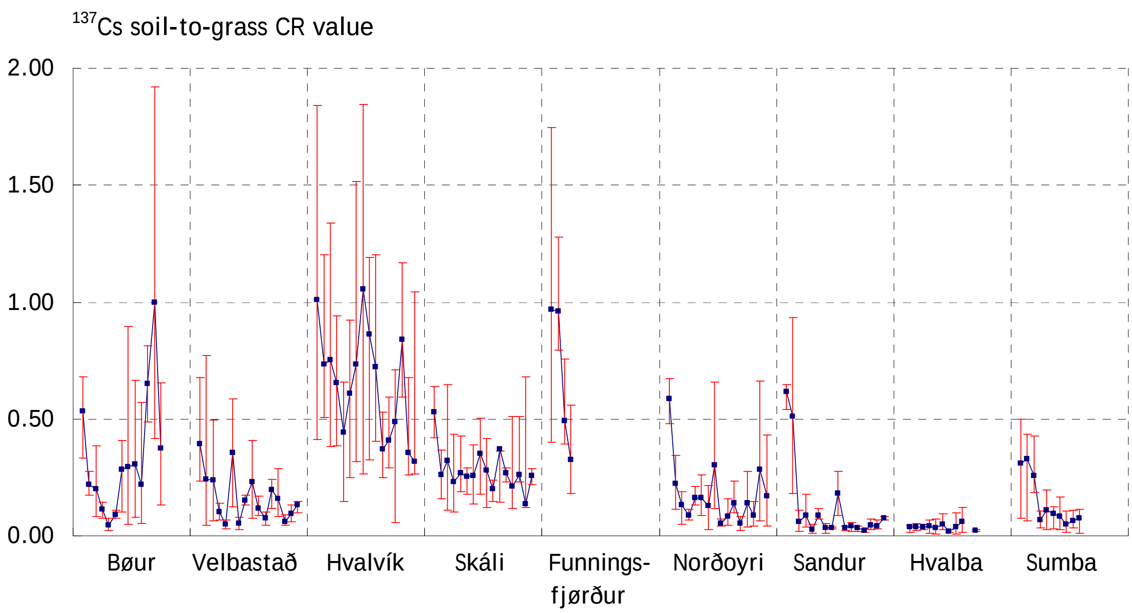
Transfer of ^{137}Cs in Faroese terrestrial environment 1990-2005

Hans Pauli Joensen



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Introduction

Activity concentration of ^{137}Cs in soil, mixed grass and lamb meat has been monitored in semi-natural pastures in the Faroe Islands since 1990 (Figure 1). The monitoring is motivated by the fact that lamb meat is an important food component for the local people.

The report presents results for the years 1990-2005. Aggregated transfer factors and concentration ratios in the lamb food chain have been calculated. Observed concentration ratios are compared to values in the international literature and to values in the ECOSYS model used by the NKS PARDNOR working group.

Figure 1. Map of the Faroe Islands showing selected sites for the study

Table 1. GPS stations used since August 2004 (for Hvalvík though since August 2006).

GPS nr	Pasture name	Sample plot 0.25 m^2	Height m a.s.l	Latitude (N)	Longitude (W)
8	Skáli	A	41	62°08.823'	006°46.434'
9	Skáli	B	45	62°08.835'	006°46.465'
11	Skáli	C	61	62°08.795'	006°46.450'
14	Skáli	D	52	62°08.808'	006°46.434'
15	Velbastaður	A	156	62°00.113'	006°53.506'
16	Velbastaður	B	179	62°00.124'	006°53.501'
17	Velbastaður	C	179	62°00.116'	006°53.536'
18	Velbastaður	D	175	62°00.100'	006°53.574'
20	Sandur	A	304	61°53.052'	006°50.693'
21	Sandur	B	302	61°53.059'	006°50.720'
22	Sandur	C	302	61°53.075'	006°50.710'
23	Sandur	D	301	61°53.083'	006°50.763'
24	Norðoyri	A	167	62°11.629'	006°30.985'
25	Norðoyri	B	168	62°11.576'	006°30.934'
26	Norðoyri	C	163	62°11.569'	006°30.940'
27	Norðoyri	D	159	62°11.584'	006°30.961'
30	Hvalvík	A	(102 ??)	62°11.959'	007°04.858'
31	Hvalvík	B	50	62°11.899'	007°04.836'
32	Hvalvík	C	55	62°11.892'	007°04.879'
33	Hvalvík	D	55	62°11.870'	007°04.908'

Material and methods

Soil, grass and lamb meat have been sampled in semi-natural pastures since 1990. The selected sampling sites are shown in Figure 1. Soil and grass were sampled in late July and early August, while lamb meat (neck muscle) was collected at the time of slaughter in October when the lambs were about 6 months old.

