Application of Faroese Whaling Records for Retrospective Assessment of Prenatal Exposure to Methylmercury

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Introduction

In regard to exposures to methylmercury, the Faroe Islands are unique, because the main exposure source is pilot whale meat. The average methylmercury concentration in the whale meat is much higher than in other types of seafood consumed in the Faroes, and assessment of traditional dietary habits of eating boiled or dried whale meat can therefore be used for exposure evaluation. The purpose of this report is to describe how to assess methylmercury exposures in Faroese communities from historical whaling records. The detailed information available can be used to assess, on a household (or ecological) basis, the exposure of subjects based on their residence and the time period. These data may also allow identification of subjects, who lived or were born at a time and in a district when no whale meat was available and comparable subjects from other districts where whale was at the same time plentiful.

Substantial information on whale catches in the Faroes has been recorded through several centuries. This subsistence whaling is conducted using small boats when pods approach the coasts. The pod is chased into a fiord, and the whales are then beached and killed, according to traditional practices.[1,2] The meat and blubber are shared locally according to ancient regulations. The whale catch is therefore communal and non-commercial. The meat is normally consumed for dinner or lunch over an extended period. Slices of the dried meat are often consumed as a snack (like pemmican).

Although whale meat and blubber are now more easily shared outside the individual communities using modern transportation facilities, inclusion of traditional food in the diet depended almost entirely on local access in the past. Thus, dietary habits are determined by seafood availability (i.e., access to whale) and less by limited differences in socioeconomic conditions.

The dietary habits depend on the availability of whale meat supplies from a recent whale kill. We have therefore examined the possibility of using the available whaling records for retrospective assessment of methylmercury exposure on a community scale. This information can then be used for epidemiological studies, e.g., of possible associations between prenatal methylmercury exposure and degenerative diseases in old age. The present report therefore provides substantial methodological detail that cannot be incorporated in published papers later on. Also, by making this methodology information available ahead of time, we document that decisions on the retrospective exposure assessment were made prior to the acquisition of other epidemiological information on outcomes and/or control groups.

Assumptions

Some assumptions must be made before these data can be used to estimate the methylmercury exposures on a community scale, or, rather, the likelihood of exposure. Whales were normally caught only during the summer months.[1,2] During the past, when refrigeration was not possible, the meat was stored after salting or drying. Although salted meat might be kept for extended periods, the majority of the supplies was probably consumed prior to next year's whaling period, i.e., mainly during the winter months. The size of most whale catches would also suggest that supplies only in rare cases would last longer than one year. One must also assume that old supplies from a previous year would most likely be discarded when a new catch was made. To simplify the calculations, we made the assumption that whale meat supplies were properly prepared and stored, but that supplies would last for a maximum of two years.

Mercury concentrations in whale meat have not indicated any clear changes during recent decades, where chemical analyses are available.[3,4] Likewise, modeling studies suggest that methylmercury concentrations may have been only slightly lower during the early decades of the 20th century.[5] Although the mercury concentrations in whale meat can vary, we used an overall average concentration of 2 μg/g[3,4] to calculate the total methylmercury dose available for each inhabitant from the whale meat allocation. In regard to other pollutants, organochlorine substances became important only after about 1950, due to the burgeoning use of PCBs, DDT, later on supplemented by additional persistent substances.[6,7] The present report focuses on the first half of the 20th century, and these substances are therefore not considered.

The detailed information on whale catches in the Faroes provides the exact location of each whale kill, the date, and the number of whales and the total weight.[8] The whale meat (and blubber) was shared according to detailed rules within the local districts.[9,10] The share was not necessarily divided evenly. The district, in which the kill took place, would get a full share and some neighboring districts only a half share, depending on the distance from the place where the whale catch occurred. However, the men who participated in the actual whaling received a larger share. Data on the exact share of individual pod catches are available from the local police officer (Sýslumonnunum), who recorded in detail the identity of each whale and how it was distributed (on a household basis). These records also show the population numbers for each district. This information is difficult retrieve and is thought to be incomplete. Further, most of the local, able men probably participated in the catch, and this additional contribution to household supplies is therefore thought to be of limited consequence. The assumption was therefore made that each inhabitant received a share calculated from the total amount of whale meat landed divided by the number of inhabitants in the community.

