.6% Cl wt. will have an atmospheric half-life longer than 49.2 h. For a given chlorination level, increasing the chain length will increase the rate constant as more C-H bonds are available for reaction, as described in paragraph 18. This can also be seen in the longer half-lives for the POPs listing of SCCPs, where estimated atmospheric half-lives ranged between 47 and 175 h (Wegmann *et al.*, 2007).

20. It should be noted that there are no measured data with which to directly compare the current estimates. As noted above, the nearest analogue in the AOPWIN training set has a much shorter carbon chain length with only a single chlorine atom, so there is considerable uncertainty in the reliability of these predictions.

21. Environment Canada (2008) estimated the atmospheric half-lives for vapour phase “MCCPs” to be 64.8 to 170.4 h (2.7 to 7.1 days). The longest half-lives for “MCCPs” were for constituents with the highest chlorine contents and shortest chain lengths, although it is not specified which constituents the predictions were run for.

22. Koh and Thiemann (2001) investigated the degradation of CPs in water through photochemical dechlorination. The reported half-life in water was 9.6 h for a C₁₇₋₂₄ n-alkane, 35% Cl wt. and 12.8 h for a C₁₂₋₁₈ n-alkane, 52% Cl wt. The relevance of photodegradation is likely to be low in most natural waters due to depth, turbidity, quenching agents, etc.

23. Due to their structure, CPs are not expected to hydrolyse significantly.

24. In summary, the available photolysis data are of limited reliability. Estimated atmospheric half-lives for two representative C₁₄ and C₁₇ constituents (ca. 52% Cl wt.) are in the range 1.7 to 2.1 days, although longer half-lives have been predicted by other authors (2.7 to 7.1 days). The relevance of this information depends on how much of the substance is present in the vapour phase. Photodegradation may occur in water, but the relevance to overall environmental persistence is limited. Hydrolysis is not a significant degradation pathway.

5.2.2 Biotic data

5.2.2.1 Biotic screening data

25. ECHA (2019) details a number of biodegradation screening studies investigating the influence of chain length and chlorination level on biodegradation potential of CPs with C₁₄₋₁₇ chain lengths. These were mostly⁶ based on the OECD TG 301 using modified conditions by

⁶ A number of studies used an inoculum that was not considered to be appropriate for the REACH Annex XIII assessment. Three tests were also performed using OECD TG 302A (Inherent Biodegradability: Modified SCAS Test), but the high inoculum concentrations used in these studies mean that the results are not relevant for persistence assessment. In both cases the data are not summarised in this proposal.

including a surfactant (alkylphenol polyalkoxylate) to increase bioavailability, and in some cases an extended time period for the test.

26. Under the conditions of these studies, C₁₄ chlorinated n-alkanes with a chlorine content of 41.3% and 45.5% were readily biodegradable within 28 days. C₁₄ chlorinated n-alkane, 50% CI wt. failed to meet the 60% pass threshold within 28 days but did meet it after 56 days.

27. Both a 55% and 60% CI wt. C₁₄ chlorinated n-alkane failed to meet the pass threshold of 60% degradation even after 60 days. A C₁₅ chlorinated n-alkane, 51% CI wt. also failed to meet the pass threshold after 60 days.

28. C₁₄₋₁₇ chlorinated n-alkane, 45.5% CI wt. achieved 51% degradation after 28 days (and so was not readily biodegradable), although a test using an extended timescale was not available. C₁₄₋₁₇ chlorinated n-alkane, 51.7% CI wt. was not readily biodegradable in 28 days (27%) and although it was extensively degraded over an extended period (57% degradation after 60 days) it still failed to meet the pass threshold. C₁₄₋₁₇ chlorinated n-alkane, 63.2% CI wt. only achieved 10% degradation under the same conditions.

29. In summary, the studies indicate that substances with a lower level of chlorination can be extensively degraded by micro-organisms under conditions of enhanced bioavailability. The degradability reduces as the number of chlorine atoms per molecule increases. Longer chain lengths are expected to be less water soluble and more adsorptive than the C₁₄ and C₁₅ substances, but there are no degradation data for specific C₁₆ or C₁₇ substances, so the actual influence of chain length cannot be confirmed.

30. It should be noted that it is not possible to extrapolate information from these tests to an environmental half-life.

5.2.2.2 Environmental simulation data

31. A measured environmental half-life in water, typically obtained using OECD TG 309 (aerobic mineralisation in surface water – simulation biodegradation test), is not available for CPs with C₁₄₋₁₇ chain lengths. Given their low water solubility, such a study would be challenging to perform.

32. An OECD TG 308 (aerobic and anaerobic transformation in aquatic sediment systems) study has been conducted using non-radiolabelled C₁₄ chlorinated n-alkane, 50% CI wt. and in accordance with GLP (Unpublished, 2019c and 2019d). The test was conducted at 12 °C in the dark under aerobic conditions. Two types of natural sediment and their associated overlying waters were used: a high organic carbon sediment (4.65%) with a fine texture (Brandywine Creek) and a low organic carbon content (0.55%) with a coarse texture (Choptank River). Test vessels were acclimated for 12 days prior to dosing. The test substance was dissolved in a solvent and mixed with fine quartz sand before the solvent was removed via rotary evaporation. The treated sand was then applied to each test vessel to give a nominal test substance concentration of 5 µg/g dry weight (dw) in sediment. Test sub-groups consisted of treated live vessels, treated inactivated vessels (inactivated by freezing immediately after dosing), and untreated (blank) control vessels. Additional vessels were set up for characterization measurements (without addition of test substance), and were maintained under the same test conditions as vessels used to monitor transformation. Parameter measurements consisted of pH, total organic carbon (TOC), dissolved oxygen (DO), redox, and microbial biomass measurements for both the water and sediment made at the start of acclimation, and day 0, 60 and 120. Test vessels were sacrificed on days 0, 15, 30, 45, 60, 91 and 120 (the test guideline specifies that the test should not be run for longer than 100 days). Chemical analysis was performed using APCI-TOF-HRMS.

33. Apart from a single measurement at 91 days, the mean measured concentrations from all sampling intervals did not deviate by greater than 8% (calculated relative standard deviation; RSD) of the applied nominal concentration. Congener-specific analyses for the extracted samples showed no significant variation between these extracts, the extracted spiked sand and the original test substance. Overall the chemical analysis showed no observable

1 biotransformation in two different sediments, and so the sediment half-life was >120 days at
2 12 °C. The study is assessed to be reliable without restriction.

3 34. No data are available on the biodegradation of CPs with C₁₄₋₁₇ chain lengths in soil, for example
4 in accordance with OECD TG 307 (aerobic and anaerobic transformation in soil).

5 35. In summary, while a modified screening biodegradation test using C₁₄ chlorinated n-alkane,
6 50% Cl wt. indicated extensive biodegradation after 56 days, no degradation occurred in the
7 OECD TG 308 study. Since the simulation test is more environmentally relevant, it is given the
8 greatest weight in the assessment of persistence. The negligible degradation rate in aerobic
9 sediment may reflect a reduction in bioavailability caused by adsorption. Longer chain lengths
10 with similar or higher degrees of chlorination appear to be less degradable than C₁₄ chlorinated
11 n-alkane, 50% Cl wt. based on screening biodegradation test data. However, C₁₄ chlorinated
12 n-alkanes with ≤45% chlorination are readily biodegradable, so should not be treated as
13 persistent. It is not known whether this finding would apply to longer chain lengths with a
14 similarly low degree of chlorination.



15 5.2.3 Environmental compartment monitoring

16 36. Environmental monitoring data are summarised in Appendix 4. This section focuses on
17 sediment core monitoring as this is relevant to the laboratory data summarised in Section
18 5.2.2.2.

19 37. CPs have been detected in sediments cores taken from several locations around the world.
20 Iozza *et al.* (2008) took a 60 m sediment core from Lake Thun, Switzerland in May 2004. The
21 lake is located in a rural, densely populated alpine catchment area without any known point
22 sources (e.g. metal or polymer industries). The average sedimentation rate was determined to
23 be 0.45 cm/year. The level of “MCCPs” in the sediment core showed an increasing trend from
24 1965 onwards reaching a level of 26 µg/kg dw in the surface layer (i.e. 2004). Concentrations
25 between 15 and 20 µg/kg dw were evident in the samples dated to the 1980s. The C₁₄ carbon
26 chain length was the most abundant constituent present (accounting for 41 to 64% of the total
27 “MCCPs”). Chlorine content was higher from the cores dated between 1994 and 2004
28 (generally between 53.3% and 56.6% by weight).

29 38. Chen *et al.* (2011) took a sediment core from the Dongjiang River within Dongguan in the Pearl
30 River Delta area of South China. The sediment core was collected to a depth of approximately
31 68 cm and was thought to contain about 15 years of deposition as it was known that the
32 sedimentation rate in the area was 4 to 6 cm/year. The concentrations of “MCCPs” were higher
33 in the upper layers of the core than in the deeper layers of the core, with the concentration
34 determined to be 1 400 to 3 800 µg/kg dw between 0 and 32 cm depth compared with 1
35 100 to 1 400 µg/kg dw between 36 and 68 cm depth. The increasing concentrations in the
36 upper layers were thought to be a result of increasing use of “MCCPs” in the area. The “MCCP”
37 concentrations in the lower layers were relatively constant. It was noted that there was a higher
38 relative abundance of C₁₆ and C₁₇ substances in the upper layers (from 0 cm to around 44 cm
39 depth) than in the lower layers, with the relative proportion of C₁₄ substances being higher in
40 the lower layers than the upper layers. It was suggested that this may reflect changes in the
41 composition of “MCCPs” used in the area over time. Similar to Iozza *et al.* (2008), higher levels
42 of chlorination were seen for more recent cores.

43 39. “MCCPs” were detected at concentrations ranging from 0.75 to 1.2 mg/kg dw in sediment cores
44 from Lake St. Francis, downstream of Cornwall, Ontario, Canada taken by Muir *et al.* 2002.
45 Based on the data, Environment Canada (2008) estimated the half-life of “MCCPs” in
46 sediments to be longer than 1 year. Sediment cores taken by Yuan *et al.* (2017) at different
47 locations in Sweden found “MCCPs” at concentrations of < 6.5 to 93 µg/kg dw. This included
48 detection in sediment from cores dated as 1954 and 1960.

49 40. In summary, measurable levels of “MCCPs” are present in deeper (older) sediment layers that
50 are of the same order of magnitude as levels in surface (recent) layers. This provides indirect
51 evidence that the substance may be persistent in sediments over many years. It is

acknowledged that degradation conditions (e.g. redox potential) will vary with depth, and levels will also depend on the environmental emission at the time of deposition.

5.2.4 Persistence synthesis

41. The key data are the absence of transformation of a C₁₄ chlorinated n-alkane, 50% Cl. wt. substance after 120 days at 12 °C in a reliable OECD TG 308 study performed to GLP. The absence of degradation at 120 days in the study suggests that it is very unlikely that significant degradation would subsequently occur between 120 and 180 days. This hypothesis is supported by the sediment core monitoring data as "MCCPs" with chlorine contents of ca. 55% were found to persist in sediments for more than a decade.
42. All of the substances that were tested and shown to be less degradable than C₁₄ chlorinated n-alkane, 50% Cl. wt. in the modified and enhanced ready tests are likely to have similar or longer sediment half-lives to the C₁₄ (50% Cl wt.) congener block. Given the predicted and observed trends in physico-chemical properties, it is likely that C₁₅₋₁₇ constituents with similar or higher chlorine contents to C₁₄ chlorinated n-alkane, 50% Cl. wt. will be equally or more adsorptive to sediment. They are therefore likely to be equally or more persistent in sediment (i.e. the sediment half-lives will exceed 180 days).
43. Some constituents with lower chlorine content (≤45% Cl wt.) are readily biodegradable, although it is noted that the C₁₄₋₁₇ chlorinated n-alkane, 45.5% Cl wt. was not readily biodegradable. It is possible that adsorption could cause these substances to have longer sediment half-lives than expected, but no data are available to allow a conclusion to be drawn. Given that the test results for these specific constituents would meet the OECD definition of "readily biodegradable", chain lengths below 45% Cl wt. are excluded from this proposal.
44. Overall, the Annex D criteria for persistence 1b(i) are considered to be met as the half-life for sediment is assessed to exceed 180 days for C₁₄ constituents, and by analogy C₁₅₋₁₇ constituents, with chlorination levels ≥45 Cl wt. C₁₄₋₁₇ constituents with lower chlorination levels are not considered to be persistent.

5.3 Bioaccumulation

5.3.1 Screening information

45. As shown in Table 3, the constituents of CPs with C₁₄₋₁₇ chain lengths have a range of log K_{OW} values, but all measured values exceed 5. C₁₄ chlorinated n-alkane, 50% Cl wt. has a reliable measured log K_{OW} of 6.6. Given the expected increase in hydrophobicity with increasing chain length and chlorination level, the majority of constituents within CPs with C₁₄₋₁₇ chain lengths are likely to have a log K_{OW} around or above this value.

5.3.2 Aquatic fish bioaccumulation studies

46. A modern fish bioconcentration study with Rainbow Trout (*Oncorhynchus mykiss*) was conducted according to OECD TG 305 and GLP using a ¹⁴C radio-labelled C₁₄ chlorinated n-alkane, 45% Cl wt. product (Unpublished, 2010a). The test used a single aquatic exposure concentration during uptake. This was nominally 0.5 µg/L, which was well below the water solubility limit. The mean measured concentration was 0.34 µg/L. Dimethyl formamide was used as a solvent with a concentration in the vessel of 0.004 mL/L. The fish were exposed to the substance for 35 days followed by a 42-day depuration period, under flow-through conditions. Measurements of fish lipid and growth were made during the study, and fish growth was found to be significant. In follow up analytical work, it was determined that around 79% of the measured radioactivity was likely to be parent substance (Unpublished, 2010b). The remaining 21% was associated with non-polar non-extractable metabolites. These were not further identified, and so it is not known whether these are toxic or accumulative. For the purpose of this proposal, the fish bioconcentration factor (BCF) is calculated using a

conservative assumption that all measured radioactivity is relevant. The growth-corrected and lipid-normalised kinetic BCF is therefore 14 600 L/kg. If the apparent metabolites are ignored, the value would be around 11 500 L/kg for parent substance alone. The study is assessed to be 'reliable without restriction', although the reported lipid-normalised steady state BCF (BCF_{ss}) of 3 230 L/kg should be treated with considerable caution as the fish were growing so a true steady state had not been reached.

47. A recent fish dietary bioaccumulation test with Rainbow Trout (*Oncorhynchus mykiss*) was conducted according to OECD TG 305 and GLP using a C₁₄ chlorinated n-alkane, 50% CI wt. substance in a flow-through system (Unpublished, 2019e and 2019f). A dosed treatment containing the test substance at a nominal concentration of 15 µg/g, and a positive control treatment dosed with both a nominal 15 µg/g of test substance plus 3 µg/g of hexachlorobenzene were used. An uptake period of 14 days was followed by 56 days of depuration during which the fish were fed non-dosed food. Chemical analysis was performed using APCI-QToF-HRMS. The growth-corrected depuration half-life was 108.9 days and growth-corrected and lipid-normalised BMF was 0.448 (Unpublished, 2019d). The 15 models within the OECD TG 305 BCF estimation tool all predict that the BCF significantly exceeds 5 000 L/kg. The study is assessed to be reliable without restrictions.

48. Several more studies provide information about fish bioaccumulation of other relevant constituents, as summarised in Table 4.

Table 4: Results of additional fish bioaccumulation studies of lower reliability

Chlorine content,% w/w	Carbon chain length				
	C ₁₄	C ₁₅	C ₁₆	C ₁₇	C ₁₈
<40			>5 000 L/kg (extrapolated from a dietary test) Fisk <i>et al.</i> , 1996		
40 - 45					
45 - 50	>5 000 L/kg (extrapolated from a dietary test) Fisk <i>et al.</i> , 1998 [#]				>5 000 L/kg (extrapolated from a dietary test) Fisk <i>et al.</i> , 2000
50 - 55		2 072 L/kg* Thompson <i>et al.</i> , 2000			
55 - 65	>5 000 L/kg (extrapolated from a dietary test) Fisk <i>et al.</i> , 2000				
>65			>5 000 L/kg (extrapolated from a dietary test) Fisk <i>et al.</i> , 1996		

Note: # May be unreliable. * Not lipid corrected.

