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Proposed Environmental Quality Standards (EQSs) for blue mussel (*Mytilus edulis*)

Photograph: Janne K. Gitmark, NIVA

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Summary - sammendrag

The Norwegian Environment Agency recognizes the need to further develop Environmental Quality Standards (EQSs) under EU's Water Framework Directive. As one step in this direction the Norwegian Institute for Water Research (NIVA) was tasked to propose EQSs for a selection of contaminants in blue mussel (Mytilus edulis). The proposed EQS are derived either from the current EQS for coastal water, using a bioconcentration factor (BCF) or bioaccumulation factor (BAF) that is most relevant for blue mussel, or from the current EQS for biota, e.g. by correcting for a lower trophic level than fish. EQS are proposed for 24 selected contaminants that included six metals, 16 PAH compounds and two perfluorinated alkylated substances. The practical applicability of a few are questionable.

4 emneord

Marine organismer
Blåskjell
Miljøkvalitetsstandarder
Miljøgifter

4 subject words

Marine organisms
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Content

1. Preface

One purpose of EU's Water Framework Directive is to ensure good environmental quality in water. The chemical status, as well as the ecological status in part, of a water body is determined by contaminant concentrations found and how they compare to so called Environmental Quality Standards (EQS). EQS are established for water, and to a lesser degree also for sediment and organisms (biota). Development of EQS is ongoing and this report is a contribution to this progress. It presents suggested EQS for the blue mussel.

This investigation was prompted and funded by the Norwegian Environment Agency as part of the implementation of the Water Framework Directive in Norway with regard to contaminants in marine waters. The investigation was initiated and completed during the autumn of 2020 and early winter of 2021 by the Norwegian Institute for Water Research (NIVA). The coordinator at the Norwegian Environment Agency was Rune Pettersen and the project manager at NIVA was Norman W. Green. Anders Ruus was mainly responsible for deriving the suggested EQS from the literature. Jonny Beyer was mainly responsible for collecting and screening relevant literature. The report was quality assured by Marianne Olsen.

Oslo, 5 February 2021

Norman W. Green
Project Manager
NIVA

2. Abbreviations and terms

Abbreviations and terms	
Acronym	**Explanation**
AA	Annual average
ACNE	Acenaphthene
ACNLE	Acenaphthylene
ANT	Anthracene
As	Arsenic
BAA	Benzo[a]anthracene
BAF	Bioaccumulation Factor
BAP	Benzo[a]pyrene
BBF	Benzo[b]fluoranthene
BCF	Bioconcentration Factor
BGHIP	Benzo[g,h,i]perylene
BKF	Benzo[k]fluoranthene
BMF	Biomagnification factor
bw	Body weight
Cd	Cadmium
CHR	Chrysene
Cr	Chromium
Cu	Copper
DBAHA	Dibenzo[a,h]anthracene
EC	European Commission
EC10	Effect Concentration observed for 10% of the population
EC50	Effect Concentration observed for 50% of the population
ECHA	European Chemicals Agency
EFSA	European Food Safety Authority
EQS	Environmental Quality Standard
EU	European Union
FLE	Fluorene
FLU	Fluoranthene
HC-5	Hazardous Concentration for 5% of species
Hg	Mercury
ICDP	Indeno[1,2,3-cd]pyrene
K_{ow}	Octanol-water partitioning coefficient

Abbreviations and terms

Acronym	Explanation
LC10	Lethal Concentration for 10% of the population
LC50	Lethal Concentration for 50% of the population
NAP	Naphthalene
NAP	Naphthalene
Ni	Nickel
NIVA	Norwegian Institute for Water Research
NOEC	No Observed Effect Concentration
PA	Phenanthrene
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
PROREF	Norwegian provisional high reference contaminant concentration
PS	Priority substance
PYR	Pyrene
QS	Quality Standard
RAR	Risk Assessment Report
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals [EU]
SCHER	Scientific Committee on Health and Environmental Risks [EU]
SS	Steady State
SSD	Species Sensitivity Distribution
TDI	Tolerable daily intake
TMF	Trophic Magnification Factor
TMS	Trophic magnification slope
TWI	Tolerable weekly intake
USEPA	United States Environmental Protection Agency
Zn	Zinc

3. Summary

With the application of the EU's Water Framework Directive in Norway there is an ongoing need to further develop Environmental Quality Standards (EQS) to assess the marine environment in order to achieve good environmental status. These should be applicable to both EU's priority substances and River Basin Specific substances. As step in this regard the Norwegian Environment Agency (Miljødirektoratet) requested that the Norwegian Institute for Water Research (NIVA) propose, if feasible, EQS for 28 contaminants in blue mussel (*Mytilus edulis*).

The proposed EQS for blue mussel for the aforementioned substances are based on published EQS_{biota} and EQS_{water}. As such, The $EQS_{blue\ mussel}$ is derived using a bioconcentration factor (BCF) or bioaccumulation factor (BAF) that is most relevant for blue mussel, or by correcting for a lower trophic position than fish. Calculations of EQS for blue mussel are based on EU documentation such as EU dossier/datasheets and Risk Assessment Reports (RAR) as well as national publications such as the guidelines for the application of the Water Framework Directive. In addition, we have done some exploratory literature review to better assess the relevance of the conversion factors (e.g. BCF, BAF) that we have chosen.

This report proposes EQS for 24 of the 28 substances including six metals and 16 PAH compounds (**Table 1**). Of the 24, 19 were higher than concentrations that would likely be found in less-impacted areas indicated by Provisional high reference contaminant concentration (PROREF, see factbox on page 13), suggesting them operational. On the other hand, one third of these are so high that practical applicability is questionable. Common for most of the hazardous substances of which the EQSs are judged likely too high to be operational is that they are deduced from acute water toxicity data (LC50; anthracene and pyrene), or EC10 (acenaphthylene, acenaphthene, fluorene), in combination with a BCF (necessarily also hampered with some uncertainty). Hence these EQS values should be applied with caution. A few EQSs, including those for mercury and arsenic, are lower than expected low reference concentrations (i.e. PROREF), thus the practical applicability is questionable (i.e. most areas will not achieve good status). The last two EQSs concern the PFAS compounds PFOS and PFOA where PROREF values in blue mussel have not been determined, and hence the applicability of these two proposed EQS was not fully conclusive.

Table 1: Proposed EQS for selected contaminants in blue mussel (*Mytilus edulis*).

Parameter code	Parameter name	Proposed EQS µg/kg wet weight	Comments regarding applicability
Hg	Mercury	**5.7**	Likely that monitoring results will exceed EQS because EQS is low.
Pb	Lead	**615**	
As	Arsenic	**210**	Likely that monitoring results will exceed EQS because EQS is low.
Cd	Cadmium	**199**	
Cr	Chromium	**425**	
Ni	Nickel	**2322**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is high.

Table 1:	Proposed EQS for selected contaminants in blue mussel (*Mytilus edulis*).		
Parameter code	**Parameter name**	**Proposed EQS µg/kg wet weight**	**Comments regarding applicability**
Zn	Zinc	**-**	
Cu	Copper	**-**	
BAP	Benzo[a]pyrene	**5**	
BBF	Benzo[b]fluoranthene	**5**	
NAP	Naphthalene	**54**	
FLU	Fluoranthene	**30**	
BKF	Benzo[k]fluoranthene	**5**	
BGHIP	Benzo[g,h,i]perylene	**5**	
ICDP	Indeno[1,2,3-cd]pyrene	**5**	
ANT	Anthracene	**254**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
BAA	Benzo[a]anthracene	**5**	
ACNLE	Acenaphthylene	**495**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
ACNE	Acenaphthene	**2888**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
FLE	Fluorene	**1527**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
PA	Phenanthrene	**2435**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
PYR	Pyrene	**30**	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is high.
CHR	Chrysene	**5**	
DBAHA	Dibenzo[a,h]anthracene	**5**	
PFOS	Perfluorooctanesulfonic acid	**0.36**	
PFOA	Perfluorooctanoic acid	**36**	

4. Sammendrag

*Med implementering av EUs Vanndirektiv i Norge er det stadig behov å videreutvikle miljøkvalitetsstandarder (*Environmental Quality Standards – *EQS). EQS brukes til å vurdere det marine miljøets oppnåelse av god miljøtilstand. Dette gjelder både EUs prioriterte stoffer og Norges vannregionspesifikkestoffer. Med hensyn på utvikling av EQS verdier, har Miljødirektoratet bedt Norsk institutt for vannforskning (NIVA) om å foreslå, om mulig, EQS for 28 miljøgifter i blåskjell (Mytilus edulis).*

De foreslåtte EQS-verdiene for blåskjell for de 28 miljøgiftene er basert på publisert EQS_{biota} *og* EQS_{vann}*. Da er* $EQS_{blåskjell}$ *beregnet ved bruk av en biokonsentreringsfaktor (BCF) eller bioakkumuleringsfaktor (BAF) som er mest relevant for blåskjell, eller ved korrigering for et lavere trofisk nivå enn fisk. Beregningene av EQS for blåskjell er basert på EU dokumentasjon som EU-dossier/dataark og risikovurderingsrapporter (*Risk Assessment Reports - RAR)*, så vel som nasjonale publikasjoner, som veiledere for implementering av Vanndirektivet. I tillegg har vi gjort noe litteratursøk for å bedre vurdere relevans av de omregningsfaktorene (f.eks. BCF og BAF) som vi har valgt.*

*Denne rapporten foreslår EQS for 24 av de 28 stoffene. Disse omfatter seks metaller og 16 PAH-forbindelser (***Table 1***). Av disse 24 var 19 høyere enn konsentrasjoner som antas finnes i områder fjernt fra punktkilder, hvilket antydes ved hjelp av «*Provisional high reference contaminant concentration» (PROREF, *se faktaboks på side 13)*. Dette tyder *på at disse EQS kan ha praktisk relevans. Imidlertid er en tredjedel av disse så høye at det kan stilles spørsmål til hvordan disse kan brukes til å vurdere miljøtilstand. Felles for de fleste stoffene som har EQS-verdier som sannsynligvis er for høye til at de er praktiske, er at de er utledet fra akutt-toksisitetsdata for vann (LC50; antracen og pyren), eller EC10 (acenaftylen, acenaften, fluoren), i kombinasjon med en BCF (som nødvendigvis også er beheftet med usikkerhet). Disse EQS-verdiene bør derfor anvendes med varsomhet. Noen EQSer, bl.a. for kvikksølv og arsen, er lavere enn PROREF, som leder til spørsmålet om hvor praktisk anvendbare de er (de fleste områder vil ikke oppnå god status). For PFOS og PFOA foreligger det ingen PROREF å sammenligne EQS-verdiene med.*

5. Introduction

With the implimentation of the Water Framework Directive (WFD) in 2000 (2000/60/EC 2000) and the consequent adoption in Norwegian legislation in 2006, the level of contamination could be assessed using a risk-based approach (2013/39/EU 2013). This was largely based on individual toxicological studies on some species, not always marine. Amount of available data (anduncertianty of relevance to the marine ecosystem) was compensated by assessment factors; the less data/more the uncertainty, the higher the assessment factor, lowering the concentration of the quality standard. These environmental quality standards (EQSs) are prevalent for contaminants in water and a few are also defined for organisms (i.e. biota), primarily fish. EQS for biota are currently not species or tissue specific. In this regard, the EU has developed technical guidance documents (CIS 2011a, 2014) so that each member state could opt for deriving their own EQS as long as these provided the same level of environmental protection (2013/39/EU 2013, see §17). Norway has supplemented EU's list of EQS with quality standards of their own for biota for other contaminants known as River Basin Specific substances (Direktoratsgruppen_vanndirektivet 2018; Arp et al. 2014; Norwegian_Environment_Agency 2016).