Four plots with the width of 0.25 m^2 were used for grass and soil sampling in each pasture. Three soil cores, 5.7 cm in diameter and 10 cm in depth, were collected from each plot. GPS positions have been attached to some of the sampling stations (Table 1).

Soil characteristics are presented in Table 2. The low pH and high loss on ignition are conditions that favour high uptake of radiocesium.

The main pathway of ^{137}Cs to the terrestrial environment is by precipitation. Precipitation data are available near some of the selected sites (Table 3). There is a factor of nearly 4 between the lowest and highest precipitation rate in Table 3.

The geographic variability in the soil parameters and the precipitation rate (Tables 2 and 3) imply variation of the ^{137}Cs activity concentration of in soil, mixed grass and lamb meat (Figures 2-4).

Table 3. Precipitation rate in mm per year. (Ref: Cappelen and Laursen, 1998).

Bøur (1988-97)	Hvalvík (1988-97)	Norðoyri (1961-90)	Sandur (1961-90)	Sumba (1961-90)
1555	3261	2710	1193	884

Behaviour of ^{137}Cs in the food chain of lamb

The ^{137}Cs activity in soil, mixed grass and lamb meat has decreased at most sites from 1990 to 2005, although not monotonically (Figures 2-4). The highest values occurred at the site with the highest precipitation rate, Hvalvík (Table 3).

The effective ecological half-life of ^{137}Cs could in some cases be estimated by a one-component exponential decay function (Table 4), with the ranges 11.4-21.7 years for deposition (3 sites), 3.6-16.5 years for grass (6 sites) and 5.1-9.9 for lamb meat (2 sites).

Table 4. Effective ecological half-life in years, based on measurements 1990-2005. All time series do, however, not cover the same time period. Numbers in brackets represent R^2 from a linear regression between time and natural logarithm of ^{137}Cs concentration in the samples. No estimates are given when $R^2<0.300$.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
Grass Bq/kg dw	- (0.027)	8.1 (0.329)	12.8 (0.437)	16.5 (0.357)	7.8 (0.302)	5.0 (0.384)	- (0.005)	3.6 (0.667)
Meat Bq/kg ww	5.1 (0.668)	- (0.194)	- (0.162)	- (0.148)	- (0.295)	- (0.202)	9.9 (0.781)	- (0.069)
Soil Bq/m^2	11.4 (0.528)	21.7 (0.462)	13.9 (0.636)	- (0.005)	- (0.044)	- (0.015)	- (0.253)	- (0.035)

Aggregated transfer factors and concentration ratios for ^{137}Cs

Soil-to-grass and soil-to-meat T_{ag}'s are presented in Figures 5 and 6, respectively. Soil-to-grass and grass-to-meat concentration ratios, CR, are presented in Figures 7 and 8, respectively.

The soil-to-grass T_{ag}'s and CR's are calculated for every 0.25 m^2 sampling plot. The T_{ag}'s for soil-to-meat transfer are calculated as the ratio between activity concentration in the single lamb meat samples and the average activity deposition in soil at the particular pasture. The CR's for grass-to-meat transfer are similarly calculated as ratio between activity concentration in the single lamb meat samples and the average activity concentration in grass at the particular pasture.

At most sites, there is no clear trend with time in the observed transfer parameters. There is a significant variation in the values within and between sites.

The highest soil-to-grass and soil-to-meat transfer parameters were generally observed in Hvalvík, while the lowest values occurred in Hvalba (Figures 5 - 7). This may partly be related to the soil characteristics at the two sites (Table 2). The observed pH and K-content are higher in Hvalba than in Hvalvík.

Soil-to-grass annual average T_{ag} values were below 0.02 m^2/kg dw in most cases, although the annual averages vary by more than an order of magnitude across the country. The highest value observed for a 0.25 m^2 plot was 0.15 m^2/kg dw, and the lowest was $0.5 \cdot 10^{-3}$ m^2/kg dw.

Soil-to-meat annual average T_{ag} values were generally below $0.4 \cdot 10^{-2}$ m^2/kg dw. The highest annual average was $1.3 \cdot 10^{-2}$ m^2/kg dw.

The grass/soil annual average concentration ratio was typically below 0.4, although values above 1.0 were observed as well. The highest value observed for a 0.25 m^2 plot was 1.9, and the lowest was $0.7 \cdot 10^{-2}$.