49. The bioaccumulation of a C₁₅ chlorinated n-alkane, 51% CI wt. substance in Rainbow Trout (*Oncorhynchus mykiss*) was measured by Thompson *et al.* (2000). This was a GLP study performed according to OECD TG 305. It used flow-through exposure and a ¹⁴C radiolabelled test substance. Two test concentrations (nominally 1 µg/L and 5 µg/L) were used, although the higher concentration was considered to have exceeded the water solubility as lower BCF values were determined. Fish lipid content was not measured so lipid normalisation is not possible. BCF values were calculated based on total radioactivity. The growth-corrected kinetic BCF for the low concentration was 2 072 L/kg, and the growth corrected depuration half-life was 29 days. While the BCF value is significantly lower than for the C₁₄ substance, the

depuration half-life suggests significant concern for bioaccumulation (a depuration half-life around 8-10 days is indicative of a lipid-normalised and growth-corrected BCF above 5 000 L/kg according to the analysis in Environment Agency (2012)). The apparent and unexplained disparity between BCF value and depuration half-life means that the test results should be treated with caution. It is considered to be a supporting study.

50. Fisk *et al.* (1996, 1998 and 2000) performed a series of fish dietary bioaccumulation studies using Rainbow Trout (*Oncorhynchus mykiss*) from which BCF values can be derived using the OECD estimation tool. These used C₁₄ (in two separate studies), C₁₆ and C₁₈ chain lengths with varying levels of chlorination⁷, some of which were run together in the same experiment. The test substances were specifically synthesised and had chlorine atoms on the terminal carbon atoms (which could have affected metabolic potential). The tests were not conducted to a standard test guideline or GLP, and key information to validate the studies run in 1996 and 1998 is not available. In particular Fisk *et al.* (1998) may be unreliable. Although several important aspects are missing for the Fisk *et al.* (2000) study (e.g. demonstrating food homogeneity, measurement of oxygen content and water temperature), information about other key aspects of the study (e.g. control validity and consistency of test substance uptake) suggests that it was likely to have been adequately performed. The chemical analysis in all of the tests used suggests that measurements would have been semi-quantitative, so some caution is needed regarding the exact results. It is also not possible to verify the growth correction or lipid normalisation that was performed. Overall, these studies are assessed to be of unknown reliability. The results from the studies indicate that depuration half-lives were between 29 and 91 days, with estimated BCF values exceeded 5 000 L/kg for all constituents. The C₁₈ result suggests that a similar result would have been seen if a C₁₇ constituent had been tested.
51. Collectively these four supporting laboratory studies are considered to indicate that constituents with carbon chains longer than C₁₄ may have significant bioaccumulation potential in fish, but this cannot be reliably confirmed. They are considered to be supporting studies.

5.3.3 Other aquatic taxa of potential concern

52. Castro *et al.* (2019) determined BCF values considerably above 5 000 L/kg for a C₁₃-C₁₈ chlorinated n-alkane (45% Cl wt.) substance in a non-standard, non-GLP laboratory bioaccumulation study using the water flea *Daphnia magna*. However, there is significant uncertainty for the result due to the single water concentration measurement and use of dry weight rather than wet weight animal concentration measurements.
53. Renberg *et al.* (1986) and Madeley & Thompson (1983) used a C₁₄₋₁₇ chlorinated n-alkane (52% Cl wt.), a C₁₆ chlorinated n-alkane (34% Cl wt.) in non-standard, non-GLP bioaccumulation tests using Blue Mussel *Mytilus edulis*. The bioaccumulation factors (BAFs) exceeded 2 000 L/kg and 5 000 L/kg, respectively. The age of these two studies, together with the use of nominal exposure concentrations exceeding the water solubility (it is therefore unclear if the resulting BAF is over or under-estimated when adsorption to food is taken into account) means that their reliability is considered to be low.
54. These three studies are not considered sufficiently reliable to support the proposal, but they do indicate a concern that other aquatic taxa besides fish may experience high bioaccumulation of CPs with C₁₄₋₁₇ chain lengths
55. A biota-sediment accumulation factor (BSAF) of 4.4 on a lipid-normalised basis was determined for a C₁₆ chlorinated n-alkane, 35% Cl wt. in a study using *Lumbriculus variegatus*; the BSAF for a C₁₆ chlorinated n-alkane, 69% Cl wt. substance was 0.6 (Fisk *et al.*, 1998a).

⁷ C₁₄H₂₆Cl₄ 42% Cl wt.; C₁₄H₂₅Cl₅ 48% Cl wt. (two different isomers); C₁₄H₂₄Cl₆ 53% Cl wt. (two different isomers); C₁₄H_{23.3}Cl_{6.7} 55% Cl wt.; C₁₆H₃₁Cl₃ 35% Cl wt. (two different isomers); C₁₆H₂₁Cl₁₃ 69% Cl wt. (three different isomers); C₁₈H_{31.4}Cl_{6.6} 48% Cl wt.

56. In summary, laboratory bioaccumulation studies using fish indicate high levels of bioaccumulation for different constituents of CPs with C₁₄₋₁₇ chain lengths. In particular, reliable aqueous and dietary exposure studies for C₁₄ chain lengths with chlorine contents in the range 45-50% CI wt. have measured or extrapolated BCF values above 5 000 L/kg. Several other fish bioaccumulation studies of lower reliability suggest BCF values ranging from around 2 000 L/kg to above 5 000 L/kg for carbon chain lengths longer than C₁₄. Other available laboratory bioaccumulation data for invertebrates are less reliable but suggest that the concern for high bioaccumulation may not be limited to fish.

5.3.4 Field biomagnification and monitoring studies

57. The Swedish Environmental Protection Agency (1998) found no evidence for biomagnification in a herring to seal food chain for CPs based on the results of Jansson *et al.* (1993) (the levels found in herring were higher than in seals by an order of magnitude on a lipid weight basis). The actual CPs determined in the Jansson *et al.* (1993) study were of unspecified carbon chain length, with between 6 and 16 chlorine atoms per molecule, and so may have included CPs other than C₁₄₋₁₇.

58. Muir *et al.* (2002) found no indication of biomagnification in three Lake Trout-fish food chains, but did suggest biomagnification factors (BMFs) above 1 for “MCCPs” in a fish-invertebrate food chain. Furthermore, there were some indications that the actual bioaccumulation seen in fish was higher than would be expected by bioconcentration processes alone (although it should be noted that there is considerable uncertainty in these data).

59. A similar study (possibly including some of the same information as Muir *et al.*, 2002) was published by Houde *et al.* (2008). In this study C₁₄, C₁₅, C₁₆ and C₁₇ CP levels were determined in samples of biota collected in Lake Ontario and northern Lake Michigan, North America between 1999 and 2004. The data are presented as mean concentrations over the period 1999 – 2004. The highest average concentrations were found in Slimy Sculpin and Rainbow Smelt (0.11 mg/kg). When “MCCPs” was detected, C₁₄ CPs were the predominant constituents found in samples from Lake Michigan. However, samples from Lake Ontario generally showed that C₁₅ constituents were present at similar, and in several cases higher, concentrations than the C₁₄ constituents in those samples. An indication of potential variability is that the mean concentration of “MCCPs” in Lake Trout from Lake Ontario reported by two different papers was 25 µg/kg in 1998, 15 µg/kg in 2001 and 8 µg/kg in 2004 (Muir *et al.*, 2002; Ismail *et al.*, 2009).

60. Houde *et al.* (2008) compared these biota concentrations with the mean level of “MCCPs” determined in water samples from 2004 (0.9 pg/L). Based on these results, lipid normalised bioaccumulation factors (BAFs, expressed as log BAF_{lipid}) for C₁₄ and C₁₅ CPs were determined as 6.2 and 6.6 in plankton, 7.0 and 6.8 in Alewife (*Alosa pseudoharengus*), 7.4 and 7.2 in Slimy Sculpin (*Cottus cognatus*), 7.4 and 7.1 in Rainbow Smelt (*Osmerus mordax*) and 6.8 and 6.5 in Lake Trout (*Salvelinus namaycush*), respectively. Again the lipid-normalised BMF values for total “MCCPs” were below 1 in food chains consisting of Lake Trout–Alewife (BMF 0.22 - 0.25), Lake Trout–Rainbow Smelt (BMF 0.14), Lake Trout–Slimy Sculpin (BMF 0.11 - 0.94). The lipid-normalised BMF was above 1 for the Slimy Sculpin–*Diporeia* food chain in Lake Ontario (BMF 8.7), but below 1 in the same food chain from Lake Michigan (BMF 0.88). It was noted that the BMF for Slimy Sculpin–*Diporeia* in Lake Ontario was based on the detectable concentration in one sample only. Trophic magnification factors (TMFs) were determined to be in the range 0.06 to 0.36 for fourteen individual constituents in the C₁₄ to C₁₆ chain length range for the Lake Ontario food chain (a similar analysis could not be carried out for Lake Michigan samples), suggesting trophic dilution was occurring overall. When considering these data it should be noted that the water concentrations relate to samples collected in 2004 whereas the biota samples were taken between 1999 and 2004. No information was provided about how the dissolved concentration in water varied between 1999 and 2004 and so this means that the reported BAFs in particular are highly uncertain.

61. Bennie *et al.* (2000) reported levels of “MCCPs” up to around 80 mg/kg wet weight (ww) in blubber samples from stranded Beluga Whales (*Delphinapterus leucas*) from the St. Lawrence

River, Canada, although the analytical method may have been affected by the possible presence of co-eluting interfering organochlorine substances⁸.

62. Reth *et al.* (2006) found “MCCPs” to be present in liver and muscle samples from two Arctic Char (*Salvelinus alpinus*), two Little Auk (*Alle alle*) and two Black-legged Kittiwake (*Rissa tridactyla*) specimens collected from the Arctic (Bear Island). The highest concentration was 0.37 mg/kg (in Little Auk liver tissue). The relative abundance of C₁₄ substances was between 55 and 82% (mean 65.8%) and the ratio of C₁₄/C₁₅ substances was around 2 (higher ratios up to around 4 to 5 were found in some Cod samples). This C₁₄/C₁₅ ratio was reported to be similar to that found in commercially supplied products. The “MCCPs” had between 6 and 9 chlorine atoms per molecule, and the mean chlorine content of the “MCCPs” found was estimated to be 55.85% (range 54.5 - 57.4%). The very small sample size used in this study means that limited weight should be placed on the findings.
63. Du *et al.* (2018) investigated the occurrence of CPs in wildlife from paddy fields in the Yangtze River Delta, China. Nine species (2 fish, 3 reptiles, 1 mammal and 3 birds) were sampled: Pond Loach (*Misgurnus anguillicaudatus*), Rice Field Eel (*Monopterus albus*), Red-backed Rat-snake (*Elaphe rufodorsata*), Short-tailed Mamushi Snake (*Gloydius brevicaudus*), Red-banded Snake (*Dinodon rufozonatum*), Yellow Weasel (*Mustela sibirica*), Peregrine Falcon (*Falco peregrinus*), Collared Scops-owl (*Otus lettia*) and Common Cuckoo (*Cuculus canorus*). Numerical values are provided in Appendix 4. The highest values were found in snakes, the weasel and predatory birds (up to 33 mg/kg lipid weight (lw) or 4.7 mg/kg dw). The authors found that the average concentrations were in the order “MCCPs” > SCCPs > LCCPs, except in birds where SCCPs were found to be more abundant. “MCCPs” appears to be widely dispersed in wildlife at the sampling locations. The concentrations refer to specific tissues (rather than whole body), the sampled species were not necessarily part of the same food web, and there is no information about dietary concentrations. It is therefore not possible to draw firm conclusions about trophic magnification from this study.
64. Yuan and de Wit (2018) and Yuan *et al.* (2019) analysed for CPs with a chain length up to C₃₀ in the Swedish environment using APCI-QTOF-MS. Numerical values are provided in Appendix 4. In the marine food web, concentrations of C₁₄₋₁₇ congeners in White-tailed Sea-eagles, Grey Seal, Harbour Seal and Harbour Porpoise (around 0.2 to 0.5 mg/kg lipid) were generally similar to or higher than those in Herring (around 0.03 to 0.44 mg/kg lipid). The concentrations refer to specific tissues (rather than whole body), the sampled species were not necessarily part of the same food web, and there is no information about dietary concentrations. It is therefore not possible to draw firm conclusions about trophic magnification from this study.
65. Several studies have indicated that “MCCPs” can undergo maternal transfer to birds’ eggs, the highest reported concentration being 0.135 mg/kg ww (e.g. Heimstad *et al.*, 2017; Ruus *et al.*, 2018; Green *et al.*, 2018; Yuan *et al.*, 2019).

5.3.5 Terrestrial organisms



66. An earthworm-soil accumulation factor of 2.4 for adults and 2.3 for juveniles was determined for a C₁₅ chlorinated n-alkane, 51% CI wt. in a 56-day study using *Eisenia fetida* (Thompson *et al.*, 2001). This is assessed to be reliable with restrictions.
67. Yuan and de Wit (2018) and Yuan *et al.* (2019) analysed for CPs with a chain length up to C₃₀ in the Swedish environment using APCI-QTOF-MS. Numerical values are provided in Appendix 4. In the terrestrial food web, Bank Voles were found to contain the lowest amounts of C₁₄₋₁₇ congeners. The detected concentrations of C₁₄₋₁₇ congeners in muscle were

⁸ A gas-chromatography-low resolution negative ion mass spectrometry method was used. Although no comparison was carried out for “MCCPs”, Bennie *et al.* (2000) compared their results for SCCPs with those obtained on Beluga Whale samples using a gas-chromatography-high resolution negative ion mass spectrometry method from another study. They found that the concentrations were one to two orders of magnitude *lower* using the high resolution method than the low resolution method.

comparable in Eurasian Lynx and Grey Wolf (0.75 to 0.83 mg/kg lipid), whilst Moose muscle contained the highest concentrations (1.6 mg/kg lipid). C₁₄₋₁₇ congeners were also detected in muscle or eggs of terrestrial birds of prey (Tawny Owl, Eagle Owl, Marsh Harrier, Golden Eagle and Peregrine Falcon) up to 0.72 mg/kg lipid. The concentrations refer to specific tissues (rather than whole body), the sampled species were not necessarily part of the same food web, and there is no information about dietary concentrations. It is therefore not possible to draw firm conclusions about trophic magnification from this study.

68. In summary, despite the general uncertainty in the available aquatic and terrestrial monitoring data due to the analytical challenges described in paragraph 17, CPs with C₁₄₋₁₇ chain lengths are present (often based on the detection of “MCCPs”) in a wide range of organisms living and feeding in locations that are close to input sources (i.e. industrial and urban areas). Whilst more limited in number, “MCCPs” have also been detected in samples from remote regions, including the Arctic, and also in top predators. Only limited information is available on the actual carbon chain length distribution and chlorine contents of “MCCPs” detected in most environmental samples, although advances in analytical methodologies have meant that this has been possible in some of the more recent studies. C₁₄ chain lengths are frequently the predominant constituents of “MCCPs” when more detailed information is available. This chain length is a significant constituent of commercial product types (see paragraph 9), and in other environmental media such as sediment (Hüttig and Oehme, 2006).

5.3.6 Mammalian data relevant to bioaccumulation

69. Laboratory data for mammals were assessed in EC (2007). Mammalian studies using radiolabelled “MCCPs” have shown that absorption following oral exposure is significant (probably at least 50% of the administered dose; however the concentration reached in the organism is generally lower than that in food). Following absorption there is an initial preferential distribution of the radiolabel to tissues of high metabolic turnover/cellular proliferation. Subsequently there is a re-distribution of radiolabel to fatty tissues where half-lives of up to 8 weeks have been determined for abdominal fat. Of special interest is the study by CXR Biosciences Ltd (2005a) that found that a steady state concentration in white adipose tissue was reached after approximately 13 weeks’ exposure via the diet. The elimination from this tissue was found to be biphasic with an initial half-life of 4 weeks followed by a much slower elimination.

70. Greenpeace (1995) analysed human breast milk for “MCCP” content using pooled samples from six fish-eaters (who ate fish a minimum of once per week) and two non-fish-eaters (who ate fish a maximum of once a month). Similar results were obtained for both groups. The total CP content of the fish-eating group was 50.4 µg/kg lipid, compared to 40.5 µg/kg lipid in the non-fish-eaters; the low sample size meant that it was not possible to determine if any significant differences were apparent between the two groups.

71. Thomas and Jones (2002) detected “MCCPs” in 1 out of 22 samples of human breast milk from the UK, at 61 µg/kg lipid, although the analytical detection limit was relatively high. A follow-up study (Thomas *et al.*, 2003) detected “MCCPs” in 25 samples of human breast milk at 6.2 to 320 µg/kg lipid. The median and 95th percentile levels were 21 and 127.5 µg/kg lipid, respectively.

