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Impact of mercury released from permafrost on food safety in Switzerland.

Current situation and possible future lines of surveillance.

Photography: Eroding permafrost on Alaska's Arctic Coast. © USGS/Christopher Arp

IMPRESSUM

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ABSTRACT (English)

Climate change has caused the permafrost to thaw, releasing the previously sequestered mercury into the environment. Mercury has the ability to convert to methylmercury, a bioaccumulative neurotoxin. Exposure occurs in humans through the ingestion of contaminated food and it is associated with adverse health effects. In the context of global warming, this report aims to provide a basis for discussion on the impact of mercury released from permafrost on Switzerland's food safety.

Data available in the scientific literature and in databases were reviewed in order to identify the relevant fish indicating the mercury exposure of the Swiss population and the potential evolution of the situation in the coming years. To assess the current relevance for Switzerland of undertaking mercury monitoring in indicator fish, gaps in the literature were identified. In addition, several experts were contacted regarding the topics described above in order to complement and refine the results of the literature review.

The main results suggest that the current situation does not yet pose a threat to the Swiss population. However, mercury is certainly being released from the permafrost and its future impact remains uncertain at present. Two species provide some indication of the amount of mercury released by thawing permafrost: Atlantic cod *Gadus morhua*, one of the fish most imported into Switzerland from FAO zones 18, 21, 27 and 67, and Arctic cod *Boreogadus saida* because of its position in the Arctic food chain.

To conclude, although fish is not a major component of the Swiss diet, it would be worthwhile to monitor the contamination of mercury in the two species mentioned above due to the uncertainty of the situation. It is not necessary for Switzerland to conduct its own chemical analyses of mercury in fish but it is important to regularly consult databases such as, the Arctic database(s) Seafood Data and to identify any possible increasing trend.

ABSTRACT (Deutsch)

Der Klimawandel hat zum Auftauen der Permafrostböden geführt, und das zuvor gebundene Quecksilber wird in die Umwelt freigesetzt. Quecksilber kann sich in Methylquecksilber, ein bioakkumulatives Neurotoxin, umwandeln. Die Exposition des Menschen erfolgt durch die Aufnahme von kontaminierten Lebensmitteln und geht mit gesundheitsschädlichen Auswirkungen einher. Vor dem Hintergrund der globalen Erwärmung soll dieser Bericht eine Grundlage für die Diskussion über die Auswirkungen von Quecksilber aus dem Permafrost auf die Lebensmittelsicherheit in der Schweiz bieten.

In diesem Bericht werden die in der wissenschaftlichen Literatur und in Datenbanken verfügbaren Daten zusammengefasst, um jene Fische zu bestimmen, die für die Quecksilberexposition der Schweizer Bevölkerung von Bedeutung und für die mögliche Entwicklung der Situation in den kommenden Jahren ausschlaggebend sind. Ferner werden Lücken in der Literatur identifiziert, um die aktuelle Bedeutung eines Quecksilbermonitorings bei Indikatorfischen für die Schweiz zu beurteilen. Des Weiteren wurden zu den oben beschriebenen Themen mehrere Expertinnen und Experten kontaktiert, um die Ergebnisse der Literaturübersicht zu ergänzen und zu verfeinern.

Die wichtigsten Ergebnisse legen nahe, dass in der aktuellen Situation noch keine Gefährdung für die Schweizer Bevölkerung besteht. Allerdings wird Quecksilber erwiesenermassen aus dem Permafrost freigesetzt und die zukünftigen Auswirkungen sind derzeit noch unklar. Zwei Fischarten können Hinweise darauf geben, wie viel Quecksilber durch den auftauenden Permafrostboden freigesetzt wird: Atlantischer Kabeljau (*Gadus morhua*), einer der am häufigsten aus den FAO-Zonen 18, 21, 27 und 67 in die Schweiz importierten Fische, sowie Polardorsch (*Boreogadus saida*) aufgrund seiner Stellung in der arktischen Nahrungskette.

Zusammenfassend lässt sich sagen, dass aufgrund der unsicheren Lage ein Monitoring zur Quecksilberkontamination der beiden oben genannten Fischarten sinnvoll wäre, auch wenn Fisch kein Hauptbestandteil der Schweizer Ernährung ist. Es ist nicht notwendig, dass die Schweiz eigene chemische Analysen zu Quecksilber in Fischen durchführt, hingegen ist eine regelmässige Datenbanksichtung, z. B. die Arktische(n) Datenbank(en) wie «Seafood data», angezeigt, um mögliche Entwicklungen zu erkennen.

ABSTRACT (français)

Sous l'effet du changement climatique, le pergélisol dégèle et libère du mercure dans l'environnement. Or le mercure peut se transformer en méthylmercure, une neurotoxine bioaccumulable. L'exposition chez l'homme intervient par l'ingestion d'aliments contaminés et s'accompagne d'effets néfastes sur la santé. Ce rapport vise à fournir une base de discussion sur l'impact du mercure libéré par le pergélisol sur la sécurité des denrées alimentaires en Suisse.

Les données disponibles dans les publications scientifiques et dans les bases de données ont été analysées de façon à identifier les poissons indicateurs de l'exposition au mercure de la population suisse et de l'évolution possible de la situation au cours des prochaines années. Les lacunes de la littérature ont été identifiées afin d'évaluer l'intérêt qu'il y a pour la Suisse de mener un monitoring du mercure dans les poissons indicateurs. Par ailleurs, plusieurs experts ont été contactés sur les sujets décrits précédemment dans le but de compléter et d'affiner les résultats de l'analyse documentaire.

Pour l'heure, la situation ne constitue pas encore une menace pour la population suisse. Tel est le principal constat. Si la libération de mercure par le pergélisol est une certitude, son impact reste incertain à l'heure actuelle. Deux espèces de poisson fournissent des indications sur la quantité de mercure libérée sous l'effet du dégel du pergélisol : la morue de l'Atlantique (*Gadus morhua*), l'un des poissons les plus importés en Suisse en provenance des zones FAO 18, 21, 27 et 67, et la morue polaire (*Boreogadus saida*) de par sa position dans la chaîne alimentaire de l'Arctique.

En conclusion, bien que le poisson ne soit pas une composante majeure du régime alimentaire suisse, il serait intéressant de surveiller la contamination au mercure des deux espèces susmentionnées du fait des incertitudes liées à la situation. Il n'y a pas lieu que la Suisse procède à ses propres analyses chimiques du mercure dans le poisson. Toutefois, il importe qu'elle consulte régulièrement les bases de données telles que les bases de données arctiques de Seafood Data de façon à identifier toute tendance à la hausse des contaminations.

TABLE DES MATIERES

I. Introduction

Permafrost is a soil where temperature stays at or below 0°C for at least two consecutive years. It is overlaid with an active layer that thaws in summer and refreezes in winter. Inorganic mercury (Hg) from the atmosphere deposits onto the soil surface where it bonds with organic matter such as plant roots. Simultaneously, microorganisms will consume the organic matter releasing the bonded Hg into the atmosphere while the sedimentation burry Hg bond to organic matter into the permafrost (Smith-Downey, et al. 2010). Once frozen, the microbial decay ceases, locking the Hg into the permafrost (Obrist, et al. 2017). As this process has taken place over thousands of years, permafrost could be one of the largest sinks of Hg on the planet. Schuster, et al. (2018) estimated the amount of Hg likely stored in both the permafrost and the active layer to contain nearly twice as much Hg as all the other soils, the ocean and the atmosphere combined. Alarmingly, global warming causes the permafrost to thaw, causing the restart of microbial decomposition releasing previously sequestered Hg back into the environment potentially impacting human health (Basu, et al. 2022).

The potential release of such a large amount of Hg is of concern because of its ability be convert into organic mercury through a biological bacterial process. Its most common form, methylmercury (MeHg), is a bioaccumulative neurotoxin that biomagnifies along the aquatic food chain (Lavoie, et al. 2013). Fish muscle is the main fish tissue consumed by humans and was also found to act as a mercury (Hg) reservoir (de Oliveira Ribeiro, et al. 2008). Compared to other organs, muscle has also shown the capacity to enhance long-term bioaccumulation due to its increased capacity to accumulate MeHg. (Sandheinrich, et al. 2011). As a result, the highest concentrations of MeHg are often found in piscivorous[1] fish and top marine predators. However, Hg release from the permafrost is mainly found in the sediment and Hg concentrations in fish muscle is found to be positively associated with increasing sediment contamination (Ho, et al. 2021). Thus, demersal[2] species, who are bottom feeders, would better indicate the impact of Hg release from the permafrost thaw. The fishing areas particularly concerned by Hg contamination from the permafrost thaw are FAO areas 18 (Arctic Ocean), 21 (North West Atlantic Ocean), 27 (North East Atlantic Ocean (NEAO)) and 67 (North East Pacific Ocean) (Figure 1).

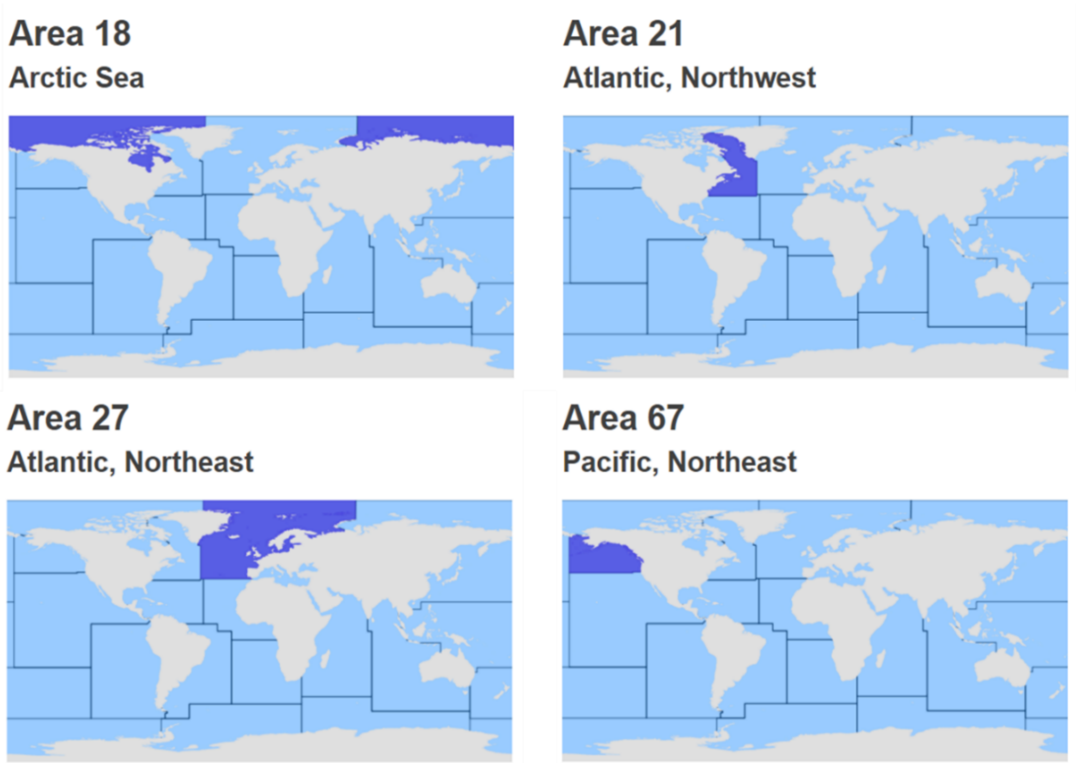

Figure 1 Map of the world representing FAO's fishing area 18, 21, 27 and 67. Source : **Fishing areas (europa.eu)**

1 A carnivorous animal that primarily eats fish.
2 Fishes that live and feed on or near the bottom of seas or lakes, also known as groundfish.