The meat/grass concentration ratios were generally below 0.5. The site Sandur and partly Norðoyri, however, are outliers in the context, as the values were generally above 0.6. The high values may express that the grass samples don't represent the food selected by the lambs used for meat sampling.

Parameter review

Howard *et.al.* (2009) present transfer coefficients for radiocesium to sheep meat. The estimates of the transfer coefficients are presented as measured fresh weight activity concentration in meat divided by the daily intake of radionuclide. An extensive part of the compilation by Howard *et.al.* (2009) derives from Russian language literature. The (arithmetic) mean ± 1 SD was 0.27±0.26 d kg^{-1}. They also report a geometric mean ± 1 GSD of 0.19±2.2 d kg^{-1}. The range was $5.3 \cdot 10^{-2}$ – 1.3 d kg^{-1}. These parameter values are also reported in the revised version of the IAEA handbook TRS-364 and in IAEA (2009).

Howard *et.al.* (2009) use 1.5 kg d^{-1} as estimate for daily intake of dry matter for sheep. Multiplying the reported transfer coefficients by 1.5 kg d^{-1} gives the following estimates for, respectively, geometric means and arithmetic means of the concentration ratios, CR's: 0.29±3.3 and 0.41±0.39, and the range $8.0 \cdot 10^{-2}$ – 2.0.

The estimate of daily intake is clearly a source of uncertainty when estimating transfer coefficients, especially in the case of monitoring or field studies. The revised TRS-364 handbook recommends the daily intake of dry matter to be 1.22 kg d^{-1} for adult sheep and 1.0 kg d^{-1} for lamb. This reduces the CR's for sheep meat by around 20% as compared to the values referred to above. The geometric means and arithmetic means of the CR's as derived from Howard *et.al.* (2009) then become 0.23±2.7 and 0.33±0.32, respectively, and the range becomes $6.5 \cdot 10^{-2}$ – 1.6.

Fesenko *et.al.* (2009) have reviewed more than 150 publications in the former USSR on transfer of radionuclides to animal muscle. They use the same definition of the transfer coefficient as Howard *et.al.* (2009). The publications reviewed by Fesenko *et.al.* (2009) cover experiments using chronic administration of intake of radionuclides. The reported transfer coefficients were generally considered to correspond to activity concentration in meat closest to equilibrium. Fesenko *et.al.* (2009) operate with threshold ages for animals, as the transfer of radionuclides depends on the age of the animals. For sheep, adults are considered to be older than 6 months while lambs are considered to be up to 6 months of age. Typical slaughter age for lamb in former USSR was reported to be 3-6 months, and above 12 months for sheep. The mean transfer coefficients in the compiled study were in the range 0.13 – 0.15 d kg^{-1} and 0.27 – 0.51 d kg^{-1} for, respectively, sheep muscle and lamb muscle. Using 1.22 kg d^{-1} and 1.0 kg d^{-1} (TRS-364) for the daily dry matter intake by sheep and lamb, respectively, gives the CR mean value ranges 0.16 – 0.18 for sheep and 0.27 – 0.51 for lamb.

Smith *et.al.* (2005) report transfer coefficients and concentration ratios regarding sheep meat and lamb meat. They use a daily dry mater intake of 1.3 kg d^{-1} and 1.1 kg d^{-1} for, respectively, sheep and lamb. The transfer coefficients for meat was $5.8 \cdot 10^{-2}$ d kg^{-1} and 0.49 d kg^{-1} for, respectively, sheep and lamb. The corresponding concentration ratios were 0.075 and 0.54 for, respectively, sheep and lamb. The transfer coefficients and CR's for lamb was thus almost an order of magnitude higher than for adult sheep.

Estimates of transfer parameters in the ECOSYS model (Müller and Pröhl, 1993) is currently considered by the NKS PARDNOR project group. ECOSYS is essentially the food chain module in the European state-of-the-art decision support systems ARGOS and RODOS, used by e.g. some of the Nordic countries. Knowledge of Nordic transfer parameters have still to be implemented in the ECOSYS model, as the default model parameters refer to environmental conditions of Southern Germany.

The ECOSYS model operates with an equilibrium fodder-to-lamb meat transfer "factor" of 0.5 d kg^{-1} for ^{137}Cs under equilibrium conditions (Müller and Pröhl, 1993; Müller and Pröhl, *Ecosys for Excel*). The exact definition of the transfer factor is not clear from Müller and Pröhl (1993). If it is the ratio between fresh weight activity in meat and dry weight activity intake from grass, the value 0.5 d kg^{-1} corresponds very well to the transfer coefficients mentioned above. Using a daily intake of 1.0 kg d^{-1} for lamb, as recommended in the revised TRS-364 handbook, the ECOSYS model transfer factor corresponds to a CR of 0.5 for grass-to-meat transfer of radiocesium.