5.1 Background

Contaminants found in the environment have different attributes that impact how they are transmitted in the foodweb. Species and species-tissues will react differently when exposed to these contaminants. Many different factors can compound this reaction, such as ambient conditions and trophic position, age and life history of the organism. For example, lipophilic contaminants will tend to accumulate in the fatty tissue of organisms and reach detectable, even high, concentrations while the same contaminant may be hardly detectable at all in the water column. This is one reason monitoring of biota is often a preferred matrix, in particular fish and mussels. Monitoring of organisms can also be favourable because they represent exposure of a contaminant integrated over time or even geographically (e.g. through fish movement).

Considering biota as a well incorporated monitoring matrix, it is important that application of this matrix is as operational as possible. This is especially relevant when assessing the impact of contaminants on the environment and possible remedial action. As such, the Norwegian Environment Agency (Miljødirektoratet) is interested in establishing EQS relevant for specific organisms.

OSPAR (2016) has done an initial study on converting the EQS for mercury in biota (20 µg/kg wet weight) to an appropriate limit for each of the indicator species-tissues that the OSPAR monitoring programme uses. This was done by using the aforementioned EU technical guidance documents. This work-intensive study demonstrated that the conversion could be done but highlighted the uncertainties that were involved.

There are two main challenges with these quality standards for contaminants in biota that prevent them from being easily applied. The first, as mentioned, is that they are generally not species- or tissue-specific but refer to whole organisms. To address this, the monitoring programme must either analyse the whole organism, currently done for blue mussel (*Mytilus edulis*[1]) but not for fish where liver and fillet are monitored, or convert the concentrations found to apply to the whole organisms. The latter was tested for mercury on the indicator species-tissues that OSPAR applies (OSPAR 2016). The study revealed that with conversion applying EU's technical guidance documents (CIS 2011a, 2014), 99 % of the OSPAR data exceeded the EQS and would not be compliant. Furthermore, they concluded that a goal to reduce this portion significantly would not be feasible. The authors note that the EQS approach is not readily extendable to the marine environment and that bioaccumulation factors and trophic magnification factors, which are key variables for the conversion, should not be generic, but rather species/region specific. EQS in general apply to fish, and to apply an EQS for a contaminant which demonstrates trophic magnifications to a species at a lower trophic level, e.g. blue mussel, the EQS will be lower. OSPAR (2016) showed that direct application of the EQS to shellfish resulted in a significant number of exceedences. Hence, applying a lower EQS to species at a lower trophic level would only show a worse environmental status.

The second main challenge is that it is in conflict with different classification systems based on concentrations expected in less impacted areas, such as the Norwegian provisional high reference contaminant concentrations (PROREF, see fact-box) developed through the MILKYS programme. For example for mercury the EQS is 20 µg/kg w.w. whereas PROREF is 12 µg/kg w.w. for blue mussel and 56 µg/kg w.w. for cod fillet, and for hexachlorobenzene (HCB) the EQS is 10 µg/kg w.w., whereas PROREF is 0.1 µg/kg w.w. for blue mussel and 14 µg/kg w.w. for cod liver (Green et al. 2020). In other words, the quality standards appear to be too lax for Hg and HCB if applied directly to blue mussel, but too stringent (too low) if applied directly to tissues commonly monitored in cod.

If the proposed EQS deviates strongly from the concentrations we expect to find in unimpacted areas (based on monitoring data, e.g. PROREF), the application of EQSs with respect to regulation, or remedial action, should be done with caution. Otherwise it is considered operational.

The implementation of any system to assess anthropogenic impact should be a tool to guide management towards achieving a better environment. The system should be fact-based and provide enough nuance to be operational. A risk-based system and a classification that has been based on presumed background levels have each their merits and can be useful tools. However, the usefulness of current risk-based quality standards should be improved to be more operational.

[1] In this study, no distinction is made among other *Mytilus* species that have been identified in Norwegian waters, i.e. *M. trossulus* and *M. galloprovincialis* (Brooks and Farmen 2013).

FACTBOX

NORWEGIAN PROVISIONAL HIGH REFERENCE CONTAMINANT CONCENTRATIONS (PROREF)

PROREF is a comprehensive set of species-tissue-basis-specific contaminant concentrations that are statistically low when considering all results from the Norwegian Environment Agency's monitoring programme "Contamiants in coastal waters of Norway" (MILKYS) for the period 1991-2015. This tool sets reference concentrations for contaminants, mostly in areas presumed remote from point sources of contamination, and thus provides a valuable method of assessment of levels of contaminants in addition to EQS. It was first introduced and compared with EQS in 2017 (Green et al. 2017) and slightly modified in 2019 (Green et al. 2019). MILKYS annual reports (Green et al. 2017; 2018; 2019; 2020), monitoring of industrial effluents (Schøyen et al. 2019; Øxnevad 2019a, 2019b) and national indicators for example for the Norwegian Sea (for *G. morhua** and *M. edulis***). Even so, PROREF values should be periodically reviewed in the light of additional results from reference or presumed background localities as well as the introduction of new analytical methods.

*)https://miljostatus.miljodirektoratet.no/tema/hav-og-kyst/havindikatorer/barentshavet/forurensende-stoffer/forurensning-i-torsk-i-barentshavet/
**)https://miljostatus.miljodirektoratet.no/tema/hav-og-kyst/havindikatorer/barentshavet/forurensende-stoffer/forurensning-i-blaskjell-langs-kysten-av-nordland-troms-og-finnmark/

The Norwegian Environment Agency recognizes that EQS in biota primarily concerns "fish" and sees the obvious need to develop EQS that are specific for other species, in particular sessile organisms. However, these are often at lower trophic levels than the fish, which implies the need to convert the EQS. Blue mussel has been and is commonly used in monitoring and indeed, a *Norsk Standard* has been established that is applicable to both mussels found naturally or transplanted (NS 2017). Furthermore, blue mussel has been recommended as an indicator species under national monitoring when implementing the Water Framework Directive (Direktoratsgruppen_vanndirektivet 2018). Hence, developing EQSs in blue mussel would further the effort to assess environmental status.

5.2 Purpose

Norwegian Environment Agency sees the need to develop species-specific EQS for other contaminants than those already adopted, and that these EQS would provide the same (or better) protection of the environment as EQS in water. In this regard, the agency would like to develop EQS in a sessile species at a low trophic level. Furthermore, the agency views this development as an operational tool when addressing possible remedial action where discharges to the marine environment are of concern.

This report investigates and, where possible, proposes EQS in blue mussel for 28 contaminants identified and prioritized by the agency (**Table 2**).

Table 2: Selection of pollutant substances for which improved knowledge of bioaccumulation factors and/or bioconcentration factors in blue mussel are wanted by the Norwegian Environment Agency. The numbers indicate their priority in the present assignment.

Priority	Parameter code	Parameter name	CAS no.
1	**Hg**	Mercury	7439-97-6
2	**Pb**	Lead	7439-92-1
2	**As**	Arsenic	7440-38-2
2	**Cd**	Cadmium	7440-43-9
2	**Cr**	Chromium	7440-47-3
3	**Ni**	Nickel	7440-02-0
3	**Zn**	Zinc	7440-66-6
3	**Cu**	Copper	7440-50-8
4	**BAP**	Benzo[a]pyrene	50-32-8
4	**BBF**	Benzo[b]fluoranthene	205-99-2
4	**NAP**	Naphthalene	91-20-3
4	**FLU**	Fluoranthene	206-44-0
4	**BKF**	Benzo[k]fluoranthene	207-08-9
5	**BGHIP**	Benzo[g,h,i]perylene	191-24-2
5	**ICDP**	Indeno[1,2,3-cd]pyrene	193-39-5
5	**ANT**	Anthracene	120-12-7
5	**BAA**	Benzo[a]anthracene	56-55-3
5	**ACNLE**	Acenaphthylene	208-96-8
6	**ACNE**	Acenaphthene	83-32-9
6	**FLE**	Fluorene	86-73-7
6	**PA**	Phenanthrene	85-01-8
6	**PYR**	Pyrene	129-00-0
6	**CHR**	Chrysene	218-01-9
6	**DBAHA**	Dibenzo[a,h]anthracene	53-70-3
7	**PFOS**	Perfluorooctanesulfonic acid	1763-23-1
7	**PFOA**	Perfluorooctanoic acid	335-67-1
8	**dl-PCB**	Dioxin-like PCBs	
9	**CN**	Cyanide	57-12-5

6. Materials and methods

6.1 Calculation

The proposed EQS for blue mussel for the aforementioned substances are based on published EQS_{biota} and EQS_{water}. For the substances where secondary poisoning is not relevant the EQS_{water} is applied in deriving the $EQS_{blue\ mussel}$. The EQS_{water} is set to protect organisms in the marine environment. The $EQS_{blue\ mussel}$ is further derived using a bioconcentration factor (BCF) or bioaccumulation factor (BAF) that is most relevant for blue mussel, thus the $EQS_{blue\ mussel}$ should theoretically represent a safe concentration in water, noting that blue mussel acts like a type of water sampler. In some cases, when secondary poisoning is relevant, the existing EQS_{biota} can be an adequate EQS for blue mussel provided provisions are made for trophic level. Existing EQS_{biota} are intended to guard against possible risk via oral intake for humans and wildlife.

Calculations of EQS for blue mussel are based on EU documentation such as EU dossier/datasheets and Risk Assessment Reports (RAR) as well as national publications such as the guidelines for the application of the Water Framework Directive (Direktoratsgruppen_vanndirektivet 2018) or the report on how EQS are derived for *inter alia* river basin specific substances (Arp et al. 2014).

In addition, we have done some exploratory literature review to better assess the relevance of the conversion factors (e.g. BCF, BAF) that we have chosen.

As a result of this process, a short list of EQS candidates are presented for certain substances, based on different approaches and conversion factors. One EQS per substance for blue mussel is proposed as an initial starting point in this development.

The proposed EQS for blue mussel are, if possible, compared to the Norwegian provisional high reference contaminant concentration (PROREF) for the corresponding substances established through the MILKYS programme (Green et al. 2020). This comparison provides an indication as to how useful the proposed EQSs for blue mussel will be in practice.

