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Sigurður H. Magnússon and Björn Thomas

Unnið fyrir Norðurál ehf og Íslenska járnblendifélagið

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NÁTTÚRUFRÆÐISTOFNUN ÍSLANDS

Hlemmi 3 105 Reykjavík
Sími 590 0500 Fax 590 0595
http://www.ni.is ni@ni.is

Borgum
við Norðurslóð 602 Akureyri
Sími 460 0500 Fax 460 0501
http://www.ni.is nia@ni.is

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Sigurður H. Magnússon and Björn Thomas

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ABSTRACT

In 2005, as a part of the UN-ECE International Cooperative Programme on vegetation, moss samples were taken all over Iceland and analysed for heavy metals (As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V, and Zn) and Sulphur (S). Additionally, more intensive sampling was conducted at three industrial sites in Iceland: a) the ferro-silicon plant and aluminium smelter at Grundartangi, western Iceland; b) the aluminium smelter in Straumsvík, southwestern Iceland; and c) a new aluminium smelter site at Reyðarfjörður, eastern Iceland. This report uses the data of the 2005, and previous 2000 survey, for monitoring airborne depositions in these areas and to identify different emission sources.

In general, all measured elements except cadmium had higher concentration in the vicinity of the Grundartangi industrial site than in the background area. The concentration was highest around the industrial site and toward northeast and southwest. The distribution pattern indicates two main sources of elements. The first source is the aluminium smelter, represented by arsenic (As), nickel (Ni) and zinc (Zn). The second probable source is the ferro-silicon plant, represented by chromium (Cr), copper (Cu), iron (Fe), vanadium (V) and to some extent also lead (Pb) and mercury (Hg). Sulphur (S), which is known to be emitted from both factories, showed somewhat different pattern but had highest concentration to the northeast and southwest of the two factories.

Arsenic (As) and nickel (Ni) in moss increased between 2000 and 2005 reflecting the increased aluminium production at Grundartangi in recent years.

Lykilorð
heavy metals, sulphur, deposition patterns, mosses, industrial sites, aluminium smelter, ferro-silicon plant, Iceland

Yfirfarið
BM, SB, PH

ÁGRIP

Sumarið 2005 fór fram á Náttúrufræðistofnun Íslands rannsókn á þungmálmum og brennisteini í mosa á Íslandi í samvinnu við Umhverfisstofnun og fleiri aðila. Rannsóknin er liður í fjölþjóðlegu verkefni þar sem meginmarkmið er að fylgjast með mengun sem berst með loftstraumum og finna helstu uppsprettur hennar. Í þessum tilgangi hefur tildurmosa (*Hylocomium splendens*) verið safnað víðs vegar um land á 5 ára fresti allt frá árinu 1990 og þungmálmar greindir. Árið 2005 var mosa einnig safnað til mælinga á þungmálmum og brennisteini á allmörgum stöðum í nágrenni járnblendiverksmiðjunnar og álversins á Grundartanga í Hvalfirði. Er það hugsað sem upphaf að vöktun þessara efna við verksmiðjurnar en sams konar vöktun hófst árið 2000 í Straumsvík og í Reyðarfirði.

Við rannsóknirnar árið 2005 voru tekin 12 mosasýni í nágrenni Grundartanga og styrkur As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V, Zn og S ákvarðaður með ICP-tækni. Við úrvinnslu voru notaðar niðurstöður úr þeim sýnum sem safnað var á landinu öllu árin 2000 og 2005. Styrkur þungmálma og brennisteins var kannaður eftir fjarlægð frá verksmiðjunum (<3 km, 3–100 km, >100 km) og einnig borinn saman við styrk efna við álverið í Straumsvík (<3 km) og við álverið sem verið er að reisa í Reyðarfirði (<3 km). Til þess að lýsa dreifingu efna á Grundartanga og nágrenni nánar voru teiknuð kort sem sýna styrk efnanna á einstökum sýnatökustöðum.

Niðurstöðurnar benda til þess að á Grundartanga hafi verksmiðjurnar aukið styrk allra mældra efna í umhverfinu nema kadmíums. Eins og búast mátti við út frá staðsetningu og ríkjandi vindáttum gætti áhrifanna mest næst verksmiðjunum og á aflöngu svæði bæði til norðausturs en þó einkum til suðvesturs í stefnu á Akrafjall. Út frá dreifingarmynstri efnanna mátti greina tvo meginflokka. Annars vegar eru arsen (As), nikkel (Ni) og sink (Zn) sem hafa meginútbreiðslu á austurhluta þessa svæðis og eiga að öllum líkindum upptök í álverksmiðjunni. Hins vegar eru króm (Cr), kopar (Cu), járn (Fe) og vanadíum (V) sem hafa þungamiðju dreifingar nokkru vestar og koma því sennilega frá járnblendiverksmiðjunni. Sama gildir um blý (Pb) og kvikasilfur (Hg) en þau sýna svipað útbreiðslumynstur. Brennisteinn hefur nokkra sérstöðu vegna þess að útbreiðsla hans er óskýrari en annarra efna en styrkur hans er þó mestur norðaustur og suðvestur af verksmiðjunum.

Miðað við önnur svæði hér á landi voru hæstu gildi á Grundartanga og nágrenni miðlungi há fyrir kadmíum, króm, járn, blý og vanadíum, allhá fyrir arsen, kopar, nikkel og sink, en há fyrir kvikasilfur og brennistein.

Mælingarnar benda til þess að styrkur bæði arsens og nikkels hafi aukist nokkuð á Grundartanga frá 2000 til 2005 sem endurspeglar að hluta aukna framleiðslu áls á þessum tíma. Utan iðnaðarsvæða urðu einnig töluverðar breytingar á styrk sumra efna sem ekki verða raktar til innlends iðnaðar eða beint til umsvifa manna hér á landi. Styrkur nikkels, járns og vanadíums jókst t.d. sem að öllum líkindum má rekja til aukins áfoks. Styrkur kvikasilfurs, sinks, blýs og brennisteins minnkaði hins vegar, sennilega vegna minni mengunar erlendis frá.

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1 INTRODUCTION

In Europe, carpet-forming mosses have been widely used since the late 1960's for assessing regional and temporal variability of atmospheric heavy-metal deposition (see e.g. Rühling and Tyler 1969). In Iceland, concentrations of heavy metals have been systematically monitored since 1990, at a five-year interval, as a part of the UN-ECE International Cooperative Programme on vegetation (Rühling et al. 1992, Rühling and Steinnes 1998, Buse et al. 2003).

The moss technique for monitoring of heavy metal depositions has several advantages (see e.g. Rühling and Steinnes 1998, Buse et al. 2003). Mosses lack a cuticle and transport tissue. Therefore, they absorb whatever is around them. In addition particles are adsorbed on their surface. This results in accumulation of heavy metals in the moss both from dry and wet deposition (Rühling and Steinnes 1998). As moss sampling is relatively simple and the concentration of heavy metals is generally much higher in the moss than in the air, analysis of the moss tissue is both a cheap and easy way to identify pollution of the environment and their sources.

As in any indirect method, there are factors other than pollution that influence the concentration of heavy metals in mosses (Berg et al. 1995, Steinnes 1995, Reimann et al. 2001). Input from the marine environment is known to affect the metal concentration; metals can be transported from the soil to root of plants and subsequently can later reach the mosses from the living or dead plant tissue. In moist or wet areas, especially after the snowmelt, contact between the soil and backwater can transport metals from the soil to the mosses. Furthermore windblown dust from soil can affect the metal content of mosses.

The results of the 1990s and 1995s moss surveys in Iceland indicated an increased concentration of some heavy metals in the vicinity of the aluminium smelter in Straumsvík, southwestern Iceland (Rühling et al. 1992, Rühling and Steinnes 1998). In the 2000 survey, additional samples were taken around the Straumsvík smelter and also around the proposed aluminium smelter in Reyðarfjörður. The purpose was to obtain a clearer spatial picture of the heavy metal concentrations around the smelter in Straumsvík. The sampling was further seen as first step in monitoring the discharge of heavy metals from these smelters. In the 2000 survey 11 elements were analyzed, 10 heavy metals (As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V, Zn) and sulphur (S).

In the 2005 survey, sampling at these sites was repeated. The industrial site at Grundartangi in western Iceland where a ferro silicon-plant and an aluminium smelter is situated was also added to the study. The aluminium smelter at Grundartangi started operation in 1998 with an annual production capacity of 60,000 tons. Since then the production capacity has been increased to 90,000 tons in 2001 and to 180,000 tons in 2006 (Norðurál ehf. 2007). The ferro-silicon plant of Icelandic Alloys Ltd. is situated about 750 m southwest of the aluminium smelter. In 1979 the first furnace of the plant started operation, one year later the second and since 1999 a third furnace has been running. The core product is FeSi 75% and also SiO_2 is produced as a by-product (Íslenska járnblendifélagið 2007).

This report focuses on the heavy metal and sulphur concentration in mosses around the aluminium smelter and ferro-silicon plant at Grundartangi and compares these findings with areas close to the aluminium smelter in Straumsvík and the smelter site in Reyðarfjörður and to other areas in Iceland. The aim is to display and explain the spatial distribution of heavy metal concentrations around the Grundartangi industrial area. In the discussion concentration values from Europe are considered. In the future this study will serve as a baseline for continued monitoring of the impacts of the industries at Grundartangi.

2 METHODS

In the vicinity of the aluminium smelter and ferro-silicon plant at Grundartangi the moss *Hylocomium splendens* was sampled at 12 points on August 29th and September 14th – 15th, 2005 (Figure 1). During the earlier surveys in 1990, 1995 and 2000, only four samples, (V1, V2, V4, 88) were taken within the area. As *Hylocomium splendens* was quite sparse in part of the area, the new sampling points were selected with regard to abundance of the moss. Five of the 12 sample points were located north and northeast of the industries, while six were located southwest of the plants where highest accumulation of heavy metals was expected (Hönnun 2002). One sample (V1) was taken southeast of the industries on the other side of the fjord (Figure 1).

In the 2000 survey, the main characteristics of the sampling points V1, V3 and V4 were described (Magnússon 2002b). In the 2005 sampling, they were revised and the information about the new sampling points added (Table 1).

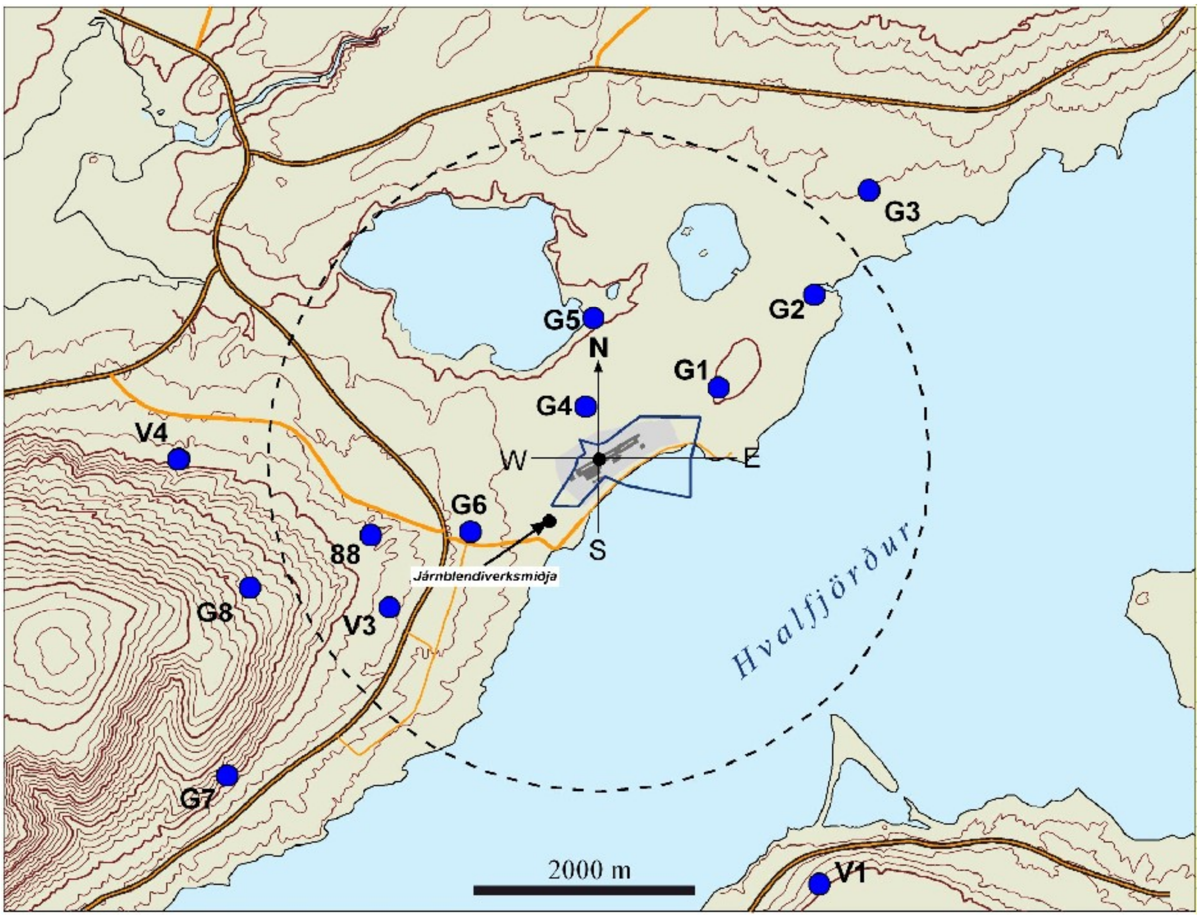


Figure 1. The industrial site at Grundartangi and adjacent area. Locations of the ferro-silicon plant and the aluminium smelter are marked with black dots and the sampling sites of the 2005 moss survey are marked with blue dots. The relative frequency of wind directions from 2002 to 2004 (only April to October) is also shown. The dashed circle defines the area with a radius of 3 km from the smelter. - Iðnaðarsvæðið á Grundartanga og nágrenni. Staðsetning járnblendiverksmiðju og álvers eru táknaðir með svörtum punktum og sýnatökustaðir mosa árið 2005 eru táknaðir með bláum punktum. Sýnd er tíðni vindátta á árunum 2002–2004 mánuðina apríl til október. Brotinn hringferill afmarkar það svæði sem er innan við 3 km frá miðju álvers.

Table 1. *Location and characteristics of the sampling points near the industries at Grundartangi.* - Staðsetning og helstu einkenni sýnatökustaða á Grundartanga og nágrenni.

No. Númer	*Distance to smelter [m]* Fjarlægð frá miðju alvers	*m asl* Hæð yfir sjó [m]	*Slope [°]/ direction* Halli [°]/ Hallastefna	*Vegetation type* Landgerð	*Dominant vascular plants*	Ríkjandi háplöntutegundir
G1	1300	10	0	Moist grassland *Rakt graslendi*	*Anthoxanthum odoratum* *Festuca vivipara* *Carex nigra* *Thalictrum alpinum*	Ilmreyr Blávingull Mýrastör Brjóstagras
G2	2500	10	3/NW	Grassland *Graslendi*	*Agrostis capillaris* *Festuca vivipara* *Anthoxanthum odoratum* *Carex bigelowii*	Hálíngresi Blávingull Ilmreyr Stinnastör
G3	3500	20	5/SE	Grassland *Graslendi*	*Agrostis capillaris* *Festuca vivipara* *Galium verum* *Kobresia myosuroides*	Hálíngresi Blávingull Gulmaðra Þursaskegg
G4	500	10	0	Grassland *Graslendi*	*Agrostis capillaris* *Festuca vivipara* *Empetrum nigrum* *Thalictrum alpinum*	Hálíngresi Blávingull Krækilyng Brjóstagras
G5	1300	10	4/SW	Mire *Mýri*	*Carex nigra* *Empetrum nigrum* *Agrostis stolonifera* *Festuca vivipara*	Mýrastör Krækilyng Skriðlíngresi Blávingull
G6	1300	40	3/NE	Sloping mire *Hallamýri*	*Carex nigra* *Thalictrum alpinum* *Bistorta vivipara* *Vaccinium uliginosum*	Mýrastör Brjóstagras Kornsúra Bláberjalyng
G7	4400	120	22/E	Grassland *Graslendi*	*Agrostis capillaris* *Anthoxanthum odoratum* *Festuca vivipara* *Carex bigelowii*	Hálíngresi Ilmreyr Blávingull Stinnastör
G8	3400	260	13/NE	Grassland *Graslendi*	*Deschampsia caespitosa* *Agrostis capillaris* *Empetrum nigrum* *Anthoxanthum odoratum*	Snarrótarpuntur Hálíngresi Krækilyng Ilmreyr
V1	4400	100	10/NW	Sloping grassland Graslendi í halla	*Agrostis capillaris* *Deschampsia caespitosa* *Juncus trifidus* *Anthoxanthum odoratum*	Hálíngresi Snarrótarpuntur Móasef Ilmreyr
V3	2300	40	3/NE	Sloping grassland in a birch forest *Graslendi í birkikjarri*	*Deschampsia flexuosa* *Deschampsia caespitosa* *Anthoxanthum odoratum* *Agrostis capillaris*	Bugðupuntur Snarrótarpuntur Ilmreyr Hálíngresi
V4	3800	100	5/N	Sloping mire *Hallamýri*	*Carex nigra* *Carex rostrata* *Juncus arcticus* *Vaccinium uliginosum*	Mýrastör Tjarnastör Hrossanál Bláberjalyng
88	2200	80	4/N	Heathland *Mólendi*	*Empetrum nigrum* *Salix herbacea* *Vaccinium uliginosum* *Festuca richardsonii*	Krækilyng Grasvíðir Bláberjalyng Túnvingull

The sampling was conducted according to the monitoring manual of the European heavy metal deposition monitoring program (Harmens 2005). At every sampling point, 5–10 sub-samples of the moss *Hylocomium splendens* were taken within a 50 m to 50 m plot and placed together in a plastic bag. At the points where the moss was rare a larger area was sampled. The locations of the samples were determined by GPS. In addition photos were taken in order to give an overview of the present situation.

