Geochemical mapping of agricultural soils and grazing land (GEMAS) in Norway, Finland and Sweden – regional report

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September 2013

SGU-rapport 2012:17

Sveriges geologiska undersökning
Geological Survey of Sweden

Cover photograph: Sheep in grazing land, Handöl, Jämtland.
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Sveriges geologiska undersökning
Box 670, 751 28 Uppsala
tel: 018-17 90 00
fax: 018-17 92 10
e-post: sgu@sgu.se
www.sgu.se

Layout: Rebecca Litzell, Jeanette Bergman Weihed, SGU

CONTENTS

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Anna Ladenberger[1], Madelen Andersson[1], Clemens Reimann[2], Timo Tarvainen[3], Peter Filzmoser[4], Jo Uhlbäck[1], George Morris[1] & Martiya Sadeghi[1]

[1] Geological Survey of Sweden, Box 670, SE-751 28 Uppsala, Sweden,
[2] Geological Survey of Norway,
[3] Geological Survey of Finland, [4] Vienna University of Technology

INTRODUCTION

Several European agencies and legal institutions handling chemicals and soil protection have demanded additional knowledge about "soil quality" at the European scale (Van Camp et al. 2004, EC 2006a, 2006b, 2009). It has been decided that industry dealing with natural resources should prove that it can produce and use its substances safely. Because most of their "products" also occur naturally, the natural background levels need to be established. In addition, a methodology which allows the differentiation of the industrial impact from the natural geogenic background needs to be defined. Moreover, long term residence times of metals and chemical compounds added to the soil have to be established (Reimann et al. 2011).

Geological surveys have been documenting the natural geochemical background of chemical elements in a variety of sample materials for more than 50 years. The existing datasets, however, vary between one another making it impossible to construct harmonised pan-European geochemical reference maps. Harmonised geochemical data on agricultural soil only exists for ten countries in north-eastern Europe (Reimann et al. 2003), while data on grazing land soil are completely absent. Food production and quality depend largely on the physical and chemical properties of agricultural and grazing soils.

In 1996, permitted concentrations of elements were defined for agricultural soils and sewage sludge used as fertiliser (EEC 1996). The main focus was on the toxic concentrations, without realising that "too low", i.e. deficient element concentrations also have a severe influence on plant and animal productivity as well as human health. Documentation of element concentrations and their variation in arable soil at the pan-European scale is, therefore, urgently needed (Reimann et al. 2011).

ABOUT THE PROJECT

The GEMAS project has been carried out by the Geochemistry Working Group of EuroGeoSurveys (EGS) in cooperation with Eurometaux and managed for EGS by the Geological Survey of Norway (NGU). Each member of geological surveys in EGS agreed to collect the samples needed for the GEMAS project in its own country, according to a jointly agreed field procedure (EGS 2008). In a couple of countries, non-EGS organisations joined the project to facilitate mapping of all EU territory, including the new member states and aspiring countries. Eurometaux agreed to fund part of the analytical work in exchange for access to the data as soon as this became available (Reimann et al. 2011).

The GEMAS project provides good quality and comparable concentration data of metals and soil properties in agricultural and grazing land soil. In Scandinavia, this is the first such attempt to constrain a common soil sample archive which can be used by different authorities and research groups in the Nordic countries. This report examines data from Norway, Sweden and Finland in detail.

TOPOGRAPHY AND CLIMATE

Norway, Sweden and Finland show differences in elevation, precipitation, climate, terrain etc. Low lands occur in Finland and Sweden around the Gulf of Bothnia and the Baltic Sea, in the Oslo Rift valley and locally along the Norwegian coast. The north-eastern part of Finland and the central part of Sweden are characterised by mid to high altitudes of c. 200–800 m a.s.l. The Caledonides in Sweden and Norway and the south part of Norway have the highest altitudes of 1 000–2 000 m a.s.l. Norway is characterised by the extreme differences in altitude between fjords and high mountains. Typical features of the Finnish landscape are numerous lakes and islands in a rather flat topography. In Sweden, the landscape is more variable, with high mountains in the west and lowlands in the south and east. Due to the high latitude, alpine topography and vegetation start at much lower elevations (at c. 800 m a.s.l. in the south and at c. 300 m a.s.l. in the north) than in continental Europe.