6.2 Literature search and limitations

A literature survey was performed to review BAF and BCF data for the selected contaminants (**Table 2**) in blue mussel. BAF and BCF data was collected both from previous NIVA projects and literature as well as from relevant literature obtained at Web of Science (research articles) and from data material that were found by use of Google searches (the latter including also non-article sources). The objective of this work was to provide a brief and descriptive overview of relevant data/information of BAF or BCF. The study field of pollutant bioaccumulation is a highly complex one, especially when the study includes both hydrophilic metal pollutants and hydrophobic organic pollutants, as these pollutant classes in general behaves very differently. Given the confines of this project, this overview is not to be considered in any way exhaustive, but rather show that variation exists and that more appropriate values may be adopted in the future, for revisions of this initial starting point in the $EQS_{Blue\ mussel}$ development.

7. Results and discussion

7.1 BAF and BCFs for selected contaminants

7.1.1 Introduction and objectives

The bioconcentration factor (BCF) or the bioaccumulation factor (BAF) is largely determinant for the EQS-values derived here. For that reason, the theory and experience associated with BCF and BAF for the pollutants in question, in blue mussel is briefly described in this chapter, also including a presentation of relevant literature.

When the ratio of contaminant concentration in blue mussel sentinels to the contaminant concentration in exposure media is under Steady-State conditions (SS, i.e. the contaminant concentration is in equilibrium between the water and the mussel) it is referred to either as the BCF (when the contaminated exposure media is seawater) or as the BAF (when the exposure media is a combination of contaminated seawater and diet). They are calculated in the same way.

BCF and BAF data can be described on a wet-weight or a dry-weight basis, and for the cases of lipophilic organic contaminants the BCF and BAF are often normalized to a lipid basis. The uptake of metal ions from seawater and diet and into mussels occurs mainly by active uptake processes. The uptake of nonpolar non-ionized chemicals into blue mussel from the seawater or from the gut content occurs mainly by a passive partitioning process.

7.1.2 Bioaccumulation and factors of concern

There are many factors that influence the bioavailability, uptake, distribution, accumulation, and elimination processes of different inorganic and organic pollutant chemicals in blue mussel (Schøyen et al. 2017; Beyer et al. 2017). As noted above, the hydrophilic (ionic) heavy metal pollutants and hydrophobic (non-ionic) organic pollutants behave very differently from each other in regard to basic mechanisms for their dispersal in aquatic environments and for their uptake and concentration/accumulation in aquatic biota. However, although they are highly different, bioaccumulation and bioconcentration factors are still common tools used for describing the overall behaviour of pollutant specimens within both these major chemical groups.

The simplest way to define BAF and BCF in water-living organisms is as follows:

BCF or BAF = (Tissue Concentration) / (Water Concentration) -

Where:
BCFs are based on water only exposures (lab data).
BAFs are derived from water and dietary exposure (field data).

BCF and BAF are most applicable for persistent, hydrophobic organic contaminants. For these substances, a high value of BCF or BAF, e.g. ≥2000 as given in REACH (Gobas et al. 2009) can be used to signify possible risk to organisms in that there is a potential for the contaminant to bioaccumulate in individual aquatic organisms and along aquatic food chains (biomagnification), potentially leading to chronic ecotoxicological effects. The BCF or BAF properties of a toxic, hydrophobic, persistent chemicals are to a large extent directly correlated with the chemicals' intrinsic hydrophobicity. Intrinsic hydrophobicity is a stable property which can easily be measured by the octanol-water partitioning coefficient (K_{ow}) method.

BCF and BAF data for specific metals are not stable indicators of their intrinsic toxicokinetic properties in aquatic systems, as explained by McGeer et al. (2003). They are characterized by extreme variability depending on several factors. Most important, there is an inverse relationship between the BCF or BAF value for a metal and its aqueous exposure concentration. Therefore, BCF/BAF criteria of metals are not usable for simple identification and classification of the hazard of that metal as a pollutant chemical. Furthermore, using BCF and BAF data leads to conclusions that are inconsistent with the toxicological data, in that BCF and BAF values are highest (indicating a risk to organisms) at low exposure concentrations and are lowest (indicating less risk) at high exposure concentrations, where adverse impacts in biota are likely. Furthermore, BAF and BCF values do not distinguish between essential metals, normal background metal bioaccumulation, the adaptive capabilities of animals to regulate metals (i.e. utilize, sequester, detoxify, store) from metal uptake that results in adverse effect.

Advantages and difficulties of using blue mussel (or other marine bivalve species) as environmental sentinels for quantitative assessments and monitoring of metal contamination have been discussed in many reviews, e.g. (Cossa 1989; Luoma and Rainbow 2005; Chapman 2008; Stankovic and Jovic 2012; Zuykov, Pelletier, and Harper 2013; Beyer et al. 2017). Apart from being inversely influenced by variable exposure concentrations, the uptake and accumulation of heavy metals in mussels also depend on a variety of other factors, such as multiple routes of exposure (diet and solution), metal speciation, ligand associations and complexation, chemical composition of the surrounding medium and physiological or biochemical effects on bioavailability.

BCF and BAF values for organic contaminants in blue mussel are less influenced by confounding factors than inorganic contaminants (e.g. metals), though some variability or uncertainty is inevitable. BCF and BAF values for organic pollutants are typically denoted with a margin of error or expressed as a specific range of values. The review paper by Arnot and Gobas (2006) constitutes the largest collection of pollutant BAF and BCF data for organic pollutant compounds in marine species. That paper includes a review of 392 scientific sources and provides 5317 BCFs and 1656 BAFs for 842 organic chemicals in 219 aquatic species. The review discusses a broad range of factors that influence the uncertainty and variability of BCF and BAF values. BCFs are generally difficult to measure and tests are most valid when following recommended guidelines and for stable organic chemicals with log K_{OW} range 1.5–6.0 (OECD 1996).

Recent overviews have provided information of bioconcentration and bioaccumulation of metals and organic contaminants in blue mussel, including the BAF estimations for many of the selected contaminants in this study (**Table 2**) (Schøyen et al. 2017; Beyer et al. 2017). These overviews included values from investigations on native and caged or transplanted blue mussel and from passive sampler devices for both metals and hydrophobic organic contaminants such as PAHs. These bioaccumulation data helped in deriving concentrations of the target pollutants in the seawater from where the caged and native mussels were collected. One overview-study showed that the overall estimated BAF values were in the approximate ranges 200 – 32000, 6000 – 160000 and 1600 - 25000 for metals, PCBs and PAHs, respectively (Schøyen et al. 2017).

7.2 Suggested EQS for blue mussel

In this chapter EQS for blue mussel for 26 of the 28 contaminants are proposed and their derivation explained. We could not obtain sufficient information to derive an $EQS_{Blue\ mussel}$ for cyanide. Furthermore, dioxin-like PCBs represent a group of contaminants with considerable differences in physical and chemical attributes. Thus, no attempt was done to derive an $EQS_{Blue\ mussel}$ for these compounds.

All values given for biota are on a wet weight basis.

7.2.1 Mercury (Hg)

Mercury is a priority substance (CAS 7439-97-6).

Five different EQS_{biota} may be exemplified for mercury:

There is no annual average (AA)-EQS for mercury in seawater (2013/39/EU 2013). The upper limit for class II for mercury in seawater, in the Norwegian classification system (Norwegian_Environment_Agency 2016), is **0.047 µg/L**. This is based on species sensitivity distribution (SSD)/HC5 NOEC of 0.142 and assessment factor of 3, referred to in the EU dossier (CIS 2005b).

The lowest BCF of (inorganic) Hg in blue mussel referred to in the EU dossier is **190 L/kg** (CIS 2005b).

Thus, a corresponding EQS_{biota} is 0.047 µg/L × 190 L/kg = **8.93 µg/kg** (example 1)

This is meant to protect the aquatic environment from direct effects, but not account for secondary poisoning.

The geometric mean (from OSPAR 1996) BCF for (inorganic) Hg in blue mussel referred to in the EU dossier is **1750 L/kg.**

Thus, a corresponding EQS_{biota} is 0.047 µg/L × 1750 L/kg = **82 µg/kg** (example 2)

This is meant to protect the aquatic environment from direct effects, but not account for secondary poisoning.

The existing EQS_{biota} for Hg is **20 µg/kg** (example 3)

This can be used for blue mussel but will then not account for the lower trophic level of blue mussel, compared to fish. This will be a breach of the guidance from the EU that it shall offer equal protection.

Lavoie et al. (2013) compiled data from 69 studies that determined total Hg (THg) or methyl Hg (MeHg) trophic magnification slopes (TMS values) in 205 aquatic food webs worldwide. Their results corresponded to a mean Hg trophic magnification factor (TMF) of **3.5**, assuming an enrichment of $\delta^{15}N$ equal to 3.4 per (integer) trophic level. If TMF=BMF (biomagnification factor), the following EQS_{biota} may be proposed:

20 µg/kg / 3.5 = **5.7 µg/kg** (example 4)

This EQS accounts for a difference in one trophic level between fish (of which the 20 µg/kg EQS is valid for) and blue mussel.

One may also account for two trophic levels between fish (of which the 20 µg/kg EQS is valid for) and blue mussel (CIS 2011a):

20 µg/kg / (3.5 × 3.5) = **1.6 µg/kg** (example 5)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5.7 µg/kg** to account for the biomagnifying properties of mercury, correcting for one trophic level (not two) below fish.

The point of origin for the proposed EQS is the existing EQS_{biota}.

The PROREF for Hg in blue mussel is 12 µg/kg. This indicates that most environmental concentrations will exceed the proposed EQS.

7.2.2 Lead (Pb)

Lead is a priority substance (CAS no. 7439-92-1).

Two different EQS_{biota} may be exemplified for lead:

The EQS for lead in seawater is **1.3 µg/L** (2013/39/EU 2013). This is based on species sensitivity distribution (SSD); HC-5-50 and assessment factor of 3 referred to in the EU dossier (CIS 2011c).

The EU dossier refers to a median BAF for molluscs of **473 L/kg** (CIS 2011c).

Thus, a corresponding EQS_{biota} is 1.3 µg/L × 473 L/kg = **615 µg/kg** (example 1)

The EU dossier (Pb) also refers to a median BAF for molluscs where the results of filtered samples were used: **925 L/kg**.

Thus, a corresponding EQS_{biota} is 1.3 µg/L × 925 L/kg = **1203 µg/kg** (example 2)

We propose the above example 1: $EQS_{Blue\ mussel}$ = **615 µg/kg**, as this is lowest (safest).

The point of origin for the proposed EQS is the existing $EQS_{coastal\ water}$.

The PROREF for Pb in blue mussel is 195 µg/kg.

7.2.3 Arsenic (As)

Arsenic is a river basin specific substance (CAS no. 7440-38-2).

Two different EQS_{biota} may be exemplified for arsenic:

The Norwegian EQS for arsenic in seawater is **0.6 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This is based on lowest EC10/NOEC for *Strongylocentrotus purpuratus* (6 µg/L) and an assessment factor of 10 (Norwegian_Environment_Agency 2016; UK-EA 2007).

The UK Environment Agency refers to a BCF for gastropods: **17 L/kg**.

Thus, a corresponding EQS_{biota} is 0.6 µg/L × 17 L/kg = **10 µg/kg** (example 1)

The UK Environment Agency also refers to a BCF for oysters: **350 L/kg**.