Thus, in conjunction with census lists, the assignment of whale meat per resident can be computed from the size of the whale catches, the detailed rules for distribution within each district, and the number of residents. Because the census was carried out every five years and varied only little between the years, we used the population number from the census closest in time to the whale catch. For example, for the period 1 August 1918 to 1 July 1923, we used the census data from 1 February 1921.

The statistical data on whale catches show much variation. Most pods include a substantial number of whales, often more than 100. Such large catches will contribute large amounts of whale meat to the local community, depending of the size of the population. However, some catches were small, and a decision was therefore made to simplify the calculations by leaving out all catches below 10 whales.

Within the period 1911-1960, the records for seven catches state the total number of whales, but not the total weight. For these catches (between 81 and 256 whales), we used the average pilot whale weight (6.1 skinn/whale) obtained from all catches during this time period. The traditional measure of one skinn corresponds to about 34 kg blubber and 38 kg meat.

While allowance for the formal requirement of sharing with neighboring districts can be easily incorporated, any further dissemination of whale meat is disregarded. We believe that this assumption is appropriate, because tunnels and regular ferries were not part of the Faroese transportation system during the early decades of the past century. In relative terms, dissemination beyond the local districts was therefore considered negligible. Again this factor may contribute imprecision to the exposure assessment, but probably only to a limited extent.

Anecdotal evidence and historical accounts suggest that whale meat was consumed for dinner about three times a week on average. Our own analyses of hair samples collected in the past show that hair-mercury concentrations up to 90 μg/g occurred, but average exposures may have been closer to 30 μg/g. Using the toxicokinetic model developed by the (U.S.) National Academy of Sciences,[11] this average level would, at steady state, correspond to average daily intakes of about 3 μg/kg body weight. For a subject weighing about 60 kg, this number would translate to a daily intake approximating of 200 μg of mercury. With an unchanged average mercury concentration of 2 μg/g in whale meat,[3,4] this dose level corresponds to approximately 100 g of whale meat per day, or 3 kg per month. This consumption level appears in accordance with historical evidence. A higher consumption rate of 5 kg per month would be possible, if whale meat was eaten for dinner most days of the week, but families with easy access to fish or mutton may, on the other hand, have eaten whale meat only once or twice per week.

As previously noted,[12] not all the meat and blubber are used for consumption. Some invariably gets spoiled, and some is likely discarded after long storage times, especially when a new supply has arrived. But we believe that discarding food was not customary in the early part of the previous century, the way it would occur today. We therefore assume that all whale meat was consumed, except for any amounts that may remain after an assumed maximum two years.

Methylmercury absorption in the gut is virtually complete, and the elimination half-time (first-order kinetics) is about 45 days.[11] Previous estimates of the elimination half-life was 70 days,[13] which would suggest longer retention times. When the supplies have run out, it takes at least four biological half-lives (i.e., six months), for a subject to decrease the accumulated methylmercury burden to approach background levels. Accordingly, the increased methylmercury body burden after a large whale catch can last for a total maximum of 2.5 years.

Methods

From the whaling records, we have included each whale catch from 1911 and onwards with the date and the total size of the catch. In our spreadsheet, we indicate the district, i.e., where the whales were landed. For each whaling district, each of the villages, in which the whale catch was distributed, is listed in accordance with the regulations in force. The amount of whale meat that each village received is then calculated. The number of inhabitants of each of these villages is retrieved from the census data, which then allows calculation of the amount of whale meat allocated to each subject.