While Norwegian topography is mostly a result of intensive glacial erosion, in Sweden and Finland the influence of glacial deposition and postglacial history is the most important factor responsible for vast till deposits and landscape forms such as eskers and drumlins. The postglacial rebound is most prominent in the Gulf of Bothnia with an uplift of c. 1 cm per year continuing to this day.

The climate differs over the area, from subarctic conditions in the northern part of Norway, cold climate in most of Sweden and parts of central Norway and Finland to a mild and humid climate in the south of Norway and Sweden. Large areas at higher altitudes have an alpine tundra climate. The climate of western Scandinavia is strongly influenced by the warm Gulf Stream, while the eastern part is dominated by a continental climate.

The high altitude in the Caledonides is a natural barrier for precipitation. Norway has higher annual precipitation than Sweden, and Finland has the lowest. Altitude and the varying climate affect weathering conditions and the development of soil regions.

GEOLOGY

Bedrock

The bedrock of Norway, Sweden and Finland can be divided into major lithotectonic units, many of which contain rocks with a distinct tectonothermal history and geochemical character. Most of the bedrock belongs to the Fennoscandian Shield. The shield consists of the Svecokarelian orogen, partly affecting Archaean rocks in the north, post-Svecokarelian magmatic and sedimentary provinces unaffected by orogenic activity, the Blekinge-Bornholm orogen in south-easternmost Sweden and the Sveconorwegian orogen in south-western Sweden and southern Norway. The remaining units include the Caledonian orogen (Norway, north-western Sweden and northernmost Finland), and sedimentary cover rocks, dolerite and basalt resting on the Fennoscandian Shield (found predominantly in Sweden, Fig. 1).

The oldest Archaean rocks (c. 3.2–2.6 Ga tonalite-trondhjemite-granodiorite gneiss, granitoid, diorite, paragneiss and metavolcanic rocks) occur in eastern and north-eastern Finland and in northern Sweden and Norway. Most of these rocks resulted from a metamorphic event at c. 2.7 Ga ago and were partly deformed and metamorphosed during the Svecokarelian orogeny. The majority of the bedrock consists of rocks that formed along an active continental margin during the Svecokarelian orogeny (1.9–1.8 Ga ago). This orogenic system also affected older, 2.4–2.0 Ga sedimentary and igneous rocks. Characteristic features of the Svecokarelian orogen are the presence of large felsic batholiths, felsic volcanic rocks and siliciclastic sedimentary rocks which were variably metamorphosed under low pressure conditions and with a metamorphic grade reaching amphibolite to granulite facies, partly with migmatisation. Late Palaeoproterozoic magmatic rocks

