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and the Environment
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A proposal in accordance with the methodology of the Water Framework Directive

RIVM Letter report 2017-0044
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Colophon

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Synopsis

Water quality standards for PFOA
A proposal in accordance with the methodology of the Water Framework Directive

RIVM proposes water quality standards for PFOA. This perfluoro compound has been used for the production of teflon and is found in many surface waters around the world. The quality standard for chronic exposure accounts for the accumulation of PFOA in fish. Using this information, RIVM calculated a safe concentration in water of 48 nanograms per liter, which is protective for lifetime consumption of fish by humans and wildlife.

For this research an extensive overview was made of the scientific data on effects of PFOA on aquatic organisms and the accumulation in biota. Based on the oral risk limit for humans as derived recently by RIVM, a maximum allowable concentration in fish was calculated assuming a lifetime daily consumption. This biota standard is converted to an equivalent safe concentration in water using information on the uptake of PFOA from water by fish.

Data on bioaccumulation are needed because the water quality standard for ecological effects on aquatic organisms is not sufficiently protective for food chain effects. PFOA has a relatively low toxicity for water organisms, but may pose a problem when entering the food chain via fish.

The use of PFOA is restricted by European law, but it can still reach the environment from PFOA-containing products that were produced in the past. Because of its high persistence, emissions will lead to long term presence in the environment. An initial comparison with monitoring data indicates that the safe concentration derived in this research is not exceeded in Dutch surface waters.

Keywords: PFOA; water quality standards; perfluoro compounds

Publiekssamenvatting

Waterkwaliteitsnormen voor PFOA
Een voorstel volgens de methodiek van de Kaderrichtlijn Water

Het RIVM doet een voorstel voor waterkwaliteitsnormen voor PFOA. Deze perfluorverbinding is jarenlang gebruikt bij de productie van teflon en wordt overal ter wereld in het oppervlaktewater aangetroffen. De norm voor de langetermijn-blootstelling houdt rekening met de mate waarin PFOA zich ophoopt in vis. Met die informatie heeft het RIVM berekend dat een concentratie van 48 nanogram per liter veilig is als mensen, vogels en zoogdieren hun leven lang vis uit dat water zouden eten.

Voor dit onderzoek is een uitgebreid overzicht gemaakt van wat er in de wetenschappelijke literatuur bekend is over de effecten van PFOA op waterorganismen en in welke mate ze deze stof opnemen. In eerder onderzoek heeft het RIVM bepaald hoeveel een mens van de stof zou mogen binnenkrijgen zonder daar schadelijke gevolgen van te ondervinden. Vervolgens is berekend wat er maximaal in vis zou mogen zitten als mensen elke dag gedurende hun hele leven vis zouden eten. Deze waarde in vis is vertaald naar een veilige concentratie in water. Dit is gedaan met behulp van gegevens over de mate waarin vissen PFOA opnemen vanuit het water.

Deze werkwijze is gevolgd omdat de voedselketen onvoldoende wordt beschermd door de ecologische norm voor waterorganismen. PFOA is relatief weinig giftig voor waterorganismen zelf, maar kan een probleem vormen als de stof via vis in de voedselketen terechtkomt.

Het gebruik van PFOA is in Europa inmiddels aan banden gelegd, maar kan nog wel vrijkomen uit producten waarin de stof in het verleden is verwerkt. Omdat PFOA nauwelijks afbreekt, zullen restanten nog lang in het milieu aanwezig blijven. Uit een eerste vergelijking met meetgegevens blijkt echter dat de veilige concentratie momenteel niet wordt overschreden in Nederlands oppervlaktewater.

Kernwoorden: PFOA; waterkwaliteitsnormen; perfluorverbindingen

Contents

Summary

In this report a proposal is made for environmental quality standards (EQS) for perfluoro octanoic acid (PFOA) in surface water. PFOA is subject of public debate because of emissions from a teflon production plant at Dordrecht, the Netherlands. Environmental quality standards for surface water have not been derived to date, but are needed to evaluate the impact of emissions on water quality and to decide on further regulatory actions.

The derivation of quality standards is in accordance with the methodology of the European Water Framework Directive (WFD). EQS aim at the protection of the aquatic ecosystem, including predatory birds and mammals feeding on water organisms, and the protection of human health. The standards with regard to human health should ensure that water quality is sufficient to protect against adverse effects of consuming contaminated fish products.

From existing evaluations it is known that PFOA has a relatively low toxicity for water organisms, but may pose a problem when entering the food chain via fish. Based on the recently derived oral risk limit for humans, it is expected that human fish consumption is the critical route in the case of PFOA. Therefore, the research was focused on deriving human health based quality standards for fish consumption. Using the oral risk limit for humans, a concentration in fish was calculated considered not to have a negative impact on human health. To convert this biota-based standard to an equivalent concentration in water, data on the bioaccumulation of PFOA in fish and other aquatic organisms were collected from the literature, including laboratory data as well as field monitoring studies.

From the results it can be concluded that bioaccumulation is highly variable, even within taxonomically related species. For both fish and bivalves, there is rather strong evidence that this variation is related to the fact that the bioaccumulation factor (BAF) is dependent on the exposure concentration. Therefore, the bioaccumulation data were used to establish a concentration-bioaccumulation relationship. From this relationship, a safe concentration in water of 48 ng/L is derived. This value is protective for lifetime consumption of fish by humans, birds and mammals and for direct ecotoxicity to aquatic organisms. It is also protective for intake of surface water for production of drinking water. An initial comparison with monitoring data indicates that the safe concentration derived in this research is currently not exceeded in Dutch surface waters.

1 Introduction

1.1 Context of the report

In this report a proposal is made for water quality standards for perfluoro octanoic acid (PFOA) in surface water. PFOA is subject of public debate because of emissions from a teflon production plant at Dordrecht, the Netherlands. By order of the Ministry of Infrastructure and the Environment (I&M), RIVM evaluated the potential risks for humans resulting from past emissions to exposure via air and tap water [1,2]. Environmental quality standards for surface water have not been derived to date, but are needed to evaluate the impact of emissions on water quality and to decide on further regulatory actions. In this report, a proposal for water quality standards is made in accordance with the methodology of the Water Framework Directive [3]. The derived values are advisory values and will only be effective as quality standards after official approval by the Ministry of I&M.

1.2 Standards considered

Under the WFD, two types of environmental quality standards (EQSs) are derived to cover both long- and short-term effects resulting from exposure: an annual average concentration (AA-EQS) to protect against the occurrence of prolonged exposure, and a maximum acceptable concentration (MAC-EQS) to protect against possible effects from short term concentration peaks.
Next to the AA-EQS and MAC-EQS, the WFD also considers a standard for surface water used for drinking water abstraction. Below, a short explanation on the respective standards is provided and the terminology is summarised in Table 1. Note that all standards refer to dissolved concentrations in water.

- Annual Average EQS (AA-EQS) – a long-term standard, expressed as an annual average concentration (AA-EQS) and normally based on chronic toxicity data which should protect the ecosystem against adverse effects resulting from long-term exposure.

  The AA-EQS should not result in risks due to secondary poisoning and/or risks for human health aspects. These aspects are therefore also addressed in the AA-EQS, when triggered by the characteristics of the compound (i.e. human toxicology and/or potential to bioaccumulate). Separate AA-EQSs are derived for the freshwater and saltwater environment.

- Maximum Acceptable Concentration EQS (MAC-EQS) for aquatic ecosystems – the concentration protecting aquatic ecosystems from effects due to short-term exposure or concentration peaks. The MAC-EQS is derived for freshwater and saltwater ecosystems, and is based on direct ecotoxicity only.

- Quality standard for surface water that is used for drinking water abstraction ($QS_{dw, hh}$). This is the concentration in surface water that meets the requirements for use of surface water for drinking water production.

The quality standards in the context of the WFD refer to the absence of any impact on community structure of aquatic ecosystems. Hence, not the potential to recover after transient exposure, but long-term undisturbed function is the protection objective under the WFD. Recovery in a test situation, after a limited exposure time, is therefore not included in the derivation of the AA- and MAC-EQS.

Table 1. Overview of the different types of WFD-quality standards for freshwater (fw), saltwater (sw) and surface water used for drinking water (dw) considered in this report.

Type of QS	Protection aim	Terminology for intermediate standard[1]	Notes	Final selected quality standard
longterm	Water organisms	$QS_{fw, eco}$ $QS_{sw, eco}$	Refers to direct ecotoxicity	lowest water-based QS is selected as AA-EQS_{fw} and AA-EQS_{sw}
	Predators (secondary poisoning)	$QS_{biota, secpois, fw}$ $QS_{biota, secpois, sw}$	QS for fresh- or saltwater expressed as concentration in biota, converted to corresponding concentration in water	
		$QS_{fw, secpois}$ $QS_{sw, secpois}$		
	Human health (consumption of fishery products)	$QS_{biota, hh food}$	QS for water expressed as concentration in biota, converted to corresponding concentration in water; valid for fresh- and saltwater	
		$QS_{water, hh food}$		
short-term	Water organisms	MAC-$QS_{fw, eco}$ MAC-$QS_{sw, eco}$	Refers to direct ecotoxicity; check with $QS_{fw, eco}$ and $QS_{sw, eco}$	MAC-EQS_{fw} MAC-EQS_{sw}
dw	Human health (drinking water)		Relates to surface water used for abstraction of drinking water	$QS_{dw, hh}$

1: Note that the subscript "fw" refers to the freshwater, "sw" to saltwater; subscript "water" is used for all waters, including marine.

1.3 Methodology

1.3.1 General remarks

The methodology for derivation of quality standards in the Netherlands is described in an on-line guidance document, available via the RIVM-website[1]. The methodology for surface water standards is in accordance with the European guidance document for derivation of environmental quality standards under the WFD [3], further referred to as the WFD-guidance. The WFD-guidance is currently under revision, adaptations involve the defaults used for the derivation of the quality standards for human fish consumption ($QS_{water,\ hh\ food}$) and drinking water abstraction ($QS_{dw,\ hh}$). In this report, the adapted methodology is used, which is in line with the recent derivation of a drinking water limit for PFOA by RIVM [1]. Further details are given below in section 1.3.2.

The WFD-guidance requires that all available literature is collected and evaluated regarding scientific quality and relevance. However, PFOA has been evaluated in several frameworks. It was part of the OECD programme on High Production Volume Chemicals [4,5] and is classified as a Substance of Very High Concern (SVHC) under REACH [6]. Canada published a screening assessment report [7] and WFD-water quality standards were derived recently by Italy [8]. It was decided to make efficient use of existing evaluations and supplement these with new data when needed.

Based on the already derived risk limits for human toxicology and drinking water [1,2], and the ecotoxicity data in the Italian EQS-dossier [8], it is expected that the $QS_{water,\ hh\ food}$ and $QS_{dw,\ hh}$ will be more critical as compared to direct ecotoxicity. The assessment of secondary poisoning may also lead to relatively low standards and will most likely more critical than direct ecotoxicity. Therefore, the emphasis in this report will be on the human health based quality standards for drinking water and fish consumption and on secondary poisoning, followed by the assessment of direct ecotoxicity. The methodology for the respective parts of the EQS-derivation is outlined below.

1.3.2 Derivation of the $QS_{water,\ hh\ food}$

The methodology to derive human health based water quality standards comprises two steps. The first step is to calculate the concentration in fish considered not to have a negative impact on human health. This biota-based standard is referred to as $QS_{biota,\ hh\ food}$. The second step is to convert the $QS_{biota,\ hh\ food}$ to an equivalent concentration in water, based on information on the accumulation of contaminants in fish.
The starting point for derivation of the $QS_{biota,\ hh\ food}$ is a human toxicological threshold limit (TL_{hh}), such as the Acceptable or Tolerable Daily Intake (ADI, TDI), or Reference dose (RfD). To convert the TL_{hh} to a $QS_{biota,\ hh\ food}$, the default assumption in the current WFD-guidance is that an average adult person weighing 70 kilogram consumes 115 gram fish per day. The contribution of fish consumption is set at 10% of the threshold limit. This allocation factor of 10% takes into account other routes that may contribute to total intake, such as inhalation, drinking

[1] http://www.rivm.nl/rvs/Normen/Milieu/Milieukwaliteitsnormen/Handleiding_normafleiding

water, and other foods. It also provides a safety margin for vulnerable groups, such as pregnant women and people with high fish consumption.
Based on an evaluation of the methodology [9], the default for fish consumption will be maintained in the revised WFD-guidance, but will be expressed on a body weight basis as 1.63 g/kg_{bw} per day. The allocation factor will be brought in line with the WHO-default for the derivation of drinking water guidelines and set to 20%. In this report, the $QS_{biota,\ hh\ food}$ will thus be calculated using the following equation:

$$QS_{biota,\ hh\ food} = \frac{TL_{hh} \times 0.2}{0.00163} \qquad \text{Eq. 1}$$

with:
$QS_{biota,\ hh\ food}$: biota-based quality standard, µg/kg fish
TL_{hh} : human toxicological threshold, µg/kg_{bw} per day

The next step is to convert the $QS_{biota,\ hh\ food}$ to an equivalent concentration in water, denoted as the $QS_{water,\ hh\ food}$. This conversion is based on information on the accumulation of contaminants in fish. For aquatic ecosystems, assuming the trophic level for algae, zooplankton, small fish and large fish are 1, 2, 3, and 4, respectively, the $QS_{biota,\ hh\ food}$ is set on trophic level 4 (TrL4) to protect humans that consume larger fish. Concentrations in TrL4-fish depend on the accumulation of substances from the aqueous phase by lower aquatic organisms (bioconcentration) and accumulation in the food chain from TrL1-3 to TrL4 (biomagnification), if relevant. These processes are represented by a bioconcentration factor (BCF) and biomagnification factors (BMF), if biomagnification occurs.

The BCF is the ratio of the concentration in the organism divided by the water concentration, where the water phase is the only exposure route. BCF values are mostly determined in the laboratory. The BMF is the ratio of the concentration in a predator organism divided by the concentration in its prey. The BMF is usually determined on the basis of field studies. Two BMFs are distinguished in the current WFD-guidance [3]. The first, BMF_1, describes the overall biomagnification from aquatic organisms to larger fish (TrL4) in the aquatic environment that in turn is eaten by predators (including humans). Following this approach, the $QS_{water,\ hh\ food}$ is calculated according to Equation 2 as follows:

$$QS_{water,\ hh\ food} = \frac{QS_{biota,\ hh\ food}}{BCF \times BMF_1} \qquad \text{Eq. 2}$$

with:
$QS_{water,\ hh\ food}$: water-based quality standard, µg/L
$QS_{biota,\ hh\ food}$: biota-based quality standard, µg/kg fish
BCF : bioconcentration factor, L/kg
BMF_1 : biomagnification factor, kg/kg

For substances that do not biomagnify, BMF is not relevant and can be omitted from the equation. In other cases, BMFs may be derived from laboratory and field studies, but recent literature often involves studies into the transfer of a compound through the food chain as a function of trophic level. In such studies the levels of contaminants in several

species in an ecosystem are measured and expressed as a function of the trophic level. The trophic level is mostly derived from stable nitrogen isotope ratios and a regression is made between contaminant concentration and trophic level. The contaminant values should preferably be normalised to the fraction in the organisms that contains the substance e.g. lipids in the case for lipophilic organic chemicals. However, a normalisation to protein content seems not possible at this moment, because protein content is not a commonly measured parameter. The resulting Trophic Magnification Factor (TMF) from such studies denotes the average increase in concentrations per trophic level. For biomagnifying substances, only the first trophic level of primary consumers is in equilibrium with the water phase. The next trophic levels deviate from equilibrium if biomagnification occurs. The overall BMF up to the fourth trophic level in the aquatic environment thus actually comprises three biomagnification steps. If biomagnification is expressed as a TMF, then the overall biomagnification step to TrL 4 is equal to TMF^3 [10,11].

Instead of using the product of BCF and BMF, a field based BAF may be used that includes both uptake from the water phase and uptake via food. The use of BAFs is generally preferred, because the BAF is based on field samples and includes all possible uptake routes, and it can be directly derived from concentrations in biota at the appropriate trophic level. For a valid BAF, however, insight into the corresponding concentrations in water is needed. For biomagnifying substances, care should also be taken that the BAF is derived for the appropriate trophic level. For human fish consumption, a BAF at TrL4 can replace the product of BCF and BMF_1. The $QS_{water,\ hh\ food}$ can thus also be calculated according to Equation 3:

$$QS_{water,\,hh\,food} = \frac{QS_{biota,\,hh\,food}}{BAF_{TrL4}} \qquad \text{Eq. 3}$$

with:
$QS_{water,\ hh\ food}$: water-based quality standard, µg/L
$QS_{biota,\ hh\ food}$: biota-based quality standard, µg/kg fish
BAF_{TrL4} : bioaccumulation factor at Trophic Level 4, L/kg

If the substance does not biomagnify, the trophic level is less relevant and BAF values will mostly resemble BCF values. In summary, the derivation of water-based quality standards for human exposure via fish requires the derivation of a human toxicological risk limit, and information on BCF and BMF/TMF, or BAF.

As indicated in section 1.3.1, existing evaluations were used as much as possible. However, in particular for the BAF there appeared to be unclarities in the way the data were reported. Therefore, it was decided to re-evaluate the available studies. Further details are given in section 3.3.

1.3.3 Derivation of the $QS_{fw,\ secpois}$ and $QS_{sw,\ secpois}$

Two different biota QS for secondary poisoning can be derived, one for freshwater (fw) and one for marine or salt waters (sw). A distinction between fresh and marine water quality standards could be appropriate

when fish-eating birds and mammals that serve at their turn as food for the marine top predators, are a more critical food item than fish. Similar to the quality standard for human fish consumption the biota standards for secondary poisoning can be expressed as equivalent water quality standards.

A biota-based quality standard for secondary poisoning to protect wildlife is derived based on the methodology as described in the draft update of the WFD-guidance. This methodology is more extensively described by Verbruggen [11]. In comparison to the methods previously adopted in the guidance document, this methodology accounts for the energy content of the food items and, as a result, (default) assessment factors to convert laboratory diet to natural diet in the field are avoided. This methodology consist of the following steps, including:

1. selection of the most critical food item in the food chain
2. collection of relevant mammal and bird toxicity data,
3. transformation of the (bird and mammal) effect concentrations to energy normalised effect concentrations,
4. the expression of energy normalised effect concentrations to concentrations in the most critical food item,
5. subsequent derivation of quality standards for secondary poisoning, followed by
6. the transformation of effect concentrations in food items to concentrations in water bodies.

The different steps are briefly explained below, detailed information can be found in the underlying report [11].

Step 1. Selection of most critical food item

In order to protect all predator wildlife organisms, the QS for secondary poisoning needs to be expressed in the food item (i.e. prey organism) that leads to the highest PFOA exposure of birds or mammals that purely feed on this food item. Therefore, first, the most critical food item needs to be selected before energy normalised effect concentrations can be converted to an effect concentration in (the most critical) food item.

The substance concentration in prey organisms is related to the bioaccumulation potential in the different organisms. Thus, the most critical food item can be selected based on the bioaccumulation characteristics of a substance throughout the food chain in combination with the energy content of food items in the food chain. The latter is important, because it is proportional to the amount of food that is consumed by the predator. The energy normalised concentration of a food item can be calculated by dividing the concentration of a substance by the energy content of the food item, e.g. for mussels:

$$C_{norm,\ mussel} = \frac{C_{mussel}}{EC_{dwt,\ mussel} \times (1 - MC_{mussel})} \qquad \text{Eq. 4}$$

with:

$C_{norm,\ mussel}$: energy normalised (no) effect concentration for mussel, mg/kJ
C_{mussel} : (no) effect level as concentration in mussel
$EC_{dwt,\ mussel}$: energy content of mussels, kJ/g_{dwt}
MC_{mussel} : moisture content of mussels, mass fraction

Default values for 'energy content' and 'moisture fraction' can be used for each organism (see Table 2). In general, the food item in the food chain with highest energy normalised concentration will be the critical food item. Predators preying on this food item will have the highest exposure to the substance. It follows that the critical food item is the one with the highest ratio of bioaccumulation factor and energy content.

Table 2. Energy content, moisture content, lipid content and protein content for food items addressed in risk assessment schemes for aquatic and terrestrial food webs. Values taken from draft WFD-guidance, 2016 (revision of [3] in analogy with [11]).

Food item	**Energy content [kJ/g_{dwt}]**	**Moisture content [%]**	**Lipid content [%]**	**Protein content [%]**
Bivalves	19.3	91.7	1	10
Fish	21.0	73.7	5	18
Vertebrates	23.2	68.4	10	21

For selecting the most critical food item, some guidance values are given based on trophic magnification factors, which basically comes down to whether a substance biomagnifies in the food chain or whether there is biodilution [11]. For substances that biomagnify, fish at the higher trophic level (by default TrL4) will be the critical food item, for substances for which biodilution occurs, food items at the bottom of the food chain such as molluscs will be critical. An extensive evaluation of bioaccumulation is made for several taxonomic groups from the food chain, including fish, molluscs, crustaceans and aquatic plants (see Chapter 3). The selection of the most critical food items follows from this assessment of bioaccumulation factors.

For the marine food chain an additional step is considered in the food chain, since fish-eating predators like birds and mammals could be eaten by a top predator, such as killer whales and polar bears. To account for this additional step in the marine food chain, an additional biomagnification factor in mammals and birds ($BMF_{b/m}$) should be taken into account. Similar to the pelagic food chain only, on the basis of such BMF data it can be assessed whether this extra step in the food chain will result in the critical food item.

Step 2. Collection of relevant mammal and bird toxicity data
In order to derive the biota and water-based QS for secondary poisoning, bird and mammal toxicity data were retrieved from the Italian EQS-dossier [8] and from the ECHA restriction dossier [12], together with data from the evaluations by the US EPA [13,14] and Environment Canada [7] on the health effects of PFOA. From the studies described in these publications, we only considered population relevant endpoints (i.e. systemic effects: growth, reproduction, mortality), which is normal practice for the derivation of a QS for secondary poisoning. In other words, organ effects (e.g., liver effects) or more specific effects were not considered. Furthermore, when available, preference was given to chronic experiments above (sub)acute experiments. Additional searches for specific representatives of wildlife species that are sometimes used for toxicity experiments (e.g., mink and kestrel) did not result in relevant data.

Step 3. Conversion to energy normalised concentrations
For the derivation of a quality standard for secondary poisoning, the mammalian and bird toxicity values are converted to energy normalised concentrations: concentrations are expressed based on energy content of the food. This conversion is based on data reported in the performed studies. When concentrations are expressed as food concentrations, the conversion is based on the energy content of the food source (in kJ/kg), if known, using Equation 4.

$$C_{norm} = \frac{C_{diet}}{EC_{diet}} \quad \text{Eq. 5}$$

with:
C_{norm} : energy normalised (no) effect concentration, mg/kJ
C_{diet} : (no) effect concentration, mg/kg feed
EC_{diet} : energy content of the diet, kJ/kg

When concentrations are expressed as a dose, the conversion is based on known relationships between energy demands and body weight of the test organism. For this conversion, the daily energy expenditure (DEE) for mammals and birds is calculated using Equation 6 or 7. Subsequently, the energy normalised concentration is calculated with Equation 8, using the parameters: body weight of the test organism (BW) and the dose at which the endpoint is affected (NOAEL, LOAEL, etc.).

$$\log DEE = 0.8136 + 0.7149 \times \log BW_{mammal} \quad \text{Eq. 6}$$

$$\log DEE = 1.032 + 0.6760 \times \log BW_{bird} \quad \text{Eq. 7}$$

$$C_{norm} = C_{dose} \times \frac{BW}{DEE} \quad \text{Eq. 8}$$

with:
C_{norm} : energy normalised (no) effect concentration, mg/kJ
C_{dose} : (no) effect level as dietary dose, in mg/kg bw per d
BW : body weight, kg
DEE : daily energy expenditure, kJ/d

If both dose and diet concentrations are given, both calculations can be made and an assessment can be made which value is most appropriate, e.g., based on the certainty of the reported data on body weight, energy content of the food or the reported dose, which often depends on the daily food intake of the organisms.

Step 4. Conversion to concentrations in the most critical food item
After selecting the most critical food item, the energy normalised concentrations can be expressed in concentrations in the food item using Equation 9 or 10. These concentrations expressed in food items eaten by predators correspond to the concentrations or doses or diet concentration used, or reported as endpoints (e.g. NOAEL, NOEC, ED10 or EC10) in the toxicity studies. Within Equation 9 and 10, the properties 'energy content' and 'moisture fraction' are related to the most critical food item (see Table 2).

$$C_{food\ item} = C_{norm} \times EC_{food\ item,\ dwt} \times (1 - MC_{food\ item}) \quad \text{Eq. 9}$$

$$C_{food\ item} = C_{norm} \times EC_{food\ item,\ wwt} \quad \text{Eq. 10}$$

with:
$C_{food\ item}$: (no) effect concentration as dietary dose, mg/kg$_{wwt\ feed}$
C_{norm} : energy normalised (no) effect concentration, mg/kJ
$EC_{food\ item,\ dwt}$: energy content of the dry feed, kJ/kg$_{dwt\ feed}$
$EC_{food\ item,\ wwt}$: energy content of the wet feed, kJ/kg$_{wwt\ feed}$
$MC_{food\ item}$: moisture content of the feed

Step 5. Derivation of biota-based quality standards for secondary poisoning

For deriving QS for secondary poisoning, all effect concentrations need to be corrected for study duration. If a mammalian or bird toxicity experiment does not consider chronic toxicity, an assessment factor should be applied in order to extrapolate a (sub)acute or subchronic effect concentration in the critical food item to a chronic effect concentration. The applied assessment factors are 1, 3, 10 or 100 for a chronic, subchronic, subacute or acute study, respectively. Only the most critical effect is selected per species, if more than one study is available with the same species. This most sensitive endpoint does not necessarily originate from the study with the longest test duration. However, the applied assessment factors may be adjusted for shorter toxicity studies, when at the same time a chronic study is available showing effects only at higher concentrations.

Subsequently, the $QS_{biota,\ secpois,\ fw}$ for secondary poisoning in freshwater organisms can be derived by applying an assessment factor of 10 to the lowest selected effect concentration in the most critical food item (Equation 11). This assessment factor is applied for the extrapolation from the most sensitive laboratory toxicity study to all birds and mammals in the whole ecosystem.
When fish-eating birds and/or mammals are the most critical food item for the marine environment, the $QS_{biota,\ secpois,\ sw}$ for secondary poisoning is derived with Equation 12 (if concentrations are based on wet weight), instead of Equation 11. If not, $QS_{biota,\ secpois,\ sw} = QS_{biota,\ secpois,\ fw}$. Birds and mammals are unsuitable for environmental monitoring due to practical and ethical reasons, even when they are the critical food item. Therefore, the critical concentrations in birds and mammals are recalculated to a corresponding concentration in the prey organisms lower in the food chain that can be monitored routinely. These can be fish, but might be mussels as well if mussels accumulate the substance to the highest extent. Similar as for the derivation of a $QS_{biota,\ secpois,\ fw}$, an assessment factor is applied to extrapolate from laboratory studies to the ecosystem.

$$QS_{biota,\ secpois,\ fw} = \frac{\text{lowest chronic effect concentration in critical food item}}{10} \quad \text{Eq. 11}$$

$$QS_{biota,\ secpois,\ sw} = \frac{\text{lowest chronic effect concentration in critical food item}}{10 \times BMF_{b/m}} \quad \text{Eq. 12}$$

with:
$QS_{biota,\ secpois,\ fw}$: biota standard for secondary poisoning in freshwater
$QS_{biota,\ secpois,\ sw}$: biota standard for secondary poisoning in marine waters
$BMF_{b/m}$: biomagnification factor for birds or mammals

Step 6. Conversion to quality standards in water
When effect concentrations have been expressed in the most critical food item, this concentration can be converted to an effect concentration in water bodies by using the bioaccumulation factor of this most critical food item. For this conversion Equation 13 and 14 can be used.

$$QS_{fw,\ secpois} = \frac{QS_{biota,\ secpois,\ fw}}{BAF} \qquad \text{Eq. 13}$$

$$QS_{sw,\ secpois} = \frac{QS_{biota,\ secpois,\ sw}}{BAF} \qquad \text{Eq. 14}$$

with:
$QS_{fw,\ secpois}$: freshwater quality standard for secondary poisoning, ng/L
$QS_{sw,\ secpois}$: saltwater quality standard for secondary poisoning, ng/L
$QS_{biota,\ secpois,\ fw}$: biota standard for secondary poisoning in freshwater, ng/kg
$QS_{biota,\ secpois,\ sw}$: biota standard for secondary poisoning in marine waters, ng/kg
BAF : biomagnification factor for birds or mammals, L/kg

Within this equation, the BAF of the most critical food item in the aquatic freshwater food chain is used. If relevant for the marine environment, the additional biomagnification factor that describes the accumulation in the food of the top predators is taken into account in the biota standard.

1.3.4 Derivation of the QS_{eco} and MAC-QS_{eco} for direct ecotoxicity

For the derivation of the quality standards for direct ecotoxicity, ecotoxicity data for aquatic species are collected. From the available valid laboratory tests, a single endpoint per species is presented based on the lowest relevant endpoint observed. If multiple reliable values are available for the same species and the same endpoint originating from similar tests, the geometric mean is taken. An appropriate assessment factor is applied to the lowest endpoint, the height of the factor depends on the number of acute and chronic endpoints that are available for different taxa. Unbound values are not used for EQS-derivation, but are included in the tables to show that a particular taxon has been tested. In addition, if on the basis of such values it appears that the derived value is not protective, the assessment factor may be adapted. If enough data are available, species sensitivity distributions (SSDs) may be applied as well, and reliable semi-field data are taken into account. Details of the methods can be found in the WFD-guidance [3].

For the present assessment, the valid ecotoxicity data of the Italian EQS-dossier [8] were taken over. Open literature included in the EQS-derivation of PFOS [15] was also checked, because many authors test

both PFOA and PFOS. In general, no further evaluation of the studies was carried out. However, in case of deviating views regarding reliability between the Italian EQS-dossier and the RIVM-report on PFOS [15], a re-evaluation was performed (see section 6.1.1 for further information). A literature screening with SCOPUS was performed to retrieve additional studies that were not included in the Italian dossier, or that were published since then. This resulted in a few additional studies. As regards the reliability assessment, it is noted that studies without analytical verification of test concentrations were accepted if there were no other major deficiencies. Although measurement of test concentrations is highly recommended in general, this approach is considered justified for PFOA in view of its water solubility and chemical stability.

2 Information on the substance

2.1 Identity and physico-chemical properties

The identity of PFOA is described in Table 3, physico-chemical properties are summarised in Table 4. The REACH restriction dossier was used as the primary source of information, supplemented with data from other sources when needed.

Table 3. Identity of PFOA.

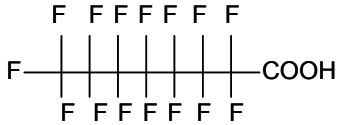
Common name	PFOA
Chemical name (IUPAC)	Pentadecafluorooctanoic acid
Synonym(s) and names of the acid form	Perfluorooctanoic Acid; PFOA; Pentadecafluoro-1-octanoic acid; Perfluorocaprylic acid; Perfluoroheptanecarboxylic acid; Perfluoro-n-octanoic acid; Pentadecafluoro-n-octanoic acid; Pentadecafluorooctanoic acid; n-Perfluorooctanoic acid 1-Octanoic acid, 2,2,3,3,4,4,5,5,6,6, 7,7,8,8,8-pentadecafluoro
Chemical class	Perfluoroalkyl acids (PFAAs)
CAS number	335-67-1 (Perfluorooctanoic acid) 3825-26-1 (Perfluorooctanoate, ammonium salt, APFO) 335-95-5 (Perfluorooctanoate, sodium salt) 2395-00-8 (Perfluorooctanoate, potassium salt) 335-93-3 (Perfluorooctanoate, silver salt)
EC/EINECS number	206-397-9 (Perfluorooctanoic acid) 223-320-4 (Perfluorooctanoate, ammonium salt) 206-404-5 (Perfluorooctanoate, sodium salt) 219-248-8 (Perfluorooctanoate, potassium salt) 206-402-4 (Perfluorooctanoate, silver salt)
Molecular formula	$C_8F_{15}O_2$
Molecular structure	
Molecular weight (g/mol)	414.07
SMILES code	FC(F)(C(F)(F)C([O-])=O)C(F)(F)C(F)(F)C(F)(F)C(F)(F)C(F)(F)F

Table 4. Physicochemical properties of PFOA. References refer to secondary sources in which values are cited.

Parameter	Unit	Value	Remark	Reference
Water solubility	[g/L]	9.5 4.14	25 ºC 22 °C	[4,6,12] [6,12]
pK_a	[-]	2.8[a] 1.5-2.8[a] <0.5[b]	50% aqueous ethanol	[4,6,12] [4,6,12] [12]
log K_{OW}	[-]	2.69[c] 6.3[c]	pH 7, 25 °C; estimated	[6,12] [6,12]
log K_{OC}	[-]	1.9 - 4		[8]
Vapour pressure	[Pa]	4.2 2.3 128	25°C; extrapolated 20 °C; extrapolated 53.9 °C; measured	[6,12] [6,12] [6,12]
Melting point	[°C]	54.3 44-56.5		[6,12]
Boiling point	[°C]	188 189		[4,6,12]
Henry's law constant	[$Pa.m^3/mol$]		not measurable	[16]

a: value for the ammonium salt, APFO
b: value for PFOA
c: it is indicated that both values are not valid for PFOA

2.2 Behaviour in the environment

2.2.1 General remarks

In aqueous media, the free perfluoroocanoic acid (PFOA) is in equilibrium with the conjugate base perfluorooctanoate (PFO). The expected environmental fate will depend on the environmental conditions, which influence the equilibrium between base and acid (pH and pKa). In view of the low pKa of PFOA, the compound will occur in its anionic form (i.e., PFO) under most environmental conditions.
The ammonium salt (APFO), which is often used in animal experiments, is very soluble in water, and also has a relatively low pKa. In aqueous solution it is present as anion PFO and the ammonium cation. The dissolved anion PFO will stay in equilibrium with the corresponding acid in aqueous media [6,7].

Currently available analytical methods cannot distinguish between PFO and PFOA in samples. As indicated above, experimental studies are often performed with APFO. In human and environmental monitoring studies, concentrations are referred to as PFOA or APFO, but always both species (PFO and PFOA) are included in the given concentration [6].

In the support document for SVHC identification [6], PFOA refers to the acid (PFOA) as well as to its conjugate base PFO. Only in cases where it is important to distinguish between both species and where species specific knowledge is available it is clearly indicated that either the acid PFOA or the conjugate base PFO is meant. This strategy is followed in the present report as well.