The human exposure of MeHg, through the ingestion of contaminated food items, such as fish, is associated with adverse health outcomes across life stages, ranging from neurodevelopmental outcomes in young children to cardiovascular disease in adults (Díez 2009 ; Mergler, et al. 2007). For example, due to their diet rich in fish and marine mammals, Hg exposure in indigenous Arctic populations is high enough to cause a health impact (Basu, et al. 2022). Striking a balance between the risks associated with MeHg exposure and the benefits of seafood consumption is of critical concern, as seafood is also an important source of animal protein for a large proportion of the world's population and its consumption is associated with many health benefits (Basu, et al. 2022). In 2012, the European Food Safety Authority (EFSA) adopted an opinion on Hg and MeHg in food. In that opinion, the EFSA established a tolerable weekly intake ('TWI') of 4 µg Hg/kg body weight (bw) and of 1,3 µg MeHg/kg bw (EFSA, 2012). In 2014, the EFSA recommended 1 to 4 fish servings per week to protect against neurodevelopmental toxicity of MeHg (EFSA, 2014).

The European Commission fixes in the Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 the maximum level of total Hg in the muscle of most fish species for human consumption at **0.5 mg Hg/kg wet weight (ww).** For the most consumed fish such as the Atlantic cod (*Gadus morhua*), the upper limit is set **at 0.3 mg Hg/kg ww**, while for some predatory species such as the Atlantic halibut (*Hippoglossus hippoglossus*), the limit is **1.0 mg Hg/kg ww** (Annex 1). For Switzerland, the regulation is the same with the exception that the limit of 0.3 mg Hg/kg ww set by the EU is not yet in force (Annex 2). Therefore, the threshold for the concerned seafood is currently set at 0.5 mg Hg/kg ww (Kontaminantenverordnung (VHK). SR 817.022.15).

This report aims to provide a basis for discussion on the relevance for Switzerland of undertaking mercury monitoring in indicator fish. In order to achieve it, this report aims to answer the following three questions: 1) Does the current situation of Hg and MeHg contamination in fish sourced from risk areas pose a threat to the health of the Swiss consumer? 2) Will the mercury release from the thaw of the permafrost become a problem in future? 3) Is it worthwhile for Switzerland to undertake analyses of mercury in fish in order to be aware of any increasing trend?

II. Method

Two methods were combined in order to regroup the most relevant data for this report. A classic review of the scientific literature was conducted and experts on the topic were contacted. Additionally, a database recommended by one of the experts was used to gather data about mercury in fish.

a. Review of the literature

In order to write this report, a review of the scientific literature was conducted on three databases : Pubmed, ScienceDirect and Wiley Online Library. The term "mercury in permafrost" was the key descriptor used in the information search. Additionally, "mercury" and "methylmercury" together with the combination of the following keywords "fish", "arctic food web", "aquatic ecosystems", "effect on biota" "effects on human health" and "¨future trends" were also considered in the search and selection of papers. Books, book chapters and technical reports from authorities on environmental health issues linked to mercury were considered (Arctic Monitoring and Assessment Program (AMAP), Minamata Convention on Mercury and the United Nations Environment Program (UNEP)).

b. Experts' opinion

Several experts were contacted in order to refine the literature search. Each of them answered questions specific to their field of expertise. The experts contacted were recommended by the Federal Food Safety and Veterinary Office, FSVO's Early Detection Evaluation Committee (Seismo). The contacted experts could then redirect the enquiry to other experts they knew when needed. The list of the experts who were contacted can be found in Annex 3.

c. Seafood Data

A database called Seafood Data shows monitoring results of contaminants in Arctic seafood. It enables to search for and compare the contents of contaminants and nutrients in fish and other seafood. However, the precise location of the fish caught is not specified. This database belongs to the Institute of Marine Research in Norway.

III. RESULTS

In order to answer the first question whether the current situation of Hg and MeHg contamination in fish sourced from risk areas pose a threat to the health of the Swiss consumer, relevant fish species that could give an indication of the current state of Hg were identified.

In order to answer both the second and third questions if the mercury release from the thaw of the permafrost will become a problem in future and if it is worthwhile for Switzerland to undertake analyses of mercury in fish in order to be aware of any increasing trend, a brief literature review was undertaken in which gaps in the knowledge were identified.

The results are summarized in table 1.

a. Identification of relevant fishes

The aim of this paragraph is to identify relevant fish indicating the current state and health impact of Hg release from the permafrost in dietary intake for human. These fish need to meet the following criteria:

- They should live in the FAO areas 18, 21, 27 and 67
- They should be demersal fish[3] species
- They should either have a central role in the Arctic food web or they should be widely consumed by the Swiss population.

Based on a review of the literature and expert opinion, the following fishes have been identified as potentially relevant indicator fish. In order to select the most relevant fish, their habitat and role in the Arctic food web, their place in the Swiss diet and the available data on mercury contamination are presented and compared below.

[3] Fishes that live and feed on or near the bottom of seas or lakes, also known as groundfish.

i. Polar cod (*Arctogadus glacialis*)

Habitat and role of fish in web of food in the Arctic

The polar cod *Arctogadus glacialis* (Figure 2) also known as Arctic cod or ice cod in the scientific literature, is one of the most numerous fish species in the Arctic. This cod lives up to 1000m depth and take a central role in linking the water column food webs to higher level consumers in the food chain (Norcross and Iken, 2016). Numerous Arctic mammals depend heavily on polar cod. He is also subject to specific concern in a climate change context because its young life stages depend on sea ice as a habitat, and this central species in the Arctic food web may be severely impacted by the ongoing and projected sea ice loss (Norcross and Iken, 2016). This fish is namely present in the FAO Areas 18, 21 and 27 (ec.europa).

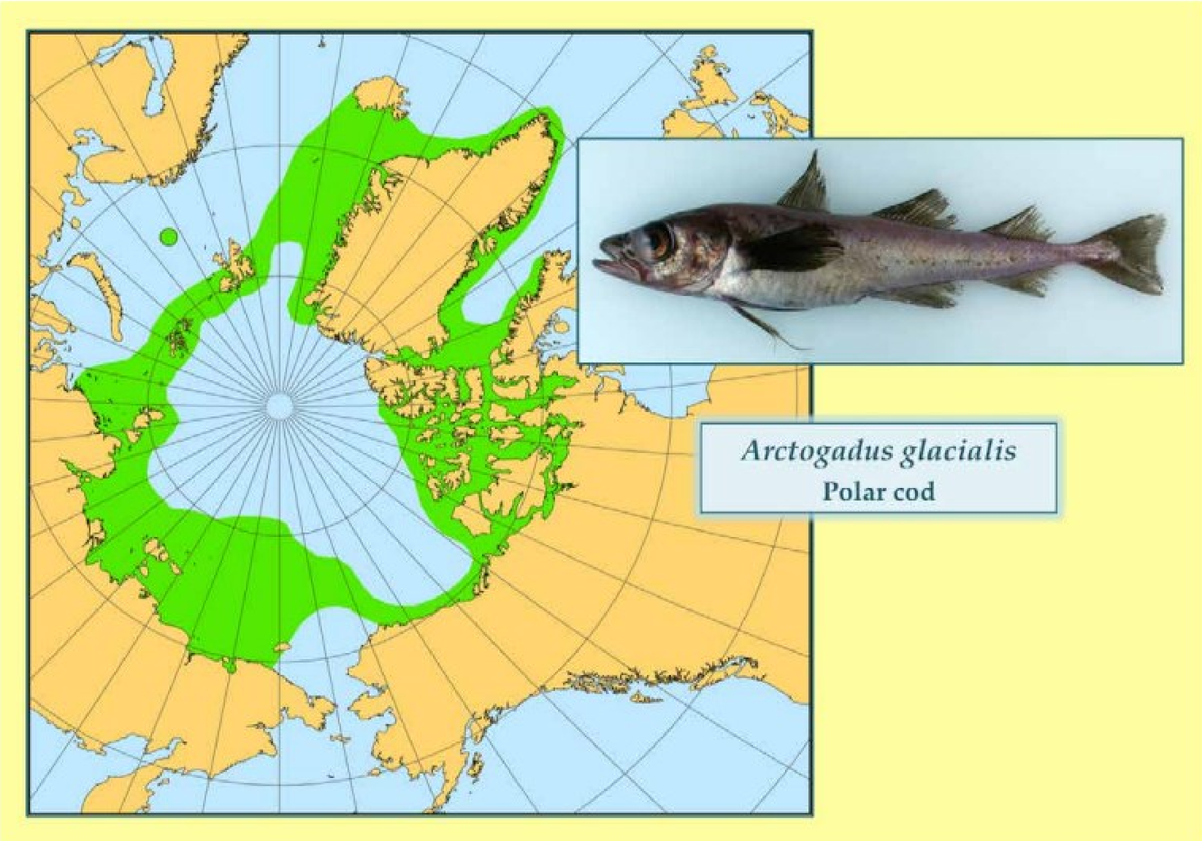

Figure 2 World distribution of Polar cod *Arctogadus glacialis*. Source : **Mecklenburg, C.W., and D. Steinke. 2015.** More info : ***Arctogadus glacialis*, Arctic cod : fisheries (fishbase.se)**

Place in the Swiss diet

Even if *Arctogadus glacialis* is numerous in the Arctic, it is, to our knowledge, not imported into Switzerland (see Annex 4) nor consumed by humans in general.

Available data on mercury contamination

In 2008, Kirk et al. investigated the mercury in the Canadian Arctic waters. Hg concentrations in Polar cod (*Arctogadus glacialis*) were collected in spring under the ice in the Amundsen Gulf/Franklin Bay in the Beaufort Sea (Figure 3). Results showed, on average total Hg concentrations of 0.37 µg/g dw (dry weight) and were significantly higher than those also collected in 2008 from the epibenthic[4] food web present in coastal shelf region of the Beaufort Sea, near the Mackenzie Delta (0.16 µg/g dw) (Loseto et al. 2008). Variability in Polar cod total Hg concentrations are also observed across the circumpolar Arctic with concentrations in Lancaster Sound and North Water Polynya being considerably higher (0.2 µg/g dw) (Atwell et al. 1998, Campbell et al. 2005) than those measured in Kongsfjorden near Svalbard (0.05 µg/g dw) (Jaeger et al. 2009) (Figure 3).

[4] Organisms that live on the surface of sediments at the bottom of the sea.

The similarities in Hg concentrations among fish from the coastal shelf region and the differences in Hg concentrations of Arctic cod observed between the different regions show the potential influence of regional Hg sources and food web structure on the fish Hg concentrations. However, it is still unclear how to distinguish between these two factors. Differences in Hg concentration between Arctic cod from the open sea and the shelf could be caused, for example, by regional sources of Hg or by seasonal influences on foraging or by the physiology of the fish, which may affect the bioaccumulation and/or distribution of mercury in the body (Kirk, et al. 2012). Additionally, causes of the differences in total Hg contamination are difficult to assess as illustrated by the results of the studies presented in paragraph 4.1.2 from the review of Kirk, et al. (2012), which seem to be mixing the polar cod *Arctogadus glacialis with another fish also known as polar cod, the Boreogadus saida.*

Arctogadus glacialis is not referenced in the Arctic database Seafood Data.