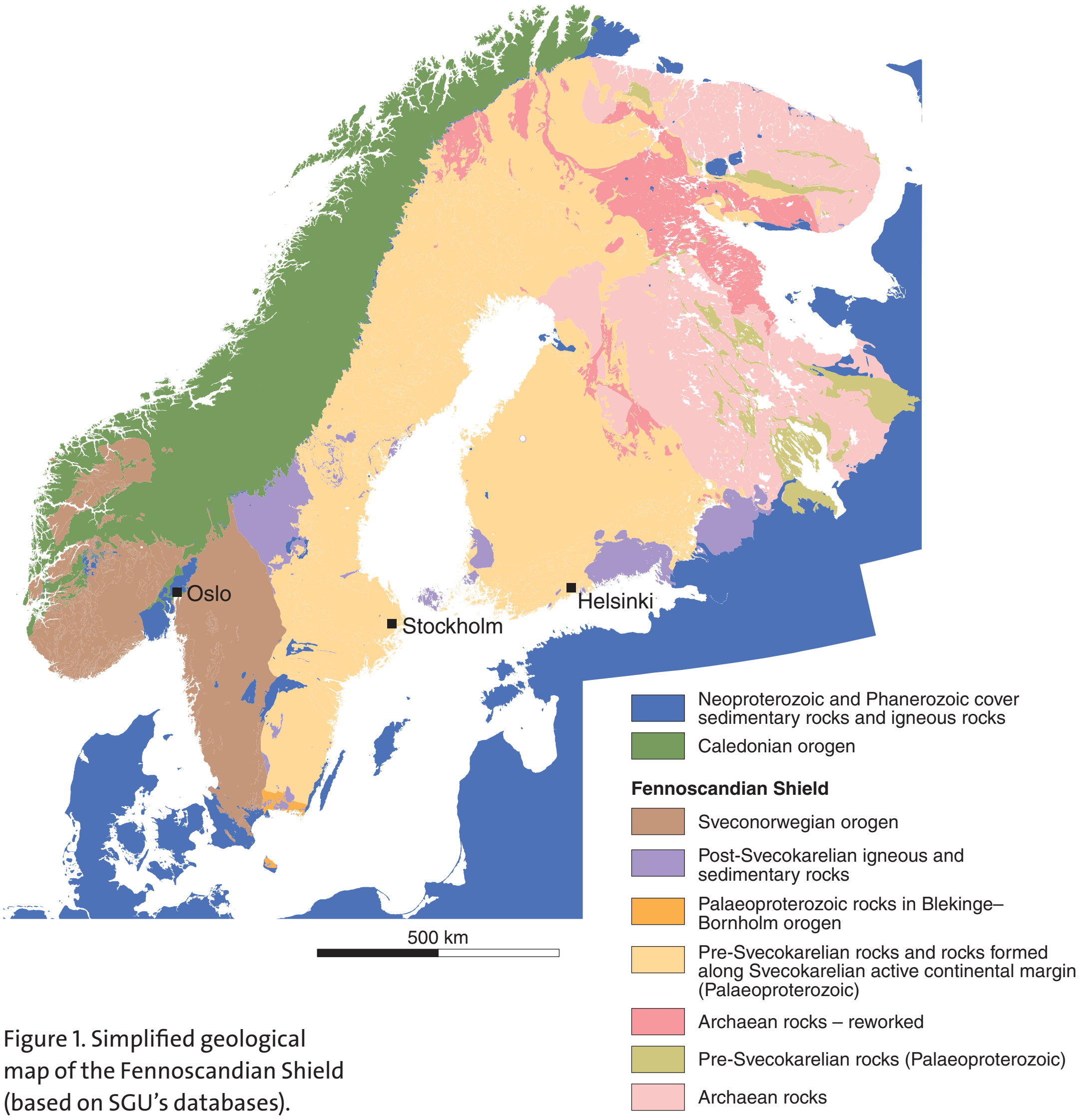


Figure 1. Simplified geological map of the Fennoscandian Shield (based on SGU's databases).

which formed during (c. 1.87–1.84 and 1.8 Ga) and after (c. 1.7 Ga) the Svecokarelian orogeny consist of gabbro, monzodiorite, syenitoid and granite and associated volcanic rocks. The post-Svecokarelian evolution continued with the intrusion of Mesoproterozoic gabbro and rapakivi granite (at c. 1.6–1.5 Ga), deposition of sandstone with basalt intercalations (at c. 1.5–1.4 Ga) and the intrusion of dolerite dykes and sills (at c. 1.3 Ga).

The Blekinge–Bornholm orogen in south-easternmost Sweden consists of sedimentary, volcanic and intrusive rocks which are 1.8–1.7 Ga. They were affected by ductile deformation, medium- to high-grade metamorphism and igneous activity during the Danopolonian orogeny at 1.5–1.4 Ga.