72. C₁₄ CPs were found to be the predominant constituents of “MCCPs” present in samples of human breast milk from Bavaria (Hilger *et al.*, 2011b).

73. Li *et al.* (2017) determined the concentration of CPs in 50 human blood samples taken from the general population in Shanghai, China. The “MCCP” concentrations were reported as 130 to 3 200 µg/kg lipid. The relative exposure of the participants is unknown. “MCCPs” were also detected in human breast milk, human blood and human placenta samples in additional studies from China (Xia *et al.*, 2017; Wang *et al.*, 2018b).

74. The European Food Standards Agency (2019) quotes levels of “MCCPs” between < LOQ (5.5 µg/kg lipid) to 112 µg/kg lipid in human breast milk across 11 European countries, sampled

as part of the WHO/UNEP Coordinated Survey of Human Milk for Persistent Organic Pollutants.

5.3.7 Bioaccumulation synthesis

75. Two reliable fish bioaccumulation studies conducted according to OECD TG 305 and to GLP show that a C₁₄ chlorinated n-alkane, 45% Cl wt. product has a BCF value significantly in excess of 5 000 L/kg in Rainbow Trout (*Oncorhynchus mykiss*), and that a C₁₄ chlorinated n-alkane, 50% Cl wt. substance has a dietary BMF value that is consistent with this level of bioaccumulation.

76. Supporting laboratory evidence indicates that there may be a high bioaccumulation potential in fish for CPs with chain lengths longer than C₁₄. They are an aqueous exposure test performed with a C₁₅ chlorinated n-alkane, 51% Cl wt. substance and a series of dietary bioaccumulation studies using C₁₄, C₁₆ and C₁₈ chain lengths with different levels of chlorination. The measured and estimated BCF values range from around 2 000 L/kg to above 5 000 L/kg, and all substances had long depuration half-lives (consistent with a BCF exceeding 5 000 L/kg). Invertebrate data also suggest that other taxonomic groups might bioaccumulate C₁₄₋₁₇ CPs significantly. However, these studies are all of lower and mixed reliability and are therefore considered to carry a lower weight in this assessment.

77. Monitoring studies demonstrate widespread contamination of wildlife by CPs with C₁₄₋₁₇ chain lengths at all trophic levels (including predatory species and people). The available (limited) field bioaccumulation studies are equivocal: TMFs below and above 1 have been derived for "MCCPs", and although most BMFs are below 1, some individual BMF values above 1 have been derived.

78. Overall, the Annex D criteria for bioaccumulation 1c(i) are considered to be met as BCF values exceed 5 000 L/kg for at least the C₁₄ constituents with a chlorination level in the range 45-50%. Less reliable data suggest that the C₁₅₋₁₇ constituents may also meet the criteria. This is supported by monitoring data for "MCCPs" indicating widespread uptake by biota.

5.4 Potential for long-range environmental transport

5.4.1 Modelling

79. As detailed in paragraph 20, there are no measured atmospheric half-lives available for CPs with C₁₄₋₁₇ chain lengths, and instead half-lives for two representative constituents (C₁₄H₂₄Cl₆ (52.6% Cl wt.) and C₁₇H₂₉Cl₇ (51.6% Cl wt.)) have been estimated using AOPWIN v1.92. The C₁₄ constituent was selected based on the available laboratory data for persistence and bioaccumulation, and a C₁₇ with an equivalent chlorination level was chosen for comparison. The results indicate half-lives slightly above and slightly below 2 days (49 and 40 hours). These estimates should be treated with caution, as the closest chlorinated alkane in the model training set is a C₆ alkyl substance with a single chlorine atom.

80. The OECD P_{OV} & LRTP Screening Tool⁹ can be used to estimate the long-range transport potential (LRTP) of organic chemicals at a screening level. It predicts two characteristics that can be used to provide an indication of the LRTP of a substance: Characteristic Travel Distance (CTD) and Transfer Efficiency (TE). Overall persistence (P_{OV}) is also calculated to provide a more general measure of persistence. The same C₁₄ and C₁₇ constituents used to determine atmospheric half-lives have been run in the model. The input parameters for these constituents are shown in Table 5, which rely on physicochemical values predicted by EPI Suite™ (US EPA, 2020). There may be some uncertainty as ECHA (2019) notes that EPI Suite™ might not be

⁹ <http://www.oecd.org/chemicalsafety/risk-assessment/oecd-pov-and-lrtp-screening-tool.htm>

the most appropriate model to estimate physico-chemical values for CPs, and this is considered later in a sensitivity analysis in footnote 12.

81. The predictions from the OECD screening tool for the two constituents are shown in Table 6.

Table 5: Input values for two constituents used to predict their LRTP

Parameters	C ₁₄ constituent (52.6% CI wt.)*	C ₁₇ constituent (51.6% CI wt.)*
SMILES	C(Cl)CC(Cl)CC(Cl)CC(Cl)CCC(Cl)CC(Cl)CC	CC(Cl)CC(Cl)CC(Cl)CC(Cl)CCC(Cl)CC(Cl)CC(Cl)CC
Molecular mass (g/mol)	405.07	481.5
Molecular formula	C ₁₄ H ₂₄ Cl ₆	C ₁₇ H ₂₉ Cl ₇
Log K _{AW}	-0.64 (-2.0) [#]	-0.725
Log K _{OW}	8.37 (6.58) [#]	9.95 *
Log K _{OA}	9.01 (8.58) [#]	10.675
OH rate constant (cm ³ /molecule-sec)	7.83 x 10 ⁻¹²	9.58 x 10 ⁻¹² 8
Half-life in air (h)	49.2	40.2
Half-life in water (h)	4 320	4 320
Half-life in soil (h)	8 640	8 640

Note: * Derived using EPI SUITE™.

Measured values.

Table 6: Predictions from the OECD screening tool for the two constituents

Predictions	C ₁₄ constituent (52.6% CI wt.)	C ₁₇ constituent (51.6% CI wt.)
Characteristic Travel Distance (km)	1 022	1 042
Transfer Efficiency (%)	0.032	0.49
P _{OV} (days)	512	519

82. The OECD LRTP screening tool provides plots allowing a comparison of the “MCCP” predictions to a range of substances, as shown in Figure 2 and Figure 3. Figure 4 is taken from the submission for the POPs listing of SCCPs¹⁰ to specifically show where SCCPs is on the plot. The LRTP modelling for this substance used an atmospheric half-life value of 3.7 days (Wegmann *et al.*, 2007), although the specific congener modelled is not stated.

83. No absolute criteria for classifying chemicals as compounds with high or low overall persistence (P_{OV}) and LRTP have been established. Klasmeier *et al.* (2006) proposed threshold values based on limit values for 6 reference POPs, which were a P_{OV} of 195 days, Characteristic Travel Distance of 5 097 km and Transfer Efficiency of 2.248%. The P_{OV} results for the representative C₁₄ and C₁₇ CP constituents are above the 195 days value, but the estimated CTD and TE values are below the reference POPs values suggesting that LRT is less efficient for the C₁₄ and C₁₇ constituents compared to those substances. Nevertheless, their positions in Figure 2 and Figure 3 indicates that the LRTP is similar to, but slightly less than, SCCPs¹¹, which is already listed as a POP. Given the lower atmospheric half-life predicted for the C₁₄ and C₁₇ constituents compared to SCCPs, this position is not surprising.

¹⁰

<http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC2/AnnexEinformationYear2007/tabid/465/Default.aspx>

¹¹ Note that a single constituent was modelled for SCCPs, but as noted Wegmann *et al.* (2007) does not specify the chain length or level of chlorination. An uncertainty analysis in the article does assess the impact of varying the model input parameters.

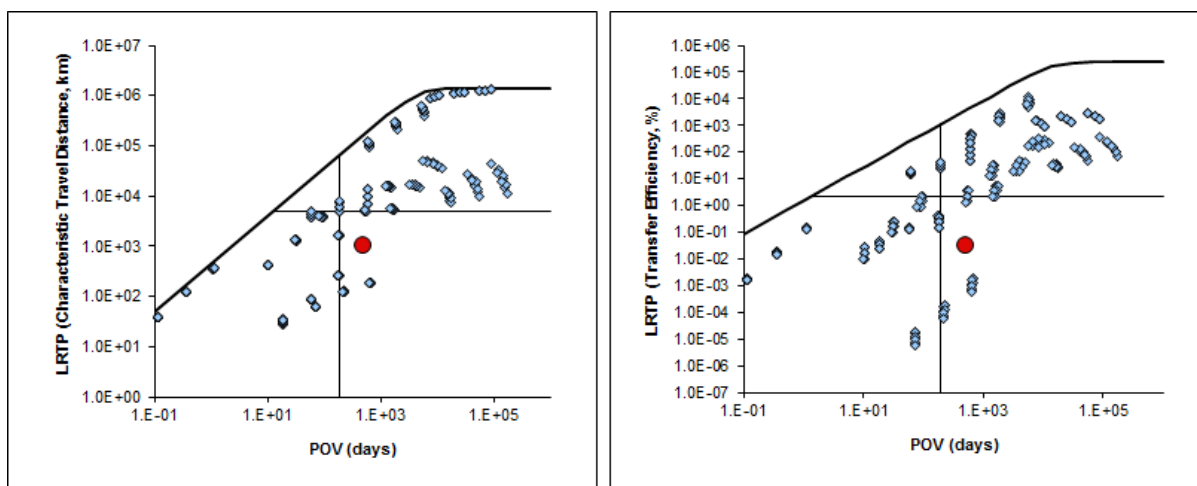


Figure 2: Output plots for CTD and TE for the $C_{14}H_{24}Cl_6$ constituent (red dot)

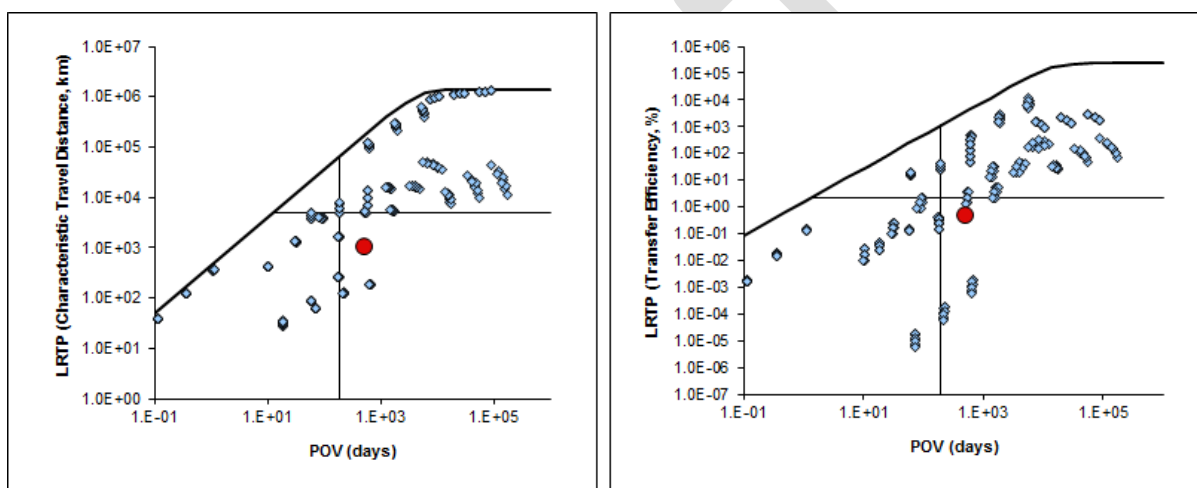


Figure 3: Output plots for CTD and TE for the $C_{17}H_{29}Cl_7$ constituent (red dot)

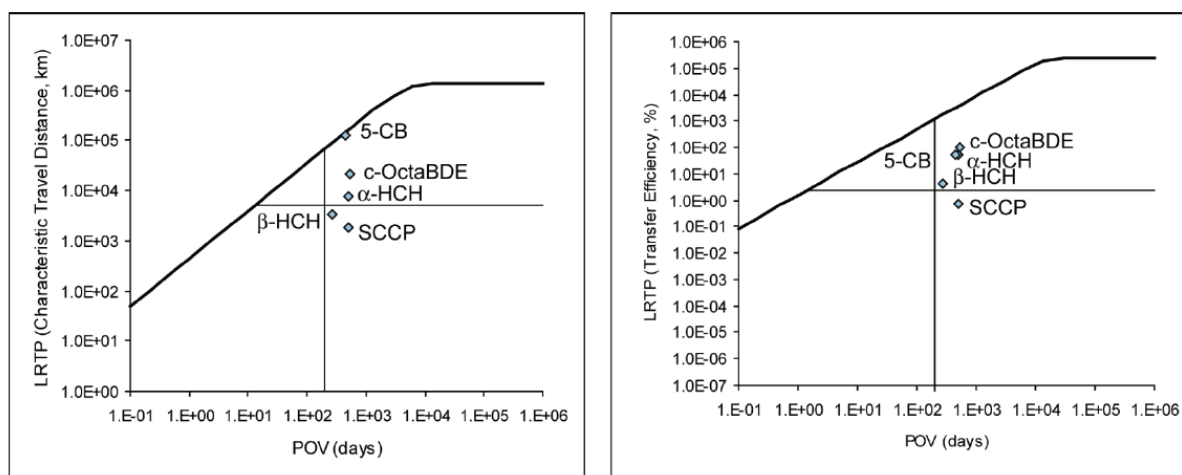


Figure 4: L RTP plots submitted for SCCPs (specific values are not provided in the document)

84. The high K_{OW} ¹² and K_{OC} values and low vapour pressure imply that CPs with C_{14-17} chain lengths, once emitted, will strongly partition to organic matter, including adsorption into and onto aerosol particles in air, as well as to suspended solids in water. Long range transport of CPs with C_{14-17} chain lengths to remote regions is likely to be governed by sorption to particulates with subsequent deposition to soil, vegetation and water when conditions permit. CPs with C_{14-17} chain lengths are also likely to be transported via water while adsorbed to suspended particles.
85. The relative proportions of CPs with C_{14-17} chain lengths present in either the gaseous or particulate atmospheric phases has a strong influence on the potential for long range transport. For example, sorption to particulates reduces the potential for photodegradation during atmospheric transport relative to the gaseous phase. The high log K_{OA} value suggests that the proportion of CPs with C_{14-17} chain lengths present in the gas phase is very low; the OECD tool predicts the fraction in aerosols in air to be between 0.85% and 28.4%. The absence of degradation in the OECD TG 308 study could be a result of strong binding to the sediment, and consequent lack of bioavailability. This would then suggest the level of gaseous partitioning may be over-estimated by the LRT model.
86. The long-range atmospheric transport potential for CPs with C_{14-17} chain lengths has also been assessed by Environment Canada (2008). They concluded that the atmospheric half-lives for vapour phase “MCCPs” ranged from 2.7 to 7.1 days (64.8 to 170.4 hours). The longest half-lives were for constituents with the highest chlorine contents and shorter chain lengths, although the specific constituents are not specified. The sensitivity of the OECD LRTP model to this range of half-lives is shown in Table 7. It can be seen that CTD increases significantly and TE also increases with a longer half-life, but there is little change to P_{OV} .

Table 7: Sensitivity of the LRTP predictions to different atmospheric half-lives

Predictions	C₁₄ constituent (52.6% Cl wt.)		C₁₇ constituent (51.6% Cl wt.)	
Atmospheric half-life (h)	64.8	170.4	64.8	170.4
Characteristic Travel Distance (km)	1 344	3 476	1 575	3 275
Transfer Efficiency (%)	0.056	0.374	1.13	4.88
P_{OV} (days)	513	513	519	519

87. Environment Canada (2008) further concluded that “MCCPs” have estimated vapour pressures and Henry’s Law constants in the range of values for several POPs that are known to undergo long-range atmospheric transport, such as lindane, heptachlor and mirex.

5.4.2 Air monitoring data

88. Several monitoring studies have reported the detection of “MCCPs” in the air of Polar Regions and other remote areas such as the high altitude Tibetan Plateau, which provides evidence of long-range transport occurring (Wu *et al.*, 2019; Ma *et al.*, 2014 and Bohlin-Nizzetto *et al.*, 2020). Table 8 summarises these studies.
89. Data from the Chinese Bohai sea (Ma *et al.*, 2018) provide supporting evidence of the potential mechanisms of LRT as the researchers detected “MCCPs” in air samples (both gaseous and particulate) and seawater samples (both dissolved and particulates).