2.2.2 Persistence and mobility

PFOA is hydrolytically stable under relevant environmental conditions and direct photolysis does not occur in natural waters [6]. Standard screening studies indicate that PFOA is not ready biodegradable. The results of simulation tests and field monitoring data give additional support that biodegradation in water, soil and sediment does not occur [6]. Monitoring data show that PFOA in soil leaches over time and can be a long term source to underlying groundwater. PFOA is therefore considered as very persistent [6,16].

2.2.3 Partitioning to sediment

PFOA may partition from water to sediments, but a comparison of concentrations observed in the aqueous phase and in sediments suggests that sediments are unlikely to be a major sink for PFOA [7]. The Canadian screening assessment reports that Koc-values range from 48.8 to 229 L/kg. The Italian EQS-dossier reports that the log Koc ranges from 1.9 to 4 [8], but notes that the higher value was obtained in a river bank filtration experiment which is not representative of rivers sediment. It is further noted that the use of log Koc as a measure of sorption is probably not valid for PFOA. Based on monitoring data, the authors conclude that the accumulation of PFOA to sediment is most likely limited. In addition, no experimental data on ecotoxicity to sediment organisms were available and it was concluded that insufficient information was available to support derivation of a sediment quality standard [8]. In the Netherlands, sediment standards are normally not derived in the context of the WFD.

3 Bioconcentration, bioaccumulation and food chain transfer

3.1 General remarks

According to the WFD-guidance, secondary poisoning should be included in the EQS-derivation for compounds a bioconcentration factor (BCF) or bioaccumulation factor (BAF) ≥ 100 L/kg. If such data are not available, a log K_{ow} ≥ 3 is used as a trigger. In addition, other evidence of bioaccumulation potential or high intrinsic toxicity to mammals or birds may be used to motivate the inclusion of this route [3].

Extensive evaluations of the bioaccumulation potential are included in the support document for SVHC identification [6], the screening assessment of Environment Canada [7] and the Italian EQS-dossier [8]. These evaluations put emphasis on the fact that due to the specific properties of PFOA, the general assumptions of hydrophobic and lipophilic interactions being the main mechanisms governing partitioning may not be applicable for PFOA. Although the octanol-water partition coefficient (K_{ow}) has been calculated or modelled for the neutral form of PFOA and its various salts, experimental determination of K_{ow} is not feasible because ionised surfactants have a tendency to aggregate at the interface of a liquid-liquid system [6,7]. Perfluorinated substances have combined properties of oleophobicity, hydrophobicity, and hydrophilicity distributed over fragments of a particular molecule, making a straightforward prediction of bioaccumulation impossible [5-8]. Like other perfluorinated compounds, PFOA primarily binds to albumin proteins in the blood of biota and, as a result, is present in blood and highly perfused tissues such as liver and kidney, rather than lipid tissue [7].

Experimental data indicate that bioconcentration in fish is relatively low (see further below). The relatively high water solubility of PFOA may enable gill breathing organisms to quickly excrete the substance via gill permeation, while air breathing and terrestrial species do not have this ability of excretion. Bioconcentration values in fish may therefore not be the most relevant endpoint to consider, because other mechanisms of accumulation might be of more relevance [6]. Based on a weight of evidence approach, both the European and the Canadian authorities also concluded that PFOA may not meet the numerical regulatory criteria for bioaccumulation in the context of a PBT assessment (BCF >2000 L/kg), but there is sufficient evidence for bioaccumulation in the food chain [6,7]. As indicated above, this triggers the inclusion of secondary poisoning in the present EQS-derivation, and the necessary data to assess this route are summarised in the following sections.

3.2 Laboratory studies

Laboratory BCFs from the existing international evaluations are included in the assessment of laboratory BCF studies. The SVHC support document summarises the whole-body based BCFs as a range of 1.8 to 8.0 L/kg [6], the Italian EQS-dossier takes the highest value of 9.4 L/kg for carp forward for further assessment [8]. Next to that, several additional recent bioaccumulation studies retrieved in the context of this

report are added. Study details on all of these studies are presented in Annex 1.

The BCF-study in carp seems to have been cited twice in the Italian dossier, but the original reference differs. The first study [17] that is also referred to in the OECD SIDS report [4], the SVHC support document [6] and the Canadian evaluation [7], is an industry report from a study performed at the Japanese Kurume laboratory. The second study, cited in the Italian dossier, was published in the open literature in 2012 [18]. However, from the study description, the exact similarity of the results, and the author's affiliation, this is most likely a publication of earlier undisclosed data. In this report, the data from the original Japanese report obtained from the website of the National Institute of Technology and Evaluation (NITE) were used (http://www.safe.nite.go.jp/jcheck/). The original data were fitted to a kinetic one-compartment uptake model, leading to BCF values of 2.9 and 5.4 L/kg_{wwt} at PFOA concentration of 48 and 4.7 µg/L.

In another study with carp, two-year old carp were exposed for 56 days under flow-through conditions to either 200 ng/L or 2 mg/L PFOA [19]. The study was not designed to follow the uptake of PFOA by the fish in time and thus no kinetic BCF could be calculated. From the accompanying paper [20], it appears that the fish in the control, low and high concentration weighed on average 100.5, 123.3, and 90.0 g. Given this rather high weight of the fish, it is thus especially important to investigate whether steady state concentrations were achieved after the 56 days of exposure. Although smaller fish of the same species as described above in the Japanese study have estimated half-lives in the order of 1 day, it is uncertain if the 56 days of exposure under flow-through conditions are enough to achieve steady-state. Further, no data for whole body homogenate are reported, instead data for blood, liver, gonad, muscle, kidney, gills and brain are given. Together with data for the relative weight of organs in the fish, a whole body BCF can be calculated. For common carp of approximately the same weight (114, 134, and 136 g), the average body weight fractions are 2.1% for liver, 1.2% for gonad, 42.9% for muscle, 0.6% for kidney, 1.4% for gills, and 0.4% for brain [21]. For blood, a value of 4.11% for rainbow trout has been reported [22]. For the remaining parts (skin, scales, bones, intestines and head), a concentration half of that in muscle was assumed for other PFCs in crucian carp [23]. The resulting BCF at the very high exposure concentration of 2 mg/L is only 0.0041 L/kg_{wwt}, a very low value compared to the other values. The calculated BCF for whole body is similar to the value for muscle, which is 0.0037 L/kg_{wwt}. Given the uncertainties in this study, this value can only be used for comparative purposes to show that the BCF at very high concentration is remarkably low.

A study that has been cited by the OECD SIDS report [4], the SVHC support document [6], the Canadian evaluation [7], and the Italian EQS-dossier [8] is the BCF study with fathead minnows (*Pimephales promelas*) [24]. This study received a Klimisch score of 2 in the OECD SIDS report and the SVHC support document. However, the concentrations in fish in this study are extremely high (up to 50 µg/g_{wwt}). These concentrations were measured with an organic halide

analyser, which measures the element fluorine. This concentration was then recalculated in a concentration of APFO. The fluorine concentration is related to the exposure time, and thus the concentration in fish is treatment related. However, it is not certain that the accumulated substance is PFOA, as impurities were present in the substance amongst which the more bioaccumulative perfluorononanoic acid (PFNA). The BCF is thus not reliable (Ri3).

In another study, zebrafish were exposed to three high concentrations of PFOA, being 100, 500 and 1000 µg/L [25]. The BCF values for both males and females appeared to be slightly dependent on the exposure concentration with the BCF increasing from 0.55 and 0.30 L/kg_{wwt} for males and females respectively at 1000 µg/L to 0.83 and 0.44 L/kg_{wwt} at 100 µg/L. The very low BCF values at these high concentrations are also pointing at a concentration dependency.
In a similar experiment with the same species [26] such an effect was not clearly observed within the study with BCF values at 0.3, 1, 3, and 10 µg/L being rather constant at 20 to 43. A kinetic study was also carried out at 10 µg/L and the kinetic BCFs calculated from the presented data were 28 and 25 for males and females, respectively. In this study liquid scintillation counting was used as analytical method. This method measures total radioactivity and no distinction can be made between radiolabelled PFOA and impurities. Therefore, also these BCF values are considered to be not reliable (Ri3).

The bioaccumulation of four PFASs was determined simultaneously in liver and plasm (serum) of blackrock fish (*Sebastes schlegeli*) at four different salinities [27]. The concentrations of the individual test compounds varied around 7 to 9 µg/L at all salinities. The test consisted of an uptake phase of 28 d and a depuration phase of 28 d. For PFOS, PFUnA and PFDA a positive correlation between BCF and salinity existed, but not for PFOA. The BCF in liver varied between 73 and 93 L/kg_{wwt}, while the BCF in serum was between 357 and 578 L/kg_{wwt}. It should be noted that these BCF values are remarkably higher than in a similar study with the freshwater fish from the BCF study with rainbow trout [28], where the BCF for liver was 8.0 L/kg_{wwt} and the BCF for blood 27 L/kg_{wwt}.
Similarly high values were found for field bioaccumulation factors (BAF) for blood and liver of freshwater fish from South Korea, but these were obtained at much lower exposure concentrations of on average 2.5 ng/L. The BAF for liver and blood of crucian carp (*Carassius auratus*) were 134 and 611 L/kg_{wwt} and for mandarin fish (*Siniperca scherzeri*) 601 and 739 L/kg_{wwt} [29].

The study with rainbow trout had an uptake phase of 12 days and a depuration phase of 33 days performed at 1.7 µg/L together with 11 other perfluorinated compounds at equal or lower concentrations [28]. The kinetic BCF for carcass was 4.0 L/kg_{wwt}. A whole body BCF of 4.4 L/kg_{wwt} was calculated, based on presented BCF values carcass, liver and blood, together with the mass fraction (1.16%) of liver in rainbow trout [22] and the volume of the drawn blood sample. The reported half-life was 5.2 days, which is slightly shorter than the half-life for large rainbow trout confined to respirometer-metabolism chambers [30]. In the latter study fish were not freely swimming and were sedated, which

could have an effect on the activity of the fish. This study had an uptake phase of 3 days at an aqueous concentration of 500 µg/L. Although depuration kinetics are not very reliable in such a short uptake phase, it is clear that the concentrations in the eight fish start to level off in this short time period. The BCF for plasm estimated from the presented data is only 0.56 L/kg_{wwt}. This is remarkably lower than the value of 27 reported for blood in the former study at 1.7 µg/L. With the ratio between plasm and muscle at the end of the uptake experiment, the BCF for muscle is only 0.018 L/kg_{wwt}, which is comparably low as the BCF for common carp at 2 mg/L. However, fish were not free swimming and were sedated, although ventilation volumes were in the order of magnitude that could be expected for fish from this size. Because of the uncertainties regarding the kinetics and the fact that fish were sedated and not free swimming, this BCF can only be regarded as supplemental information.

Bioaccumulation factors (BAFs) are expressed as the ratio between concentrations in the organisms and the surrounding water, but also include exposure via diet [6]. In most cases, BAFs are based on field sampling data, but BAFs are sometimes also derived from laboratory experiments. Pacific oysters (*Crassostrea gigas*) were exposed to contamined seawater with a mixture containing PFOS, PFOA, PFDA and PFUnDA at four different salinities (10-34‰) in the absence and presence of contaminated algae [31]. BAFs were between 9.6 and 19.4 L/kg_{wwt}. The study indicates that dietary exposure leads to an increase in accumulation in oysters. Besides that, it was observed that the highest BCF and BAF values were generally observed for the highest salinity. However, for all PFCs these differences were in the order of a factor of 2.

Another laboratory study was performed with green mussels (*Perna viridis*), exposed to two concentrations of PFOS, PFOA, PFNA, PFDA simultaneously [32]. Although only two concentrations were tested, the data showed a concentration dependency and this was supported by fitting the model to a kinetic model in which concentration dependency was incorporated. BCF values for PFOA at 1 and 10 µg/L were 15 and 12 L/kg_{dwt}.

In a study with freshwater zebra mussels (*Dreissena polymorpha*) very low concentrations of PFOS and PFOA were found in mussels, which were exposed to three concentrations of PFOS and PFOA simultaneously [33]. Again, a concentration dependency was found for both PFOS and PFOA over the tested concentrations of 1, 10 and 1000 µg/L. The reported BCF was was high, varying from around 10 L/kg_{wwt} at 1000 µg/L to 400 L/kg_{wwt} or higher in the lowest concentration of 1 µg/L. However, these BAF values appear to be erroneous, which was verified by the authors. The concentrations in mussels are in ng/g_{wwt}, which is just above the LOQ of 0.1 ng/g_{wwt}. The BAF values calculated from the average concentrations in mussels and the time-weighted-average water concentrations are varying from 0.40 L/kg_{wwt} at 1 µg/L to 0.015 L/kg_{wwt} 1000 µg/L.

3.3 Field bioaccumulation data

3.3.1 Overview of field bioaccumulation studies

The SVHC support document summarises the reported field BAFs as being in the range from 0.9 to 292 L/kg [6]. The additional data in the Canadian assessment and the Italian EQS-dossier are generally in the same order of magnitude, but in the latter some higher values are reported too. From the reviews it is not fully clear what is the basis of the reported BAFs. For the derivation of $QS_{biota,\ hh\ food}$ and $QS_{biota,\ secpois}$, wet weight based BAFs for fillet or whole body, respectively, are preferred. Inspection of the cited papers indicates that some reported values for fish refer to liver based BAFs, and both wet and dry weight values are included in the reviews. In addition, mean BAFs reported by authors are taken forward, while data for individual samples or species are available from the original papers. Therefore, the relevant studies were re-evaluated and wet weight based BAFs were derived where possible. BAFs were only considered reliable if reported concentrations in water were representative for the time and place of biota sampling. The studies that were considered reliable or reliable with some restrictions are briefly described here. Study details are presented in Annex 2, the evaluation of the reliability is further explained in the footnotes in this Annex. Table 7 on page 40 summarises the accepted data. Data that were reported as smaller than the LOQ were kept in the data set as LOQ/2 to ensure that the BAF values were not biased towards high values.

3.3.1.1 Two trophic magnifications studies in Lake Taihu, China

In a trophic magnification study from a large freshwater lake in China, phytoplankton, zooplankton, two bivalve species, two shrimp species and ten fish species were sampled in May 2012 in the Meiliang area of Lake Taihu, China [34]. The average water concentration from five sampling points was 30.5 ± 3.0 ng/L. Concentrations were expressed on wet weight basis for muscle of prawns and fish and soft tissues for bivalves. The number of individuals varied from 3 to 60 per species. The obtained BAF values calculated from the tabulated concentrations range from <11 to 13 L/kg_{wwt} from shrimps, <11 to 40 L/kg_{wwt} for bivalves and from 12 to 284 L/kg_{wwt} for fish.

The second study covered the whole area of Lake Taihu [35]. As a result the water concentration was more variable than that from the study mentioned above although the mean was very similar: 28.1 ± 16 ng/L based on 30 samples taken on locations spread over the entire lake. Sampled biota consisted of phytoplankton, zooplankton, zoobenthos (mixed species of molluscs including bivalves and gastropods), one shrimp species, nine fish species and two heron species taken together. Concentrations were expressed on a wet weight basis for whole body homogenate for most species and muscle for some fish species and for the birds. The number of individuals per species varied from 5 to >100 for the shrimp and fish species. The BAF for shrimp was 31 L/kg_{wwt}, the BAF for eight fish species varied from 17 to 66 L/kg_{wwt}. The BAF for the ninth fish species could not be calculated as the concentration in fish was below the limit of quantification and LOQ was not exactly given (0.05-0.30 ng/g for different PFCs).

3.3.1.2 Trophic magnification study in Charleston Harbor and Sarasota Bay, USA

The food chain of the bottlenose dolphin (*Tursiops truncatus*) was examined at two marine locations [36]. Next to plasm of dolphins, six species of fish were sampled at Charleston Harbor, SC, USA in 2002-2003 and 5 fish species at Sarasota Bay, FL, USA in 2004. Although the number of water samples was rather large (18 and 10, respectively), the variability was considerable: 9.5 ± 13 ng/L (mean ± s.d.) at Charleston Harbor and 3.6 ± 9.2 ng/L at Sarasota Bay, which renders the exact value for the BAF to be less certain. The number of individuals ranged from 3 to 11 per species at each location. The concentrations in biota were expessed on a wet weight basis for whole body homogenates. The BAF values that were calculated from the tabulated concentrations ranged from <53 to 189 L/kg$_{wwt}$ for the species from Charleston Harbor and <139 L/kg$_{wwt}$ for all species from Sarasota Bay.

3.3.1.3 Trophic magnification study in Mai Po Marshes Nature Reserve, Hong Kong, China

Phytoplankton, zooplankton, gastropods (mixed species), three different families of worms (with unknown species), two species of shrimps, five species of fish, and two heron species were sampled in a brackish food web (typical salinity of 5 to 16‰) in a nature reserve in the vicinity of Hong Kong [37]. The water concentration of PFOA was 7.69 ± 2.73 ng/L (mean ± s.d.) determined from 12 samples. Concentrations in biota were expressed on a wet weight basis for whole body of all aquatic organisms and liver for the heron species. The number of individuals per species was 2 to 6, with the exception of one small fish species for which 2 pooled samples of 27 individuals each were used. The BAF values were <33 L/kg$_{wwt}$ for the two shrimp species and 17 L/kg$_{wwt}$ for four fish species based on LOQ/2, because the substance was detected in 33 to 50% of the cases and 9 L/kg$_{wwt}$ (LOQ/4) for one species for which the PFOA was not detected at all.

3.3.1.4 Three monitoring studies in the western coastal area of Korea

There are three monitoring studies available from the west coast of Korea covering the years 2008 [38], 2009 [39], and 2010 [40]. From the data presented for biota and water collected in May of 2008 BAF values based on dry weight of <169 and 240 L/kg$_{dwt}$ can be calculated for fillet of striped mullet and rockfish respectively. The concentrations in intestines, liver and gills (the latter only for rockfish) were below detection limit, leading to BAFs of <169 and <82 L/kg$_{dwt}$ for striped mullet and rockfish, respectively [38]. With a default moisture content of 73.7% for whole fish [41] the BAFs for fresh weight fillet are approximately <45 and 63 L/kg$_{wwt}$, for striped mullet and rockfish respectively. BAF for invertebrates, all based on dry weights, vary from <47 to 319 L/kg$_{wwt}$ for molluscs and 22 L/kg$_{wwt}$ for soft tissue of crabs. Based on default moisture contents [41], the fresh weight BAFs are approximately <4 to 27 L/kg$_{wwt}$ for molluscs and 6 L/kg$_{wwt}$ for soft tissue of crabs.

In the study from May 2009 [39] data are only presented per taxon. The fresh weight BAF for fish is 11 L/kg$_{wwt}$ for whole body, 16 L/kg$_{wwt}$ for fillet and 174 L/kg$_{wwt}$ for gills. The BAFs for crabs are 30, 78, 42, and 49 L/kg$_{wwt}$ for whole body, soft tissue, shall and legs, respectively. The BAFs for whole body of gastropods and bivalves (both groups belong to the Mollusca) are 50 and 45 L/kg$_{wwt}$, respectively.

The third study sampled water and biota in May 2010 [40]. This study contains most measurements in biota of the three studies. From the reported concentrations in biota and water from matching locations the BAFs can be calculated. The fresh weight BAFs for fish vary from 32 to 547 L/kg_{wwt} with a geometric mean of 84 L/kg_{wwt}. The corresponding log value of 1.92 is similar to the the mean log value of 1.9 ± 0.40 that is reported in the supplemental materials. The fresh weight BAFs for crab vary from 38 to 4368 L/kg_{wwt} with a geometric mean of 395 L/kg_{wwt} (log value 2.60 corresponds to the reported mean log value of 2.6 ± 0.53). For prawns and shrimp the fresh weight BAFs vary from 3 to 1000 L/kg_{wwt} with a geometric mean of 51 L/kg_{wwt} (log value 1.7 ± 0.87; reported mean log value is 1.8 ± 0.88). The fresh weight BAFs for bivalves vary from 9 to 875 L/kg_{wwt} with a geometric mean of 124 L/kg_{wwt} (log value 2.09 corresponds with the reported mean log value of 2.1 ± 0.77). The fresh weight BAFs for gastropods vary from 15 to 3318 L/kg_{wwt} with a geometric mean of 311 L/kg_{wwt} (reported mean log value in the supplemental materials is 2.5 (2.49) ± 0.79, which can be derived by taking the method detection limit divided by 3 for the non-detected sample). It is remarkable that although all three studies examined the bioaccumulation of PFCs in exactly the same area, there appear to be strong increasing trends in the BAF, especially for crustaceans and molluscs (see Table 5).

Table 5. BAF values for different taxonomic groups from the western coast of Korea during the years 2008, 2009, and 2010 [38-40].

Species	**2008**	**2009**	**2010**
Fish (fillet)	1.56 ± 0.32 [a]	1.05; 1.21	1.92 ± 0.40
Bivalve	0.57 ± 0.30 [a]	1.65 ± 0.20	2.09 ± 0.77
Gastropod	1.10 ± 0.31 [a]	1.70 ± 0.28	2.51 ± 0.76 [a]
Crab (soft tissue)	0.71	1.47 ± 0.64 1.89 ± 0.54	2.60 ± 0.53
Shrimp			1.71 ± 0.87

a: If PFOA was not detected in biota half of the method detection limit was used

The increasing BAF values may be explained by the fluctuating water concentrations. It appears that there is a large variability in the water concentration on each location from year to year (see Figure 1), mostly strongly declining from 2008 to 2012, but this is not observed at all sites. Very high BAF values for low water concentrations might be explained by either the fact that the biota retain PFOA for a longer time and are not reflecting eqluibrium with the water concentrations, or uptake by biota is mainly through sediment and this sediment is not in equiblibrium with the decreasing water concentrations.

However, the higher BAF values at low exposure concentrations correspond with the observations from laboratory tests and other field studies. It appears that for this subset there is an unusual strong dependence of log BAF on log water concentrations, with a slope smaller than minus one, if all data are considered together. This actually would imply that the concentration in biota is independent of the water concentration and could be an indication that the BAF may be hampered by decreasing PFOA concentrations. On the other hand, the range of aqueous concentrations is still rather small (for the BAF values only a factor of 16), which limits the value of the actual slope. However, a

dependency of bioaccumulation and aqueous concentration is clear from these data. Taking into account all these considerations, it was decided not to omit these data, because it is evident that there is a potential for significant accumulation by especially molluscs, a taxonomic group which is not well represented in other studies. It should be realized that the spread in data could be a result from the fact that water concentrations fluctuate in time as well as the fact that BAF values are mainly based on individuals (e.g. a factor of 20 was observed between two individuals from the same species from the same site).

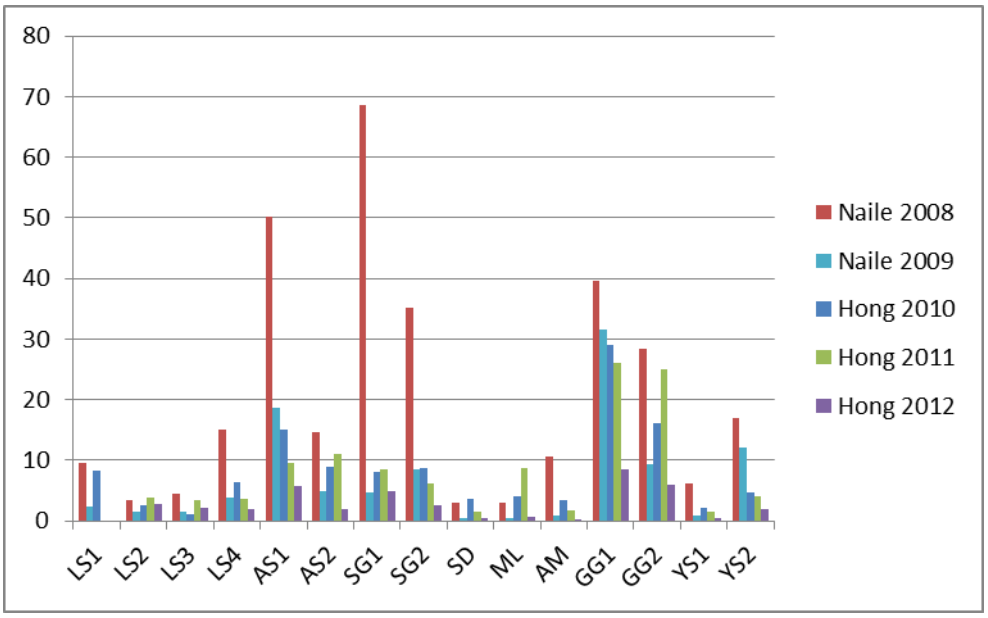


Figure 1. Water concentrations [ng/L] at different sites on the Korean coast as reported in three field bioaccumulation studies [38-40].

3.3.1.5 Two monitoring studies in Lake Baiyangdian, China

In the first study [42], monitoring data from August 2008 are reported for a turtle species, a crab species, a lobster species, a shrimp, seven fish species and three species of water plants. The freshwater lake that consists of several parts has a big difference between the northern part and the southern part of the lake, with the northern part having an average concentration of 31 ± 19 ng/L (geomean 25 ng/L; 10 locations) and the southern part an average concentration of 2.9 ± 1.7 ng/L (geomean 2.6 ng/L). For all species except for the water plants the location of sampling in the lake is fully unknown. Hence, no BAF values can be derived for these species. For the three water plant species dry weight concentrations for 8, 9, and 8 exact locations are given. From these data BAF values can be calculated, which range from 78 to 4600 L/kg_{dwt}. The geometric mean value is 595 L/kg_{dwt}, which corresponds to 111 L/kg_{wwt}, based on wet weight with a default water content for aquatic vegetation of 81.4%.

In the second study from the same lake [43], plankton, a gastropod species, two species of crustaceans, two species of fish, two species of aquatic plants and a bird species were reported. The BAF values for these species are reported as well as the sites where they were sampled. For each site the water concentrations was also reported, which ranged from 6.8 to 56.8 ng/L. These concentrations from October

2010 show the same distribution pattern but tend to be higher than in the first study, especially in the south. The BAF values were expressed on dry weight and were 318 L/kg_{dwt} for the river snail, 211 to 364 L/kg_{dwt} for the crustaceans, 182 to 585 L/kg_{dwt} for the fish species and 407 to 603 L/kg_{dwt} for the aquatic plants. Dry weight contents were not reported, thus default values have been used to recalculate the BAF to wet weight.

3.3.1.6 Monitoring study in Anhui Chinese Alligator Nature Reserve, China

Five fish species and one prawn species were samples in November 2009 from this nature reserve, together with serum from alligators and water [44]. The water concentrations was 5.3 ng/L. The obtained BAF values based on wet weight concentration were 85 L/kg_{wwt} for prawn and varied from 21 to 120 L/kg_{wwt} for four fish species. For common carp the concentration in fish was below the detection limit, which was not reported.

3.3.1.7 Monitoring study in Paraíba do Sul River and Guanabara Bay in Rio de Janeiro, Brasil

One study reports the concentrations of PFCs in several areas in the vicinity of Rio de Janeiro, Brasil [45] and in three fish species, brown mussels (*Perna perna*) and tucuxi dolphins (the latter were archived samples collected along the coast of Rio de Janeiro). PFOA concentrations from two sites in the river were 1.22 ± 0.18 and 1.13 ± 0.72 ng/L. Water concentrations at five sites in Guanabara Bay ranged from 0.77 to 3.24 ng/L. If the BAF values are calculated from the reported liver and water concentrations, the BAFs for scabbardfish and croaker from the Paraíba do Sul River are 494 and 400 L/kg_{wwt}, while the BAFs for scabbardfish, croaker and mullet from Guanabara Bay are 526, 329, and 551 L/kg_{wwt} respectively. The BAFs calculated from the concentrations in mussels and water range from <258 to 2015 L/kg_{wwt}. BAF values for liver of fish and for mussels are reported in the study. The BAF for PFOA in scabbardfish liver from the Paraíba do Sul River is reported as 2.2-11 L/kg_{wwt} while the BAF in liver of croaker from the same area is 18-96 L/kg_{wwt}. The BAFs for PFOA in scabbardfish liver from Guanabara Bay is reported as 1.8-4.4 L/kg_{wwt}, the BAF for liver of croaker from the same area is 0.9-2.8 L/kg_{wwt} and the BAF for liver of mullet from the area is reported as 8.1–14 L/kg_{wwt}. It appears that the BAF for scabbardfish is similar for the two areas, while for the BAF of croaker there is a difference of approximately a factor 30 between the two areas. BAF values for PFOA are also reported for mussels from Guanabara Bay. The reported BAFs range from 63.5 to 266 L/kg_{wwt}.
It is obvious that there is a large discrepancy between the reported BAF values and the ones calculated from the tabulated concentrations, especially for fish (see Table 6). The reason for this discrepancy could not be elucidated. Also for PFOS the reported BAF values were different from the ones calculated from the tabulated data. Another observation is that the concentrations in liver are even lower than in muscle. In several other studies it has been shown that liver concentrations of PFOA are much higher than muscle concentrations. Only the BAF values calculated from the tabulated concentration in the study were further considered in the selection of the BAF for PFOA. The reason for the difference between the reported values for the BAF and the calculated BAF remains unknown.

Table 6. Comparison between reported BAF values and BAF values calculated from tabulated concentrations in biota and water in [45].

Species, location	**BAF [L/kg$_{wwt}$]**	
	Reported	**Calculated**
silver scabbardfish(*Lepidopus caudatus*), Paraíba do Sul River	2.2 – 11	494
whitemouth croaker (*Micropogonias furnieri*), Paraíba do Sul River	18 – 96	400
silver scabbardfish (*Lepidopus caudatus*), Guanabara Bay	1.8 - 4.4	526
whitemouth croaker (*Micropogonias furnieri*), Guanabara Bay	0.9 - 2.8	329
mullet (*Mugil liza*), Guanabara Bay	8.1 – 14	551
brown mussel (*Perna perna*), Guanabara Bay	63.5 – 266	<258 – 2015

3.3.1.8 Monitoring study in the Orbetello lagoon, Italy

A monitoring study was performed in the Orbetello lagoon at the coast of the Tyrrhenian sea in Italy with a salinity between 20 and 35‰ [46]. Aquatic plants (*Alsidium corallinum*, *Chaetomorpha linum*, *Cymodocea nodosa*, *Ruppia cirrhosa*) bivalves (*Mytilus galloprovincialis*, *Ruditapes decussatus*), crustaceans (*Palaemon serratus*, *Carcinus aestuarii*), and fish (*Parablennius* sp., *Zosterisessor ophiocephalus*, *Atherina* sp., *Gobius niger*) were sampled. Water was sampled at 6 locations. Average concentrations of PFOA ranged from 0.73 to 2.03 ng/L. Concentrations in biota were reported on dry weight basis, but moisture content of biota was reported as well. BAFs could be calculated from the concentrations in biota and the water concentrations on the locations where they were caught. On wet weight basis the BAFs varied from 17 to 29 L/kg$_{wwt}$ for plants, from 107 to 198 L/kg$_{wwt}$ for crustaceans, from 80 to 551 L/kg$_{wwt}$ for bivalves, and from 86 to 271 L/kg$_{wwt}$ for fish.

3.3.1.9 Monitoring study in three lakes at Conwallis Island, Canadian Arctic

Juvenile and adult char were sampled in Arctic lakes in the months July and August of the years 2010 and 2011 [47]. In three lakes PFOA could be detected in fish. Two of these lakes were probably impacted by a nearby airfield. Water samples were taken in the same periods. In the three Lakes Meretta, Resolute and 9-Mile, the aqueous concentrations were 17, 9.4 and 0.69 ng/L, respectively. It appeared that one of the juvenile char samples from Lake Resolute contained an extraordinary high concentration of 454 ng/g$_{wwt}$, which was confirmed by contact with the authors. After removing this outlier, the concentrations in juvenile char from the three lakes were 1.51, 0.15 and 0.30 ng/g$_{wwt}$, leading to BAF values of 77, 16, and 435 L/kg$_{wwt}$, respectively. For adult char of the Lakes Meretta and Resolute only muscle concentrations were reported. These were 0.10 and 0.35 ng/g$_{wwt}$ leading to BAF values of 5.9 and 37 L/kg$_{wwt}$, respectively.

3.4 Mechanism of accumulation

From the results presented above, it can be concluded that the BAF values are highly variable and that there may be rather large differences between similar species, e.g. mussels. Further, salinity and exposure concentration seem to influence the height of the BAF values. However, the fact that in one experiment a positive correlation between BAF and salinity was found does not imply that the highest BAF values are found in the marine environment.

There is rather strong evidence that the bioaccumulation potential of PFOA is dependent on the exposure concentration. This has been observed for both fish and bivalves. The bioconcentration studies mentioned above with rainbow trout [28] and carp [18] were modelled by means of a mechanistic compartment model [48]. The protein binding was described by binding to albumin in blood and the interstitial fluids, fatty acid binding proteins (FABPs) in the liver and active renal clearance and reabsorption by organic anion transporters (OAT) proteins in kidney tissue. Although not explicitly mentioned in the study the model is concentration dependent, as it models the protein binding as a function of available binding sites. The mechanistic model (not calibrated to the experimental data) fitted the experimental data rather well.

In freshwater zebra mussels the activity of multixenobiotic transporter (MXR) activity were affected by PFOA (inhibited most of the time, but induced at intermediate concentration of 10 µg/L after 10 days). Above 9 ng/g_{wwt} the accumulated amounts of PFOA and PFOS were inversely related with MXR activity and it was suggested that at high tissue concentrations PFOA was actively excreted by efflux transporters [33]. However, in a study with the cellular efflux transporter p-glycoprotein (p-gp), it was elucidated that this efflux transporter was not directly involved in the excretion by assessing the binding of PFCs to p-gp in the absence and presence of a strong binder (verapamil). As a consequence, the observed effects (including the inhibited MXR activity) might be caused by a general stress response [49]. Indeed the data in zebra mussels [33] confirm that the respiration rate increases with increasing PFC concentration. However, also a negative correlation between MXR activity and PFC concentrations was observed. For the highest exposure concentrations of 1000 µg/L, the MXR activity increased again to almost normal levels at 10 d after a significant decrease of the activity after 1 d of exposure. At the same time, the PFCs concentrations gradually decreased from 1 to 10 d despite the continuous aqueous exposure during this period. This finding supports the hypothesis that the PFC fraction not strongly bound to proteins, i.e. the labile fraction which is higher in the higher exposure concentrations, are detoxicated by MXR activity.
Also for mussels a concentration dependent bioaccumulation model was proposed that includes free binding sites for PFCs (similar to the mechanistic model proposed for fish mentioned above). Taking this concentration dependency into account resulted in the best fit of the experimental data [32].

In conclusion it can be stated that the bioaccumulation of PFOA is concentration dependent. This might partly explain the observed variability in bioconcentration and bioaccumulation factors. The exact mechanism is not known, but from modelling with both fish and mussels, adsorption of PFCs to a limited number of binding sites seems to be a plausible explanation, as well as active regulation by efflux transporters in some organisms. Besides the concentration dependency, bioaccumulation might differ between different species and could be influenced by salinity as well.