Müller and Pröhl (1993) define the transfer factor for soil-to-plants as the ratio between activity concentration in plant (fresh weight) and soil (dry weight). They use a default soil-to-grass transfer factor of $5 \cdot 10^{-2}$ and 1.0 for, respectively, intensive and extensive grass in the ECOSYS model. Using 20% as an estimate of dry matter content in fresh grass leads to a corresponding CR equal to 0.25 and 5.0 as defaults in the ECOSYS model (ratio between activity concentration in grass (dry weight) and soil (dry weight)).

Discussion

Ward and Johnson (1965) invented a diet-to-muscle transfer coefficient for ^{137}Cs as the ratio of the ^{137}Cs activity concentration in boneless meat to the dietary daily intake of ^{137}Cs. Radionuclide transfer in the ecosystem has since then been described in this way. It has, however, been demonstrated in the literature that many factors affect transfer coefficients, e.g. animal age, dry matter intake and dietary source (Howard *et.al.*, 2001).

In later literature, the aggregated transfer factor (T_{ag}) has been widely used.

The best way of estimating transfer of radionuclides in ecosystems is a matter of discussion, and may depend on the particular circumstances. For field studies and monitoring, Beresford *et.al.* (2007) conclude that the concentration ratio (CR) is a robust and potentially generic parameter.

Transfer of ^{137}Cs has been presented both as T_{ag}'s and CR's in the current field study in the Faroe Islands. The observed CR values for grass-to-lamb meat are generally comparable to values found in the literature, although larger values are observed in some cases in the study. The value of 0.5 d kg^{-1} used as default for the transfer factor in the ECOSYS model tends, however, to be relatively high for the Faroe Islands.

The observed CR's for soil-to-grass transfer of ^{137}Cs vary significantly across the Faroe Islands, documenting the need for adjusting the default value when the ECOSYS model is used locally. The grass samples in the study correspond to "extensive grass" in the ECOSYS model, but the observed CR's are significantly lower than the corresponding default ECOSYS value. The adjustments of the ECOSYS parameters need to be related to local soil characteristics.

References

Beresford, N.A., Mayes, R.W., Barnett, C.L., Howard, B.J.: The transfer of radiocaesium to ewes through a breeding cycle e an illustration of the pitfalls of the transfer coefficient. *Journal of Environmental Radioactivity 98 (2007) 24-35*

Cappelen, J. and Laursen, E.V. (1998): The Climate of the Faroe Islands – with Climatological Standard Normals, 1961-1990. *Technical Report 98-14, Danish Meteorological Institute.*

Fesenko, S., Isamov, N., Howard, B. J., Beresford, N.A., Barnett, C.L. Sanzharova, N., Voigt, G.: Review of Russian language studies on radionuclide behaviour in agricultural animals: 3.Transfer to muscle. *Journal of Environmental Radioactivity 100 (2009) 215–231.*

Howard, B.J., Beresford, N.A., 2001: Advances in animal radioecology. In: Radioactive Pollutants: Impact on the Environment and Humans. *Proceedings of International Symposium in Aix-en-Provence, France, 3rd-7th September 2001. EDP Science, Les Ulis, pp. 187-207.*

Howard, B.J., Beresford, N.A., Barnett, C.L., Fesenko, S.: Radionuclide transfer to animal products Revised recommeded transfer coefficient values. *Journal of Environmental Radioactivity 100 (2009) 263–273.*

IAEA, 2009. Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments. IAEA-TECDOC-1616 (2009). International Atomic Energy Agency, Vienna.

IAEA, 1994. Handbook of parameter values for the prediction of radionuclide transfer in temperate environments. IAEA Technical Reports Series No. 364. International Atomic Energy Agency, Vienna.

Joensen, H.P.: Long-Term Variation of Radiocaesium in the Foodchain of Lamb in the Faroe Islands. *Journal of Environmental Radioactivity 46 (1999), pp 345-360.*

Müller, H., Pröhl, G. (1993). ECOSYS-87: a dynamic model for assessing radiological consequences of nuclear accidents. *Health Physics 64(3), pp. 232-252*.