¹² As a test of sensitivity and the use of predicted physico-chemical values, experimental values for log K_{OW} (6.58) and a log K_{AW} at -2.0 were used as input values for the C_{14} constituent (see Table 7 above). The log K_{AW} of -2.0 is calculated from experimental values for vapour pressure (2.7E-04 Pa at 20 °C) and water solubility (6.1 µg/L at 20 °C). Using these values but with the same degradation half-lives predicts a P_{OV} of 503 days, a CTD of 1 010 km and a TE of 0.11%. Therefore overall, the use of the measured data makes little difference to the modelled outcome. The predicted CTD and TE are heavily influenced by partitioning to the particle phase. A lower input value of log K_{AW} results in an increase in the log K_{OA} and in the predicted CTD and TE% as the predicted proportion of CPs with C_{14-17} chain lengths in the particle phase increases.

Table 8: Summary of “MCCP” air monitoring data from remote regions

Location	Comment	Units	Concentration	Reference
Shergyla Mountain (Tibetan Plateau)	82 air samples	pg/m ³	52.6 to 687.5	Wu <i>et al.</i> (2019)
Zeppelin (Svalbard, Norway) and Birkenes (Norway)	Air samples (2019): Weekly (Svalbard) Monthly (Birkenes)	pg/m ³	<44 to 3 900 (mean: 270) <95 to 1 500 (mean: 330)	Bohlin-Nizzetto <i>et al.</i> (2020)
Georgia King Island, Fildes Peninsula of Antarctica (Great Wall Station)	24 air samples: gaseous phase particulates	pg/m ³	3.0 to 4.5 (average: 3.8) 0.5 to 0.9 (average: 0.7)	Ma <i>et al.</i> (2014)

90. Iozza *et al.* (2009a and 2009b) detected “MCCPs” in spruce needles sampled from the European Alps at concentrations of 0.0052 to 0.095 mg/kg in 8 samples collected in October 2004. C₁₄ substances with 6 to 8 chlorine atoms per molecule predominated, although 5, 9 and 10 chlorine atom substances and substances with longer chain lengths were also detectable at a few percent relative abundance. Wang *et al.* (2016) measured “MCCP” concentrations in Masson Pine (*Pinus massoniana*) needles from Shanghai, China. The measured concentrations were 0.012 to 33.5 mg/kg dw with a geometric mean value of 0.7 mg/kg dw. The details of the analytical method were not available. These findings are likely to reflect atmospheric deposition rather than plant uptake.

91. According to Glüge *et al.* (2018) “MCCP” concentrations in air measured in Asia and Europe are in the same order of magnitude as SCCP concentrations measured at the same locations and points in time. “MCCP” concentrations in air in the Arctic are, however, around one order of magnitude lower than the SCCP concentrations which indicates a slightly lower long-range atmospheric transport potential of “MCCPs” compared with SCCPs (Glüge *et al.*, 2018). This observation aligns with the OECD model prediction for LRT for “MCCPs” and SCCPs.

5.4.3 Other environmental monitoring data

92. Appendix 4 provides a summary of environmental monitoring data, based on ECHA (2019). CPs with C₁₄₋₁₇ chain lengths are not routinely included in environmental monitoring programmes. However, the available European monitoring data generally show widespread occurrence of “MCCPs” in water (at concentrations typically up to a few µg/L), sediment (at concentrations typically up to a ca. 2 mg/kg dw) and biota (typically below 1 mg/kg ww although higher concentrations up to around 80 mg/kg have been reported in some studies). “MCCPs” is also found in sewage sludge up to 9 700 mg/kg dw. Levels in dust were reported to be in the low mg/kg range. “MCCPs” was present at concentrations of <0.81 to 14.5 ng/m³ (mean 3.0 ng/m³) in air samples from the Hazelrigg field station near Lancaster, UK in 2005.

93. In a comprehensive review, Glüge *et al.* (2018) compared monitoring levels of SCCPs with “MCCPs” in urban, rural and remote locations. For the remote locations, the “MCCP” concentrations from the fish sampled in the Reth *et al.* (2006) study (described in paragraph 62) were noted to be in the upper 50th percentile of the observed concentrations in fish sampled from Canada and Europe (principally Norway). “MCCP” concentrations in the bird eggs were comparable between the Arctic and Norway. It is notable that in the same Arctic study, “MCCP” concentrations in eggs covered a similar concentration range to SCCPs. In the Reth *et al.* (2006) study “MCCP” and SCCP concentrations in the bird muscle and liver tissue were also comparable. As previously noted, the representivity of the Reth *et al.* (2006) study is limited by the small sample size.

94. In a review article, Vorkamp *et al.* (2019) summarise monitoring of SCCPs and “MCCPs” in environmental compartments and biota in the Arctic. The authors note detection of both substances in sediments, mussels, fish, seabirds and marine mammals. In the case of sediment, “MCCPs” was below the limit of detection (0.1-0.3 ng/g dw) in all but one sample (4.8 ng/g dw).

95. "MCCPs" has been detected in the plasma of Ringed Seals and Polar Bears from the Arctic with quoted concentrations of 74 and 600 µg/kg lipid. These were in the same order of magnitude as SCCPs in the same samples, but at marginally lower values (NILU, 2013).

5.4.4 Long range transport synthesis

96. The predicted atmospheric half-life for two relevant C₁₄ and C₁₇ constituents are 49 and 40 hours. It is difficult to validate these estimated values, and so they are uncertain. The higher value exceeds the 48 hour threshold in Annex D. The lower value, below 48 hours, is for the higher chain length. This constituent is less relevant for (gaseous) atmospheric photodegradation as a greater fraction will be adsorbed to aerosols. More highly chlorinated constituents will be more photolytically stable and more adsorptive.

97. Using the OECD LRTP model, the LRTP for these two representative constituents is lower than the 6 reference POPs in the model. However, they are comparable to, but slightly below that for SCCPs, which is a POP. CPs with C₁₄₋₁₇ chain lengths have low volatility and are expected to adsorb strongly to particulates. Given the relatively high gaseous fraction predicted for the C₁₄ constituent in the OECD LRTP tool, it is not clear how well the adsorption of the constituents is actually modelled. The atmospheric transport of airborne particulates provides a potential route for long range transport, and this is supported by the detection of "MCCPs" at low levels in air samples taken in remote locations such as the Polar Regions.

98. The modelled comparability to SCCPs is supported by the detection of "MCCPs" in environmental samples from remote regions, such as the Arctic, including in top predators. In some instances, the levels of "MCCPs" appear to be similar to SCCPs. There is also environmental monitoring data showing the detection of "MCCPs" in different matrices at locations in the following countries: Australia, Belgium, Canada, China, Czech Republic, Denmark, France, Germany, India, Ireland, Japan, Norway, Pakistan, Sweden, Switzerland, UK and USA, as well as various marine locations such as the Baltic Sea, Irish Sea, North Sea in Europe and Chinese Bohai Sea (refer to Appendix 4).

99. Overall, the Annex D criteria for Long Range Transport 1d(i), (ii) and (iii) are considered to be met. Limited biota monitoring data indicate detection of "MCCPs" in remote areas, with similar concentrations to SCCPs suggested in some studies. Air sampling data are also limited, but the available information confirms the potential for transport via this media. The predicted atmospheric half-life of constituents is around 2 days with values above and below the threshold, although it remains unclear how far gaseous transport of CPs with C₁₄₋₁₇ chain lengths is relevant compared to adsorption to particles. The accuracy of the predictions is unknown. Other monitoring data indicate that "MCCPs" are widely detected in the environment.

100. In conclusion, the limited data indicate that there is both a pathway and delivery of CPs with C₁₄₋₁₇ chain lengths to remote locations. The concern is that the characteristics of these constituents, while slightly less efficiently transported over long distances than SCCPs, appear to be similar to SCCPs.

5.5 Adverse effects

5.5.1 Ecotoxicity

101. Since CPs with C₁₄₋₁₇ chain lengths contain thousands of constituents, the reported toxicity end points effectively reflect an average of the contributions that individual constituents make. The influence of varying degrees of chlorination and chain length on toxicity is not known. It is therefore assumed that if toxicity is demonstrated for one type of product, it will be applicable for all.

102. The key data for the proposal are 2 aquatic toxicity studies performed with *Daphnia magna* using a C₁₄₋₁₇ chlorinated n-alkane, 52% Cl wt. The first is an acute test performed according to OECD TG 202 and GLP that is considered to be reliable without restriction. This determined

a 48-h EC₅₀ value of 5.9 µg/L, based on (arithmetic) mean measured concentrations (Thompson *et al.*, 1996). The second is long-term test performed according to OECD TG 202 (later superseded by OECD TG 211) and GLP that is also considered to be reliable without restriction (Thompson *et al.*, 1997). The study met the validity criteria of the later test guideline as well as OECD TG 202. Based on the chemical analysis, results were calculated as time-weighted mean values, with the 21-day NOEC for reproduction and length being 8.7 µg/L.

103. The available acute and chronic data for fish and algae cited in ECHA (2019) and EC (2005) suggest that these taxa are less sensitive to “MCCPs” than *Daphnia magna*. Long-term fish data are limited, but a GLP 60-d study using Rainbow Trout (*Oncorhynchus mykiss*) exposed to C₁₄₋₁₇ CP, 52% CI wt. found no effects on mortality, growth or behaviour at 4.5 mg/L (Madeley and Thompson, 1983). In a 72-h study performed with a C₁₄₋₁₇ CP, 52% CI wt. according to OECD TG 201 and GLP (Thompson *et al.*, 1997), little or no toxic effect on the growth of the green alga *Selenastrum capricornutum* occurred at concentrations up to 3.2 mg/L.

104. A further long-term invertebrate toxicity study was summarised in EC (2005). This reported a 60-d NOEC of 0.22 mg/L for a C₁₄₋₁₇, 52% CI wt. substance with Blue Mussel *Mytilus edulis* (Madeley and Thompson, 1983).

105. Reflecting the toxicity to *Daphnia magna*, “MCCPs” has a harmonised EU environmental classification of Aquatic Acute 1, Aquatic Chronic 1 (H400, H410) in accordance with the UN Globally Harmonised System. More recent self-classification by the lead EU REACH Registrants includes an M-factor for acute and chronic aquatic hazards of 100 and 10, respectively. Given the stringent environmental classification, no further toxicity studies for pelagic aquatic organisms are summarised in this proposal.

106. Three reliable prolonged sediment toxicity studies for “MCCPs” conducted in accordance with GLP using three taxa (*Hyalella azteca*, *Lumbriculus variegatus* and *Chironomus riparius*) are summarised in EC (2005 & 2007). These used sediment spiked with a C₁₄₋₁₇, 52% CI wt. substance. The lowest NOEC was 130 mg/kg dw (~ 50 mg/kg ww), obtained in the study with *Lumbriculus variegatus* and also *Hyalella azteca*. EC (2005 & 2007) also reports 3 reliable long-term terrestrial toxicity studies conducted in accordance with GLP with the same chemical using earthworms (OECD TG 222), terrestrial plants (OECD TG 208) and soil microorganisms (OECD TG 216). Earthworms were the most sensitive species, with a 56-d NOEC of 280 mg/kg dw.

5.5.2 Human health toxicity

107. The EU human health risk assessment report (HSE, 2008b) provides a summary of the available laboratory mammalian testing, which used one commercial product type (a C₁₄₋₁₇, 52% CI wt. substance) for the majority of regulatory studies.

108. The target organs for repeated oral dose toxicity are liver, thyroid and kidney. The lowest reliable NOAEL is 23 mg/kg/day from a 90-d study with F344 rats *Rattus norvegicus* (CXR Biosciences Ltd, 2005b), based on increased relative kidney weights. The European Food Safety Authority (EFSA, 2019) has derived a BMDL₁₀¹³ of 36 mg/kg bw/day from this study.

109. No carcinogenicity studies have been conducted. “MCCPs” is generally unreactive and not mutagenic. The carcinogenic potential of “MCCPs” is expected to be similar – at least in qualitative terms – to that of SCCPs, although direct read across is not appropriate. SCCPs induce liver and thyroid adenomas and carcinomas and kidney tubular cell adenomas and carcinomas in animal studies. The liver and thyroid tumours are considered to be of little or no relevance to human health. It cannot be completely ruled out that the kidney toxicity observed for “MCCPs” might lead to kidney cancer in rats through a non-genotoxic mode of action. However, “MCCPs” is not classified for this end point under Regulation EC No. 1272/2008, which implements the UN GHS in the EU.

¹³ Benchmark Dose Level associated with a 10% response adjusted for background.

110. "MCCPs" has no apparent effect upon fertility in rats up to approximately 400 mg/kg/day in the diet. No adverse developmental effects occurred during gestation in rats or rabbits in two conventional developmental studies using maternal doses up to 5 000 and 100 mg/kg/day, respectively. In contrast, exposure of Wistar rats *R. norvegicus* to C₁₄₋₁₇ n-chloroalkane, 52% Cl wt. at a maternal dietary dose of 74 mg/kg/day (1 000 ppm) up to approximately 400 mg/kg/day (6 250 ppm) produced internal haemorrhaging and deaths in the pups (IRDC, 1985). Follow-up studies with Sprague Dawley and CD rats (CXR Biosciences Ltd, 2003, 2004 & 2006) demonstrated that "MCCPs" can perturb blood clotting. In adult females that had been treated for 7-8 weeks including pregnancy and lactation, decreased levels of vitamin K and of the clotting factors VII and X were found, and 5 out of 32 dams showed signs of haemorrhaging during parturition. However, these decreases did not affect their prothrombin times, indicating that the functional reserve in the majority of these adult animals was sufficient. The foetus *in utero* apparently receives sufficient vitamin K via the placenta, but after birth becomes severely deficient in vitamin K and related clotting factors and relies on the mothers' milk to receive them. Exposure to "MCCPs" in the milk may also further reduce their vitamin K levels. This in turn leads to a severe vitamin K deficiency in the neonates and consequently to haemorrhaging. This is the basis for the harmonised EU classification for effects via lactation (H362 – May cause harm to breast-fed children) according to Regulation EC No. 1272/2008.
111. From the studies available, an overall NOAEL of 47 mg/kg/day (600 ppm) as a maternal dose was identified for these effects mediated via lactation (EC, 2005). However, it should be noted that the effects (11% reduction in pup survival and related haemorrhaging) observed at the LOAEL (74 mg/kg/day; 1 000 ppm) were not statistically significant. Haemorrhaging was also seen in one study at the time of parturition in 16% of dams given 538 mg/kg/day (6 250 ppm), but not up to 100 mg/kg/day (1 200 ppm) in other studies. The NOAEL of 100 mg/kg/day (1 200 ppm) was therefore selected for the risk characterisation of haemorrhaging effects potentially occurring in pregnant women at the time of parturition.
112. "MCCPs" does not meet the criteria for classification as carcinogenic (category 1A or 1B), germ cell mutagenic (category 1A or 1B), toxic for reproduction (category 1A, 1B, or 2) or specific target organ toxicity after repeated exposure (STOT RE category 1 or 2) according to Regulation EC No. 1272/2008.

5.5.3 Adverse effects synthesis

113. A C₁₄₋₁₇ chlorinated n-alkane, 52% Cl wt. has a 48-h EC₅₀ of 0.0059 mg/L for *Daphnia magna*. The 21-day NOEC for the same species and substance is 0.0087 mg/L. These two results, from reliable laboratory studies performed to recognised OECD test guidelines and to GLP, indicate that constituents of CPs with C₁₄₋₁₇ chain lengths are very toxic to aquatic invertebrates in the environment.
114. The concern for adverse effects is supported by the internal haemorrhaging and death observed in rodent offspring in the mammalian reproduction study resulting in a harmonised EU classification for "MCCPs" as H362 (May cause harm to breast-fed children). Potential adverse effects could therefore occur in mammalian wildlife.
115. Overall, the Annex D criteria for adverse effects are considered to be met.

6 Manufacture, supply and environmental emission

6.1.1 Uses and supply

116. Within the EU, there are 10 active REACH Registrants of "MCCPs" listed on the ECHA dissemination portal¹⁴, 6 of which are manufacturers. The registered tonnage lies in the band

¹⁴ <https://echa.europa.eu/registration-dossier/-/registered-dossier/15252>, Checked December 2020

10 000 – 100 000 tonnes per year. Based on the EU REACH registration information, the substance has a number of uses, such as:

- a secondary plasticizer in PVC, adhesives, sealants, paints and coatings;
- a flame retardant in PVC and rubber compounds, adhesives, sealants, paints and coatings, and textiles;
- an extreme pressure lubricant and anti-adhesive for metal working fluids;
- a waterproofing agent for paints, coatings and textiles; and
- a carrier solvent for colour formers in paper manufacture.