3.5 Selection of BAF values

3.5.1 Slope determined on all data per taxonomic group

As expected from the data presented above a concentration dependent bioaccumulation is observed. If laboratory and field data are combined a strong relationship between BCF and BAF and the aqueous exposure concentration is obtained (Figure 2). Individual data for fish, molluscs, crustaceans and aquatic plants all show a concentration dependency.

If data are pooled together for each taxonomic group, the resulting relationship for fish is (Figure 2a):

$\log BAF = -0.449 \log C_w\ [ng/L] + 2.241$, $r^2 = 0.674$, $Sy.x = 0.447$ Eq. 19

Also for molluscs, a correlation between BAF/BCF values and aqueous exposure concentrations is observed (Figure 2b). Although also in this case the relationship is very significant, the variability in individual species is higher than the variability observed for fish, as can be seen from the standard deviation of the residuals (Sy.x) which is more than one and a half times as high:

$\log BAF = -0.614 \log C_w\ [ng/L] + 2.451$, $r^2 = 0.490$, $Sy.x = 0.821$ Eq. 20

For crustaceans (Figure 2c) and aquatic plants (Figure 2d) only field BAF values are available. These data fit into the same pattern observed for fish and molluscs. For crustaceans, the relationship is:

$\log BAF = -0.683 \log C_w\ [ng/L] + 2.567$, $r^2 = 0.184$, $Sy.x = 0.683$ Eq. 21

For aquatic plants and macroalgae, the relationship is:

$\log BAF = -0.564 \log C_w\ [ng/L] + 2.382$, $r^2 = 0.283$, $Sy.x = 0.510$ Eq. 22

Of the obtained relationships, the slope for fish is significantly shallower than the slope for molluscs. From this analysis, it can also be concluded that the variability in BAF for molluscs (data to the left of Figure 2f) is similar to the variability in the BCF values (data to the right), but for fish the variability in BAF values is higher than the variability in BCF values (Figure 2e). The variability in field BAF values could be expected to be higher than of a laboratory data obtained under controlled conditions, but this difference is absent for molluscs.

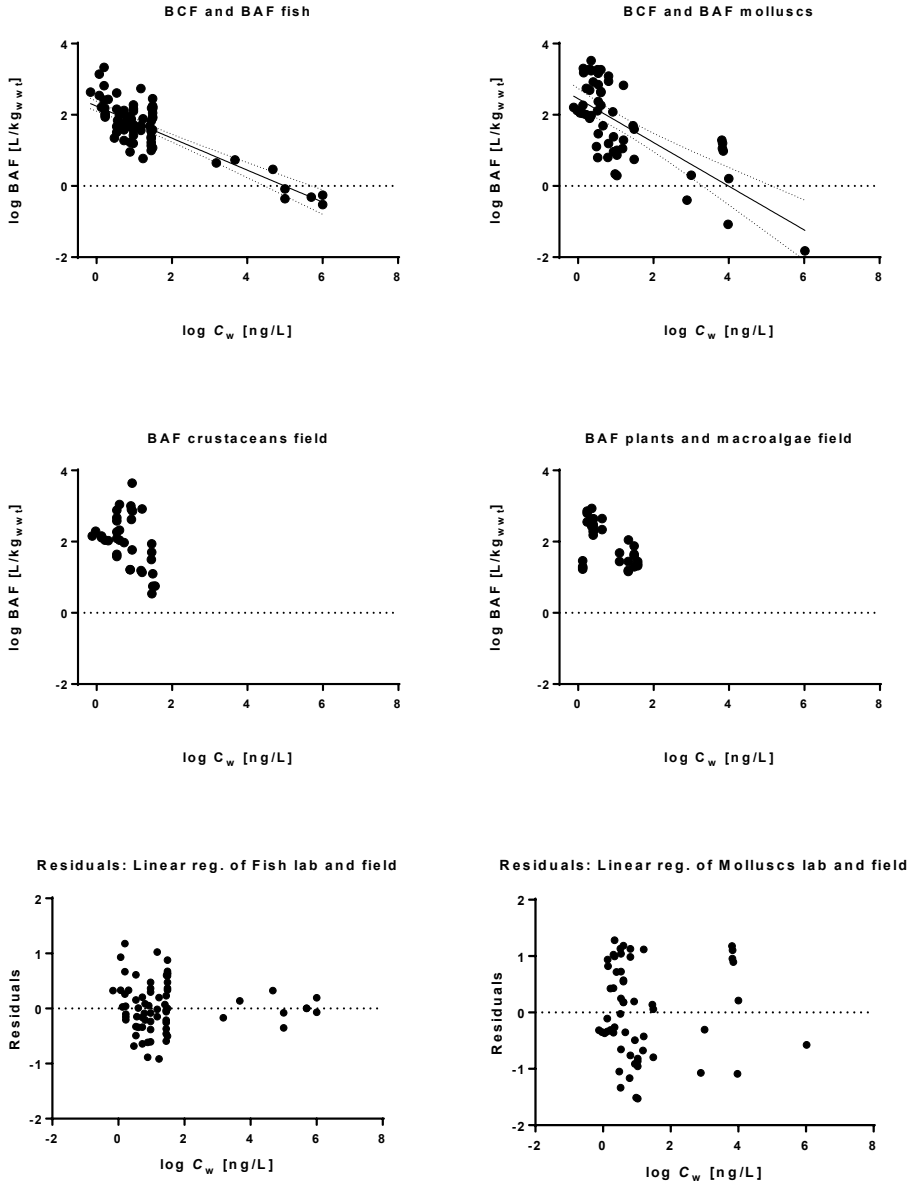


Figure 2. Bioaccumulation as a function of the aqueous exposure concentrations for a) fish b) molluscs c) crustaceans and d) plants and macroalgae. For fish and molluscs field BAF and laboratory BCF have been combined. Residual plots for the linear regression of e) fish and f) molluscs.

For each datapoint the BAF value at the intercept (log C_w = 0, i.e. 1 ng/L) can be calculated with the slope of the regression line for the whole taxon (fish, molluscs, crustaceans, or aquatic plants). In this way, an average log BAF value at 1 ng/L (intercept at log C_w = 0) can be calculated for each species that defines the BAF at other concentrations in combination with the dependence of the BAF on the aqueous concentrations for that specific taxonomic group. The obtained BAF values at 1 ng/L are tabulated in Table 7 (page 40). The species distribution of the BAF values per taxon is shown in Figure 3.

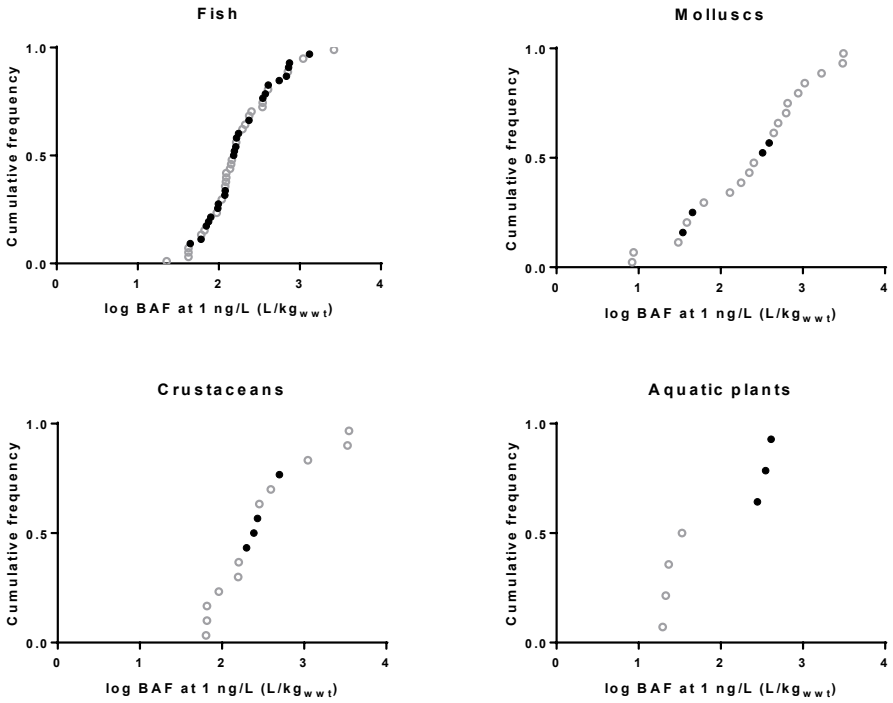


Figure 3. Species distribution of values for log BAF extrapolated to 1 ng/L (species specific intercepts) with the slope obtained by regression of all BAF data vs. aqueous concentration per taxonomic group for a) fish, b) molluscs, c) crustaceans, and d) aquatic plants.

The log BAF values for fish, molluscs and crustaceans follow a normal distribution very well (Anderson-Darling, Kolmogorov-Smirnov, and Cramer von Mises test past at all levels up to 0.1). Of all species per taxonomic group, the average values for log BAF at 1 ng/L are 2.246 for fish, 2.330 for molluscs, 2.453 for crustaceans and 1.874 for aquatic plants. The reason that the values are not the same as the intercepts in Equations 19-22 is that the average value of multiple data for one species is calculated first (apparently the majority of these species have BAF values that are higher than average).

For the same three taxonomic groups (fish, molluscs, and crustaceans) there appears to be no significant differences between freshwater and saltwater and/or brackish species. For this comparison data for saltwater and brackish water were combined. Some freshwater species were sampled in brackish waters. At these locations the salinity could be assumed to be markedly higher than in freshwater (e.g., the tidal shrimp ponds in Mai Po Marshes Nature Reserve in Hong Kong). Therefore, these species were considered as saltwater species. However, the resemblance of freshwater and saltwater data is such that this does not influence the outcome of the statistical comparison.

Only for aquatic plants and macroalgae, there is a significant difference between freshwater and saltwater species. Further, the normal distribution of the BAF values for aquatic plants and macroalgae is rejected at some of the significance levels. However, the meaning of

these findings can be questioned, because the analysis is based on two very small datasets originating from two studies.

3.5.2 *Generic slope based on data for individual species*

Another possibility to assess the concentration dependency of the bioaccumulation, is a regression with data sets per species instead of the whole taxonomic group. In this case, the slope is fixed among all species, while the intercept is allowed to vary. In doing so, it is presumed that the dependence of the bioaccumulation on the exposure concentration is equal for all species (same slope of log BAF vs. log C_w), although the level of bioaccumulation itself may vary between the species (different intercepts (log BAF at 1 ng/L) for each species).

An advantage of this method is the fact that it allows the BAF to be different for different species from the beginning of the analysis. At the same time, a drawback is that only those datasets for each species contribute to the regression of the slope that contain two or more BAF values at different concentrations. However, for many species in Table 7 only one single BAF value is available, and these data would not be accounted for in the regression. This renders the analysis per taxonomic group less meaningful, because of the lack of sufficient data.

With this analysis, the opposite result is obtained as described above: the slope for fish is steeper (-0.509) than the slope for molluscs (-0.192). The slopes for crustaceans and aquatic plants and macroalgae (-0.979) obtained in this way are steeper, possibly due to the limited number of data and the small range in environmental exposure concentrations.

If a regression for all species of all taxonomic groups is performed, a good fit of the data is obtained with a shared slope of -0.428 (Figure 4a; note that here a parallel individual line for each species could be drawn). If the slope is fixed to this value, the resulting equation for all individual data is the following (Figure 4a):

$$\log BAF = -0.428 \log C_w\ [ng/L] + 2.256,\ r^2 = 0.480,\ Sy.x = 0.632 \quad \text{Eq. 23}$$

If the data are treated in this way, there appears to be no significant systematic bias in the residuals of the individual data points for all taxonomic groups: at low and high concentrations the data points are equally distributed along the regression line, as can be seen from the residuals (Figure 4b). Further, the residuals of all combined data are normally distributed. There are no statistical differences between the different taxonomic groups (Figure 4c). There appears to be no statistical difference between the data for freshwater organisms and brackish and marine water organisms (Figure 4d). Normalisation to (mostly default) dry weight contents does not strongly reduce the observed variability, not within groups (except for the aquatic plants and macroalgae) and not at all when all data are considered together. The latter is remarkable, because if dry weight normalisation would result in a reduced variability, this would especially be expressed in a comparison between the taxonomic groups.

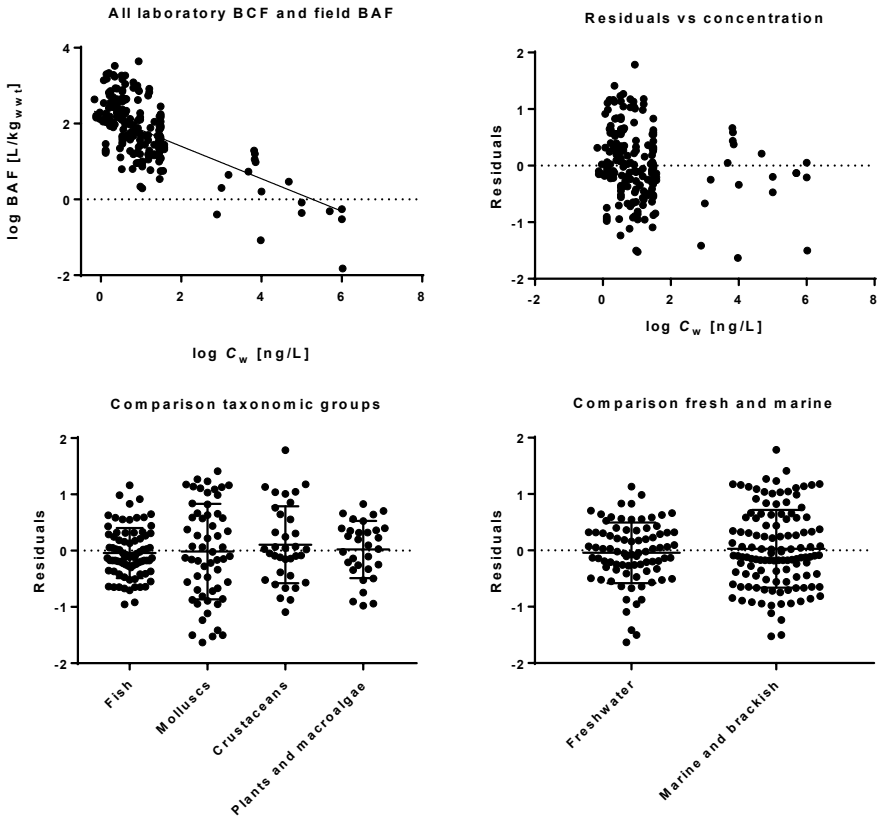


Figure 4. Linear regression of log BCF/BAF values versus log C_w ontained with a generic slope for all species (4a; upper left) with analysis of residuals as a function of exposure concentration (4b; upper right), for each taxonomic group (4c; lower left) and for freshwater and marine or brackish water organisms (4d; lower right).

In this evaluation, each species data set results in a species specific log BAF value at 1 ng/L (intercept at log C_w=0). These data are reported in Table 7 (page 40). Similar to the results obtained with a slope per taxonomic group, it appears that with the generic slope for all species there is no significant difference between freshwater and saltwater species for the taxonomic groups fish, molluscs and crustaceans and for all data together. It appears that there is very little difference in the geometric wet weight BAF values between the different taxonomic groups.

The species distribution of the log BAF values at 1 ng/L are shown in Figure 5 for each of the taxonomic groups. The average log BAF extrapolated to 1 ng/L for the taxonomic groups fish, molluscs, crustaceans and aquatic plants are 2.222, 2.103, 2.226 and 1.814, respectively.

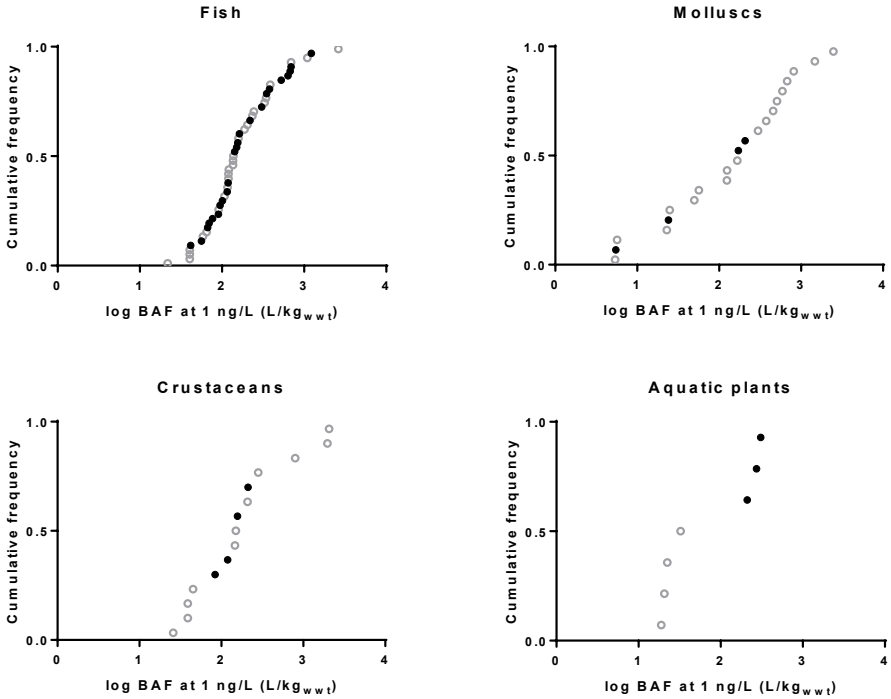


Figure 5. Species distribution of values for log BAF extrapolated to 1 ng/L (species specific intercepts) with a generic slope for all species and species specific intercepts for a) fish, b) molluscs, c) crustaceans, and d) aquatic plants.

3.5.3 *Comparison of both methods and choice for final method*

The use of the generic slope does not lead to a further reduction in the variability of the data.

Interspecies variability

For individual species of fish, molluscs, and crustaceans for which two or more data are available, the variability is reduced by taking a generic slope for all individual data sets in approximately half of the species. For the other half of the species frm these groups, the variability is smaller if a regression is performed on all data combined per taxonomic group. The latter applies to all three species of aquatic plants for which two or more data are available (see Table 7).

Intraspecies variability

Besides that, the variability in species specific BAF values is comparable between both methods for fish. For molluscs and crustaceans, the variability in BAF values per species is slightly smaller for the regression per taxonomic group. However, for aquatic plants this variability is smaller if the generic slope for all individual data sets is used (compare Figure 3 with Figure 5).

Other considerations

Further, the generic slope over all species assumes that the accumulation process, will be similar for all taxonomic groups, which is not a certain (see section 0). Another observation that could be taken into account in selecting the final value, is the fact that the data for fish

show much less variability than for the other taxonomic groups, and especially than for molluscs.

Based on the data presented, both methods seem to perform equally well. For that reason both methods presented above will be considered in the derivation of the $QS_{water, hh food}$, the $QS_{fw, sec pois}$ and the $QS_{sw, sec pois}$.

Table 7. Summary of bioaccumulation factors (BAFs) from field studies combined with bioconcentration factors (BCFs) from laboratory studies. BAFs for fish and crustaceans refer to muscle or whole body, BAFs for molluscs to soft tissue. Study details can be found in Annex 2. Common names according to www.fishbase.org if not provided by authors. For some biota concentrations (reported as <- values), BAF is calculated using the reported limit of detection divided by two.

Common Name	**Latin name**	**Location**	**Y-intercept log BAF at 1 ng/L, slope per taxon**	**Y-intercept log BAF at 1 ng/L, generic slope individual species**	**Ref.**
Freshwater fish					
bighead carp	*Aristichthys nobilis*	CHI, Taihu Lake	2.21	2.18	[35]
crucian carp	*Carassius carassius*	S-KOR west coast; CHI, Anhui Chinese Alligator Nature Reserve	1.85 ± 0.35	1.83 ± 0.34	[40,44]
Japanese white crucian carp	*Carassius cuveiri*	CHI, Taihu Lake	2.57	2.54	[34]
northern snakehead fish	*Channa argus*	CHI, Anhui Chinese Alligator Nature Reserve	1.90	1.89	[44]
Japanese grenadier anchovy	*Coilia ectenes*	CHI, Taihu Lake	2.18	2.15	[35]
lake saury	*Coilia mystus*	CHI, Taihu Lake	3.12	3.09	[34]
goby	*Ctenogobius giurinus*	CHI, Taihu Lake	2.24	2.21	[34]
Mongolian culter	*Culter mongolicus*	CHI, Taihu Lake	2.87	2.84	[34]
common carp	*Cyprinus carpio*	CHI, Taihu Lake; CHI, Lake Baiyangdian; Laboratory	2.54 ± 0.27	2.48 ± 0.28	[18,34,43]
zebrafish	*Danio rerio*	Laboratory	2.19 ± 0.18	2.07 ± 0.17	[25,26]
redfin culter	*Erythroculter ilishaefor*	CHI, Taihu Lake	1.87	1.84	[35]
sharpbelly	*Hemiculter leucisculus*	CHI, Taihu Lake	2.37 ± 0.49	2.34 ± 0.49	[34,35]
silver carp	*Hypophthalmichthys molitrix*	CHI, Taihu Lake; CHI, Anhui Chinese Alligator Nature Reserve	2.22 ± 0.42	2.19 ± 0.42	[34,35,44]
Asian pencil halfbeak	*Hyporhamphus intermedius*	CHI, Taihu Lake	1.65	1.62	[35]

Common Name	**Latin name**	**Location**	**Y-intercept log BAF at 1 ng/L, slope per taxon**	**Y-intercept log BAF at 1 ng/L, generic slope individual species**	**Ref.**
tire track eel	*Mastacembelus armatus*	CHI, Anhui Chinese Alligator Nature Reserve	2.08	2.06	[44]
oriental weatherfish	*Misgurnus anguillicaudatus*	CHI, Taihu Lake; CHI, Lake Baiyangdian	2.86 ± 0.03	2.83 ± 0.03	[34,43]
rainbow trout	*Oncorhynchus mykiss*	Laboratory	2.07	2.01	[28]
yellow catfish	*Pelteobagrus fulvidraco*	CHI, Taihu Lake	1.78	1.75	[35]
clearhead icefish	*Protosalanx hyalocranius*	CHI, Taihu Lake	1.99	1.96	[35]
whitebait	*Reganisalanx brachyrostralis*	CHI, Taihu Lake	2.83	2.80	[34]
paradise goby	*Rhinogobius giurinus*	S-KOR west coast	2.75 ± 0.73	2.72 ± 0.73	[40]
Chinese bitterling	*Rhodeus sinensis Gunther*	CHI, Taihu Lake	2.61	2.58	[34]
Arctic char	*Salvelinus alpinus*	CAN, Arctic, Conwallis Island, Lake Meretta, Resolute and 9-Mile	1.99 ± 0.52	1.98 ± 0.53	[47]
Saltwater fish					
yellowfin goby	Acanthogobius flavimanus	S-KOR west coast	2.08 ± 0.24	2.07 ± 0.24	[40]
javeline goby	Acanthogobius hasta	S-KOR west coast	2.29	2.27	[40]
flag-tailed glass perchlet	Ambassis miops	CHI, Mai Po Marsh	1.36	1.34	[37]
sheephead	Archosargus probatocephalus	USA, Saratosa Bay	2.09	2.08	[36]
silverside sp.	Atherina spp.	IT, Orbetello lagoon	2.04	2.03	[46]
small snakehead	Channa asiatica	CHI, Mai Po Marsh	1.63	1.61	[37]
spotted seatrout	Cynoscion nebulosus	USA, Saratosa Bay; USA, Charleston Harbor	2.40 ± 0.44	2.39 ± 0.44	[36]
ladyfish	Elops saurus	CHI, Mai Po Marsh	1.63	1.61	[37]
black goby	Gobius niger	IT, Orbetello lagoon	2.09	2.08	[46]
fat greenling	Hexagrammos otakii	S-KOR west coast	2.33	2.31	[40]
pinfish	Lagodon rhomboids	USA, Saratosa Bay; USA, Charleston Harbor	1.98 ± 0.16	1.96 ± 0.17	[36]

Common Name	**Latin name**	**Location**	**Y-intercept log BAF at 1 ng/L, slope per taxon**	**Y-intercept log BAF at 1 ng/L, generic slope individual species**	**Ref.**
spotfish	Leiostomus xanthurus	USA, Charleston Harbor	2.16	2.14	[36]
silver scabbardfish	Lepidopus caudatus	BRA, Paraibo do Sul; BRA, Guanabaray Bay	3.04 ± 0.19	3.04 ± 0.19	[45]
whitemouth croaker	Micropogonias furnieri	BRA, Paraibo do Sul; BRA, Guanabaray Bay	2.54 ± 0.05	2.54 ± 0.05	[45]
Atlantic croaker	Micropogonias undulatus	USA, Charleston Harbor	2.61	2.59	[36]
striped Mullet	Mugil cephalus	S-KOR west coast; USA, Saratosa Bay; USA, Charleston Harbor; CHI, Mai Po Marsh	1.78 ± 0.24	1.77 ± 0.24	[36-38]
mullet	Mugil liza	BRA, Guanabaray Bay	3.42	3.42	[45]
mozambique tilapia	*Oreochromis mossambicus*	CHI, Mai Po Marsh	1.63	1.61	[37]
pigfish	*Orthopristis chrysoptera*	USA, Saratosa Bay	2.09	2.08	[36]
combtooth blenny sp.	*Parablennius* spp.	IT, Orbetello lagoon	2.14	2.13	[46]
red drum	*Sciaenops ocellatus*	USA, Charleston Harbor	2.54	2.52	[36]
rockfish	*Sebastes schlegeli*	S-KOR west coast	2.15	2.14	[38]
grass puffer	*Takifugu niphobles*	S-KOR west coast	2.85	2.84	[40]
trident goby	*Tridentiger brevispinis*	S-KOR west coast	2.22 ± 0.26	2.20 ± 0.26	[40]
chameleon goby	*Tridentiger trigonocephalus*	S-KOR west coast	1.82 ± 0.11	1.81 ± 0.11	[40]
grass goby	*Zosterisessor ophiocephalus*	IT, Orbetello lagoon	2.37 ± 0.17	2.37 ± 0.17	[46]
Freshwater molluscs					
zebra mussel	*Dreissena polymorpha*	Laboratory	1.54 ± 0.29	0.74 ± 0.11	[33]
freshwater mussel	*Lamellibranchia* sp.	CHI, Taihu Lake	1.66	1.38	[34]
pearlmussel	*Lamellibranchia* sp.	CHI, Taihu Lake	2.51	2.23	[34]
river snail	*Viviparus*	CHI, Lake Baiyangdian	2.59	2.32	[43]
Saltwater molluscs					
Pacific oyster	*Crassostrea gigas*	Laboratory	3.49 ± 0.13	2.77 ± 0.13	[31]

Common Name	**Latin name**	**Location**	**Y-intercept log BAF at 1 ng/L, slope per taxon**	**Y-intercept log BAF at 1 ng/L, generic slope individual species**	**Ref.**
oyster	*possibly Crassostrea* sp.	S-KOR west coast	1.48 ± 0.34	1.36 ± 0.34	[38,40]
dove snail	Columbellidae	S-KOR west coast	2.65	2.47	[40]
Asian Periwinkle	*Littorina brevicula*	S-KOR west coast	2.35 ± 0.95	2.22 ± 0.98	[38,40]
periwinkle	*Littorina littorea*	S-KOR west coast	3.49	3.39	[40]
lipped periwinkle	*Monodonta labio*	S-KOR west coast	2.94 ± 0.42	2.83 ± 0.41	[40]
blue Mussel	*Mytilus edulis*	S-KOR west coast	0.92	0.73	[38]
Mediterranean mussel	*Mytilus galloprovincialis*	IT, Orbetello lagoon	2.70 ± 0.31	2.66 ± 0.30	[35]
mussel	possibly *Mytilus* sp.	S-KOR west coast	2.25 ± 1.06	2.10 ± 1.12	[38,40]
neritid Gastropod	Neritidae	S-KOR west coast	1.59	1.40	[38]
brown mussel	*Perna perna*	BRA, Guanabaray Bay	3.23 ± 0.46	3.17 ± 0.48	[45]
green mussel	*Perna viridis*	Laboratory	2.40 ± 0.37	1.75 ± 0.23	[32]
sand snail	possibly *Polinices* sp.	S-KOR west coast	1.79	1.70	[40]
grooved carpet shell	*Ruditapes decussatus*	IT, Orbetello lagoon	2.11 ± 0.02	2.09 ± 0.04	[46]
razor clam	*Siliqua patula*	S-KOR west coast	2.80 ± 1.09	2.57 ± 1.09	[40]
surf Clam	*Spisula solida*	S-KOR west coast	0.94	0.76	[38]
blood cockle	*Tegillarca granosa*	S-KOR west coast	2.81 ± 0.88	2.71 ± 0.82	[40]
Manila clam	*Venerupis philippinarum*	S-KOR west coast	3.02	2.91	[40]
Freshwater crustaceans					
Chinese mitten crab	*Eriocheir sinensis*	CHI, Lake Baiyangdian	2.70	2.33	[43]
white shrimp	*Exopalaemon* sp. (*modestus*)	CHI, Taihu Lake	2.30 ± 0.26	1.92 ± 0.27	[34,35,43]
oriental river prawn	*Macrobrachium nipponense*	CHI, Taihu Lake; CHI, Anhui Chinese Alligator Nature Reserve; CHI, Lake Baiyangdian	2.39 ± 0.59	2.08 ± 0.62	[34,44]
lake prawn	*Palaemon paucidens*	S-KOR west coast	2.43 ± 0.77	2.20 ± 0.82	[40], both fresh and marine waters

Common Name	**Latin name**	**Location**	**Y-intercept log BAF at 1 ng/L, slope per taxon**	**Y-intercept log BAF at 1 ng/L, generic slope individual species**	**Ref.**
Saltwater crustaceans					
snapping shrimp	*Alpheus brevicristatus*	S-KOR west coast	1.96	1.65	[40]
crab	*Carcinus aestuarii*	IT, Orbetello lagoon	2.20	2.17	[46]
flat shore crab	*Gaetice depressus*	S-KOR west coast	2.45	2.32	[40]
grapsid crab	*Grapsidae* sp.	S-KOR west coast	3.53	3.29	[40]
penicillate shore crab	*Hemigrapsus penicillatus*	S-KOR west coast	3.55 ± 0.51	3.31 ± 0.47	[40]
sand prawn	*Metapenaeus ensis*	CHI, Mai Po Marsh	1.82	1.59	[37]
beach crab	possibly Ocypodidae sp.	S-KOR west coast	3.05 ± 0.58	2.90 ± 0.56	[40]
hermit crab	*Pagurus* sp.	S-KOR west coast	2.59 ± 0.54	2.45 ± 0.54	[40]
common prawn	*Palaemon serratus*	IT, Orbetello lagoon	2.20 ± 0.08	2.18 ± 0.07	[46]
black tiger prawn	*Penaeus monodon*	CHI, Mai Po Marsh	1.82	1.59	[37]
unknown crab species		S-KOR west coast	1.81	1.41	[38]
Freshwater plants					
coontail	*Ceratophyllum demersum*	CHI, Lake Baiyangdian	2.45 ± 0.32	2.32 ± 0.37	[42,43]
frogbit	*Hydrocharis dubia*	CHI, Lake Baiyangdian	2.54 ± 0.36	2.44 ± 0.42	[42]
floating watermoss	*Salvinia natans*	CHI, Lake Baiyangdian	2.61 ± 0.34	2.49 ± 0.39	[42,43]
Saltwater plants & macroalgae					
red algae	*Alsidium corallinum*	IT, Orbetello lagoon	1.36	1.35	[46]
green algae	*Chaetomorpha linum*	IT, Orbetello lagoon	1.53	1.51	[46]
little Neptune grass	*Cymodocea nodosa*	IT, Orbetello lagoon	1.33	1.31	[46]
spiral ditchgrass	*Ruppia cirrhosa*	IT, Orbetello lagoon	1.29	1.22	[46]

3.6 Trophic magnification in plankton, invertebrates and fish

The BMF is the ratio of the concentration in a predator organism divided by the concentration in its prey. The BMF per trophic level is referred to as TMF, which is the average increase in concentrations per trophic level. There is considerable variation in reported BMFs and TMFs for PFOA. A recent review reports a range of field BMFs of 0.04 to 125, the TMF varies from 0.58 to 13 [50]. One of the factors contributing to the variation is that BMFs and TMFs are expressed in different ways, e.g. based on whole body, tissues, organs or blood. Other factors mentioned by Franklin are exposure to hotspots of contamination, differences in feeding ecology and biological variables. The variation in BMFs is also recognised in the SVHC support document [6], and the difference between gill breathing organisms and marine mammals is emphasised.

According to the SVHC support document [6], gill breathing predatory fish do not show biomagnification of PFOA, whereas marine mammals like dolphins do. Four of the studies included in Table 7 report trophic levels determined by stable isotope analysis [34-37].
Figure 6 shows the log BAFs for pelagic organisms obtained in the present report plotted against the trophic levels. Regression analysis with Graphpad Prism shows that there is no significant relationship between log BAF and trophic level when all data are considered or for fish separately. The data from field studies used in the present report thus confirm the absence of biomagnification in plankton, aquatic invertebrates and fish.

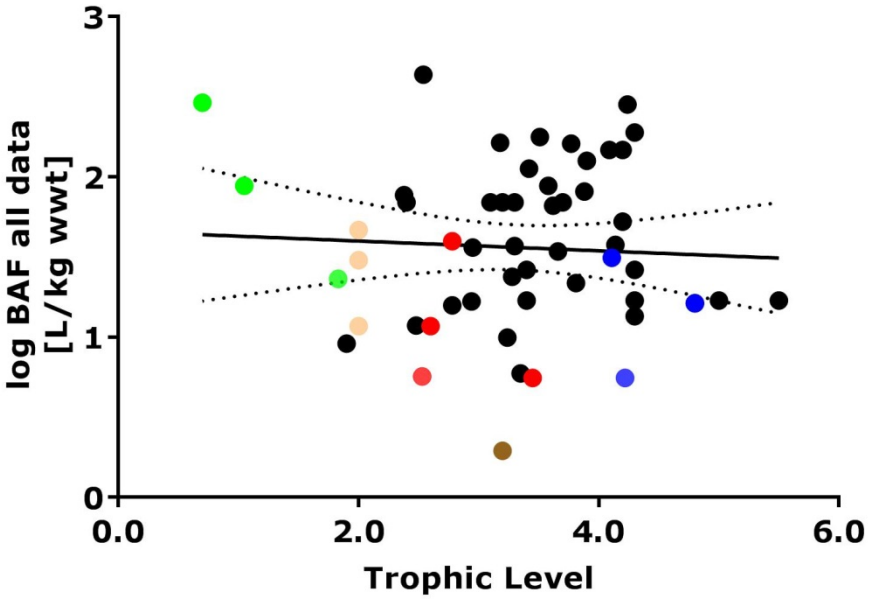


Figure 6. Relationship between reported trophic level and bioaccumulation for fish (black dots), molluscs (red dots), crustaceans (blue dots), phytoplankton (green dots), zooplankton (pink dots), and annelids (brown dot) based on data from field studies discussed in section 3.3. The solid line represents the linear regression, dotted lines are the 95% confidence bands.