The Sveconorwegian orogen dominates in the south-western part of the Fennoscandian Shield and can be divided into several north–south trending segments separated by ductile deformation zones. The orogen consists predominantly of intrusive, sedimentary and volcanic rocks formed during older orogenic events, i.e. the Svecokarelian, Gothian and Hallandian–Danopolonian orogenies. Intrusive and siliciclastic sedimentary rocks, which formed after 1.3 Ga, are also present. All these rock units were deformed and metamorphosed c. 1.0 Ga ago in connection with continent–continent collision. High pressure conditions prevailed, with a metamorphic grade up to amphibolite and granulite facies conditions, locally with the formation of eclogite. The late orogenic phase is characterized by intrusion of granite, pegmatite and several generations of dolerite and the deposition of sandstone.

In north-western Fennoscandia, the Caledonian orogen was formed during the Early to Mid Palaeozoic as a result of continent–continent collision between North America and Greenland (Laurentia) and Scandinavia (Baltica). The Caledonian orogen is mainly composed of Neoproterozoic to Silurian sedimentary, volcanic and intrusive rocks. These units together with slices of older basement were thrust eastwards onto the Fennoscandian Shield in several large thrust sheets. The metamorphic grade within the Caledonian thrust sheets varies from greenschist to amphibolite facies and locally to high pressure granulite and eclogite facies.

Neoproterozoic and early Palaeozoic rocks outside the Caledonian orogen occur in central and southern Fennoscandian Shield. The former are represented by the Alnö carbonatite complex (central Sweden), the Fen carbonatite complex (southern Norway) and by the sedimentary rocks of the Visingsö Group along lake Vättern in Sweden. The latter are remnants of the Cambro-Silurian platformal deposits (sandstone, shale and limestone) and occur in central and southern Sweden (e.g. in Skåne), and on Gotland and Öland.

The youngest bedrock is preserved in the southern part of the Fennoscandian Shield where Permian rift-related magmatic activity was followed by Mesozoic and Cenozoic subsidence, deposition of sandstone, shale and limestone, and locally by basaltic volcanism.

Superficial Quaternary deposits

Most of the youngest cover has been formed during the last glaciation (Weichselian) and deglaciation. At its maximum, the Weichselian ice sheets covered Finland and the entire Scandinavian peninsula (Fig. 2, Wohlfarth et al. 2008). Glaciers generally spread from the Scandinavian mountain range. These were thick ice sheets, transporting loosened bedrock fragments, weathered soils and pre-Quaternary debris. U-shaped valleys, fjords and lakes were formed by the ice. The glacial systems, serving as reservoirs, locked away large quantities of water. In the melting phase, subglacial streams transported sand and gravel which were deposited to form eskers. The topography in the pristine landscape was dominated by barren bedrock or a cover composed of sand, gravel, till or marine clay. In the postglacial phases, vegetation spread, clays were deposited and peat land developed.

The last deglaciation (9–7 ka BP) was very rapid and isostatic rebound continues in present time with a rate of 0–10 mm per year. Some of the most spectacular results of glacial erosion are the Norwegian deep fjords and thick glacigenic deposits (up to 4 km thick) occurring along the western Scandinavian continental margin (Wohlfarth et al. 2008).

In Scandinavia, most soils have developed from glacial debris from the last glaciations, and from marine or postglacial deposits. Norway, Finland and Sweden have rather thin soil layers compared with the rest of Europe. The glacial debris is mainly composed of sandy till, and is especially common above the highest coastline. In central Sweden and the southern part of Finland, heavy glacial or postglacial clays are common. Peat lands dominate in north-eastern Scandinavia.

Mineral occurrences

Norway, Sweden and Finland have a long tradition of mining and ore processing. Some geological areas are richer than average in elements of economic value and, depending on the number of deposits, are defined as metallogenic provinces or districts. The impact on the geochemistry of the environment is substantial and is generally stronger for metallic ores than for industrial minerals.