117. Former uses reported in EC (2005) were for leather fat liquors and carbonless copy paper. These are no longer included in the latest REACH registration dossiers. However, it is possible that these uses continue elsewhere.

118. Most “MCCPs” used in the EU is manufactured within the EU with only a small proportion (<10%) imported from outside the bloc. “MCCPs” may also be imported into the EU in finished or semi-finished articles (e.g. textiles, electrical items). The total mass of “MCCPs” entering the EU in imported articles is unknown, so it is not possible to gain a full insight into stocks and mass flows. KEMI (2018) estimated that the EU imported approximately 2 100 tonnes of “MCCPs” in electrical cables in 2014. There are 532 notifiers of “MCCPs” in ECHA’s Classification & Labelling Inventory¹⁵, which suggests a large number of downstream users in Europe.

119. Outside Europe, Glüge *et al.* (2018) cite the following production volumes of “MCCPs”: North America (17 800 tonnes in 1998), Russia (21 000 tonnes in 2007 and 27 000 tonnes in 2011), Thailand (20 000 tonnes in 1994) and China (estimated to be 600 000 tonnes in 2013, extrapolated from CP-52 production). Some of these values are more than 20 years old, and so current supply volumes may have changed. Glüge *et al.* (2018) suggest that Chinese production may have continued to increase after 2013, based on the supply trend prior to that year. In Australia, the total annual introduction volumes in 2002 and 2006 were between 1 000 and 9 999 tonnes (NICNAS, 2002 & 2006). Manufacture in India, possibly at a significant supply volume, is also suggested (Lassen *et al.*, 2014), but information specific to CPs with C₁₄₋₁₇ chain lengths is not available.

120. Based on the available supply data, there could be up to about 750 000 tonnes/year of CPs with C₁₄₋₁₇ chain lengths produced globally.

6.1.2 Emissions estimates

121. As part of the Risk Management Options Analysis for “MCCPs” in the EU, the release estimates for the different lifecycle stages were estimated based on information¹⁶ in the REACH Registrants’ Chemical Safety Reports (Unpublished, 2019g). These values are shown in Table 9 and Table 10. The total estimated release to surface water in Table 10 reflects the removal of “MCCPs” from aqueous waste streams by wastewater treatment plants. This diverts approximately 149 tonnes/year of “MCCPs” to sludges, which may be landfilled, used in agriculture or incinerated.

122. Based on this information, if the proportion of “MCCPs” released per year in the EU is applied to the estimated global supply tonnage¹⁷, this suggests between 2 785 and 27 855 tonnes per year is being released to the environment at a global scale. Clearly the global tonnage is an

¹⁵ <https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/94445>, checked December 2020.

¹⁶ Tonnage relevant for the lifecycle and quoted emission factor.

¹⁷ 305 tonnes/year released from the range of 10 000 to 100 000 tonnes supplied in the EU applied to the estimated global use volume of 750 000 tonnes/year.

approximation, and this calculation assumes that the EU use pattern and emission controls are similar across the world (which is unlikely to be the case).

Table 9: Estimated total releases of “MCCPs” to the EU environment by use (from all lifecycle stages (except waste such as sewage sludge))

Use	Total releases per year (tonnes)
“MCCPs” manufacture	0
PVC and rubber (formulation, conversion, service life)	41
Adhesives/sealants (formulation, use, service life)	126
Metalworking fluids (formulation and use)	100
Textiles (formulation and service life)	13
Paints/coatings (formulation, use, service life)	10
Paper manufacturing/recycling	15
TOTAL	305

Table 10: Estimated total releases of “MCCPs” to the EU environment from all lifecycle stages (except waste, such as sewage sludge)

Release route	Total releases per year (tonnes)
Water	4
Air	89
Soil	61

7 Conclusion and need for action



123. For CPs with C₁₄₋₁₇ chain lengths, there are reliable laboratory data clearly indicating that constituents with a C₁₄ chain length and chlorination levels around 45-50% Cl wt. *meet all* of the Annex D screening criteria for persistence, bioaccumulation and adverse effects. Data for C₁₅, C₁₆ and C₁₇ constituents suggest that these also meet the persistence and toxicity screening criteria. These longer chains may meet the bioaccumulation criteria, but fully reliable data to confirm this are not available. Long range transport potential is assessed to be shown for all chain lengths.

124. The persistence information indicates that the concern is for all constituents with chlorination levels at or exceeding 45%.

125. The C₁₄ constituents are a major congener group in commercial CP products currently being supplied. This indicates that CPs with C₁₄₋₁₇ chain lengths will contain a significant fraction of constituents that meet the Annex D screening criteria. Of the remaining fraction, a significant proportion meets three out of the four criteria, with weaker evidence for the bioaccumulation endpoint. Given the potential bioaccumulation concern from the available data for these longer chains together with the evidence for the other criteria, it is proposed to include all four carbon chain lengths in the listing.

126. It is noted that laboratory bioaccumulation data of limited reliability are available for a C₁₈ constituent. The focus of this proposal is the C₁₄-C₁₇ chain lengths, and this reflects the data available for the other endpoints and generally the monitoring data. Therefore chain lengths longer than C₁₇ are not included within the proposal. As noted in paragraph 14 an update of a national assessment of “LCCPs” is currently in progress by the UK, which will assess C₁₈ chain lengths (and above).

127. As a result of its PBT properties, “MCCPs” is of regulatory concern in the UK, EU, Switzerland, Australia and Canada. The different applications and ongoing use of CPs with C₁₄₋₁₇ chain lengths globally is estimated to result in around 2 785 to 27 855 tonnes being potentially emitted

- 1 to the environment each year. Due to the hazard concerns for the substance, and the estimated
2 level of environmental emissions, global action is required to manage the risks from CPs with
3 C₁₄₋₁₇ chain lengths.
- 4 128. In conclusion, it is proposed to list carbon chain lengths in the range C₁₄₋₁₇ and chlorination
5 levels $\geq 45\%$ chlorine by weight in the Convention.

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Appendix 1: Abbreviations

1	APCI-QToF-HRMS	Atmospheric-Pressure Chemical Ionization Quantitative Time of Flight High Resolution Mass Spectrometry
2	BAF	Bioaccumulation Factor
3	BCF	Bioconcentration Factor
4	BMF	Biomagnification Factor
5	BOD	Biological Oxygen Demand
6	BSAF	Biota-sediment accumulation factor
7	Ca.	Circa ("approximately")
8	Cl wt.	Chlorine content by weight
9	CLP	Classification, Labelling and Packaging
10	CSR	Chemical Safety Report
11	DOC	Dissolved Organic Carbon
12	dw	Dry weight
13	EC ₅₀	Half maximal effective concentration
14	ECHA	European Chemicals Agency
15	GC-ECNI-LRMS	Gas Chromatography Electron Capture Negative Ionisation Low Resolution Mass Spectrometry
16	GCxGC-ECD	Two Dimensional Gas Chromatography with Electron Capture Detector
17	GLP	Good Laboratory Practise
18	k₁	Uptake rate constant
19	k₂	Overall depuration rate constant
20	k_M	Rate constant for metabolism
21	K _{OC}	Organic carbon-water partition coefficient
22	K _{OW}	Octanol/water partition coefficient
23	LCCP(s)	Long chain chlorinated paraffin(s)
24	LOD	Limit of detection
25	lw	Lipid weight
26	MCCP(s)	Medium chain chlorinated paraffin(s)
27	M-factors	Multiplication Factors
28	NOEC	No Observed Effect Concentration
29	NER	Non-extractable residues
30	NPOC	Non-Purgeable Organic Carbon
31	OECD	Organisation for Economic Co-operation and Development
32	OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
33	PBT	Persistent, Bioaccumulative and Toxic
34	POC	Particulate Organic Carbon
35	QSAR	Quantitative Structure Activity Relationships

1	REACH	Registration, Evaluation and Authorisation of Chemicals
2	RMOA	Risk Management Option Analysis
3	SCCP(s)	Short chain chlorinated paraffin(s)
4	SMILES	Simplified Molecular Input Line Entry System
5	SVHC	Substance of very high concern
6	TG	Test Guideline
7	ThOD	Theoretical Oxygen Demand
8	TMF	Trophic Magnification Factor
9	UVCB	Unknown Variable Concentration or Biological
10	ww	Wet weight

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Appendix 2: List of references



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Appendix 3: Further information on substance identity

Table 11: Constituents present in amounts <1% by weight in “MCCPs” on the EU market

Constituent	Typical concentration (w/w)	Concentration range	Remarks
Chlorinated alkanes with carbon chain lengths <C ₁₄	<1%	Not specified	Based on information in EC (2005) and information in the REACH registration dossiers, assuming that the alkanes in the feedstock are chlorinated during manufacture of “MCCPs”.
Chlorinated aromatics	<100 mg/kg	Not specified	Based on information in EC (2005) assuming that aromatics and isoparaffins in the feedstock are chlorinated during manufacture of “MCCPs”.
Chlorinated isoparaffins	<1 - 2%	Not specified	

All constituents in commercial CPs are likely to be related to those present in the n-paraffin feedstock, in which the major non-paraffinic constituent is a small proportion of aromatics and isoparaffins. EU producers of MCCPs represented by EuroChlor have, since 1991, used paraffin feedstocks in the production process with a C_{<14} content of <1% by weight and reported that the actual levels are often much lower than this (EC, 2005).

Various stabilisers can be added to commercial CPs at <1% by weight to improve thermal or light stability (EC, 2005). These include epoxidised soya oil and glycidyl ethers.

The details of substance identity for short chain chlorinated paraffins (SCCPs) and long chain chlorinated paraffins (LCCPs) from the EU REACH registrations can be found in Table 12.

Table 12: Substance identity of relevant structural analogues

EC name	Alkanes, C ₁₀₋₁₃ , chloro	Paraffin waxes and hydrocarbon waxes, chloro
EC number	287-476-5	264-150-0
CAS number	85535-84-8	63449-39-8
Molecular formula	C _x H _(2x - y+2) Cl _y , where x = 10 - 13 and y = 1 - 13	C _x H _(2x - y+2) Cl _y , where x = 18 - 30 and y = 1 - 30
Molecular weight range	320 - 500 g/mole (approximately)	420 - 1 355 g/mole (approximately)
Synonyms	Short-chain chlorinated paraffins (SCCPs); alkanes, C ₁₀₋₁₃ , chloro; chlorinated paraffins, C ₁₀₋₁₃ (used in Annex VI of the CLP Regulation)	Long-chain chlorinated paraffins (LCCPs); alkanes, C ₁₈₋₃₀ , chloro; chlorinated paraffins, C ₁₈₋₃₀

Around forty CAS numbers have been used to describe the whole CP family at one time or another. Some of these are now historical, and others may be in use for the sole purpose of compliance with national or regional chemical inventories. A list has been provided by representatives of the EU REACH LCCPs Consortium (Personal Communication, 2019). This is shown in Table 13, and is not necessarily exhaustive. Those CAS numbers that may be associated with C₁₄₋₁₇ chain lengths are highlighted in bold.

1 **Table 13: CAS numbers associated with CPs**

CAS Number	CAS name	Note	Regulatory Regions
915-934-2	Reaction mass of alkanes, C ₁₄₋₁₇ , chloro and paraffin waxes and hydrocarbon waxes, chloro	-	-
61788-76-9 ^a	Alkanes, chloro; alkanes, chlorinated	c	[1a], [1c], [2], [3], [4], [5a], [6a], [7], [8], [10], [11], [12]
63449-39-8 ^b	Paraffin waxes and hydrocarbon waxes, chloro	b	[1a], [1b], [1c], [2], [3], [4], [5a], [6a], [6b], [7], [8], [9], [10], [11], [12]
68920-70-7	Alkanes, C ₆₋₁₈ , chloro	a	[1a], [1b], [1c], [2], [3], [4], [5a], [6a], [7], [8], [12]
71011-12-6	Alkanes, C ₁₂₋₁₃ , chloro	d	[2], [3], [5a]
84082-38-2	Alkanes, C ₁₀₋₂₁ , chloro	a	[1a], [1c], [3], [4], [5a], [7], [8], [9], [12]
84776-06-7	Alkanes, C ₁₀₋₃₂ , chloro	a	[1a], [1c], [3], [4], [5a], [7], [8], [9], [12]
84776-07-8	Alkanes, C ₁₆₋₂₇ , chloro	a	[1a]
85049-26-9	Alkanes, C ₁₆₋₃₅ , chloro	a	[1a], [4]
85422-92-0	Paraffin oils and hydrocarbon oils, chloro	c	[1a], [9]
85535-84-8	Alkanes, C ₁₀₋₁₃ , chloro	d	[1a], [1b] ^c , [1c], [3], [4], [5a], [6a], [7], [8], [12]
85535-85-9	Alkanes, C ₁₄₋₁₇ , chloro	b	[1a], [1b], [1c], [2], [3], [4], [5a], [5b], [7], [8], [9], [10], [12]
85535-86-0	Alkanes, C ₁₈₋₂₈ , chloro	a	[1a], [3], [4], [6a], [7], [9]
85536-22-7	Alkanes, C ₁₂₋₁₄ , chloro	a	[1a], [3], [4], [6a], [9], [12]
85681-73-8	Alkanes, C ₁₀₋₁₄ , chloro	a	[1a], [5a]
97553-43-0	Paraffins (petroleum), normal C _{>10} , chloro	a	[1a], [5a]
97659-46-6	Alkanes, C ₁₀₋₂₆ , chloro	a	[1a], [9]
106232-85-3	Alkanes, C ₁₈₋₂₀ , chloro	b	[2], [3], [4], [5a], [9], [10], [12]
106232-86-4	Alkanes, C ₂₂₋₄₀ , chloro	a	[1a], [4], [9]
108171-26-2	Alkanes, C ₁₀₋₁₂ , chloro	a	[1a], [7], [8], [9]
108171-27-3	Alkanes, C ₂₂₋₂₆ , chloro	a	[1a], [5a] [12]
288260-42-4	Alkanes, C ₂₂₋₃₀ , chloro	b	[2], [7]
198840-65-2	Tetradecane, chloro derivatives	b	[2]
1372804-76-6	Alkanes, C ₁₄₋₁₆ , chloro	b	[2]
2097144-48-2	Octadecane, chloro derivatives	b	[2]
2097144-45-9	Alkanes, C ₂₀₋₂₄ , chloro	b	[2]
2097144-43-7	Alkanes, C ₂₀₋₂₈ , chloro	b	[2]
2097144-44-8	Slackwax (petroleum), chloro	b	[2]
1417900-96-9	Alkanes, C ₂₁₋₃₄ -branched and linear, chloro	b	[2]
1401974-24-0	Alkanes, C ₂₂₋₃₀ -branched and linear, chloro	b	[2]
1402738-52-6	Alkanes, C ₂₄₋₂₈ , chloro	b	[2]
2097144-46-0	Hexacosane, chloro derivatives	b	[2]
2097144-47-1	Octacosane, chloro derivatives	b	[2]

^aCAS 61788-76-9 replaces 11104-09-9, 12633-77-1, 51059-93-9, 53572-39-7 and 69430-53-1; ^bCAS 63449-39-8 replaces 8029-39-8, 11098-33-2, 37187-40-9, 39279-65-7, 39406-09-2, 39444-36-5, 50646-90-7, 51990-12-6, 52276-52-5, 52555-47-2, 52622-66-9, 52677-73-3, 52677-74-4, 52677-75-5, 53028-59-4, 53028-60-7, 53200-35-4, 54577-71-8, 55353-50-9, 56509-64-9, 56730-95-1, 58516-52-2, 60202-64-4, 66746-35-8 and 108688-63-7; ^cwithdrawn

Note: a - Listed on at least one national inventory; b - Registered under legislation requiring dossier submission in 21st century; c - Broad scope with no carbon number definition (not favoured by some authorities); d - Subject to ban or restriction, substance of very high concern (EU) or Toxic Release Inventory requirement (USA).

Regulatory Regions: [1a] EU REACH pre-registered; [1b] EU REACH registered; [1c] EU CLP Inventory [2] USA TSCA (active list); [3] Canada DSL; [4] Australia (AICS); [5a] Korean Gazette No.; [5b] Korean REACH registered; [6a] Japan ENCS; [6b] Japan examined; [7] Philippines; [8] New Zealand; [9] Taiwan; [10] Turkey; [11] Switzerland; [12] China.

Appendix 4: Summary of environmental monitoring data

The following tables outline the available environmental monitoring data for “MCCPs” in surface water, sediment and biota taken from ECHA (2019).