Thus, a corresponding EQS_{biota} is 0.6 µg/L × 350 L/kg = **210 µg/kg** (example 2)

It should be noted that the EQS for As in seawater is low. According to Donat and Bruland (1995), common concentrations of As in seawater are between 1.5 and 1.8 µg/L (20 – 24 µM).

Furthermore, a significant proportion of arsenic in marine organisms is organic As species (such as arsenobetaine), which are much less toxic than inorganic As (Amlund 2005).

We propose the above example 2: $EQS_{Blue\ mussel}$ = **210 µg/kg**, the highest, for the above mentioned reasons, and since it is derived with a bivalve based BCF.

The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$.

The PROREF for As in blue mussel is 2503 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.4 Cadmium (Cd)

Cadmium is a priority substance (CAS no. 7440-43-9).

Two different EQS_{biota} may be exemplified for cadmium:

The EQS for cadmium in seawater is **0.2 µg/L** (2013/39/EU 2013). This is based on species sensitivity distribution (SSD); HC-5-COV and an assessment factor of 2 as referred to in the EU dossier (CIS 2005a).

The EU dossier refers to a lowest BCF (from a range) for invertebrates of **396 L/kg**.

Thus, a corresponding EQS_{biota} is 0.2 µg/L × 396 L/kg = **79 µg/kg** (example 1)

The EU dossier also refers to a median BCF for invertebrates (from Taylor, 1983): **994 L/kg**.

Thus, a corresponding EQS_{biota} is 0.2 µg/L × 994 L/kg = **199 µg/kg** (example 2)

We propose the above example 2: $EQS_{Blue\ mussel}$ = **199 µg/kg**, as likely the most realistic BCF has been applied.

The point of origin for the proposed EQS is the existing $EQS_{coastal\ water}$.

The PROREF for Cd in blue mussel is 180 µg/kg.

7.2.5 Chromium (Cr)

Chromium is a river basin specific substance (CAS no. 7440-47-3.

The Norwegian EQS for chromium in seawater is **3.4 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is adopted from the EU Risk Assessment Report (RAR) (RAR 2005) = 3.4 µg/L (Cr VI) and it is deduced by species sensitivity distribution (SSD) of toxicity data for freshwater organisms.

The EU RAR refers to USEPA and a BCF of 125 - 200 for Cr IV (oyster and blue mussel), and furthermore a BCF of 86 - 155 for Cr III (blue mussel and the bivalve *Mya arenia*). As such, **125 L/kg** appears like a representative value.

Thus, a corresponding EQS_{biota} is 3.4 µg/L × 125 L/kg = **425 µg/kg**

We propose $EQS_{Blue\ mussel}$ = **425 µg/kg**.

The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$.

The PROREF for Cr in blue mussel is 361 µg/kg.

7.2.6 Nickel (Ni)

Nickel is a priority substance (CAS no. 7440-02-0).

The EQS for nickel in seawater is **8.6 µg/L** (2013/39/EU 2013). This is based on species sensitivity distribution (SSD); HC-5 (50%) and an assessment factor of 2 referred to in the EU dossier (CIS 2011e).

The EU dossier proposes a BCF = 270. It is mentioned a “highest bioconcentration factors for *Cerastoderma edule* (marine bivalve): 26,500”. Furthermore, “The EU RAR identified a BCF of 270 L/kg based on the median of BCFs for bivalves and for fish from studies using measured whole organism tissue Ni concentrations and paired dissolved Ni concentrations”. As such, **270 L/kg** appears like a representative value.

Thus, a corresponding EQS_{biota} is 8.6 µg/L × 270 L/kg = **2322 µg/kg**

We propose $EQS_{Blue\ mussel}$ = **2322 µg/kg**.

The point of origin for the proposed EQS is the existing $EQS_{coastal\ water}$.

The PROREF for Ni in blue mussel is 290 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.7 Zinc (Zn)

Zinc is a river basin specific substance (CAS no. 7440-66-6).

The Norwegian EQS for Zn in seawater is **3.4 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This is based on species sensitivity distribution (SSD); HC-5 and an assessment factor of 2 (UKTAG 2012).

The EU RAR (RAR 2010) does not propose any BCF value for Zn.

Furthermore, Zn is an essential metal, which blue mussel is capable of regulating (Lobel and Marshall 1988, and references therein).

Thus, no EQS_{biota} is suggested

We cannot propose any $EQS_{Blue\ mussel}$. The PROREF for Zn in blue mussel is 17660 µg/kg.

7.2.8 Copper (Cu)

Copper is a river basin specific substance (CAS no. 7440-50-8).

The Norwegian EQS for Cu in seawater is **2.6 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This is based on species sensitivity distribution (SSD); HC-5 NOEC = 5.2 µg/L and an assessment factor of 2 referred to by EC's SCHER (2008).

Note, however, that in the Norwegian classification system (Norwegian_Environment_Agency 2016), there is no class III and that even a slight exceedance of class II (upper limit equivalent to EQS) corresponds to class IV.

There is apparently no appropriate available BCF value for Cu.

Furthermore, Cu is an essential metal, which blue mussel is capable of regulating (Lobel and Marshall 1988, and references therein).

Thus, no EQS_{biota} is suggested.

We cannot propose any $EQS_{Blue\ mussel}$. The PROREF for Cu in blue mussel is 1400 µg/kg.

7.2.9 Benzo[a]pyrene

Benzo[a]pyrene is a priority substance (CAS no. 50-32-8).

Benzo[a]pyrene is also classified as a human carcinogen (IARC group 1).

Two different EQS_{biota} may be exemplified for Benzo[a]pyrene:

The EQS for Benzo[a]pyrene in seawater is **0.00017 µg/L** (2013/39/EU 2013) (i.e. 10 µg/kg / 57981 L/kg). This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC 2006), for bivalves, and a BCF of 57981 L/kg referred to by the EU dossier (CIS 2011f). The maximum allowable concentrations in food stuffs (1881/2006/EC) for bivalves, specifically, is **10 µg/kg**,

Thus, EQS_{biota} is **10 µg/kg** (example 1)

The current EQS_{biota} (2013/39/EU 2013) is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC) , for crustaceans and cephalopods referred to by the EU dossier. According to Directive 2013/39/EU, “for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs”.

Thus, EQS_{biota} is **5 µg/kg** (example 2)

We propose the above example 2: $EQS_{Blue\ mussel}$ = **5 µg/kg** as this is lowest (safest), and that it is the current EQS_{biota} already applicable to molluscs (not fish).

The point of origin for the proposed EQS is the existing EQS_{biota}.(based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for benzo[a]pyrene in blue mussel is 1.2 µg/kg.

7.2.10 Benzo[b]fluoranthene

Benzo[b]fluoranthene is a priority substance (CAS no. 205-99-2).

Four different EQS_{biota} may be exemplified for benzo[b]fluoranthene:

According to Directive 2013/39/EU (2013), “for the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), the biota EQS and corresponding AA-EQS in water refer to the concentration of benzo[a]pyrene, on the toxicity of which they are based. Benzo[a]pyrene can be considered as a marker for the other PAHs...”. Therefore, there is no AA-EQS or biota EQS for benzo[b]fluoranthene.

The upper limit for class II for benzo[b]fluoranthene in seawater, in the Norwegian classification system (Norwegian_Environment_Agency 2016), is **0.017 µg/L**. This is based on EC10 = 1.7 µg/L for *Brachydanio rerio*, and an assessment factor of 100 referred to by the EU dossier (CIS 2011f). Note, however, that there is no class III and that even a slight exceedance of class II corresponds to class IV.

The geometric mean for benzo[b]fluoranthene in molluscs referred to in the EU dossier is **57981 L/kg**.

Thus, a corresponding EQS_{biota} is 0.017 µg/L × 57981 L/kg = **986 µg/kg** (example 1)

The EU dossier also refers to a study (Richardson et al. 2005) resulting in a BCF for the mussel *Perna viridis* of **8500 L/kg**.

Thus, a corresponding EQS_{biota} is 0.017 µg/L × 8500 L/kg = **145 µg/kg** (example 2)

Note that these two EQS examples are meant to protect the aquatic environment from direct effects, but not account for poisoning through oral intake of the mussels.

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene since benzo[b]fluoranthene is possibly also carcinogenic (IARC group 2B) and a 5-6 ring PAH:

The maximum allowable benzo[a]pyrene concentrations in food stuffs (1881/2006/EC 2006) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **10 µg/kg** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC 2006), for crustaceans and cephalopods referred to by the EU dossier. According to Directive 2013/39/EU, "for substances numbered 15 (Fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs".

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[b]fluoranthene is possibly also carcinogenic (IARC group 2B) and a 5-6 ring PAH.

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for the sum of benzo[b]fluoranthene and benzo[j]fluoranthene in blue mussel is 6.24 µg/kg[2].

[2] Benzo(b,j)fluoranthene (BBJF) used as a proxy for benzo(b)fluoranthene.

7.2.11 Naphthalene

Naphthalene is a priority substance (CAS. No 91-20-3).

Three different EQS_{biota} may be exemplified for naphthalene:

The EQS for naphthalene in seawater is **2 µg/L** (2013/39/EU 2013). This is based on LC10 = 0.02 mg/L (*Oncorhyncus mykiss*) and an assessment factor of 10 referred to by the EU dossier (CIS 2011d).

The EU dossier refers to a BCF for naphthalene of **515 L/kg** (used in calculations of $QS_{biota\ secpois}$).

Thus, a corresponding EQS_{biota} is 2 µg/L × 515 L/kg = **1030 µg/kg** (example 1)

The EU dossier also refers to a BCF for naphthalene of **27 - 38 L/kg** for blue mussel (Hansen et al. 1978). We choose the lowest of this range:

Thus, a corresponding EQS_{biota} is 2 µg/L × 27 L/kg = **54 µg/kg** (example 2)

The current Norwegian EQS_{biota} (Direktoratsgruppen_vanndirektivet 2018) is **2400 µg/kg**. This is based on TDI = 40 µg/kg body weight/day and an anticipation that naphthalene is not carcinogenic. The TDI is based on experiments with petroleum products on mammals. PAHs are not subject to biomagnification and the EQS_{biota} is therefore applicable to mussels.

Thus, EQS_{biota} is **2400 µg/kg** (example 3)

Note that naphthalene is listed by the IARC as 2B (possibly carcinogenic to humans).

We propose the above example 2: $EQS_{Blue\ mussel}$ = **54 µg/kg** as this is lowest (safest).

The point of origin for the proposed EQS is the existing $EQS_{coastal\ water}$.

The PROREF for naphthalene in blue mussel is 17.3 µg/kg.

7.2.12 Fluoranthene

Fluoranthene is a priority substance (CAS no. 206-44-0).

Two different EQS_{biota} may be exemplified for fluoranthene:

The EQS for fluoranthene in seawater is **0.0063 µg/L** (2013/39/EU 2013). This is based on human health, more specifically, the **EQS_{biota} = 30 µg/kg** and a **BCF = 4800 L/kg** referred to by the EU dossier (CIS 2011g). PAHs are not subject to biomagnification, and the EQS_{biota} is applicable to blue mussel. Directive 2013/39/EU (2013) states that "for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs".