It is concluded that for the derivation of the $QS_{water, hh\ food}$ and the $QS_{fw, secpois}$, the BAFs for fish, molluscs and crustaceans of PFOA as a function of aqueous exposure concentration (section 3.5) can be used without further differentiation to trophic level.

3.7 Biomagnification in the marine food chain

For derivation of the $QS_{sw, secpois}$, an additional biomagnification step should be taken into account to protect marine top predators. For this, BAFs representing air-breathing organisms that feed on aquatic organisms would be needed. In the absence of valid BAFs for this trophic level, an estimate should be made for the biomagnification step from aquatic organisms to air-breathing organisms. An overview of the BMF data on birds and mammals is presented in Table 8.

Overall, the quality of the available field studies reporting on BMF values of higher trophic level, air-breathing organisms is relatively low. This is also reflected by the assigned Ri scores. In many studies the BMF values to higher trophic levels are calculated by comparing liver (or muscle) concentrations to whole body concentrations of the prey organism. However, as higher concentrations of PFOA might be expected in protein rich organs like the liver, biomagnification could be overestimated when compared to whole body concentrations of the prey organism.

Butt et al. [51] studied the biomagnification of PFOA from seals to polar bears, using polar bear data from a study by Smithwick et al. [52]. BMF values ranged from 45 to 125 and were determined based on liver concentrations in prey and predator. As stated by the author, biomagnification might be overestimated if based on liver concentrations. Polar bears primarily consume the skin and blubber tissues of ringed seals. Therefore, focusing on liver concentrations might not be representative. In addition, it is known that polar bears do not only consume wild animals, but also gather food at human settlements. Furthermore, the usage of data from another study increases uncertainty as analytical techniques are not totally similar. Considering all the uncertainties, this study cannot be considered as reliable.

In studies from Tomy et al. [53,54], the biomagnification in arctic food webs was determined. These studies included fish-eating mammals (beluga, narwhal, walrus and seals) and birds (glaucous gulls and black-legged kittiwake). In the study published in 2004 [53], most BMF values were determined based on liver-whole body comparisons and the reported BMF values could not be reproduced basis on the provided concentrations. Therefore, this study was considered as not reliable. In the study from 2009 [54], BMF values were deduced from liver concentrations in prey and predator. However, as in the other study, three out of four BMF values could not be reproduced from the reported data and, consequently, were considered as not reliable.

In a study at the Paraíba do sul river in Brazil, biomagnification from croaker and scabbard fish to tucuxi dolphin was investigated [45]. The Paraíba do Sul River is heavily contaminated as it flows through the most important urban and industrial centers in Brazil. The determined BMF values range from 1.3 to 2.6 and are based on liver concentrations.

The dolphin samples were obtained from the Laboratory of Environmental Sciences (CBB) at the University Estadual Norte Fluminense, Brasil who archived the samples. However, the sampling period as well as the sampling location of the archived samples is unclear. In addition, the sampling period of croakers and scabbard fish is not presented. Due to this uncertainty, this study could not be considered as reliable.

Xu et al. [35] and Loi et al. [37] determined trophic magnification factors in food webs in a Chinese lake and reserve, respectively. From their published data, we determined BMF values for the biomagnification from relevant fish species to the analysed bird species (i.e. egrets, grey heron, Chinese pond heron). BMF values were calculated by dividing the concentration in the predator, by the concentration in the prey organism.
Loi et al. [37] analysed liver samples of birds, and livers of large fish were dissected and analysed separately. Published fish concentrations refer to whole body concentrations. Biomagnification can thus only be assessed based on liver concentrations in the herons and whole body concentrations in the fish. Besides that, PFOA occurrence was less than 50% in fish and, as result, reported concentrations seem to be determined by the limit of quantification.
Xu et al. [35] analysed muscle samples of egrets and some fish species. As no prey species of egrets were specified in the article, all fish species for which muscle samples have been analysed are used to derive a BMF value. Fish species which were only analysed on whole body concentrations were not used to derive a BMF value as organ-whole body comparison may overestimate biomagnification (as described above).

Zhou et al. [43] determined PFOA in muscles of the Chinese pond heron (*Ardeola bacchus*) and common carp (*Cyprinus carpio*) simultaneously at four sites in Lake Baiyangdian and reported average concentrations. The BMF value was 0.6. Kelly et al. [55] also derived TMF values, but no BMF values for an arctic food web including eider ducks, white winged scoters and beluga. However, concentrations in fish were determined in a different matrix than concentrations in birds or mammals. Therefore, no relevant BMF values could be derived from this study.

Table 8. Summary of biomagnification factors (BMFs) of higher tier organisms from field studies. Bold BMFs are used in the geometric mean.

Location	Predator			Prey			BMF	Ri	Note	Ref.
	Common name	Latin name	Based on	Common name	Latin name	Based on				
Canada, Arctic	Polar bear	*Ursus maritimus*	Liver	Ringed seal	*Pusa hispida*	Liver	8	3	a	[56]
Canada, Eastern Arctic	Beluga whale	*Delphinapterus leucas*	Liver	Redfish	*Sebastes mentella*	Liver	0.8	3	b,c	[53]
	Beluga whale	*Delphinapterus leucas*	Liver	Cod	*Boreogadus saida*	Whole body	2.7	3		
	Narwhal	*Monodon monoceros*	Liver	Cod	*Boreogadus saida*	Whole body	1.6	3		
	Walrus	*Odobenus rosmarus*	Liver	Clam	*Serripes groenlandica*	Whole body	1.8	3		
	Glaucous gulls	*Larus hyperboreus*	Liver	Cod	*Boreogadus saida*	Whole body	0.6	3		
	Black-legged kittiwake	*Rissa tridactyla*	Liver	Zooplankton	-	Whole body	0.3	3		
USA, Charleston Harbor	Bottlenose Dolphin	*Tursiops truncatus*	Whole body*	striped mullet	*Mugil cephalus*	Whole body	>6.5	2		[36]
	Bottlenose Dolphin	*Tursiops truncatus*	Whole body*	Pinfish	*Lagodon rhomboides*	Whole body	>6.5	2		
	Bottlenose Dolphin	*Tursiops truncatus*	Whole body*	red drum	*Sciaenops ocellatus*	Whole body	**2.7**	2		
	Bottlenose Dolphin	*Tursiops truncatus*	Whole body*	Atlantic croaker	*Micropogonias undulatus*	Whole body	**2.3**	2		
	Bottlenose Dolphin	*Tursiops truncatus*	Whole body*	Spotfish	*Leiostomus xanthurus*	Whole body	**6.4**	2		
	Bottlenose Dolphin	*Tursiops truncatus*	Whole body*	spotted seatrout	*Cynoscion nebulosus*	Whole body	**1.8**	2		
Canada, Arctic	Polar bear	*Ursus maritimus*	Liver	Ringed seal	*Phoca hispida*	Liver	119	3	d	[51]
	Polar bear	*Ursus maritimus*	Liver	Ringed seal	*Phoca hispida*	Liver	125	3	e	

Location	Predator			Prey			BMF	Ri	Note	Ref.
	Common name	**Latin name**	**Based on**	**Common name**	**Latin name**	**Based on**				
	Polar bear	*Ursus maritimus*	Liver	Ringed seal	*Phoca hispida*	Liver	107	3	f	
	Polar bear	*Ursus maritimus*	Liver	Ringed seal	*Phoca hispida*	Liver	45	3	g	
Canada, Western Arctic	Ringed seal	*Phoca hispida*	Liver	Cod	*Boreogadus saida*	Liver	0.1	3	b	[54]
	Beluga	*Delphinapterus leucas*	Liver	Herring	*Clupea pallasi*	Liver	1.3	3		
	Beluga	*Delphinapterus leucas*	Liver	Cisco	*Coregonus autumnalis*	Liver	0.7	3		
	Beluga	*Delphinapterus leucas*	Liver	Cod	*Boreogadus saida*	Liver	0.9	2	c	
Brazil, Rio de Janeiro	Tucuxi dolphin	*Sotalia guianensis*	Liver	Croaker	*Micropogonias furnieri*	Liver	1.3-2.6	3	h	[45]
	Tucuxi dolphin	*Sotalia guianensis*	Liver	Scabbard fish	*Lepidopus caudatus*	Liver		3		
The Netherlands, Westerschelde	Harbour seal	*Phoca vitulina*	-	Herring	-	-	14	4	a	[57]
	Harbour seal	*Phoca vitulina*	-	Sea bass	-	-	23			
	Harbour seal	*Phoca vitulina*	-	Flounder	-	-	3.8			
Canada, Northwest Terretories /Western Nunavat	Wolf	*Canis Lupus*	Liver	Caribou	*Rangifer tarandus groenlandicus*	Liver	0.9	2	i	[58]
	Wolf	*Canis Lupus*	Muscle	Caribou	*Rangifer tarandus groenlandicus*	Muscle	3.8	2	j	
	Wolf	*Canis Lupus*	Muscle	Caribou	*Rangifer tarandus groenlandicus*	Muscle	2.6	2	1	
	Wolf	*Canis Lupus*	Whole body*	Caribou	*Rangifer tarandus groenlandicus*	Whole body*	**2.4**	2	j	
	Wolf	*Canis Lupus*	Whole body*	Caribou	*Rangifer tarandus groenlandicus*	Whole body*	**2.1**	2	i	

Location	Predator			Prey			BMF	Ri	Note	Ref.
	Common name	Latin name	Based on	Common name	Latin name	Based on				
China, Mai Po reserve	Grey heron	*Ardea cinerea*	Liver	Grey mullet	*Mugil cephalus*	Whole body	3.1	3	k, l	[37]
	Grey heron	*Ardea cinerea*	Liver	Mozambique tilapia	*Oreochromis mossambicus*	Whole body	3.1	3		
	Chinese pond heron	*Ardeola bacchus*	Liver	Grey mullet	*Mugil cephalus*	Whole body	5.8	3		
	Chinese pond heron	*Ardeola bacchus*	Liver	Mozambique tilapia	*Oreochromis mossambicus*	Whole body	5.8	3		
China, Taihu lake	Egrets	*Egretta garzetta*	Muscle	Silver carp	*Hypophthalmichthys molitrix*	Muscle	0.9	2	k	[35]
	Egrets	*Egretta garzetta*	Muscle	Bighead carp	*Aristichthys nobilis*	Muscle	1.6	2		
	Egrets	*Egretta garzetta*	Muscle	Asian pencil halfbeak	*Hyporhamphus intermedius*	Muscle	4.4	2		
	Egrets	*Egretta garzetta*	Muscle	Yellowhead catfish	*Pelteobagrus fulvidraco*	Muscle	4.4	2		
Chine, Lake Baiyangdian	Chinese pond heron	*Ardeola bacchus*	Muscle	Common carp	*Cyprinus carpio*	Muscle	0.6	2		[43]

*: estimated
a: data from presentation
b: BMFs could not be recalculated;
c: TL adjusted BMFs
d: origin polar bear unknown; Sublocation: Southeast beaufort sea
e: origin polar bear unknown; Sublocation: Hudson bay
f: origin polar bear unknown; Sublocation: South baffin island and Labrador
g: origin polar bear unknown; Sublocation: High Arctic
h: unclear which value is correct
i: sublocation: Bathorst
j: sublocation: Porcupine
k: BMF is not reported, recalculated based on reported concentrations
l: only for most relevant prey species

3.8 Selection of biomagnification parameters

Many reported BMF values for birds and mammals are based on liver concentrations in these animals and whole body concentrations of their prey. As described in section 3.7, these BMF values may overestimate the BMF values based on whole body concentrations in both prey and predator. Besides the use of organ-whole body comparisons for biomagnification, calculating biomagnification based on organ concentrations in the prey and predator (e.g. liver to liver comparisons) also seem not to be an adequate substitute for the use of whole body levels. Müller et al. [58] and Houde et al. [36] investigated biomagnification in a terrestrial and marine food chain respectively, and both calculated BMF values based on organ- as well as on estimated whole body concentrations. The results indicate that the use of organ concentrations over- or underestimates biomagnification compared to whole body biomagnification. In a recent review [50], various explanations are given: 1) some predators may not consume a specific prey's organ (e.g. liver), 2) a specific organ may represent a varying proportion of overall mass from one organism to another, and 3) if only one organ is analysed, one may neglect substantial contributions of a contaminant from other organs, tissues, or fluids, given the greater mass fractions of the latter, even if their contaminant concentrations are lower.

Overall the reliability of the available biomagnification experiments is limited and studies reporting on biomagnification using whole body concentrations (for prey and predator) seem most reliable. A BMF value of for birds and mammals is derived by calculating a geometric mean value of the reliable whole body-whole body BMF values only (BMF values from [36,58]).

In the study of Houde et al. [36] the concentrations in two prey organisms were below the limit of detection (for the striped mullet and the pinfish). Therefore the author used a concentration of LOD/2 to determine a BMF value of 13. In Table 8, however, we set the BMF value to ">6.5". However, in the final calculation of the BMF these the value of 13 has been used in order not to bias the BMF towards lower values (compare with the BAF derivation, for which this approach was also followed to prevent bias towards to high BAF values).

The $BMF_{b/w}$ values apply to different food chains and thus the food items that were used in the BMF calculation are not similar. The food of dolphins consists of fish, while the food for wolves consisted of caribous. Usually, a normalisation step will be applied to BMF values to express them on the same basis (e.g. lipid normalisation). However, normalisation of perfluorinated compounds is not straightforward, because their accumulation behaviour is different from lipophilic substances. From the pelagic bioaccumulation it was concluded that normalisation to dry weight did not reduce the variability of the data either. Thus, normalisation of PFOA concentrations on dry weight or lipid weight did not seem appropriate. To make a distinction between different food items of which the energy content differs markedly, it was decided to normalise the whole body BMF values to the default energy content of the prey and predator (see Table 2 in section 1.3.3).

This normalisation to energy content assumes that the BMF of PFOA is proportional to the intake. The intake of food items with low energy content is higher to meet the predator's energy requirement. At the same time, this implies that the elimination of PFOA from the predator will be independent of the type of food it consumes. The BMF values reported by Müller et al. [58] refer to $kg_{wwt\ b/m}/kg_{wwt\ b/m}$. Similarly, the BMF values reported by Houde et al. [36] refer to $kg_{wwt\ fish}/kg_{wwt\ b/m}$. These values have been converted to $kg_{wwt\ fish}/kg_{wwt\ b/m}$ for biomagnification from fish or $kg_{wwt\ bivalves}/kg_{wwt\ b/m}$ for bivalves. For derivation of the $QS_{sw,\ secpois}$, a geometric mean $BMF_{b/m}$ value of 4.25 $kg_{wwt\ fish}/kg_{wwt\ b/m}$ has been derived for biomagnification from fish to fish-eating predators and 14.7 $kg_{wwt\ bivalves}/kg_{wwt\ b/m}$ for biomagnification from mussel to mussel-eating predators. These geometric means only consider whole body-whole body BMF values.

If normalisation was performed on default protein contents, the geometric mean $BMF_{b/m}$ values would be somewhat lower: 4.12 $kg_{wwt\ fish}/kg_{wwt\ b/m}$ for biomagnification from fish to fish-eating predators and 7.42 $kg_{wwt\ bivalves}/kg_{wwt\ b/m}$ for biomagnification from mussel to mussel-eating predators. In the calculations for secondary poisoning the more conservative values based on normalisation to energy content have been used. It should be noted that the provisional default values for protein content [59] are not fully in line with the moisture and lipid contents [41], i.e. the sum is greater than 100%.

4 Derivation of human-health based quality standards

4.1 Human toxicological risk limit

In 2016, RIVM derived a new human toxicological risk limit for lifetime exposure [2]. This derivation is based on existing evaluations of international bodies such as the United States Environmental Protection Agency (US EPA) and Agency for Toxic Substances and Disease Registry (ASTDR), the Risk Assessment Committee (RAC) of the European Chemical Agency (ECHA) and the European Food Safety Authority (EFSA). The risk limit is based on liver toxicity as the most sensitive parameter in laboratory animals. PFOA and other perfluorinated compounds typically show large differences in bioaccumulation between experimental animals and humans due to differences in kinetic behaviour. This was only accounted for in a qualitative way in previous evaluations by EFSA and RAC, but was addressed quantitatively in the recent RIVM-derivation. Based on a tolerable level of 89 ng/ml in serum, the new risk limit was set to 0.0125 µg/kg body weight per day (12.5 ng/kg_{bw} per day). This value is a factor of 120 lower than the TDI proposed by EFSA of 1.5 µg/kg_{bw} per day [60], but in line with the Reference Dose (RfD) of 20 ng/kg_{bw} per day reported by the US EPA Office of Water [13,14].

4.2 Quality standard for drinking water abstraction

A health based drinking water limit of 87.5 ng/L was derived by RIVM in March 2016 [1]. The derivation is based on the TDI of 12.5 ng/kg_{bw} per day, a body weight of 70 kg, a daily water consumption of 2 L and assuming that drinking water contributes for at most 20% to the tolerable intake. The value of 87.5 ng/L is in line with the drinking water health advisory value of 70 ng/L derived by the US EPA [14]. The calculation method applied by the US EPA is basically similar to the WFD-methodology, but the US EPA used the RfD of 20 ng/kg_{bw} per day in combination with the 90th percentile consumers only estimate of combined direct and indirect community water ingestion for lactating women [14].

The defaults for body weight and daily water consumption are in accordance with the WFD-guidance, but the latter uses an allocation factor of 10% [3]. However, for the coming revision of the guidance a change to 20% is proposed [9] in line with the approach used by the World Health Organisation (WHO). The drinking water limit of 87.5 ng/L is thus in line with the new WFD-guidance and is adopted as $QS_{dw,\ hh}$.

4.3 Quality standard for human fish consumption

Using Equation 1 (see section 1.3.2), the $QS_{biota,\ hh\ food}$ is calculated as

12.5 x 0.2 / 0.00163 = 1534 ng/kg_{wwt} = 1.53 µg PFOA/kg_{wwt} food.

According to Equation 3, the $QS_{water,\ hh\ food}$ is then calculated by dividing the $QS_{biota,\ hh\ food}$ by the appropriate BAF. Equation 3 cannot be applied as such, because the BAF itself is dependent on the aqueous concentration. Therefore, the following equation is used to calculate

$QS_{water,\ hh\ food}$ (by using Equation 3 and replacing BAF by the quotient of $QS_{biota,\ hh\ food}$ and $QS_{water,\ hh\ food}$):

$$QS_{water,\ hh\ food} = 10^{\frac{\log QS_{biota,\ hh\ food} - \log BAF\ at\ 1\ ng/L}{slope+1}} \qquad \text{Eq. 24}$$

With the slope for all fish data of -0.449 and the average log BAF at 1 ng/L of 2.246 for fish species, the resulting $QS_{water,\ hh\ food}$ is 51 ng/L.

Here it is assumed that the consumption of seafood is restricted to fish only. To gain insight into the consumption of fish, crustaceans and molluscs, the Comprehensive European Food Consumption Database of the European Food Safety Authority (EFSA) was consulted [61]. This database contains results of national food consumption surveys. We used the data of the most recent Dutch food survey, and within the main group 'Fish and other seafood' we selected the mean consumption data for fish meat, crustaceans and molluscs by adults. The other categories in this group (fish products, fish offal and reptiles/ amphibians/ snails) were considered less relevant, or zero consumption was reported. The daily intake is reported as 0.12, 0.02 and 0.01 g/kg_{bw} per day for fish meat, crustaceans and molluscs, respectively, meaning a relative contribution of 81.5, 14.9 and 3.6%. When looking at consumers only, the contribution of crustaceans increases and the figures are 67.4, 30.1 and 2.5% for fish meat, crustaceans and molluscs, respectively. The contribution of fish meat is more or less comparable in all other countries, but the relative contribution of crustaceans and molluscs differs between countries. Generally speaking, the contribution of molluscs is higher in Mediterranean countries, whereas relatively more crustaceans are consumed in the Northern-Europe. When taking the relative contributions of fish, molluscs, and crustaceans into account, the calculated $QS_{water,\ hh\ food}$ are 56 ng/L for the general population pattern and 62 ng/L for the consumers pattern, due to the steeper slope of the relationship between log BAF and C_w for molluscs and crustaceans. It can thus be concluded that the value of 51 ng/L derived from the data for fish only is protective for the consumption of other seafood.

If instead the values obtained with the generic slope are used, the obtained $QS_{water,\ hh\ food}$ is 48 ng/L (49 ng/L for the general public and the consumers patterns). This value obtained by the generic slope of log BAF values per species is very similar to the first value of 51 ng/L with the slope of all log BAF data for fish together.

The value of 48 ng/L is selected as $QS_{water,\ hh\ food}$, because it is the most conservative one but still very comparable to the value based on the data for fish only.

5 Derivation of quality standards for secondary poisoning

5.1 Effects on birds and mammals

For the derivation of the $QS_{secpois}$, data from the Italian EQS-dossier [8], the ECHA restriction dossier [12], the dossiers from the US EPA [13,14] and Environment Canada [7] on the health effects of PFOA were used. Within these publications, toxicity data on six different species were available, including mice, rats, monkeys, rabbits, chickens and quails, of which most experiments have been conducted with mice or rats. Only for mice, rats and monkeys relevant (systemic) toxicity data have been obtained. As a result no species sensitivity distribution could be developed. Table 9 presents an overview of the most relevant critical toxicity endpoint for these species. A full overview of all studies is presented in Annex 3.

Based on the included studies, reprotoxic effects seem to be the most relevant/critical toxicity endpoint for mice. The most critical effects were observed for pregnant mice exposed to PFOA from gestation day 1 to 17 with analysis of the effects on dams and offspring [62]. Highest toxicity was observed on the endpoints litter loss and pup survival (between postnatal day 1 to 22) at a concentration of 0.6 $mg/kg_{bw}/d$ (LOAEL). At a concentration of 0.3 $mg/kg_{bw}/d$ no effects were observed (NOAEL). This dose corresponds to an energy normalised diet concentration of 123 ng/kJ_{diet}. An even higher toxicity was observed on the reprotoxic effects of PFOA on the uterine weight of immature mice at a dose of 0.01 $mg/kg_{bw}/d$ [63], corresponding to an energy normalised diet concentration of 3.1 ng/kJ_{diet}. However, as no dose response effect was observed and the study only considers a short term exposure experiment (3 days), this result is not considered relevant for the effects of secondary poisoning.

The most critical study with rats considers a two generation experiment [64]. Within this study, 6 week old rats were exposed for at least 70 days prior to mating, until sacrifice (after mating for male rats and after weaning for female rats). F1 offspring were similarly exposed as the P-generation and the experiment ended after weaning (PND 22) of the F2-generation. The most critical relevant (i.e. systemic) effect was a decreased body weight in the F1-generation males at sacrifice, with a LOAEL of 0.96 $mg_{PFOA}/kg_{bw}/d$, corresponding to an energy normalised diet concentration of 880 ng/kJ_{diet}. Within this study, no NOAEL could be determined. As it is difficult to determine when a decreased body weight can be considered as a population relevant effect, the same data have been used to calculate a LBMD10 of 1.5 $mg/kg_{bw}/d$ on body weight change [64]. This LBMD10 is equal to an energy normalised diet concentration of 1360 ng/kJ_{diet}. Besides the two-generation study, a NOAEL for decreased body weight of 0.96 $mg/kg_{bw}/d$ has been derived from two short-term exposure studies of 28 days [65]. These NOAELs correspond to an energy normalised diet concentration of 830 ng/kJ_{diet} and 850 ng/kJ_{diet}.

Table 9. Overview of critical toxicity data for mammals used for the derivation of the $QS_{biota,\ secpois}$. Studies were performed with the ammoniumsalt APFO, result are expressed on the basis of PFOA. GD = gestational day; BW = body weight; C_{norm} = energy normalised effect value; AF = assessment factor based on study type; $C_{norm,\ AF}$ = energy normalised effect concentration including assessment factor.

Species	**BW [g]**	**Test compound**	**Route**	**Exposure duration**	**Observed effect**	**Criterion**	**Value PFOA [mg/kg$_{bw}$.d]**	**C_{norm} [mg/kJ]**	**AF**	**$C_{norm,\ AF}$ [mg/kJ]**	**Ref.**
Mice	30.9	APFO	oral	GD1-17	litter loss and pup survival	NOAEL	0.3	0.00012	3	0.000041	[62]
Rats	500	APFO	oral	2 gen.	body weight change (F1)	LBMD10	1.5	0.00136	1	0.00136	[64] in [66]
Monkey	3850	APFO	oral	182 d	body weight change	LBMD10	10	0.01617	3	0.005389	[67] in [66]

Although lower energy normalised concentrations are derived in these short-term exposure studies, it is assumed that the LBMD10 can be considered as protective as it concerns a population relevant effect after chronic exposure. This is partially supported by the EC10 values, which have been calculated for these three studies (using Graphpad [68]), indicating a higher toxicity (lower EC10 value) for the chronic exposure study (see Annex 3).

A decreased body weight is the most critical effect observed in monkeys [67]. Similar to the effects in rats, also for the effects in monkeys an LBMD10 has been derived of 10 $mg/kg_{bw}/d$ corresponding to an energy normalised diet concentration of 16 $\mu g/kJ_{diet}$ [66].

Besides experiments with mice, rats and monkeys, some studies have been conducted with rabbits, chickens and quails. However, no relevant systemic effects have been observed in these organisms. These studies focus on more specific effects (e.g. immune response) and/or did not observed (dose-response) effects on general toxicity outcomes like body weight. One study with quails was available, indicating strong effects of 8 weeks PFOA exposure on growth rate [69]. Growth rate was increased at 0.2 $mg/kg_{bw}/d$ (LOAEL), and no no-effect concentration was determined. However, no clear dose-response effects were observed and quails were challenged with a moderately pathogenic *Escherichia coli* infection at week six of PFOA exposure. Therefore, this study has not been used in the derivation of a QS for secondary poisoning.

After application of an assessment factor to account for exposure time to the most critical study per species, mice seems to be most susceptible to PFOA exposure. Therefore, this study has been used to derive a QS for secondary poisoning. The applied assessment factor is 3 because of the relative short-term exposure. This leads to a critical energy normalised NOEC of 41 ng/kJ_{diet}.

5.2 Derivation of the $QS_{biota, secpois}$

For the derivation of the $QS_{biota, secpois}$, the most critical energy normalised effect concentration has been converted to concentrations in the critical food item (see section 1.3.3), to which an assessment factor of 10 is applied to extrapolate from the most sensitive tested species to all predators in the whole ecosystem. For fish and molluscs, the $QS_{biota, sec\ pois, fw}$ is 23 and 6.5 $\mu g/kg_{wwt}$, respectively.

For the marine food chain an additional step is considered in the food chain, since predators like birds and mammals could be eaten by a top predator (like killer whales and polar bears). Birds and mammals are the most critical food item for the marine food chain as the biomagnification factor to these birds and mammals is above 1 (geometric mean $BMF_{b/m}$ = 4.3 and 15, for accumulation from fish and molluscs, respectively, to birds or mammals; section 3.7). As a result the $QS_{biota, secpois, sw}$ should be stricter compared to the $QS_{biota, secpois, fw}$. A $QS_{biota, secpois, sw}$ of 7.0 and 2.0 $\mu g/kg_{wwt}$ in fish and mussels, respectively, was derived by dividing the equivalent concentration in birds and mammals (the most critical food-item) by the $BMF_{b/m}$ for fish and mussels. If the default protein contents instead of default energy contents for the groups mussels, fish

and birds and mammals would have been used to normalize the BMF values, $QS_{biota, secpois, sw}$ would be 7.3 and 4.0 µg/kg_{wwt} in fish and mussels, respectively.

5.3 Derivation of the $QS_{fw, secpois}$ and $QS_{sw, secpois}$

The critical food item follows from the ratio of the bioaccumulation factor and the energy content of the food items in the food chain. Because the bioaccumulation factor is dependent on the aqueous concentration and not the same for the different taxonomic groups, a comparison between the outcome of the scenarios is made first. For the freshwater food chain, fish appear to be the most critical food item if the regression of all data per taxonomic group is used. The corresponding value for $QS_{water, sec pois, fw}$ is 6700 ng/L. However, if the regression of the generic slope for individual species is used, the $QS_{water, sec pois, fw}$ for molluscs is 990 ng/L, and thus substantially lower than the value for fish.

For the marine environment, the $QS_{water, sec pois, sw}$ are 810 and 370 ng/L for fish and molluscs, respectively, if the BAF is based on all data per taxonomic group. However, similar as for the freshwater compartment, the lowest value is obtained for molluscs if the regression of the generic slope for individual species is used. The resulting $QS_{water, sec pois, sw}$ = 130 ng/L. For comparison, with a $BMF_{b/m}$ normalized to standard protein content, the $QS_{water, sec pois, sw}$ would have been 420 ng/L.

6 Derivation of quality standards for direct ecotoxicity

6.1 Ecotoxicological effect data

6.1.1 Laboratory toxicity data

As indicated in section 1.3.4, data from the Italian EQS-dossier [8] were used for the present assessment. A detailed description of the Italian dataset is presented in the Supplementary Information to that publication. The literature screening resulted in a few additional studies. Study details and evaluation are presented in the data tables in Annex 4. The Italian data are copied in the Annex and additional information collected for the present report is indicated in red. The valid acute laboratory ecotoxicity data for freshwater and marine organisms are summarised in Table 10. Chronic data are presented in Table 11. Marine species are organisms that are representative for marine and brackish water environments and that are tested in water with salinity >0.5 ‰. The tables list the lowest relevant endpoint per species, or the geometric mean if multiple reliable values are available for the same combination of species and endpoint.

In a few cases, the interpretation of test results differs from the Italian EQS-dossier, and this influences the selected endpoint for some species:

- Studies with fertilised fish eggs or embryo's are short term studies, but in view of the life stage and endpoints, the test results are considered as chronic. This means that the NOEC or EC10 values of these test are included in the chronic dataset. In the Italian dossier, the EC50 is used as an acute test result.
- Reliable results are available for photosynthesis inhibition in the algae *Pseudokirchneriella subcapitata* measured by pulse amplitude modulated fluorometry (PAM) in a 4.5 hours test [70]. The relationship of this endpoint with population level effects measured in 'traditional' algae studies is not clear as yet. Because other algae data are available, the result is not included in the dataset.
- In the Italian dossier, the acute toxicity data from Li [71] are considered not reliable. Main reasons were that the temperature in the *Daphnia* test was higher than allowed according to OECD 202, and the validity criteria of the other tests could not be verified because the test guideline was not available. Besides, nominal test concentrations were used whereas test substance stability was considered not be guaranteed in view of the 96-hours exposure time. This study was already evaluated in the context of the EQS-derivation of PFOS and considered reliable with restrictions [15]. The study was checked again and Ri 2 was assigned in line with that assessment becausecontrol mortality was acceptable (10% for shrimp, no mortality for the other organisms) and stability is not considered an issue for PFOA.
- Microcosm data for fish [72], zooplankton [73,74], and macrophytes [75] are included in the OECD SIDS report [4]. The results of these studies are not included in the laboratory datatables, but are discussed separately in section 6.1.2. The fish study is critical in the Italian EQS-derivation.

Table 10. Acute laboratory ecotoxicity data for freshwater and marine organisms. Endpoints per species are based on the valid data in the Italian EQS-dossier and additional studies collected for the present report. Study details are given in Annex 4.

Taxon	**Species**	**Duration**	**Endpoint**	**Criterion**	**Value [mg/L]**	**Remark**
Freshwater						
Cyanobacteria	*Anabaena*	24 h	Bioluminescence	EC50	39.53	geometric mean of 19.81 and 78.88
	Geitlerinema amphibium	72 h	Biomass	EC50	247.8	
Algae	*Chlamydomonas reinhardtii*	96 h	growth inhibition	EC50	51.9	
	Chlorella vulgaris	72 h	Biomass	EC50	974.82	
	Pseudokirchneriella subcapitata	72 h	growth rate	EC50	> 100	
	Scenedesmus obliquus	96 h	growth inhibition	EC50	44	
	Scenedesmus quadricauda	96 h	growth inhibition	EC50	269.63	
Crustacea	*Chydorus sphaericus*	48 h	Immobilisation	EC50	103.0	geometric mean of 116.48 and 91.1, most relevant test duration
	Daphnia magna	48 h	Immobilisation	EC50	305.7	geometric mean of 476.52, 480, 211.07 and 181
	Macrobrachium nipponense	96 h	Mortality	LC50	201.85	
	Moina macrocopa	48 h	Immobilisation	EC50	366.66	most relevant test duration
	Neocaridina denticulata	96 h	Mortality	LC50	454	most sensitive test duration
Rotifera	*Brachionus calyciflorus*	24 h	Mortality	LC50	150	
Insecta	*Chironomus plumosus*	96 h	Mortality	LC50	402.24	
Gastropoda	*Cipangopaludina cathayensis*	96 h	Mortality	LC50	740.07	
	Physa acuta	96 h	Mortality	LC50	672	most sensitive test duration
Mollusca	*Lampsilis siliquoidea*	96 h	Mortality	LC50	>500	lowest relevant endpoint
	Ligumia recta	96 h	Mortality	LC50	>500	lowest relevant endpoint
Platylhelminthes	*Dugesia japonica*	96 h	Mortality	LC50	392.9	geometric mean of 458 and 337, most sensitive test duration
Annelida	*Limnodrilus hoffmeisteri*[a]	96 h	Mortality	LC50	568.2	
Amphibia	*Bufo gargarizans*	96 h	Mortality	LC50	114.74	
Pisces	*Carassius auratus*	96 h	Mortality	LC50	606.61	
	Cyprinus carpio	96 h	mortality	LC50	> 55.6	

Taxon	Species	Duration	Endpoint	Criterion	Value [mg/L]	Remark
	Oncorhynchus mykiss	96 h	mortality	LC50	752.1	geometric mean of 707 and 800
	Pseudorasbora parva	96 h	mortality	LC50	365.02	
marine organisms						
Algae	*Isochrysis galbana*	72 h	growth inhibition	EC50	163.6	
	Skeletonema marinoi	72 h	Biomass	EC50	367.52	
Crustacea	*Sirella armata*	96 h	Mortality	LC50	15.5	
Echinodermata	*Paracentrotus lividus*	48 h	growth inhibition	EC50	110	
Pisces	*Psetta maxima*	144 h	Mortality	LC50	11.9	

a: species is indicated as marine species in some internet sources, but was tested in freshwater

Table 11. Chronic laboratory ecotoxicity data for freshwater and marine organisms. Endpoints per species are based on the valid data in the Italian EQS-dossier and additional studies collected for the present report. Study details are given in Annex 4.