Müller, H. and Pröhl, G.: ECOSYS for Excel. A radioecological model for assessing contamination of foodstuffs and radiation exposure following a release of radionuclides. *ConRad Consulting in Radioecology.*

Smith, J., Beresford, N.A., Shaw, G.G., Moberg, L., 2005. Radioactivity in Terrestrial Ecosystems. In: Smith, J.T., Beresford, N.A. (Eds.), *Chernobyl - Catastrophe and Consequences. Springer/Praxis Publishing, Chichester, pp. 81-137.*

Ward, G.M., Johnson, J.E., 1965. The caesium-137 content of beef from dairy and feed lot cattle. *Health Physics 11, 95-100.*

Table 2. Soil characteristics for the top 10 cm soil layer. Average for the eight years 1990-97 ± 1 SE. (Adapted from Joensen, 1999)

	Bøur	Velbastað	Hvalvík	Skáli	Funnings-fjørður	Norðoyri	Sandur	Hvalba	Sumba
pH	4.9 ± 0.05	5.1 ± 0.11	4.8 ± 0.09	4.9 ± 0.06	4.8 ± 0.07	4.7 ± 0.10	4.8 ± 0.11	5.1 ± 0.07	4.9 ± 0.07
K, mg/100g	63.2 ± 8.0	60.0 ± 6.3	51.4 ± 7.4	67.8 ± 8.6	45.5 ± 6.0	64.3 ± 5.9	56.5 ± 5.0	77.2 ± 8.0	65.8 ± 6.8
Na, mg/100g	39.3 ± 4.0	39.8 ± 4.3	31.3 ± 5.1	34.2 ± 4.2	31.9 ± 3.4	43.8 ± 4.9	39.5 ± 2.8	108.7 ± 15.6	58.5 ± 5.9
Loss on ignition, %	52 ± 4.1	30 ± 3.1	67 ± 3.8	56 ± 3.6	51 ± 3.1	67 ± 4.0	52 ± 4.4	63 ± 2.7	56 ± 5.2

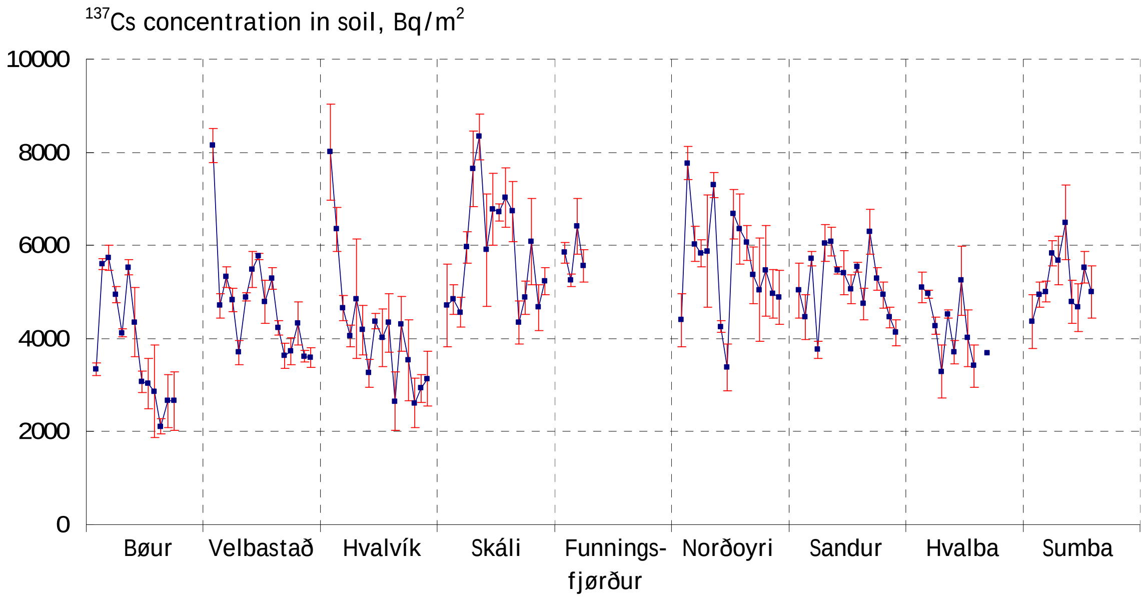

Figure 2. ^{137}Cs (Bq/m^2) in upper 10cm soil since 1990. Annual average ± 1 SE. The first data for Hvalba are from 1991.