Table 14: Summary of levels of “MCCPs” in surface water and sludge

Location	Year/Comment	Units	Concentration	Reference
Derwent Reservoir	1986	µg/L	1.46	ICI (1992)
River Trent, Newark	1986	µg/L	0.86	ICI (1992)
Trent Mersey Canal	1986	µg/L	0.62	ICI (1992)
River Derwent, Derby	1986	µg/L	0.64	ICI (1992)
Walton on Trent	1986	µg/L	1.07	ICI (1992)
River Ouse, Goole	1986	µg/L	0.94	ICI (1992)
River Don, Rotherham	1986	µg/L	1.13	ICI (1992)
River Aire/Ouse	1986	µg/L	1.13	ICI (1992)
River Ouse, York	1986	µg/L	1.36	ICI (1992)
River Cover, Wilton	1986	µg/L	0.84	ICI (1992)
River Ure, Mickley	1986	µg/L	1.46	ICI (1992)
River Trent, Gainsborough	1986	µg/L	2.49	ICI (1992)
River Trent, Burton	1986	µg/L	2.46	ICI (1992)
River Rother	1986	µg/L	2.11	ICI (1992)
River Trent, Humber	1986	µg/L	3.75	ICI (1992)
Hull Docks	1986	µg/L	2.69	ICI (1992)
River Lech at Augsburg	1987	µg/L	<0.05	Ballschmiter (1984)
	1994			
River Lech at Gersthofen (upstream from a CP production site)	1987	µg/L	4.5	Ballschmiter (1984)
	1994		0.094	
River Lech at Langweid (downstream from a CP production site)	1987	µg/L	4	Ballschmiter (1984)
	1994		0.185	
River Lech at Rain	1987	µg/L	0.170	Ballschmiter (1984)
	1994			
River Danube at Marxheim (downstream from the mouth of the River Lech)	1987	µg/L	20	Ballschmiter (1984)
	1994		0.072	
River Danube at Marxheim (upstream from the mouth of the River Lech)	1987	µg/L	4	Ballschmiter (1984)
	1994		≤0.055	
Irish Sea: Site a	Relates to C ₁₀₋₂₀	µg/L	1	Campbell and McConnell (1980)
Irish Sea: Site b	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Irish Sea: Site c	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Irish Sea: Site d	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Irish Sea: Site e	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
Irish Sea: Site f	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
Barmouth Harbour	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Menai Straights (Caernarvon)	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Tremadoc Bay (Llandanwg)	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
North Minch: Ardmair	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
North Minch: Port Bùn á Ghlinne	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
North Minch: Port of Ness	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Goile Chròic (Lewis)	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)

Location	Year/Comment	Units	Concentration	Reference
Sound of Taransay (Harris)	Relates to C ₁₀₋₂₀	µg/L	4.0	Campbell and McConnell (1980)
Sound of Arisaig	Relates to C ₁₀₋₂₀	µg/L	1.0	Campbell and McConnell (1980)
North Sea: N55° 5.7' W1° 9.3'	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
North Sea: N57° 26.2' W1° 17.0'	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
North Sea: N57° 56.5' W1° 22.0'	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
River Banwy, Llangadfan	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
River Lea, Welwyn	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
River Lea, Batford	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
River Clwyd, Ruthin	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
Bala Lake	Relates to C ₁₀₋₂₀	µg/L	1.0	Campbell and McConnell (1980)
River Dee, Corwen	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
River Wnion, Merioneth	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Firth of Lorne, Ganevan	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Loch Linnhe, Corran Narrows	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
Firth of Clyde, Ashcraig	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
Firth of Clyde, Girvan	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
An Garbh Allt	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
Five drinking water reservoirs, Manchester area	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
River Aire, Leeds	Relates to C ₁₀₋₂₀	µg/L	2.0	Campbell and McConnell (1980)
River Aire, Woodlesford	Relates to C ₁₀₋₂₀	µg/L	2.0	Campbell and McConnell (1980)
River Ouse, Boothberry edge	Relates to C ₁₀₋₂₀	µg/L	1 - 2	Campbell and McConnell (1980)
River Trent, West Bromwich	Relates to C ₁₀₋₂₀	µg/L	1 - 2	Campbell and McConnell (1980)
River Trent, Walton-upon-Trent	Relates to C ₁₀₋₂₀	µg/L	2 - 3	Campbell and McConnell (1980)
River Trent, Swarkestone	Relates to C ₁₀₋₂₀	µg/L	1 - 2	Campbell and McConnell (1980)
River Trent, Newark	Relates to C ₁₀₋₂₀	µg/L	4.0	Campbell and McConnell (1980)
River Trent, Gainsborough	Relates to C ₁₀₋₂₀	µg/L	2.0	Campbell and McConnell (1980)
River Trent, confluence with Humber	Relates to C ₁₀₋₂₀	µg/L	6.0	Campbell and McConnell (1980)
Humber Estuary, Hull	Relates to C ₁₀₋₂₀	µg/L	1 - 2	Campbell and McConnell (1980)
Humber Estuary, Grimsby	Relates to C ₁₀₋₂₀	µg/L	3.0	Campbell and McConnell (1980)
Mersey Estuary, New Brighton	Relates to C ₁₀₋₂₀	µg/L	3.0	Campbell and McConnell (1980)
Mersey Estuary, Liverpool Pier Head	Relates to C ₁₀₋₂₀	µg/L	4.0	Campbell and McConnell (1980)
River Thames, Oxford	Relates to C ₁₀₋₂₀	µg/L	2.0	Campbell and McConnell (1980)
River Thames, Sanford	Relates to C ₁₀₋₂₀	µg/L	1 - 2	Campbell and McConnell (1980)
Wyre Estuary	Relates to C ₁₀₋₂₀	µg/L	not detected - 1.5	Campbell and McConnell (1980)
River Tees, Low Dinsdale	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)

Location	Year/Comment	Units	Concentration	Reference
River Tees, North Gare breakwater	Relates to C ₁₀₋₂₀	µg/L	0.5	Campbell and McConnell (1980)
River Tees, Middlesbrough	Relates to C ₁₀₋₂₀	µg/L	not detected	Campbell and McConnell (1980)
Sugar Creek, upstream of discharge		µg/L (particulate)	not detected	Murray <i>et al.</i> (1987a and 1987b)
Sugar Creek, just upstream of discharge		µg/L (particulate)	0.05 - 0.17	Murray <i>et al.</i> (1987a and 1987b)
Sugar Creek, just downstream of discharge		µg/L (particulate)	0.16 - 0.2	Murray <i>et al.</i> (1987a and 1987b)
Sugar Creek, downstream of discharge		µg/L (particulate)	0.20 - 0.24	Murray <i>et al.</i> (1987a and 1987b)
Upstream of sewage treatment plant, Germany		µg/L	not detected	Rieger and Ballschmiter (1985)
Downstream of sewage treatment plant, Germany		µg/L	not detected	Rieger and Ballschmiter (1985)
Tributary, upstream of sewage treatment plant, Germany		µg/L	not detected	Rieger and Ballschmiter (1985)
Downstream of a chlorinated paraffin manufacturing plant, Canada		µg/L	<1	Tomy <i>et al.</i> (1998)
Surface water near to industrial sites, UK	1998	µg/L	<0.1	Cefas (1999)
Water samples from Norway	Two samples. Concentration refers to total (dissolved + particulate) in one sample. The concentrations present in the other sample was much lower (shown graphically only but was probably <0.1 µg/L.	µg/L	1.49	Petersen <i>et al.</i> (2006)
Filtered river water samples, Europe	8 Samples filtered using a membrane glass fibre filter before analysis	µg/L	<0.10	Coelhan (2009 & 2010)
Influent to waste water treatment plants, Europe	15 Samples. "MCCPs" detectable in 12 samples.	µg/L (particulate)	not detected – 4.6	Coelhan (2009 & 2010)
Effluent from waste water treatment plants, Norway	Samples from 8 waste water treatment plants (4 samples from each location). "MCCPs" detectable in 13% of samples analysed.	µg/L	not detected – 0.942	Thomas <i>et al.</i> (2011)
Dewatered sludge from waste water treatment plants, Norway	Samples from 8 waste water treatment plants (4 samples from each location). "MCCPs" detectable in all samples.	µg/kg	14 - 7 000 (median 385)	Thomas <i>et al.</i> (2011)
Snow (melted) from urban areas of Gothenburg, Sweden	8 Samples. "MCCPs" detectable in 2 samples (the concentrations may relate to SCCPs + MCCPs in the samples)	µg/L	0.33 - 32	Björklund <i>et al.</i> (2011)
Great Lakes Basin	Mean concentration based on an analysis of published studies	µg/L	9×10 ⁻⁷	Klečka <i>et al.</i> (2010)
Storm water	Norway	µg/L	0.0685	Ruus <i>et al.</i> (2018)
Sludge	Norway average (minimum-maximum)	µg/kg	4 031 (120-17 000)	Norsk Vann (2018)
Sludge	Norway average (minimum-maximum)	µg/kg	3 964 (77-11 800)	Fjeld (2008)

Table 15: Summary of levels of “MCCPs” in sediment

Location	Year/ Comment	Units	Concentration	Reference
River Lech, upstream from chlorinated paraffin production plant	1987	µg/kg dw	2200	Unpublished (1987)
	1994	µg/kg dw	<10	Ballschmiter (1994)
River Lech, downstream from chlorinated paraffin production plant	1987	µg/kg dw	1 700	Unpublished (1987) [reference no long attributable]
	1994	µg/kg dw	325	Ballschmiter (1994)
Bodensee (middle) - 0 to 5 cm depth	1994	µg/kg dw	70	Ballschmiter (1994)
River Rhein (141 km) at Rheinfelden	1994	µg/kg dw	60	Ballschmiter (1994)
River Rhein (152 km) at Rheinfelden, upper layer	1994	µg/kg dw	140	Ballschmiter (1994)
River Rhein (152 km) at Rheinfelden, lower layer	1994	µg/kg dw	85	Ballschmiter (1994)
River Rhein (853.8 km), near German-Dutch border	1994	µg/kg dw	205	Ballschmiter (1994)
River Rhein (863.8 km), near German-Dutch border	1994	µg/kg dw	145	Ballschmiter (1994)
River Main (16.2 km)	1994	µg/kg dw	260	Ballschmiter (1994)
River Main (at Griesheim)	1994	µg/kg dw	190	Ballschmiter (1994)
River Main (55 km)	1994	µg/kg dw	160	Ballschmiter (1994)
Outer Alster, Hamburg	1994	µg/kg dw	370	Ballschmiter (1994)
River Elbe, Hamburg (610 km)	1994	µg/kg dw	130	Ballschmiter (1994)
River Elbe, Hamburg (629.9 km)	1994	µg/kg dw	230	Ballschmiter (1994)
River Danube, downstream of the confluence with the River Lech		µg/kg dw	1800	BUA (1992)
Irish Sea: Site a	Relates to C ₁₀₋₂₀	µg/kg	100	Campbell and McConnell (1980)
Irish Sea: Site b	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Irish Sea: Site c	Relates to C ₁₀₋₂₀	µg/kg	not measured	Campbell and McConnell (1980)
Irish Sea: Site d	Relates to C ₁₀₋₂₀	µg/kg	100	Campbell and McConnell (1980)
Irish Sea: Site e	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Irish Sea: Site f	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Barmouth Harbour	Relates to C ₁₀₋₂₀	µg/kg	500	Campbell and McConnell (1980)
Menai Straights (Caernarvon)	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Tremadoc Bay (Llandanwg)	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
North Minch: Ardair	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
North Minch: Port Bùn á Ghlinne	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
North Minch: Port of Ness	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Goile Chròic (Lewis)	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)

Location	Year/ Comment	Units	Concentration	Reference
Sound of Taransay (Harris)	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Sound of Arisaig	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
North Sea: N55° 5.7' W1° 9.3'	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
North Sea: N57° 26.2' W1° 17.0'	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
North Sea: N57° 56.5' W1° 22.0'	Relates to C ₁₀₋₂₀	µg/kg	50	Campbell and McConnell (1980)
River Banwy, Llangadfan	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
River Lea, Batford	Relates to C ₁₀₋₂₀	µg/kg	1 000	Campbell and McConnell (1980)
River Clwyd, Ruthin	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
River Dee, Corwen	Relates to C ₁₀₋₂₀	µg/kg	300	Campbell and McConnell (1980)
River Wnion, Merioneth	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Five drinking water reservoirs, Manchester area	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
River Aire, Leeds	Relates to C ₁₀₋₂₀	µg/kg	10 000	Campbell and McConnell (1980)
River Ouse, Goole	Relates to C ₁₀₋₂₀	µg/kg	2 000	Campbell and McConnell (1980)
River Trent, West Bromwich	Relates to C ₁₀₋₂₀	µg/kg	6 000	Campbell and McConnell (1980)
River Trent, Walton-upon-Trent	Relates to C ₁₀₋₂₀	µg/kg	1 000	Campbell and McConnell (1980)
River Trent, Swarkestone	Relates to C ₁₀₋₂₀	µg/kg	14 000	Campbell and McConnell (1980)
River Trent, Newark	Relates to C ₁₀₋₂₀	µg/kg	8 000	Campbell and McConnell (1980)
River Trent, Gainsborough	Relates to C ₁₀₋₂₀	µg/kg	3 000	Campbell and McConnell (1980)
Humber Estuary, Hull	Relates to C ₁₀₋₂₀	µg/kg	2 000	Campbell and McConnell (1980)
Humber Estuary, Stone Creek	Relates to C ₁₀₋₂₀	µg/kg	2 000	Campbell and McConnell (1980)
Mersey Estuary, New Brighton	Relates to C ₁₀₋₂₀	µg/kg	3 000	Campbell and McConnell (1980)
Mersey Estuary, Liverpool Pier Head	Relates to C ₁₀₋₂₀	µg/kg	8 000	Campbell and McConnell (1980)
River Thames, Sanford	Relates to C ₁₀₋₂₀	µg/kg	1 000	Campbell and McConnell (1980)
Wyre Estuary	Relates to C ₁₀₋₂₀	µg/kg	not detected - 1 600	Campbell and McConnell (1980)
Mersey Estuary, 14 sediment samples	Relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
River Tees, Low Dinsdale	Relates to C ₁₀₋₂₀	µg/kg	300	Campbell and McConnell (1980)
River Tees, North Gare breakwater	Relates to C ₁₀₋₂₀	µg/kg	50	Campbell and McConnell (1980)
River Tees, Middlesbrough	Relates to C ₁₀₋₂₀	µg/kg	15 000	Campbell and McConnell (1980)
Japan	1979 – no information on type	µg/kg	600 - 10 000	Environment Agency Japan (1991)
Japan	1980 – no information on type	µg/kg	500 - 8 500	Environment Agency Japan (1991)

Location	Year/ Comment	Units	Concentration	Reference
Downstream of production site, US		µg/kg dw	6.8 - 8.2	Murray <i>et al.</i> (1987a and 1987b)
Rotterdam harbour mud		µg/kg	7 - 10	Greenpeace (1995)
Hamburg harbour mud		µg/kg	8	Greenpeace (1995)
Mud flats, Kaiser Wilhelm Koog		µg/kg	98	Greenpeace (1995)
Mud flats, Den Helder		µg/kg	3	Greenpeace (1995)
St. Lawrence River, Canada, downstream of a chlorinated paraffin manufacturing plant		µg/kg dw	<3 500	Tomy <i>et al.</i> (1998)
Industrial areas of the UK	A total of 77 samples from 1998. Highest concentration, downstream of a lubricant blending/metal working site.	µg/kg dw	65 000	Cefas (1999)
Mersey and Seine estuaries	Mean levels of total CPs - predominantly LCCPs (only traces of "MCCPs" present)	µg/kg dw	10.5	van Zeijl (1997)
Schelde estuary	Mean levels of total CPs - predominantly LCCPs (only traces of "MCCPs" present)	µg/kg dw	5.5	van Zeijl (1997)
Liffey River estuary	Mean levels of total CPs - predominantly LCCPs (only traces of "MCCPs" present)	µg/kg dw	4.8	van Zeijl (1997)
Forth estuary	Mean levels of total CPs - predominantly LCCPs (only traces of "MCCPs" present)	µg/kg dw	3.3	van Zeijl (1997)
Humber estuary	Mean levels of total CPs - predominantly LCCPs (only traces of "MCCPs" present)	µg/kg dw	1.2	van Zeijl (1997)
Sediment core, Lake St. Francois, St. Lawrence River	1972	µg/kg dw	1 200	Muir <i>et al.</i> (2002)
Sediment core, Lake St. Francois, St. Lawrence River	1976	µg/kg dw	1 000	Muir <i>et al.</i> (2002)
Sediment core, Lake St. Francois, St. Lawrence River	1981	µg/kg dw	700	Muir <i>et al.</i> (2002)
Sediment core, Lake St. Francois, St. Lawrence River	1986	µg/kg dw	750	Muir <i>et al.</i> (2002)
Sediment core, Lake St. Francois, St. Lawrence River	1990	µg/kg dw	400	Muir <i>et al.</i> (2002)
Sediment core, Lake St. Francois, St. Lawrence River	1995	µg/kg dw	700	Muir <i>et al.</i> (2002)
Lake Zürich		µg/kg	5	Schmid and Müller (1985)
Close to chlorinated paraffin manufacturing site, Australia	Sample I	µg/kg dw	1 108	Kemmlein <i>et al.</i> (2002)
Close to chlorinated paraffin manufacturing site, Australia	Sample II	µg/kg dw	1 168	Kemmlein <i>et al.</i> (2002)