Many types of ore deposits have been recognised: volcanogenic massive sulphide deposits (VMS) with Cu, Zn, Pb, Au, Ag, orogenic gold deposits (Au), layered intrusions (Ni, PGE, Ti±V), intrusive

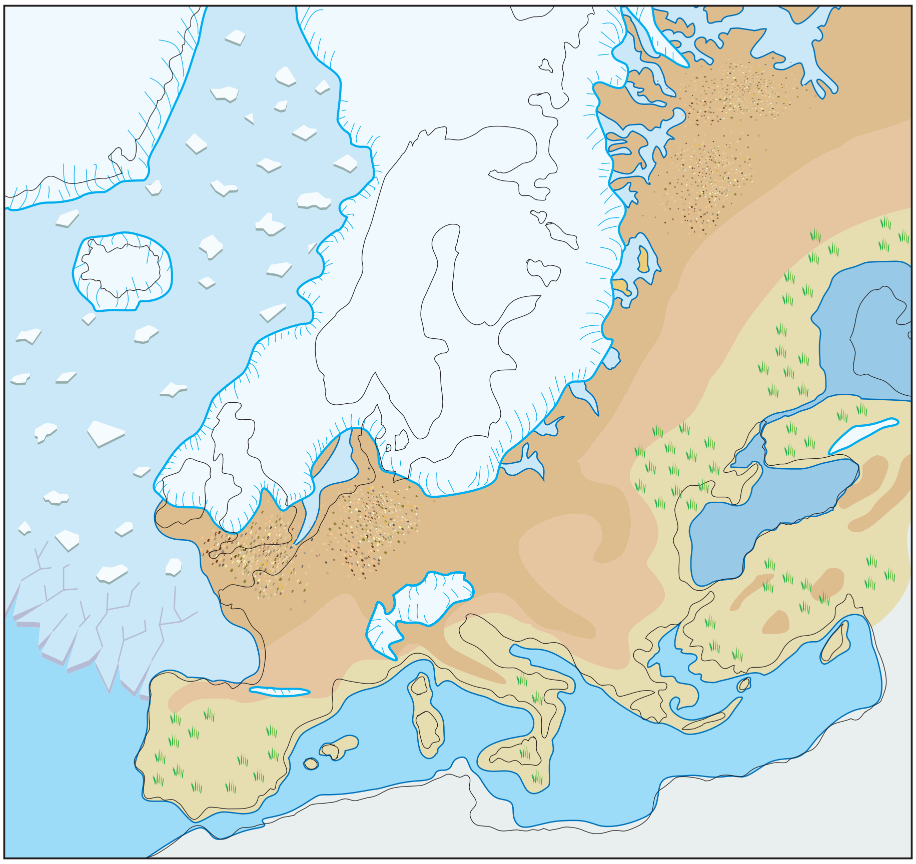


Figure 2. Extent of the Weichselian ice sheet (white), steppe (light green) and tundra (brown). Illustration: A. Åberg, H. Masaki.

hosted copper-gold deposits, apatite-bearing iron oxide deposits, chromite- and anorthosite-hosted Ti deposits, iron oxide-copper-gold (IOCG) deposits, shale-hosted nickel-zinc-copper deposits and different types of uranium deposits (Weihed et al. 2008).

The largest deposits of Fe, Cu and Ni in Europe occur within the Palaeoproterozoic units of the Fennoscandian (Baltic) Shield (Fig. 3). Many of these deposits are situated in a composite sulphidic ore belt running south-east north-west through central Finland into Sweden, and include the Outokumpu region in the south-east, Pyhäsalmi in the centre and the Swedish Skellefte district in the north-west. Garpenberg and Zinkgruvan in the Swedish Bergslagen region, the Viscaria mine in north-western Sweden and the Pahtavaara Cu-Zn mine in Finland are sometimes classified as VMS deposits. The metamorphic host-rocks of the VMS deposits have volcanic and sedimentary origin and consist of rock types such as schist, gneiss, serpentinite, dolomite and skarn (with an average age of 1.9 Ga).

The biggest VMS ore district in Sweden, the Skellefte district, includes the Boliden polymetallic deposit, which was once the richest Au-As deposit in Europe, and also produced Cu, Ag, Pb and Zn. Geologically, these ore bodies are related to quartz porphyry or other granitoid intrusions cutting volcanic units of dacitic to rhyolitic composition (Eilu et al. 2012).