After sampling, the moss samples were kept frozen until February 2006. Then they were thawed and cleaned of dead material and attached litter. Segments from the 2005 growing season were separated and discarded and only the growth segments of 2002, 2003 and 2004 were kept for analysis. The separated material was then put into paper bags and dried at room temperature. The samples were sent to the Section of Plant Ecology and Systematics of the University of Lund, Sweden for analysis. Before analysis the samples were dried at 40 °C and wet ashed with nitric acid. From each sample, 1g of moss was used for the analysis. Cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn) were measured with inductively coupled plasma emission spectrometry (ICP-ES) and arsenic (As), mercury (Hg) and sulphur (S) with inductively coupled plasma mass spectrometry (ICP-MS) technique. The quantification limits are listed in Appendix 1. The remaining part of each moss sample was dried at room temperature and will be stored for possible future investigations.

3 DATA ANALYSES

For the analyses, the data from the 2000 and 2005 surveys were used. The dataset was divided into three groups according to the distance from the Grundartangi smelter; <3 km, 3–100 km, >100 km. In addition, sample points within 3 km from the aluminium smelter in Straumsvík and the aluminium smelter site in Reyðarfjörður were grouped respectively and used for comparison to the Grundartangi data. The mean for each distance class was calculated together with its standard error (SE) and presented in graphs. Comparison of the elements between sites and distance classes were made with one-way ANOVA on log transformed values for each survey respectively. Comparisons of site means were then made with the Tukey-Kramer HSD test (JMP 2005).

Comparison between years (2000 vs. 2005) was done on paired samples with a paired t-test on log transformed values for each site or distance class separately; 3–100 km (n=29), >100 km (n=70), Straumsvík <3 km (n=11), Reyðarfjörður < 3 km (n=4). The sampling points close to Grundartangi (<3 km) were excluded from this test due to few samples (n=2).

The results are also presented with maps showing the metal concentration at each sampling point, thus giving an overview of the spatial distribution of heavy metal concentrations near the Grundartangi industries. In accordance with the European moss sampling program (Buse et al, 2003) the legend of the maps is adapted to the colours generally used in their presentation of overall results. This ensures a more objective view of the data, as only highest values in the European context are highlighted in red or orange. In addition the samples from the Icelandic surveys of 2000 and 2005 are ranked in order to make their relative comparison more easy (Appendix 2).

4 RESULTS AND DISCUSSION

During the deposition period (2002-2004) the most frequent wind directions in the Grundartangi area were from northeast and southeast. Wind from southwest was also quite frequent (Figure 1).

4.1 Arsenic (As)

In 2005, arsenic concentrations between 0.10 and 0.50 µg/g were measured in the surroundings of Grundartangi (Figure 2). The highest values were found close to the smelter and the ferro-silicon plant. The concentration decreased with distance indicating an elongated ring of deposition around the industries from northeast towards southwest.

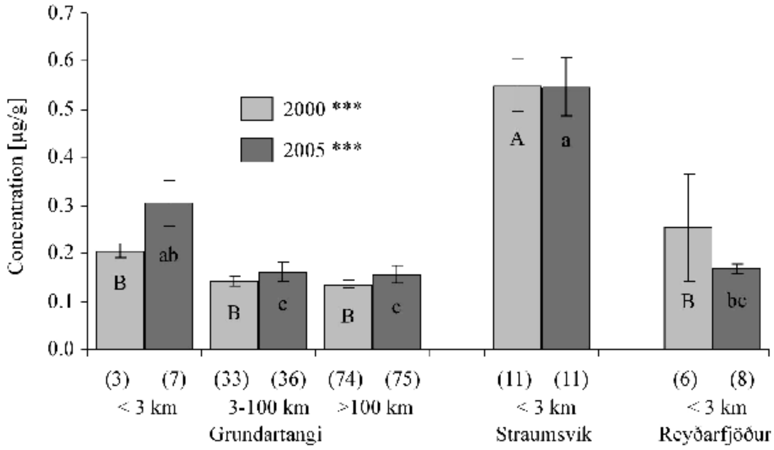
In 2005, the arsenic concentration was significantly higher close (< 3 km) to the industries at Grundartangi than in the zones further away (3-100 km, >100 km), but it did not differ significantly from the samples around the Straumsvík smelter (< 3 km) or Reyðarfjörður (< 3 km) (Figure 2). In the vicinity of Grundartangi only four samples (V1, V3, V4 and 88) were sampled at the same locations in the 2000 and 2005 survey. Comparison among them indicates an increase in the arsenic concentration during this period (average 0.19 vs. 0.22 µg/g). The increase was greatest in the samples closest to the industries (Figure 3). Comparison of paired samples for the different distance classes and sites did not reveal any significant difference between years.

Compared to other samples in Iceland, the highest values at Grundartangi in the 2005 survey are rather high (Appendix 2). However, the present results show that the concentration of arsenic at Grundartangi is similar to values found in many areas in Northern Europe and Scandinavia (Buse et al. 2003).

Averages and spatial arsenic distribution at Grundartangi in the 2005 survey strongly indicates an impact from the industries on the arsenic deposition. Especially the southeast gradient in arsenic contents suggests that arsenic is coming from the aluminium smelter. The findings are consistent with earlier results around aluminium smelters both in Norway and in Straumsvík Iceland (Steinnes et al. 2001, Magnússon 2002a, Magnússon and Thomas 2007a). It is, however, difficult to confirm that the ferro-silicon plant distributes additional arsenic.

Arsenic (As)

A.



B.

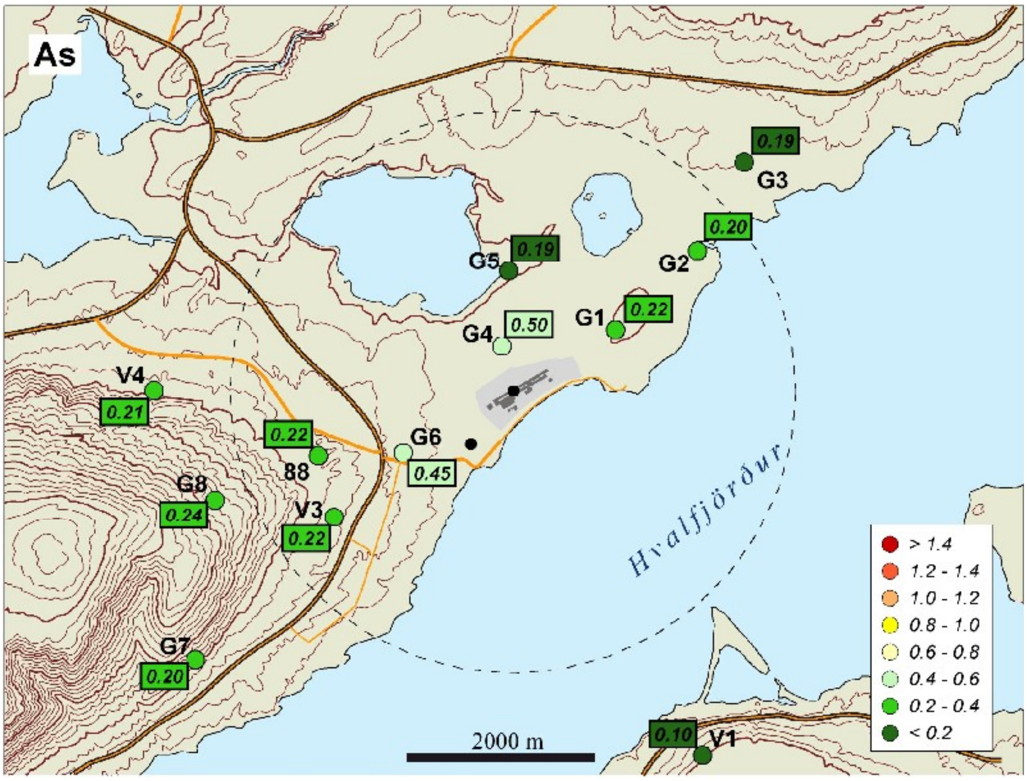


*Figure 2. (A) Average arsenic (As) concentration at different distances (<3 km, 3–100 km, >100 km) from the aluminium smelter and ferro- silicon plant at Grundartangi in the 2000 and 2005 moss survey. For comparison the average arsenic concentration close to (<3 km) the aluminium smelter at Straumsvík and the aluminium smelter site in Reyðarfjörður is given. Standard error is shown with vertical lines and the number of samples is given in parentheses below. Stars denote difference between classes tested with ANOVA, NS: not significant; *: p <0.05; **: p<0.01; ***: p<0.001. Different letters in the columns denote significant difference between distance classes and site within each year, (p<0.05, Tukey test).* - Styrkur arsens í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur arsens í nágrenni álversins í Straumsvík og við álver í Reyðarfirði. Lóðréttar línur tákna staðalskekkju. Innan sviga er sýndur fjöldi sýna í hverjum flokki. Stjörnur við ártöl tákna marktækan mun á svæðum og stöðum metið með fervikagreiningu (NS: ekki marktækt, *:p <0,05, **: p<0,01, ***:p<0,001). Mismunandi bókstafir tákna marktækan mun milli svæða, stórir stafir fyrir árið 2000 en litlir fyrir árið 2005, metið með Tukey prófun (p<0,05).

(B) Spatial distribution of arsenic concentration in mosses at the sampling sites close to the industries at Grundartangi. The dashed circle shows the area <3 km of the aluminium smelter centre. The colour scale reflects the European range for arsenic (Buse et al. 2003). - Styrkur arsens í mosa á Grundartanga og nágrenni. Brotin hringferill afmarkar það svæði sem er innan við 3 km frá miðju álvers. Litakvarði er miðaður við skýrslu Buse og fleiri frá árinu 2003.

4.2 Cadmium (Cd)

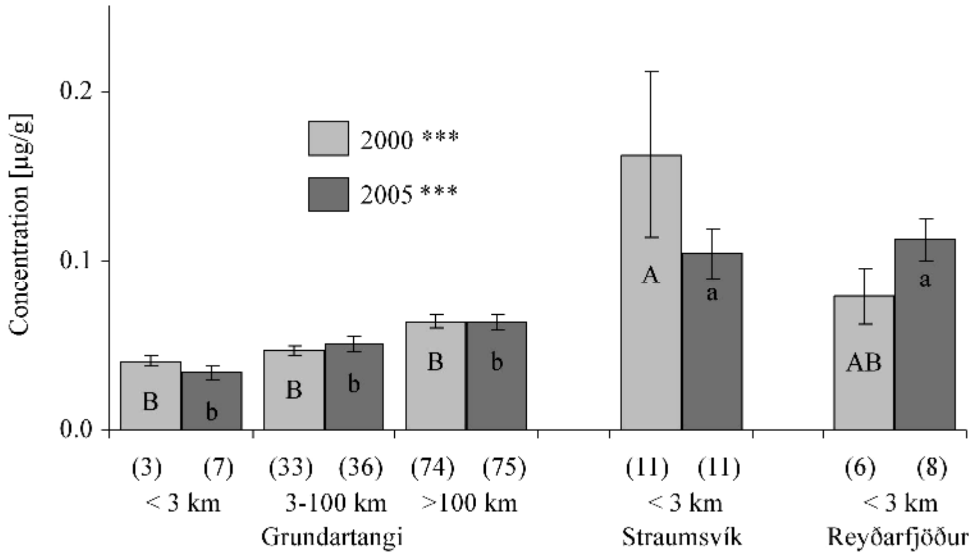
In the surroundings of Grundartangi there was low variability in cadmium concentration in the 2005 survey (0.03– 0.05 µg/g) and no distinct concentration pattern was observed (Figure 3).

The results show that cadmium concentrations in the 2005 survey at Grundartangi (>3 km) are significantly lower than in Straumsvík (<3 km) and in Reyðarfjörður (<3 km) but similar to the other distance classes compared. Also, the data values close to the industries at Grundartangi belong to the lower concentrations of the Icelandic samples (Appendix 2). In addition, no significant difference was found between the results of 2000 and 2005 for the sites and distance classes compared.

According to the moss survey in 2000/2002, the background concentration in Northern-Europe is below 0.10 µg/g (Buse et al. 2003). Due to drift of volcanic ash and soil dust in Iceland, higher values occur in affected areas (Rühling and Steinnes 1998, Buse et al. 2003). Low values around the industries at Grundartangi compared to Europe and even to the other Icelandic data, shows no obvious influence on the cadmium deposition by the industries in the area which is in line with results from aluminium smelters in Norway and in Straumsvík (Steinnes et al. 2001, Magnússon 2002a).

Cadmium (Cd)

A.



B.

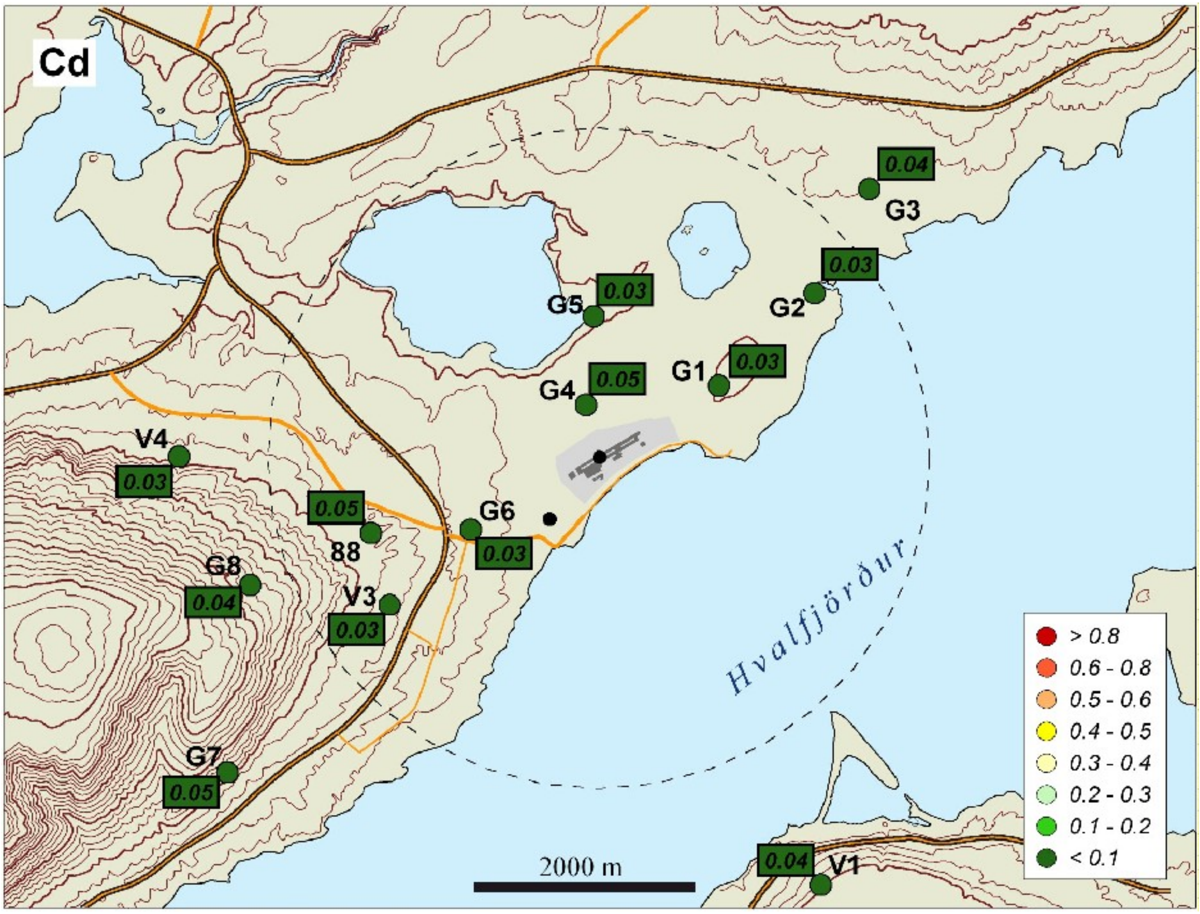


Figure 3. (A) Average cadmium (Cd) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður. - Styrkur kadmíums (Cd) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur kadmíums í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of cadmium concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur kadmíums í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.3 Chromium (Cr)

In 2005, the highest concentrations of chromium at Grundartangi were encountered close to the factories, especially west of the ferro-silicon plant (4.58 µg/g), but the lowest values were on the opposite site of the fjord to the southeast (1.0 µg/g) (Figure 4). The concentration decreased with distance from the industries with an elongated effect from southeast to southwest.

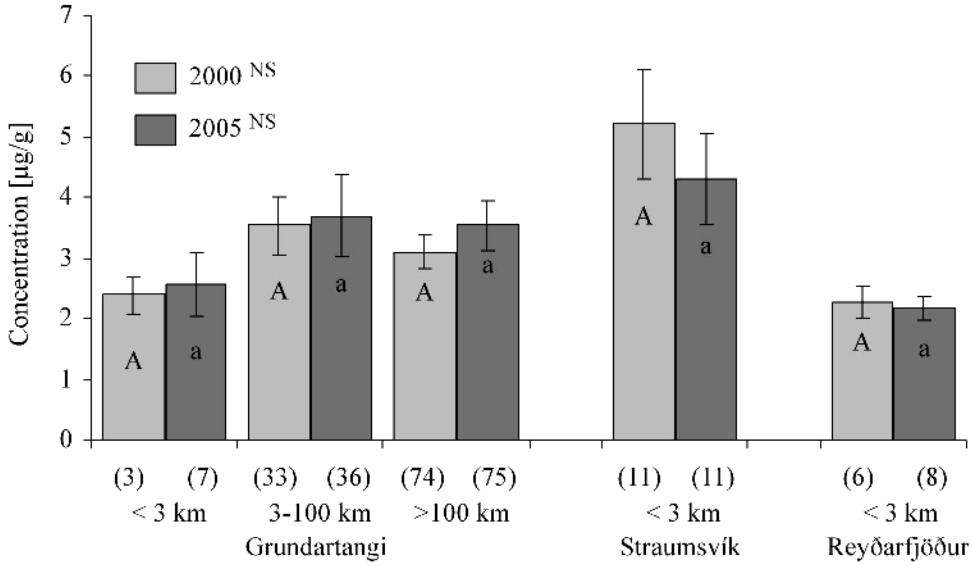
In 2005, the samples close to the industries at Grundartangi (<3 km) were not significantly different from the other distance classes or areas (Figure 4). For Iceland the chromium values ranged over a large scale and the samples closest to the industries (88, G4 and G6) are all relatively high (Appendix 2). Furthermore, comparison of paired values for different sites or distance classes revealed no significant difference between years of survey except for Straumsvík (>3 km). There the concentration had decreased on average from 5.21 to 4.30 µg/g from 2000 to 2005 ($P<0.01$, $n=11$).