Location	Year/ Comment	Units	Concentration	Reference
Close to chlorinated paraffin manufacturing site, Australia	Sample II	µg/kg dw	3 108	Kemmlein <i>et al.</i> (2002)
Close to chlorinated paraffin manufacturing site, Australia	Sample IV	µg/kg dw	16 403	Kemmlein <i>et al.</i> (2002)
Lake Thun, Switzerland	Sediment core, surface layer corresponding to around 2004	µg/kg dw	26	Iozza <i>et al.</i> (2008)
Czech Republic	Highest concentration	µg/kg	5 575	Pribylová <i>et al.</i> (2006)
North and Baltic Sea	Sample 1 (relates to C ₁₄₋₁₅ CPs)	µg/kg dw	87	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 2 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	48	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 3 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	34	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 4 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	149	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 5 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	23	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 6 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	43	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 7 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	85	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 8 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	72	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 9 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	39	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 10 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	22	Hüttig and Oehme, (2006)
North and Baltic Sea	Sample 11 (MCCP relates to C ₁₄₋₁₅ CPs)	µg/kg dw	33	Hüttig and Oehme, (2006)
North and Baltic Sea	Highest concentration - relates to SCCP+MCCP (MCCP/SCCP ratio 1.7 - 2.4)	µg/kg dw	499	Hüttig and Oehme, (2005)
Firth of Clyde, Scotland	"MCCPs" detected but not quantified		detected	Hussy <i>et al.</i> (2012)
Sediments from Norway	Twenty sediments analysed	µg/kg dw	50 - 3 240	Petersen <i>et al.</i> (2006)
Pearl River Delta, South China	Range	µg/kg dw	880 to 38 000	Chen <i>et al.</i> (2011)
Pearl River Delta, South China. Pond sediments in the vicinity of an electronic waste recycling area	Mean	µg/kg dw	21 000	Chen <i>et al.</i> (2011)
Pearl River Delta, South China. River sediments from industrialised areas.	Mean	µg/kg dw	3 900	Chen <i>et al.</i> (2011)
Yellow River, China	2018 (mean, normal season)	ng/g	35	Li <i>et al.</i> (2018)
Yellow River, China	2018 (mean, wet season)	ng/g	89	Li <i>et al.</i> (2018)
Yellow River, China	2018 (mean, dry season)	ng/g	167	Li <i>et al.</i> (2018)
Yellow River, China	2016	ng/g dw	44.81538462	Qiao <i>et al.</i> (2016)
Pearl River Delta, China	2017	ng/g dw	102 - 6650	Zeng <i>et al.</i> (2017)

Location	Year/ Comment	Units	Concentration	Reference
Shenzhen, China	2017	ng/g dw	10.9 - 2500	Zeng <i>et al.</i> (2017)
Hong Kong, China	2017	ng/g dw	<LOD - 286	Zeng <i>et al.</i> (2017)
Tokyo Bay, Japan	2017	ng/g dw	3.2 - 56.8	Zeng <i>et al.</i> (2017)
Laizhou Bay, China	2009	ng/g dw	6 - 63	Pan <i>et al.</i> (2018)
Rivers around Laizhou Bay, China	2009	ng/g dw	1.8 - 3200	Pan <i>et al.</i> (2018)
Inner Oslofjord, Norway	2017	mg/kg dw	0.14	Ruus <i>et al.</i> (2018)
Oslo, Norway	Soil	ng/g dw	Mean = 183 Median = 193 Minimum = 57 Maximum = 282	Heimstad <i>et al.</i> (2017)
Chongming Island, China	Soil	ng/g	Minimum = 2.56 Maximum = 96.3 Median = 7.32	Sun <i>et al.</i> (2013).
Jiaojiang River, China	Soil samples within 5 km of the e-waste dismantling centres	ng/g dw	507 to 4.40×10^6	Xu <i>et al.</i> (2019)
Jiaojiang River, China	Sediment samples from the surrounding area	ng/g dw	$271 - 2.72 \times 10^4$	Xu <i>et al.</i> (2019)
Yangtze River, China	Sediments from the middle reaches of the Yangtze River	ng/g dw	Not detected to 14.6 ng/g dw	Qiao <i>et al.</i> (2017)
Yellow River, China	Sediment samples from the middle reaches of the Yellow River	ng/g dw	20.5 - 93.7	Xia <i>et al.</i> (2016)
Pearl River Delta, South China	Soil	ng/g	Minimum = 1.95 Maximum = 188 Median = 7.98	Wang <i>et al.</i> (2014)
Switzerland	Soil	ng/g	5.1 - 160	Bogdal <i>et al.</i> (2015)
China	Core soils from Chinese nation-wide agricultural lands	ng/g dw	127 - 1969	Aamir <i>et al.</i> (2019)
Dongjiang River, China	Top soils (0-5 cm) at 60 sites	ng/g	59.3	Wang <i>et al.</i> (2013)
China	In-plant coniferous leaves and soil, 2016 (average)	ng/g dw	3481.8	Xu <i>et al.</i> (2016)
Shanghai, China	Suburb soils, 2017	ng/g dw	ND - 666	Wang <i>et al.</i> (2017)
Australia (Sewage sludge)	2017	ng/g dw	542 - 3645	Brandsma <i>et al.</i> (2017)
Effluent water	Bekkelaget STP, Norway	µg/L	0.08	Ruus <i>et al.</i> (2018)
Sludge	Bekkelaget STP, Norway	ng/g dw	2470-2500	Ruus <i>et al.</i> (2018)

Table 16: Summary of levels of “MCCPs” in biota (and some foodstuffs)

Sample	Location	Comment	Units	Level	Reference
Mussel	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	3 250	Campbell and McConnell (1980)
Plaice <i>Pleuronectes platessa</i>	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	30	Campbell and McConnell (1980)
Pouting <i>Trisopterus luscus</i>	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	100	Campbell and McConnell (1980)
Pike <i>Esox lucius</i>	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	25	Campbell and McConnell (1980)
Grey Seal <i>Halichoerus grypus</i>	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	75 (liver and blubber)	Campbell and McConnell (1980)
Grey Heron <i>Ardea cinerea</i>	United Kingdom	Relates to C ₁₀₋₂₀	µg/kg	100 - 1 200 (liver)	Campbell and McConnell (1980)
Common Guillemot <i>Uria aalge</i>	United Kingdom	Relates to C ₁₀₋₂₀	µg/kg	100 - 1 100 (liver)	Campbell and McConnell (1980)

Sample	Location	Comment	Units	Level	Reference
Herring Gull <i>Larus argentatus</i>	United Kingdom	Relates to C ₁₀₋₂₀	µg/kg	200 – 900 (liver)	Campbell and McConnell (1980)
Seabirds' eggs	United Kingdom	Relates to C ₁₀₋₂₀	µg/kg	up to 2 000	Campbell and McConnell (1980)
Dairy products	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	300	Campbell and McConnell (1980)
Vegetable oils and derivatives	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	150	Campbell and McConnell (1980)
Fruit and vegetables	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	5	Campbell and McConnell (1980)
Beverages	United Kingdom	Mean concentration – relates to C ₁₀₋₂₀	µg/kg	not detected	Campbell and McConnell (1980)
Domestic Sheep <i>Ovis aries</i>	United Kingdom, remote from industry	Relates to C ₁₀₋₂₀	µg/kg	not detected in liver, brain kidney, mesenteric fat	Campbell and McConnell (1980)
	United Kingdom, close to chlorinated paraffin production site			200 (liver); 50 (mesenteric fat); 50 (kidney); not detected in heart, lung or perinephritic fat	
Mussel	Upstream of CP production site		µg/kg	<7	Murray <i>et al.</i> (1987a)
	Downstream of CP production site			170	
Mackerel			µg/kg lw	46	Greenpeace (1995)
Herring oil			µg/kg lw	12	Greenpeace (1995)
Margarine containing fish oil			µg/kg lw	28	Greenpeace (1995)
Common Porpoise <i>Phocoena phocoena</i>			µg/kg lw	3 - 7	Greenpeace (1995)
Fin Whale <i>Balaenoptera physalus</i>			µg/kg lw	144	Greenpeace (1995)
Pork			µg/kg lw	11	Greenpeace (1995)
Cow's milk			µg/kg lw	16	Greenpeace (1995)
Rabbit <i>Oryctolagus cuniculus</i>	Revingehed, Skåne, Sweden 1986	Unspecified chain length, with 6-16 chlorine atoms/molecule	µg/kg lw	2 900 (muscle)	Jansson <i>et al.</i> (1993)
Moose <i>Alces alces</i>	Grimsö, Västmanland, Sweden 1985 - 86	Unspecified chain length, with 6-16 chlorine atoms/molecule	µg/kg lw	4 400 (muscle)	Jansson <i>et al.</i> (1993)
Reindeer <i>Rangifer tarandus</i>	Ottsjö, Jämtland, Sweden 1986	Unspecified chain length, with 6-16 chlorine atoms/molecule	µg/kg lw	140 (suet)	Jansson <i>et al.</i> (1993)
Osprey <i>Pandion haliaetus</i>	Sweden, 1982 - 1986	Unspecified chain length, with 6-16 chlorine atoms/molecule	µg/kg lw	530 (muscle)	Jansson <i>et al.</i> (1993)
Arctic Char <i>Salvelinus alpinus</i>	Lake Vättern, Central Sweden, 1987	Unspecified chain length, with 6-16 chlorine atoms/molecule	µg/kg lw	570 (muscle)	Jansson <i>et al.</i> (1993)
Whitefish <i>Coregonus sp.</i>	Lake Storvindeln, Lapland, 1986	Unspecified chain length, with 6-16 chlorine atoms/molecule	µg/kg lw	1 000 (muscle)	Jansson <i>et al.</i> (1993)

Sample	Location	Comment	Units	Level	Reference
Herring <i>Clupea harengus</i>	Bothnian Sea, Sweden 1986	Unspecified chain length, with 6-16 chlorine atoms/molecule	$\mu\text{g/kg lw}$	1 400 (muscle)	Jansson <i>et al.</i> (1993)
	Baltic proper, Sweden 1987			1 500 (muscle)	
	Skagerrak, Sweden 1987			1 600 (muscle)	
Ringed Seal <i>Pusa hispida</i>	Kongsfjorden, Svalbard 1981	Unspecified chain length, with 6-16 chlorine atoms/molecule	$\mu\text{g/kg lw}$	130 (blubber)	Jansson <i>et al.</i> (1993)
Grey Seal <i>Halichoerus grypus</i>	Baltic Sea, Sweden 1979 - 85	Unspecified chain length, with 6-16 chlorine atoms/molecule	$\mu\text{g/kg lw}$	280 (blubber)	Jansson <i>et al.</i> (1993)
Benthos	Industrial areas of the United Kingdom 1998	Highest concentration - tentatively identified as MCCPs	$\mu\text{g/kg}$	800	Cefas (1999)
Fish	Industrial areas of the United Kingdom 1998	Highest concentration - tentatively identified as MCCPs	$\mu\text{g/kg}$	2 800 (pike liver)	Cefas (1999)
Human milk			$\mu\text{g/kg lw}$	7	Greenpeace (1995)
Human milk	Lancaster and London, UK	Highest concentration	$\mu\text{g/kg lw}$	61	Thomas and Jones (2002)
Human milk	Lancaster and London, UK	95th percentile	$\mu\text{g/kg lw}$	127.5	Thomas <i>et al.</i> (2003)
Human milk	Bavaria	60 Samples. "MCCPs" detected in 58% of the samples. Range reflects the quantified levels.	$\mu\text{g/kg lw}$	9.6 - 903 [median 115.4]	Hilger <i>et al.</i> (2011b)
Human milk	China	2007 (median value)	$\mu\text{g/kg lw}$	60.4	Xia <i>et al.</i> (2017)
Human milk	China	2011 (median value)	$\mu\text{g/kg lw}$	64.3	Xia <i>et al.</i> (2017)
Human blood	China	2017	$\mu\text{g/kg lw}$	130 - 3200	Li <i>et al.</i> (2017)
Human placenta	China	2018	$\mu\text{g/kg lw}$	80.8 - 954	Wang <i>et al.</i> (2018)
Cows' milk	Lancaster, UK		$\mu\text{g/kg lw}$	63	Thomas and Jones (2002)
Butter	Denmark		$\mu\text{g/kg lw}$	11	Thomas and Jones (2002)
	Wales			8.8	
	Ireland			52	
Beluga Whale <i>Delphinapterus leucas</i>	St. Lawrence River, Canada	Blubber samples from 15 females	$\mu\text{g/kg ww}$	79 000 (max.)	Bennie <i>et al.</i> (2000)
		Blubber samples from 10 males		80 000 (max.)	
		Liver samples from 3 females		20 900 (max.)	
		Liver samples from 3 males		5 820 (max.)	
Carp	Lake Ontario, Canada	Whole body homogenates from 3 individuals	$\mu\text{g/kg ww}$	563 (max.)	Bennie <i>et al.</i> (2000)
Trout	Lake Ontario, Canada	Whole body homogenates from 10 individuals	$\mu\text{g/kg ww}$	4 390 (max.)	Bennie <i>et al.</i> (2000)

Sample	Location	Comment	Units	Level	Reference
Mussel	Close to a chlorinated paraffin manufacturing plant in Australia		µg/kg lw	23 200	Kemmlein <i>et al.</i> (2002)
Crabs	Close to a chlorinated paraffin manufacturing plant in Australia		µg/kg lw	30 500	Kemmlein <i>et al.</i> (2002)
Lake Trout <i>Salvelinus namaycush</i>	Lake Ontario	Archived samples from 1998	µg/kg	25	Ismail <i>et al.</i> (2009)
		Archived samples from 2004		8	
<i>Diporeia</i>	Lake Ontario	Mean concentration, 2001	µg/kg	12	Muir <i>et al.</i> (2002)
Rainbow Smelt <i>Osmerus mordax</i>	Lake Ontario	Mean concentration, 2001	µg/kg	109	Muir <i>et al.</i> (2002)
Slimy Sculpin <i>Cottus cognatus</i>	Lake Ontario	Mean concentration, 2001	µg/kg	108	Muir <i>et al.</i> (2002)
Alewife <i>Alosa pseudoharengus</i>	Lake Ontario	Mean concentration, 2001	µg/kg	35	Muir <i>et al.</i> (2002)
Lake Trout <i>Salvelinus namaycush</i>	Lake Ontario	Mean concentration, 2001	µg/kg	15	Muir <i>et al.</i> (2002)
Plankton	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	not detected	Houde <i>et al.</i> (2008)
	Lake Michigan			not detected	
<i>Diporeia</i>	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	4.2	Houde <i>et al.</i> (2008)
	Lake Michigan			not detected	
<i>Mysis</i>	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	not detected	Houde <i>et al.</i> (2008)
	Lake Michigan			not detected	
Rainbow Smelt <i>Osmerus mordax</i>	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	109	Houde <i>et al.</i> (2008)
	Lake Michigan			not detected	
Slimy Sculpin <i>Cottus cognatus</i>	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	108	Houde <i>et al.</i> (2008)
	Lake Michigan			2.9	
Alewife <i>Alosa pseudoharengus</i>	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	35	Houde <i>et al.</i> (2008)
	Lake Michigan			5.6	
Lake Trout <i>Salvelinus namaycush</i>	Lake Ontario	Mean concentration, 1999 - 2004	µg/kg	24	Houde <i>et al.</i> (2008)
	Lake Michigan			5.6	
Dab, cod and flounder	North and Baltic Sea	Highest	µg/kg	260 (liver)	Reth <i>et al.</i> (2005)
Atlantic Cod <i>Gadus morhua</i>	Iceland and Norway	Highest concentration	µg/kg	47 (liver)	Reth <i>et al.</i> (2006)
Arctic Char <i>Salvelinus alpinus</i>	Bear Island	Highest concentration	µg/kg	43 (liver)	Reth <i>et al.</i> (2006)
				47 (muscle)	
Little Auk <i>Alle alle</i>	Bear Island	Highest concentration	µg/kg	370 (liver)	Reth <i>et al.</i> (2006)
				55 (muscle)	
Black-legged Kittiwake <i>Rissa tridactyla</i>	Bear Island	Highest concentration	µg/kg	39 (liver)	Reth <i>et al.</i> (2006)
				38 (muscle)	
Spruce needles	The Alps	Eight samples collected in October 2004. Concentrations refer to "MCCPs".	µg/kg	5.2 - 95	Ioza <i>et al.</i> (2009a)