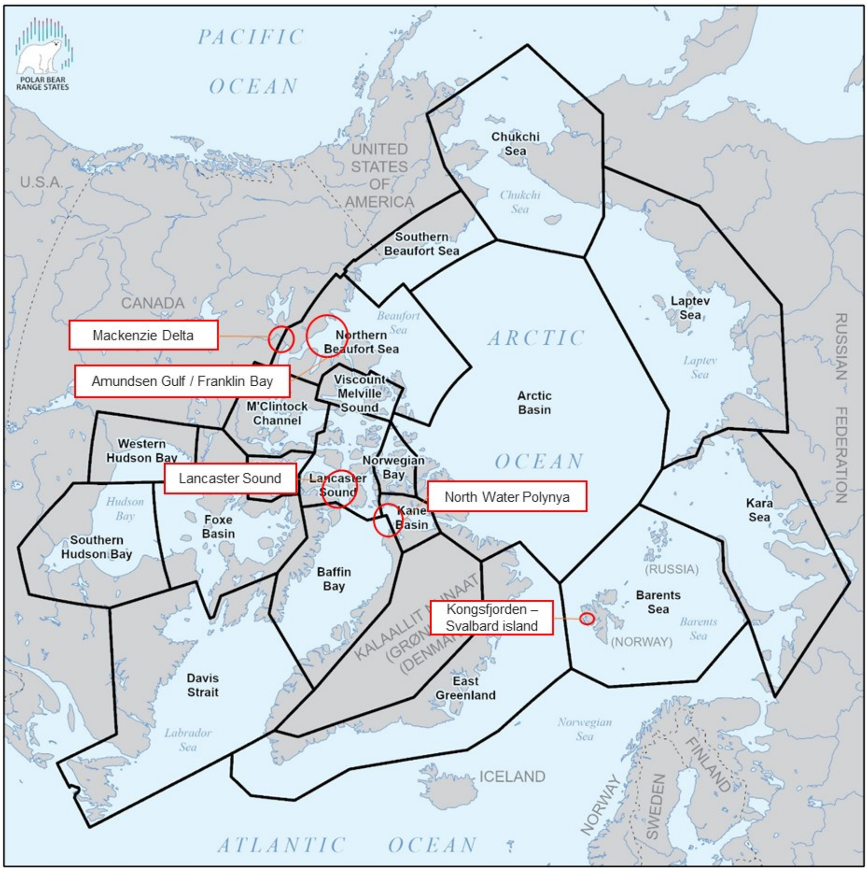

Figure 3 Map representing the polar range states and the places where *Arctogadus glacialis* sampling took place (circled in red). Source : **polarbearagreement.org**

Conclusion

Arctogadus glacialis does not seem to be an easily accessible indicator for mercury concentration in fish as no data, apart from punctual environmental analysis, are available. It is therefore not recommended to use it as an indicator species.

ii. Polar cod (*Boreogadus saida*)

Habitat and role of fish in web of food in the Arctic

The *Boreogadus saida* (Figure 4) is also known as polar cod or Arctic cod and it is the most common species found in the Northeast Atlantic Ocean. *Arctogadus glacialis* and *Boreogadus saida*, often coexist in the fjords and shelf areas of the Arctic seas, where they likely share the same food resources (Christiansen, 2012). *Boreogadus saida* is most commonly found at the water's surface, but is also known to travel at depths greater than 900 metres. In the same way as the *Arctogadus glacialis, Boreogadus saida* (Figure 4) is a key species in the Arctic marine food web, and it is an important prey for piscivorous fish, seabirds and marine mammals in the area. This fish is namely present in the FAO Areas 18, 21, 27, 61 and 67.

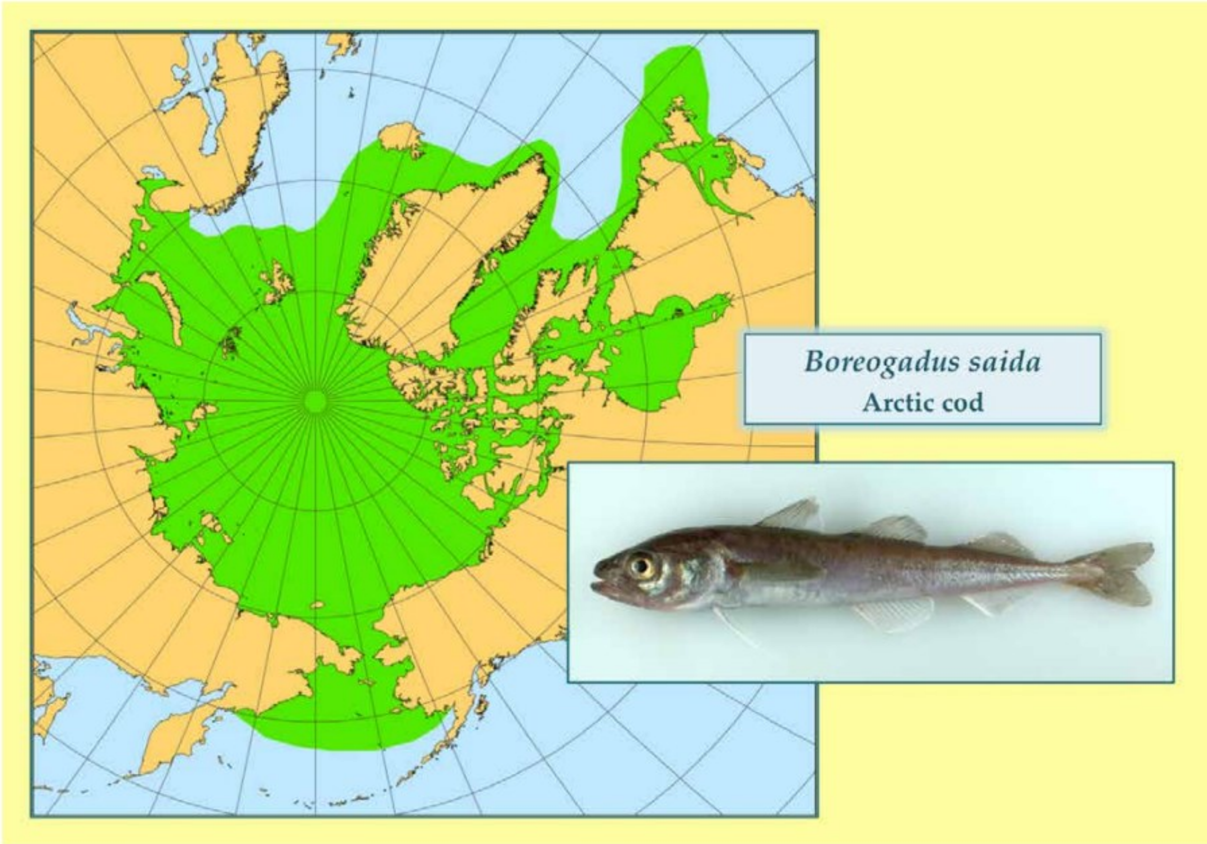

Figure 4 World distribution of Arctic cod *Boreogadus saida*. Source : **Mecklenburg, C.W., and D. Steinke. 2015** More info : **europa.eu**, ***Boreogadus saida*, Polar cod : fisheries (fishbase.se)**

Place in the Swiss diet

As with *Arctogadus glacialis,* even if *Boreogadus saida* is found in high numbers in the Arctic, it is to our knowledge not imported to Switzerland (Annex 4) nor consumed by humans in general.

Available data on mercury contamination

In 2021, Gopakumar et al. quantified and compared total Hg concentration in three key Arctic fish species sampled during the polar night, two of which were sampled in both the North-West and North-East regions of the Barents Sea (Figure 5). total Hg concentrations varied from 14 to 84 ng/g dry weight (dw) dependent on region, but were well below the toxicity threshold for fish health and the EU-accepted maximum level for human consumption of 0.5 mg Hg/kg ww according to the researchers. Spatial differences in polar cod with higher total Hg concentrations in the North-East than the North-West were likely due to a combination of differences in food web structure and Hg exposure.

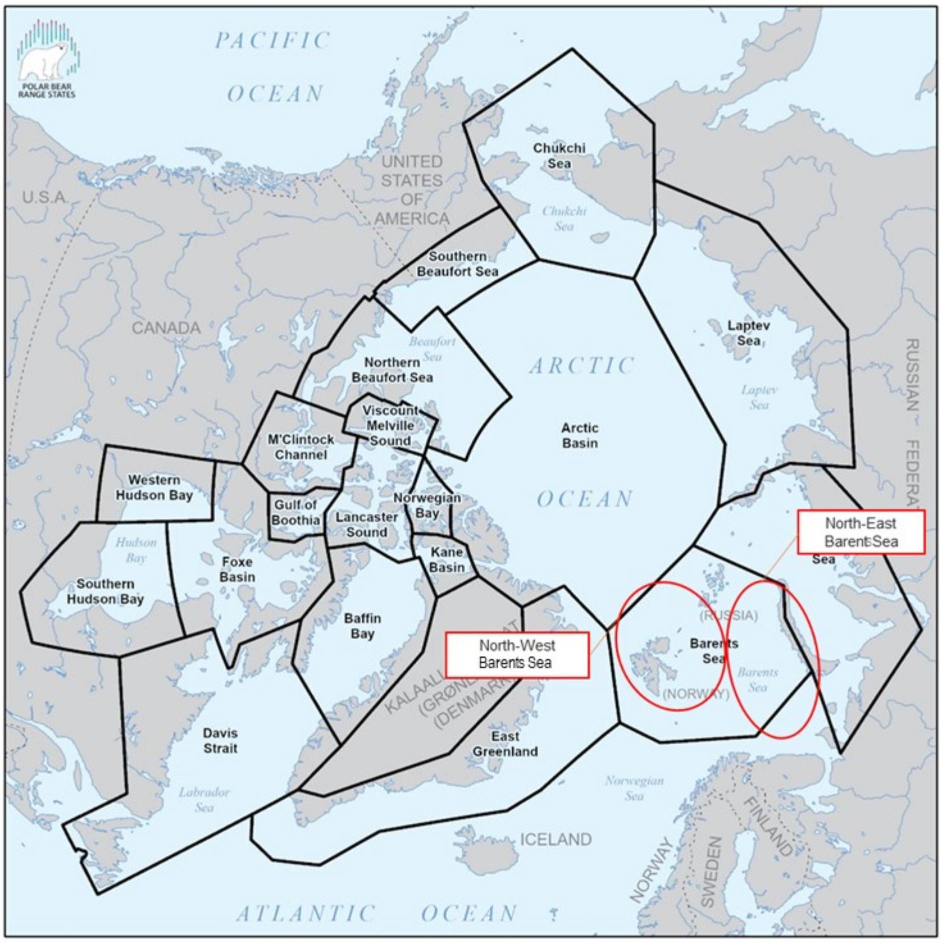

Figure 5 Map representing the polar range states and the places where *Boreogadus saida* sampling took place (circled in red). Source : **polarbearagreement.org**

The Seafood Data monitors, among others, total Hg concentrations in *Boreogadus saida*. Since 2008, the polar cod doesn't show any significant increase in total Hg concentration (Figure 6). Data used by Seafood Data are depicted in Annex 5.