The present results from Grundartangi are in line with earlier studies at aluminium smelter sites in Norway which show a small increase in chromium close to the smelters compared to the background areas (Steinnes et al. 2001, Magnússon 2002a). In recent surveys of rural areas of Scandinavia, concentrations have been found to lie below 0.20 µg/g in most cases (Rühling and Steinnes 1998, Buse et al. 2003).

The distribution pattern of chromium at Grundartangi strongly indicates that the element is emitted from the industrial area with the main transport to southwest (Figure 4). The high value at G6 west of and close to the ferro-silicon plant and low concentrations north of the factories lead to the conclusion that the ferro-silicon plant is the main emission source.

Chromium (Cr)

A.



B.

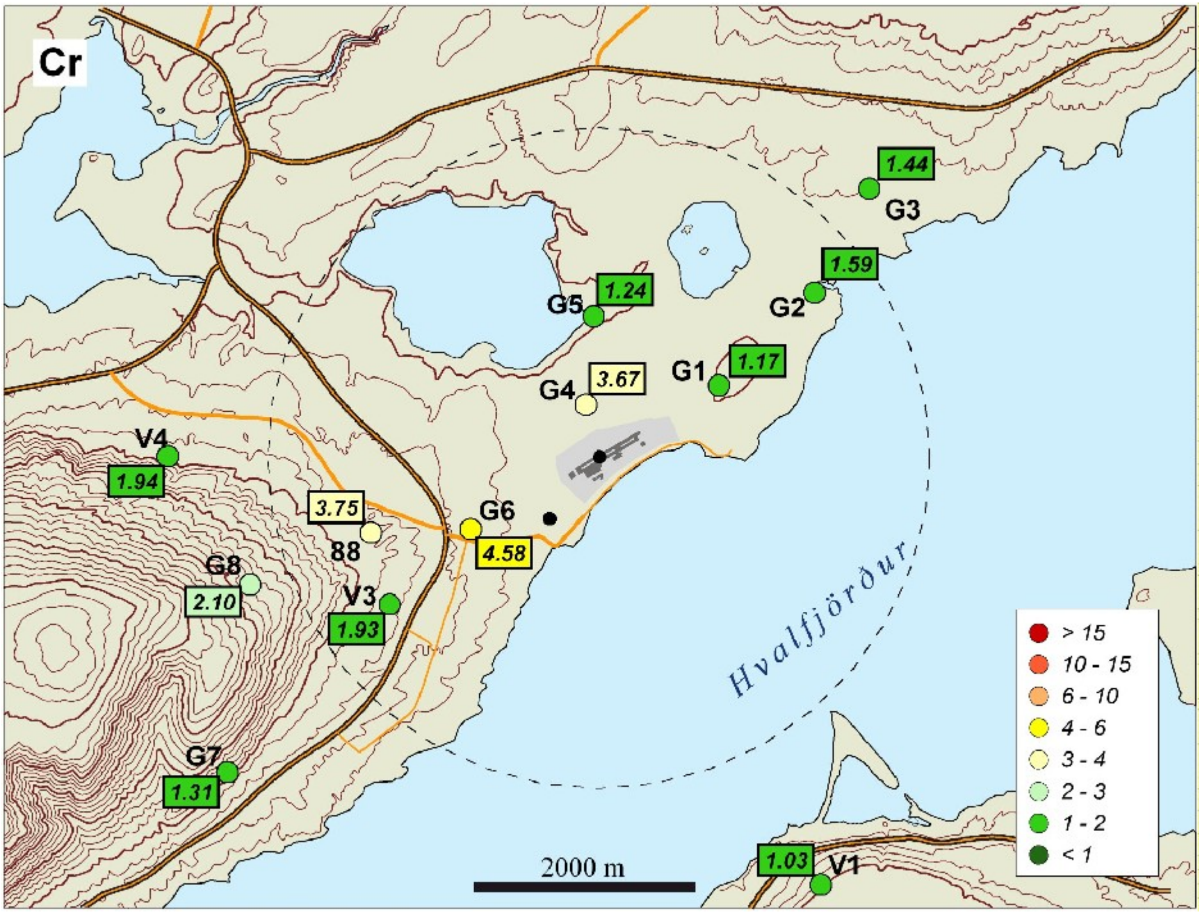


Figure 4. (A) Average chromium (Cr) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður. - Styrkur króms (Cr) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga í Hvalfirði (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur króms í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of chromium concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur króms í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.4 Copper (Cu)

In the 2005 survey, the copper concentration ranged from 4.83 to 13.29 µg/g in the vicinity of Grundartangi (Figure 5). The maximum value was found in sample G6 west of the ferro-silicon plant and the distribution pattern showed a clear decrease with distance from the industrial site with an elongated distribution mainly to the southwest (Figure 5). However, the concentration of copper within 3 km from the industries at Grundartangi was not significantly different from the other distance classes or areas.

Compared to all samples in Iceland, the values close (>3 km) to Grundartangi were medium to low, except sample G4, G6, and 88 which were remarkably higher than other samples in the area (Appendix 2). Comparison of paired samples did not show any significant difference between years for the distance classes or sites except for Straumsvík. There the concentration decreased from 14.29 to 11.92 µg/g between 2000 and 2005 ($P<0.01$, $n=11$).

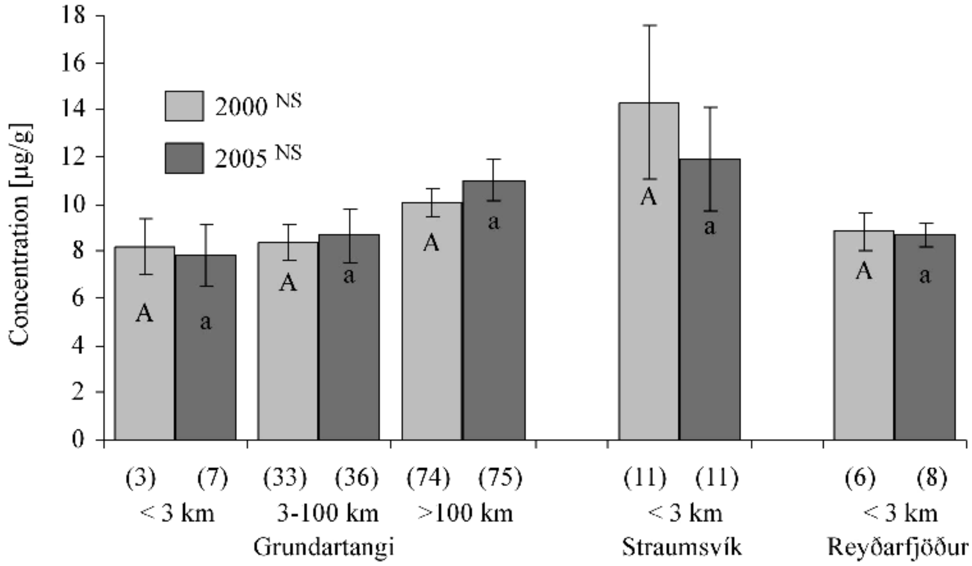
The present findings from Grundartangi are similar to results from previous studies in Norway. There copper concentration has been found to be somewhat higher in the vicinity of aluminium smelters than in the background areas (Steinnes et al. 2001, Magnússon 2002a).

The values from Grundartangi, and for Iceland as a whole, are relatively high in a European context which is partly related to volcanism and extensive soil erosion in the country (Rühling and Steinnes 1998, Buse et al. 2003).

The concentration pattern of copper around the industries at Grundartangi indicates that the industries are emitting low quantities of the element into the environment. Higher concentration at G6 and sites southwest of the industries compared to G4 and nearby sites northeast of the industries indicates that the ferro-silicon plant is the main emission source of the element in the area.

Copper (Cu)

A.



B.

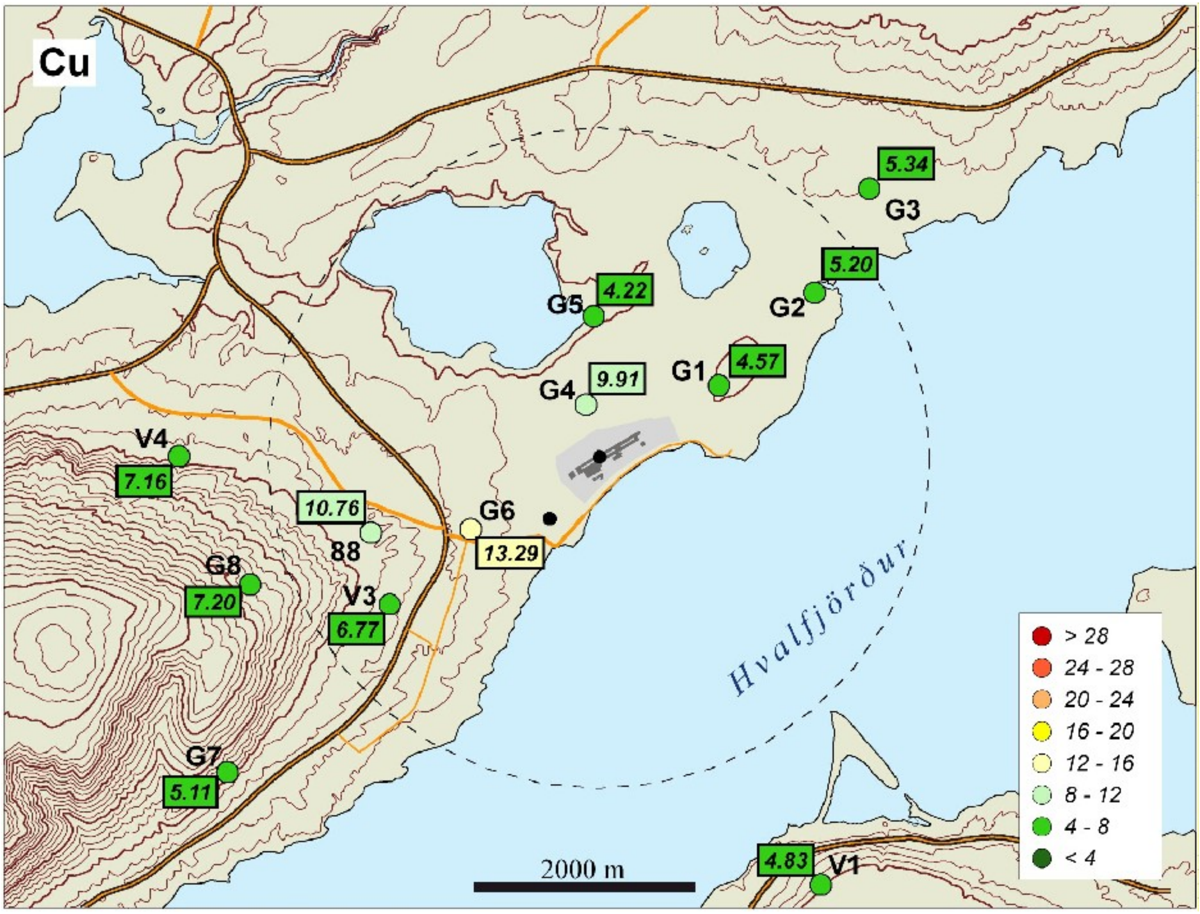


Figure 5. (A) Average copper (Cu) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður. - Styrkur kopars (Cu) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga í Hvalfirði (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur kopars í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of copper concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur kopars í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.5 Iron (Fe)

In 2005, iron concentration in mosses around the industrial sites at Grundartangi ranged from 2018 to 7391 µg/g with the highest values close to the industries and toward southwest, especially in samples G4, G6 and 88 (Figure 6). This is also striking when looking at all the Icelandic samples (Appendix 2).

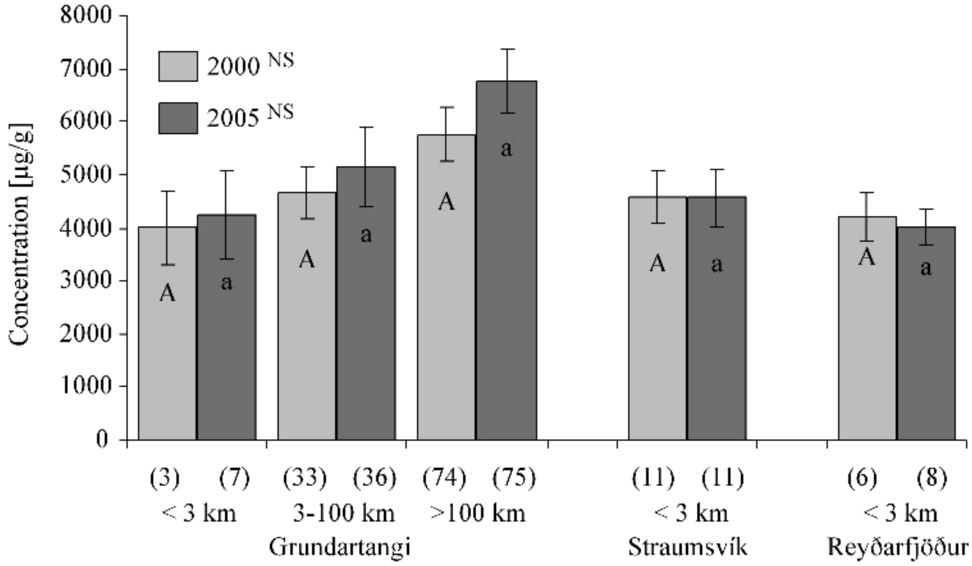
In spite of the high concentration of iron in the vicinity of Grundartangi, the values close to the industries (>3 km) were not significantly different from the concentration within other distance classes or sites (Figure 6). In addition, comparison of paired values did not reveal significant difference between the years of survey except for the distance class 3–100 km from Grundartangi where the iron concentration had increased significantly between the years 2000 and 2005, or from 5919 to 6901 µg/g, respectively ($P<0.05$, $n=70$).

It should be noted that the background concentration of iron is very high in Iceland, which is very likely due to the chemical composition of the bedrock, extensive soil erosion and air born dust content, especially within the volcanic active zone (Rühling et al. 1992, Magnússon 2002a). Therefore, comparison to the European values is not relevant. According to earlier moss surveys in Iceland, the Grundartangi area is just west of the area of high concentration of iron (Rühling et al. 1992, Rühling and Steinnes 1998).

Although earlier results from Norwegian smelters show slightly higher concentrations in mosses around aluminium smelters than in the background regions (Steinnes et al. 2001, Magnússon 2002a), the high values of iron to the west of the industrial site at Grundartangi, found in the present study, are very likely due to emission from the ferro-silicon plant.

Iron (Fe)

A.



B.

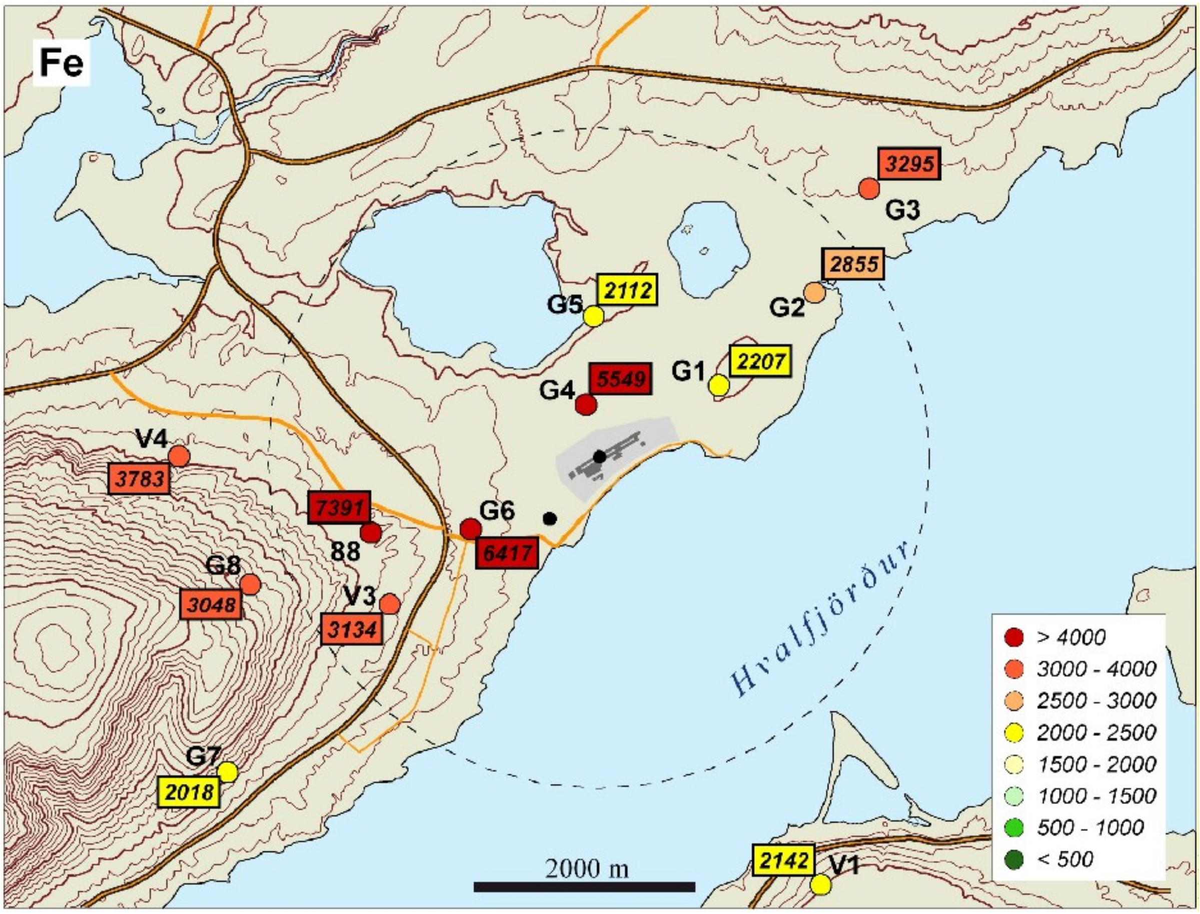


Figure 6. (A) Average iron (Fe) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður. - Styrkur járns (Fe) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur járns í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of iron concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur járns í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.6 Mercury (Hg)

In the 2005 survey the mercury concentration in the Grundartangi area was low and ranged from 0.008 to 0.041 µg/g (Figure 7). In spite of low values, the concentration was highest in an area close to the industries with an elongated effect to southwest. Compared to the Icelandic data, the samples close to the industries at Grundartangi (>3 km) are spread over the whole range of concentration where the sample 88 is the highest encountered in Iceland (Figure 7, Appendix 2).