These data can then be applied to calculate body burdens of individual residents. In regard to prenatal methylmercury exposure, the assessment is based on the mother's residence and the whaling data that relate to the pregnancy period. Given the biological half-life of methylmercury, all subjects are assumed to have been born at term. The three months prior to the parturition will therefore constitute the third trimester of pregnancy, where methylmercury could in particular cause functional changes.[11] However, the average for the whole pregnancy (area under the curve) may also be relevant, as may the calculated dose level at the beginning of the third trimester.

Although many of a district's whale catches have occurred at considerable time intervals, some districts have experience many catches within a short period of time. In the latter case, the supplies have not run out before the next catch occurred or, alternatively, the supply may have run out, but the contribution from the previous catch (the methylmercury burden) has not yet reached background levels. Account must therefore be taken of the contributions of all relevant whale catches prior to the time period of interest. In regard to prenatal exposures, all whale catches up to two years prior to the birth date are therefore considered.

Certain districts at certain time periods could be classified as virtually unexposed, due to the absence of whale landings for extended periods of time. Likewise, highly exposed districts with ample and almost continuous supplies of whale meat, can be identified. In some cases, low and high exposures have existed during the same time periods, thus allowing comparisons of subjects of the same age, but with widely different prenatal exposure potentials.

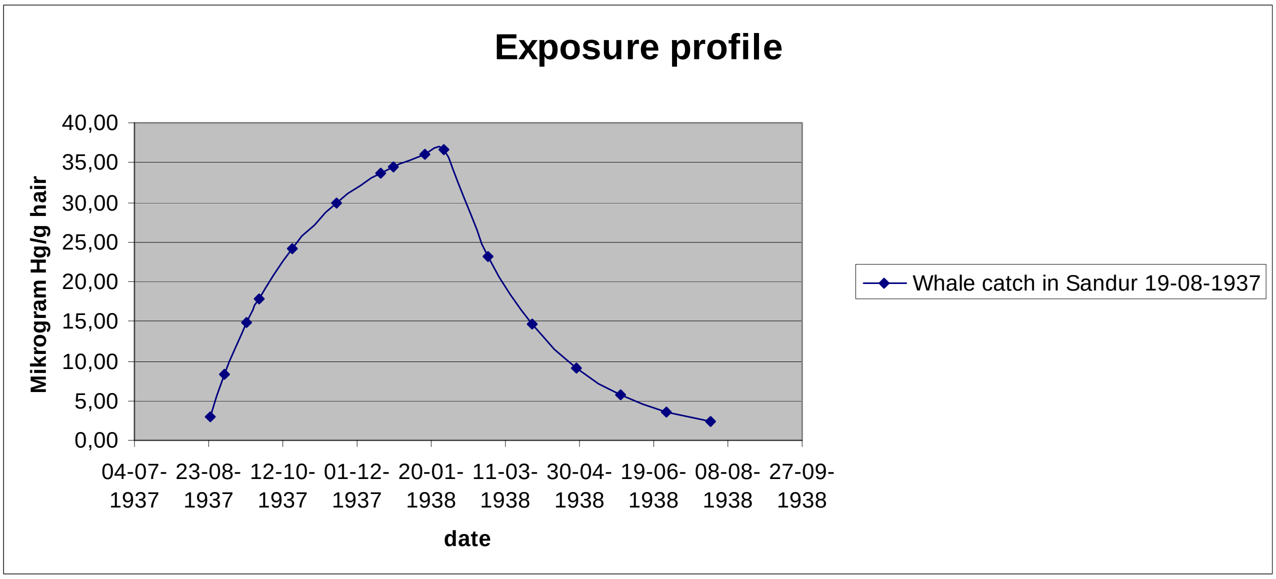
A more refined model to estimate actual exposure levels takes into account the build-up of methylmercury in the body while the calculated community supplies last (assumed consumption of 3 kg/month and maximum storage time of two years) and the decay given an elimination half-life of 45 days. In all these calculations, methylmercury concentrations of the whale meat is assumed to be the same, i.e., similar to the current average concentration of 2 μg/g[12]. Given the pace of mercury kinetics in the oceans,[14] this concentration is unlikely to have changed much during the last several decades.