Thus, EQS_{biota} is **30 µg/kg** (example 1)

The EU dossier refers to both a $MAC\text{-}QS_{eco.water}$ and an $AA\text{-}QS_{eco.water}$ of **0.12 µg/L** (based on species sensitivity distribution (SSD)). It also refers to a **BCF = 3932 L/kg**, which is the geometric mean for molluscs (Bleeker and Verbruggen 2009).

Thus, a corresponding EQS_{biota} is 0.12 µg/L × 3932 L/kg = **472 µg/kg** (example 2)

We propose the above example 1: $EQS_{Blue\ mussel}$ = **30 µg/kg** as this is lowest (safest), and that it is the current EQS_{biota} already applicable to molluscs (not fish).

The point of origin for the proposed EQS is the existing EQS_{biota}.

The PROREF for fluoranthene in blue mussel is 5.35 µg/kg.

7.2.13 Benzo[k]fluoranthene

Benzo[k]fluoranthene is a priority substance (CAS no. 207-08-9).

Four different EQS_{biota} may be exemplified for benzo[k]fluoranthene, and this is exactly the same as for benzo[b]fluoranthene:

According to Directive 2013/39/EU (2013), "for the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), the biota EQS and corresponding AA-EQS in water refer to the concentration of benzo[a]pyrene, on the toxicity of which they are based. Benzo[a]pyrene can be considered as a marker for the other PAHs...". Therefore, there is no AA-EQS or biota EQS for benzo[k]fluoranthene.

The upper limit for class II for benzo[k]fluoranthene in seawater, in the Norwegian classification system (Norwegian_Environment_Agency 2016), is **0.017 µg/L**. This is based on EC10 = 1.7 µg/L for *Brachydanio rerio*, and an assessment factor of 100 referred to by the EU dossier (CIS 2011f). Note, however, that there is no class III and that even a slight exceedance of class II corresponds to class IV.

The geometric mean for benzo[k]fluoranthene in molluscs referred to in the EU dossier is **57981 L/kg**.

Thus, a corresponding EQS_{biota} is 0.017 µg/L × 57981 L/kg = **986 µg/kg** (example 1)

The EU dossier also refers to a study (Richardson et al. 2005) resulting in a BCF for the mussel *Perna viridis* of **8500 L/kg**.

Thus, a corresponding EQS_{biota} is 0.017 µg/L × 8500 L/kg = **145 µg/kg** (example 2)

Note that these two EQS examples are meant to protect the aquatic environment from direct effects, but not account for poisoning through oral intake of the mussels.

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[k]fluoranthene is possibly also carcinogenic (IARC group 2B) and a 5-6 ring PAH:

The maximum allowable benzo[a]pyrene concentrations in food stuffs (1881/2006/EC 2006) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **10 µg/kg** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC), for crustaceans and cephalopods referred to by the EU dossier. According to Directive 2013/39/EU, "for substances numbered 15 (Fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs".

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[k]fluoranthene is possibly also carcinogenic (IARC group 2B) and a 5-6 ring PAH.

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for the sum of benzo[k]fluoranthene in blue mussel is 1.5 µg/kg.

7.2.14 Benzo[g,h,i]perylene

Benzo[g,h,i]perylene is a priority substance (CAS no. 191-24-2).

Four different EQS_{biota} may be exemplified for benzo[g,h,i]perylene:

According to Directive 2013/39/EU (2013), "for the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), the biota EQS and corresponding AA-EQS in water refer to the concentration of benzo[a]pyrene, on the toxicity of which they are based. Benzo[a]pyrene can be considered as a marker for the other PAHs...". Therefore, there is no AA-EQS or biota EQS for benzo[g,h,i]perylene.

The upper limit for class II for benzo[g,h,i]perylene in seawater, in the Norwegian classification system (Norwegian_Environment_Agency 2016), is **0.00082 µg/L**. This is based on EC10 for *Ceriodaphnia dubia* (reproduction), and an assessment factor of 100 referred to by the EU dossier (CIS 2011f) . Note, however, that there is no class III and that even a slight exceedance of class II corresponds to class IV.

The geometric mean for benzo[g,h,i]perylene in molluscs referred to in the EU dossier is **57981 L/kg**.

Thus, a corresponding EQS_{biota} is 0.00082 µg/L × 57981 L/kg = **<u>48 µg/kg</u>** (example 1)

The EU dossier also refers to a study (Richardson et al. 2005) resulting in a BCF for the mussel *Perna viridis* of **8500 L/kg**.

Thus, a corresponding EQS_{biota} is 0.00082 µg/L × 8500 L/kg = **<u>7 µg/kg</u>** (example 2)

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[g,h,i]perylene also is a 5-6 ring PAH, although not classified as carcinogenic (IARC group 3):

The maximum allowable benzo[a]pyrene concentrations in food stuffs (1881/2006/EC) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **<u>10 µg/kg</u>** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food s (1881/2006/EC 2006), for crustaceans and cephalopods referred to by the EU dossier. According to Directive 2013/39/EU, “for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs”.

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[g,h,i]perylene also is a 5-6 ring PAH, although not classified as carcinogenic (IARC group 3).

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for benzo[g,h,i]perylene in blue mussel is 2.07 µg/kg.

7.2.15 Indeno[1,2,3-cd]pyrene

Indeno[1,2,3-cd]pyrene is a priority substance (CAS no. 193-39-5).

Four different EQS_{biota} may be exemplified for indeno[1,2,3-cd]pyrene:

According to Directive 2013/39/EU (2013), "for the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), the biota EQS and corresponding AA-EQS in water refer to the concentration of benzo[a]pyrene, on the toxicity of which they are based. Benzo[a]pyrene can be considered as a marker for the other PAHs...". Therefore, there is no AA-EQS or biota EQS for indeno[1,2,3-cd]pyrene.

The upper limit for class II for indeno[1,2,3-cd]pyrene in seawater, in the Norwegian classification system (Norwegian_Environment_Agency 2016), is **0.0027 µg/L**. This is based on EC10 for *Ceriodaphnia dubia* (reproduction), and an assessment factor of 100 referred to by the EU dossier (CIS 2011f). Note, however, that there is no class III and that even a slight exceedance of class II corresponds to class IV.

The geometric mean for indeno[1,2,3-cd]pyrene in molluscs referred to in the EU dossier is **57981 L/kg**.

Thus, a corresponding EQS_{biota} is 0.0027 µg/L × 57981 L/kg = **157 µg/kg** (example 1)

The EU dossier also refers to a study (Richardson et al. 2005) resulting in a BCF for the mussel *Perna viridis* of **8500 L/kg**.

Thus, a corresponding EQS_{biota} is 0.0027 µg/L × 8500 L/kg = **23 µg/kg** (example 2)

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene,since indeno[1,2,3-cd]pyrene also is (possibly) carcinogenic (IARC group 2B) and a 5-6 ring PAH:
The maximum allowable benzo[a]pyrene concentrations in food is (1881/2006/EC 2006) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **10 µg/kg** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC), for crustaceans and cephalopods referred to by the EU dossier. According to Directive 2013/39/EU, “for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs”.

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since indeno[1,2,3-cd]pyrene also is (possibly) carcinogenic (IARC group 2B) and a 5-6 ring PAH.

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for indeno[1,2,3-cd]pyrene in blue mussel is 1.73 µg/kg.

7.2.16 Anthracene

Anthracene is a priority substance (CAS no. 120-12-7).

Three different EQS_{biota} may be exemplified for anthracene:

The EQS for anthracene in seawater is **0.1 µg/L** (note: both AA-EQS and MAC-EQS) (2013/39/EU 2013). This is based on LC50 for *Daphnia pulex* and an assessment factor of 10.

Note, however, that in the Norwegian classification system (Norwegian_Environment_Agency 2016), there is no class III and that even a slight exceedance of class II (upper limit equivalent to EQS) corresponds to class IV.

The only BFC for molluscs mentioned in the EU dossier (CIS 2011b) is **19000 L/kg**, and it is labelled "questionable".

Thus, EQS_{biota} is 0.1 µg/L × 19000 L/kg = **<u>1900 µg/kg</u>** (example 1)

The EU dossier presents a geometric mean for BCF for crustaceans of **2536 L/kg,** which may be adopted.

Thus, EQS_{biota} is 0.1 µg/L × 2536 L/kg = **<u>254 µg/kg</u>** (example 2)

The Norwegian EQS_{biota} is **2400 µg/kg**, and is based on human health via consumption of fishery products referred to by the EU dossier.

Thus, EQS_{biota} **<u>2400 µg/kg</u>** (example 3)

We propose the above example 2: $EQS_{Blue\ mussel}$ = **<u>254 µg/kg</u>**, since this is lowest (safest).

The point of origin for the proposed EQS is the existing $EQS_{coastal\ water}$.

The PROREF for anthracene in blue mussel is 0.8 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.17 Benzo[a]anthracene

Benzo[a]anthracene is a river basin specific substance (CAS no. 56-55-3).

Four different EQS_{biota} may be exemplified for benzo[a]anthracene:

The Norwegian EQS for benzo[a]anthracene in seawater is **0.012 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is based on EC10 for algae (*P. subcapitata*, EC10 = 1.2 µg/L) and an assessment factor of 100 (Verbruggen 2012).

Bleeker (2009) does not refer to any reliable BCF for molluscs. Therefore, the BCF presented for fish (*Pimephales promelas*) is adopted (conservative, since low). **BCF = 260 L/kg**.

Thus, a corresponding EQS_{biota} is 0.012 µg/L × 260 L/kg = **3.1 µg/kg** (example 1)

The current Norwegian EQS_{biota} is **304 µg/kg** (Direktoratsgruppen_vanndirektivet 2018). This is based on TDI = 5 µg/kg body weight/day (human health). PAHs are not subject to biomagnification and the EQS_{biota} is therefore applicable to mussels.

Thus, EQS_{biota} is **304 µg/kg** (example 2)

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[a]anthracene is possibly also carcinogenic (IARC group 2B) and a 5-6 ring PAH:

The maximum allowable benzo[a]pyrene concentrations in food stuffs (1881/2006/EC 2006) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **10 µg/kg** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC), for crustaceans and cephalopods referred to by the EU dossier (CIS 2011f). According to Directive 2013/39/EU, “for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs”.

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since benzo[a]anthracene is possibly also carcinogenic (IARC group 2B) and a 5-6 ring PAH.

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for benzo[a]anthracene in blue mussel is 1.49 µg/kg.

7.2.18 Acenaphthylene

Acenaphthylene is a river basin specific substance (CAS no. 208-96-8).

Two different EQS_{biota} may be exemplified for acenaphthylene:

The Norwegian EQS for acenaphthylene in seawater is **1.28 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is based on lowest chronic EC10 for *Ceriodaphnia dubia*, 64 µg/L) and an assessment factor of 50.

Bleeker (2009) refers to a BCF for blue mussel, although labelled "validity not assignable": **2892 L/kg**.