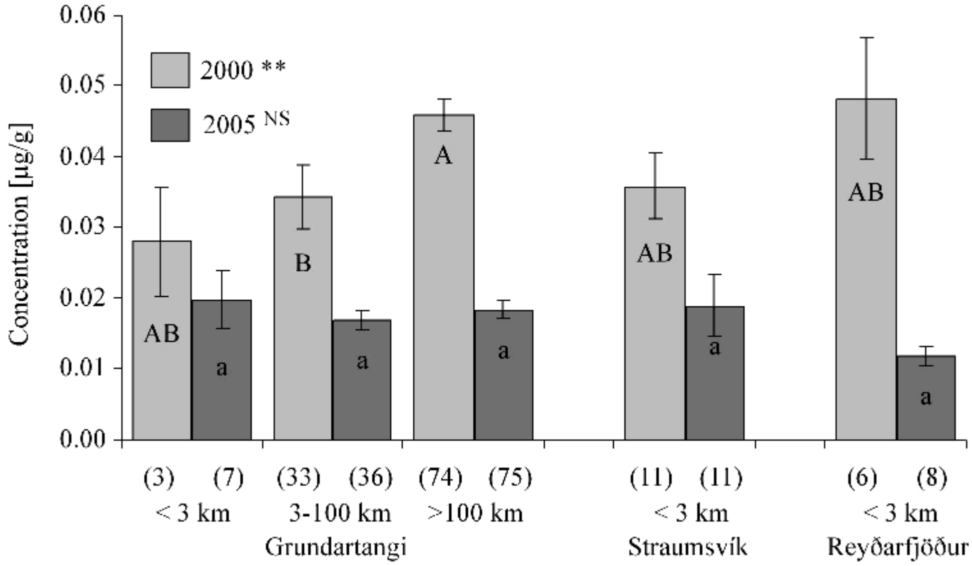
On average the concentration of mercury is similar over the distance classes and sites and no significant difference was found among them (Figure 7). Comparison of paired values showed that the concentration of mercury had decreased significantly between years for all distance classes and sites compared. Between the surveys of 2000 and 2005 the mercury concentration decreased as follows: in the 3–100 km distance class, from 0.036 to 0.017 µg/g ($P<0.001$, $n=29$), in distance class >100 km, from 0.046 to 0.019 µg/g ($P<0.001$, $n=70$), at Straumsvík from 0.036 to 0.019 µg/g ($P<0.001$, $n=11$) and Reyðarfjörður, from 0.048 to 0.010 µg/g ($P<0.01$, $n=4$).

The present results from Iceland also show that mercury concentrations are in general similar or lower than found in many areas in Scandinavia and northern part of Central Europe (Rühling and Steinnes 1998, Buse et al. 2003).

According to earlier investigations in Norway, mercury concentrations in mosses around aluminium smelters do not differ from background regions indicating no or minor impact from the smelters (Steinnes et al. 2001, Magnússon 2002a). The present results from Grundartangi do not change that picture. However, some of the samples have quite high values for Iceland so that a small impact by the industries can not be excluded. Mercury is one of the metals which are readily transported over long distances (Poikolainen et al. 2004). In Iceland no strong local emission sources for mercury are known. Therefore, the consequent decrease in concentration found in the 2005 survey is likely to be a result of decrease in the long-range transport of mercury to the country (Working Group on Effects 2004).

Mercury (Hg)

A.



B.

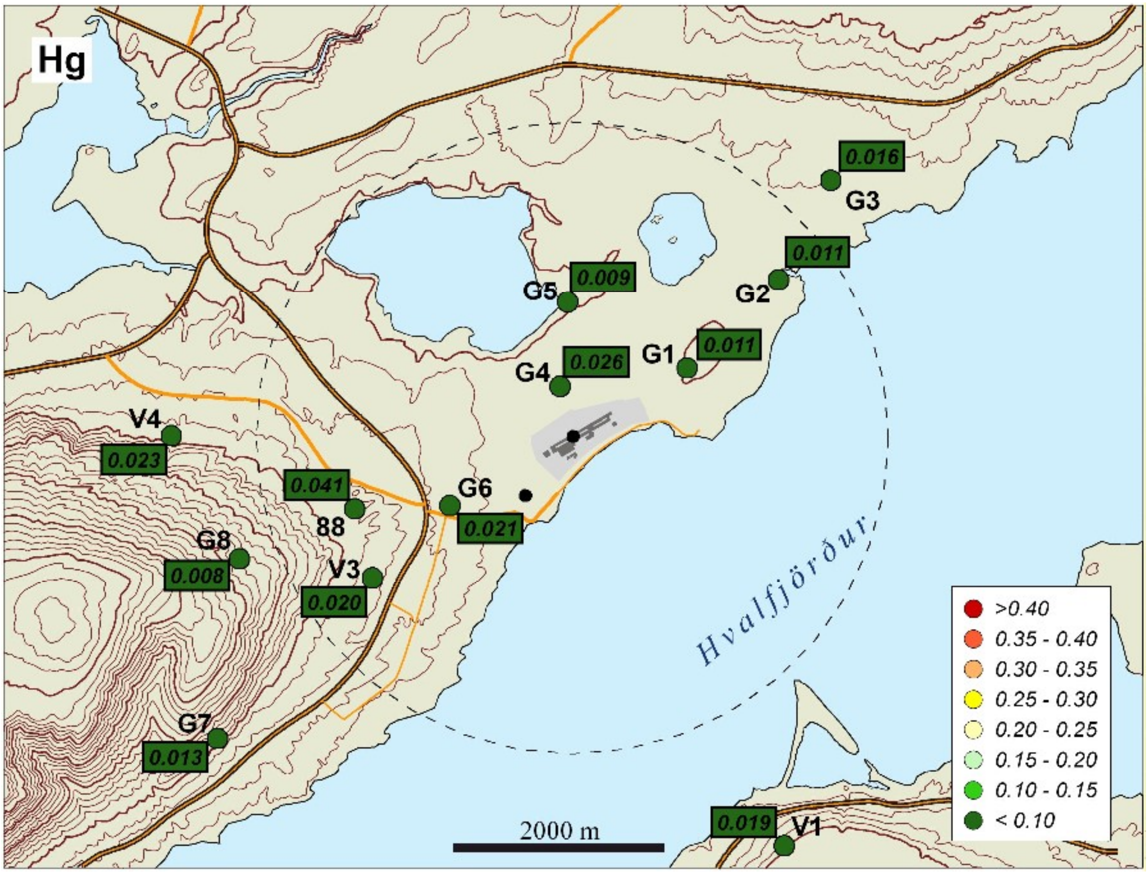


Figure 7. (A) Average mercury (Hg) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður. - Styrkur kvikasilfurs (Hg) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga í Hvalfirði (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur kvikasilfurs í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of mercury concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur kvikasilfurs í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.7 Nickel (Ni)

In the 2005 survey the nickel concentration ranged from 2.33 to 10.30 µg/g in the vicinity of Grundartangi (Figure 8). The maximum value was found in sample G4 north of the aluminium smelter. The distribution pattern showed a clear decrease with distance from the industrial site with an elongated distribution pattern mainly to the southwest.

In spite of relatively high concentration in some of the samples close to the industries at Grundartangi (<3 km) they were not significantly different from other distance classes, or the aluminium smelter site in Reyðarfjörður, but were significantly lower than samples from the Straumsvík smelter area (Figure 8). Compared to the Icelandic data concentration at Grundartangi is medium to high (Appendix 2).

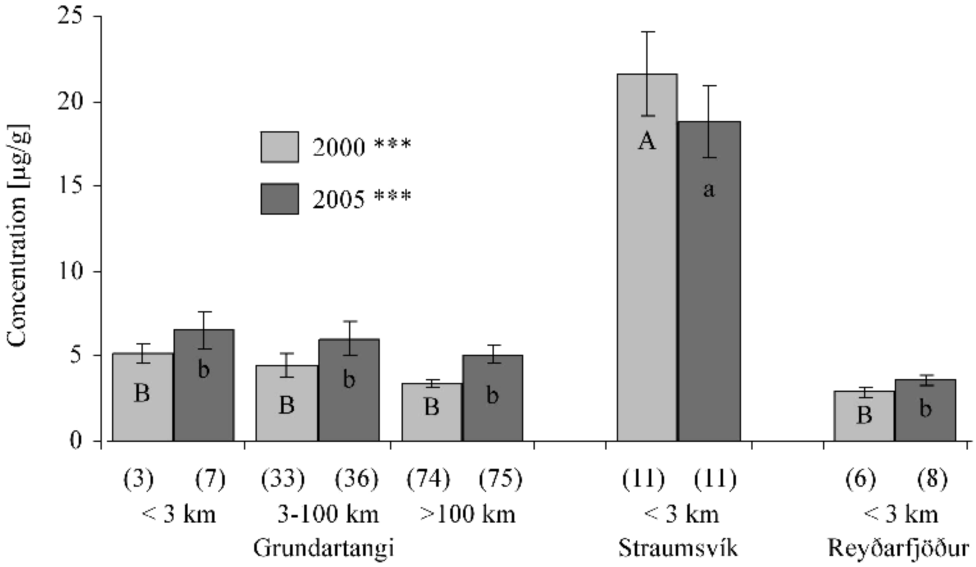
Comparison of paired values revealed a significant increase in nickel concentration between 2000 and 2005 for the two distance classes compared (3-100 km, >100 km) but a decrease at the Straumsvík site. The results were as follows for the 2000 and 2005 surveys respectively: distance 3–100 km, 4.66 and 6.13 µg/g ($P<0.05$, n=29), distance >100 km, 3.34 and 5.11 µg/g ($P<0.001$, n=70), Straumsvík, 21.64 and 18.78 µg/g ($P<0.05$, n=11), Reyðarfjörður, 2.67 and 3.57 µg/g ($P = 0.083$, n=4)

High nickel concentrations around the smelter at Grundartangi and the high value at G4 identify the smelter as the major source for nickel in the area. These results are similar to earlier findings from aluminium smelters in Norway and also to results from the Straumsvík smelter Iceland (Steinnes et al. 2001, Magnússon 2002a, Magnússon and Thomas 2007a). However, it is not possible to separate some additional effects by the ferro-silicon plant at Grundartangi. The higher concentrations towards the southwest seems to be due to the wind frequency (Figure 1).

The present and earlier moss surveys show that the nickel concentration in the Icelandic samples often exceeds the North-European background concentration of less than 2.0 µg/g (Rühling and Steinnes 1998, Buse et al. 2003). As these relatively high background levels in Iceland are associated with areas of high volcanism and soil erosion they are evidently related to soil dust (Rühling et al. 1992, Rühling and Steinnes 1998).

Nickel (Ni)

A.



B.

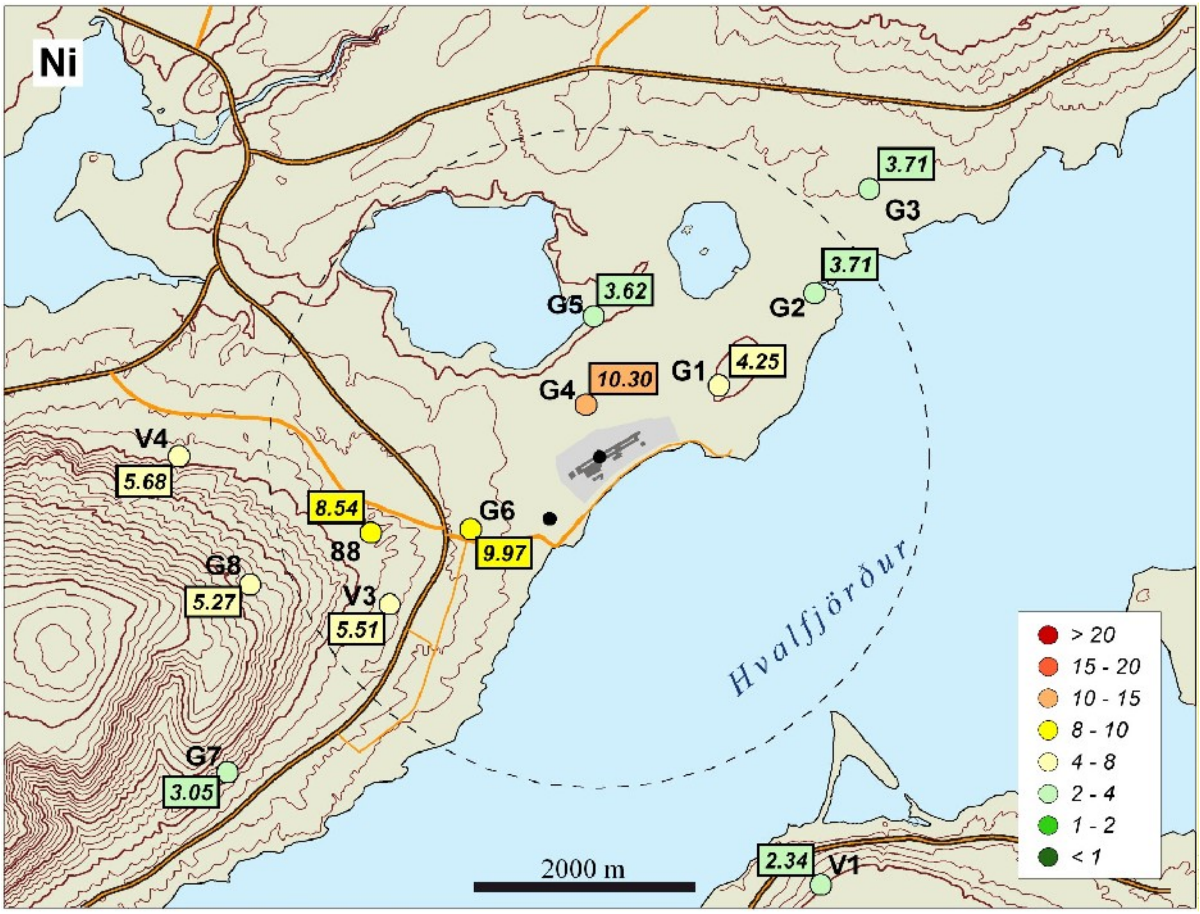


Figure 8. ***(A)*** *Average nickel (Ni) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður.* - Styrkur nikkels í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga í Hvalfirði (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur nikkels í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of nickel concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur nikkels í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.8 Lead (Pb)

Results of the 2005 survey show low lead concentrations in the Grundartangi area, range between 0.99 and 2.33 µg/g (Figure 9). The highest concentration values were found near the factories (G4, G6, and 88).

In 2005, the concentration of lead in samples close to the industries at Grundartangi (<3 km) was not significantly different from the other distance classes or Reyðarfjörður but was significantly lower than values in Straumsvík (Figure 9). Comparison of paired values showed that lead had decreased between years at all sites and areas compared, although not significant for Reyðarfjörður. The results were as follows for the years 2000 and 2005 respectively: distance class 3–100 km, 1.72 and 1.42 µg/g ($P<0.01$. $n=29$), distance class >100 km, 1.51 and 1.44 µg/g ($P<0.01$, $n=70$), Straumsvík, 11.74 and 8.39 µg/g ($P<0.001$, $n=11$), Reyðarfjörður, 4.46 and 3.15 µg/g ($P=0.85$, $n=4$).

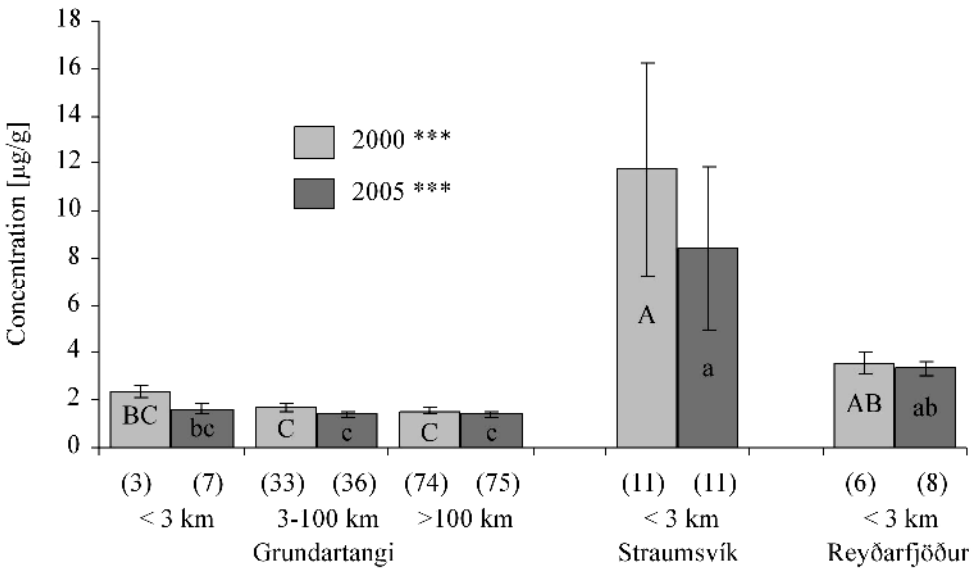
In comparison to all samples taken in Iceland, lead concentrations at Grundartangi were in the medium range (Appendix 2).