In regard to our study of Parkinson's disease in the Faroe Islands, we have recorded the birth date and the birth place for each patient. The prenatal exposure of each subject can then be determined from the spreadsheets according to the above methods for calculations. In addition, the project calls for drawing of controls from the population registry for each patient. These subjects will be matched only by sex and age, and their place of birth will therefore determine their prenatal exposure. We have therefore developed spreadsheets to cover all Faroese districts for the relevant time period. As soon as these subjects have been drawn, retrospective exposure assessment can be easily completed using the above methodology decided upon a priori.

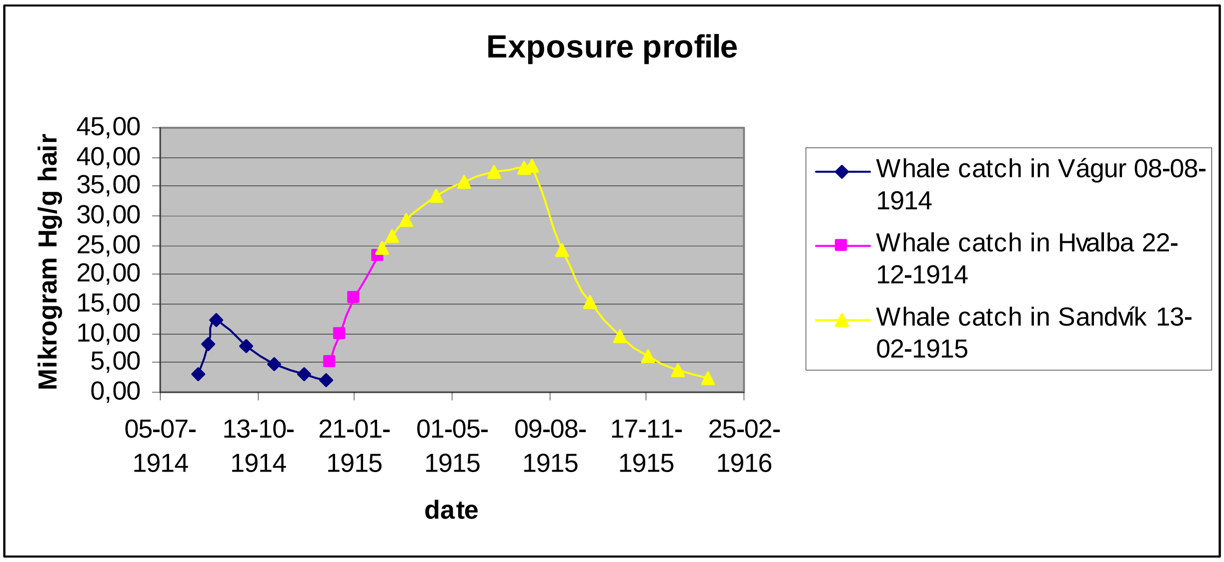
Sensitivity analysis

The assumptions made above are based on the most appropriate information available, while taking into regard feasibility of the calculations. Although whale availability refers to individual household in the whaling districts, some sources of inaccuracy cannot be eliminated, and the choices, e.g., in regard to consumption patterns and elimination half-life may confer some imprecision to the results.

The exposure assessment can be illustrated some examples. Consider a subject born in Skálavík on 25 December 1937. The prenatal exposure assessment requires consideration of whale catches during the two years prior to the birth date. One relevant whale catch in the district was on 19 August 1937 in Sandur (see below graph). This catch will cause methylmercury exposures that will last through 28 January 1938, i.e., it will include the last four months of this pregnancy. The previous catch in this district was in 1933, but no contribution would be considered from that catch to the body burden of methylmercury during the pregnancy.