Taxon	Species	Duration	Endpoint	Criterion	Value [mg/L]	Remark
Freshwater						
Cyanobacteria	*Anabaena*	24 h	bioluminescence	EC10	49.05	EC10 preferred over NOEC
Algae	*Pseudokirchneriella subcapitata*	96 h	growth rate, biomass	NOEC	12.5	lowest endpoint for relevant test duration
Crustacea	*Daphnia magna*	21 d	Reproduction	EC10	7.02	lowest endpoint for relevant test duration (21 d)
	Moina macrocopa	7 d	Reproduction	NOEC	3.125	
Rotifera	*Brachionus calyciflorus*	4 d	intrinsic rate of population increase	NOEC	4	most relevant endpoint
Amphibia	*Bufo gargarizans*	30 d	Mortality	LC10	5.89	
Pisces	*Danio rerio*	120 h	Malformations	NOEC	≥ 33	test with fertilised eggs
	Gobiocypris rarus	28 d	adverse effects	NOEC	≥ 30	
	Oncorhynchus mykiss	85 d	mortality, growth	NOEC	40	
	Pseudorasbora parva	30 d	mortality	LC10	11.78	
marine organisms						
Algae	*Isochrysis galbana*	72 h	growth inhibition	EC10	41.6	EC10 preferred over NOEC

As can be seen from the tables, the acute L(E)C50 range from 12 to about 750 mg/L, whereas chronic NOEC or EC10 values are in the low mg/L range.

In addition to the studies listed in the table above, a very low NOEC of 0.01 µg/L is available for the marine mussel *Mytilus galloprovincialis*. This value was derived in a short-term test [76], but in view of the life-stage and endpoints considered, it may be considered as a chronic test result. The NOEC is based on a 17% decline in the number of D-shaped veliger larvae produced within 48 hours at 0.1 µg/L as compared to the control. The maximum effect was about 40% decline with no clear increase in effect between 100 and 1000 µg/L. There was no significant difference in shell malformations. In a positive control with $CuCl_2$, the number of D-shaped larvae declined to 0 after 48 hours at 40 µg Cu^{2+}/L. The test conditions were such that ≥80% of the control embryos reached the D-shaped stage within 48 hours, and a decrease in numbers indicates a delay in larval development. It is not clear if this delay in development is temporary, and it is thus not fully clear how the effect should be interpreted in terms of development success. In a study with PFOS, it was shown that long-term exposure of female brooding mussels decreased the duration of viability of larvae (glochidiae) at much lower concentrations than when free larvae were exposed [77]. This may indicate that early developmental stages are more sensitive than later ones. Unfortunately, no long-term tests with PFOA are available for mussels. In view of the uncertainties in the interpretation of the NOEC, the result as such is not included in the EQS-derivation, but will be taken into account in the choice of the assessment factor.

6.1.2 Microcosm studies

Three microcosm studies are available, with fish [72], zooplankton [73,74] and macrophytes [75]. Summaries of the studies are included in the OECD SIDS dossier [4], relevant parts are presented here and information from the original publications is added where necessary.

6.1.2.1 Fish

The fish study [72] investigated reproductive impairment and biochemical changes in fathead minnow (*Pimephales promelas*) exposed for 39 days to 0, 0.3, 1.0, 30, and 100 mg PFOA/L in microcosms. Mean measured exposure concentrations were 0.27, 0.65, 23.9, and 74.1 mg/L. Microcosms consisted of steel panels (Ø 3.9 m, depth 1.2 m) with sediment trays and potted macrophytes (*Myriophyllum spicatum*). Three replicate cosms were used per treatment, breeding pairs of fathead minnow were held in two cages per microcosm. Each cage was divided into four quadrants, and each quadrant contained a single breeding pair for a total of 16 fish per microcosm. A cut PVC-pipe served as breeding substrate within each quadrant and was examined for egg deposition daily. Both egg production and oviposition (spawning) frequency were recorded with the subsequent calculation of egg and oviposition frequency per female, per microcosm, and cumulatively per dose. After 39 days of exposure, fish blood samples were taken and fish were sacrificed. Length, weight, gonad and liver weight were determined and livers and gonads were analysed for biochemical assays.

PFOA exposure did not result in fish mortality, the NOEC for survival was greater than 100 mg/L. Modest changes were observed in condition factor and in relative liver and gonad size. Time to first oviposition was significantly increased in fish exposed to 100 mg/L relative to 0.3 and 1.0 mg/L, but was not significantly different from the control and 30 mg/L treatment. The NOEC for this endpoint was reported as 50 mg/L in the OECD SIDS dossier [4], but in view of the exposure concentrations, this should read 30 mg/L. No changes were observed in total oviposition events or mean oviposition events per female, eggs produced per female or mean egg production per microcosm. The authors indicate that a trend was observed toward reduced cumulative egg production across all microcosms, with ≈40% reduction at 100 mg/L as compared to the control. However, visual inspection of the data on this parameter (see figure below) suggests that an effect is present at 1 mg/L and higher.

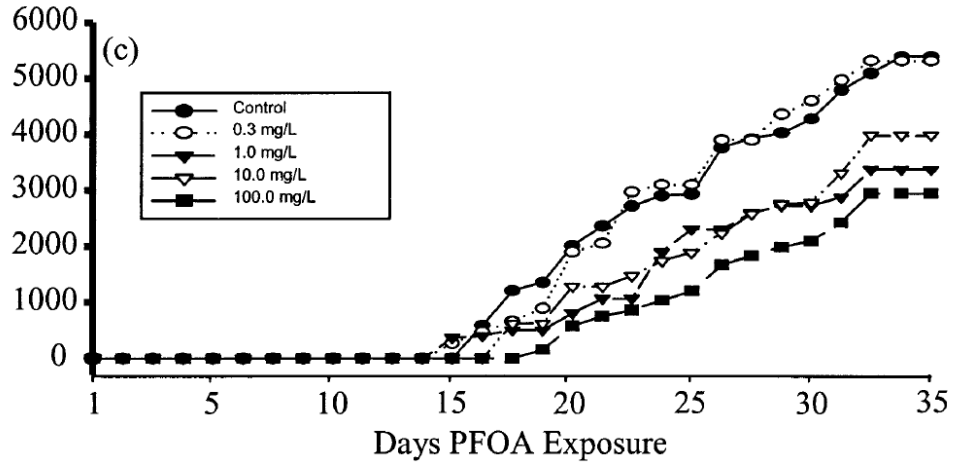


Figure 7. Cumulative egg production of Pimephales promelas during 35 days exposure to PFOA in outdoor microcosms. Figure copied from [72].

Significant declines in circulating plasma steroids were observed at 1 mg/L and higher. The OECD SIDS dossier reports a NOEC of 0.3 mg/L for male plasma 11-ketotestosterone and testosterone, which is listed as the critical endpoint in the Italian EQS-dossier [8]. Changes in male sex hormones may be an indication for endocrine disrupting properties of PFOA. According to the WFD-guidance [3], the EQS-derivation should be based on endpoints for wich a relationship with population level effects is apparent. In case of indications of endocrine disruption, it should be considered whether the assessment factor would be sufficient to protect against effects caused by such a mode of action, or whether a larger factor is needed. Following the guidance, a NOEC for plasma hormone level would probably not be used directly for the EQS-derivation, but should be considered in the choice of the assessment factor. However, in view of the observed decrease in cumulative egg production at 1 mg/L and higher, it is considered justified to set the NOEC for *P. promelas* at the treatment level of 0.3 mg/L. Actual concentrations were close to nominal at this level. Since fish were kept in cages, interactions with other species are limited and the experiment may be considered as a single species outdoor bioassay. The results are used for derivation of the AA-QS.

6.1.2.2 Macrophytes

The study with plants investigated the effects of PFOA on sediment potted *Myriophyllum spicatum* and *M. sibiricum* [75]. The experiment was performed in the same microcosm facility as the fish study. Three replicate microcosms were treated with 0, 0.3, 1, 30, and 100 mg PFOA/L and assessed at regular intervals over 35 days. The reported actual PFOA concentrations in this study are the same as reported above for the fish study, which indicates that the experiments were performed in parallel, and the same cosms were used for analytical sampling. From the description of the fish study, it is clear that *M. spicatum* was present in the fish-microcosms, but the macrophyte study does not report any information on the presence of fish. It is therefore assumed that the macrophyte study was performed in different cosms than the fish study. No statistically significant differences or concentration-response trends were noted after 7 days of exposure to PFOA in both macrophyte species. Dose-response relationships for several endpoints could be established over the time-period 14 to 35 days. The lowest reported NOEC is 23.9 mg/L for several endpoints in both species (length, biomass, root length, etc.). The EC10 as reported in the OECD SIDS dossier are 5.7 mg/L for length of *M. spicatum* after 14 days, and 8.4 mg/L for root length of *M. sibiricum* after 21 days [4]. The latter value was derived from a regression line with a poor fit. When only selecting the values from fits with $r^2 \geq 0.8$, the lowest EC10 values were the above mentioned 14-days EC10 of 5.7 mg/L for *M. spicatum*, and the 35-days EC10 of 7.8 mg/L for node number of *M. sibiricum*. In the Italian dossier, only the 35-days NOEC and EC10 values are selected. In principle, 7- or 14-days EC50 from macrophyte studies may be used as acute toxicity values. The 14-days EC50 values were all derived from fits with low regression coefficients, but it can be concluded that the 7-days EC50 is higher than 100 mg/L (74.1 mg/L actual). Similar to the fish study, the experiment may be considered as a single species outdoor bioassay and the results are used in this way.

6.1.2.3 Zooplankton

The zooplankton study was performed in indoor microcosms [73,74]. Natural pond water was added to 30 L PVC aquariums with sediment. The zooplankton community consisted of following representative species: *Cyclops diaptomus*, *Cyclops strenuus*, *Cyclops canthocamptus staphylinus* , *Daphnia magna*, *Keratella quadrata*, *Phyllopoda sp., Echninorhynchus* sp., *Ostracoda* sp., and total *Rotifera* sp. In addition to zooplankton and pond snails, occasional macrophytes (*Elodea canadansis* and *Myriophyllum spicatum*) and larger invertebrates (*Ephemeroptera* sp., *Assellus aquaticus*) were present. *Scenedesmus acutus* (100 mL of 10 cells/mL concentrated algae) was added each week as a supplementary food supply to each aquarium. After a stabilisation period of 4 weeks, PFOA was added to the water and hand mixed in the aquariums, nominal concentrations were 0 (control), 1, 10, 20, 30, and 70 mg/L. Biological sampling was performed 24 hours before dosing, and 1, 2, 4, 7, 14, 21, 28 and 35 days post-treatment. Modified zooplankton funnel traps were used for pelagic sampling. Traps were suspended 3 cm above the sediment floor in the middle of the aquariums, animals were trapped during their cyclic vertical migration. Test conditions: 12:12 hours L:D, 19 °C, DO 6 mg/L.

Water samples were taken from the 10, 20 and 30 mg/L treatments at the start and end of the study. Measured concentrations were between 106 and 183% of nominal at the start of the experiment and between 76 and 107% of nominal after 35 days. The deviation from nominal concentrations at the start is probably due to insufficient mixing.

Fluctuations in zooplankton abundance were observed, however, a NOEC could not be calculated. LOECs for various species varied between 10 and 70 mg/L. Total zooplankton abundance was significantly increased at 1, 10, 20, and 30 mg/L, but not at 70 mg/L. However, the overall species richness was significantly reduced at 10, 30, and 70 mg/L indicating a simplification of the community structure. This was seen with a shift from a more diverse community with more total zooplankton species towards less richness where it was dominated by smaller zooplankton species (*Rotifera* sp.). According to the authors, high variability within treatments impeded the probability of detecting significant changes and decreasing statistical power of the study. Hence, a total community NOEC was not determined [73]. In a follow-up, based on a further analysis of data it is stated that a tentative LOEC for the community with questionable ecological significance could be set in the range from 30 to 70 mg/L. Sensitivity decreased from cladocerans to copepods to rotifers [74]. The lower sensitivity of rotifers as compared to cladocerans observed in the microcosm study is not in line with the laboratory data which suggest that the rotifer *Brachionus calyciflorus* is relatively sensitive towards PFOA. Due to the uncertainty in actual exposure concentrations and the limited statistical power, the results of this microcosm experiment are not further considered for EQS-derivation.

6.2 Pooling of freshwater and marine effect data

According to the WFD-guidance, ecotoxicity data for freshwater and marine species should be pooled for organic compounds, if statistical comparison of data shows that both datasets are not significantly different. There are only few marine ecotoxicity data, and a comparison can only be made for the acute data. In line with the guidance, datasets were compared after log-transformation of the individual data per species from Table 10. Analysis with GraphPad Prism shows that variances are equal (F-test, $P<0.05$), but the freshwater data are not normally distributed (Shapiro-Wilk's test). Therefore, the non-parametric two-tailed Mann-Whitney U-test was used to compare the two datasets, indicating that both datasets are not significantly different. However, the p-value is on the edge of significance ($p=0.062$) and acute L(E)50 values for marine algae, crustaceans and fish seem to be lower than the freshwater equivalents. Altough the number of data is small, and the statistical analysis should be considered with care, it should be noted that PFOA is present as an anion in the aquatic environment. For anionic compounds, water characteristics are expected to influence behaviour and bioavailability. This is considered as an argument to keep the laboratory datasets separated. Because of the uncertainty with respect to the need for splitting or lumping the data, both options will be explored when deriving the MAC-$QS_{eco,\ fw}$ and MAC-$QS_{eco,\ sw}$. For the chronic dataset, this is not an option, because the only marine NOEC is for an algae species with a higher NOEC than all

freshwater species. Moreover, it should be noted that the relevance of the MAC-EQS is limited, because PFOA will be chronically present in the aquatic environment.

6.3 Derivation of the MAC-EQS$_{eco}$

6.3.1 AF approach

The lowest relevant value from the laboratory freshwater dataset is the EC50 of 44 mg/L for *Scenedesmus obliquus*. The acute baseset (algae, *Daphnia*, fish) is available and the standard deviation of the log-transformed L(E)50-values is <0.5. The MAC-QS$_{fw, eco}$ can be derived by applying an assessment factor of 10 to the lowest test value, resulting in an AF-based MAC-QS$_{fw, eco}$ of 4.4 mg/L. If the freshwater and marine data are combined, the standard deviation of log-transformed L(E)50-values is 0.5. Applying an assessment factor of 10 to the lowest LC50 of 11.9 mg/L would then result in a MAC-QS$_{fw, eco}$ of 1.2 mg/L.

Considering the marine data, the lowest marine L(E)50 value is 11.9 mg/L for the marine fish *Psetta maxima*. An initial assessment factor of 1000 should be applied to derive the MAC-QS$_{sw, eco}$. Because a specifically marine taxon is included in the dataset, the assessment factor can be lowered to 500. Further lowering is not possible, because the standard deviation of the log-transformed marine L(E)50 values is >0.5. With an assessment factor of 500 to the LC50 of 11.9 mg/L, the AF-based MAC-QS$_{sw, eco}$ is 0.02 mg/L (20 µg/L). If the combined dataset is used for derivation of the MAC$_{sw, eco}$, the variation in the dataset is lower, and a factor of 50 can be applied, resulting in a MAC-QS$_{sw, eco}$ of 0.2 mg/L (200 µg/L).

6.3.2 Species Sensitivity Distributions

The criteria for construction of a Species Sensitivity Distribution (SSD) are listed in the WFD-guidance. The output from an SSD-based quality standard is considered reliable if the database contains preferably more than 15, but at least 10 datapoints, from different species covering at least eight taxonomic groups. The freshwater dataset covers 22 species from 10 taxonomic groups. Below, the criteria are copied, together with the representative species from the present dataset:

- Fish: *Carassius auratus* (family Cyprinidae)
- A second family in the phylum Chordata: *Oncorhynchus mykiss* (family Salmonidae)
- A crustacean: Chydorus sphaericus
- An insect: *Chironomus plumosus* (order Diptera, family Chironomidae)
- A family in a phylum other than Arthropoda or Chordata: *Dugesia japonica* (phylum Plathyltelminthes, family Dugesiidae)
- A family in any order of insect or any phylum not already represented: *Limnodrilus hoffmeisteri* (phylum Annelida), *Cipangopaludina cathayensis* (phylum Gastropoda)
- Algae: *Scenedesmus obliquus*
- Higher plants: no laboratory data, but outdoor bioassay indicates that 7-days EC50 for *Myriophyllum spicatum* and *M. sibiricum* is > 100 mg/L.

The HC5 value is estimated using ETX 2.0 [78] with all freshwater L(E)C50 data. The result is presented in Figure 8, details can be found in Annex 4. The assumption of normality is accepted with all tests, except for the Anderson-Darling test at 0.1. The HC5 is 53.5 mg/L (27.3-85.2 mg/L). Taking freshwater and marine data together, the HC5 is 27.8 mg/L (13.4-46.9 mg/L), but the fit is less well. The assumption of normality is accepted at all levels with the Kolmogorov-Smirnov test, but is rejected with the Cramer-Von Mises test at 0.1 and the Anderson-Darling test at 0.1 and 0.05. (see Figure 9). The HC5 of 27.8 mg/L is close to the value derived in the Italian assessment (HC5 22 mg/L), the difference is explained by the difference in study selection explained in section 6.1.1. Applying the standard factor of 10 to the HC5, the SSD-based MAC-$QS_{fw, eco}$ is 5.4 mg/L when including freshwater data only, and 2.8 mg/L when using the combined freshwater and marine data.

For the marine compartment, not enough data are available to apply the SSD-method to the separate marine dataset. Using the combined dataset, the SSD-based MAC-$QS_{sw, eco}$ may be derived by applying an additional assessment factor of 5 to the freshwater value, resulting in a an SSD-based MAC-$QS_{sw, eco}$ of 0.56 mg/L.

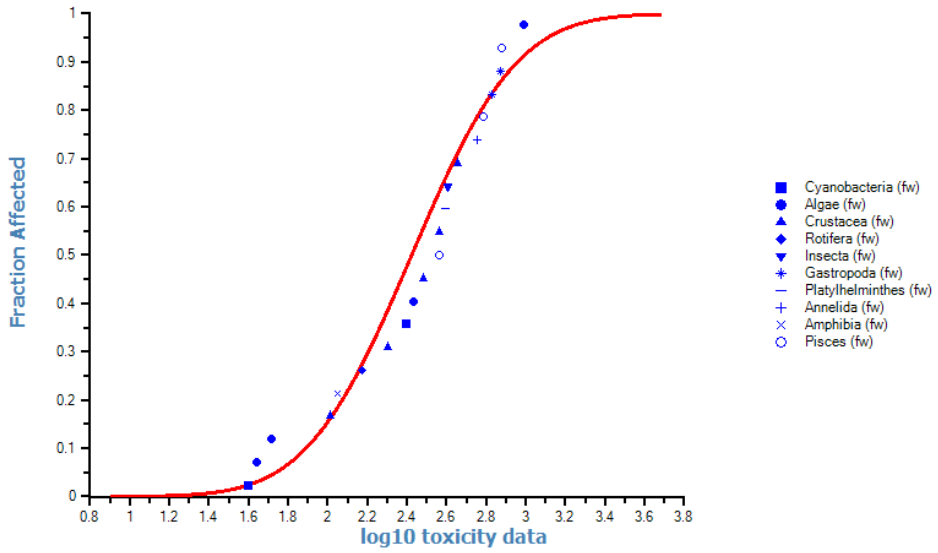


Figure 8. Species Sensitivity Distribution for PFOA based on acute toxicity data for freshwater species. The X-axis represents log-transformed L(E)C50 values in mg/L, the Y-axis represents the fraction of species affected.

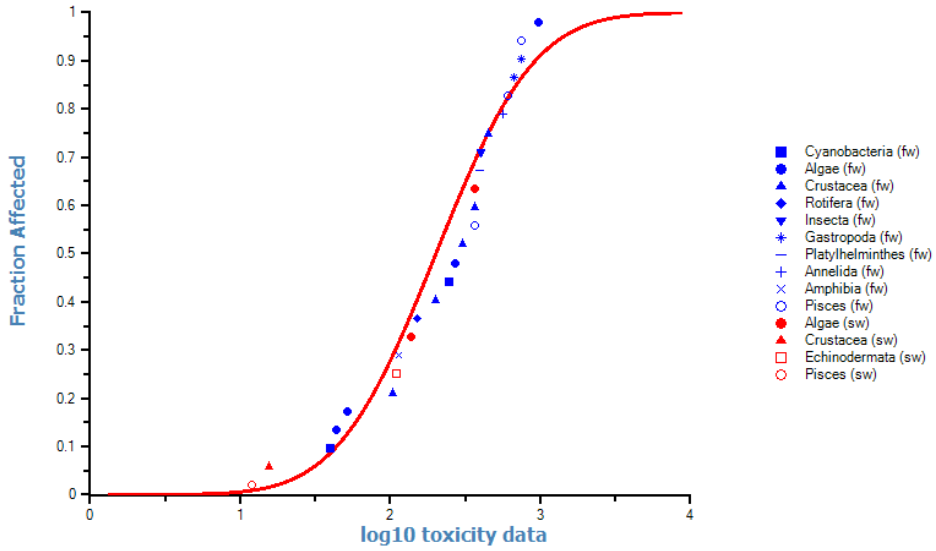


Figure 9. Species Sensitivity Distribution for PFOA based on acute toxicity data for freshwater and marine species. The X-axis represents log-transformed L(E)C50 values in mg/L, the Y-axis represents the fraction of species affected.

6.3.3 *Conclusions on the MAC-EQS*

There is uncertainty as to whether the acute toxicity data for freshwater and marine organisms can be combined. The results of the different options are given in the table below.

Table 12. Results of the different options for derivation of the MAC-EQS. All values in mg/L.

Type of MAC	Dataset	AF-method	SSD-method
MAC-$QS_{fw, eco}$	fresh only	4.4	5.4
	fresh and marine	1.2	2.8
MAC-$QS_{sw, eco}$	marine only	0.02	
	fresh and marine	0.2	0.56

Considering the lowest marine LC50 of 11.9 mg/L, the AF-based MAC-$QS_{sw, eco}$ of 0.02 mg/L seems to be unrealistically low, and the SSD-based value of 0.56 mg/L from the combined dataset may be considered protective for acute effects. For the freshwater environment, the values derived from the split dataset are about a factor of two higher than those derived with the combined dataset. The data do not fully support the combination of the freshwater and marine data, but using the combined dataset for the marine compartment would support to do the same for the freshwater compartment. The Italian dossier arrives at MAC values of 2.2 mg/L for freshwater and 0.45 mg/L for saltwater. In line with this, it is proposed to set the MAC-$EQS_{fw, eco}$ to 2.8 mg/L and the MAC-$EQS_{sw, eco}$ to 0.56 mg/L.

6.4 Derivation of the AA-QS_{eco}

For the AA-QS_{eco}, only the AF-method is applicable since too few data are available for the SSD-approach. The lowest chronic value from laboratory tests is the NOEC of 3.125 mg/L for the crustacean *Moina macrocopa*. In addition, the outdoor tests delivered a NOEC of 0.3 mg/L for the fish *Pimephales promelas*, and EC10 values of 5.7 and

8.7 mg/L for the macrophytes *Myriophyllum spicatum* and *M. sibiricum*. In line with the Italian assessment, the NOEC of 0.3 mg/L for *P. promelas* is selected as the basis for EQS-derivation. Using the default assessment factor of 10, the AA-$QS_{fw, eco}$ is 0.030 mg/L (30 µg/L). Lowering the assessment factor is not justified because the microcosm results for fish relate to single species outdoor tests. The corresponding AA-$QS_{sw, eco}$ is derived with an additional assessment factor of 10, because chronic data for specific marine taxa are not available. The AA-$QS_{sw, eco}$ is 0.003 mg/L (3.0 µg/L). As indicated in section 6.1.1, the results of the study with the marine mussel *Mytilus galloprovincialis* should be taken into account. Given the effect percentages seen in this study (17% 0.1 µg/L, 40% at 100 and 1000 µg/L) setting the AA-$QS_{sw, eco}$ to 3.0 µg/L is considered reasonable.

7 Discussion and conclusions

In this report, environmental quality standards are derived for PFOA based on direct ecotoxicity, secondary poisoning and human fish consumption according to the WFD-methodology. An overview of the values derived in this report is given in Table 13, the selected values are indicated in bold. Human fish consumption appears to be the most critical route in the derivation. It may be considered that the defaults used for fish consumption (115 g per day) is well above the average consumption in the Netherlands. However, the defaults under the WFD are chosen to ensure a high level of protection also for people that particularly like fish. It is also noted that the standard for surface water used for drinking water abstraction is in the same range.

Table 13. Overview of derived water quality standards for PFOA. Final proposed values are indicated in bold.

Type	**Water type**	**Protection aim**	**Intermediate standard**	**Value**
AA-EQS	fresh	direct ecotoxicity	$QS_{fw, eco}$	30 µg/L
		secondary poisoning	$QS_{fw, secpois}$	990 ng/L
		fish consumption	$QS_{water, hh food}$	48 ng/L
		final value	**$AA\text{-}EQS_{fw}$**	**48 ng/L**
	salt	direct ecotoxicity	$QS_{sw, eco}$	3.0 µg/L
		secondary poisoning	$QS_{sw, secpois}$	130 ng/L
		fish consumption	$QS_{water, hh food}$	48 ng/L
		final value	**$AA\text{-}EQS_{sw}$**	**48 ng/L**
MAC-EQS	fresh	direct ecotoxicity	**$MAC\text{-}EQS_{fw, eco}$**	**2800 µg/L**
	salt		**$MAC\text{-}EQS_{sw, eco}$**	**560 µg/L**
QS_{dw}	fresh	drinking water abstraction	**$QS_{dw, hh}$**	**87.5 ng/L**

To date, only Italy has set water quality standards according to the WFD-methodology. Italy derived a final EQS of 0.1 µg/L (100 ng/L), based on a $QS_{biota, secpois}$ of 0.9 µg/kg_{wwt}, a BCF of 9.4 L/kg and assuming a BMF of 1 [8]. The quality standards based on human fish consumption were 9.7 and 1.9 µg/L for fresh- and saltwater, based on the EFSA TDI of 1.5 µg/kg_{bw}/d, the BCF of 9.4 L/kg, a BMF of 5 for the saltwater environment.

In our evaluation, a much higher $QS_{biota, secpois}$ was derived using the energy-based approach. Further, we used BAF values that are concentration dependent, based on field BAFs and laboratory BCFs. The resulting $QS_{biota, secpois, fw}$ is still remarkably higher. However, due to the incorporation of an additional biomagnification factor for the marine environment, the $QS_{biota, secpois, sw}$ is similar to the value derived by Italy. The main difference in our evaluation as compared to the Italian EQS-dossier is the use of a much lower human toxicological threshold limit. In combination with a higher BAF at low concentrations, this leads to a lower value than the $QS_{water, hh food}$ derived by Italy.

Table 14 summarises monitoring data from the Association of River Water Supply Companies (RIWA) at selected drinking water intake points in the Rivers Rhine (2015)[2] and Meuse (2014)[3].

Table 14. Summary of monitoring data from RIWA. Concentrations in ng/L.

	min.	**max.**	**P10**	**P90**	**mean**
Lobith	2.0	5.0	2.0	4.6	2.9
Nieuwegein	1.5	4.8	1.5	4.7	2.7
Nieuwersluis	2.4	5.9	2.4	5.8	4.0
Andijk	2.1	4.1	2.3	3.9	3.0
Heel	2.5	5.9	*	*	*
Brakel	4.0	6.1	4.0	6.1	5.0
Keizersveer	2.1	10	*	*	4.7
Stellendam	3.1	22	3.3	19.3	8.4

*: not determined (insufficient number of data)

Table 15 shows recent monitoring data from Rijkswaterstaat (RWS) in discharge water and in surface water at locations in the vicinity of the Chemours-plant in Dordrecht [79]. These data show that discharge water from the industrial plant and from industrial and municipal sewage treatment plants (STP) contains high levels of PFOA. Despite this, the maximum level in surface water of 12 ng/L remains below the proposed water quality standard of 48 ng/L. This is due to a high dilution rate of the receiving water.

Table 15. Summary of monitoring data from RWS of discharge water and surface water in the vicinity of Dordrecht. Concentrations in ng/L.

Sample type	**min.**	**max.**
Effluent on-site STP	<1	82
Waste water (influent STP Dordrecht)	51	4931
Effluent STP Dordrecht	179	364
Waste water (direct discharge to surface water)	< 1	6895
Surface water downstream	<1	12
Surface water upstream	<1	4.1

[2] https://www.riwa-rijn.org/publicaties/jaarrapporten/

[3] http://www.riwa-maas.org/nc/kwaliteitgegevens.html

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Annex 1. Summary of bioconcentration studies with fish and bivalves

Legend to column headings	
WT	water type: fw = freshwater; sw = marine water
Tax	taxonomic group: moll = mollusc
Details	Details about the species, e.g. weight, size or age
LC	reported lipid content [%]
Exposure	F = Flow-through; R = Renewal; S = Static
Pur	Purity of test substance [%]
A	analysis method: L = LC-MS or LC-MS/MS; O = organic halide analyzer; R = liquid scintillation counter (LSC)
Temp	Test temperature [°C]
Cw	concentration in water [µg/L]
Corg	concentration in organism [ng/g]
T exp	Duration of exposure phase [d]
T dep	Duration of depuration phase [d]
Calc	Method of calculation of the BCF; kin = kinetic, i.e. k1/k2; ss = steady-state, i.e. Corg/Cw
Based on	expression of Corg: wwt = wet weight; dwt = dry weight; wb = whole body; s = serum; l = liver; st = soft tissue
log BAF	log bioaccumulation factor used for further evaluation based on wet weight [L/kg]
N	Notes
Ref	Reference

Table A1.1 Summary of laboratory bioconcentration studies.

WT	Tax	Common name	Latin name	Details	LC	E	Pur	A	pH	Temp	Cw	Corg	T exp	T dep	Calc	Based on	log BCF	N	Ri	Ref
fw	fish	Common carp	*Cyprinus carpio*	1-y, 3.2-7.8 g, 6.8-8.6 cm	2.8-3.1	F	98	L	7.7-8.1	25	47.55	94-197	28	-	kin	wwt; wb	0.463	1	2	[18]
fw	fish	Common carp	*Cyprinus carpio*	1-y, 3.2-7.8 g, 6.8-8.6 cm	2.8-3.1	F	98	L	7.7-8.1	25	4.705	<24-44	28	-	kin	wwt; wb	0.729	1	2	[18]

WT	Tax	Common name	Latin name	Details	LC	E	Pur	A	pH	Temp	Cw	Corg	T exp	T dep	Calc	Based on	log BCF	N	Ri	Ref
fw	fish	Common carp	*Cyprinus carpio*	2-y, 90 g, 19 cm		F	96	L	6.7-8.0	10-15	2000	8.4	56	-	ss	wwt; wb	-2.379	2	4	[19,20]
fw	fish	Fathead minnow	*Pimephales promelas*	64-d		S	> 96.5	O	8.5	20	24460	1700-46700	13	15	kin	wwt; wb	0.248	3	3	[24]
fw	fish	Zebrafish	*Danio rerio*	Adult, male		R	96	L		26	100	83	28	-	ss	wwt; wb	-0.082	4	2	[25]
fw	fish	Zebrafish	*Danio rerio*	Adult, male		R	96	L		26	500	243	28	-	ss	wwt; wb	-0.314	4	2	[25]
fw	fish	Zebrafish	*Danio rerio*	Adult, male		R	96	L		26	1000	550	28	-	ss	wwt; wb	-0.259	4	2	[25]
fw	fish	Zebrafish	*Danio rerio*	Adult, female		R	96	L		26	100	44	28	-	ss	wwt; wb	-0.356	4	2	[25]
fw	fish	Zebrafish	*Danio rerio*	Adult, female		R	96	L		26	500	242	28	-	ss	wwt; wb	-0.316	4	2	[25]
fw	fish	Zebrafish	*Danio rerio*	Adult, female		R	96	L		26	1000	301	28	-	ss	wwt; wb	-0.521	4	2	[25]
fw	fish	Zebrafish	*Danio rerio*	male		S	97	R	8.0	25	9.58	2-740	40	80	kin	wwt; wb	1.452	5	3	[26]
fw	fish	Zebrafish	*Danio rerio*	female		S	97	R	8.0	25	9.43	1-460	40	80	kin	wwt; wb	1.412	5	3	[26]
fw	fish	Zebrafish	*Danio rerio*	male		S	97	R	8.0	25	0.31	6.7-15	40	-	ss	wwt; wb	1.544	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	male		S	97	R	8.0	25	1.1	16-37	40	-	ss	wwt; wb	1.355	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	male		S	97	R	8.0	25	3.14	79-180	40	-	ss	wwt; wb	1.612	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	male		S	97	R	8.0	25	10.27	190-250	40	-	ss	wwt; wb	1.329	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	male		S	97	R	8.0	25	30.25	810-1900	40	-	ss	wwt; wb	1.630	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	female		S	97	R	8.0	25	0.3	7.8-19	40	-	ss	wwt; wb	1.620	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	female		S	97	R	8.0	25	1.09	17-49	40	-	ss	wwt; wb	1.449	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	female		S	97	R	8.0	25	3.14	89-160	40	-	ss	wwt; wb	1.588	6	3	[26]
fw	fish	Zebrafish	*Danio rerio*	female		S	97	R	8.0	25	10.45	150-410	40	-	ss	wwt; wb	1.417	6	3	[26]

WT	Tax	Common name	Latin name	Details	LC	E	Pur	A	pH	Temp	Cw	Corg	T exp	T dep	Calc	Based on	log BCF	N	Ri	Ref
fw	fish	Zebrafish	*Danio rerio*	female		S	97	R	8.0	25	30.6 1	550-690	40	-	ss	wwt; wb	1.305	6	3	[26]
sw	fish	Blackrock fish	*Sebastes schlegeli*	210 g		R	90	L		8-12	7.5-8.6	200-1200	28	28	kin	wwt; s	2.621	7	4	[27]
sw	fish	Blackrock fish	*Sebastes schlegeli*	210 g		R	90	L		8-12	7.5-8.6	13-240	28	28	kin	wwt; l	1.923	7	4	[27]
fw	fish	Rainbow trout	*Oncorhynchus mykiss*	Juvenile, 7.3 g		F	98	L		12	1.5	0.39-5.0	12	33	kin	wwt; wb	0.647	8	2	[28]
fw	fish	Rainbow trout	*Oncorhynchus mykiss*	1147 g		F	>98	L	7.6-7.8	11	500	0.25-12	3	-	kin	wwt; wb	-1.393	9	3	[30]
sw	moll	Pacific oyster	*Crassostrea gigas*	20 g		R	90	L		9-12	7.1	0-110	28	28	kin	wwt; st	0.982	10	2	[31]
sw	moll	Pacific oyster	*Crassostrea gigas*	20 g		R	90	L		9-12	6.7	0-80	28	28	kin	wwt; st	1.057	10	2	[31]
sw	moll	Pacific oyster	*Crassostrea gigas*	20 g		R	90	L		9-12	6.8	0-130	28	28	kin	wwt; st	1.204	10	2	[31]
sw	moll	Pacific oyster	*Crassostrea gigas*	20 g		R	90	L		9-12	6.5	0-170	28	28	kin	wwt; st	1.288	10	2	[31]
sw	moll	Green mussel	*Perna viridis*	60-65 mm	1.4	R	96	L		25	10	0-130	56	28	kin	dwt; st	1.079	11	2	[32]
sw	moll	Green mussel	*Perna viridis*	60-65 mm	1.4	R	96	L		25	1	0-16	56	28	kin	dwt; st	1.176	11	2	[32]
fw	moll	Zebra mussel	*Dreissena polymorpha*	2 cm		R	96	L		20	1000	9.1-25	10	-	ss	wwt; st	-0.396	12	2	[33]
fw	moll	Zebra mussel	*Dreissena polymorpha*	2 cm		R	96	L		20	9.5	0.44-1.4	10	-	ss	wwt; st	-1.078	12	2	[33]
fw	moll	Zebra mussel	*Dreissena polymorpha*	2 cm		R	96	L		20	0.77	0.23-0.38	10	-	ss	wwt; st	-1.820	12	2	[33]

Notes

1 Data recalculated based on a kinetic fit of the original data from the Japanese report. Data below the detection limit in the lower concentration were replaced by LOQ/2. Original report can be retrieved from National Institute of Technology and Evaluation (NITE) (http://www.safe.nite.go.jp/jcheck/).