In Europe, lead is mainly emitted by industries and traffic. Earlier studies have shown that the south-eastern part of Iceland is affected through long-range transport (Rühling et al. 1992, Rühling and Steinnes 1998). The present results show that concentration of lead has decreased in Iceland which is a similar trend as observed in other countries in Europe (Working Group on Effects 2004). The values in Iceland are generally low and comparable to northern Scandinavia where the background concentration is generally lower than 5 µg/g (Rühling and Steinnes 1998, Buse et al. 2003).

The concentration and distribution pattern of lead within the Grundartangi area show only a low pollution effect from the industries (Figure 9). Earlier investigations on aluminium smelters in Norway and Straumsvík Iceland are in line with these results as lead concentrations in mosses were not or only slightly affected (Steinnes et al. 2001, Magnússon 2002a).

Lead (Pb)

A.



B.

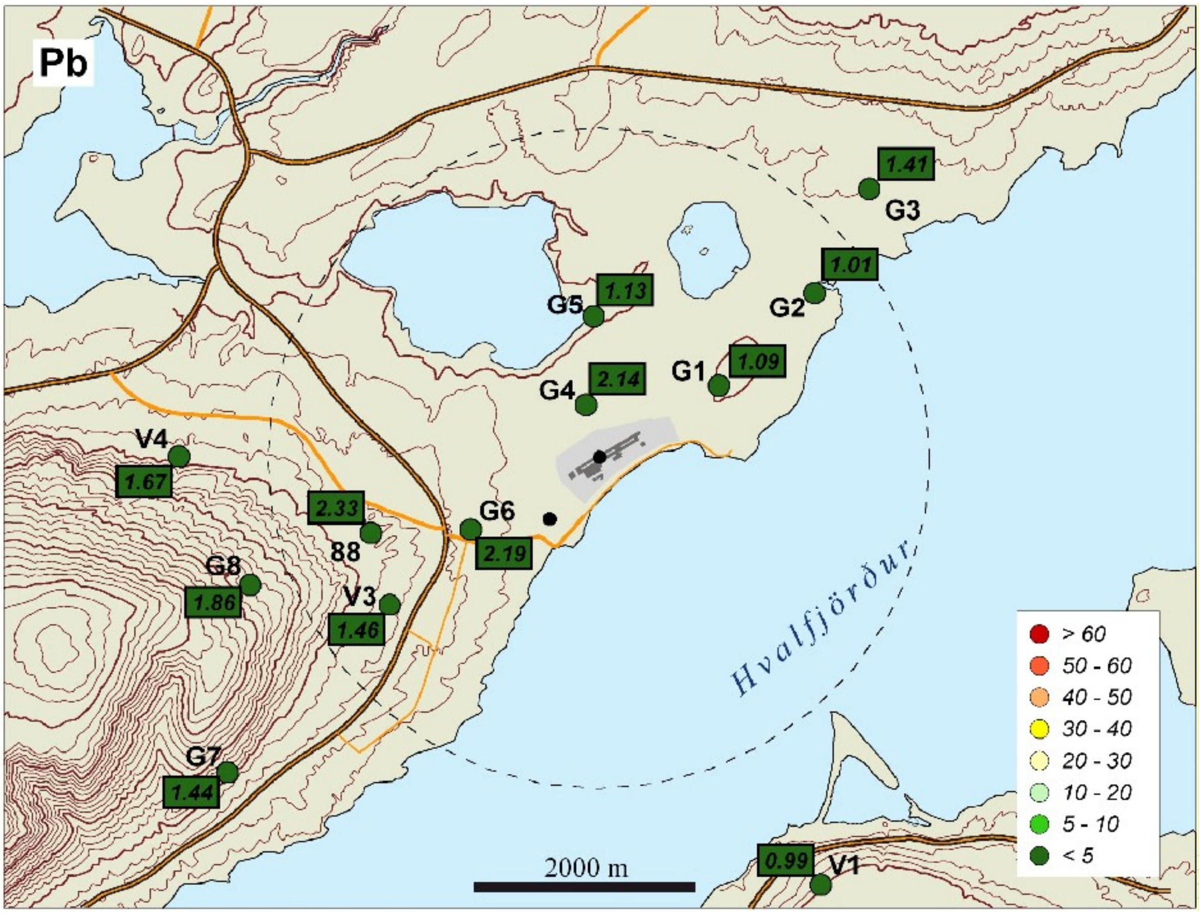


Figure 9. ***(A)*** *Average lead (Pb) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður.* - Styrkur blýs (Pb) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur blýs í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of lead concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur blýs í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.9 Vanadium (V)

In the 2005 survey the concentration of vanadium in the Grundartangi area ranged from 5.18 to 22.19 µg/g with the highest values close to the industries and showing high concentration toward southwest, especially sample G6 and 88 (Figure 10).

Comparison of distance classes and sites did not reveal statistically significant differences of the vanadium concentration in the 2005 survey (Figure 10). However, a significant increase was found with time in the vanadium concentration both for the 3–100 km distance class and for the areas further away (>100 km). In the distance class 3–100 km the average vanadium concentration for paired values was 10.88 and 14.62 µg/g for 2000 and 2005 respectively ($P<0.05$, $n=29$). Comparable values for the distance class >100 km were 13.05 and 21.10 µg/g ($P<0.001$, $n=70$).

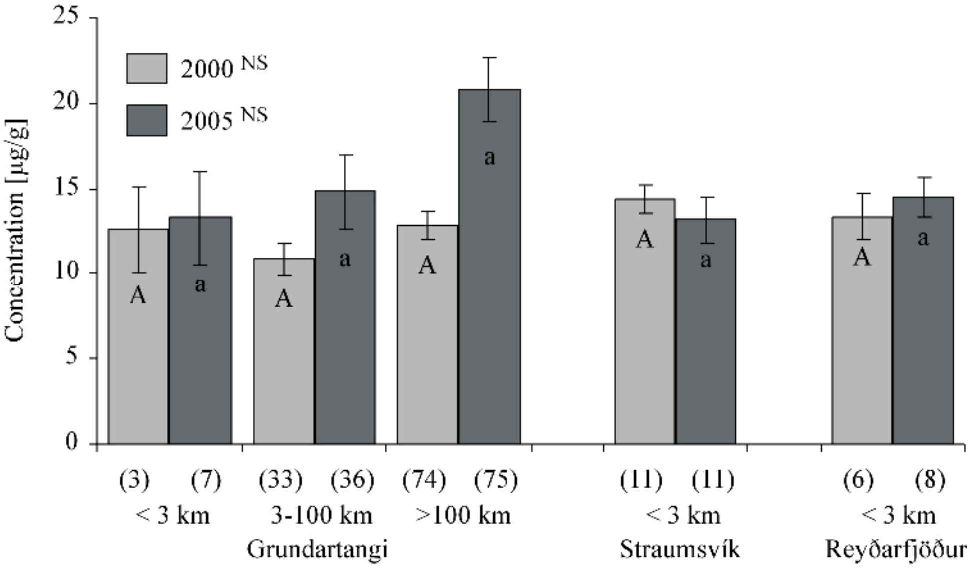
It should be noted that sample G6 and 88 had the highest concentration of vanadium of all samples from the three monitoring sites in Iceland, while most of the other samples from Grundartangi were medium to low in vanadium concentration compared to the other Icelandic samples (Appendix 2).

The volcanic activity and high soil dust in the air result in very high vanadium deposition in most parts of Iceland. Therefore, it is not possible to compare the present findings to moss results in Europe (Rühling and Steinnes 1998). However, earlier results from Norwegian aluminium smelters and from Straumsvík show higher vanadium concentrations than the background concentration in mosses (Steinnes et al. 2001, Magnússon 2002a).

The spatial distribution of vanadium in mosses clearly indicates an impact by the industries at Grundartangi. Low concentrations in the north east of the smelter suggest that the ferro-silicon plant is more likely to be the main source. Values close to the ferro-silicon plant exceed the natural concentration range in this area and are only found within the volcanic active zone in areas with high soil erosion (Arnalds 1990).

Vanadium (V)

A.



B.

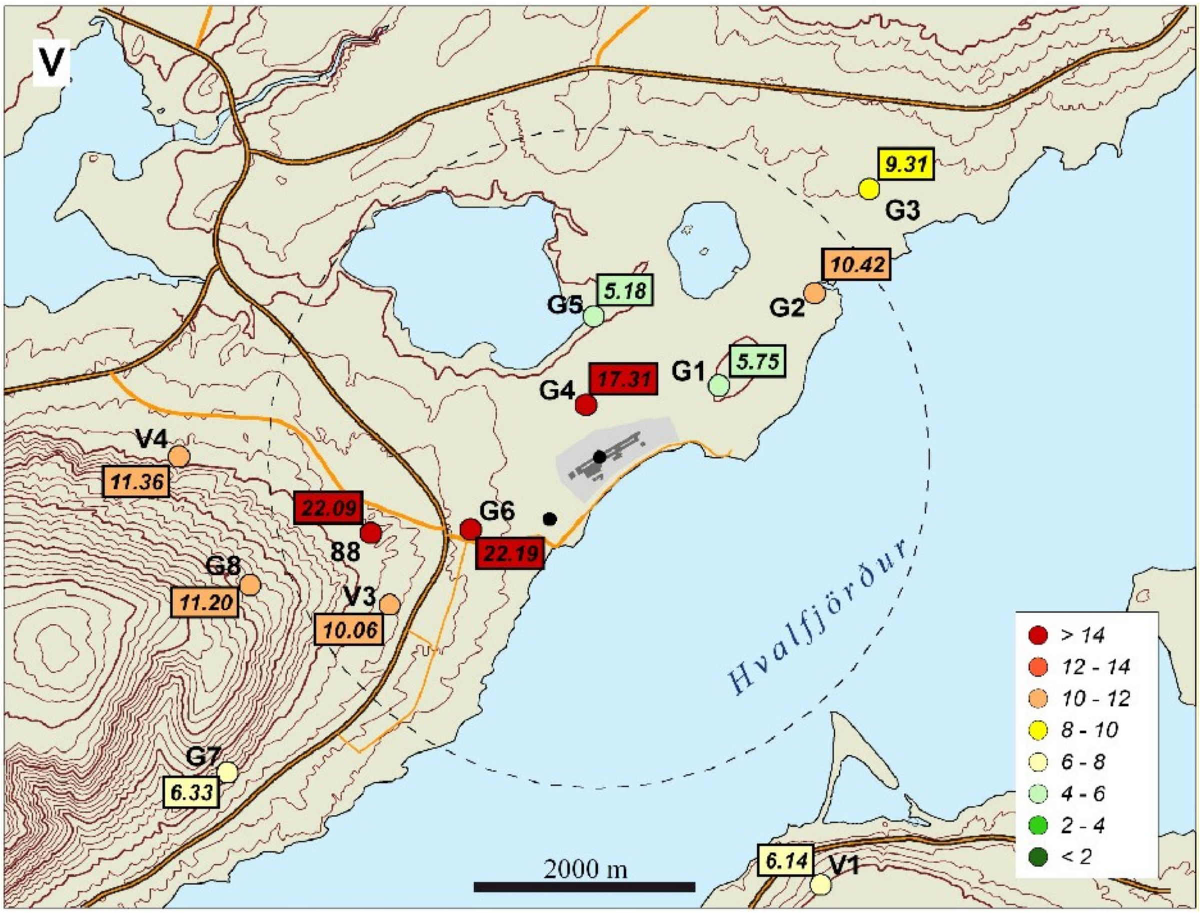


Figure 10. ***(A)*** *Average vanadium (V) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður.* - Styrkur vanadíums (V) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga í Hvalfirði (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur vanadíums í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of vanadium concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur vanadíums í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.10 Zinc (Zn)

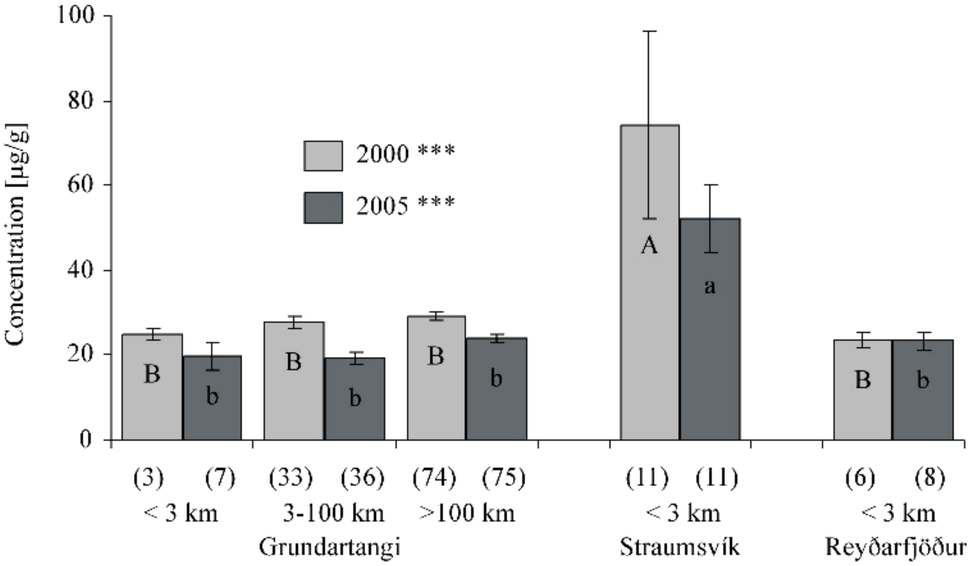
Zinc concentrations in mosses around the industrial sites at Grundartangi were generally low in 2005. Values ranged from 9.70 to 36.91 µg/g, with the highest concentration close to the industries (Figure 11). Compared to other Icelandic samples, those at Grundartangi spanned almost the whole spectrum of concentration, with G4 and G6 among the highest in the country (Appendix 2).

The results show that the zinc concentration in 2005 close to the industries at Grundartangi (<3 km) were similar to other areas and sites, but significantly lower than values around the Straumsvík smelter (Figure 11). Also, comparison of paired values showed a significant decrease in zinc concentration between 2000 and 2005 for the two distance classes compared (3–100 km, >100 km). In the distance class 3–100 km, the average zinc concentration was 27.38 and 19.75 µg/g for the 2000 and 2005 respectively ($P<0.001$, $n=29$). Comparable values for the distance class >100 km were 29.35 and 24.25 µg/g ($P<0.001$, $n=70$). Although not significant, a similar trend was found for Straumsvík and Reyðarfjörður.

The spatial distribution of zinc at Grundartangi suggests a small impact from the aluminium smelter. However, all samples have very low values compared to industrial areas in Europe (Rühling and Steinnes 1998, Buse et al. 2003). Similar studies around aluminium smelters in Norway also indicate very low effects on the zinc content of moss (Steinnes et al. 2001, Magnússon 2002a). The decrease of zinc in mosses since 2000 can be explained by decreasing long-range transport.

Zinc (Zn)

A.



B.

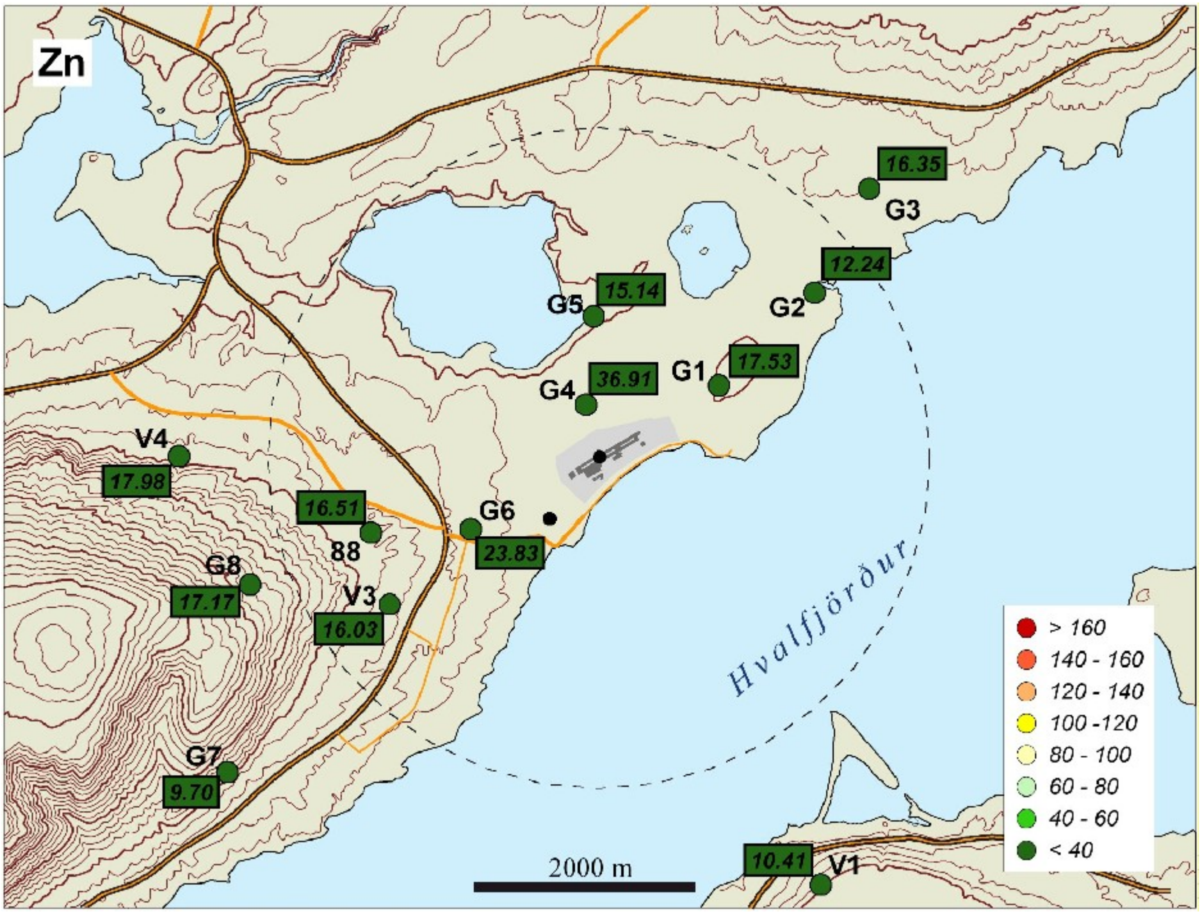


Figure 11. ***(A)*** *Average zinc (Zn) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður.* - Styrkur sinks (Zn) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga í Hvalfirði (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur sinks í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of zinc concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur sinks í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

4.11 Sulphur (S)

In 2005, the sulphur concentration in mosses in the vicinity of the industries at Grundartangi was rather high and decreased with distance from the industries forming an elongated effect towards southwest (Figure 12). Concentrations ranged from 561 µg/g to 745 µg/g with G8 as the highest concentration. This sample site is on the slopes of the mountain Akrafjall, about 3500 m away from the aluminium smelter.