As a second example, consider a subject born on 20 October 1915 in Sumba on the island of Suderoy. Three relevant whale catches in the Suderoy district happened on 8 August 1914, 22 December 1914, and 13 February 1915. The two most recent ones add to the supplies already available from the first catch. According to the calculations described above, the supplies from the second catch will last until 15 March 1915, but the elimination will not be complete before the subsequent catch. The third whale catch will therefore result in mercury burdens that do not start from zero. The calculations must therefore take into account the contribution from the previous catch/catches, when the elimination of accumulated methylmercury burden has not reached background levels.



In both examples, the calculations are based on the assumptions outlined above. However, as already indicated, whale meat consumption could be both lower and higher than the 3 kg per month thought to be an appropriate average. Likewise, some might argue that the elimination half-life during pregnancy may be greater than the 45 days usually assumed. We have therefore carried out some sensitivity analyses, where we examine the impact of changing these assumptions. As outcomes, we have calculated the average exposure during the third trimester (the last three months before birth), the overall average for the full duration of the pregnancy (the nine months prior to birth), and the point estimate for the beginning of the third trimester.

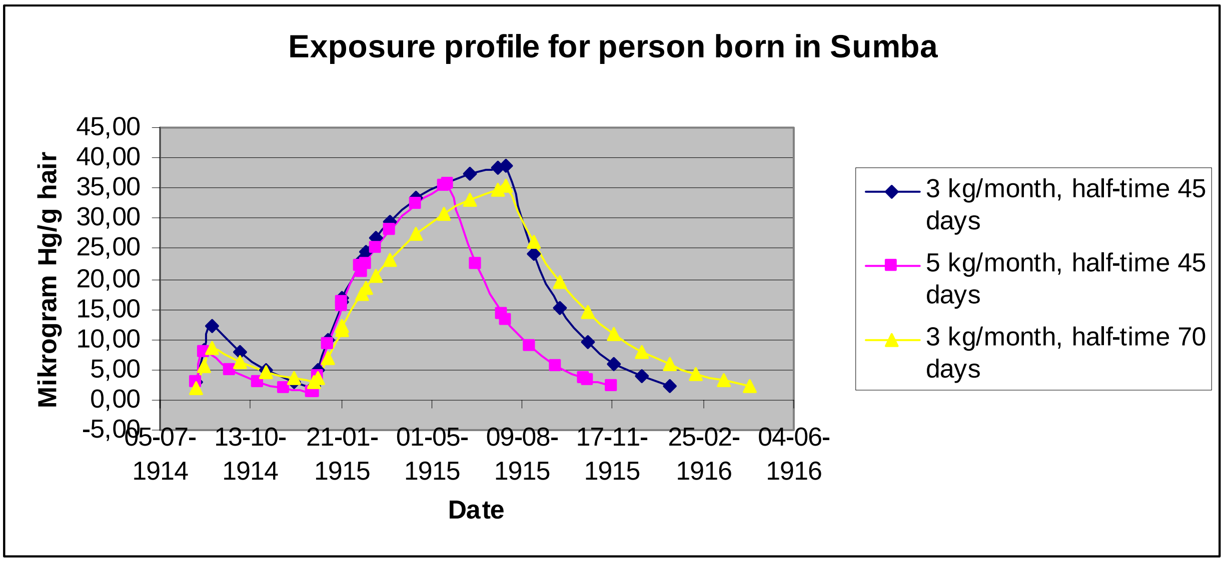
The table below shows that a change in dietary intake from 3 kg/month to 5 kg/month can affect the three calculated exposure indicators (expressed in terms of µg mercury per g of hair). A higher consumption will cause a higher maximum, but supplies will then run out more rapidly.