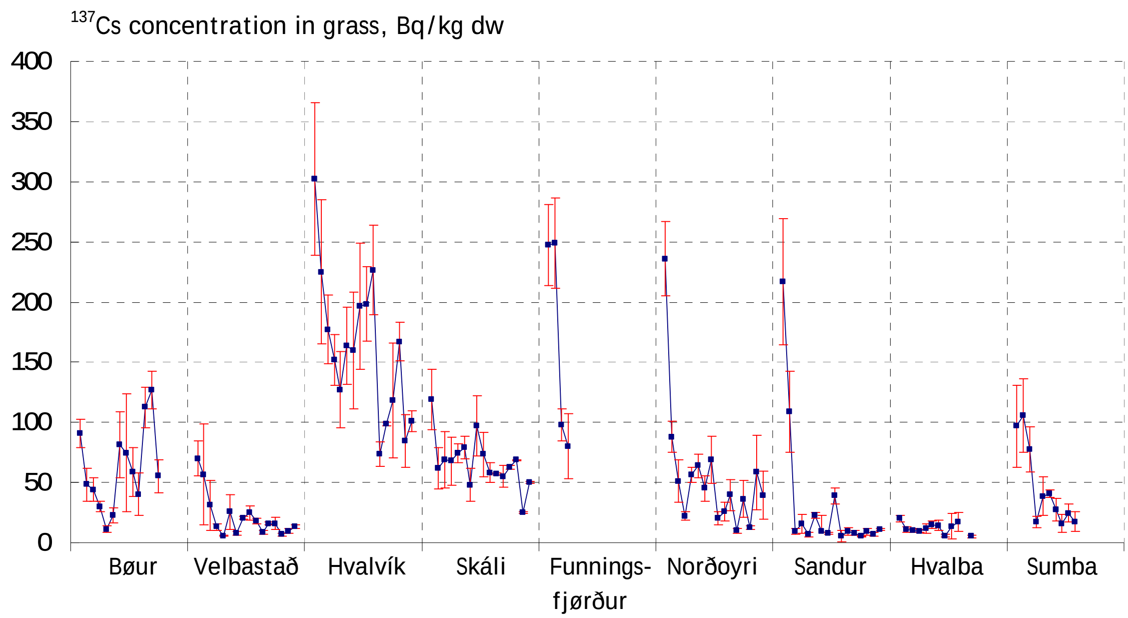

Figure 3. ^{137}Cs (Bq/kg dw) in mixed grass since 1990. Annual average ± 1 SE.

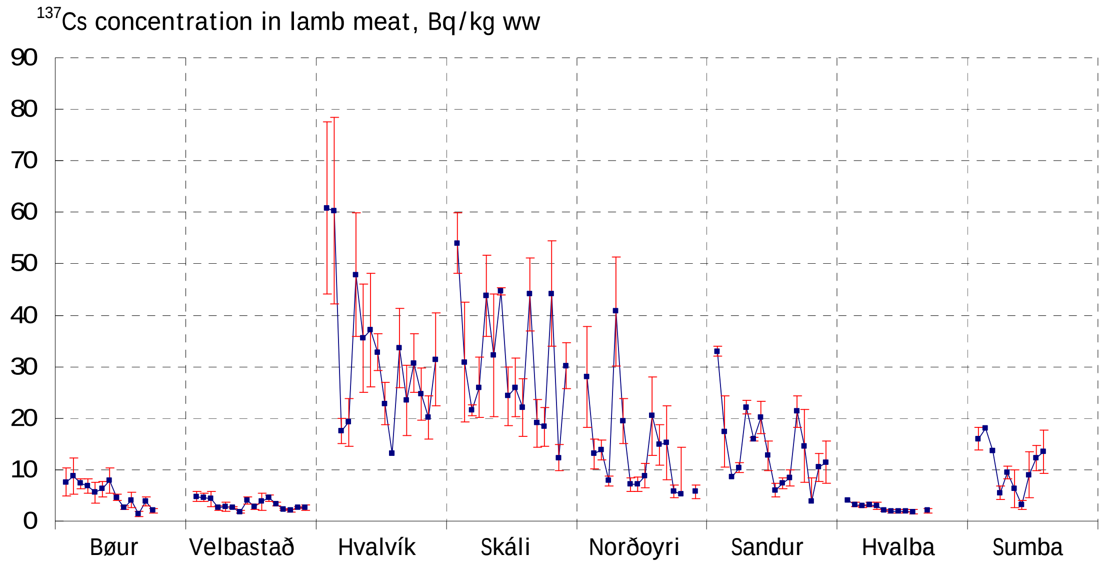

Figure 4. ^{137}Cs (Bq/kg ww) in lamb meat since 1990. Annual average ± 1 SE.