The largest Cu-Au mine in Scandinavia, the Aitik mine in northern Sweden, occurs within Svecofennian volcaniclastic rocks and is classified as a porphyry deposit (Eilu et al. 2012).

Orogenic gold deposits occur within Archaean and Proterozoic units and many have an epithermal origin (Weihed et al. 2008). The largest gold deposits are Boliden (Sweden), Cu-Au ores in Bidjovagge (northern Norway) and Suurikuusikko, Pahtavaara and Saattopora (northern Finland).

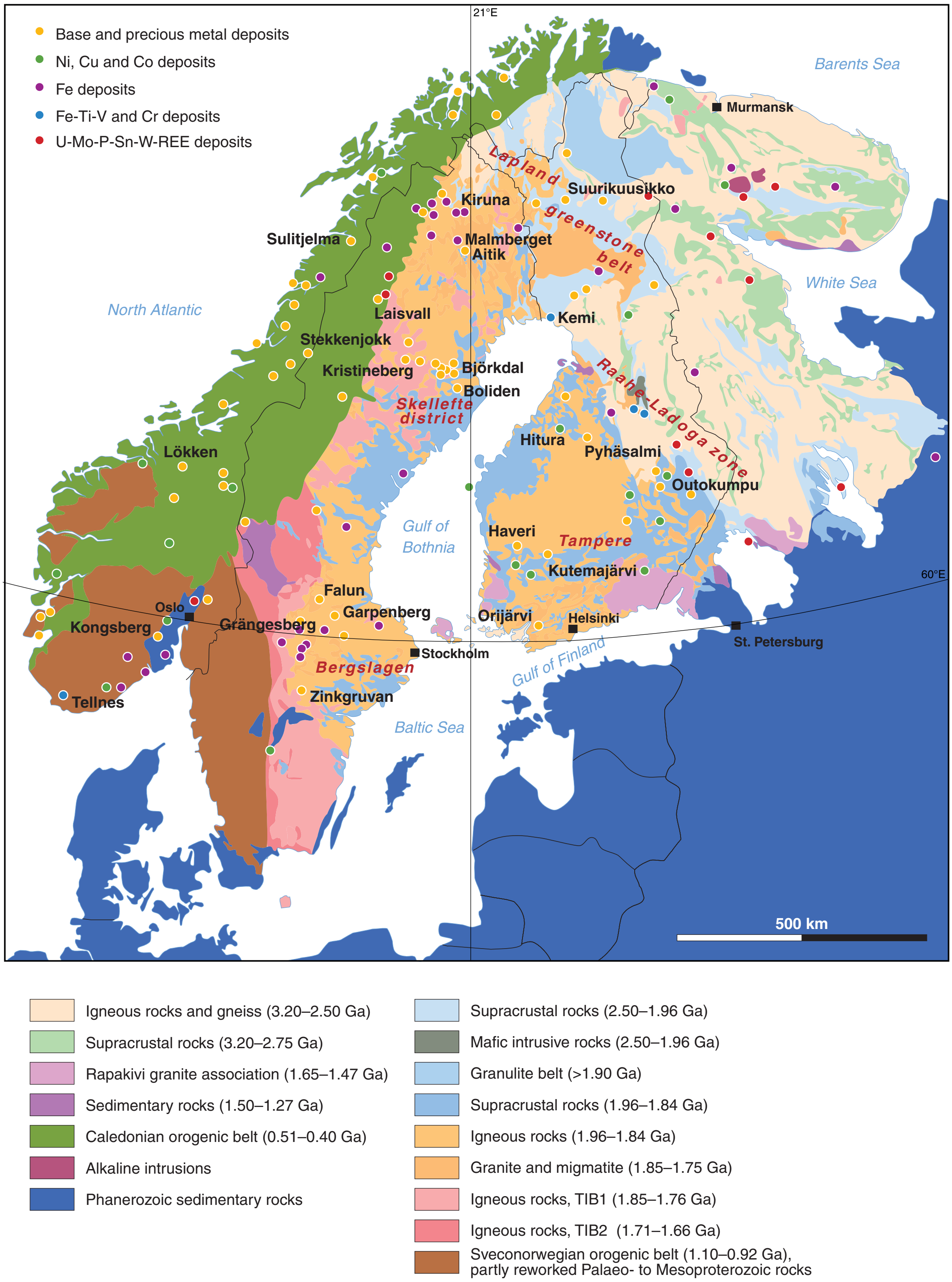


Figure 3. Geological map with major ore deposits in Scandinavia. Modified from Lahtinen et al. (2005).