Thus, a corresponding EQS_{biota} is 1.28 µg/L × 2892 L/kg = **3702 µg/kg** (example 1)

Since the abovementioned BCF for molluscs in not reliable, the BCF presented for fish (Bleeker and Verbruggen 2009) is adopted. **BCF = 387 L/kg**.

Thus, a corresponding EQS_{biota} is 1.28 µg/L × 387 L/kg = **495 µg/kg** (example 2)

We propose the above example 2: $EQS_{Blue\ mussel}$ = **495 µg/kg**, since this is lowest (safest).

The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$.

The PROREF for acenaphthylene in blue mussel is 1 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.19 Acenaphthene

Acenaphthene is a river basin specific substance (CAS no. 83-32-9).

Two different EQS_{biota} may be exemplified for acenaphthene:

The Norwegian EQS for acenaphthene in seawater is **3.8 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is based on lowest EC10 for *Pseudokirchneriella subcapitata*, 38 µg/L) and an assessment factor of 10.

Note, however, that in the Norwegian classification system (Norwegian_Environment_Agency 2016), there is no class III and that even a slight exceedance of class II (upper limit equivalent to EQS) corresponds to class IV.

Bleeker (2009) refers to a BCF for blue mussel, although labelled “validity not asignable”: **1308 L/kg**.

Thus, a corresponding EQS_{biota} is 3.8 µg/L × 1308 L/kg = **4970 µg/kg** (example 1)

Since the abovementioned BCF for molluscs in not reliable, the BCF presented for fish (Bleeker and Verbruggen 2009) is adopted. **BCF = 760 L/kg**.

Thus, a corresponding EQS_{biota} is 3.8 µg/L × 760 L/kg = **2888 µg/kg** (example 2)

We propose the above example 2: $EQS_{Blue\ mussel}$ = **2888 µg/kg**, since this is lowest (safest).

The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$.

The PROREF for acenaphthene in blue mussel is 0.8 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.20 Fluorene

Fluorene is a river basin specific substance (CAS no. 86-73-7).

Two different EQS_{biota} may be exemplified for fluorene:

The Norwegian EQS for fluorene in seawater is **1.5 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is based on lowest EC10 for *Daphnia magna*, 15 µg/L) and an assessment factor of 10.

Bleeker (2009) refers to a BCF for blue mussel, although labelled “validity not asignable”: **1018 L/kg**.

Thus, a corresponding EQS_{biota} is 1.5 µg/L × 1018 L/kg = **1527 µg/kg** (example 1)

Since the abovementioned BCF for molluscs in not reliable, the BCF presented for fish (Bleeker and Verbruggen 2009) may adopted. **BCF = 1459 L/kg**.

Thus, a corresponding EQS_{biota} is 1.5 µg/L × 1459 L/kg = **2189 µg/kg** (example 2)

We propose the above example 1: $EQS_{Blue\ mussel}$ = **1527 µg/kg**, since this is lowest/safest.

The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$.

The PROREF for fluorene in blue mussel is 1.6 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.21 Phenanthrene

Phenanthrene is a river basin specific substance (CAS no. 85-01-8).

The Norwegian EQS for phenanthrene in seawater is 0.5 µg/L (Direktoratsgruppen_vanndirektivet 2018). This is based on human health, more specifically 2435 µg/kg (TDI = 40 µg/kg bw/day) and a BCF = 4751 L/kg.

Thus, EQS_{biota} is 2435 µg/kg

PAHs are not subject to biomagnification and the EQS_{biota} is therefore applicable to mussels.

We propose the above example: $EQS_{Blue\ mussel}$ = <u>2435 µg/kg</u> The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$ (based on human health) The PROREF for phenanthrene in blue mussel is 2.28 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.22 Pyrene

Pyrene is a river basin specific substance.

Two different EQS_{biota} may be exemplified for pyrene:

The Norwegian EQS for pyrene in seawater is **0.023 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is based on lowest acute LC50 for *Mulinea lateralis*, 0.23 µg/L) and an assessment factor of 10 (after read-across with anthracene, fluoranthene and benzo[a]pyrene).

Note, however, that in the Norwegian classification system (Norwegian_Environment_Agency 2016), there is no class III and that even a slight exceedance of class II (upper limit equivalent to EQS) corresponds to class IV.

Bleeker (2009) refers to a BCF for blue mussel: **4430 L/kg**.

Thus, a corresponding EQS_{biota} is 0.023 µg/L × 4430 L/kg = **102 µg/kg** (example 1)

Bleeker (2009) also refers to a BCF for fish (*Pimephales promelas*): **BCF = 1297 L/kg**.

Thus, a corresponding EQS_{biota} is 0.023 µg/L × 1297 L/kg = **30 µg/kg** (example 2)

We propose the above example 2: $EQS_{Blue\ mussel}$ = **30 µg/kg**, since this is lowest/safest.

The point of origin for the proposed EQS is the existing Norwegian $EQS_{coastal\ water}$

The PROREF for pyrene in blue mussel is 1.02 µg/kg. Thus, the practical applicability of this EQS is questionable.

7.2.23 Chrysene

Chrysene is a river basin specific substance (CAS no. 218-01-9).

Four different EQS_{biota} may be exemplified for chrysene:

The Norwegian EQS for chrysene in seawater is **0.07 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This value is based on EC50 for *Daphnia magna*, EC50 = 0.7 µg/L) and an assessment factor of 10 (Verbruggen 2012).

Note, however, that in the Norwegian classification system (Norwegian_Environment_Agency 2016), there is no class III and that even a slight exceedance of class II (upper limit equivalent to EQS) corresponds to class IV.

Bleeker (2009) does not refer to any reliable BCF for molluscs, only for crustaceans: The BCF for *Daphnia magna* (the highest reliable BCF presented) may be adopted. **BCF = 6088 L/kg**.

Thus, a corresponding EQS_{biota} is 0.07 µg/L × 6088 L/kg = **426 µg/kg** (example 1)

Bleeker (2009) also presents a reliable BCF for the crustacean *Eurytemora affinis*, which may be adopted. **BCF = 950 L/kg**.

Thus, a corresponding EQS_{biota} is 0.07 µg/L × 950 L/kg = **67 µg/kg** (example 2)

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene, since chrysene also is (possibly) carcinogenic (IARC group 2B) and a 5-6 ring PAH):

The maximum allowable benzo[a]pyrene concentrations in foods (1881/2006/EC 2006) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **10 µg/kg** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC), for crustaceans and cephalopods (EU dossier (5,6-ring PAH)). According to Directive 2013/39/EU, "for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs".

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since chrysene also is (possibly) carcinogenic (IARC group 2B) and a 5-6 ring PAH.

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for chrysene in blue mussel is 0.52 µg/kg.

7.2.24 Dibenzo[a,h]anthracene

Dibenzo[a,h]anthracene is a river basin specific substance (CAS no. 53-70-3).

Three different EQS_{biota} may be exemplified for dibenzo[a,h]anthracene:

The Norwegian EQS for dibenzo[a,h]anthracene in seawater is **0.0006 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This is based on human health, more specifically **30 µg/kg** (TDI = 0.5 µg/kg bw/day) and a **BCF = 50119 L/kg** (The only reliable BCF presented for dibenzo[ah]anthracene by RIVM (2009); for *Daphnia magna*).

Thus, EQS_{biota} is **30 µg/kg** (example 1)

Another approach is to adapt the suggested EQS_{biota} from benzo[a]pyrene, since dibenzo[a,h]anthracene is probably also carcinogenic (IARC group 2A) and a 5-6 ring PAH:

The maximum allowable benzo[a]pyrene concentrations in food stuffs (1881/2006/EC 2006) for bivalves, specifically, is **10 µg/kg**.

Thus, EQS_{biota} is **10 µg/kg** (example 3)

The current EQS_{biota} (2013/39/EU 2013) for benzo[a]pyrene is **5 µg/kg**. This is based on the limit for maximum allowable concentrations in food stuffs (1881/2006/EC), for crustaceans and cephalopods (EU dossier (5,6-ring PAH)). According to Directive 2013/39/EU, "for substances numbered 15 (fluoranthene) and 28 (PAHs), the biota EQS refers to crustaceans and molluscs".

Thus, EQS_{biota} is **5 µg/kg** (example 4)

We propose the above example 4: $EQS_{Blue\ mussel}$ = **5 µg/kg**, i.e. adapt the suggested EQS_{biota} from benzo[a]pyrene, since dibenzo[a,h]anthracene is probably also carcinogenic (IARC group 2A) and a 5-6 ring PAH.

The point of origin for the proposed EQS is the existing EQS_{biota} for benzo[a]pyrene (based on the limit for maximum allowable concentrations in food stuffs).

The PROREF for dibenzo[a,h]anthracene in blue mussel is 0.5 µg/kg[3].

[3] Dibenzo[a,c/a,h]anthracene (DBA3A) used as a proxy

7.2.25 Perfluorooctanesulfonic acid (PFOS)

Perfluorooctanesulfonic acid (PFOS) is a priority substance (CAS no. 335-67-1).

Two different EQS_{biota} may be exemplified for PFOS:

The EQS for PFOS in seawater is **0.00013 µg/L** (2013/39/EU 2013). This is derived from the existing EQS_{biota} (Directive 2013/39/EU), based on human health, more specifically **91 µg/kg** (TDI = 0.15 µg/kg bw/day), a **BCF = 2796 L/kg** (applies to fish according to the EU dossier (PFOS)), a BMF_1 = 5 and a BMF_2 = 5.

Thus, to account for the biomagnifying properties of PFOS, an EQS_{biota} for mussels may be calculated that is a factor of 25 ($BMF_1 \times BMF_2$) lower than the existing EQS for biota (that applies to fish).

Thus, EQS_{biota} is 9.1 µg/kg / 25 = **0.36 µg/kg** (example 1)

A less conservative EQS_{biota} for mussels may be calculated, still accounting for the biomagnifying properties of PFOS, however only taking into account a BMF of 5 (one, not two BMFs).

Thus, EQS_{biota} is 9.1 µg/kg / 5 = **1.82 µg/kg** (example 2)

It should be noted that EFSA recently changed the TDI for PFOS, which the EQS is based on. The new threshold – a group tolerable weekly intake (TWI) of 4.4 nanograms per kilogram of body weight per week (0.0044 µg/kg bw/week) applies to the four PFAS compounds perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorononanoic acid (PFNA) and perfluorohexane sulfonic acid (PFHxS) (EFSA 2020). This is equivalent to a reduction by a factor >200, besides it applies to the sum of 4 compounds, not only PFOS.

We propose the above example 1: $EQS_{Blue\ mussel}$ = **0.36 µg/kg**, since this is lowest (safest).

The point of origin for the proposed EQS is the existing EQS_{biota}.

There is not sufficient data to provide a PROREF for PFOS in blue mussel. However, data from coastal monitoring (Green et al. 2020) indicates that concentrations at remote (low impacted) stations is less than the limit of quantification (LoQ), i.e. <0.1 µg/kg.

7.2.26 Perfluorooctanoic acid (PFOA)

Perfluorooctanoic acid (PFOA) is a river basin specific substance (CAS no. 335-67-1).