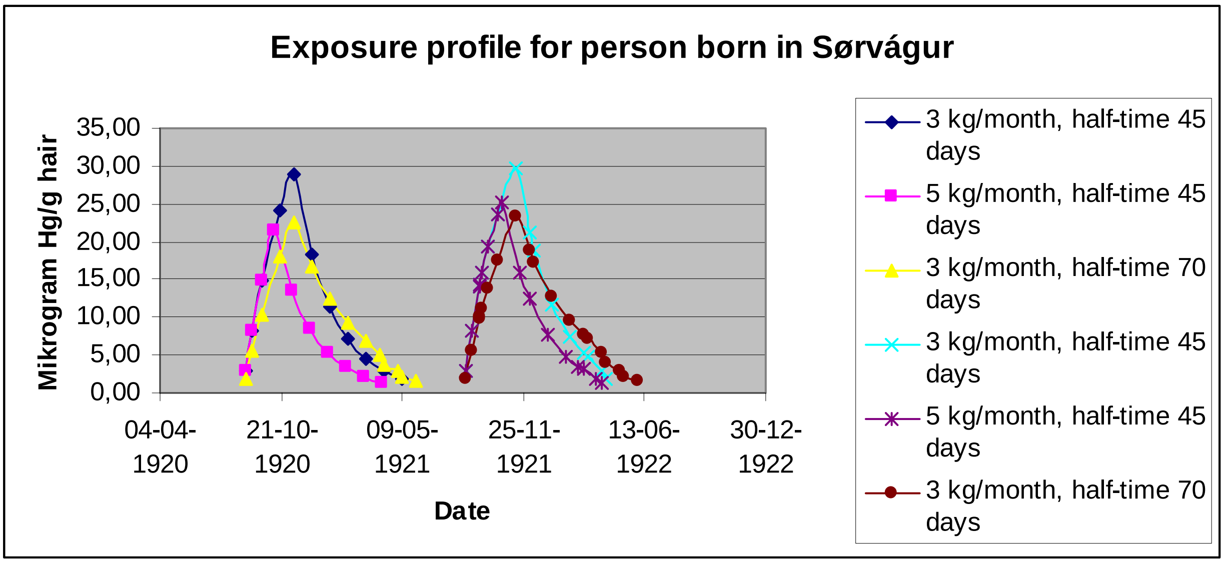
Place of birth	Date of birth	Average intake 3 kg/month			Average intake 5 kg/month		
		Entire pregnancy	Third trimester	Start of third trimester	Entire pregnancy	Third trimester	Start of third trimester
Sumba	20-10-1915	28.04	16.41	38.56	20.13	9.67	17.01
Sørvágur	04-03-1922	16.38	9.00	21.15	11.33	5.25	12.35
Skálavík	25-12-1937	21.21	24.06	17.72	22.16	25.41	17.72

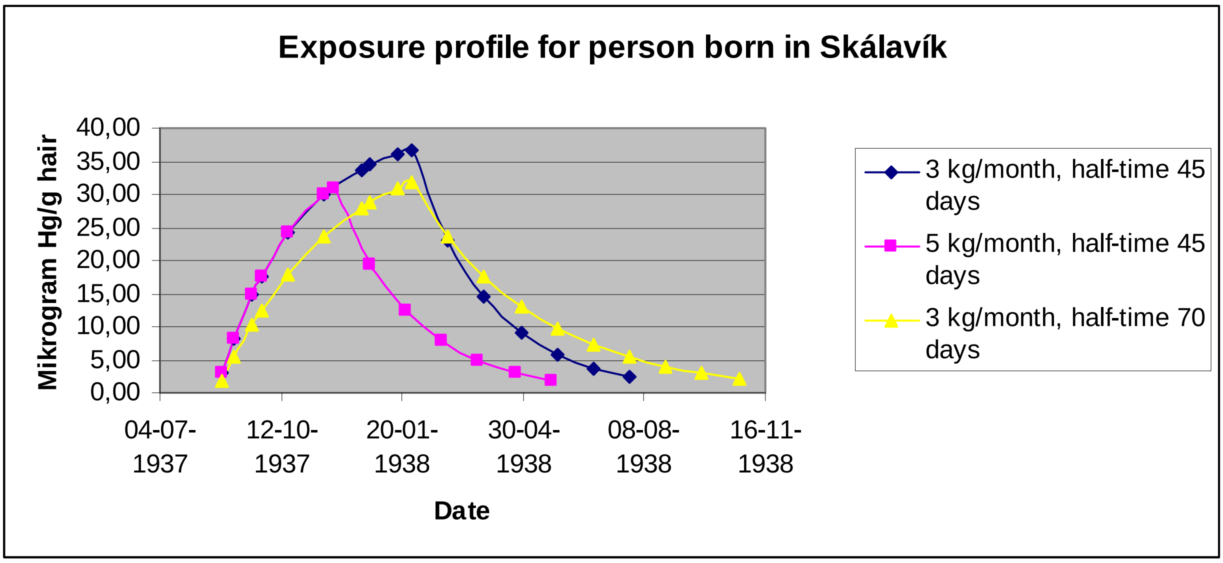
The following table shows the impact of a change in elimination half-life from 45 days to 70 days on the calculations of the three exposure indicators (again expressed in terms of µg mercury per g of hair). Here the longer half-life results both in a greater accumulation, and also in a slower elimination.