In Sweden, the so-called Gold Line has been recognised in the Västerbotten County with two recent mines at Svartliden and Blaiken. The Gold Line refers to a south-east trending Au anomaly detected by the State Mining Property Commission (NSG) during a till geochemistry survey in the late 1980s.

The iron ores in Scandinavia are among the biggest iron ore deposits in the world with the main mines located in northern Sweden, the Kiruna and Malmberget mines. The iron ore deposits belong to different genetical types: apatite-bearing iron oxide ores (Kiruna mine, Grängesberg mine), the Archaean-type banded-iron formations (BIFs, e.g. the Dannemora ore in Bergslagen in central Sweden), and skarn type iron ores. The largest iron-ilmenite deposits are known from south-west Norway (Tellnes deposit, Eilu et al. 2012).

Ni-Cu±PGE deposits occur in several different settings within the Fennoscandian Shield, e.g. in Finland (Kotalahti, Hitura and Vammala) and to a lesser extent in Sweden (e.g. Lainejaur).

Other types of metal occurrences in Scandinavia include Cr-, Li-, Mo-, Nb-, REE-, Sn-, Ta-, W- and U-bearing deposits. The Kemi chromite mine in Finland is one of the largest chromium deposits in Europe and the ore is hosted by mafic–ultramafic intrusive rocks (Eilu et al. 2012).

Uranium occurs in several mineralisation types in both vein-type deposits within Precambrian rocks, primarily in Finland, in younger granites and pegmatites, and in Palaeozoic shales overlying the Precambrian basement in Sweden, e.g. Cambrian alum shale (Weihed et al. 2008).

The Caledonian mountains contain many important mineralisations whose metal potential has been known for a long time. Cu-Zn-Pb sulphide deposits are known from Norway (e.g. Bleikvassli, Mofjellet, Lökken, Röros, Sulitelma) and from Sweden (Stekenjokk-Levi in northern Sweden, Bjelke and Fröå in Jämtland). Pb-Zn mineralisations in sandstones occur in Laisvall in Swedish Lapland.

Iron ores also occur within the Caledonian nappes. However, the Ørtfjell iron deposit in Norway is the only Caledonian metallic deposit being mined. Hydrothermal gold deposits are known from Bindal and Mofjellet in Norway. In northern Norway, polymetallic tungsten skarn deposits are known. Silver mineralisations in the Swedish Caledonides have been found in many places, for example Nasafjäll, Kvikkjokk and Stekenjokk.

Carbonatite hosted Nb-Fe-P-REE deposits are known in southern Norway (the Fen Complex). Ni-Cu-S and Cr deposits, locally with PGE and talc, hosted by mafic to ultramafic rocks occur both in Norway (Bruvann, Råna) and Sweden (Kukkola, Notträsk, Kläppsjö).

HUMAN IMPACT ON ARABLE LAND

Modern humans arrived in Europe some 35 000–40 000 years ago. Following the last retreat of the ice sheet, humans spread northwards, and Scandinavia started to be colonised about 14 000 years ago.

As the population grew, land for agricultural use was needed and methods to increase productivity of farmed fields were developed. The agricultural soils needed addition of organic matter and nutrients such as nitrogen, potash and phosphate in order to remain fertile and productive. The use of fertilisers resulted in elevated levels of potentially harmful elements in soils. Spreading of waste sludges on land led to accumulation of heavy metals such as lead, cadmium, copper and zinc in the surface soil layers. With the focus on plant health, the use of organic herbicides and pesticides to avoid plant diseases has led to the accumulation of toxic residues in soils.