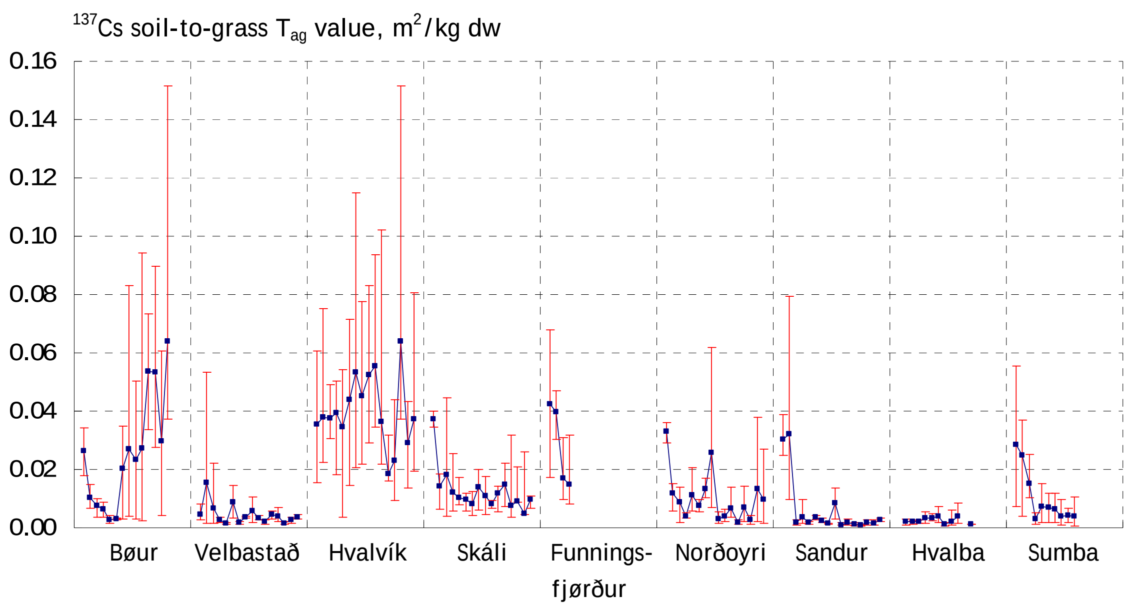

Figure 5. Soil-to-grass transfer factor of ^{137}Cs (m^2/kg dw). Annual average and ranges since 1990. The first data for Hvalba are from 1991.

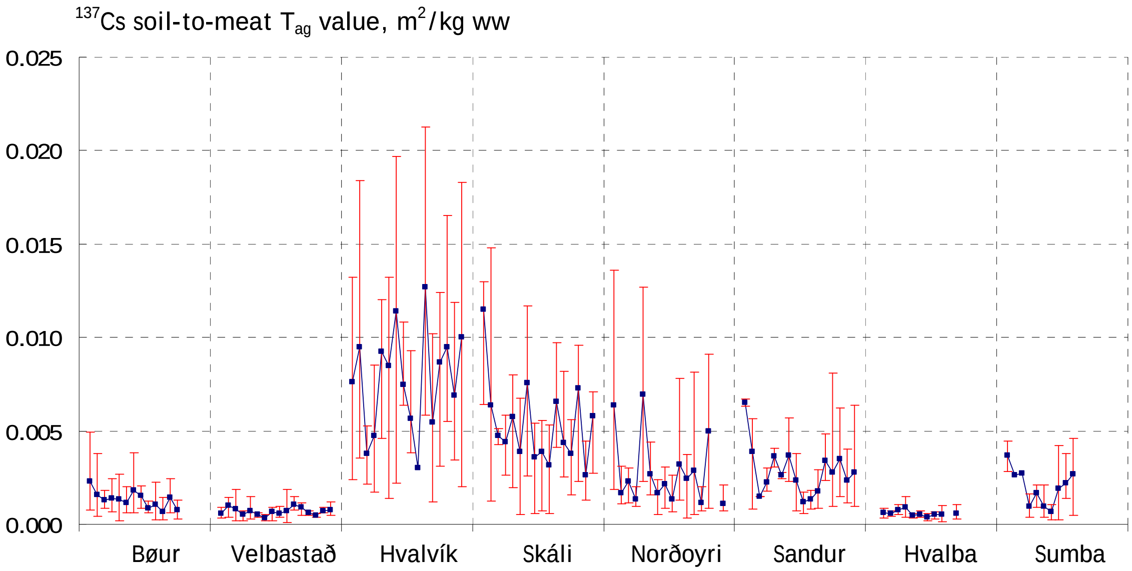

Figure 6. Soil-to-meat aggregated transfer factor of ^{137}Cs (m^2/kg ww). Annual average and ranges since 1990. The first data for Hvalba are from 1991.