2 Whole body BCF was estimated from concentrations in different organs together with information from literature in the mass fractions of these organs (liver, gonads, muscle, kidney, gills and brain) in carp [21], the mass fraction of blood in rainbow trout [22] and an assumption for the BCF of the remainder mass fraction in crucian carp [23].

3 Kinetic fit from the original data. The concentrations in fish were determined with an organic halide analyser. This analysis is not specific for PFOA. It appeared that one of the impurities is perfluorononanoic acid (PFNA), which is supposed to have a much higher BCF value.

4 Concentration in fish after four days of exposure were also reported, but these were especially for females very low. Consequently no kinetic BCF could be calculated.

5 Fish concentrations were read from presented figure. BCF was determined by a kinetic fit on the presented data. PFOA concentrations were derived from total radioactivity (LSC), while radiochemical purity was 97% and no information was given on the identity of the impurities.

6 Fish concentrations were read from presented figure. PFOA concentrations were derived from total radioactivity (LSC), while radiochemical purity was 97% and no information was given on the identity of the impurities.

7 BCFs were determined at four different salinities ranging from 10 to 34 psu. For PFOA, there was no effect of salinityon BCF. Accumulation was only determined in serum and liver. Consequently, the whole body BCF could not be determined, but with the relative mass fraction for blood and liver of rainbow trout [22], the whole body BCF would be, at least, 16 to 25 L/kg_{wwt}.

8 Simultaneous exposure to 12 PFCs at concentrations similar as or lower than PFOA. Whole body BCF (4.4 L/kg_{wwt}) was estimated from the BCF for the liver (8.0 L/kg_{wwt}) and blood (27 L/kg_{wwt}), for which 50-200 µl was withdrawn from the carcass, and the remaining carcass (4.0 L/kg_{wwt}). The relative liver weight for rainbow trout was retrieved from literature [22]. For blood an average mass of 125 mg was used in combination with the total body weight of 7.3 g.

9 Large rainbow trout were confined to respirometer-metabolism chambers. For this purpose they were sedated with tricaine methanesulfonate and immobilized by spinal transection. A BCF of 0.56 L/kg_{wwt} was calculated for the presented data of eight rainbow trout. From the presented data for the partitioning between plasma and the organs liver, kidney and muscle, a whole body BCF was estimated from the relative mass fractions of these organs in rainbow trout [22] and the assumption for the remainder of the mass fraction [23].

10 BAF (in presence of algae) were determined at four different salinities of 10, 17.5, 25, and 34 psu, respectively. Simultaneous exposure to PFOS, PFDA and PFUnDA at equal concentrations. BCF values from this study are considered not valid. Data of the 7-d water-only uptake experiment are not presented and it is assumed that no depuration takes place in this period. With half-lives in the order of 1 day this assumption is not correct.

11 Salinity was 30 ppt. Mussels were fed twice a day with algae. Simultaneous exposure to PFOS, PFNA and PFDA at equal concentrations. A concentration dependent kinetic model was applied in the study. Protein content of mussels was 12%. Based on the sum of lipid and protein content, the estimated wet weight BAFs are 1.6 and 2.0 L/kg_{wwt} at 10 and 1 µg/L, respectively.

12 Mussels were fed with algae two hours before renewal. Simultaneous exposure to PFOS at equal concentrations. BCF values were calculated as average values from the reported mussel concentrations after 1, 5 and 10 days of exposure. Reported BAF values were erroneous, as verified by the authors.

Annex 2. Summary of field bioaccumulation studies

Legend to column headings	
WT	water type: fw = freshwater; sw = marine water; bw = brackish water
Tax	taxonomic group: crust = crustacean; moll = mollusc; chlor = chlorophyte; macr = macrophyte; rodo = rodophyte; phy = phytoplankton; zoo = zooplankton
MC	reported moisture content [%]
TrL	reported trophic level
A	analysis method: U = UPLC-MS/MS; H = HPLC-MS/MS; HE = HPLC-ESI/MS/MS; L = LC-MS/MS
Cw	concentration in water [ng/L]
Corg	concentration in organism [ng/g]
Based on	expression of Corg: wwt = wet weight; dwt = dry weight; m = muscle; wb = whole body; st = soft tissue; f = fillet;
log BAF	log bioaccumulation factor used for further evaluation based on wet weight [L/kg]
N	notes
Ref	reference

Table A1.1 Summary of field bioaccumulation studies used for further calculations. All BAFs are considered reliable with Ri = 2.

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Taihu Lake	fw	crust	oriental river prawn	Macrobrachium nipponense	80	n=30, pooled into 3 samples	4.22	May, 2012	U	30.5	<0.340	wwt; m	0.746	1	[34]
CHI, Taihu Lake	fw	crust	white shrimp	Exopalaemon sp.	77	n=6, pooled into 3 samples		May, 2012	U	30.5	0.382	wwt; m	1.098	1	[34]
CHI, Taihu Lake	fw	fish	sharpbelly	Hemiculter leucisculus	75	n=10, pooled into 3 samples	3.42	May, 2012	U	30.5	3.43	wwt; m	2.051	1	[34]
CHI, Taihu Lake	fw	fish	silver carp	Hypophthalmichthys molitrix	80	n=3	2.48	May, 2012	U	30.5	0.361	wwt; m	1.073	1	[34]
CHI, Taihu Lake	fw	fish	whitebait	Reganisalanx brachyrostralis	86	n=6, pooled into 3 samples	4.09	May, 2012	U	30.5	4.49	wwt; m	2.168	1	[34]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Taihu Lake	fw	fish	Japanese white crucian carp	Carassius cuveiri	75	n=6, pooled into 3 samples	3.88	May, 2012	U	30.5	2.47	wwt; m	1.908	1	[34]
CHI, Taihu Lake	fw	fish	lake saury	Coilia mystus	79	n=10, pooled into 3 samples	4.24	May, 2012	U	30.5	8.65	wwt; m	2.453	1	[34]
CHI, Taihu Lake	fw	fish	common carp	Cyprinus carpio	77	n=3	3.51	May, 2012	U	30.5	5.41	wwt; m	2.249	1	[34]
CHI, Taihu Lake	fw	fish	Mongolian culter		77	n=20, pooled into 3 samples	3.77	May, 2012	U	30.5	4.91	wwt; m	2.207	1	[34]
CHI, Taihu Lake	fw	fish	oriental weatherfish	Misgurnus anguillicaudatus	74	n=10, pooled into 3 samples	3.18	May, 2012	U	30.5	4.98	wwt; m	2.213	1	[34]
CHI, Taihu Lake	fw	fish	Chinese bitterling	Rhodeus sinensis Gunther	79	n=60, pooled into 3 samples	3.58	May, 2012	U	30.5	2.68	wwt; m	1.944	1	[34]
CHI, Taihu Lake	fw	fish	goby	Ctenogobius giurinus	80	n=30, pooled into 3 samples	4.14	May, 2012	U	30.5	1.15	wwt; m	1.576	1	[34]
CHI, Taihu Lake	fw	moll	freshwater mussel	Lamellibranchia sp.	80	n=3	3.45	May, 2012	U	30.5	<0.34	wwt; st	0.746	1	[34]
CHI, Taihu Lake	fw	moll	pearl mussel	Lamellibranchia sp.	74	n=3	2.78	May, 2012	U	30.5	1.21	wwt; st	1.598	1	[34]
CHI, Taihu Lake	fw	crust	white shrimp	Exopalaemon modestus		n=18	4.11	May, 2010	L	28.1	0.88	wwt; wb	1.496	2	[35]
CHI, Taihu Lake	fw	fish	bighead carp	Aristichthys nobilis	81	n=5, pooled into 4 samples; 80.6% water	2.95	May, 2010	L	28.1	1.02	wwt; m	1.56	2	[35]
CHI, Taihu Lake	fw	fish	redfin culter	Erythroculter ilishaefor	81	n=20, pooled into 8 samples; 80.6% water	2.94	May, 2010	L	28.1	0.47	wwt;wb excl fins, mouth, gut	1.223	2	[35]
CHI, Taihu Lake	fw	fish	silver carp	Hypophthalmichthys molitrix	81	10 individuals; 81.2% water	3.62	May, 2010	L	28.1	1.86	wwt; wb or m	1.821	3	[35]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Taihu Lake	fw	fish	sharpbelly	Hemiculter leucisculus	79	n=33, pooled into 7 samples; 79.1% water	3.28	May, 2010	L	28.1	0.67	wwt;wb excl fins, mouth, gut	1.377	2	[35]
CHI, Taihu Lake	fw	fish	Asian pencil halfbeak	Hyporhamphus intermedius	79	n>100; pooled into 6 samples; 78.9% water	3.24	May, 2010	L	28.1	0.28	wwt;wb excl fins, mouth, gut	0.998	2	[35]
CHI, Taihu Lake	fw	fish	Japanese grenadier anchovy	Coilia ectenes	80	n>100, pooled into 22 samples; 79.8% water	3.66	May, 2010	L	28.1	0.96	wwt; wb	1.534	2	[35]
CHI, Taihu Lake	fw	fish	clearhead icefish	Protosalanx hyalocranius	86	n=12, pooled into 6 samples; 85.6% water	3.81	May, 2010	L	28.1	0.61	wwt; wb	1.337	2	[35]
CHI, Taihu Lake	fw	fish	yellow catfish	Pelteobagrus fulvidraco	76	n=6, pooled into 4 samples; 76.1% water	4.3	May, 2010	L	28.1	0.38	wwt; m	1.131	2	[35]
USA, Charleston Harbor	sw	fish	striped mullet	Mugil cephalus		n=8	3.4	fish 2002/2003; water 2004	H	9.5	<0.5	wwt; wb	1.42	4	[36]
USA, Charleston Harbor	sw	fish	pinfish	Lagodon rhomboides		n=4	4.3	fish 2002/2003; water 2004	H	9.5	<0.5	wwt; wb	1.42	4	[36]
USA, Charleston Harbor	sw	fish	red drum	Sciaenops ocellatus		n=8	3.9	fish 2002/2003; water 2004	H	9.5	1.2	wwt; wb	2.101	4	[36]
USA, Charleston Harbor	sw	fish	Atlantic croaker	Micropogonias undulatus		n=3	4.2	fish 2002/2003; water 2004	H	9.5	1.4	wwt; wb	2.168	4	[36]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
USA, Charleston Harbor	sw	fish	spotfish	Leiostomus xanthurus		n=10	4.2	fish 2002/2003; water 2004	H	9.5	0.5	wwt; wb	1.721	4	[36]
USA, Charleston Harbor	sw	fish	spotted seatrout	Cynoscion nebulosus		n=11	4.3	fish 2002/2003; water 2004	H	9.5	1.8	wwt; wb	2.278	4	[36]
USA, Saratosa Bay	sw	fish	striped mullet	Mugil cephalus		n=9	2.4	2004	H	3.6	<0.5	wwt; wb	1.842	5	[36]
USA, Saratosa Bay	sw	fish	pigfish	Orthopristis chrysoptera		n=10	3.1	2004	H	3.6	<0.5	wwt; wb	1.842	5	[36]
USA, Saratosa Bay	sw	fish	sheephead	Archosargus probatocephalus		n=3	3.2	2004	H	3.6	<0.5	wwt; wb	1.842	5	[36]
USA, Saratosa Bay	sw	fish	pinfish	Lagodon rhomboides		n=10	3.3	2004	H	3.6	<0.5	wwt; wb	1.842	5	[36]
USA, Saratosa Bay	sw	fish	spotted seatrout	Cynoscion nebulosus		n=8	3.7	2004	H	3.6	<0.5	wwt; wb	1.842	5	[36]
CHI, Mai Po Marsh	bw	crust	black tiger prawn	Penaeus monodon		n=2; 42.2-82.7 g	4.8	biota 2008; water 2008-2010	H	7.69	<0.25	wwt	1.211	6	[37]
CHI, Mai Po Marsh	bw	crust	sand prawn	Metapenaeus ensis		2 pooled samples with n=5; 25.7-27.4 g	4.8	biota 2008; water 2008-2010	H	7.69	<0.25	wwt	1.211	6	[37]
CHI, Mai Po Marsh	bw	fish	grey mullet	Mugil cephalus		n=5; 321-364 g	4.3	fish 2008; water 2008-2010	H	7.69	0.13	wwt; wb	1.228	7	[37]
CHI, Mai Po Marsh	bw	fish	ladyfish	Elops saurus		n=6; 50.7-234 g	5	fish 2008; water 2008-2010	H	7.69	0.13	wwt; wb	1.228	7	[37]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Mai Po Marsh	bw	fish	Mozambique tilapia	Oreochromis mossambicus		n=5; 55-690 g	3.4	fish 2008; water 2008-2010	H	7.69	0.13	wwt; wb	1.228	7	[37]
CHI, Mai Po Marsh	bw	fish	small snakehead	Channa asiatica		n=3; 259-500 g	5.5	fish 2008; water 2008-2010	H	7.69	0.13	wwt; wb	1.228	7	[37]
CHI, Mai Po Marsh	bw	fish	flag-tailed glass perchlet	Ambassis miops		2 pooled samples of 27 ind. Each; 0.76 g mean weight	1.9	fish 2008; water 2008-2010	H	7.69	0.07	wwt; wb	0.959	7	[37]
CHI, Mai Po Marsh	bw	moll		Thiaridae Potamididae		3 pooled samples with n=92-163; 4.4-7.7 g	2.6	biota 2009-2010; water 2008-2010	H	7.69	<0.18	wwt; st	1.068	8	[37]
S-KOR, west coast	sw	crust	Beach crab	possibly Ocypodidae sp.		location AM		2010	H	3.4	0.64	wwt; wb	2.275	9	[40]
S-KOR, west coast	sw	crust	Flat shore crab	Gaetice depressus		location AM		2010	H	3.4	0.42	wwt; wb	2.092	9	[40]
S-KOR, west coast	sw	crust	Hermit crab	Pagurus sp.		location AM		2010	H	3.4	2.6	wwt; wb	2.883	9	[40]
S-KOR, west coast	sw	crust	Hermit crab	Pagurus sp.		location AM		2010	H	3.4	0.13	wwt; wb	1.582	9	[40]
S-KOR, west coast	sw	crust	Penicillate shore crab	Hemigrapsus penicillatus		location AM		2010	H	3.4	1.3	wwt; wb	2.582	9	[40]
S-KOR, west coast	sw	crust	Penicillate shore crab	Hemigrapsus penicillatus		location AS2		2010	H	8.9	6.4	wwt; wb	2.857	9	[40]
S-KOR, west coast	sw	crust	Penicillate shore crab	Hemigrapsus penicillatus		location GG2		2010	H	16	13.3	wwt; wb	2.92	9	[40]
S-KOR, west coast	sw	crust	Grapsid crab	Grapsidae sp.		location LS1		2010	H	8.3	6.6	wwt; wb	2.9	9	[40]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
S-KOR, west coast	sw	crust	Penicillate shore crab	Hemigrapsus penicillatus		location LS1		2010	H	8.3	3.5	wwt; wb	2.625	9	[40]
S-KOR, west coast	sw	crust	Beach crab	possibly cypodidae sp.		location ML		2010	H	4	4.4	wwt; wb	3.041	9	[40]
S-KOR, west coast	sw	crust	Hermit crab	Pagurus sp.		location ML		2010	H	4	0.84	wwt; wb	2.322	9	[40]
S-KOR, west coast	sw	crust	Hermit crab	Pagurus sp.		location ML		2010	H	4	0.44	wwt; wb	2.041	9	[40]
S-KOR, west coast	sw	crust	Penicillate shore crab	Hemigrapsus penicillatus		location SG2		2010	H	8.7	38	wwt; wb	3.64	9	[40]
S-KOR, west coast	fw	crust	Lake prawn	Palaemon paucidens		location AS1		2010	H	15	0.23	wwt; wb	1.186	9	[40]
S-KOR, west coast	fw	crust	Lake prawn	Palaemon paucidens		location SG1		2010	H	8	8	wwt; wb	3	9	[40]
S-KOR, west coast	sw	crust	Lake prawn	Palaemon paucidens		location SG2		2010	H	8.7	0.51	wwt; wb	1.768	9	[40]
S-KOR, west coast	sw	crust	Lake prawn	Palaemon paucidens		location AM		2010	H	3.4	1.6	wwt; wb	2.673	9	[40]
S-KOR, west coast	sw	crust	Lake prawn	Palaemon paucidens		location AM		2010	H	3.4	0.15	wwt; wb	1.645	9	[40]
S-KOR, west coast	fw	crust	Lake prawn	Palaemon paucidens		location GG1		2010	H	29	0.1	wwt; wb	0.538	9	[40]
S-KOR, west coast	sw	crust	Snapping shrimp	Alpheus brevicristatus		location GG2		2010	H	16	0.22	wwt; wb	1.138	9	[40]
S-KOR, west coast	sw	fish	Chameleon goby	Tridentiger trigonocephalus		location ML		2010	H	4	0.17	wwt; wb	1.628	9	[40]
S-KOR, west coast	sw	fish	Chameleon goby	Tridentiger trigonocephalus		location AM		2010	H	3.4	0.11	wwt; wb	1.51	9	[40]
S-KOR, west coast	fw	fish	Crusian carp	Carassius carassius		location AS1		2010	H	15	0.55	wwt; wb	1.564	9	[40]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
S-KOR, west coast	sw	fish	Fat greenling	Hexagrammos otakii		location LS4		2010	H	6.4	0.59	wwt; wb	1.965	9	[40]
S-KOR, west coast	sw	fish	Grass puffer	Takifugu niphobles		location AM		2010	H	3.4	1.4	wwt; wb	2.615	9	[40]
S-KOR, west coast	sw	fish	Javeline goby	Acanthogobius hasta		location LS1		2010	H	8.3	0.63	wwt; wb	1.88	9	[40]
S-KOR, west coast	fw	fish	Paradise goby	Rhinogobius giurinus		location AS1		2010	H	15	8.2	wwt; wb	2.738	9	[40]
S-KOR, west coast	fw	fish	Paradise goby	Rhinogobius giurinus		location AS1		2010	H	15	0.75	wwt; wb	1.699	9	[40]
S-KOR, west coast	sw	fish	Trident goby	Tridentiger brevispinis		location LS4		2010	H	6.4	0.3	wwt; wb	1.671	9	[40]
S-KOR, west coast	sw	fish	Trident goby	Tridentiger brevispinis		location AM		2010	H	3.4	0.49	wwt; wb	2.159	9	[40]
S-KOR, west coast	sw	fish	Yellowfin goby	Acanthogobius flavimanus		location ML		2010	H	4	0.38	wwt; wb	1.978	9	[40]
S-KOR, west coast	sw	fish	Yellowfin goby	Acanthogobius flavimanus		location AM		2010	H	3.4	0.16	wwt; wb	1.673	9	[40]
S-KOR, west coast	sw	moll	Blood cockle	Tegillarca granosa		location LS4		2010	H	6.4	5.6	wwt; wb	2.942	9	[40]
S-KOR, west coast	sw	moll	Blood cockle	Tegillarca granosa		location YS1		2010	H	2.2	0.21	wwt; wb	1.98	9	[40]
S-KOR, west coast	sw	moll	Manila clam	Venerupis philippinarum		location ML		2010	H	4	1.8	wwt; wb	2.653	9	[40]
S-KOR, west coast	sw	moll	Mussel	possibly Mytilus sp.		location ML		2010	H	4	1.7	wwt; wb	2.628	9	[40]
S-KOR, west coast	sw	moll	Oyster	possibly Crassostrea sp.		location SG2		2010	H	8.7	0.08	wwt; wb	0.964	9	[40]
S-KOR, west coast	sw	moll	Oyster	possibly Crassostrea sp.		location AM		2010	H	3.4	0.1	wwt; wb	1.469	9	[40]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
S-KOR, west coast	sw	moll	Razor clam	Siliqua patula		location GG2		2010	H	16	10.8	wwt; wb	2.829	9	[40]
S-KOR, west coast	sw	moll	Razor clam	Siliqua patula		location GG2		2010	H	16	0.31	wwt; wb	1.287	9	[40]
S-KOR, west coast	sw	moll	Lipped periwinkle	Monodonta labio		location AM		2010	H	3.4	2.4	wwt; wb	2.849	9	[40]
S-KOR, west coast	sw	moll	Lipped periwinkle	Monodonta labio		location AM		2010	H	3.4	0.8	wwt; wb	2.372	9	[40]
S-KOR, west coast	sw	moll	Periwinkle	possibly Littorina littorea		location AM		2010	H	3.4	5	wwt; wb	3.167	9	[40]
S-KOR, west coast	sw	moll	Sand snail	possibly Polinices sp.		location AM		2010	H	3.4	0.1	wwt; wb	1.469	9	[40]
S-KOR, west coast	sw	moll	Dove snail	Columbellidae		location LS1		2010	H	8.3	1	wwt; wb	2.081	9	[40]
S-KOR, west coast	sw	moll	Asian periwinkle	Littorina brevicula		location LS2		2010	H	2.5	2.1	wwt; wb	2.924	9	[40]
S-KOR, west coast	sw	moll	Lipped periwinkle	Monodonta labio		location LS4		2010	H	6.4	7.8	wwt; wb	3.086	9	[40]
S-KOR, west coast	sw	moll	Asian periwinkle	Littorina brevicula		location LS4		2010	H	6.4	<0.2	wwt; wb	1.194	9	[40]
S-KOR, west coast	sw	moll	Asian periwinkle	Littorina brevicula		location ML		2010	H	4	7.4	wwt; wb	3.267	9	[40]
S-KOR, west coast	sw	moll	Lipped periwinkle	Monodonta labio		location ML		2010	H	4	0.74	wwt; wb	2.267	9	[40]
S-KOR, west coast	sw	moll	Lipped periwinkle	Monodonta labio		location ML		2010	H	4	0.73	wwt; wb	2.261	9	[40]
S-KOR, west coast	sw	moll	Asian periwinkle	Littorina brevicula		location SG2		2010	H	8.7	0.21	wwt; wb	1.383	9	[40]
S-KOR, west coast	sw	moll	Asian periwinkle	Littorina brevicula		location YS1		2010	H	2.2	3.8	wwt; wb	3.237	9	[40]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
S-KOR, west coast	sw	moll	Asian periwinkle	Littorina brevicula		location YS1		2010	H	2.2	7.3	wwt; wb	3.521	9	[40]
S-KOR, west coast	sw	crust	Crab			n=10; location SG2		2008	H	35.1	0.76	dwt; soft tissue	0.75		[38]
S-KOR, west coast	sw	fish	Striped Mullet	Mugil cephalus		n=1; location SD		2008	H	2.95	<0.5	dwt; f	1.348		[38]
S-KOR, west coast	sw	fish	Rockfish	Sebastes schlegeli		n=1; location YS1		2008	H	6.09	1.46	dwt; f	1.8		[38]
S-KOR, west coast	sw	moll	Surf Clam	Spisula solida		n=7; location LS1		2008	H	9.58	<0.5	dwt; st	0.336		[38]
S-KOR, west coast	sw	moll	Oyster	possibly Crassostrea sp.		n=20; location LS2		2008	H	3.3	<0.5	dwt; st	0.799		[38]
S-KOR, west coast	sw	moll	Mussel	possibly Mytilus sp.		n=4; location AM		2008	H	10.6	0.94	dwt; st	0.867		[38]
S-KOR, west coast	sw	moll	Blue Mussel	Mytilus edulis		n=15; location AM		2008	H	10.6	<0.5	dwt; st	0.292		[38]
S-KOR, west coast	sw	moll	Asian Periwinkle	Littorina brevicula		n=50; location LS3		2008	H	4.54	1.45	dwt; st	1.695		[38]
S-KOR, west coast	sw	moll	Asian Periwinkle	Littorina brevicula		n=50; location LS4		2008	H	15.1	1.1	dwt; st	1.053		[38]
S-KOR, west coast	sw	moll	Asian Periwinkle	Littorina brevicula		n=200; location ML		2008	H	3.04	<0.5	dwt; st	1.105		[38]
S-KOR, west coast	sw	moll	Neritid Gastropod	Neritidae		n=40; location AM		2008	H	10.6	0.62	dwt; st	0.957		[38]
S-KOR, west coast	sw	moll	Asian Periwinkle	Littorina brevicula		n=100; location AM		2008	H	10.6	0.69	dwt; st	1.004		[38]
S-KOR, west coast	sw	moll	Asian Periwinkle	Littorina brevicula		n=75; location YS1		2008	H	6.09	<0.5	dwt; st	0.804		[38]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site C		2008	L	30.4	6.5	dwt	1.6	10	[42]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site E		2008	L	21.1	1.65	dwt	1.163	10	[42]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site G		2008	L	37.6	4.27	dwt	1.325	10	[42]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site J		2008	L	4.26	10.2	dwt	2.649	10	[42]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site L		2008	L	2.53	2.79	dwt	2.312	10	[42]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site N		2008	L	2.48	4.03	dwt	2.48	10	[42]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site O		2008	L	2.27	3.25	dwt	2.425	10	[42]
CHI, Lake Baiyangdian	fw	macr	frogbit	Hydrocharis dubia		site P		2008	L	1.71	5.75	dwt	2.796	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site A		2008	L	12.4	1.85	dwt	1.443	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site C		2008	L	30.4	3.22	dwt	1.294	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site E		2008	L	21.1	1.77	dwt	1.193	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site G		2008	L	37.6	4.79	dwt	1.375	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site J		2008	L	4.26	5	dwt	2.339	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site L		2008	L	2.53	3.43	dwt	2.402	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site N		2008	L	2.48	2.57	dwt	2.285	10	[42]
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site O		2008	L	2.27	5.2	dwt	2.629	10	[42]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		site P		2008	L	1.71	3.29	dwt	2.554	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site A		2008	L	12.4	3.22	dwt	1.684	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site C		2008	L	30.4	7.3	dwt	1.65	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site E		2008	L	21.1	3.13	dwt	1.441	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site G		2008	L	37.6	5.6	dwt	1.443	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site L		2008	L	2.53	6	dwt	2.645	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site N		2008	L	2.48	2.02	dwt	2.18	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site O		2008	L	2.27	10.4	dwt	2.931	10	[42]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		site P		2008	L	1.71	6.65	dwt	2.859	10	[42]
CHI, Lake Baiyangdian	fw	crust	Chinese mitten crab	Eriocheir sinensis		pooled sample of >5 organisms; location S10		2010	HE	28.8	6.09	dwt; bw	1.702	11	[43]
CHI, Lake Baiyangdian	fw	crust	oriental river prawn	Macrobrachium nipponense		pooled sample of >5 organisms; location S10		2010	HE	28.8	10.48	dwt; wb	1.938	11	[43]
CHI, Lake Baiyangdian	fw	fish	common carp	Cyprinus carpio		n=4; locations S9, S10, S11, S18		2010	HE	25.70	3.83	dwt; m	1.68	12	[43]
CHI, Lake Baiyangdian	fw	fish	oriental weatherfish	Misgurnus anguillicaudatus		pooled sample of >5 organisms; location S10		2010	HE	28.8	16.84	dwt; wb	2.187	11	[43]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
CHI, Lake Baiyangdian	fw	macr	coontail	Ceratophyllum demersum		n=4; locations S4, S9, S11, S23		2010	HE	30.225	8.62	dwt	1.88	13	[43]
CHI, Lake Baiyangdian	fw	macr	floating watermoss	Salvinia natans		n=3; locations S9, S11, S23		2010	HE	21.37	12.67	dwt	2.05	13	[43]
CHI, Lake Baiyangdian	fw	moll	river snail	Viviparus		pooled sample of >5 organisms; location S10		2010	HE	28.8	9.17	dwt; wb	1.693	11	[43]
CHI, Anhui Chinese Alligator Nature Reserve	fw	crust	oriental river prawn	Macrobrachium nipponense				2009	L	5.3	0.5	wwt; wb	1.975	14	[44]
CHI, Anhui Chinese Alligator Nature Reserve	fw	fish	silver carp	Hypophthalmichthys molitrix				2009	L	5.3	0.7	wwt; wb	2.121	14	[44]
CHI, Anhui Chinese Alligator Nature Reserve	fw	fish	northern snakehead fish	Channa argus				2009	L	5.3	0.2	wwt; wb	1.577	14	[44]
CHI, Anhui Chinese Alligator Nature Reserve	fw	fish	tire track eel	Mastacembelus armatus				2009	L	5.3	0.3	wwt; wb	1.753	14	[44]
CHI, Anhui Chinese Alligator Nature Reserve	fw	fish	crucian carp	Carassius carassius				2009	L	5.3	0.1	wwt; wb	1.276	14	[44]
BRA, Paraibo do Sul	sw	fish	silver scabbardfish	Lepidopus caudatus		n=5; from local fishermen		2008	H	1.17	1.63	wwt; m	3.142	15	[45]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
BRA, Paraibo do Sul	sw	fish	croaker	Micropogonias furnieri		n=4; from local fishermen		2008	H	1.17	<0.82	wwt; m	2.543	15	[45]
BRA, Guanabaray Bay	sw	fish	silver scabbardfish	Lepidopus caudatus		n=4; from local fishermen		2008	H	1.58	1.04	wwt; m	2.819	16	[45]
BRA, Guanabaray Bay	sw	fish	croaker	Micropogonias furnieri		n=4; from local fishermen		2008	H	1.58	<0.82	wwt; m	2.415	16	[45]
BRA, Guanabaray Bay	sw	fish	mullet	Mugil liza		n=8; from local fishermen		2008	H	1.58	3.39	wwt; m	3.332	17	[45]
BRA, Guanabaray Bay	sw	moll	brown mussel	Perna perna		n=3; location BV		2008	H	2.04	3.93	wwt; wb	3.285	17	[45]
BRA, Guanabaray Bay	sw	moll	brown mussel	Perna perna		n=4; location VC1		2008	H	3.25	6.02	wwt; wb	3.268	17	[45]
BRA, Guanabaray Bay	sw	moll	brown mussel	Perna perna		n=3; location VC2		2008	H	3.25	<0.84	wwt; wb	2.111	17	[45]
BRA, Guanabaray Bay	sw	moll	brown mussel	Perna perna		n=4; location JJ		2008	H	1.37	2.76	wwt; wb	3.304	17	[45]
BRA, Guanabaray Bay	sw	moll	brown mussel	Perna perna		n=3; location MG		2008	H	1.4	2.13	wwt; wb	3.182	17	[45]
IT, Orbetello lagoon	sw/bw	chlor	green algae	Chaetomorpha linum	93	n=18; 6 sites NC AC M FC LC PC		May, 2008	HE	1.30	0.54	dwt	1.462	18	[46]
IT, Orbetello lagoon	sw/bw	crust	crab	Carcinus aestuarii	81	n=15; 5 sites NC AC FC LC PC		May, 2008	HE	1.34	0.91	dwt	2.111	19	[46]
IT, Orbetello lagoon	sw/bw	crust	common prawn	Palaemon serratus	82	n=3; site PC		May, 2008	HE	0.76	0.604	dwt	2.155	20	[46]
IT, Orbetello lagoon	sw/bw	crust	common prawn	Palaemon serratus	82	n=3; site LC		May, 2008	HE	0.93	1.01	dwt	2.292	20	[46]
IT, Orbetello lagoon	sw/bw	crust	common prawn	Palaemon serratus	82	n=3; site AC		May, 2008	HE	1.33	1.06	dwt	2.155	20	[46]
IT, Orbetello lagoon	sw/bw	crust	common prawn	Palaemon serratus	82	n=3; site NC		May, 2008	HE	1.65	1.01	dwt	2.043	20	[46]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
IT, Orbetello lagoon	sw/bw	crust	common prawn	Palaemon serratus	82	n=3; site FC		May, 2008	HE	2.03	1.21	dwt	2.03	20	[46]
IT, Orbetello lagoon	sw/bw	fish	black goby	Gobius niger	72	n=9; 3 sites NC AC FC		May, 2008	HE	1.67	0.58	dwt	1.988	20	[46]
IT, Orbetello lagoon	sw/bw	fish	silverside sp.	Atherina spp.	76	n=9; 3 sites NC AC FC		May, 2008	HE	1.67	0.6	dwt	1.936	20	[46]
IT, Orbetello lagoon	sw/bw	fish	grass goby	Zosterisessor ophiocephalus	76	n=3; site AC		May, 2008	HE	1.33	0.906	dwt	2.213	19	[46]
IT, Orbetello lagoon	sw/bw	fish	grass goby	Zosterisessor ophiocephalus	76	n=3; site NC		May, 2008	HE	1.65	1.06	dwt	2.187	19	[46]
IT, Orbetello lagoon	sw/bw	fish	grass goby	Zosterisessor ophiocephalus	76	n=3; site FC		May, 2008	HE	2.03	2.29	dwt	2.433	19	[46]
IT, Orbetello lagoon	sw/bw	fish	combtooth blenny sp.	Parablennius spp.	75	n=9; 3 sites NC AC FC		May, 2008	HE	1.67	0.73	dwt	2.039	20	[46]
IT, Orbetello lagoon	sw/bw	macr	little Neptune grass	Cymodocea nodosa	88	n=18; 6 sites NC AC M FC LC PC		May, 2008	HE	1.30	<0.40	dwt	1.265	19	[46]
IT, Orbetello lagoon	sw/bw	macr	spiral ditchgrass	Ruppia cirrhosa	89	n=18; 6 sites NC AC M FC LC PC		May, 2008	HE	1.30	<0.40	dwt	1.227	19	[46]
IT, Orbetello lagoon	sw/bw	moll	grooved carpet shell	Ruditapes decussatus	76	n=3; site PC		May, 2008	HE	0.76	0.513	dwt	2.21	19	[46]
IT, Orbetello lagoon	sw/bw	moll	grooved carpet shell	Ruditapes decussatus	76	n=3; site LC		May, 2008	HE	0.93	0.513	dwt	2.122	19	[46]
IT, Orbetello lagoon	sw/bw	moll	grooved carpet shell	Ruditapes decussatus	76	n=3; site M		May, 2008	HE	1.12	0.528	dwt	2.054	19	[46]
IT, Orbetello lagoon	sw/bw	moll	grooved carpet shell	Ruditapes decussatus	76	n=3; site AC		May, 2008	HE	1.33	0.604	dwt	2.037	19	[46]
IT, Orbetello lagoon	sw/bw	moll	grooved carpet shell	Ruditapes decussatus	76	n=3; site NC		May, 2008	HE	1.65	0.694	dwt	2.004	19	[46]
IT, Orbetello lagoon	sw/bw	moll	grooved carpet shell	Ruditapes decussatus	76	n=3; site FC		May, 2008	HE	2.03	0.679	dwt	1.905	19	[46]