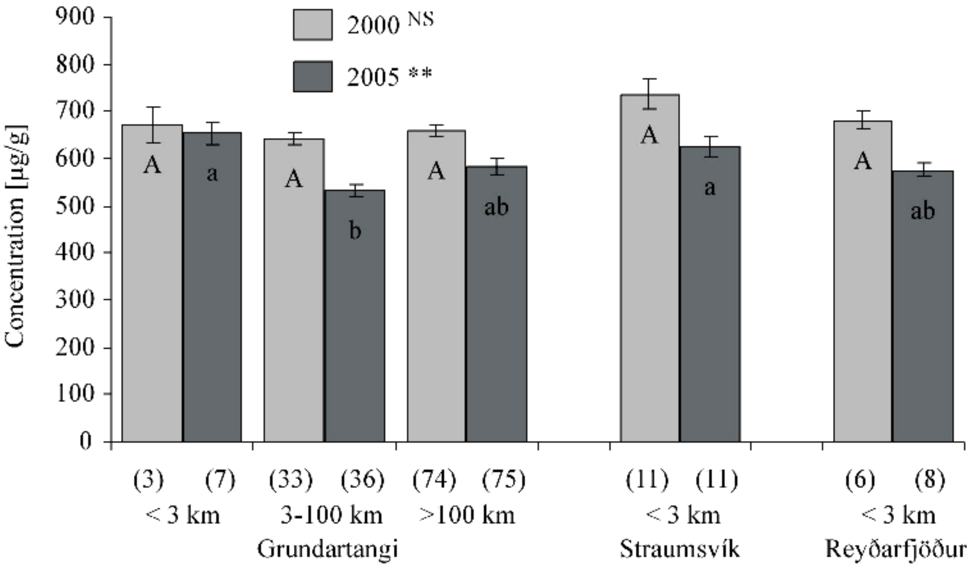
The values close to the industries at Grundartangi were significantly higher than samples taken 3–100 km away but did not differ significantly from the other sites or distance classes (Figure 12). The concentration of sulphur in the samples around Grundartangi is medium to high compared to the Icelandic data (Appendix 2).

Comparison of paired values showed that the sulphur concentration decreased significantly from 2000 to 2005 for all sites and distance classes compared. Within the 3–100 km distance class, the concentration decreased from 644.2 to 522.3 µg/g ($P<0.001$, $n=29$) and within the class >100 km from 654.5 to 586.5 µg/g ($P<0.001$, $n=70$). At Straumsvík, the values changed from 736.7 to 625.0 µg/g ($P<0.001$, $n=11$) and in Reyðarfjörður from 693.5 to 573.1 µg/g ($P<0.05$, $n=4$).

As sulphur has not been included in the UN-ECE International Cooperative Programme on vegetation, a comparison to European values is not possible (Rühling et al. 1992 and 1998, Buse et al. 2003). However, other studies have successfully used sulphur contents in mosses to identify pollution sources (Äyräs, Pavlov and Reimann 1997, Reimann et al. 2001). Results of these studies show that contour maps of sulphur concentrations are fuzzier than those of other elements. Sulphur, mostly in the form of sulphur dioxide, is known to be emitted by aluminium smelters and is also the main element emitted from the ferro-silicon plant (Starfsleyfi 1998, Hönnun 2002, 2004). Therefore, a superimposed effect of the two industries was expected.

Sulphur (S)

A.



B.

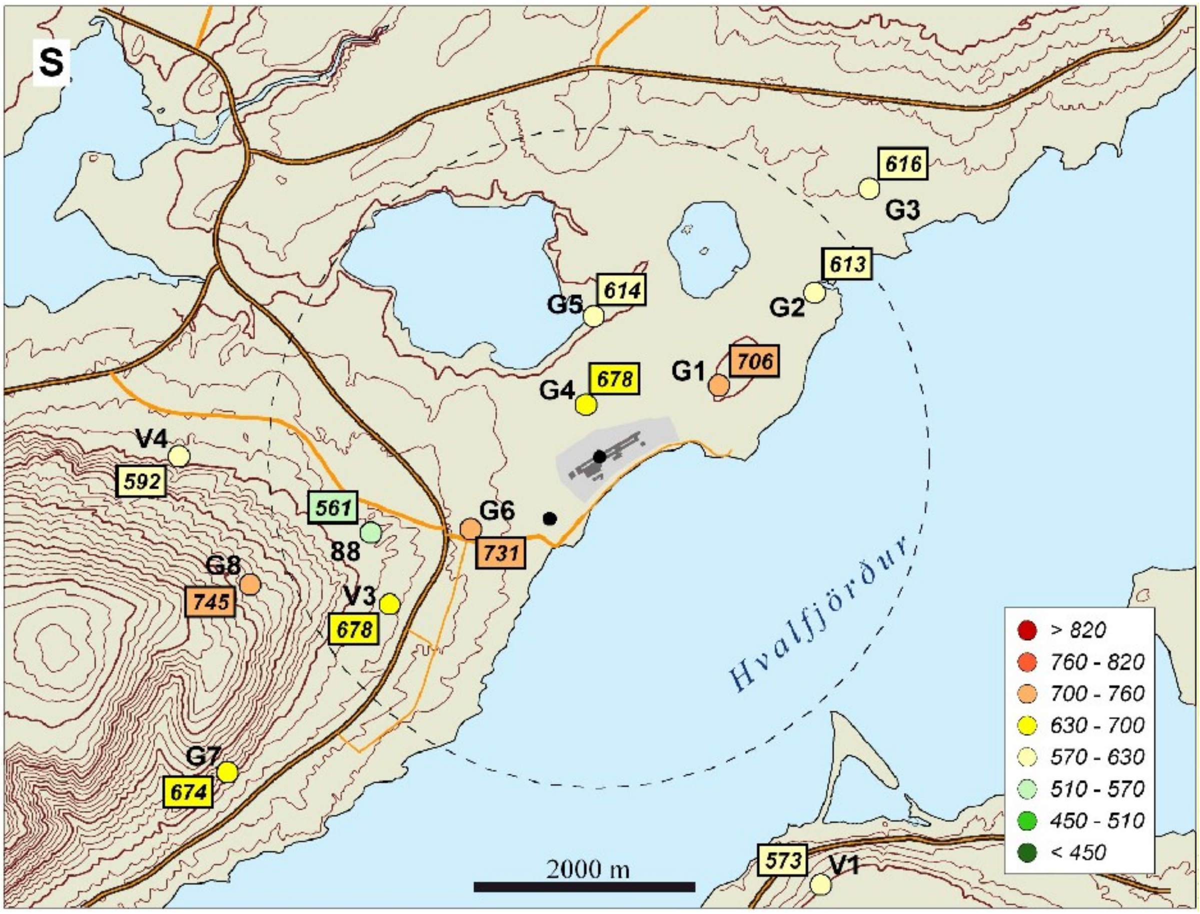


Figure 12. ***(A)*** *Average sulphur (S) concentration in moss at different distances (<3 km, 3–100 km, >100 km) from the industries at Grundartangi for the 2000 and 2005 survey and at the aluminium smelter in Straumsvík and in Reyðarfjörður.* - Styrkur brennisteins (S) í mosa í mismunandi fjarlægð frá iðjuverunum á Grundartanga (<3 km, 3–100 km, >100 km) árin 2000 og 2005. Til samanburðar er einnig sýndur styrkur brennisteins í nágrenni álveranna í Straumsvík og í Reyðarfirði.

(B) Spatial distribution of sulphur concentration in mosses at the sampling points close to the industries at Grundartangi in 2005. For details see also Figure 2. - Styrkur brennisteins í mosa á Grundartanga og nágrenni. Nánari skýringar á 2. mynd.

5 CONCLUSION

With the help of the moss data, previous studies on aluminium smelters in Norway (Steinnes et al. 2001, Magnússon 2002a) and other cited references, it was possible to obtain a picture of sources and distribution of heavy metal deposition around the Grundartangi industrial site. As expected the main pollution area was close to the factories, but with an elongated effect along the shoreline to southwest especially in the direction of Akrafjall.

All the measured substances, except cadmium, seem to be affected by the industries in the area. The effect on mercury (Hg), lead (Pb) and zinc (Zn) is very low and within the European background concentration (Buse et al. 2003). The emission pattern from the aluminium smelter is identified by higher concentrations to the north and northeast of and around the aluminium smelter. As in Norway (Steinnes et al. 2001, Magnússon 2002a), and at the other aluminium smelter in Straumsvík (Magnússon and Thomas 2007a), arsenic (As), nickel (Ni), and to some extent also zinc (Zn) concentrations, are affected by the aluminium smelter and show this distribution pattern. Both arsenic and nickel have increased between the two surveys in 2000 and 2005 which reflects the increase in aluminium production during this period. The emission pattern from the ferro-silicon plant, on the other hand, is identified by highest depositions to the west and southwest. Chrome (Cr), copper (Cu), iron (Fe) and vanadium (V) follow this pattern. The distribution pattern of sulphur (S) is not as distinct and indicates a source from both industries. Overall, the concentrations of heavy metals and sulphur in moss samples taken around the Grundartangi industrial site indicate moderate pollution effects from the industries which are locally confined for most elements.

In addition to the effects of the Grundartangi industries, the data presented allows for some analysis of distant sources for some of the heavy metals. The studies in Straumsvík and Reyðarfjörður (Magnússon and Thomas 2007a,b) show that mercury, lead, zinc and sulphur have decreased between 2000 and 2005 probably due to less long range transport (Rühling and Steinnes 1998, Poikolainen et al. 2004, Working Group on Effects 2004). Furthermore, in Iceland, high amounts of soil dust and volcanic ash affect concentrations of heavy metals. This is especially true within the volcanically active zone. Although, Grundartangi is rather far outside this zone, the high iron and vanadium concentration are probably due to these natural causes.

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APENDICES

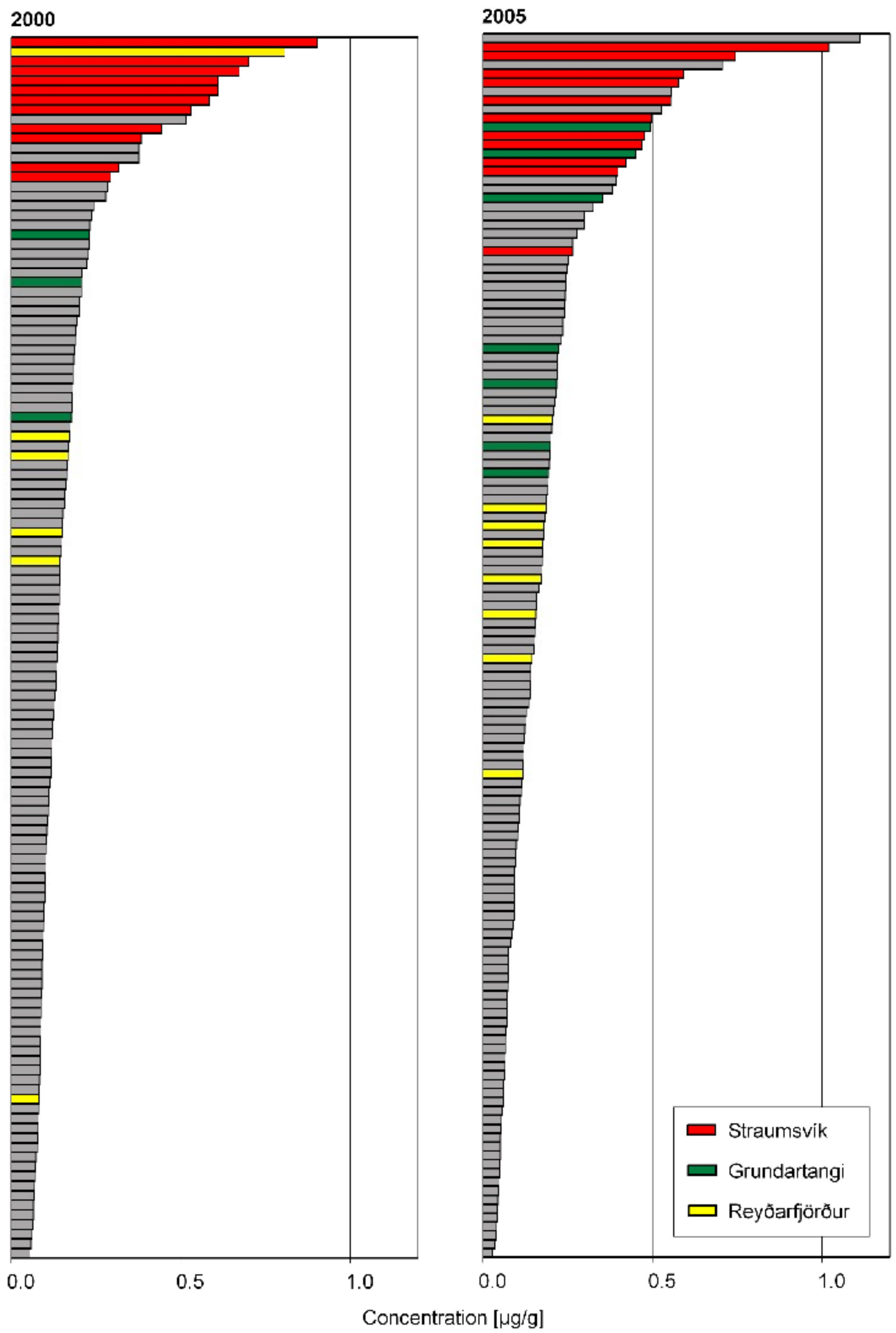
APPENDIX 1: Quantification Limits
Magngreiningarmörk

Substance *Efni*	Quantification Limit µg/g *Magngreiningarmörk*
As	0.00810
Cd	0.00075
Cr	0.00945
Cu	0.00075
Fe	0.03150
Hg	0.00315
Ni	0.03150
Pb	0.00060
S	5.10000
V	0.44550
Zn	0.05850

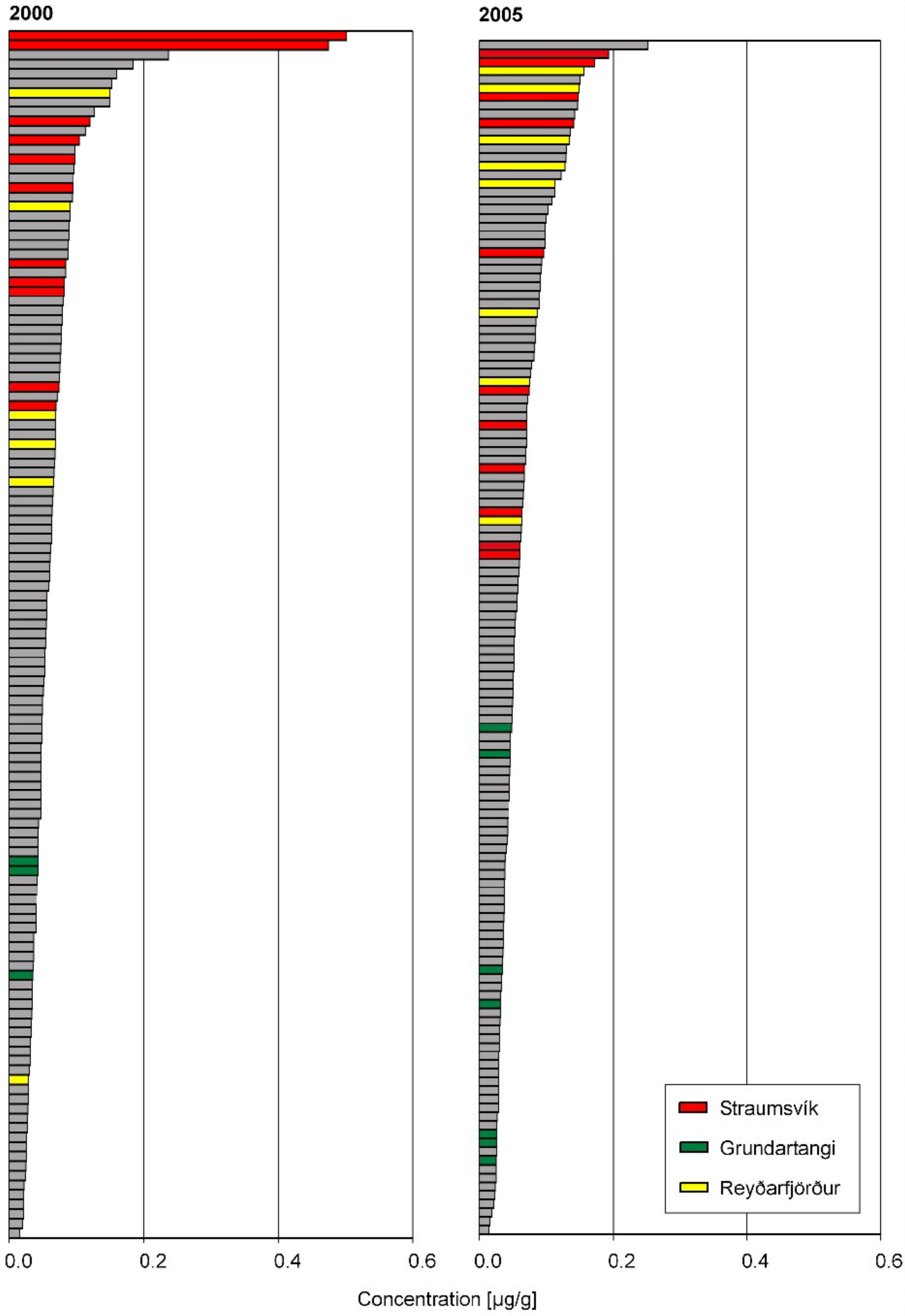
APPENDIX 2: Concentration in samples of the 2000 and 2005 Icelandic moss survey *Styrkur efna í mosasýnum frá 2000 og 2005.*