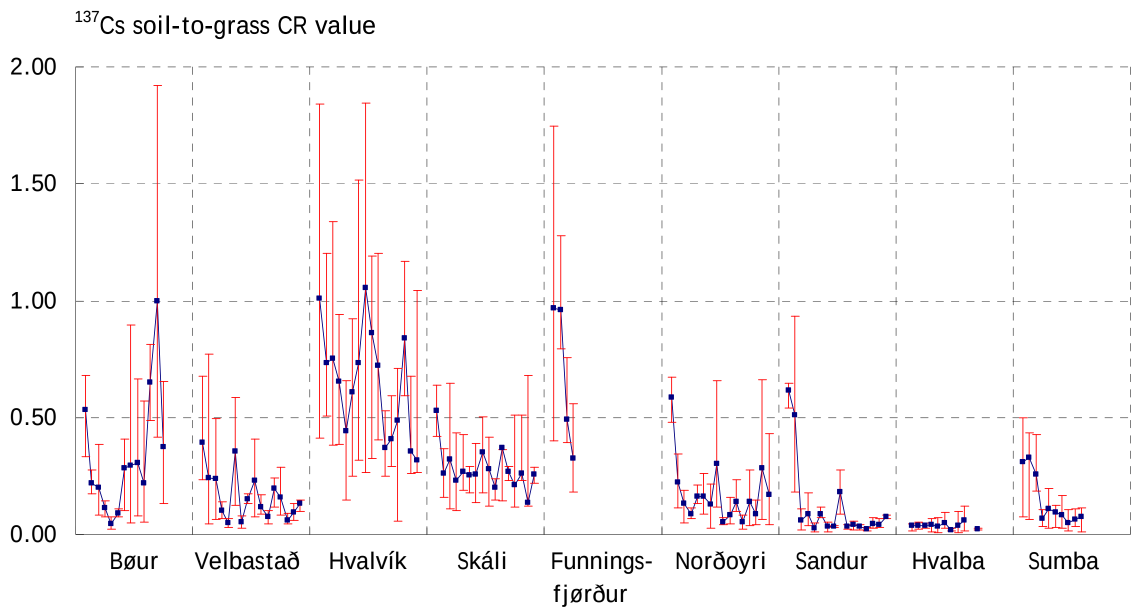

Figure 7. Grass/soil concentration ratio for ^{137}Cs. Annual average and ranges since 1990. The first data for Hvalba are from 1991.

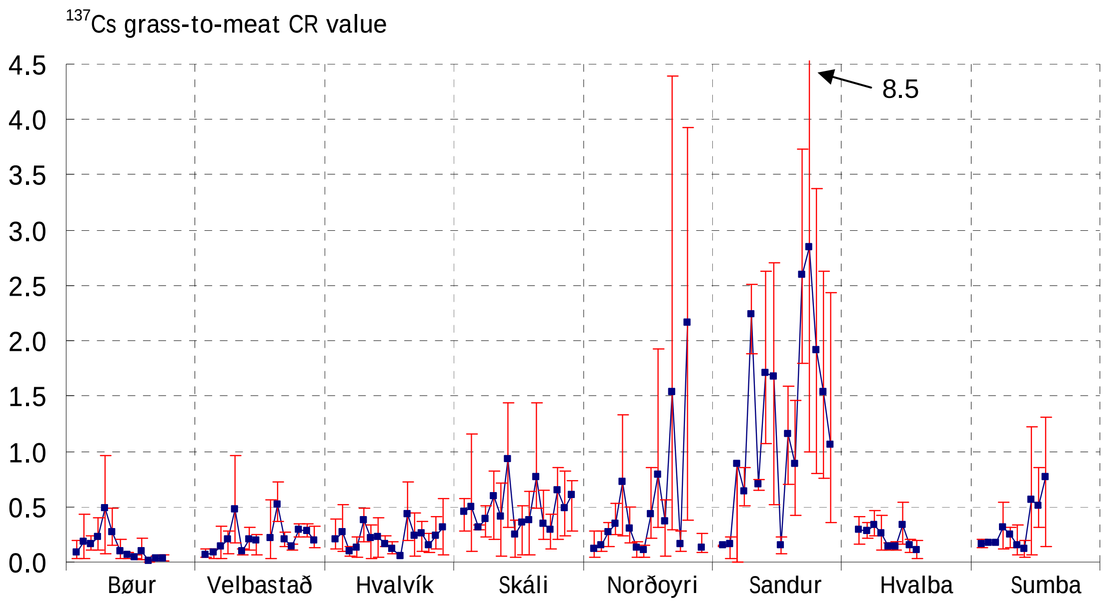

Figure 8. Meat/grass concentration ratio for ^{137}Cs. Annual average and ranges since 1990. The first data for Hvalba are from 1991.