Location	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw	Corg	Based on	log BAF	N	Ref
IT, Orbetello lagoon	sw/bw	moll	Mediterranean mussel	Mytilus galloprovincialis	75	n=3; site AC		May, 2008	HE	1.33	0.981	dwt	2.266	19	[46]
IT, Orbetello lagoon	sw/bw	moll	Mediterranean mussel	Mytilus galloprovincialis	75	n=3; site NC		May, 2008	HE	1.65	3.64	dwt	2.741	19	[46]
IT, Orbetello lagoon	sw/bw	moll	Mediterranean mussel	Mytilus galloprovincialis	75	n=3; site FC		May, 2008	HE	2.03	4.02	dwt	2.694	19	[46]
IT, Orbetello lagoon	sw/bw	rodo	red algae	Alsidium corallinum	87	n=18; 6 sites NC AC M FC LC PC		May, 2008	HE	1.30	<0.40	dwt	1.3		[46]
CAN, Arctic, Conwallis Island, Lake Meretta	fw	fish	Atlantic char	Salvelinus alpinus		juv.; n=3; Meretta lake		July, August 2010-2011	H	17	1.31	wwt; wb	1.89	21	[47]
CAN, Arctic, Conwallis Island, Lake Meretta	fw	fish	Atlantic char	Salvelinus alpinus		adult; n=21; Meretta lake		July, August 2010-2011	H	17	0.10	wwt; m	0.77	22	[47]
CAN, Arctic, Conwallis Island, Lake Resolute	fw	fish	Atlantic char	Salvelinus alpinus		juv.; n=8; Resolute lake		July, August 2010-2011	H	9.4	0.15	wwt; wb	1.20	23	[47]
CAN, Arctic, Conwallis Island, Lake Resolute	fw	fish	Atlantic char	Salvelinus alpinus		adult; n=18; Resolute lake		July, August 2010-2011	H	9.4	0.35	wwt; m	1.57	22	[47]
CAN, Arctic, Conwallis Island, 9-Mile Lake	fw	fish	Atlantic char	Salvelinus alpinus		juvenile; n=14; 9-Mile Lake		July, August 2010-2011	H	0.69	0.3	wwt; wb	2.64	24	[47]

Notes

1 recovery of individual PFOA isomers in spiked samples >95% for water, 85-95% for muscle tissue; BAF calculated by evaluator from reported concentrations in water and biota; water concentration is average ∑PFOA concentration of 5 sampling spots in Meiliang area, biota were sampled by local fisherman in same area

2 matrix recovery 98-103% for fish, 96-106% for water; BAF calculated by evaluator from reported concentrations in biota and water (Table S5); concentrations in biota are average of n samples; water concentration is mean of 30 sampling sites, reported in text as 28.1 ± 16 ng/L; fish are reported to be sampled 'around the lake'

3 matrix recovery 98-103% for fish, 96-106% for water; BAF calculated by evaluator from reported concentrations in biota (Table S5) and water; not clear if based on whole body or muscle, both are mentioned in supporting information; water concentration is mean of 30 sampling sites, reported in text as 28.1 ± 16 ng/L; fish are reported to be sampled 'around the lake'

4 concentrations in biota are average of n samples; corrected for procedural recovery 66-70%; large variation for water, SD = 13 ng/L; BAF calculated from reported concentrations in water and fish

5 concentrations in biota are average of n samples; corrected for procedural recovery 66-70%; large variation for water, SD = 9.2 ng/L; BAF calculated from reported concentrations in water and fish

6 water concentration is reported average of 12 samplings in Nov 2008, May 2009, Sept 2009 and March 2010 (range 4.74-13.3), biota was sampled in Nov 2008

7 water concentration is reported average of 12 samplings in Nov 2008, May 2009, Sept 2009 and March 2010 (range 4.74-13.3), fish was sampled in Nov 2008; reported concentrations in fish are equal to LOQ/2, which means that all samples were below LOQ, however 50% or lower were above LOD; livers of large fish were dissected and analysed separately, reported concentrations refer to whole body including liver as can be derived from the sum PFCs concentrations in liver or whole body

8 water concentration is reported average of 12 samplings in Nov 2008, May 2009, Sept 2009 and March 2010 (range 4.74-13.3), biota was sampled in Sep 2009 and Mar 2010

9 Matrix spike recovery 88% for water and biota; paper reports average BAFs per taxon; evaluator calculated BAFs for individual species based on reported concentrations and matching water locations for 2010; biota concentrations most likely based on single samples

10 BAF based on reported concentrations in plants and water from same location

11 recovery of spiked samples 78-117% for water, 75-131% for biota; based on pooled sample (n> 5), BAF calculated by evaluator from reported concentrations in organisms and water (site where organism was sampled); according to text, BAF is based on wwt, but figures match with reported dwt concentrations in biota; author confirmed that text is not correct, BAFs are expressed on dwt basis

12 recovery of spiked samples 78-117% for water, 75-131% for biota; BAF calculated from reported log BAF; according to paper, BAFs were calculated independently site to site from concentrations in the organisms and water; according to text, BAF is based on wwt, but figures match with reported dwt concentrations in biota; author confirmed that text is not correct, BAFs are expressed on dwt basis

13 recovery of spiked samples 78-117% for water, 75-131% for biota; reported location S23 does not exist, probably S13 is meant; BAF calculated from reported log BAF; according to paper, BAFs were calculated independently site to site from concentrations in the organisms and water; according to text, BAF is based on wwt, but figures match with reported dwt concentrations in biota; author confirmed that text is not correct, BAFs are expressed on dwt basis

14 recovery in spiked serum sample 87%; recovery and LOQ for biota not indicated; number of replicates not indicated; sampling in alligator pond; BAF reported in study taken as most accurate value for ratio of concentrations in water and biota

15 concentrations in biota are average of n samples; recovery in fish 94%; water concentrations are reported for 5 locations, P4 and P5 in the river with concentrations 1.22 and 1.13 ng/L, P1-3 outside the river mouth with concentrations <0.09-0.15 ng/L; fish are reported to be caught 'in the river near Campos dos Goytacases', which according to the map matches P4 and P5, but it is not clear if these sites represent the actual exposure concentration; average of P4 and P5 is taken as these represent the highest PFOA concentrations and including the other locations would probably overestimate the BAF

16 concentrations in biota are average of n samples; recovery in fish 94%; BAF calculated by evaluator from reported data; water concentration is calculated by evaluator as geomean of reported values for 5 locations in the sampling area, range 0.77-3.25 ng/L

17 concentrations in biota are average of n samples; recovery of spiked samples 79-144%, mean 105%; BAF calculated by evaluator from reported data
18 only average concentrations for 6 sites are reported for biota
19 only average concentrations for 5 sites are reported for biota; not mentioned which body parts have been used, but from the discussion on human fishery products consumption it follows that this should be whole body
20 not mentioned which body parts have been used, but from the discussion on human fishery products consumption it follows that this should be whole body
21 recovery of spiked samples 88±9% for water, 81±12% for juvenile char, 85±10% for adult char; original data obtained from authors; for juveniles muscle seems to be lower than whole body
22 recovery of spiked samples 88±9% for water, 81±12% for juvenile char, 85±10% for adult char; original data obtained from authors
23 recovery of spiked samples 88±9% for water, 81±12% for juvenile char, 85±10% for adult char; original data obtained from authors; one extraordinary high value was omitted from the analysis; for juveniles muscle seems to be lower than whole body
22 recovery of spiked samples 88±9% for water, 81±12% for juvenile char, 85±10% for adult char; original data obtained from authors
24 recovery of spiked samples 88±9% for water, 81±12% for juvenile char, 85±10% for adult char; for juveniles muscle seems to be lower than whole body

Table A1.2 Summary of field bioaccumulation studies not used for further calculations. Studies did not allow for calculation of reliable BAFs (Ri = 3). Some studies are considered reliable (Ri = 2), but the matrix is not relevant.

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CHI, Taihu Lake	fw	phy			85%	3 pooled samples	1.83	May, 2012	U	30.5	0.703	wwt	1.36	3	1	[34]
CHI, Taihu Lake	fw	zoo			81%	3 pooled samples	2	May, 2012	U	30.5	1.42	wwt	1.67	3	2	[34]
CND, Lake Superior	fw	fish	lake trout	Salvelinus namaycush		n=10; 809-1457 g		fish 2001, water 2005	L	0.6	1.1	wwt; wb	3.26	3	3	[80]
CND, Lake Huron	fw	fish	lake trout	Salvelinus namaycush		n=10; 821-2491 g		fish 2001, water 2004/2005	L	0.4	1.6	wwt; wb	3.60	3	4	[80]
CND, Lake Erie	fw	fish	lake trout	Salvelinus namaycush		n=6; 2078-2780 g		fish 2001, water 2004	L	1.9	1.6	wwt; wb	2.93	3	5	[80]
CND, Lake Ontario	fw	fish	lake trout	Salvelinus namaycush		n=10; 1324-2896 g		fish 2001, water 2002/2004/2005	L	3.5	1.5	wwt; wb	2.63	3	4	[80]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CND, Lake Michigan	fw	fish	lake trout	Salvelinus namaycush		n=10; 1052-2103 g		fish 2001, water not specified	L	1.8	4.4	wwt; wb	3.39	3	6	[80]
S-KOR, west coast	sw	ann				location AM		2010	H	3.4	2.9	wwt; wb	2.93	3	7	[40]
S-KOR, west coast	sw	ann				location GG2		2010	H	16	61	wwt; wb	3.58	3	7	[40]
S-KOR, west coast	sw	echi				location ML		2010	H	4	1.9	wwt; wb	2.68	3	7	[40]
S-KOR, west coast	sw	echi				location ML		2010	H	4	0.06	wwt; wb	1.18	3	7	[40]
S-KOR, west coast	sw	echi				location ML		2010	H	4	1.5	wwt; wb	2.57	3	7	[40]
USA, Charleston Harbor	sw	mam	bottlenose dolphin	Tursiops truncatus		n=24	4.4	2004	H	9.5	43	wwt; plasma	3.66	2	8	[36]
USA, Saratosa Bay	sw	mam	bottlenose dolphin	Tursiops truncatus		n=12	4.1	2004	H	3.6	3.4	wwt; plasma	2.98	2	9	[36]
CND, Raisin River	fw	crust	not specified					water 2001; biota 1999	H	14.7	<5	wwt; wb		3	10	[81]
CND, St Clair River	fw	crust	not specified					water 2001; biota 1999	H	4.4	<5	wwt; wb		3	10	[81]
CND, Raisin River	fw	crust	crayfish					water 2001; biota 1999	H	14.7	<0.2	wwt; wb		3	10	[81]
CND, St Clair River	fw	crust	Crayfish					water 2001; biota 1999	H	4.4	<1	wwt; wb		3	10	[81]
CND, Raisin River	fw	fish	Round gobies					water 2001; biota 1999	H	14.7	<0.2	wwt; fillet		3	10	[81]
CND, Raisin River	fw	fish	Smallmouth bass					water 2001; biota 1998/1999	H	14.7	<2	wwt; wb		3	10	[81]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CND, St Clair River	fw	fish	Round gobies					water 2001; biota 1998/1999	H	4.4	<2	wwt; fillet		3	10	[81]
CND, St Clair River	fw	fish	Smallmouth bass					water 2001; biota 1998/1999	H	4.4	<1	wwt; wb		3	10	[81]
CND, Raisin River	fw	moll	Zebra mussel	Dreissena polymorpha				water 2001; biota 1998	H	14.7	<5	wwt; st		3	10	[81]
CND, St Clair River	fw	moll	Zebra mussel	Dreissena polymorpha				water 2001; biota 1998	H	4.4	<1	wwt; st		3	10	[81]
NL, 21 locations	fw/bw	fish	eel	Anguilla anguilla		n=30 per location		2007; archived samples for 3 locations	H	6.5-43		wwt; f	1.09	3	11	[82]
CHI, Mai Po Marsh	bw	ann		Capitellidae		5 pooled samples with n=155-163; 5.27-5.61 g	3.2	biota 2009-2010; water 2008-2010	H	7.69	<0.03	wwt	<0.59	3	12	[37]
CHI, Mai Po Marsh	bw	ann		Nereidae		3 pooled samples with n=23-75; 0.74-3.29 g	0	biota 2009-2010; water 2008-2010	H	7.69	0.13	wwt	1.23	3	12	[37]
CHI, Mai Po Marsh	bw	ann		Sabellidae		2 pooled samples with n=25; 0.67 g	0	biota 2009-2010; water 2008-2010	H	7.69	0.34	wwt	1.65	3	12	[37]
CHI, Mai Po Marsh	bw	bird	Chinese pond heron			n=3		bird 2003; water 2008-2010	H	7.69	0.76	wwt; liver	1.99	3	13	[37]
CHI, Mai Po Marsh	bw	bird	Grey heron			n=3		bird 2003; water 2008-2010	H	7.69	0.4	wwt; liver	1.72	3	13	[37]
CHI, Mai Po Marsh	bw	phy			78%	2 pooled samples; >45-100 µm	0.7	biota 2009-2010; water 2008-2010	H	7.69	2.24	wwt	2.46	3	14	[37]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CHI, Mai Po Marsh	bw	zoo				3 pooled samples; 100-355 µm	2	biota 2009-2010; water 2008-2010	H	7.69	0.09	wwt	1.07	3	14	[37]
S-KOR, west coast	sw	crust	Crab			n=10; location SG2		2008	H	35.1	0.51	dwt; eggs	1.16	2		[38]
S-KOR, west coast	sw	crust	Crab			n=10; location SG2		2008	H	35.1	<0.5	dwt; shells	<1.15	2		[38]
S-KOR, west coast	sw	fish	Striped Mullet	Mugil cephalus		n=1; location SD		2008	H	2.95	<0.5	dwt; intes	<2.23	2		[38]
S-KOR, west coast	sw	fish	Striped Mullet	Mugil cephalus		n=1; location SD		2008	H	2.95	<0.5	dwt; liver	<2.23	2		[38]
S-KOR, west coast	sw	fish	Rockfish	Sebastes schlegeli		n=1; location YS1		2008	H	6.09	<0.5	dwt; intestines	<1.91	2		[38]
S-KOR, west coast	sw	fish	Rockfish	Sebastes schlegeli		n=1; location YS1		2008	H	6.09	<0.5	dwt; liver	<1.91	2		[38]
S-KOR, west coast	sw	fish	Rockfish	Sebastes schlegeli		n=1; location YS1		2008	H	6.09	<0.5	dwt; gills	<1.91	2		[38]
S-KOR, west coast	sw	crust		mixed				2009	H			wwt; wb	1.47	3	15	[83]
S-KOR, west coast	sw	fish		mixed				2009	H			wwt; wb	1.05	3	15	[83]
S-KOR, west coast	sw	moll		mixed				2009	H			wwt; wb	1.65	3	15	[83]
S-KOR, west coast	sw	moll		mixed				2009	H			wwt; wb	1.70	3	15	[83]
JPN, Toyin river estuary, tidal flat	sw/ bw	ann				n=5			H	0.64	82	wwt; wb	5.11	3		[84]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	bird	mallard			n=11; 22400 ± 13000 g			H	0.64	<3.0	wwt; liv	<3.67	3		[84]
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	bird	blackheaded gull			n=2; 1100 ± 110 g			H	0.64	<3.0	wwt; liv	<3.67	3		[84]
JPN, Toyin river estuary, tidal flat	sw/ bw	crust				n=2; 8.8 g			H	0.64	9.5	wwt; hepatopancreas	4.17	3		[84]
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	fish	filefish			n=5; 273 ± 23 g			H	0.64	<3.0	wwt; liver	<3.67	3		[84]
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	fish	sea bream			n=5; 240 ± 48 g			H	0.64	3.8	wwt; liver	3.77	3		[84]
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	fish	red sea bream			n=5; 377 ± 54 g			H	0.64	15	wwt; liver	4.37	3		[84]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	fish	right eye flounder			n=5; 353 ± 38 g			H	0.64	5.2	wwt; liver	3.91	3		[84]
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	fish	hammerhead shark			n=1; >100 cm			H	0.64	<3.0	wwt; liver	<3.67	3		[84]
JPN, Toyin river estuary, tidal flat	sw/ bw	fish	mudskipper	Boleophthalmus pectinirostris		n=10; 15 ± 5.5 g			H	0.64	<3.0	wwt; liver	<3.67	3		[84]
JPN, Toyin river estuary, tidal flat	sw/ bw	fish	mudskipper	Periophthalmus modestus		n=6; 3.5 ± 0.6 g			H	0.64	7.8	wwt; liver	4.09	3		[84]
JPN, Ariake Sea near Toyin river estuary, shallow water	sw/ bw	mam	finless porpoise			n=5; 353 ± 38 g			H	0.64	9.1	wwt; liver	4.15	3		[84]
JPN, Toyin river estuary, tidal flat	sw/ bw	moll	oyster			n=5; 270 g		2003	H	0.64	6	wwt; st	3.97	3	16	[84]
JPN, Toyin river estuary, tidal flat	sw/ bw	moll	Mussel			n=5; 25 ± 4.3 g		2003	H	0.64	9.5	wwt; st	4.17	3	16	[84]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
JPN, Toyin river estuary, tidal flat	sw/ bw	moll	clam			n=6; 6.1 ± 1.0 g		2003	H	0.64	7.2	wwt; st	4.05	3	16	[84]
BRA, Paraibo do Sul	sw	fish	silver scabbardfish	Lepidopus caudatus		n=5; from local fishermen		2008	H	1.17	0.58	wwt; liver	2.69	2	17	[45]
BRA, Paraibo do Sul	sw	fish	croaker	Micropogonias furnieri		n=4; from local fishermen		2008	H	1.17	0.47	wwt; liver	2.60	2	17	[45]
BRA, Guanabaray Bay	sw	fish	silver scabbardfish	Lepidopus caudatus		n=4; from local fishermen		2008	H	1.58	0.83	wwt; liver	2.72	2	18	[45]
BRA, Guanabaray Bay	sw	fish	croaker	Micropogonias furnieri		n=4; from local fishermen		2008	H	1.58	0.52	wwt; liver	2.52	2	18	[45]
BRA, Guanabaray Bay	sw	fish	mullet	Mugil liza		n=8; from local fishermen		2008	H	1.58	0.87	wwt; liver	2.74	2	18	[45]
BRA, Paraibo do Sul	sw	mam	tuxuci dolphin	Sotalia guianensis		n=2; along the coast		archived sample	H	<0.09-0.15	3.99	wwt; m		3	19	[45]
CHI, Lake Baiyangdian	fw	crust		Eriocheir sinensis		n=1		2008	L	25.1 / 2.6	0.02	wwt; st		3	20	[42]
CHI, Lake Baiyangdian	fw	crust		Palinuridae		n=2		2008	L	25.1 / 2.6	0.53	wwt; st		3	20	[42]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CHI, Lake Baiyangdian	fw	crust	oriental river prawn	Macrobrachium nipponense		1 pooled sample		2008	L	25.1 / 2.6	0.12	wwt; wb homogenate		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	common carp	Cyprinus carpio		n=1		2008	L	25.1 / 2.6	0.13	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	crucian carp	Carassius carassius		n=1		2008	L	25.1 / 2.6	0.08	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	yellow catfish	Pelteobagrus fulvidraco		n=1		2008	L	25.1 / 2.6	0.06	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	bluntsnout bream	Megalobrama amblycephala		n=1		2008	L	25.1 / 2.6	0.04	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	silver carp	Hypophthalmichthys molitrix		n=1		2008	L	25.1 / 2.6	0.06	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	stone moroko	Pseudorasbora parva		1 pooled sample		2008	L	25.1 / 2.6	0.35	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	fish	loach	Misgurnus anguillicaudatus		n=1		2008	L	25.1 / 2.6	0.08	wwt; m		3	20	[42]
CHI, Lake Baiyangdian	fw	reptile	Chinese softshell turtle	Pelodiscus sinensis		n=1		2008	L	25.1 / 2.6	0.06	wwt; m		3	20	[42]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CAN, Arctic, Ellesmere Island, Lake A	fw	fish	Arctic char	Salvelinus alpinus		n=32		July, August 2010-2011	H	0.134	0.008	wwt; wb (27) and m (5)	1.78	3	21	[85]
CAN, Arctic, Ellesmere Island, Lake A	fw	zoo						July, August 2010-2011	H	0.134	<0.0013	wwt; wb	<0.99	3	22	[85]
CHI, Anhui Chinese Alligator Nature Reserve	fw	fish	common carp	Cyprinus carpio				2009	L	5.3	<LOQ			2	23	[44]
CHI, Taihu Lake	fw	bird	egret black-crowned night heron	Egretta garzetta Nycticorax nycticorax		n=2	4.61	May, 2010	H	28.1	1.67	wwt; m	1.77	3	24	[35]
CHI, Taihu Lake	fw	fish	common carp	Cyprinus carpio	78%	n=11, pooled into 7 samples; 77.9% water	3.76	May, 2010	H	28.1	<LOQ	wwt; m		3	25	[35]
CHI, Taihu Lake	fw	moll	snail and basket clams	Bellamya sp. Corbiculidae		n=17, pooled into 15 samples; locations S1, S4, S29 (Bel) and S20, S24 (Cor)	2.53	May, 2010	H	28.1	0.16	wwt	0.76	3	26	[35]
CHI, Taihu Lake	fw	phy				n=17; locations S1, 4, 7, 17, 20, 24, 29	1.05	May, 2010	H	28.1	2.47	wwt	1.94	3	27	[35]
CHI, Taihu Lake	fw	zoo				n=17; locations S1, 4, 7, 17, 20, 24, 29	2	May, 2010	H	28.1	0.85	wwt	1.48	3	28	[35]

Loc	WT	Tax	Common name	Latin name	MC	Additional information	TrL	Sampling date	A	Cw [ng/L]	Corg [ng/g]	Based on	log BAF	Ri	N	Ref
CHI, Lake Baiyangdian	fw	bird	Chinese pond heron	Ardeola bacchus		n=4; locations S9, S10, S11, S18		2010	HE	25.7	2.29	dwt; m	1.95	3	29	[43]
CHI, Lake Baiyangdian	fw	plankton				n=1; location S4		2010	HE	56.8	2.17	dwt	1.58	3	29	[43]

Notes

1 recovery of individual PFOA isomers in spiked samples >95% for water, 82-98% for phytoplankton; BAF calculated by evaluator from reported concentrations in water and biota; water concentration is average ∑PFOA concentration of 5 sampling spots in Meiliang area; TL of 1.83 is reported for phytoplankton which is strange because this should be 1. Phytoplankton is separated from zooplankton by filtration over 77 µm, probably zooplankton was included as well

2 recovery of individual PFOA isomers in spiked samples >95% for water, 85-95% for muscle tissue; BAF calculated by evaluator from reported concentrations in water and biota; water concentration is average ∑PFOA concentration of 5 sampling spots in Meiliang area, biota were sampled by local fisherman in same area

3 study accepted for EQS-derivation of PFOS, but now rejected because of uncertainty with respect to water concentrations; paper reports log BAF; values are re-calculated by the evaluator based on concentrations in fish reported in the main text and water concentrations from the Supporting Information; according to SI, water sampling is described in Furdui et al 2005 but Lake Superior is not mentioned in that paper. In Furdui et al 2008, samplings of 2005 are mentioned.

4 study accepted for EQS-derivation of PFOS, but now rejected because of uncertainty with respect to water concentrations; paper reports log BAF, values are re-calculated by the evaluator based on concentrations in fish reported in the main text and water concentrations from the Supporting Information; according to SI, water sampling is described in Furdui et al 2005 and took place in 2004. Furdui et al 2008 also refer to 2005

5 study accepted for EQS-derivation of PFOS, but now rejected because of uncertainty with respect to water concentrations; paper reports log BAF, values are re-calculated by the evaluator based on concentrations in fish reported in the main text and water concentrations from the Supporting Information; according to SI, water sampling is described in Furdui et al 2005 and took place in 2004

4 study accepted for EQS-derivation of PFOS, but now rejected because of uncertainty with respect to water concentrations; paper reports log BAF, values are re-calculated by the evaluator based on concentrations in fish reported in the main text and water concentrations from the Supporting Information; according to SI, water sampling is described in Furdui et al 2005 and took place in 2004. Furdui et al 2008 also refer to 2002 and 2005

6 study accepted for EQS-derivation of PFOS, but now rejected because of uncertainty with respect to water concentrations; paper reports log BAF, values are re-calculated by the evaluator based on concentrations in fish reported in the main text and water concentrations from the Supporting Information; according to SI, water sampling is described in Furdui et al 2005, but Lake Michigan is not mentioned in that paper

7 Matrix spike recovery 88% for water and biota; paper reports average BAFs per taxon; evaluator calculated BAFs for individual species based on reported concentrations and matching water locations for 2010; biota concentrations most likely based on single samples

8 concentrations in biota are average of n samples; corrected for procedural recovery 94-98%; large variation for water, SD = 13 ng/L; BAF calculated from reported concentrations in water and plasma; based on presented data whole body wwt BAF is estimated to be 340

9 concentrations in biota are average of n samples; corrected for procedural recovery 94-98%; large variation for water, SD = 9.2 ng/L; BAF calculated from reported concentrations in water and plasma

10 uncertainty of matching of sampling spots along the river stretch; sampling dates do not match in a fluctuating river system; detection limit not adequate to determine BAFs

11 based on reported mean log BAF 1.09 ± 0.16 (range 0.82-1.43; n=18); water concentrations between 6.5 and 43 ng/L, sediment between 0.3 and 6.3 ng/g dwt; no data from individual locations available
12 water concentration is reported average of 12 samplings in Nov 2008, May 2009, Sept 2009 and March 2010 (range 4.74-13.3), biota was sampled in Sep 2009 and Mar 2010
13 water concentration is reported average of 12 samplings in Nov 2008, May 2009, Sept 2009 and March 2010 (range 4.74-13.3), birds were sampled in 2003
14 water concentration is reported average of 12 samplings in Nov 2008, May 2009, Sept 2009 and March 2010 (range 4.74-13.3), biota was sampled in Sep 2009 and Mar 2010
15 BAF calculated from reported log BAF, based on average concentration in different species; individual data not presented, only ranges
16 reported water concentration is based on a secondary source, values are for Ariake Sea and most likely not for the sampling site; actual values in the river estuary may be higher; BAFs are probably overestimated
17 concentrations in biota are average of n samples; recovery in fish 94%; water concentrations are reported for 5 locations, P4 and P5 in the river with concentrations 1.22 and 1.13 ng/L, P1-3 outside the river mouth with concentrations <0.09-0.15 ng/L; fish are reported to be caught 'in the river near Campos dos Goytacases', which according to the map matches P4 and P5, but it is not clear if these sites represent the actual exposure concentration; average of P4 and P5 is taken as these represent the highest PFOA concentrations and including the other locations would probably overestimate the BAF
18 concentrations in biota are average of n samples; recovery in fish 94%; BAF calculated by evaluator from reported data; water concentration is calculated by evaluator as geomean of reported values for 5 locations in the sampling area, range 0.77-3.25 ng/L
19 sampling dates of animals not clear; not clear which water concentrations should be used
20 large difference in water concentration between Northern part 4.26-73.5 ng/L (median 30.1, geomean 25.1) and Southern part 1.71-7.03 ng/L (median 2.38, geomean 2.6); not indicated in which part biota sampling was performed; evaluator used overall geometric mean for calculation of the BAF
21 only 16% detected; very wide range (<1.3-130); water concentration drops sharply below 10 m and exposure to this layer is unknown; possible migration to saltwater in summertime
22 Water concentration drops sharply below 10 m
23 recovery in spiked serum sample 87%; recovery and LOQ for biota not indicated; number of replicates not indicated; sampling in alligator pond; BAF reported in study taken as most accurate value for ratio of concentrations in water and biota
24 matrix recovery 87-102% for birds, 96-106% for water; BAF calculated by evaluator from reported concentrations in biota and water (Table S5); concentrations in biota are average of n samples; water concentration is mean of 30 sampling sites, reported in text as 28.1 ± 16 ng/L
25 LOQ presented as range 0.05-0.30 ng/g wwt, individual LOQ for PFOA not presented
26 matrix recovery 104-106% for zoobenthos, 96-106% for water; BAF calculated by evaluator from reported concentrations in biota and water; concentration in biota is average of n samples; water concentration is mean of 30 sampling sites, reported in text as 28.1 ± 16 ng/L
27 matrix recovery 84-91% for phytoplankton, 96-106% for water; BAF calculated by evaluator from reported concentrations in biota and water; concentration in biota is average of n samples; water concentration is mean of 30 sampling sites, reported in text as 28.1 ± 16 ng/L
28 matrix recovery 69-93% for zooplankton, 96-106% for water; BAF calculated by evaluator from reported concentrations in biota and water; concentration in biota is average of n samples; water concentration is mean of 30 sampling sites, reported in text as 28.1 ± 16 ng/L
29 recovery of spiked samples 78-117% for water, 75-131% for biota; BAF calculated from reported log BAF; according to paper, BAFs were calculated independently site to site from concentrations in the organisms and water; according to text, BAF is based on wwt, but figures match with reported dwt concentrations in biota; author confirmed that text is not correct, BAFs are expressed on dwt basis
29 recovery of spiked samples 78-117% for water, 75-131% for biota; BAF calculated by evaluator from reported concentrations in organisms and water (site where organism was sampled), this gives slight difference with reported log BAF of 1.77; according to text, BAF is based on wwt, but figures match with reported dwt concentrations in biota; author confirmed that text is not correct, BAFs are expressed on dwt basis

Annex 3. Detailed bird and mammal toxicity data

Legend to column headings	
BW	body weight
TC	Test compound
E	Exposure duration
Cnorm	energy normalised value
ECdiet	energy content of paboratory diet
Ref	reference
N	notes

Table A3.1 Summary of toxicity studies with monkey

Species	BW [g]	TC	Route	E	Effect	Criterion	Value PFOA [mg/kg bw/d]	Cnorm [mg/kJ]	Notes	Ref
macaque Cynomolgus sp.	3850	APFO	oral	182 d	BW decrease	NOAEL	9.6	0.01549	1	[67]
macaque Cynomolgus sp.	3850	APFO	oral	182 d	BW change	LBMD10	10	0.01617	1	[67] in [66]

Notes

1 based on initial body weight (3.2-4.5 kg)

Table A3.2 Summary of toxicity studies with birds

Species	BW [g]	TC	Route	E	Effect	Criterion	Value PFOA [mg/L	Value PFOA [mg/kg bw/d]	Cnorm [mg/kJ]	Notes	Ref
quail Coturnix japonica	-	PFOA	drinking water	8 w	increased growth rate	LOAEL	1	0.2		1	[69]

Notes

1 No clear dose response; calculation of energy normalised value not possible

Table A2.3 Summary of toxicity studies with mice

Strain	BW [g]	TC	Route	E	Effect	Criterion	Value PFOA [mg/kg$_{bw}$/d]	Cnorm [mg/kJ]	ECdiet [kJ/kg]	N	Ref
C57BL/6N	20.85	PFOA	liquid diet	3 w	body weight decrease	LOAEL	5	0.00183	4186.6	1	[86]
CD-1	54.7	APFO	oral	GD1-17	body weight decrease F1, delayed development	NOAEL	3	0.00144	17124.01		[87]
CD-1	53.7	APFO	oral	GD1-17	body weight decrease F1, delayed development	LOAEL	5	0.00239	17124.01		[87]
129S1/SvlmJ wild type	30.9	APFO	oral	GD1-17	survival F1	NOAEL	0.3	0.00012	17124.01		[62]
129S1/SvlmJ wild type	31.7	APFO	oral	GD1-17	survival F1	LOAEL	0.6	0.00025	17124.01		[62]
PPARa knockout	32.7	APFO	oral	GD1-17	survival F1	NOAEL	3	0.00125	17124.01		[62]
PPARa knockout	32.8	APFO	oral	GD1-17	survival F1	LOAEL	5	0.00208	17124.01		[62]
BABL/c	23.5	PFOA	oral	28 d	decreased litter weight and # mated and pregnant females per male	LOAEL	5	0.00189	-	2	[88]
C57BL/6	17.2	APFO	oral	4 w	delayed vaginal opening	NOAEL	1	0.00035	12600	3	[89]
BABL/c	17.4	APFO	oral	4 w	delayed vaginal opening	LOAEL	1	0.00035	12600	3	[89]
C57BL/6	16.8	APFO	oral	4 w	body weight decrease	NOAEL	5	0.00172	12600	3	[89]
BABL/c	16.7	APFO	oral	4 w	body weight decrease	NOAEL	5	0.00171	12600	3	[89]
CD-1	55	PFOA	oral	GD1-17	increased full litter resorption	NOAEL	3	0.00144	17124.01	4	[90]
CD-1	55	PFOA	oral	GD1-17	litter growth deficit	NOAEL	1	0.00048	17124.01	4	[90]
CD-1	55	PFOA	oral	GD1-17	litter growth deficit	LOAEL	3	0.00144	17124.01	4	[90]
CD-1	55	PFOA	oral	GD1-17	body weight F1 at weaning (PND23)	LBMD5	0.86	0.00041	17124.01	4	[90]
CD-1	55	PFOA	oral	GD1-17	survival F1 at weaning (PND23)	LBMD5	1.09	0.00052	17124.01	4	[90]
CD-1	55	PFOA	oral	GD1-17	body weight change	LBMD5	3.58	0.00172	17124.01	4	[90]
CD-1	58.8	APFO	oral	GD11-16	increased # resorptions and	LOAEL	2	0.00098	-		[91]

Strain	BW [g]	TC	Route	E	Effect	Criterion	Value PFOA [mg/kg$_{bw}$/d]	Cnorm [mg/kJ]	ECdiet [kJ/kg]	N	Ref
					dead fetuses						
ICR	63.7	PFOA	oral	GD1-17	decreased maternal weight	NOAEL	1	0.0005	-		[92]
ICR	63.7	PFOA	oral	GD1-17	decreased survival and body weight F1	NOAEL	1	0.0005	-		[92]
CD-1	12.1	APFO	oral	PND18-20	uterine weight		0.01	0.0000031	19747.2	5	[63]
129/SV	24.7	APFO	oral	6 w	sperm morphology	LOAEL	0.96	0.00037	-	6	[93]
Kunming	36	PFOA	oral	14 d	decreased sperm count	LOAEL	2.5	0.00107	-		[94]

Notes
1 Cnorm expressed in kJ/L
2 Body weight is initial bw; males have been exposed and are cohabited with non-exposed females
3 Exposure 5 days per week.
4 Body weight estimated from initial weight (25-30 g) and weight gain during pregnancy (25-30 g).
5 Relevance for population not clear, no dose related effect.
6 Relevance for population not clear.