Place of birth	Date of birth	Elimination half-time 45 days			Elimination half-time 70 days		
		Entire pregnancy	Third trimester	Start of third trimester	Entire pregnancy	Third trimester	Start of third trimester
Sumba	20-10-1915	28.04	16.41	38.56	25.92	20.07	35.31
Sørvágur	04-03-1922	16.38	9.00	21.15	14.36	10.64	18.71
Skálavík	25-12-1937	21.21	24.06	17.72	15.89	18.29	12.54

The impact of changing dietary intake or half-time is illustrated in the following graphs where the three different conditions are plotted in the same graph.


Exposure profile for person born in Sumba
Mikrogram Hg/g hair
45,00
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
-5,00
05-07-1914
13-10-1914
21-01-1915
01-05-1915
09-08-1915
17-11-1915
25-02-1916
04-06-1916
Date
3 kg/month, half-time 45 days
5 kg/month, half-time 45 days
3 kg/month, half-time 70 days


Exposure profile for person born in Sørvágur
Mikrogram Hg/g hair
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
04-04-1920
21-10-1920
09-05-1921
25-11-1921
13-06-1922
30-12-1922
Date
3 kg/month, half-time 45 days
5 kg/month, half-time 45 days
3 kg/month, half-time 70 days
3 kg/month, half-time 45 days
5 kg/month, half-time 45 days
3 kg/month, half-time 70 days


Exposure profile for person born in Skálavík
Mikrogram Hg/g hair
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
04-07-1937
12-10-1937
20-01-1938
30-04-1938
08-08-1938
16-11-1938
Date
3 kg/month, half-time 45 days
5 kg/month, half-time 45 days
3 kg/month, half-time 70 days

Both tables and the graphs reflect some variability in relation to the choice of default conditions. In addition, variations in food preferences, access to other food, and other factors may play a role that can only be modeled with difficulty. Still, the sensitivity calculations above suggest that, on a relative scale, the changes are not substantial. The ranking of the subjects is unlikely to change much. These findings suggest that the estimated exposure levels may be useful as semi-quantitative indicators of potential prenatal exposure levels. Because these calculations are based on household access to whale meat, rather than on actual individual consumption levels, they are 'ecological', although based on much more detailed information than most epidemiological studies relying on ecological exposure assessment.

Conclusions

The whaling data available from the Faroes will allow estimation of approximate individual exposures to methylmercury based on the community-based shares of each whale catch. By assuming a relatively constant average methylmercury concentration, a regular consumption of the meat at a rate of 3 kg/month, and that supplies will last for no longer than two years, body burden profiles can be generated for residents of each district, while taking into account the average biological half-life of methylmercury in the body (45 days). For assessment of prenatal exposure, the mother's exposure profile is calculated from the whaling data up to two years prior to the child birth. These numbers will allow calculation of average exposure during the whole pregnancy, during the third trimester, or the body burden at the beginning of the third trimester (i.e., three months before child birth). These numbers can then be used to compare prenatal exposures of subjects with a particular disease, such as Parkinson's disease, as compared to controls.

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