The Norwegian EQS for PFOA in seawater is **9.1 µg/L** (Direktoratsgruppen_vanndirektivet 2018). This is derived from the existing Norwegian EQS_{biota}, based on human health, more specifically **91 µg/kg** (TDI = 1.5 µg/kg bw/day; RPS (2010)), a **BCF = 4 L/kg** (applies to fish; 1.8 – 4 L/kg (ECHA, 2013); the most conservative used), a BMF_1 = 0.5 and a BMF_2 = 5.

Thus, to account for the biomagnifying properties of PFOA, an EQS_{biota} for mussels may be calculated that is a factor of 2.5 ($BMF_1 \times BMF_2$) lower than the existing EQS for biota (that applies to fish).

Thus, EQS_{biota} is 91 µg/kg / 2.5 = **<u>36 µg/kg</u>**

It should be noted that EFSA recently introduced a new threshold (see for PFOS, above) – a group tolerable weekly intake (TWI) of 4.4 nanograms per kilogram of body weight per week (0.0044 µg/kg bw/week), that applies to the four PFAS compounds perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorononanoic acid (PFNA) and perfluorohexane sulfonic acid (PFHxS) (EFSA 2020).

We propose the following: $EQS_{Blue\ mussel}$ = **<u>36 µg/kg</u>**

The point of origin for the proposed EQS is the existing Norwegian EQS_{biota}.

There is not sufficient data to provide a PROREF for PFOA in blue mussel. However, data from coastal monitoring {Green, 2018#95) indicates that concentrations at remote (low impacted) stations is less than the limit of quantification (LoQ), i.e. <0.5 µg/kg.

7.3 Comparison to monitoring data

EQS_{biota} applicable to blue mussel are presented ($EQS_{Blue\ mussel}$). These should also be applicable to other mussels/molluscs. A few of the suggested $EQS_{Blue\ mussel}$ values are low, and most samples will exceed. On the other hand, some $EQS_{Blue\ mussel}$ values are also high, rendering the practical applicability of these questionable. This applies mainly to some PAHs, and especially those that are based on acute toxicity data (such as anthracene and pyrene). Common for most of the hazardous substances that are judged likely too high to be operational is that they are deduced from acute water toxicity data (LC50; anthracene and pyrene), or EC10 (acenaphthylene, acenaphthene, fluorene), in combination with a BCF (necessarily also hampered with some uncertainty).

For $EQS_{Blue\ mussel}$ that are derived from EQS for coastal water, the choice of bioconcentration factor (BCF) is determinant for the value, and different aspects associated to BCF/BAF are discussed. More appropriate BCFs/BAFs may be adopted in the future, for revisions of this initial starting point in the $EQS_{Blue\ mussel}$ development.

In order to consider how operational the proposed EQS are, a comparison was made to the PROREF values (Green et al. 2020). PROREF could be compared to most proposed EQS (**Table 3**) with the exception of Cu and Zn, where no EQS were proposed, and PFOS and PFOA where there is no PROREF for blue mussel. Where comparisons could be made, the proposed EQSs were generally higher than PROREFs for 19 contaminants including four metals and all PAHs except benzo[b]fluoranthene. This suggests that the proposed EQSs are operational. On the other hand, one third of these are so high that practical applicability is questionable.

Where EQSs were lower than PROREF occurred for three contaminants including Hg, As, and benzo[b]fluoranthene, the latter only slightly (besides the PROREF also includes benzo[j]fluoranthene in the concentration). This indicates that even in less impacted areas concentrations of these contaminants would likely be above the EQS suggesting that the applicability of these EQSs is questionable.

Table 3: Proposed EQS for selected contaminants in blue mussel (*Mytilus edulis*). For comparison the Norwegian provisional high reference contaminant concentration (PROREF) are shown (Green et al. 2020).

Parameter code	Parameter name	CAS no.	Proposed EQS µg/kg wet weight	PROFEF µg/kg wet weight (based on st./value count)	Comment
Hg	Mercury	7439-97-6	**5.7**	12 (3/137)	Likely that monitoring results will exceed EQS because EQS is low.
Pb	Lead	7439-92-1	**615**	195 (2/75)	
As	Arsenic	7440-38-2	**210**	2503 (8/162)	Likely that monitoring results will exceed EQS because EQS is low.
Cd	Cadmium	7440-43-9	**199**	180 (3/106)	
Cr	Chromium	7440-47-3	**425**	361 (5/100)	
Ni	Nickel	7440-02-0	**2322**	290 (5/101)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is high.
Zn	Zinc	7440-66-6	**-**	17660 (3/49)	
Cu	Copper	7440-50-8	**-**	1400 (9/353)	
BAP	Benzo[a]pyrene	50-32-8	**5**	1.2 (7/354)	
BBF	Benzo[b]fluoranthene	205-99-2	**5**	6.24 (5/107)[4]	
NAP	Naphthalene	91-20-3	**54**	17.3 (3/47)	
FLU	Fluoranthene	206-44-0	**30**	5.35 (2/32)	
BKF	Benzo[k]fluoranthene	207-08-9	**5**	1.5 (7/167)	
BGHIP	Benzo[g,h,i]perylene	191-24-2	**5**	2.07 (7/254)	
ICDP	Indeno[1,2,3-cd]pyrene	193-39-5	**5**	1.73 (5/176)	
ANT	Anthracene	120-12-7	**254**	0.8 (6/208)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
BAA	Benzo[a]anthracene	56-55-3	**5**	1.49 (2/32)	
ACNLE	Acenaphthylene	208-96-8	**495**	1 (7/266)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.

[4] Benzo(b,j)fluoranthene (BBJF) used as a proxy for benzo(b)fluoranthene.

Table 3: Proposed EQS for selected contaminants in blue mussel (*Mytilus edulis*). For comparison the Norwegian provisional high reference contaminant concentration (PROREF) are shown (Green et al. 2020).

Parameter code	Parameter name	CAS no.	Proposed EQS µg/kg wet weight	PROFEF µg/kg wet weight (based on st./value count)	Comment
ACNE	Acenaphthene	83-32-9	**2888**	0.8 (5/177)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
FLE	Fluorene	86-73-7	**1527**	1.6 (9/364)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
PA	Phenanthrene	85-01-8	**2435**	2.28 (3/47)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is very high.
PYR	Pyrene	129-00-0	**30**	1.02 (1/17)	Likely that monitoring results will not exceed EQS, even in impacted areas, because EQS is high.
CHR	Chrysene	218-01-9	**5**	0.52 (1/17)	
DBAHA	Dibenzo[a,h]anthracene	53-70-3	**5**	0.5 (2/117)[5]	
PFOS	Perfluorooctanesulfonic acid (PFOS)	1763-23-1	**0.36**		
PFOA	Perfluorooctanoic acid (PFOA)	335-67-1	**36**		

[5] Dibenzo(a,c/a,h)anthracene (DBA3A) used as a proxy for dibenzo(ah)anthracene

8. References

1881/2006/EC, Regulation. 2006. 'COMMISSION REGULATION (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs', *Official Journal of the European Union*, L 364/5: 20.

2000/60/EC, Directive. 2000. 'DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy', *Official Journal of the European Communities*, L 327/1: 72.

2013/39/EU, Directive. 2013. 'DIRECTIVE 2013/39/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy', *Official Journal of the European Union*, L 226/1: 17.

Amlund, H. 2005. "The disposition of arsenobetaine in Atlantic salmon, Salmo salar L., and Atlantic cod, Gadus morhua L." In *Dissertation for the degree of Doctor Scientiarum*, edited by Bergen University of Bergen, Norway.

Arnot, J. A., and F. A. P. C. Gobas. 2006. 'A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms', *Environmental Reviews*, 14: 257-97.

Arp, HA, A Ruus, A Macken, and A Lillicrap. 2014. "Kvalitetssikring av miljøkvalitetsstandarder." In, 199. Miljødirektoratet: NIVA og NGI.

Beyer, J., N.W. Green, S. Brooks, I.J. Allan, A. Ruus, T. Gomes, I.L.N. Bråte, and M. Schøyen. 2017. 'Blue mussels (*Mytilus edulis* spp.) as sentinel organisms in coastal pollution monitoring: A review', *Marine Environmental Research*, 130: 338-65.

Bleeker, E.A.J., and E.M.J. Verbruggen. 2009. 'Bioaccumulation of polycyclic aromatic hydrocarbons in aquatic organisms', *National Institute for Public Health and the Environment (RIVM)*, Report 601779002/2009: 51 http://www.rivm.nl/bibliotheek/rapporten/601779002.pdf.

Brooks, S. J., and E. Farmen. 2013. 'THE DISTRIBUTION OF THE MUSSEL MYTILUS SPECIES ALONG THE NORWEGIAN COAST', *Journal of Shellfish Research*, 32: 265-70.

Chapman, P. M. 2008. 'Environmental risks of inorganic metals and metalloids: A continuing, evolving scientific odyssey', *Human and Ecological Risk Assessment*, 14: 5-40.

CIS. 2005a. 'Priority Substance no. 6 Cadmium and its compounds. CAS-No. 7440-43-9', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2005. Substance Data Sheet in accordance with Article 16 of the Water Framework Directive: https://circabc.europa.eu/sd/a/42a9cfc4-6f5e-41bf-8db2-d5681be56e01/06_Cadmium_EQSdatasheet_310705.pdf.

———. 2005b. 'Priority Substance no. 21 Mercury and its compounds. CAS-No. 7439-97-6', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2005. Substance Data Sheet in accordance with Article 16 of the Water Framework Directive: https://circabc.europa.eu/sd/a/ff8e163c-71f6-4fc0-98ef-875a20add4c8/21_Mercury_EQSdatasheet_150105.pdf.

———. 2011a. 'Guidance Document No. 27 - Technical guidance for deriving environmental quality standards. Brussel: European Commission', *Common implementation strategy for the Water Framework Directive (2000/60/EC) [European Communities]*, Technical Report no. 2011-055.

———. 2011b. 'Priority Substance No.2 Anthracene', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2011. Substance Data Sheet. The dossier was reviewed by Scientific Committee on Health and the Environmental Risks (SCHER): https://circabc.europa.eu/sd/a/60c3c0c0-ea7b-4aa6-81ca-91241a251a79/Anthracene%20EQS%20dossier%202011.pdf.

———. 2011c. 'Priority Substance No.20 Lead and its compounds', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2011. Substance Data Sheet. The dossier was reviewed by Scientific Committee on Health and the Environmental Risks (SCHER): https://circabc.europa.eu/sd/d/be12c5a9-19b2-40eb-87ce-f62eb3b43b39/Lead%20and%20its%20compounds%20EQS%20dossier%202011.pdf.

———. 2011d. 'Priority Substance No.22 Naphthalene', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2011. Substance Data Sheet. The dossier was reviewed by Scientific Committee on Health and the Environmental Risks (SCHER): https://circabc.europa.eu/sd/a/2fc1dfd1-fc77-44af-9d23-2a0c1735ce6d/Naphthalene%20EQS%20dossier%202011.pdf.