Table A3.4 Summary of toxicity studies with rats

Strain	BW [g]	TC	Route	E	Effect	Criterion	Value as dietary dose PFOA [mg/kg$_{bw}$/d]	Cnorm dose [mg/kJ]	Value as diet conc PFOA [mg/kg feed]	ECdiet [kJ/kg]	Cnorm diet [mg/kJ]	N	Ref
CD IGS	436	APFO	oral	29 d	decreased BW	NOAEL	9.29	0.00083	-	17207.7	-	1	[65]
CD IGS	404.1	APFO	oral	29 d	decreased BW	EC10	1.25	0.0079	-	17207.7	-	2	[65]
Sprague-Dawley	651	APFO	diet	2 y	decreased BW	NOAEL	1.53	0.00121	28.74	-	-	3	[95]
Sprague-Dawley	502	APFO	diet	2 y	decreased BW	NOAEL	18.2	0.00139	28.74	-	-	3	[95]
Sprague-Dawley	358	APFO	diet	28 d	decreased BW	LOAEL	22.04	0.01495	287.45	14740	0.0195	4	[96]

Strain	BW [g]	TC	Route	E	Effect	Criterion	Value as dietary dose PFOA [mg/kg$_{bw}$/d]	Cnorm dose [mg/kJ]	Value as diet conc PFOA [mg/kg feed]	ECdiet [kJ/kg]	Cnorm diet [mg/kJ]	N	Ref
Sprague-Dawley	403	APFO	diet	28 d	decreased BW	LOAEL	0.96	0.01872	287.45	14740	0.0195		[96]
Sprague-Dawley	527	APFO	oral	2 gen	decreased BW (F1)	LOAEL	7.28	0.00088	-	17207.7	-		[64]
Sprague-Dawley	500	APFO	oral	2 gen	decreased BW (F1)	EC10	0.96	0.00658	-	17207.7	-	5	[64]
Sprague-Dawley	575	APFO	oral	2 gen	decreased BW (F0)	NOAEL	2.87	0.0009	-	17207.7	-		[64]
Sprague-Dawley	542	APFO	oral	2 gen	decreased BW (F0)	LOAEL	6.9	0.00266	-	17207.7	-		[64]
Sprague-Dawley	524	APFO	oral	2 gen	decreased BW (F0)	EC10	9.58	0.00632	-	17207.7	-	5	[64]
Sprague-Dawley	513	APFO	oral	2 gen	decreased litter weight, delayed sexual maturation	NOAEL	28.74	0.0087	-	17207.7	-		[64]
Sprague-Dawley	432	APFO	oral	2 gen	decreased litter weight, delayed sexual maturation	LOAEL	1.5	0.0249	-	17207.7	-		[64]
Sprague-Dawley	500	APFO	oral	2 gen	BW change (F1)	LBMD10	5.2	0.00136	-	17207.7	-		[64] in [66]
Sprague-Dawley	524	APFO	oral	2 gen	BW change (F0)	LBMD10	0.96	0.00476	-	17207.7	-		[64] in [66]
CD	477.3	APFO	oral	14 d	decreased BW	NOAEL	9.58	0.00085	-	17207.7	-		[97]
CD	429.9	APFO	oral	14 d	decreased BW	LOAEL	12.07	0.00829	-	17207.7	-		[97]
CD	429	APFO	oral	14 d	decreased BW	EC10	47.91	0.01044	-	17207.7	-	5	[97]

Strain	BW [g]	TC	Route	E	Effect	Criterion	Value as dietary dose PFOA [mg/kg$_{bw}$/d]	Cnorm dose [mg/kJ]	Value as diet conc PFOA [mg/kg feed]	ECdiet [kJ/kg]	Cnorm diet [mg/kJ]	N	Ref
CD	367.5	APFO	oral	14 d	dDecreased BW	-	95.82	0.03964	1193.55	17207.7	0.06936		[97]
CD IGS	193.7	APFO	oral	GD6-15	mortality	LOAEL	1.83	0.06605	1078.76	17207.7	0.06269	6	[98]
Crl: CD BR	531	APFO	diet	91 d	decreased BW	NOAEL	6.23	0.00168	28.74	17207.7	0.00167		[99]
Crl: CD BR	494	APFO	diet	91 d	decreased BW	LOAEL	6.39	0.00561	95.82	17207.7	0.00557		[99]
Crl: CD BR	492	APFO	diet	91 d	decreased BW	EC10		0.00574	98.3	17207.7	0.00571	5	[99]
Crl: CD BR	494	APFO	diet	91 d	BW change	LBMD10	-	0.0027	-	17207.7	-	7	[99] in [66]
-	-	APFO	oral	GD6-15	decreased BW	-	-	-	-	-	-	8	[100]
Sprague-Dawley	-	APFO	diet	2 y	decreased BW	-		-	-	-	-		[101]

Notes

1 At day 23 rats were injected with sheep red blood cells, but similar trends on body weight were already observed before day 23, starting at the beginning of the study.

2 Derived using GraphPad Prism v7; At day 23 rats were injected with sheep red blood cells, but similar trends on body weight were already observed before day 23, starting at the beginning of the study.

3 EC10 could not be derived (only 2 concentrations tested), but likely above 7.6 mg/kg bw/d (Butenhoff 2004); Type of diet is not clearly reported.

3 EC10 could not be derived (only 2 concentrations tested), but likely above 7.6 mg/kg bw/d (Butenhoff 2004); Type of diet is not clearly reported.

4 Conducted in two similar experiments

5 Derived using GraphPad Prism v7

6 Based on initial body weight (151 - 198 g) and weight gain during exposure; Most concentrations were submitted through inhalation.

7 Palazzolo et al. (1993) as referred to in Butenhoff et al. 2004 is similar to data reported by Perkins et al. (2004).

8 Study is not publicly available.

Annex 4. Detailed aquatic ecotoxicity data

Legend to column headings	
Prop	Species properties
A	test water analysed Y(es)/N(o)
TT	Test type: S = static; R = renewal; F = flow through; c = closed
TC	Test compound
P	Purity: refers to purity of active substance or content of active substance in formulation; ag = analytical grade; tg = technical grade
TW	Test water: am = artificial medium; dtw = dechlorinated tap water; dw = deionised/dechlorinated/distilled water; nw = natural water; rw = reconstituted water; rtw = reconstituted tap water; tw = tap water
T	temperature
E	Exposure duration
N	Notes
Ri	Reliability index according to . Valid studies (Ri 2 or higher) are considered for EQS-derivation, depending on relevance and considering notes on data treatment. * indicates that result most likely refers to the same study.

Table A4.1. Overview of acute laboratory ecotoxicity data for freshwater organisms included in the Italian EQS-dossier. Additional information added for the present assessment is indicated in red. Italian data are taken over from the Supporting Information published with Valsecchi et al. [8], presentation of the data is adapted to the default headings of Dutch EQS reports.

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Cynaobacteria																
Anabaena	CPB4337	Y		PFOA	96					24 h	bioluminescence	EC50	19.81	2	1	[102]
Anabaena	CPB4337	N	S	PFOA	96	am		7.8	28	24 h	bioluminescence	EC50	78.88	2	2	[103]
Geitlerinema amphibium		N		PFOA			8	7.6-7.8	20	72h	biomass	EC50	247.8	2	3	[104]
Algae																
Chlamydomonas reinhardtii		N		PFOA	>96%			6.8	25±1	96 h	growth inhibition	EC50	51.9	2	4	[105]
Chlorella vulgaris		N		PFOA			8	7.6-7.8	20	72 h	biomass	EC50	974.82	2	5	[104]

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Pseudochirchneriella subcapitata		Y		PFOA			34	6-9	22.6-23.8	72 h	growth rate, biomass	EC50	>400	1	6	[4]
Pseudochirchneriella subcapitata		Y		PFOA			34	6-9	22.6-23.8	96 h	growth rate, biomass	EC50	>400	1	6	[4]
Pseudochirchneriella subcapitata		Y		PFOA	96					72	growth inibition (biomass)	EC50	96.2	3	7	[106]
Pseudochirchneriella subcapitata		Y		APFO	99.7				21-25	72 h	growth rate, biomass	EC50	>100	1	8	[107]
Pseudochirchneriella subcapitata		Y		APFO	99.7				21-25	96 h	growth rate, biomass	EC50	>100	1	8	[107]
Pseudochirchneriella subcapitata		N		PFOA	96				18±2	4.5 h	photosynthesis	EC50	746.4	2	9	[70]
Scenedesmus obliquus		N		PFOA	>96%			6.8	25±1	96 h	growth inhibition	EC50	44	2	4	[105]
Scenedesmus quadricauda		Y		PFOA	99	dtw	190	7	22±2	96 h	growth inhibition	EC50	269.63	2	10	[108]
Crustacea																
Chydorus sphaericus		Y		PFOA	96				20±1	24 h	immobilization	EC50	175.96	1	11	[109]
Chydorus sphaericus		Y		PFOA	96				20±1	48 h	immobilization	EC50	116.48	1	11	[109]
Chydorus sphaericus	<24 h old	N	S	PFOA		am			20	48 h	immobility	EC50	91.1	2	12	[110]
Daphnia magna		N		PFOA					21±1	24 h	immobilization	EC50	675.05	1	13	[111]
Daphnia magna		N		PFOA					21±1	48 h	immobilization	EC50	476.52	1	13	[111]
Daphnia magna		N		APFO			289	7.64-8.17	19.6-20.3	48 h	immobilization	EC50	480	1	6	[4]
Daphnia magna		N		APFO	99.7				18-22	48 h	immobilization	EC50	480	1*	14	[107]
Daphnia magna		Y		PFOA	96				20±1	24 h	immobilization	EC50	219.33	1	12	[109]
Daphnia magna		Y		PFOA	96				20±1	48 h	immobilization	EC50	211.07	1	12	[109]
Daphnia magna		N		PFOA	> 98			7.82	25±2	24 h	immobilization	EC50	298	2	15	[71]
Daphnia magna		N		PFOA	> 98			7.82	25±2	48 h	immobilization	EC50	181	2	15	[71]
Daphnia magna		Y		PFOA	99	dtw	190	7	22±2	48 h	mortality	LC50	201.85	2	16	[108]
Macrobrachium nipponense		Y		PFOA	99	dtw	190	7	22±2	96 h	mortality	LC50	366.66	2	10	[108]
Moina Macrocopa		N		PFOA					25±1	24 h	immobilization	EC50	348.76	1	14	[111]
Moina Macrocopa		N		PFOA					25±1	48 h	immobilization	EC50	199.51	1	14	[111]

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Neocaridina denticulata		N		PFOA	> 98				25±2	24 h	mortality	LC50	> 1000	2	17	[71]
Neocaridina denticulata		N		PFOA	> 98				25±2	48 h	mortality	LC50	712	2	17	[71]
Neocaridina denticulata		N		PFOA	> 98				25±2	72 h	mortality	LC50	546	2	17	[71]
Neocaridina denticulata		N		PFOA	> 98				25±2	96 h	mortality	LC50	454	2	17	[71]
Rotifera																
Brachionus calyciflorus		Y		PFOA	96				20	24 h	mortality	LC50	150	2	18	[112]
Insecta																
Chironomus tentans		N	R	PFOA	>97	am			23	10 d	mortality	NOEC	≥ 100	2	19	[113]
Chironomus plumosus		Y		PFOA	99	dtw	190	7	22±2	96 h	mortality	LC50	402.24	2	10	[108]
Gastropoda																
Cipangopaludina cathayensis		Y		PFOA	99	dtw	190	7	22±2	96 h	mortality	LC50	740.07	2	10	[108]
Physa acuta		N	S	PFOA	> 98				25±2	24 h	mortality	LC50	856	2	17	[71]
Physa acuta		N	S	PFOA	> 98				25±2	48 h	mortality	LC50	732	2	17	[71]
Physa acuta		N	S	PFOA	> 98				25±2	72 h	mortality	LC50	697	2	17	[71]
Physa acuta		N	S	PFOA	> 98				25±2	96 h	mortality	LC50	672	2	17	[71]
Mollusca																
Lampsilis siliquoidea	glochidia	Y	S	PFOA	96	am	150	8.5	19.2	48 h	viability (shell closure)	LC50	162.6	2	20	[77]
Lampsilis siliquoidea	juvenile	Y	R	PFOA	96	am	150	8.5	20	96 h	mortality	LC50	>500	2	21	[77]
Ligumia recta	glochidia	Y	S	PFOA	96	am	150	8.5	19.2	48 h	viability (shell closure)	LC50	161.3	2	20	[77]
Ligumia recta	juvenile	Y	R	PFOA	96	am	150	8.5	20	96 h	mortality	LC50	>500	2	21	[77]
Plathylminthes																
Dugesia japonica		N		PFOA	> 98				25±1	24 h	mortality	LC50	548	2	22	[114]
Dugesia japonica		N		PFOA	> 98				25±1	48 h	mortality	LC50	536	2	22	[114]
Dugesia japonica		N		PFOA	> 98				25±1	72 h	mortality	LC50	519	2	22	[114]
Dugesia japonica		N		PFOA	> 98				25±1	96 h	mortality	LC50	458	2	22	[114]
Dugesia japonica		N		PFOA	> 98				25±2	24 h	mortality	LC50	352	2	23	[71]
Dugesia japonica		N		PFOA	> 98				25±2	48 h	mortality	LC50	345	2	23	[71]
Dugesia japonica		N		PFOA	> 98				25±2	72 h	mortality	LC50	343	2	23	[71]
Dugesia japonica		N		PFOA	> 98				25±2	96 h	mortality	LC50	337	2	23	[71]
Annelida																

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Limnodrilus hoffmeisteri		Y		PFOA	99	dtw	190	7	22±2	96 h	mortality	LC50	568.2	2	10	[108]
Amphibia																
Bufo gargarizans		Y		PFOA	99	dtw	190	7	22±2	96 h	mortality	LC50	114.74	2	10	[108]
Pisces																
Carassius auratus	27.85±3.25 g	N	F	PFOA	>98	dtw	174.3	7.25	23 ± 2	96 h	mortality	LC50	> 5.0	3	24	[115]
Carassius auratus		Y		PFOA	99				22±2	96 h	mortality	LC50	606.61	2	10	[108]
Cyprinus carpio		A	F	PFOA	99.8	am	47.8	6.9	23	96 h	mortality	LC50	>55.6	2	25	[116]
Cyprinus carpio		A	F	PFOA	99.8	am	47.8	6.9	23	96 h	growth	NOEC	≥ 55.6	2	25	[116]
Oncorhynchus mykiss		N		PFOA			162-164	7.32-7.88	14.7-15.4	96 h	mortality	LC50	707	1	6	[4]
Oncorhynchus mykiss		Y		APFO			110-140	7.1-7.2	11.6-12.1	96 h	mortality	LC50	800	1	6	[4]
Pseudorasbora parva		Y		PFOA	99	dtw	190	7	22±2	96 h	mortality	LC50	365.02	2	10	[108]

Notes

1 Well documented studies. The PFOA stability was evalutated according to OECD GL 23 (2002) and chemical concentrations are also measured by analitical method. However, the toxicity test was conducted in accordance to author's laboratory-developed method. The test range concentration of PFOA is not reported.

2 Concentrations not measured; authors claim stability in view of previous experiments and physico-chemical properties; exposure in microtiter plates

3 Quite well documented study. Highest purity commercially available. The study was conducted in accordance with ISO 10253. Some changes included in the test performance are accurately documented. However, the study lacks analytical measurement of test substance concentrations in the test solution and the exposure of algae to toxicant was performed in glass flasks.

4 Well documented, meets validity criteria of the test. However, analytical confirmation of tested concentrations is not present.

5 Quite well documented study . The study was conducted in accordance with ISO 10253. Some changes included in the test performance are accurately documented. However, the study lacks analytical measurement of test substance concentrations in the test solution and the exposure of algae to toxicant was performed in glass flasks.

6 Based on OECD reliability

6 Based on OECD reliability

7 The study is not completely documented. Despite authors claim that PFOA toxicity was determined according to OECD TG 201, they omitted the most part of information concerning test conditions (we can only suppose the EC50 value is referred to biomass). The study was conducted with PFOA nominal concentration, because the analyses performed at the beginning and at the end of the test, did not show significant deviations. The range and the number of tested concentrations are not reported.

8 Well documented study meets validity criteria of the test. APFO stability and test concentrations are assessed by analytical method. Changes regarding test conditions are accurately documented

9 Quite well documented, meets validity criteria of the test. The chemical concn are nominal. The high toxicity (more than expected) with alga is

probably due to acidification of the test solution. NL comment: Because the relationship between short-term inhibition of photosynthesis and traditional growth rate endpoints is not clear, the endpoint is not included in the dataset.
1 Not very well documented study in relation to test conditions. Analytical confirmation of tested concentrations is present.
0
1 Well documented, meets validity criteria of the test and the chemical concentrations are also evalutated by analytical method.
1
1 Medium Dutch standard water; EC50 reported as 0.22 mM = 91.1 mg/L; concentrations not measured; raw data available
2
1 Well documented study, meets validity criteria of the test. Analytical confirmation of test substance concentrations was not conducted, but on the
3 base of the low exposure times and the used test conditions, the chemical degradation during exposure was not probable
1 Well documented study meets validity criteria of the test. While analytical confirmation of test substance concentrations was not conducted, "the
4 test substance is expected to be stable under the condition of the test".
1 Not considered reliable in Italian assessment, but assigned Ri2 in RIVM EQS-report on PFOS. Italian comment: The study do not meet validity
5 criteria of the test: too high temperature (25°C) and low oxigen concentration(< 60%) at the end of the exposure,low conductivity of tested solution. These conditions may be lethal for the organisms. The analytical confirmation of tested concentrations is not present, but on the base of the low exposure times and the used test conditions, the chemical degradation during exposure was not probable. RIVM comment: test is well described and it is reported that no control mortality occurred.
1 Not very well documented study in relation to test conditions. The reference method is unclear. Analytical confirmation of tested concentrations is
6 present.
1 Not considered reliable in Italian assessment, but assigned Ri2 in RIVM EQS-report on PFOS. Italian comment: In this study is not possible to verify
7 the validity criteria of the test: the reference method (Taiwan EPA, 2005) is not evaluable (chinese), the test conditions are not evaluable. Nominal tested concentrations are used, but a 96 h time exposure does not guarantee the test substance stability. RIVM comment: test is well described and it is reported that no control mortality occurred except 10% mortality in one treatment. Test substance stability is not considered an issue for PFOA.
1 In this study is not possible to verify the validity criteria of the test: the reference method is not reported and the species is not well known for
7 application in toxicity studies. Nominal tested concentrations are used, but a 96 h time exposure does not guarantee the test substance stability.
1 Well documented study, meets validity criteria of the test. Analytical confirmation of test substance concentrations was conducted.
8
1 Evaluated in the RIVM EQS-report on PFOS; semi-acute study in presence of clean sand
9
2 Cell viability measured as cell closure in response to NaCl; initial concentrations within 10% of nominal
0
2 Initial concentrations within 10% of nominal; renewal of 90% of the volume after 48 h
1
2 Not considered reliable in Italian assessment, but assigned Ri2 in RIVM EQS-report on PFOS. Italian comment: In this study is not possible to verify
3 the validity criteria of the test: the reference method is not reported and the species is not well known for application in toxicity studies. Nominal tested concentrations are used, but a 96 h time exposure does not guarantee the test substance stability. RIVM comment: test is well described and it is reported that no control mortality occurred except 10% mortality in one treatment. Test substance stability is not considered an issue for PFOA.
2 No mortality at 1.21 and 12.10 µmol/L; measured concentrations were 90 and 98% of nominal; PFOA concentration in control fish was 1621 ng/g,
4 PFOS 2580 ng/g; not clear if based on wet or dry weight, but breeding source is apparently contaminated and result is therefore considered not reliable
2 Study on biomarker responses, but length and weight also reported; no differences in weight and length at highest concentration; result based on
5 mean measured concentrations

Table A4.2. Overview of acute laboratory ecotoxicity data for marine organisms included in the Italian EQS-dossier. Data are taken over from the Supporting Information published with Valsecchi et al. [8], presentation of the data is adapted to the default headings of Dutch EQS reports.

Species	Prop	A	TT	TC	P	TW	Salinity $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Bacteria																
Photobacterium phosphoreum		N		PFOA					20	15 min	bioluminescence	EC50	14.65	3	1	[117]
Vibrio fischeri		N		PFOA	96				NR	30 min	bioluminescence	EC50	570.19	3	1	[118]
Vibrio fischeri		N		PFOA	96				18	15 min	bioluminescence	EC50	524	3	2	[106]
Algae																
Isochrysis galbana		N		PFOA	98				20	72 h	growth inhibition	EC50	163.6	2	3	[119]
Skeletonema marinoi		N	S	PFOA			8	7.6-7.8	20	72 h	biomass	EC50	367.52	2	4	[104]
Crustacea																
Siriella armata		N		PFOA	98		34.4-35.9		20	96 h	mortality	LC50	15.5	2	5	[119]
Echinodermata																
Paracentrotus lividus		N		PFOA	98				20	48 h	growth inhibition	EC50	110	2	6	[119]
Pisces																
Psetta maxima		N		PFOA	98		34		18	144h	mortality	LC50	11.9	2	6	[119]

Notes
1 Not well documented study. The essential information to assess data are not present
2 The study is not completely documented. Despite authors claim that PFOA toxicity was determined according to ISO 11348-3, they omitted the most part of information concerning test conditions. The study was conducted with PFOA nominal concentration, but the range or the number of tested concentrations are not reported.
3 Quite well documented study. The study was conducted according to modified OECD GL 201. However, the study lacks analytical measurement of test substance concentrations.
4 Quite well documented study . Highest purity commercially available. The study was conducted in accordance with ISO 10253. Some changes included in the test performance are accurately documented. However, the study lacks analytical measurement of test substance concentrations in the test solution and the exposure of algae to toxicant was performed in glass flasks.
5 Quite well documented study. However, the study was conducted according to laboratory-developed method and with captured organisms. In addition, the study lacks analytical measurement of test substance concentrations.
6 Quite well documented study. However, the study was conducted according to laboratory-developed method. In addition, the study lacks analytical measurement of test substance concentrations.

Table A4.3. Overview of chronic laboratory ecotoxicity data for freshwater organisms included in the Italian EQS-dossier. Additional information added for the present assessment is indicated in red. Italian data are taken over from the Supporting Information published with Valsecchi et al. [8], presentation of the data is adapted to the default headings of Dutch EQS reports.

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Cyanobacteria																
Anabaena	CPB4337	N	S	PFOA	96	am		7.8	28	24 h	bioluminescence	EC10	49.05	2	1	[103]
Anabaena	CPB4337	N	S	PFOA	96	am		7.8	28	24 h	bioluminescence	NOEC	30	2	1	[103]
Algae																
Pseudochirchneriella subcapitata		Y		PFOA			34	6-9	22.6-23.8	72 h	growth rate, biomass	NOEC	200	1	2	[4]
Pseudochirchneriella subcapitata		Y		APFO	99.7				21-25	72 h	growth rate, biomass	NOEC	200	1*	3	[107]
Pseudochirchneriella subcapitata		Y		PFOA			34	6-9	22.6-23.8	96 h	growth rate, biomass	NOEC	12.5	1	2	[4]
Pseudochirchneriella subcapitata		Y		APFO	99.7				21-25	96 h	growth rate, biomass	NOEC	12.5	1*	3	[107]
Pseudokirchneriella subcapitata		N		PFOA	96				18±2	4.5 h	photosynthesis	NOEC	413.06	2	4	[70]
Crustacea																
Daphnia magna		Y		APFO			255-289	7.56-8.26	18.4-20.4	21 d	growth (as length)	NOEC	44.2	1	2	[4]
Daphnia magna		Y		APFO	99.7				18-22	21 d	growth (as length)	NOEC	44.2	1*	5	[107]
Daphnia magna		N		PFOA	96				21±1	21 d	reproduction	NOEC	12.5	1	6	[111]
Daphnia magna		N		PFOA	> 98				20±1	21 d	survival	NOEC	>100	2	7	[120]
Daphnia magna		N		PFOA	> 98				20±1	21 d	reproduction	NOEC	10	2	7	[120]
Daphnia magna		Y		APFO			255-289	7.56-8.26	18.4-20.4	21 d	reproduction	NOEC	20	1	2	[4]
Daphnia magna				APFO			240	7.8	22	21 d	reproduction rate	NOEC	22	2	2	[4]

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Daphnia magna				APFO			240	7.8	22	14 d	reproduction	NOEC	8	2	2	[4]
Daphnia magna				APFO			240	7.8	22	14 d	survival	NOEC	60	2	2	[4]
Daphnia magna		Y		PFOA	99		190		22±2	21 d	survival	LC10	11.12	2	8	[108]
Daphnia magna		Y		PFOA	99		190		22±2	21 d	reproduction	EC10	7.02	2	8	[108]
Moina macrocopa		N		PFOA	96				25±1	7 d	reproduction	NOEC	3.125	1	6	[111]
Rotifera																
Brachionus calyciflorus	<2 h old	Y	R	PFOA	96	dw			20	4 d	intrinsic rate of population increase	NOEC	4	2	9	[121]
Brachionus calyciflorus	<2 h old	Y	R	PFOA	96	dw			20		mictic ratio of F1	LOEC	0.25	3	10	[121]
Brachionus calyciflorus	resting eggs	Y	R	PFOA	96	dw			20	6 d	hatching rate	NOEC	0.25	3	11	[121]
Brachionus calyciflorus	resting eggs	Y	R	PFOA	96	dw			20	6 d	time to hatch	NOEC	<0.125	3	12	[121]
Brachionus calyciflorus	resting eggs	Y	R	PFOA	96	dw			20	6 d	hatching rate	NOEC	0.25	2	13	[121]
Brachionus calyciflorus	resting eggs	Y	R	PFOA	96	dw			20	6 d	time to hatch	NOEC	<0.125	3	14	[121]
Brachionus calyciflorus	F0	Y	R	PFOA	97	dw			20	3 d	resting egg formation	EC10	0.07	2	15	[121]
Amphibia																
Bufo gargaarizans		Y		PFOA	99				22±2	30 d	mortality	LC10	5.89	2	8	[108]
Pisces																
Danio rerio	embryo, 6-8 hpf	N	R	PFOA		am			26	120 h	malformations	NOEC	≥ 33	2	16	[122]
Danio rerio	embryo	N	S	PFOA	95	am		8.3	28.5	72 h	mortality	LC50	262	2	17	[123]
Danio rerio	embryo	N	S	PFOA	95	am		8.3	28.5	96 h	malformations	EC50	198	2	17	[123]
Danio rerio	embryo	N		PFOA	≥ 97			7.2-7.5	26±0.3	96 hpf	mortality	LC50	>500	2	18	[124]

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Danio rerio	embryo	N		PFOA	≥ 97			7.2-7.5	26±0.3	96 hpf	malformations, growth	EC50	205.72	2	18	[124]
Danio rerio	embryo	N		PFOA	≥ 97			7.2-7.5	26±0.3	96 hpf	malformations, growth	NOEC	75	2	18	[124]
Danio rerio	embryo	N		PFOA	≥ 97			7.2-7.5	26±0.3	120 hpf	mortality	LC50	>500	2	18	[124]
Danio rerio	embryo	N		PFOA	≥ 97			7.2-7.5	26±0.3	120 hpf	malformations, growth	EC50	113.05	2	18	[124]
Danio rerio	embryo	N		PFOA	≥ 97			7.2-7.5	26±0.3	120 hpf	malformations, growth	NOEC	50	2	18	[124]
Danio rerio	embryo	N		PFOA	99				26±1	144 hpf	mortality	LC50	430	2	19	[26]
Danio rerio	embryo	N		PFOA	99				26±1	144 hpf	mortality, malformations	EC50	350	2	19	[26]
Gobiocypris rarus	9 m old, 1.3 g	N	F	PFOA	98	dtw			25 ± 2	14 d	adverse effects	NOEC	≥ 30	2	20	[125]
Gobiocypris rarus	9 m old, 1.4 g, 47.7 mm	N	F	PFOA	98	dtw			25 ± 2	28 d	mortality	NOEC	≥ 30	2	21	[126]
Oncorhynchus mykiss		Y		APFO			140-168	7.36-8.10	11.1-14.4	85 d	mortality, growth (length)	NOEC	40	1	2	[4]
Oncorhynchus mykiss		Y		APFO	99.7		150	6.0-8.5	11.1-14.4	85 d	mortality	NOEC	40	1	5	[107]
Pimephales promelas		N		PFOA	NR		31-38	7.0-7.3	25	30 d	hatchability, survival, growth, histopathology	NOEC	≥ 100	2	2	[4]
Pseudorasbora parva		Y		PFOA	99				22±2	30 d	survival	LC10	11.78	2	8	[108]
Salmo salar	eggs	N	F	PFOA	95				5-7	52 d	hatching, weight, length	NOEC	≥0.1	3	22	[127]

Species	Prop	A	TT	TC	P	TW	Hardness $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Salmo salar	eggs	N	F	PFOA	95				5-7	52 d	hatching, weight, length	NOEC	≥0.1	3	22	[128]

Notes
1 concentrations not measured; authors claim stability in view of previous experiments and physico-chemical properties; exposure in microtiter plates
2 Based on OECD reliability
3 Well documented study meets validity criteria of the test. APFO stability and test concentrations are assessed by analytical method. Changes regarding test conditions are accurately documented
4 Quite well documented, meets validity criteria of the test. The chemical concn are nominal. The high toxicity (more than expected) with alga is probably due to acidification of the test solution. NL comment: Because the relationship between short-term inhibition of photosynthesis and traditional growth rate endpoints is not clear, the endpoint is not included in the dataset.
5 Quite well documented study, meets validity criteria of the test. Stability and substance concentrations are confirmed by chemical analysis during the tests
6 Quite well documented study, meets validity criteria of the tests. Although the PFOA concentration are nominal, the renewal of the test solutions every 3 days guarantees the stability of the substance.
7 Quite well documented study. Although the PFOA concentration are nominal, the renewal of the test solutions every 3 days guarantees the stability of the substance.
8 Not very well documented study in relation to test conditions. The reference method is unclear. Analytical confirmation of tested concentrations is present.
9 B. calyciflorus can produce multiple broods and the F1 generation also produces neonates in 4 d, therefore test is chronic; <5% variation in measured concentration over 24 h
1 exposure duration not clear; mictic ratio is an indicator for a shift from asexual to sexual reproduction; sexual reproduction is induced by
0 suboptimal conditions; relevance of endpoint for population development is not fully clear
1 F0 was exposed, eggs were collected after 6 d and incubated; no consistent effect: significant increase at 0.25 and 1 mg/L, decrease at 0.5 mg/L
1
1 F0 was exposed, eggs were collected after 6 d and incubated; no consistent effect: significant delayed hatching at concentrations 0.125-0.5 and 2.0
2 mg/L, but not at 1 mg/L
1 exposure during hatching; significantly lower hatching at 0.5 mg/L and higher
3
1 exposure during hatching; reduced hatching time at all concentrations, but not indicated if difference is significant
4
1 EC10 estimated from digitised graph; resting egg production in natural communities is variable due to environmental stressors, authors argue that
5 PFOA may inhibit resting egg production to reach normal levels, but the relevance of 10% reduction in resting eggs for population development is not fully clear

1 hpf = hours post fertilisation; short-term test, but in view of life stage endpoint is considered chronic; no analysis of test concentrations; daily
6 renewal; 16:8 h L:D; solvent DMSO, 0.4% v/v, solvent control included; exposure 120 h post fertilization (hpf), assessment 144 hpf after 1 day wash-out in medium; no effects at 80 µM = 33 mg/L
1 short-term test, but in view of life stage endpoint is considered chronic; no analysis of test concentrations
7
1 Well documented, meets validity criteria of the test. Nominal test concentrations are used. hpf= hours post fertilisation
8
1 Quite well documented and meets validity criteria of the test. Nominal test concentrations are used. hpf= hours post fertilisation
9
2 16:8 h L:D; pH and hardness not reported; no decrease in food consumption or other adverse effects observed during the experiment; no analytical
0 verification of test concentrations
2 16:8 h L:D; pH and hardness not reported; no mortality; no verification of test concentrations
1
2 eggs and larvae were exposed for 52 d to 100 µg/L; 33% of volume was renewed per week, continuous flow after hatching (day 20) until end of
2 exposure (day 48); only one concentration tested, no analytical measurements; water type not indicated; solvent methanol (0.01% v/v); solvent control included

Table A2.4. Overview of chronic laboratory ecotoxicity data for marine organisms included in the Italian EQS-dossier. Additional information added for the present assessment is indicated in red. Italian data are taken over from the Supporting Information published with Valsecchi et al. [8], presentation of the data is adapted to the default headings of Dutch EQS reports.

Species	Prop	A	TT	TC	P	TW	Salinity $CaCO_3$ [mg/L]	pH	T [°C]	E	Test endpoint	Criterion	Value [mg/L]	Ri	N	Ref.
Algae																
Isochrysis galbana		N			98				20	72 h	growth inhibition	EC10	41.6	2	1	[119]
Isochrysis galbana		N			98				20	72 h	growth inhibition	NOEC	25	2	1	[119]
Mytilus galloprovincialis	fertilised eggs	Y	S	PFOA		am	36	7.9-8.1	16 ± 1	48 h	# D-shaped larvae	NOEC	0.01	2	2	[76]
Mytilus galloprovincialis	fertilised eggs	Y	S	PFOA		am	36	7.9-8.1	16 ± 1	48 h	# D-shaped larvae	LOEC	0.1	2	2	[76]

Notes
1 Quite well documented study. The study was conducted according to modified OECD GL 201. However, the study lacks analytical measurement of test substance concentrations.
2 17% decrease in normal D-shaped larvae at 0.1 µg/L, 40% at 100 µg/L, no further decline at higher concentrations; actual concentration at 0.1 µg/L was 81% of nominal

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