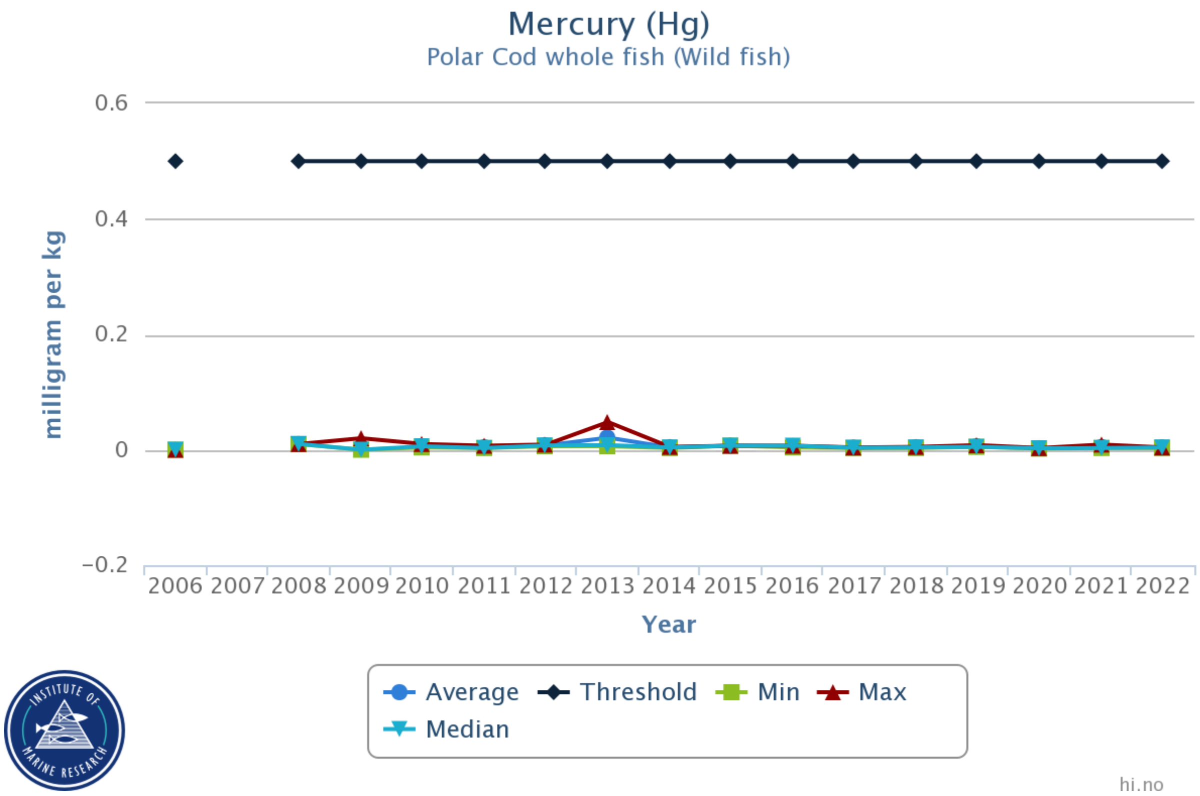

Figure 6 Mercury concentration in mg/kg ww in the polar cod *Bereogadus Saida* since 2008. Source: **Seafood Data**

Conclusion

Boreogadus saida seems to be useful as an easily accessible indicator for mercury concentration in fish. Even if there is no relevant human consumption of this species in Switzerland, lots of data are available in the scientific literature and because of its place in the Arctic food web it is recommended as an indicator species.

iii. Atlantic cod (*Gadus morhua*)

Habitat and role of fish in the web of food in the Arctic

The Atlantic cod *Gadus morhua* (Figure 7), a major fisheries species in the NEAO, is also an important component of coastal and continental shelf ecosystems (Dale, et al. 2019). The levels of undesirable substances in fish and other seafood in Norway have been monitored since 1994, with more than 20 fish species included in this surveillance program (Julshamn et al. 2013a). The sampling frequency for each species has been determined by the economic importance of the species, and cod, being a highly important commercial species for Norway, has been frequently sampled (Vethaak, et al. 2017).

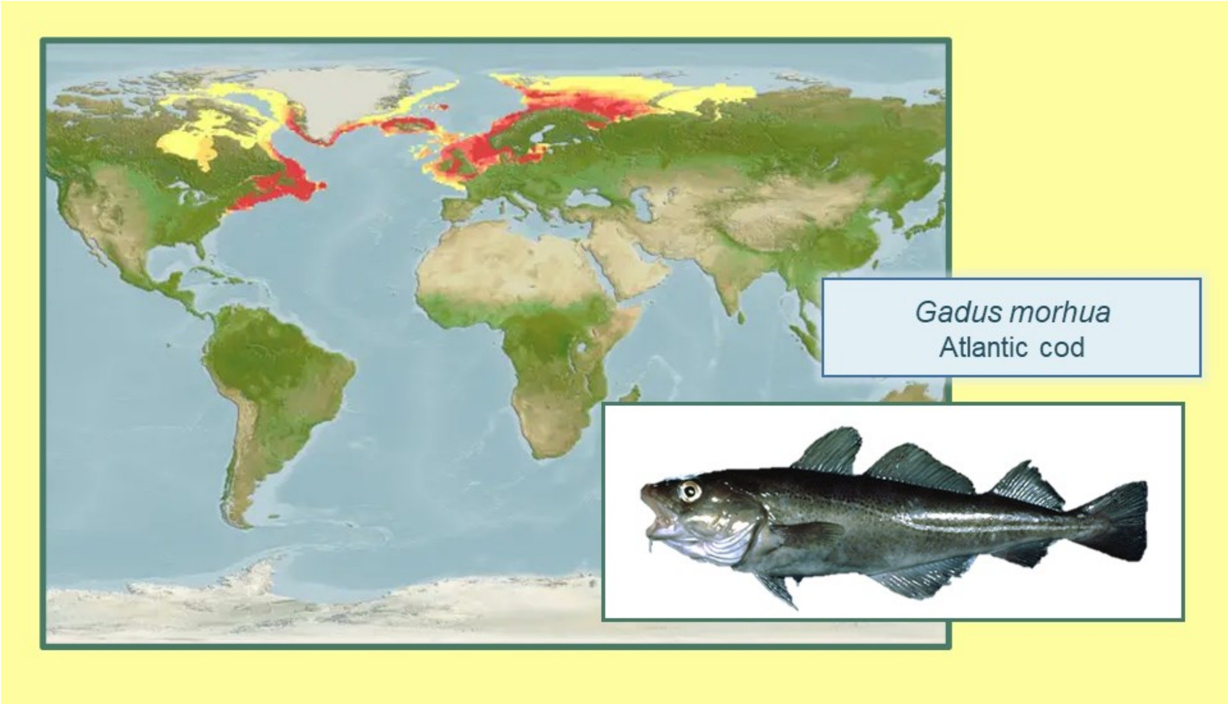

Figure 7 *Gadus morhua* (Kabeljau/Dorsch), Source : **europa.eu**, More info : **Gadus morhua, Atlantic cod : fisheries, aquaculture, gamefish (fishbase.se)**

Place in the Swiss diet
Gadus morhua is also one of the most imported fish in Switzerland from all FAO areas 18, 21, 27 and 67 combined (Annex 4).

Available data on mercury contamination
Julshamn et al. (2013a) monitored the total Hg concentration of the Atlantic cod from different regions of the Barents Sea (Figure 8). Three out of 1203 samples of muscle exceeded the maximum limit of 0.3 mg Hg/kg ww set by the EU for foodstuffs with a median Hg concentration in the muscle of **0.029 mg Hg/kg ww**. However, the data showed significant differences in Hg concentrations between fish caught in different areas of the Barents Sea with fish coming from the southwest part of the Barents Sea having the highest concentration of mercury.

In another study, Julshamn et al. (2013b). monitored the total Hg concentration of 687 cod from 13 fjords and coastal location from the Norwegian sea. In total, the mean is **0.11 mg Hg/kg ww**. However, the mercury concentration in cod muscle was higher in the North Sea and coastal areas in the southern part of Norway than in the Barents Sea and coastal areas in the northern part of Norway (Figure 8).

In both studies, differences in total Hg contamination could be -due to differences in the cod diet.

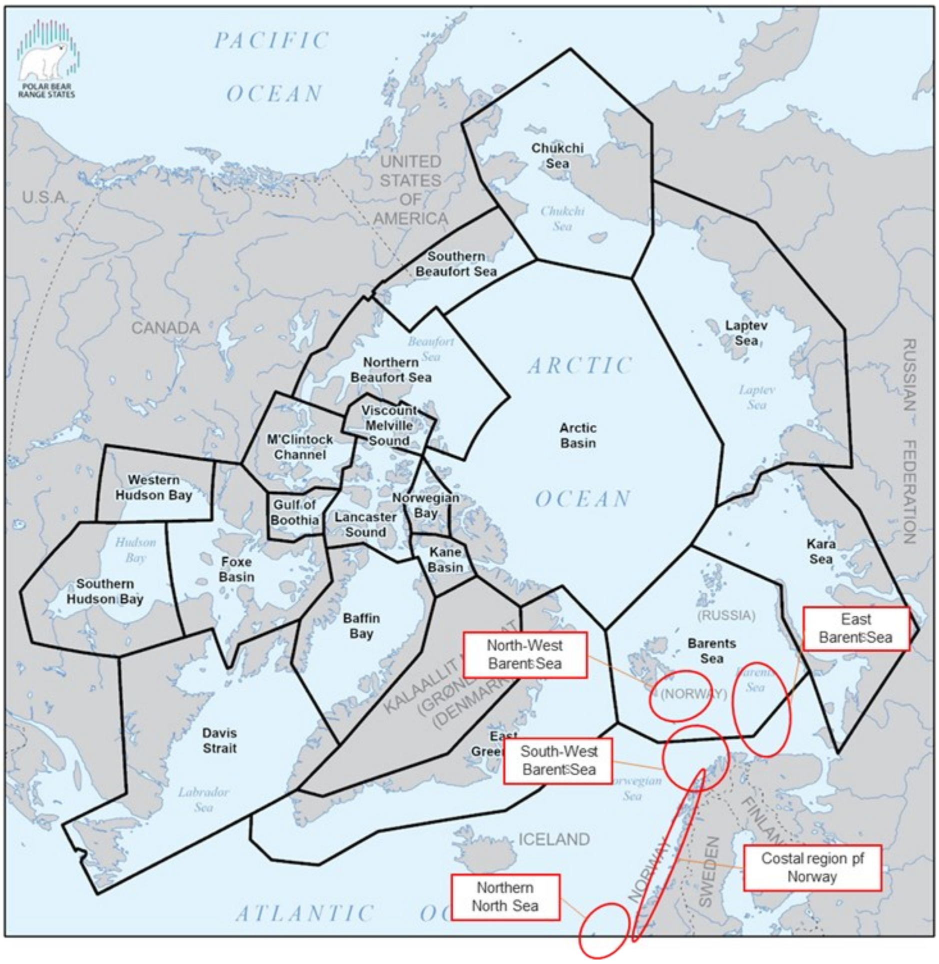

Figure 8 Map representing the polar range states and the places where *Gadus morhua* sampling took place (circled in red). Source : **polarbearagreement.org**

The Seafood Data database is also monitoring contaminants in the Atlantic cod. The data doesn't show a significant increase of Hg in the Atlantic cod fillet since 2006 (Figure 9). The data used by Seafood Data are depicted in the Annex 6. The values are more varied than *Arctogadus glacialis* but none of them exceed the maximum Hg concentration limit. Looking more closely at the median values and by adding a forecast trend line, a slight increase in Hg concentration can be observed over time (Figure 10). However, R^2 is inferior as 0.3, meaning the relationship between the concentration of Hg over years is not straightforward and other variable need to be taken into account. However, we do not have enough information on the sampling method to make any assumptions about the other variables.