Concentration of heavy metals and sulphur in moss samples collected throughout Iceland in the 2000 and 2005 moss survey, shown in a descending order. The samples 3 km around the aluminium smelter in Straumsvík (red), ferro-silicon plant and aluminium smelter at Grundartangi (green) and smelter site in Reyðarfjörður (yellow) are marked. – *Styrkur þungmálma og brennisteins í mosa sem safnað var víðsvegar um land árin 2000 og 2005. Sýnum er raðað eftir magni viðkomandi efnis. Sýni sem safnað var í nágrenni (< 3 km) verksmiðjanna eru merkt með mismunandi litum: Straumsvík (rauð), verksmiðjur á Grundartanga (græn), álver í Reyðarfirði (gul).*

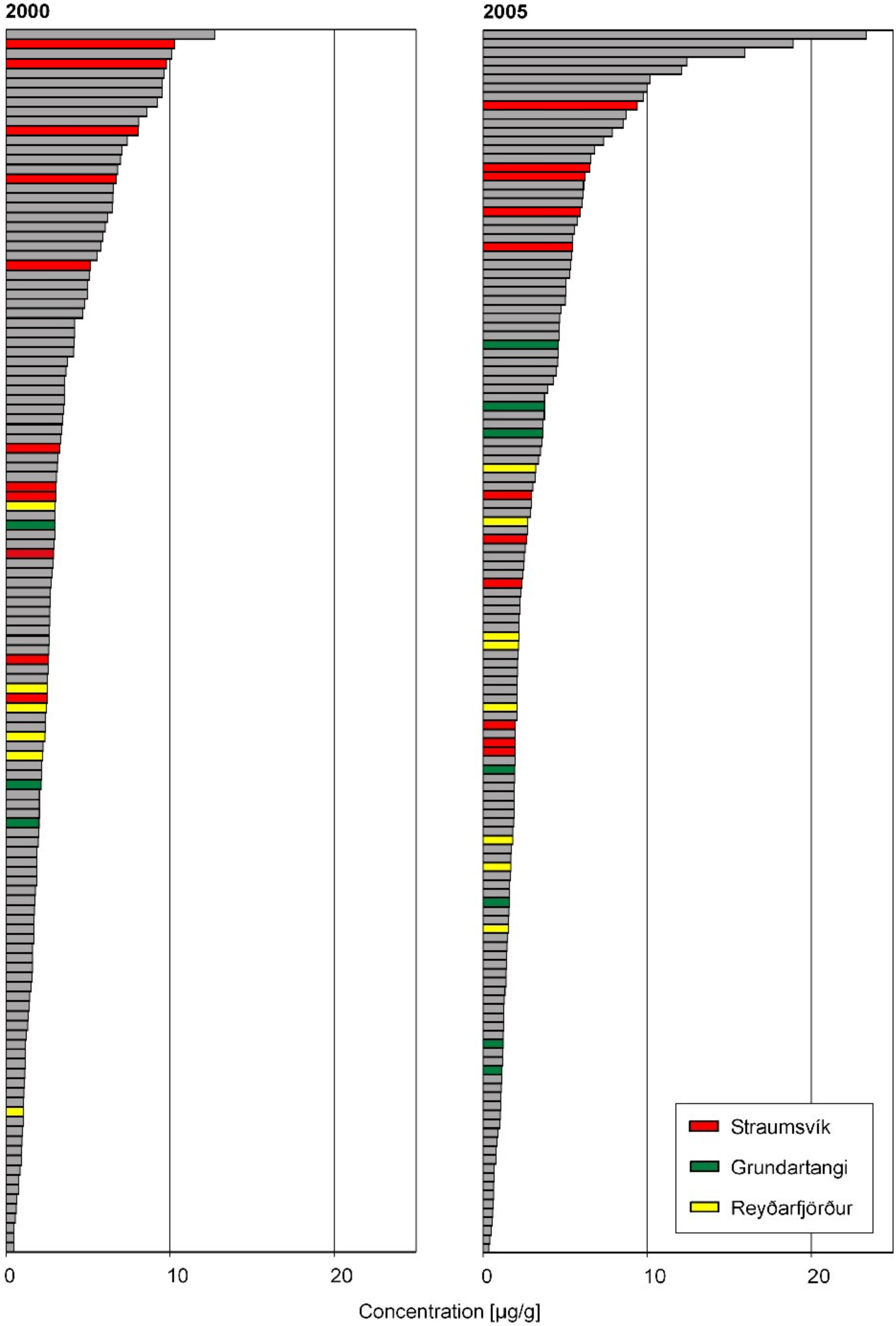
Arsenic (As)



Cadmium (Cd)

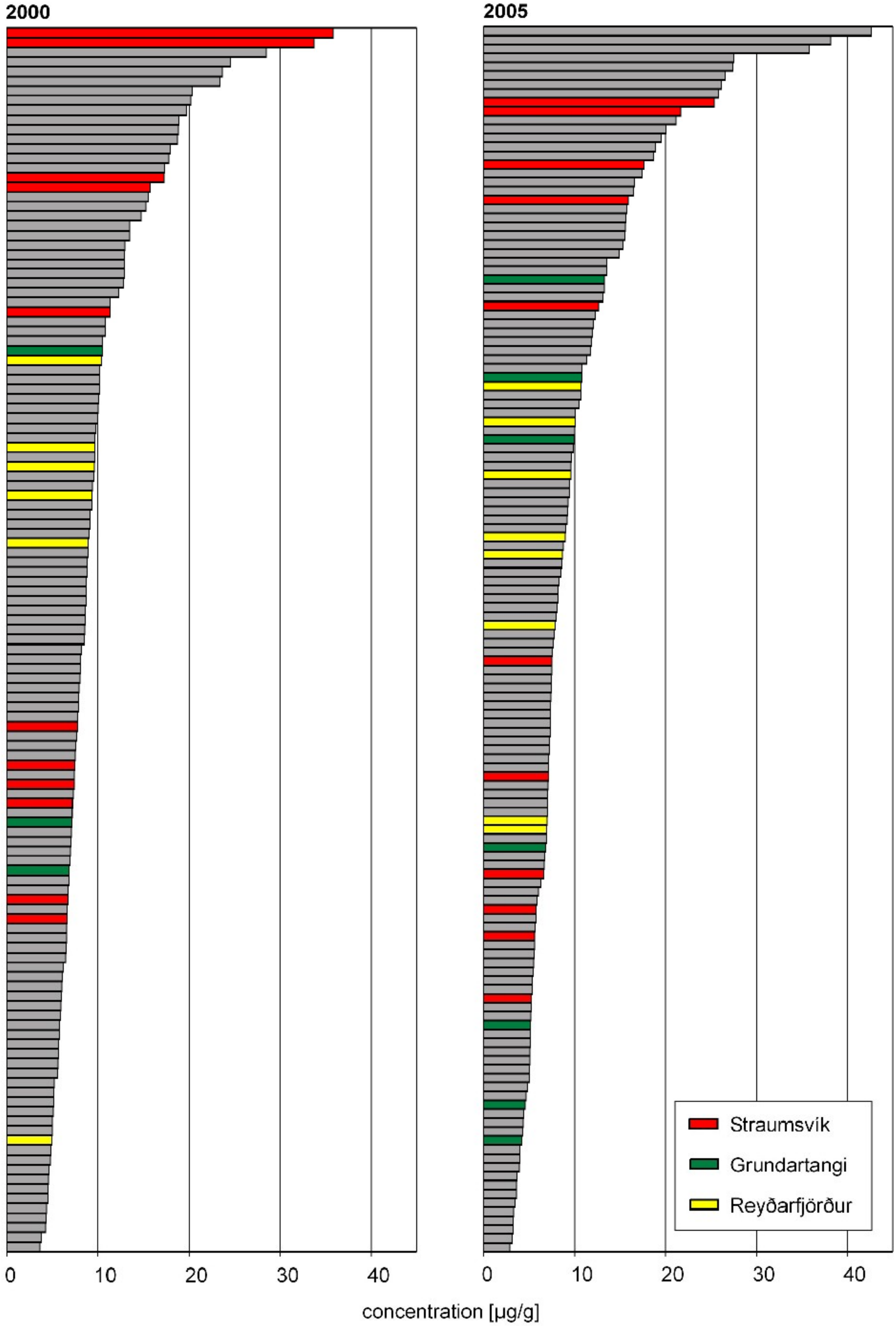

2000
2005
0.0
0.2
0.4
0.6
0.0
0.2
0.4
0.6
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

Chromium (Cr)

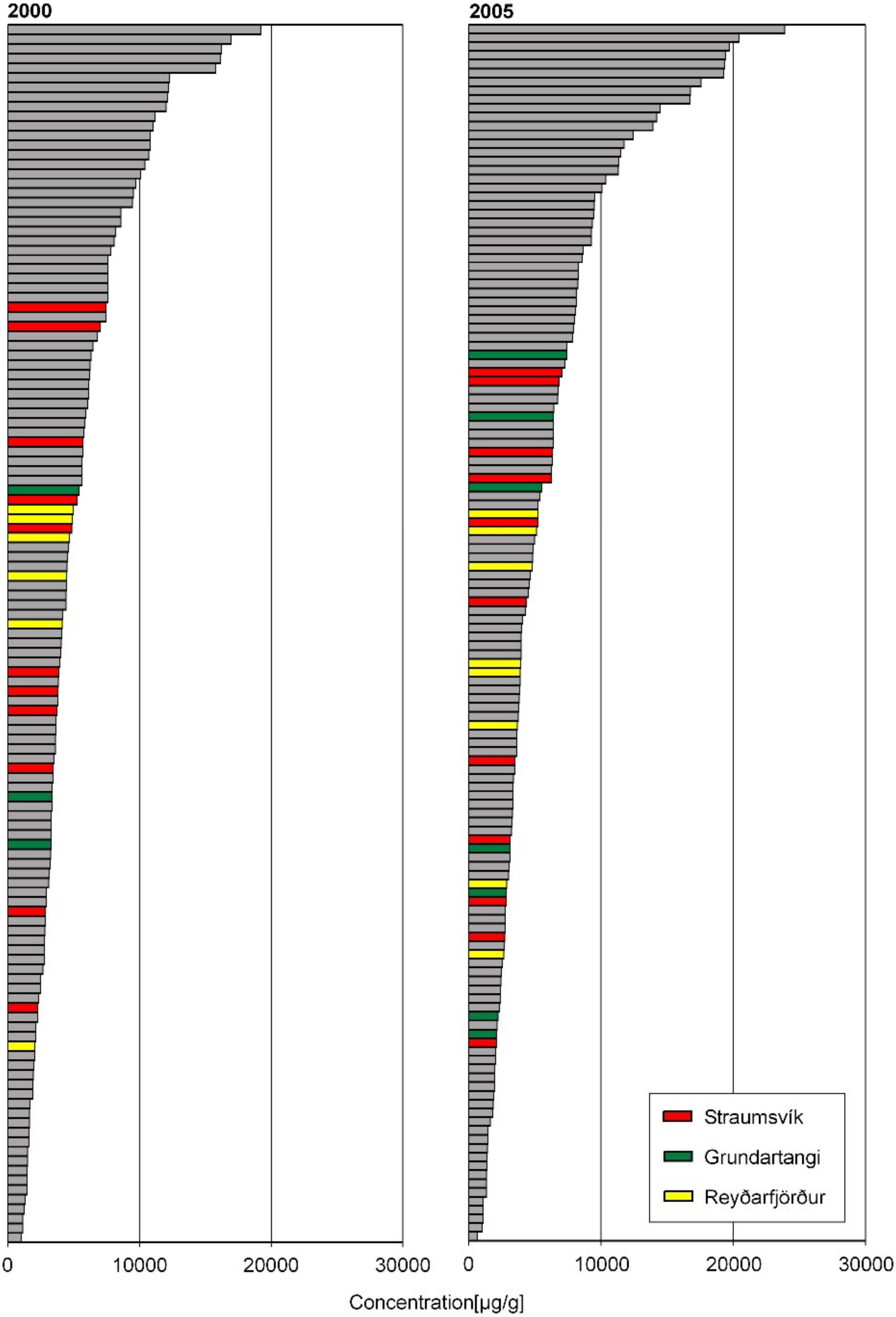


2000
2005
0
10
20
0
10
20
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

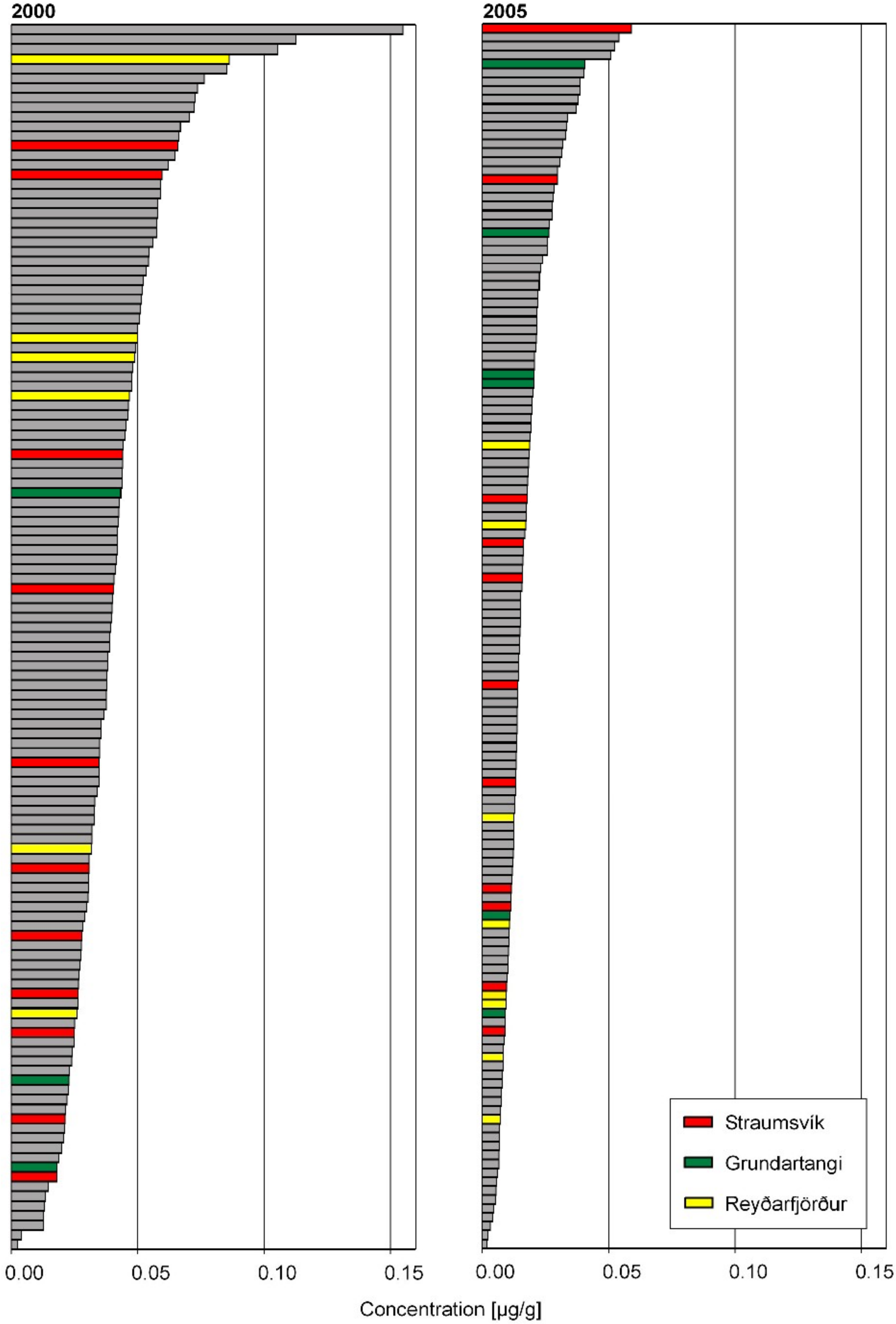
Copper (Cu)


2000
2005
0
10
20
30
40
0
10
20
30
40
concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