Sample	Location	Comment	Units	Level	Reference
Spruce needles	The Alps	Samples from various altitudes from 7 locations collected in Autumn 2004. Concentrations refer to total CPs	µg/kg	26 - 450	Iozza <i>et al.</i> (2009b)
Masson pine needles	Shanghai, China	2016	µg/kg	12.4 – 33 500	Wang <i>et al.</i> (2016)
“Biota”	Great Lakes Basin	Mean concentration based on an analysis of published studies	µg/kg	21	Klečka <i>et al.</i> (2010)
Porpoises	South China Sea	2004 - 2014	µg/kg dw	320 – 8 600	Zeng <i>et al.</i> (2015)
Dolphins	South China Sea	2004 - 2014	µg/kg dw	530 – 23 000	Zeng <i>et al.</i> (2015)
Bastard halibut	Liaodong Bay, North China	2017	µg/kg lw	706.5 ± 240.2	Huang <i>et al.</i> (2017)
Turbot	Liaodong Bay, North China	2017	µg/kg lw	5 097 ± 2 242	Huang <i>et al.</i> (2017)
Ray	Liaodong Bay, North China	2017	µg/kg lw	109.0 ± 44.6	Huang <i>et al.</i> (2017)
<i>Navodon septentrionalis</i>	Liaodong Bay, North China	2017	µg/kg lw	375.9 ± 120.2	Huang <i>et al.</i> (2017)
Yellow croaker	Liaodong Bay, North China	2017	µg/kg lw	55.19 ± 23.73	Huang <i>et al.</i> (2017)
Bass	Liaodong Bay, North China	2017	µg/kg lw	24.57 ± 10.31	Huang <i>et al.</i> (2017)
Capelin	Liaodong Bay, North China	2017	µg/kg lw	30.26 ± 11.49	Huang <i>et al.</i> (2017)
Spanish Mackerel	Liaodong Bay, North China	2017	µg/kg lw	53.92 ± 22.64	Huang <i>et al.</i> (2017)
Abalone	Liaodong Bay, North China	2017	µg/kg lw	63.48 ± 24.75	Huang <i>et al.</i> (2017)
Cod	Liaodong Bay, North China	2017	µg/kg lw	22.37 ± 9.17	Huang <i>et al.</i> (2017)
Common Barbel <i>Barbus barbus</i>	Chéran River (mean)	2019	µg/kg lw	7 123	Labadie <i>et al.</i> (2019)
	Usses River (mean)			4 615	
	Combeauté River (mean)			5 423	
	Rhône River (mean)			904	
	Morge Canal (mean)			3 292	
Earthworms	Oslo, Norway	2017	µg/kg ww	Mean: 37 Median: 39 Minimum: 25 Maximum: 46	Heimstad <i>et al.</i> (2017)
Fieldfare <i>Turdus pilaris</i>	Oslo, Norway	2017, eggs	µg/kg ww	Mean: 21 Median: 7.35 Minimum: 4.70 Maximum: 135	Heimstad <i>et al.</i> (2017)
Eurasian Sparrowhawk <i>Accipiter nisus</i>	Oslo, Norway	2017, eggs	µg/kg ww	Mean: 12.2 Median: <LOD Minimum: <LOD Maximum: 74.0	Heimstad <i>et al.</i> (2017)
Tawny Owl <i>Strix aluco</i>	Oslo, Norway	2017, eggs	µg/kg ww	Mean: <LOD Median: <LOD Minimum: <LOD Maximum: <LOD	Heimstad <i>et al.</i> (2017)
Rat <i>Rattus norvegicus</i>	Oslo, Norway	2017, liver	µg/kg ww	Mean: 183 Median: 177 Minimum: 81.0 Maximum: 327	Heimstad <i>et al.</i> (2017)

Sample	Location	Comment	Units	Level	Reference
Red Fox <i>Vulpes vulpes</i>	Oslo, Norway	2017, liver	µg/kg ww	Mean: 68.1 Median: 61 Minimum: 23 Maximum: 130	Heimstad <i>et al.</i> (2017)
Badger <i>Meles meles</i>	Oslo, Norway	2017, liver	µg/kg ww	Mean: 43 Median: 41 Minimum: 37 Maximum: 51	Heimstad <i>et al.</i> (2017)
Blue Mussel <i>Mytilus edulis</i>	Gressholmen, Inner Oslofjord, Norway	2017	µg/kg ww	Median: 11.9	Green <i>et al.</i> (2018)
	Færder, Outer Oslofjord, Norway			Median: 9.89	
	Singlekalven, Hvaler, Norway			Median: 5.82	
	Bjørkøya, Langesund-fjord, Norway			Median: 22.7	
	Sylterøya, Langesund-fjord, Norway			Median: 10.5	
	Nordnes, Bergen harbour, Norway			Median: 44.9	
	Vågsvåg, Outer Nordfjord, Norway			Median: 27.3	
	Ålesund harbour, Norway			Median: 41.6	
	Ørland area, Outer Trondheims-fjord, Norway			Median: 4.46	
	Bodø harbour, Norway			Median: 52.4	
	Mjelle, Bodø area, Norway			Median: 17.3	
	Svolvær airport area, Norway			Median: 22.2	
Atlantic Cod <i>Gadus morhua</i>	Inner Oslofjord, Norway	2017, liver	µg/kg ww	Median: 498.0	Green <i>et al.</i> (2018)
	Tjøme, Outer Oslofjord, Norway			Median: 35.15	
	Kirkøy, Hvaler, Norway			Median: 77.2	
	Stathelle area, Langesund-fjord, Norway			Median: 143.0	
	Kristiansand harbour area, Norway			Median: 226.5	
	Inner Sør fjord, Norway			Median: 100.0	
	Bømlø, Outer Selbjørnfjord, Norway			Median: 74.6	
	Bergen harbour area, Norway			Median: 310.0	
	Ålesund harbour area, Norway			Median: 842.0	
	Trondheim harbour, Norway			Median: 102.0	
	Austnesfjord, Lofoten, Norway			Median: 71.6	

Sample	Location	Comment	Units	Level	Reference
	Tromsø harbour area, Norway			Median: 123.0	
	Isfjorden, Svalbard, Norway			Median: 35.4	
Common Eider <i>Somateria mollissima</i>	Breøyane, Kongsfjorden, Svalbard, Norway	2017	µg/kg ww	Median: 2.5 (blood) Median: 8.6 (egg)	Green <i>et al.</i> (2018)
Cereal	19 Chinese provinces	1710 cereal samples giving 19 pooled samples	µg/kg ww	Mean: 213	Wang <i>et al.</i> (2019)
Legume	19 Chinese provinces	1710 legume samples giving 19 pooled samples	µg/kg ww	Mean: 184	Wang <i>et al.</i> (2019)
Herring <i>Clupea harengus</i>	Scandinavia	2011, female 4–6 years, muscle	µg/kg lw	44	Yuan <i>et al.</i> (2019)
		2014, female 4–5 years, muscle		30	
		2017, female 3–5 years, muscle		51	
		2014, female and male 7 – 13 years, liver		140	
		2014 female and male, 7–13 years, muscle		120	
		2016 female and male, 6 – 12 years, liver		170	
		2016, female and male 6 – 12 years, muscle		140	
		2015, female adults, liver		440	
Common Eider <i>Somateria mollissima</i>	Scandinavia	2015, egg	µg/kg lw	140-200	Yuan <i>et al.</i> (2019)
		2015, female adults, liver		290	
Common Guillemot <i>Uria aalge</i>	Scandinavia	2016, egg	µg/kg lw	58-67	Yuan <i>et al.</i> (2019)
White-tailed Sea-eagle <i>Haliaeetus albicilla</i>	Scandinavia	2015, egg	µg/kg lw	140-250	Yuan <i>et al.</i> (2019)
Grey Seal <i>Halichoerus grypus</i>	Scandinavia	2006 – 2008, males juveniles (0 – 1 year)	µg/kg lw	210 (liver)	Yuan <i>et al.</i> (2019)
				83 (blubber)	
		2009 – 2010, males adults (8 – 11 year)		230 (liver)	
		2014 – 2015, juveniles		32 (blubber) 540 (liver)	
Harbour Seal <i>Phoca vitulina</i>	Scandinavia	2014 – 2015, juveniles, blubber	µg/kg lw	100	Yuan <i>et al.</i> (2019)
		2012 – 2016, adults		230 (liver) 64 (blubber)	
		2006 – 2012, 3 females and 1 male adults, liver		140 (liver)	
Harbour Porpoise <i>Phocoena phocoena</i>	Scandinavia	2006 – 2012, 3 females and 1 male adults	µg/kg lw	36 (blubber)	Yuan <i>et al.</i> (2019)
		2008, 1 female and 1 male adults		440 (liver)	
				59 (blubber)	

Sample	Location	Comment	Units	Level	Reference
Moose <i>Alces alces</i>	Scandinavia	2012 – 2015, female and male adults, muscle	µg/kg lw	1 600	Yuan <i>et al.</i> (2019)
Bank Vole <i>Myodes glareolus</i>	Scandinavia	2014, female and male adults, muscle	µg/kg lw	370	Yuan <i>et al.</i> (2019)
Eurasian Lynx <i>Lynx lynx</i>	Scandinavia	2012 – 2016 female and male adults, muscle	µg/kg lw	750	Yuan <i>et al.</i> (2019)
Grey Wolf <i>Canis lupus</i>	Scandinavia	2012 – 2016 female and male adults, muscle	µg/kg lw	830	Yuan <i>et al.</i> (2019)
Starling <i>Sturnus vulgaris</i>	Scandinavia	2012 – 2015, female and male fledglings, muscle	µg/kg lw	310	Yuan <i>et al.</i> (2019)
Common Kestrel <i>Falco tinnunculus</i>	Scandinavia	2014, egg	µg/kg lw	85	Yuan <i>et al.</i> (2019)
Tawny Owl <i>Strix aluco</i>	Scandinavia	2014, egg	µg/kg lw	87	Yuan <i>et al.</i> (2019)
Eagle Owl <i>Bubo bubo</i>	Scandinavia	2013 – 2017, female and male adults, muscle	µg/kg lw	720	Yuan <i>et al.</i> (2019)
Marsh Harrier <i>Circus aeruginosus</i>	Scandinavia	2012 – 2015 female and male adults, muscle	µg/kg lw	180	Yuan <i>et al.</i> (2019)
Golden Eagle <i>Aquila chrysaetos</i>	Scandinavia	2012 – 2016 female and male adults, muscle	µg/kg lw	360	Yuan <i>et al.</i> (2019)
Peregrine Falcon <i>Falco peregrinus</i>	Scandinavia	2012 – 2016 female and male adults, muscle	µg/kg lw	410	Yuan <i>et al.</i> (2019)
Salmon	Southern Germany	2014 - 2017, 122 farmed and 11 wild salmon samples	µg/kg ww	1.1 - 79	Krätschmer <i>et al.</i> (2019)
Pond Loach <i>Misgurnus anguillicaudatus</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	2 500 (1 400 – 2 600) 270 (170 – 430)	Du <i>et al.</i> (2018)
Rice Field Eel <i>Monopterus albus</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	2 600 (820 – 3 700) 140 (50 – 270)	Du <i>et al.</i> (2018)
Red-backed Rat Snake <i>Elaphe rufodorsata</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	3 800 (2 100 – 7 900) 170 (100 – 330)	Du <i>et al.</i> (2018)
Red-banded Snake <i>Dinodon rufozonatum</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	13 000 570	Du <i>et al.</i> (2018)
Short-tailed Mamushi <i>Gloydius brevicaudus</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	17 000 (7 400 – 19 000) 990 (450 – 1 300)	Du <i>et al.</i> (2018)
Yellow Weasel <i>Mustela sibirica</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	12 000 (6 700 – 33 000) 990 (640 – 2 900)	Du <i>et al.</i> (2018)
Peregrine Falcon <i>Falco peregrinus</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	2 100 (1 300 – 29 000) 260 (190 – 4 700)	Du <i>et al.</i> (2018)
Collared Scops-owl <i>Otus lettia</i>	Paddy fields in the Yangtze River Delta, China	Median (min-max)	µg/kg lw µg/kg dw	270 (96 – 440) 74 (39 – 110)	Du <i>et al.</i> (2018)
Common Cuckoo <i>Cuculus canorus</i>	Paddy fields in the Yangtze	Median (min-max)	µg/kg lw	200 (<170 – 1 400)	Du <i>et al.</i> (2018)

Sample	Location	Comment	Units	Level	Reference
	River Delta, China		µg/kg dw	25 (<12 – 92)	
Fish (no further information provided)	Bohai Bay, China	Range	µg/kg dw	42.1 – 5 307	Xia <i>et al.</i> (2016)
Polychaetes	Inner Oslofjord	3 pooled samples (whole individuals)	µg/kg ww	Average: 12	Ruus <i>et al.</i> (2018)
Blue Mussel <i>Mytilus edulis</i>	Inner Oslofjord	3 pooled samples (soft tissue)	µg/kg ww	Average: 10	Ruus <i>et al.</i> (2018)
Krill <i>Euphausiacea</i>	Inner Oslofjord	3 pooled samples (whole individuals)	µg/kg ww	60	Ruus <i>et al.</i> (2018)
Prawn <i>Pandalus borealis</i>	Inner Oslofjord	3 pooled samples (tail soft tissue)	µg/kg ww	2	Ruus <i>et al.</i> (2018)
Herring <i>Clupea harengus</i>	Inner Oslofjord	3 pooled samples (muscle)	µg/kg ww	Average: 17	Ruus <i>et al.</i> (2018)
Atlantic Cod <i>Gadus morhua</i>	Inner Oslofjord	Liver (detected in all 15 samples)	µg/kg ww	Arithmetic mean 216 (range: 51-1050)	Ruus <i>et al.</i> (2018)
Herring Gull <i>Larus argentatus</i>	Inner Oslofjord	Blood (detected in all 15 samples)	µg/kg ww	Arithmetic mean 28.23 (range: 8.2-76)	Ruus <i>et al.</i> (2018)
	Outer Oslofjord	Blood (detected in all 15 samples)		Arithmetic mean 38.87 (range: 5.8-200)	Ruus <i>et al.</i> (2018)
	Inner Oslofjord	Egg (detected in all 15 samples)		Arithmetic mean 29.14 (range: 6.1-68)	Ruus <i>et al.</i> (2018)
	Outer Oslofjord	Egg (detected in all 15 samples)		Arithmetic mean 69.58 (range: 3.1-630)	Ruus <i>et al.</i> (2018)

Table 17: Summary of levels of “MCCPs” in air

Location	Comment	Units	Concentration	Reference
Dongjiang River, China	Air samples	µg/sampler	4.1	Wang <i>et al.</i> (2013)
	Atmospheric depositions (wet and dry) at 11 sites	µg/(m ² d)	5.3	
Shergyla Mountain and Lhasa (Tibetan Plateau)	Air samples	pg/m ³	50 – 690 800 – 6 700	Wu <i>et al.</i> (2019)
Georgia King Island, Fildes Peninsula of Antarctica (Great Wall Station)	Air samples	pg/m ³	3.7 – 5.2 (average: 4.5)	Ma <i>et al.</i> (2014)
India	Air samples (average)	ng/m ³	3.62	Chaemfa <i>et al.</i> (2014)
Pakistan	Air samples (average)	ng/m ³	4.21	Chaemfa <i>et al.</i> (2014)
Shenzhen, Guangzhou Province, China	Air samples (28 samples collected over 4 seasons, September 2013 to August 2014)	ng/m ³	0.70–12.2	Li <i>et al.</i> (2018)
Zeppelin (Svalbard, Norway) and Birkenes (Norway)	Air samples (2019) Weekly (Svalbard) Monthly (Birkenes)	pg/m ³	<44 to 3 900 (mean: 270) <95 to 1 500 (mean: 330)	Bohlin-Nizzetto <i>et al.</i> (2020)