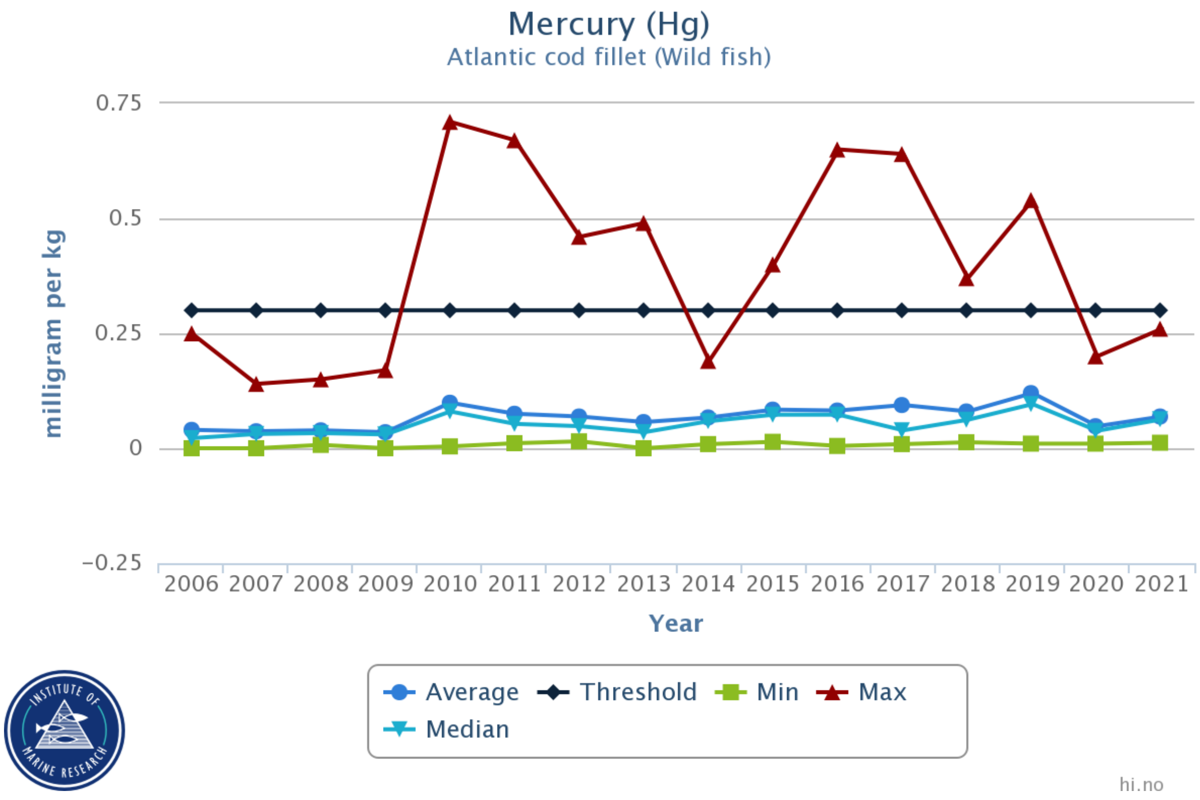

Figure 9 Graph displaying the evolution of mercury concentration (mg Hg/kg ww) in the Atlantic cod fillet *Gadus morhua* (wild fish) from 2006 to 2021. Source : [Seafood data]

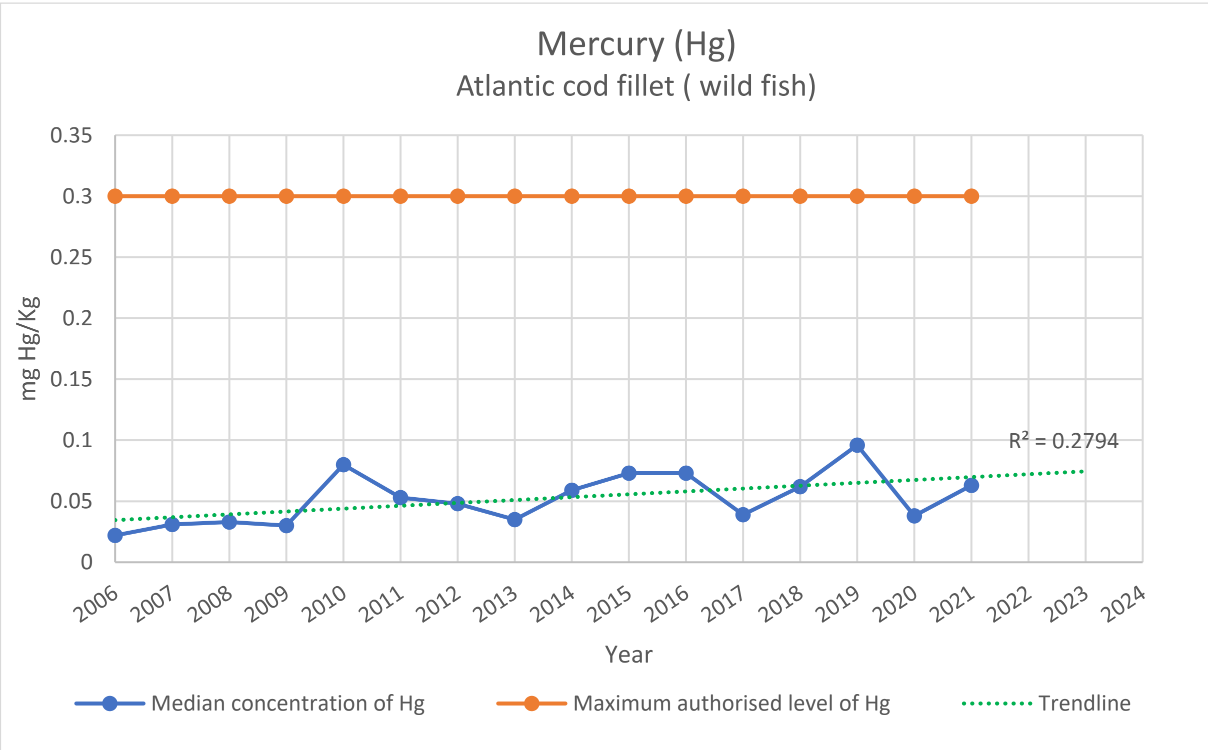

Figure 10 Graph displaying the median value of Hg concentration (mg Hg/kg ww) measured in Atlantic cod fillet *Gadus morhua* (wild fish) from 2006 to 2021 and forecasting trendline. Source : **[Seafood data]**

Conclusion
Gadus morhua is used for human consumption, it is also imported to Switzerland, data do exist from environmental samples as well as from routine surveillance. There are some samples above the limit measured by routine surveillance as well as by environmental samples, however no clear trend might be seen so far. It is therefore recommended to use it as an indicator species.

iv. Pacific cod (Gadus macrocephalus)

Habitat and role of fish in web of food in the Arctic
Pacific cod *Gadus macrocephalus* (Figure 11) are one of the top 25 commercially important species of the approximately 450 species of fish, shellfish, and crustacean species in the Bering Sea and in the North Pacific region. They are bottom dwellers and are common at depths of up to 300 m. Pacific cod are also important in the marine ecosystem, as they are eating small fish such as the polar cod *Boreogadus saida* and eaten by larger fish and by humans (DORIS. 2021). This cod is thus relatively high on the food chain, and are expected to have intermediate or higher levels of contaminants, compared to other fish (see later discussion). Thus, levels of heavy metals in cod are indicative of both their prey base, and may serve as a bioindicator of exposure for their predators that are higher on the food chain, including people (Burger et al. 2007).

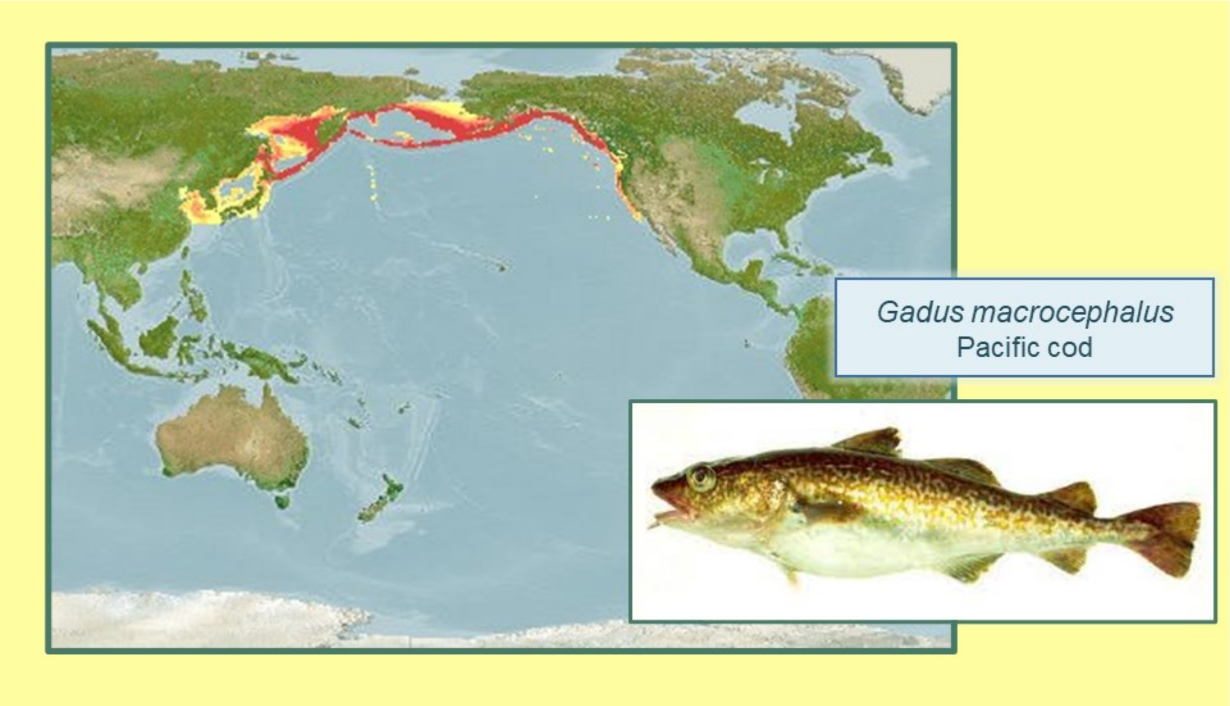

Figure 11 *Gadus macrocephalus* (Kabeljau/ Pazifischer Kabeljau), Source : europa.eu, More info : **Gadus macrocephalus, Pacific cod : fisheries, gamefish (fishbase.se)**

Place in the Swiss diet
Gadus macrocephaus is one of most imported fish in Switzerland from all FAO areas 18, 21, 27 and 67 combined (Annex 4).

Available data on mercury contamination
Burger et al. (2007a) and Burger et al. (2007b) conducted monitored heavy metals on 141 pacific cod along the islands of the Aleutian Chain of Alaska (Figure 12). On average, the total Hg concentration was 0.173 mg Hg/kg ww. The Pacific cod *Gadus macrocephalus* is not referenced in the Arctic database Seafood Data.