———. 2011e. 'Priority Substance No.23 Nickel and its compounds', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2011. Substance Data Sheet. The dossier was reviewed by Scientific Committee on Health and the Environmental Risks (SCHER): https://circabc.europa.eu/sd/d/1e2ae66f-25dd-4fd7-828d-9fd5cf91f466/Nickel%20EQS%20dossier%202011.pdf.

———. 2011f. 'Priority Substance No.28. 5-6 ring polyaromatic hydrocarbons', *Common implementation strategy for the Water Framework Directive (2000/60/EC)*, Environmental Quality Standards (EQS). EQS dossier 2011. Substance Data Sheet. The dossier was reviewed by Scientific Committee on Health and the Environmental Risks (SCHER): https://circabc.europa.eu/sd/d/4e13a4c4-07b9-4e55-a43d-823e7cd4ce82/PAH%20EQS%20dossier%202011.pdf.

———. 2011g. 'Priority Substance no. 15, Fluoranthene', *Environmental Quality Standards (EQS). EQS dossier 2011. Substance Data Sheet. The dossier was reviewed by Scientific Committee on Health and the Environmental Risks (SCHER)*: https://circabc.europa.eu/sd/a/4336e1e5-ba0c-545-abee-7743d2085bc3/Fluoranthene%20EQS%20dossier%202011.pdf.

———. 2014. 'Guidance Document No. 32 on biota monitoring and (the implementation of EQS-biota) under the Water Framework Directive', *Common implementation strategy for the Water Framework Directive (2000/60/EC) [European Communities]*, Technical Report - 2014 - 083.

Cossa, D. 1989. 'A review of the use of *Mytilus spp* as quantitative indicators of cadmium and mercury contamination in coastal waters', *Oceanologica Acta*, 12: 417-32.

Direktoratsgruppen_vanndirektivet. 2018. 'Veileder 02:2018. Klassifisering av miljøtilstand i vann. Økologisk og kjemisk klassifiseringssystem for kystvann, grunnvann, innsjøer og elver', *Direktoratsgruppen for gjennomføringen av vannforskriften*: 222.

Donat, J.R., and K.W. Bruland. 1995. 'Trace elements in the oceans.' in B. Salbu E. Steinnes (ed.), *Trace Elements in Natural Waters* (CRC Press: Boca Raton, FL).

EFSA. 2020. 'PFAS in food: EFSA assesses risks and sets tolerable intake', European Food Safety Agency (EFSA), 17.09.2020, Accessed 05.01.2021. https://www.efsa.europa.eu/en/news/pfas-food-efsa-assesses-risks-and-sets-tolerable-intake.

Gobas, F.A.P.C, W. DeWolf, L.P. Burkhard, E.M.J. Verbruggen, and K. Plotzke. 2009. 'Revisiting Bioaccumulation Criteria for POPs and PBT Assessments', *Integrated Environmental Assessment and Management*, 5, no.4: 624-37.

Green, N. W., M. Schøyen, D. Ø. Hjermann, S. Øxnevad, A. Ruus, B. Beylich, E. Lund, L. Tveiten, Jennsen M. T. S., J. Håvardstun, Ribeiro A. L., Rundeberget J. T., and K. Bæk. 2019. 'Contaminants in coastal waters of Norway 2018. Miljøgifter i norske kystområder 2018', *NIVA-report 7412-2019*: 237.

Green, N. W., M. Schøyen, D. Ø. Hjermann, S. Øxnevad, A. Ruus, M. Grung, B. Beylich, E. Lund, L. Tveiten, Jennsen M. T. S., J. Håvardstun, Ribeiro A. L., I. Doyer, and K. Bæk. 2020. 'Contaminants in coastal waters of Norway 2019. Miljøgifter i norske kystområder 2019', *Norwegian Institute for Water Research (NIVA)-report 7565-2020*: 195 + appendices.

Green, N. W., M. Schøyen, S. Øxnevad, A. Ruus, D. Ø. Hjermann, G. Severinsen, T. Høgåsen, B. Beylich, J. Håvardstun, E. Lund, L. Tveiten, and K. Bæk. 2017. 'Contaminants in coastal waters of Norway 2016', *NIVA-report 7200-2017*: 201 pp.

Green, Norman Whitaker, Merete Schøyen, Dag Øystein Hjermann, Sigurd Øxnevad, Anders Ruus, Amy Lusher, Bjørnar Beylich, Espen Lund, Lise Ann Tveiten, Jarle Håvardstun, Marthe Torunn Solhaug Jenssen, Anne Luise Ribeiro, and Kine Bæk. 2018. 'Contaminants in coastal waters of Norway 2017', *NIVA report 7302-2018*: 230.

Hansen, N., V.B. Jensen, H. Appelquist, and E. Mørch. 1978. 'The uptake and release of petroleum hydrocarbons by the marine mussel Mytilus edulis', *Ninth International Conference on Water Pollution Research*, 10: 351-59 https://www.sciencedirect.com/science/article/pii/B9780080229393500325?via%3Dihub.

Lavoie, R.A., T.D. Jardine, M.M. Chumchal, and K.A. Kidd. 2013. 'Biomagnification of Mercury in Aquatic Food Webs: A Worldwide Meta-Analysis', *Environmental Science & Technology*, 47: 13385-94.

Lobel, P.B., and H.D. Marshall. 1988. 'A unique low molecular weight zinc-binding ligand in the kidney cytosol of the musselMytilus edulis, and its relationship to the inherent variability of zinc accumulation in this organism', *Marine Biology*, 99: 101-05. https://link.springer.com/article/10.1007/BF00644982.

Luoma, S. N., and P. S. Rainbow. 2005. 'Why is metal bioaccumulation so variable? Biodynamics as a unifying concept', *Environmental Science & Technology*, 39: 1921-31.

McGeer, J. C., K. V. Brix, J. M. Skeaff, D. K. DeForest, S. I. Brigham, W. J. Adams, and A. Green. 2003. 'Inverse relationship between bioconcentration factor and exposure concentration for metals: Implications for hazard assessment of metals in the aquatic environment', *Environmental Toxicology and Chemistry*, 22: 1017-37.

Norwegian_Environment_Agency. 2016. 'Quality standards for water, sediment and biota', *Norwegian Environment Agency*, M-608: 26.

NS. 2017. 'Vannundersøkelse – Overvåking av miljøgifter i blåskjell (Mytilus spp.) – Innsamling av utplasserte eller stedegne skjell og prøvebehandling. Water Quality – Monitoring of environmental contaminants in blue mussel (Mytilus spp.) – Collection of caged or native mussels and sample treatment. ', *Norsk Standard 9434-2017*: 15.

OECD. 1996. "Bioconcentration: Flow-through fish test. OECD guidelines for the testing chemicals." In, 23 pp. Paris, France: Organization for Economic Co-operation and Development.

OSPAR. 2016. "OSPAR Coordinated Environmental Monitoring Programme (CEMP)." In *OSPAR Agreement 2016-01*, 1-142.

Øxnevad, S. 2019a. 'Tiltaksorientert overvåking av Husnesfjorden i 2018. Overvåking for Hydro Aluminium Husnes, Operational monitoring of the Husnesfjord in 2018. Monitoring on behalf of Hydro Aluminium Husnes', *NIVA*, 7346-2019: 28.

Øxnevad, S., Håvardstun, J. 2019b. 'Tiltaksorientert overvåking av Årdalsfjorden i 2018. Overvåking for Hydro Aluminium Årdal.', *NIVA report*, 7344-2019: 33.

RAR. 2005. 'Chromium trioxide, sodium chromate, sodium dichromate, ammonium dichromate, potassium dichromate', *European Union Risk Assesment Report (RAR)*, European Chemicals Bureau. Institute for Health and Concumer Protection. 3rd Priority List. Volume 53.

———. 2010. 'Zinc metal. Zn. CAS: 7440-66-6. EINECS No: 231-175-3', *European Union Risk Assesment Report (RAR)*, European Commission (EC) Joint Research Centre (JRC) EUR 24587 EN - 2010.

Richardson, B.J., B.S.-C. Tse, S.B. De_Luca-Abbott, M. Martin, and P.K.S. Lam. 2005. 'Uptake and depuration of PAHs and chlorinated pesticides by semi-permeable membrane devices (SPMDs) and green-lipped mussels (Perna viridis)', *Marine pollution bulletin*, 51 (2005): 975-93.

SCHER. 2008. 'Copper, Copper II sulphate pentahydrate, Copper(I)oxide, Copper(II)oxide, Dicopper chloride trihydroxide. Health part. CAS No:7440-50-8, 7758-99-8, 1317-39-1, 1317-38-0, 1332-65-6. EINECS No. 231-159-6, 231-847-6, 215-270-7, 215-269-1, 215-272-9', *European Comission. Scientific Committee on Health and Environmental Risks (SCHER)*.

Schøyen, M., I.J. Allen, A. Ruus, J. Håvardstun, D.Ø. Hjermann, and J. Beyer. 2017. 'Comparison of caged and native blue mussels (*Mytilus edulis* spp.) for environmental monitoring of PAH, PCB and trace metals', *Marine Environmental Research*, 130: 221-32.

Schøyen, M., J. Håvardstud, R. Næss, M. S. Brkljacic, and H. Trannum. 2019. 'Operational monitoring in compliance with the EU Water Framework Directive for DuPont Nutrition Norge AS in the Karmsund.', *NIVA-report*, 7401-2019: 43.

Stankovic, S., and M. Jovic. 2012. 'Health risks of heavy metals in the mediterranean mussels as seafood', *Environmental Chemistry Letters*, 10: 119-30.

UK-EA. 2007. 'Using science to create a better place.Preconsultation report: Proposed EQS for Water Framework Directive Annex VIII substances: arsenic (total dissolved)', *Science Report: SC040038/SR3. SNIFFER [Scotland and Northern Ireland Forum for Environmental Research]Report: WFD52(iii) SCHO0407BLVU. UK Environment Agency, 2007.*

UKTAG. 2012. 'Proposals for Further Environmental Quality Standards for Specific Pollutants. Final version for UKTAG. April 2012', *UK Technical Advisory Group on the Water Framework Directive*.

Verbruggen, E.M.J. 2012. 'Environmental risk limits for polycyclic aromatic hydrocarbons (PAHs)', *National Institute for Public Health and the Environment (RIVM)*, RIVM report 607711007/2012: 337.

Zuykov, M., E. Pelletier, and D. A. T. Harper. 2013. 'Bivalve mollusks in metal pollution studies: From bioaccumulation to biomonitoring', *Chemosphere*, 93: 201-08.

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We are a government agency under the Ministry of Climate and Environment and have 700 employees at our two offices in Trondheim and Oslo and at the Norwegian Nature Inspectorate's more than sixty local offices.

We implement and give advice on the development of climate and environmental policy. We are professionally independent. This means that we act independently in the individual cases that we decide and when we communicate knowledge and information or give advice.

Our principal functions include collating and communicating environmental information, exercising regulatory authority, supervising and guiding regional and local government level, giving professional and technical advice, and participating in international environmental activities.