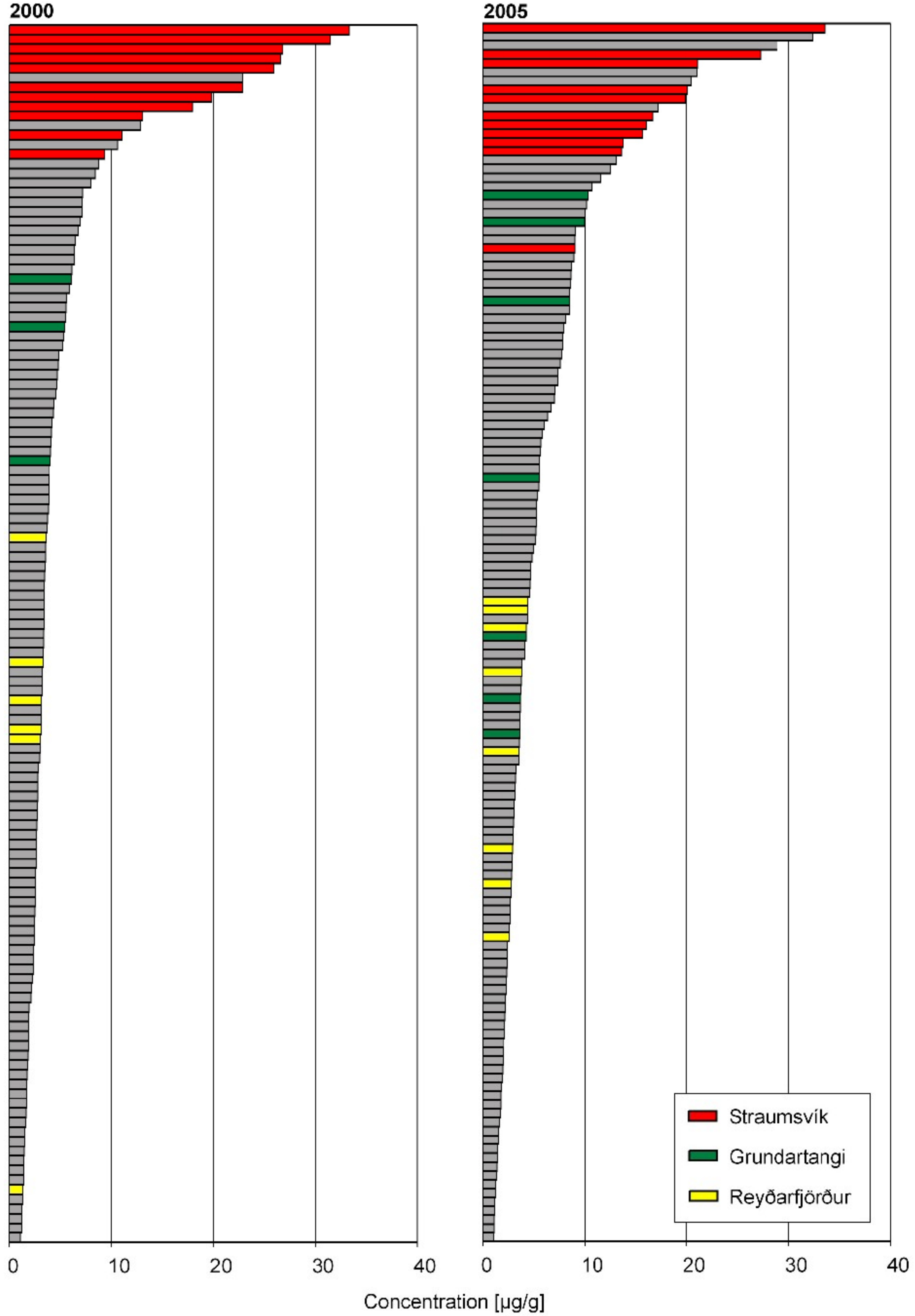
Iron (Fe)


2000
2005
0
10000
20000
30000
0
10000
20000
30000
Concentration[µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

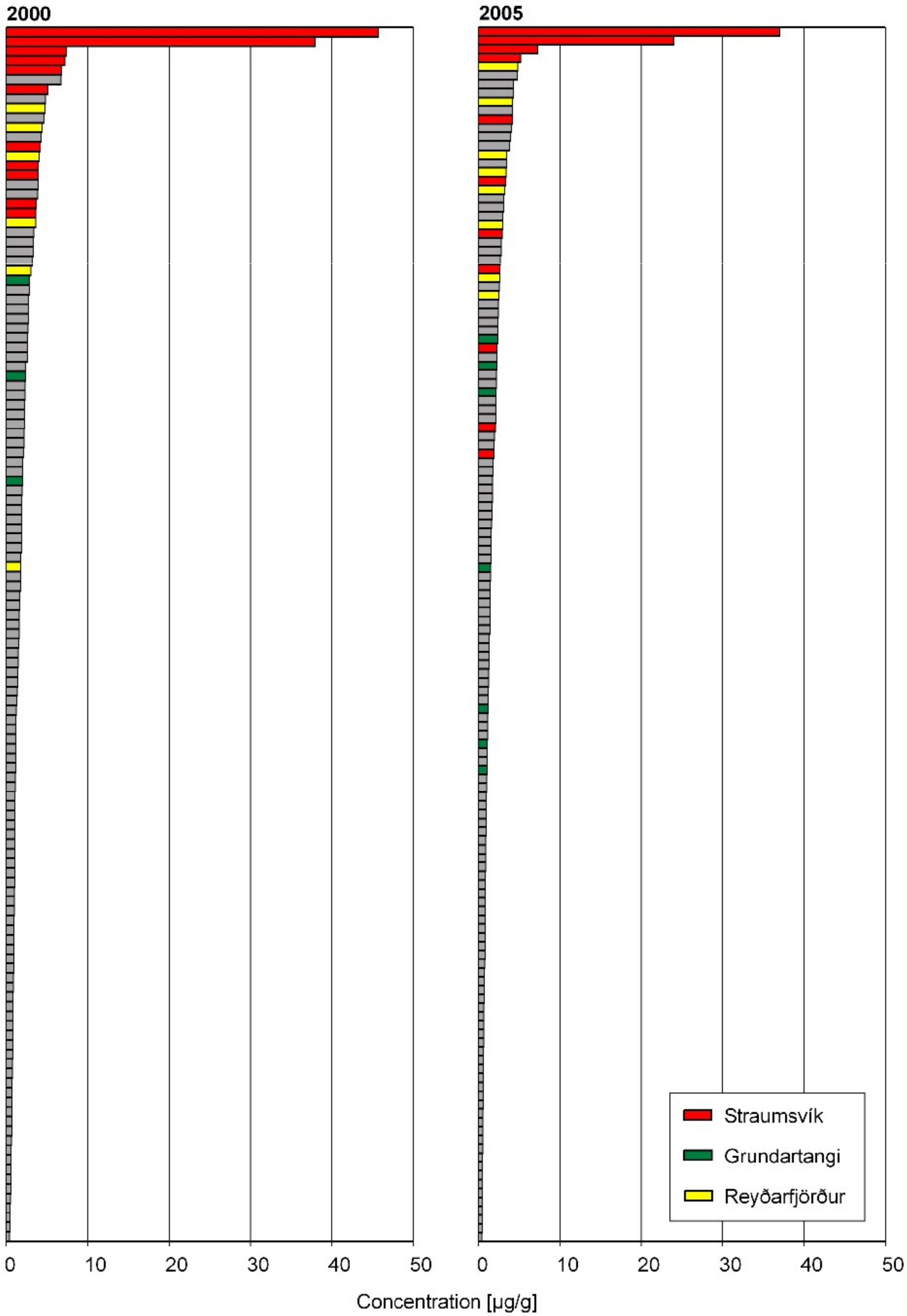
Mercury (Hg)


2000
2005
0.00
0.05
0.10
0.15
0.00
0.05
0.10
0.15
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

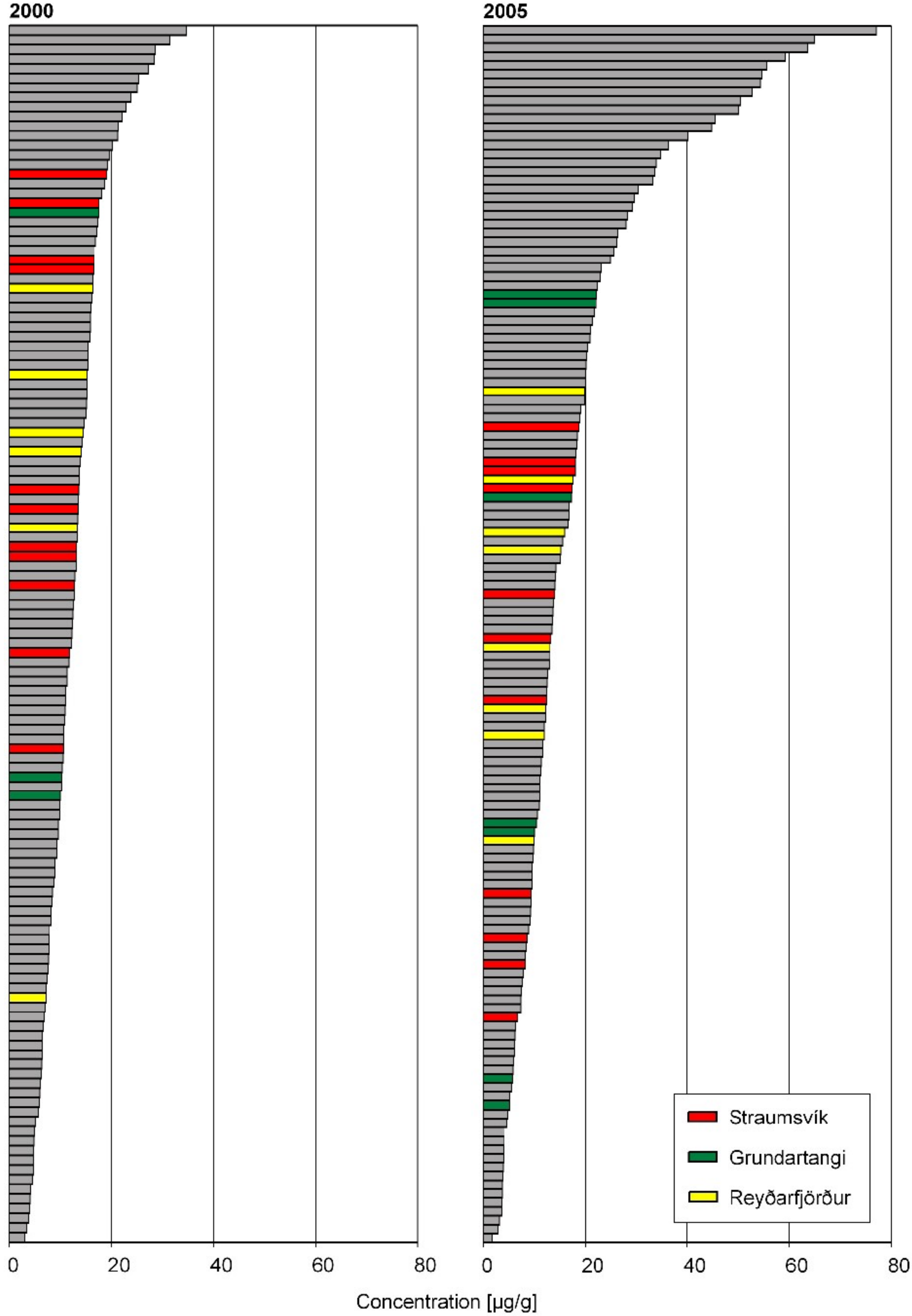
Nickel (Ni)


2000
2005
0
10
20
30
40
0
10
20
30
40
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

Lead (Pb)

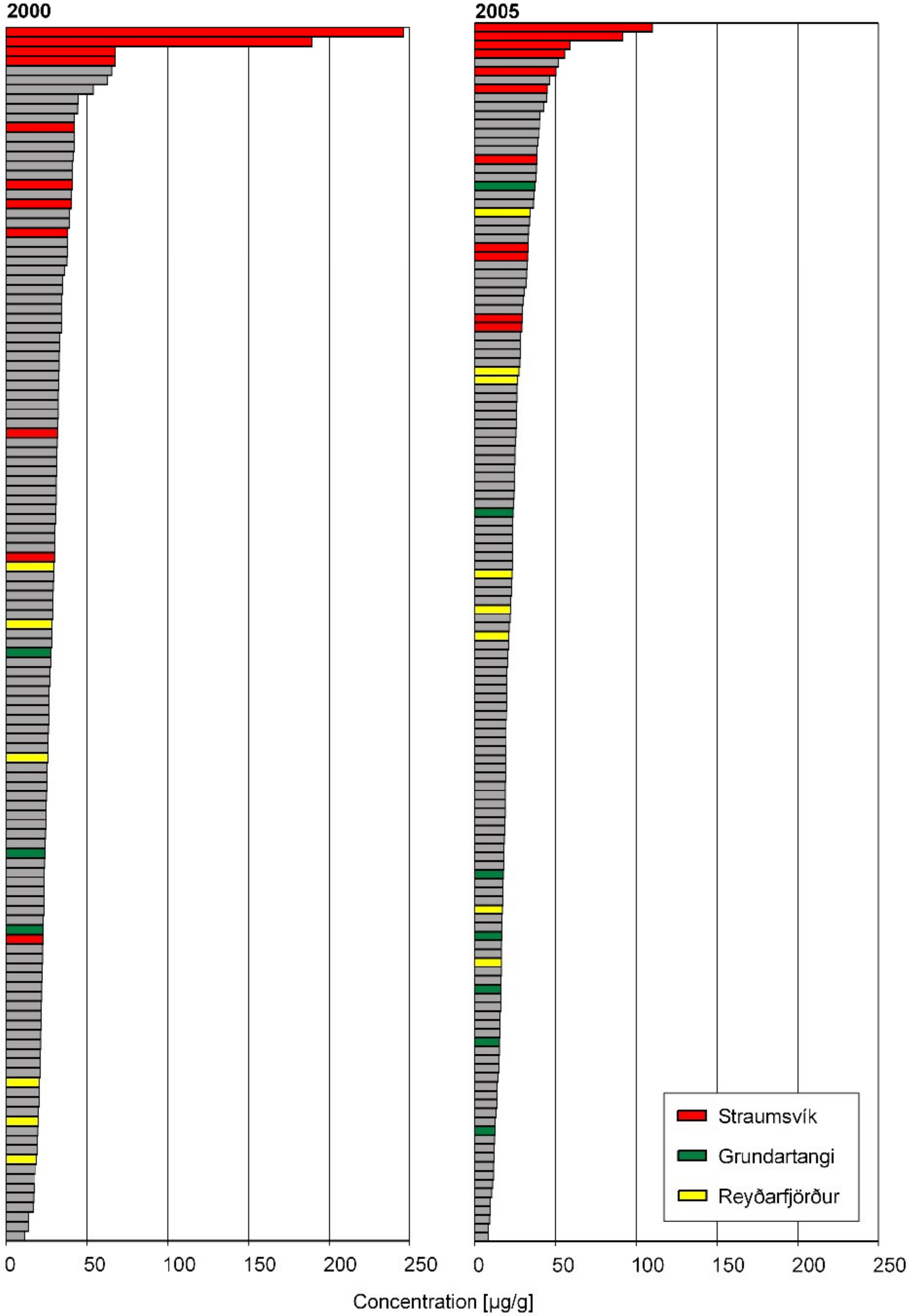

2000
2005
0
10
20
30
40
50
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

Vanadium (V)

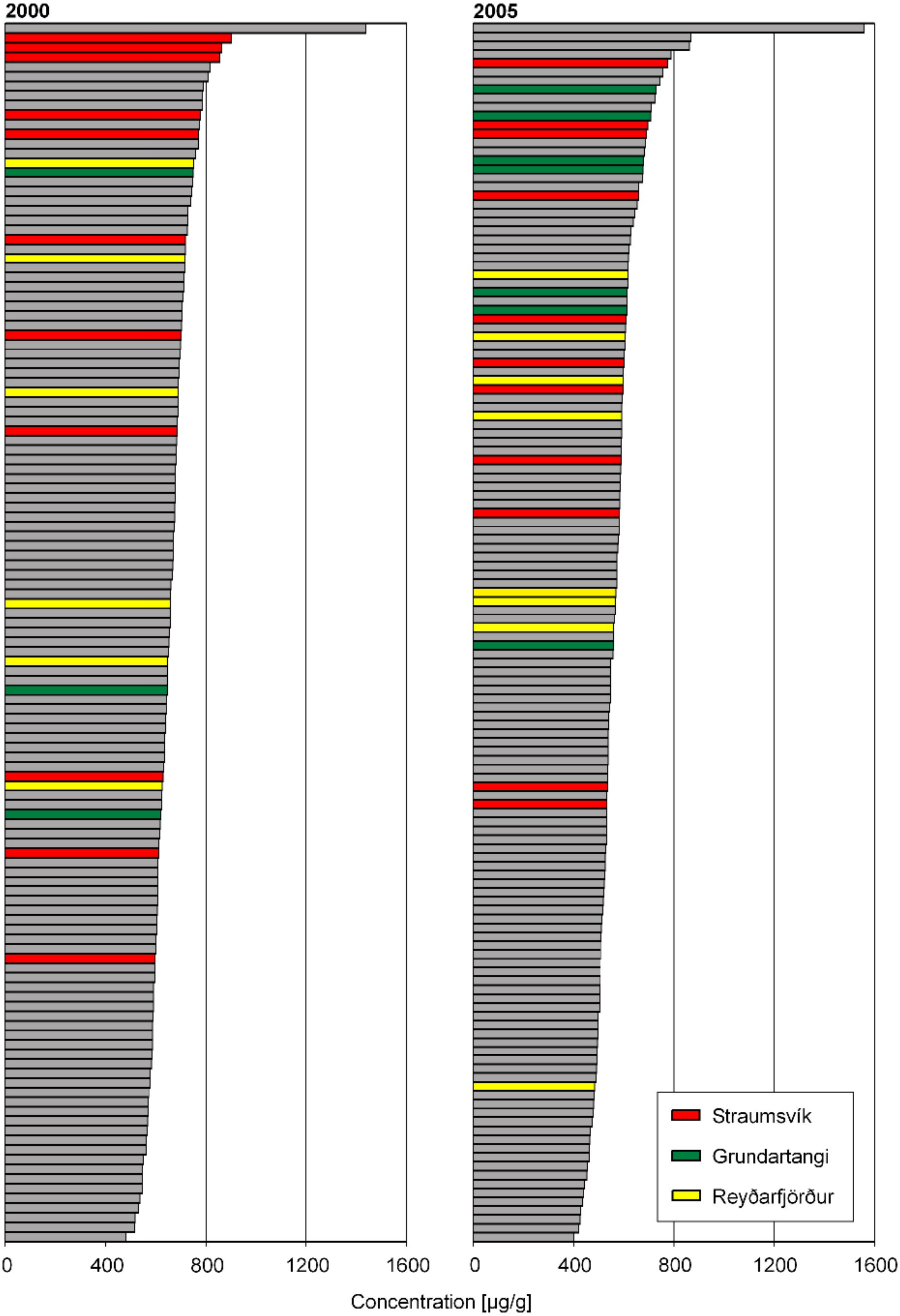


2000
2005
Straumsvík
Grundartangi
Reyðarfjörður
0
20
40
60
80
0
20
40
60
80
Concentration [µg/g]

Zinc (Zn)


2000
2005
0
50
100
150
200
250
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður

Sulfur (S)



2000
2005
0
400
800
1200
1600
Concentration [µg/g]
Straumsvík
Grundartangi
Reyðarfjörður