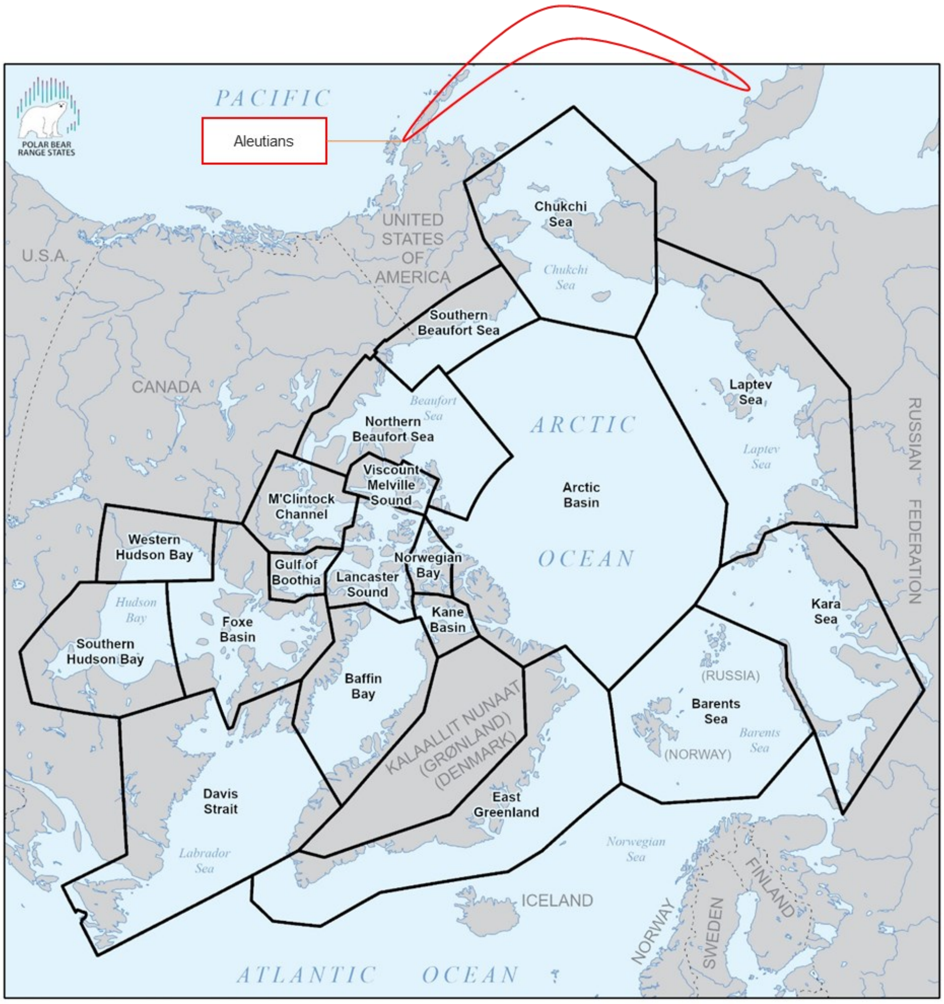

Figure 12 Map representing the polar range states and the places where *Gadus macrocephalus* sampling took place (circled in red). Source : polarbearagreement.org

<u>Conclusion</u>

Gadus macrocephalus consumed by humans, it is also imported to Switzerland. However, it mainly originates from FAO zone 67. Data do exist from environmental samples but not from routine surveillance. The average concentration of the Hg monitored in this fish are under the maximum limit allowed. It is therefore not recommended to use it as an indicator species.

v. Overview of all results

Fish's name	Import to CH *	Fishing area	Mean total Hg	Max total Hg	Number of samples per year	Reference	Recommen-dation as indicator species
Arctogadus glacialis	NO	18, 21 ,27	0.37 µg Hg/g dw	Missing data	Missing data	Loseto et al. 2008 (cited in Kirk et al. 2012)	NO
Boreogadus saida	NO	18, 21, 27, 61, 67	0.0037 mg Hg/kg ww	0.0040 mg Hg/kg ww	6	Seafood Data year 2022	YES
Gadus morhua	YES	21, 27, 31, 37, 41	0.069 mg Hg/kg ww	0.26 mg Hg/kg ww	119	Seafood data 2021	YES
Gadus macrocephalus	YES	61, 67, 77	0.173 mg Hg/kg ww	0.859 mg Hg/kg ww	142	Burger et al. (2007a)	NO

Table 1: Overview of all results. (*some limits are existing about these data, see chapter "Identification of gaps in the knowledge", subchapter "Imports volume and consumption of fish to Switzerland")

b. Identification of knowledge's gaps

i. Volume of imports and consumption of fish to Switzerland

Data used in this rapport about the species imported in Switzerland are based on illegal, unreported and unregulated (IUU) control records of the fishing areas FAO 18, 21, 27 and 67. However, the IUU control data does not cover all the imports, because many of the countries bordering these fishing areas are excluded from the IUU control ([Verordnung über die Kontrolle der rechtmässigen Herkunft von eingeführten Erzeugnissen der Meeresfischerei. SR 453.2]). However, according to the data from the Federal Office for Agriculture, Cod is among the top 10 most sold fish in Switzerland (Figure 13). All in all, even if the consumption of fish in Switzerland is not known particularly in detail, its consumption seems to remain fairly stable since 2001, with an estimated 8 kg per person in 2020. ([FSO: CH Fish production and consumption 2000-2021]).

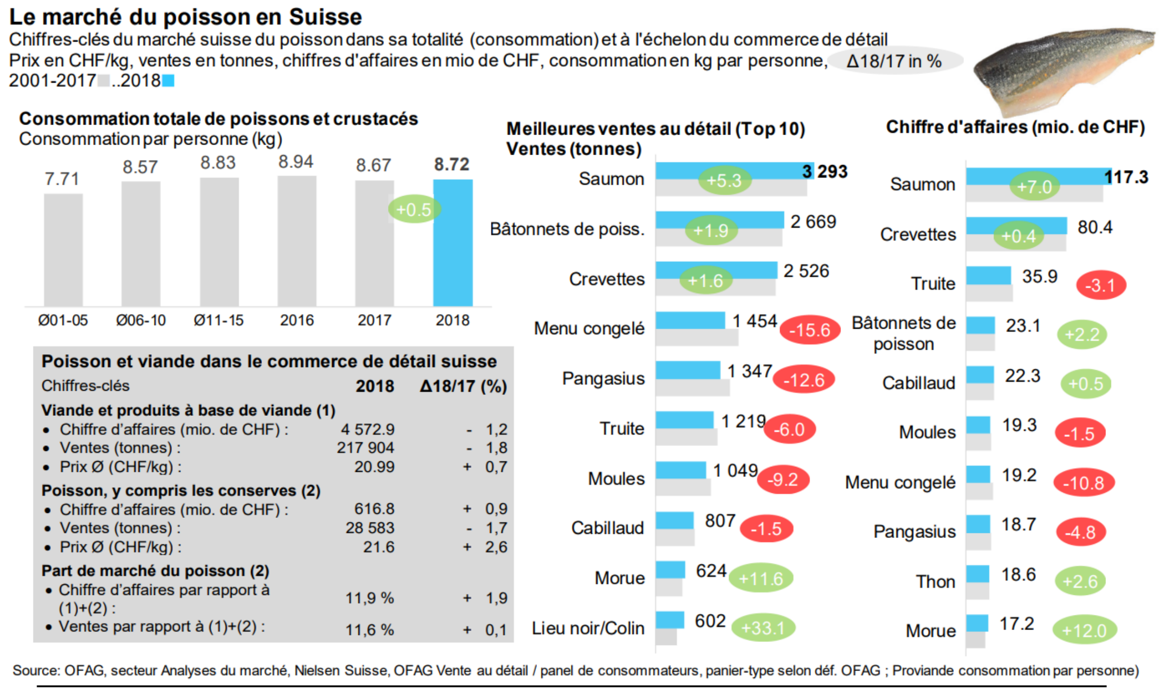

Figure 13: Fish market in Switzerland, Source : Bulletin du marché de la viande mars 2019

ii. Quality assessment of monitoring programs

The UNEP released in 2016 the [Global review of Mercury Monitoring Networks]. The review discusses, identified national networks that monitor the level of mercury in biota at a specific location. However, the assessment of the quality of the networks is not covered here and it should be evaluated in a separate study. Moreover, the limited accessibility via publicly available sources and language limitation of the search (limited to English, Spanish and French) likely resulted in an oversight of information.

iii. Species to monitor

Figuring out the best species for monitoring is an ongoing question. An important element for a standardized global biotic mercury monitoring program is the selection of the proper species or groups within relevant geographic areas, such as biomes. Bioindicators most appropriate for assessing human health and the environment are those that are at the upper trophic levels, which best reflect the ability of methylmercury to biomagnify through the food web ([Evers, D.C. and E. Sunderland. 2019]) (Figure 14). For biotic mercury monitoring purposes, trophic level 4 (tertiary consumers) or 5 (top predators) bioindicator are best for evaluating the effectiveness of reducing environmental mercury loads around the world. However, because mercury released from the permafrost finds itself in the sediment first, it is best to focus surveillance on demersal species of fish. As the food chain evolves constantly, the species identified today might no longer be relevant in some years/ (near) future? ([Moore et al. 2018]).

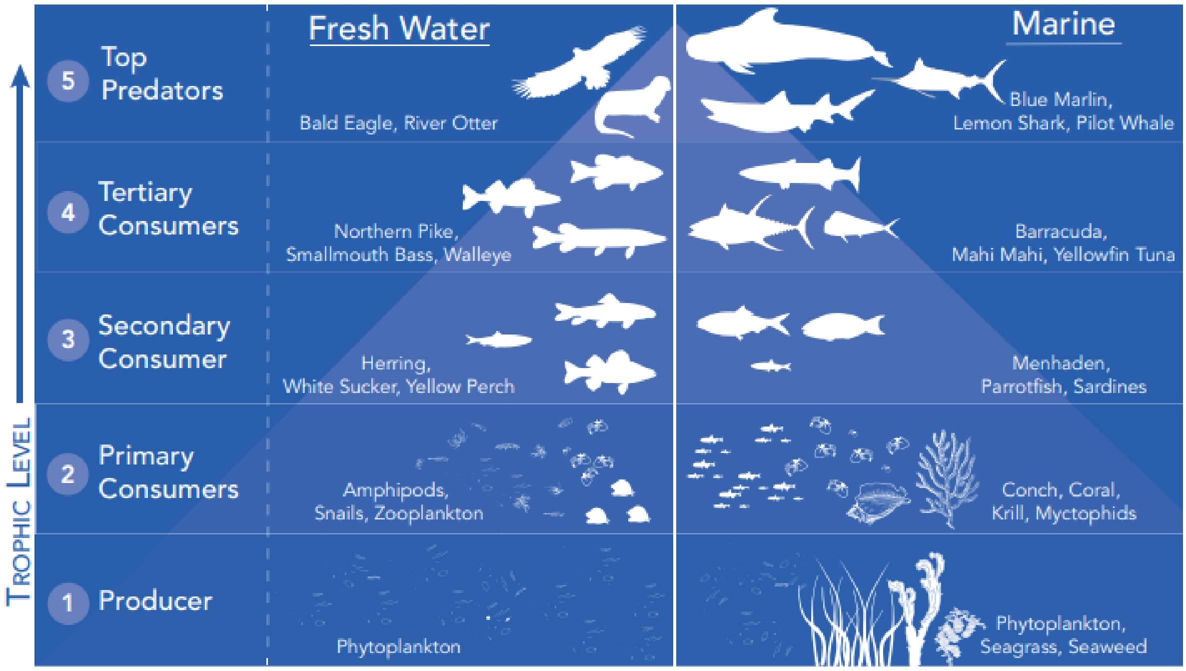

Figure 14 Trophic level categories for both freshwater and marine ecosystems with relevant associated bioindicators Source: Evers, D.C. and E. Sunderland. (2019)

iv. Bioaccumulation and biomagnification of mercury

People are commonly exposed to MeHg through the consumption of fish, and some birds and marine mammals. However, there are gaps in our understanding about the relationship between releases of mercury and its subsequent bioaccumulation and biomagnification in freshwater and marine food webs, and how that may translate to exposure and risk at the local, regional, and global scale to fish, wildlife, and humans (Evers, D.C. and E. Sunderland. 2019).

c. Bioavailability of Hg released from the permafrost

The rapid thaw of ice-rich permafrost led to the settlement of the ground resulting in land slumps. These slumps can transport vast quantities of sediments and solutes downstream. However, the effect of slumping on downstream concentrations and yields of Hg and MeHg is unknown. St Pierre et al. (2018) found that fluvial concentrations of Hg and MeHg downstream of thaw slumps on the Peel Plateau (Northwest Territories, Canada) were up to two orders of magnitude higher than upstream. MeHg concentrations were particularly elevated downstream, where debris obstructed streams to form reservoirs where microbial Hg methylation was likely enhanced. However, >95% of the Hg downstream was typically particle-bound and potentially not readily bioavailable.

d. Hg estimates in permafrost soil

Maps of soil Hg show great spatial variability reflecting different sedimentation histories (Figure **15**). The relative uncertainty per pixel is 57%, which means there is a 95% probability that the actual value lies within ±57% of the estimated value.

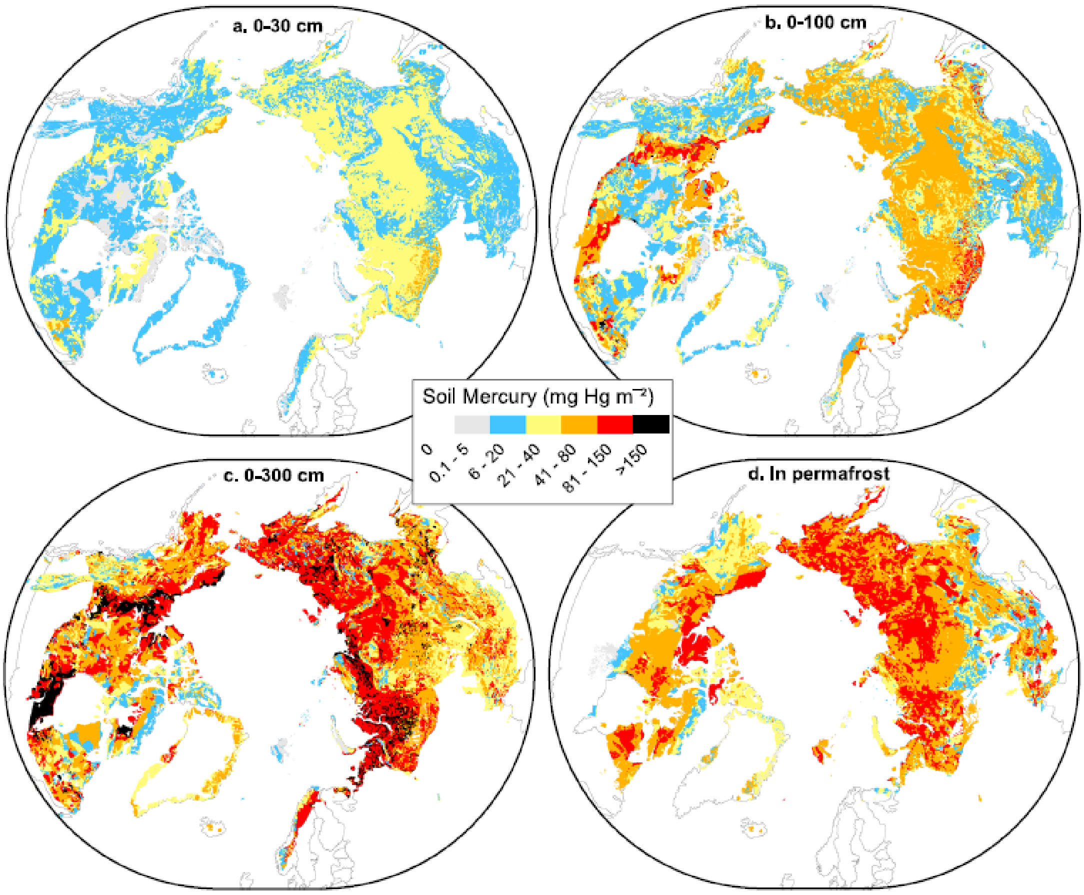

Figure 15 Maps of Hg (mg Hg m^{-2}) in Northern Hemisphere permafrost zones for four soil layers: 0–30 cm, 0-100 cm, 0–300 cm. Source : Schuster, et al. 2018

i. Estimation of potential future Hg emissions from melting permafrost

St Pierre et al. (2018) estimated that 5% of the Hg stored for centuries or millennia in northern permafrost soils (88Gg) is susceptible to be release into modern-day because of climate changes. The turnover time associated with the microbial decay of frozen organic matter is ~14,000 years making the Hg locked in permafrost effectively stable on human time scales. However, projections indicate a 30–99% reduction in near surface permafrost in the next 80 years, and, once thawed, the turnover time for microbial decay drops to ~70 years. This makes the reservoir of Hg in permafrost soils vulnerable to release over the next century, with unknown consequences to the environment (Schuster et al. 2018).

IV. Discussion

1) Data available show that the current Hg and MeHg contamination in fish does not yet pose a threat to Swiss public health because of the place that fish and seafood occupy in the diet of the Swiss population. According to the data of the Federal Office for statistics FSO (2023).

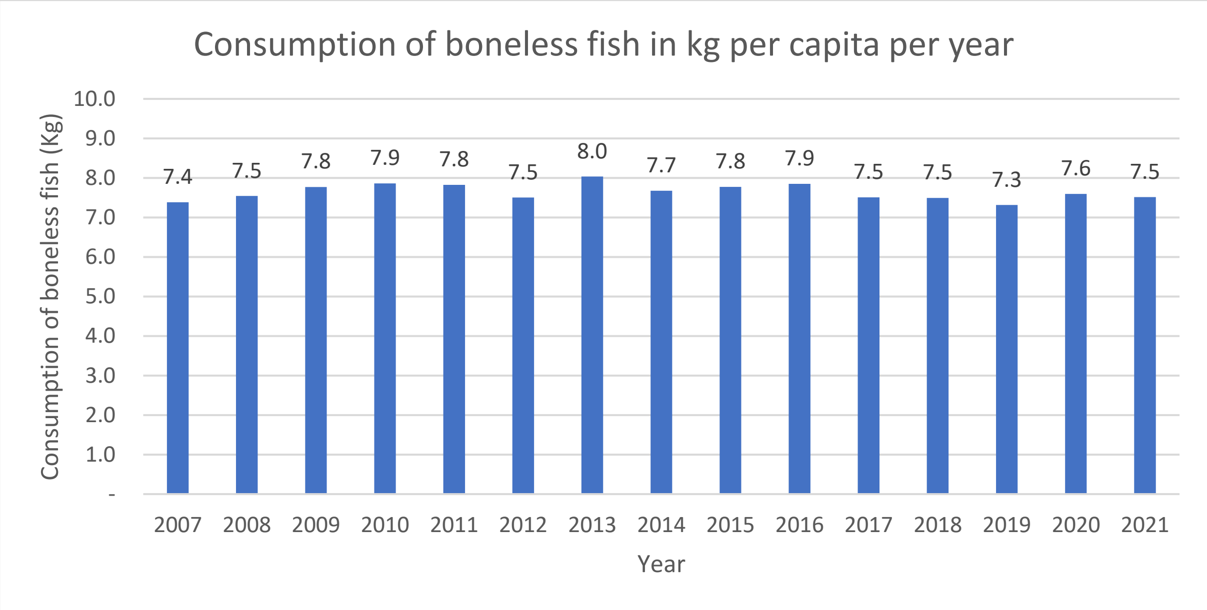

Figure 16 : Graph showing the consumption of boneless fish in kg per capita per year in Switzerland. Source : **FSO (2023)**

The consumption of fish in Switzerland remained fairly stable between 2007 and 2021, varying between 7.3 kg to 8 kg of fish consumed per person per year that is to say that the Swiss consume between 154g and 140g of fish per week (figure 16). The EFSA established a TWI of 4 µg total Hg/kg bw (EFSA, 2012). Therefore, an adult of 70 kg would have to consume 280 µg of Hg in order to reach the TWI. With the current state of mercury contamination of fish and the consumption of fish in Switzerland, the situation is not yet problematic. However, the consumption of fish by the Swiss population should continue to be monitored as well as the mercury content of fish consumed in Switzerland in order to see if it increases. Special consideration should be given to the consumption of fish by children and pregnant women. Data about these two subgroups of the population do not existat present.

2) Even if the current situation does not pose a threat to public health, permafrost soils store nearly twice as much Hg as all other soils, the ocean, and the atmosphere combined, and this Hg is vulnerable to release as permafrost thaws over the next century. Across the Arctic region, Hg is of particular concern because its neurotoxic form, methylmercury (MeHg), which biomagnifies through food webs into upper trophic level organisms that are consumed as part of human diets. It is yet unknown if the Hg releasing from the thaw of the permafrost is available to methylation. Its future impact is presently uncertain. Many variables remain unknown, therefore it is necessary to thoroughly follow the monitoring of Hg and MeHg in thaw slumps in the Northen hemisphere as well as its impact on downstream level.

3) The Atlantic Cod (*Gadus morhua*) from the FAO zones 18, 21, 27 and 67 (Fish market 2019 europa.eu) is one of the most imported fish in Europe including Switzerland (Annex 4, and it is also one of the species closely monitored in the Arctic. It might be recommended using it as a reference if research is to be undertaken. Another species to follow would be the polar cod *Boreogadus saida* because of its position in the food chain and the fact that it is referenced since 2008 in the Arctic database Seafood Data. Even though the UNEP recommends to monitor species from the predatory level for mercury, in our view, it /could be preferable to target species from which the mercury content is more influenced by the linkage from the permafrost than from other sources. Therefore, species living in the Arctic and at the beginning of the food chain are more exposed to mercury release from thaw permafrost. Nevertheless, it should be noted that the northern countries already continuously monitor

the mercury contamination of fish and these data are made publicly available. Therefore, at present, it does not seem necessary to undertake chemical analyses to monitor Hg in Arctic fish species, however, it would be appropriate to follow the situation closely.

v. Conclusion

1) The current situation does not pose a threat to public health in Switzerland.
2) Mercury is undoubtfully released from permafrost but its future impact remains at present uncertain as we are unsure of whether the Hg released from the permafrost is available for methylation and if how quickly will this occur.
3) In our view, at the moment, it doesn't seem necessary to undertake chemical analyses of mercury in fish from these areas but it would be recommended to regularly analyse the Arctic database(s) such as Seafood Date in order to identify any potential increasing trend.

Recommendation:

a) Closely and regularly monitor the data development of the mercury contamination of the following two fish species, through databases such as Seafood Data and SGS Digicomply as well as new scientific publications.

Nr	Name	Common name in DE, FR, EN	Data source(s) for data analysis
1	*Gadus morhua*	Atlantischer Kabeljau (DE) Morue de l'Atlantic (FR) Atlantic cod (EN)	Seafood data SGS Digicomply
2	*Boreogadus saida*	Polardorsch (DE) Morue polaire (FR) Arctic cod (EN)	Seafood data

b) Asses the mercury exposure of the Swiss population based on the current level of mercury contamination of fish and the data of menu CH in order to confirm that the Hg exposure does not exeed the TWI of 4 µg Hg/kg bw and of 1,3 µg MeHg/kg bw. Special attention should be given to pregnant women and toddlers, with unborn children constituting the most vulnerable group.
c) Depending on how the situation evolves, give nutritional and diet recommendations especially for the group at risk.

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Annex 1: Amendment of the Annex to Regulation (EC) No 1881/2006, Section 3: Metals, subsection 3.3 (Mercury) :

'3.3	Mercury	Teneur maximale (mg/kg)
3.3.1	Fishery products and muscle meat of fish, excluding species listed in 3.3.2 and 3.3.3. The maximum level for crustaceans applies to muscle meat from appendages and abdomen. In case of crabs and crab-like crustaceans (Brachyura and Anomura), it applies to muscle meat from appendages.	0.50
3.3.2	Muscle meat of the following fish: • Axillary seabream (Pagellus acarne) • Black scabbardfish (Aphanopus carbo) • Blackspot seabream (Pagellus bogaraveo) • Bonito (Sarda sarda) • Common pandora (Pagellus erythrinus) • Escolar (Lepidocybium flavobrunneum) • Halibut (Hippoglossus species) • Kingklip (Genypterus capensis) • Marlin (Makaira species) • Megrim (Lepidorhombus species) • Oilfish (Ruvettus pretiosus) • Orange roughy (Hoplostethus atlanticus) • Pink cusk-eel (Genypterus blacodes) • Pike (Esox species) • Plain bonito (Orcynopsis unicolor) • Poor cod (Tricopterus species) • Red mullet (Mullus barbatus barbatus) • Roundnose grenadier (Coryphaenoides rupestris) • Sail fish (Istiophorus species) • Silver scabbardfish (Lepidopus caudatus) • Snake mackerel (Gempylus serpens) • Sturgeon (Acipenser species) • Surmullet (Mullus surmuletus) • Tuna (Thunnus species, Euthynnus species, Katsuwonus pelamis) • Shark (all species) • Swordfish (Xiphias gladius)	1,0
3.3.3	Cephalopods Marine gastropods Muscle meat of the following fish: • Anchovy (Engraulis species) • Alaska pollock (Theragra chalcogrammus) • Atlantic cod (Gadus morhua) • Atlantic herring (Clupea harengus) • Basa (Pangasius bocourti) • Carp (species belonging to the Cyprinidae family) • Common dab (Limanda limanda) • Mackerel (Scomber species) • European flounder (Platichthys flesus) • European plaice (Pleuronectes platessa) • European sprat (Sprattus sprattus) • Mekong giant catfish (Pangasianodon gigas) • Pollock (Pollachius pollachius)	0.5

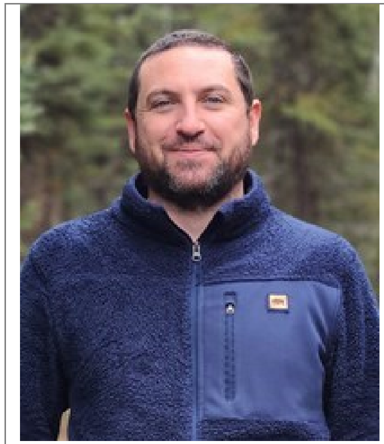
	• Saithe (Pollachius virens) • Salmon & Trout (Salmo species and Oncorhynchus species, except Salmo trutta) • Sardine or Pilchard (Dussumieria species, Sardina species, Sardinella species and Sardinops species) • Sole (Solea solea) • Striped catfish (Pangasianodon hypothalamus) • Whiting (Merlangius merlangus	

Annex 2: Ordonnance sur les contaminants (OCont) 817.022.15, Annexe 3, Teneurs maximales en métaux et métalloïdes, Partie B: tableau

Substance	Denrée alimentaire	Teneur maximale (mg/kg)	Remarques
Mercure	Chair musculaire des poissons suivants: • baudroies ou lottes (*Lophius species*) • loup de l'Atlantique (*Anarhichas lupus*) • bonite (*Sarda sarda*) • anguille (Anguilla species) • empereur, hoplostète orange ou hoplostète de Méditerranée (*Hoplostethus species*) • grenadier (*Coryphaenoides rupestris*) • flétan de l'Atlantique (*Hippoglossus hippoglossus*) • abadèche du cap (*Genypterus capensis*) • marlin (*Makaira species*) • cardine (*Lepidorhombus species*) • mulet (*Mullus species*) • abadèche rose (*Genypterus blacodes*) • brochet (*Esox lucius*) • palomète (*Orcynopsis unicolor*) • capelan de Méditerranée (*Tricopterus minutes*) • pailona commun (*Centroscymnus coelolepis*) • raies (*Raja species*) • grande sébaste (*Sebastes marinus, S. mentella, S. Viviparus*) • voilier de l'Indo-Pacifique (*Istiophorus platypterus*) • sabre argent et sabre noir (*Lepidopus caudatus, Aphanopus carbo*) • dorade, pageot (*Pagellus species*) • requins (*toutes espèces*) • escolier noir ou stromaté, rouvet, escolier serpent (*Lepidocybium flavobrunneum, Ruvettus pretiosus, Gempylus serpens*) • esturgeon (*Acipenser species*) • espadon (*Xiphias gladius*) • thon (*Thunnus species, Euthynnus species, Katsuwonus pelamis*)	1	
Mercure	Produits de la pêche et chair musculaire des poissons	0.5	autres

Annex 3: List of external experts contacted, by order of contact

Name	Position	Place	Areas of expertise	Link	Date of contact
 Pr Dr Celia Y. Chen	Research professor	Dartmouth University	Fate of metal contaminants in freshwater and marine ecosystems. My main interest is in the sources, fate, and bioaccumulation of the neurotoxic contaminant, mercury, that biomagnifies in aquatic food webs.	Celia Y. Chen | Department of Biological Sciences (dartmouth.edu) Celia.Y.Chen@dartmouth.edu	13.03.2023
 Pr Dr Anders Goksøyr	Professor	University of Bergen	Toxicology, environmental toxicology, microplastics, biomarkers, endocrine disruptors, toxicogenomics, environmental genomics, proteomics, and systems toxicology focusing on marine organisms such as fish and marine mammals.	Anders Goksøyr | University of Bergen (uib.no) anders.goksoyr@uib.no	13.03.2023

 Dr Benjamin Barst	Research assistant professor	University of Alaska	Contaminant effects in fish and wildlife, their variation in time and space, their movement through food webs, and how their exposures are influenced by diet and non-chemical threats, such as climate change and invasive species.	Benjamin Barst (uaf.edu) bdbarst@alaska.edu	14.03.2023
 Pr Dr Amund Maage	Senior Adviser, Marine Director	University of Bergen	Food chemistry, analytical chemistry, fish, food quality, marine science, nutrition, pollution	Amund Maage | University of Bergen (uib.no) amund.maage@uib.no	22.03.2023

Annex 4: Import weight of the fish controlled by IUU from FAO 18, 21, 27 and 67 in Switzerland

Table 1 Species of fish imported from FAO 18/21/27/67 zones into Switzerland in 2021 and 2022, ranked by import weight (Kg). Source: IUU, IMPEC

FAO Zone	Species	Year	Import weight (Kg)
27	*Gadus morhua*	2022	63287
27	*Gadus morhua*	2021	61071
67	*Gadus macrocephalus*	2021	48122
67	*Oncorhynchus keta*	2022	35847
67	*Gadus macrocephalus*	2022	33964
67	*Oncorhynchus keta*	2021	23353
67	*Merluccius productus*	2022	22728
67	*Merluccius productus*	2021	21973
27	*Engraulis encrasicolus*	2022	17890
67	*Thunnus alalunga*	2021	16954
67	*Gadus chalcogrammus*	2021	16677
27	*Engraulis encrasicolus*	2021	7839
67	*Theragra chalcogramma*	2022	5259
67	*Theragra chalcogramma*	2021	4405
67	*Anoplopoma fimbria*	2022	2841
27	*Pollachius virens*	2022	1280
67	*Limanda aspera*	2021	998
27	*Mallotus villosus*	2022	900
67	*Gadus chalcogrammus*	2022	756
27	*Scomberomorus spp*	2022	510
27	*Sebastes mentella*	2022	499
67	*Limanda aspera*	2022	499

Annex 5: Hg concentration in polar cod whole fish Boreogadus saida from 2006 to 2022 expressed in mg Hg/Kg, source : Polar cod whole fish | Seafood data | hi.no

Year	Maximum level	Mean	Min	Max	Median	Number of analyses	Below LOQ
2022	0.50	0.0037	0.0030	0.0040	0.0040	6	0
2021	0.50	0.0048	0.0030	0.0090	0.0030	6	0
2020	0.50	0.0025	0.0020	0.0030	0.0025	6	0
2019	0.50	0.0060	0.0050	0.0080	0.0050	3	0
2018	0.50	0.0040	0.0030	0.0050	0.0040	3	0
2017	0.50	0.0035	0.0030	0.0040	0.0035	2	0
2016	0.50	0.0060	0.0040	0.0070	0.0070	3	0
2015	0.50	0.0070	0.0070	0.0070	0.0070	3	0
2014	0.50	0.0040	0.0030	0.0050	0.0040	2	0
2013	0.50	0.021	0.0060	0.048	0.0080	3	0
2012	0.50	0.0075	0.0060	0.0090	0.0075	2	0
2011	0.50	0.0043	0.0030	0.0070	0.0030	3	0
2010	0.50	0.0062	0.0040	0.0100	0.0060	5	0
2009	0.50	-	<0.0086	0.020	<0.011	3	2
2008	0.50	0.0099	0.0097	0.0100	0.0100	5	0
2006	0.50	-	<0.0081	<0.0081	<0.0081	1	1

Annex 6: Hg concentration in Atlantic cod fillet Gadus morhua from 2006 to 2021 expressed in mg Hg/Kg, source : [Atlantic cod fillet | Seafood data | hi.no]

Year	Maximum level	Mean	Min	Max	Median	Number of analyses	Below LOQ
2021	0.30	0.069	0.012	0.26	0.063	119	0
2020	0.30	0.048	0.010	0.20	0.038	136	0
2019	0.30	0.12	0.010	0.54	0.096	97	0
2018	0.30	0.080	0.013	0.37	0.062	120	0
2017	0.30	0.094	0.0090	0.64	0.039	175	0
2016	0.30	0.082	0.0050	0.65	0.073	222	0
2015	0.30	0.084	0.014	0.40	0.073	198	0
2014	0.30	0.067	0.0090	0.19	0.059	210	0
2013	0.30	0.057	<0.00090	0.49	0.035	124	1
2012	0.30	0.069	0.015	0.46	0.048	167	0
2011	0.30	0.075	0.011	0.67	0.053	264	0
2010	0.30	0.099	0.0040	0.71	0.080	1164	0
2009	0.30	0.035	<0.0062	0.17	0.030	681	1
2008	0.30	0.039	0.0073	0.15	0.033	100	0
2007	0.30	0.037	<0.069	0.14	0.031	99	1
2006	0.30	0.040	<0.030	0.25	0.022	71	10