METHODOLOGY

Sampling and sample preparation

The Geological Surveys of Sweden, Norway and Finland have collected samples of agricultural and grazing land soils according to the manual provided to all project members (EGS 2008). Field equipment (e.g. RILSAN bags) was also provided by the central organisation. Sampling took place during

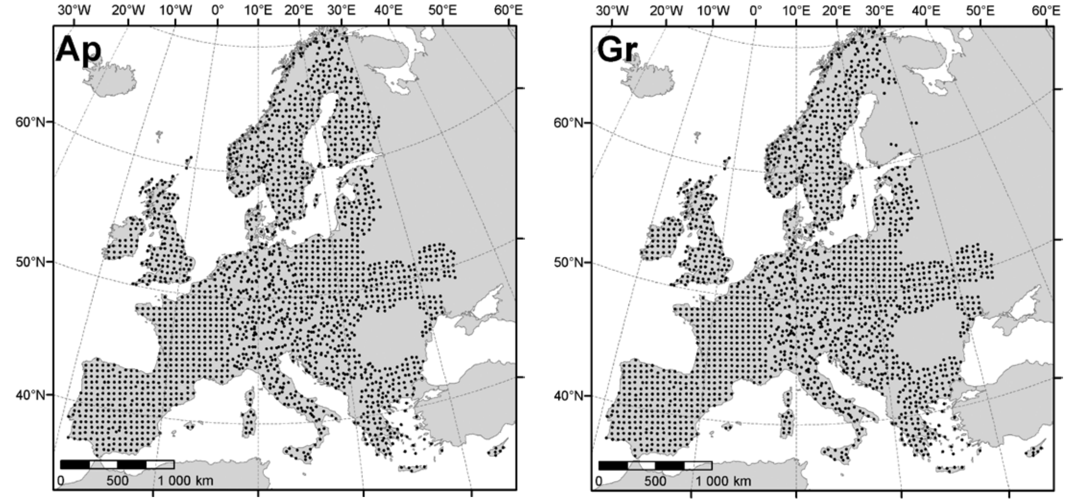


Figure 4. Sample locations for the agricultural soils (Ap) and for the grazing land (Gr) in Europe.

the summer and autumn of 2008 and 453 samples (excluding field duplicates) of agricultural soil (Ap, Ap-horizon, 0–20 cm) and 350 samples (excluding field duplicates) of grazing land (Gr, land under permanent grass cover, topsoil 0–10 cm) were collected in Norway, Sweden and Finland (Fig. 4).

All samples were shipped to a central sample preparation facility at the Geological Survey of Slovakia which also prepared the two project standards, Ap and Gr, for monitoring the quality of analytical results. The samples were air dried, sieved to <2 mm using a nylon screen, homogenised and finally split into sub-samples. Randomised sample series were sent to the respective laboratories.

Analytical methods

More details on the analytical methods are provided in Reimann et al. (2009a, 2011).

ICP MS and ICP AES

All analyses were carried out within a twenty-day period at ACME laboratories in Vancouver, Canada. A weight of 15 g of the sieved mineral soil samples (<2 mm) were digested in aqua regia and analysed using an inductively coupled plasma atomic emission spectrometer (ICP-AES) and an inductively coupled plasma mass spectrometer (ICP-MS).

Practical detection limits and precision, as well as the analytical results for the two project standards Ap and Gr, are provided for 53 elements (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr). All results are reported as mg/kg (Reimann et al. 2009a).

XRF and LOI

The elements Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, S, Cl, F, As, Ba, Bi, Ce, Co, Cr, Cs, Cu, Ga, Hf, La, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Sn, Sr, Ta, Th, U, V, W, Y, Zn and Zr were determined by wavelength dispersive X-ray fluorescence spectrometry (WD-XRF) at Bundesanstalt für Gewissenshaften und Rohstoffe (BGR) in Germany. The major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P) are reported as weight percent oxide (wt.%) with Fe reported as Fe^{3+} (Fe_2O_3) while the trace and rare earth elements are reported as mg/kg. Loss on ignition (LOI) was determined for all samples by slow heating to 1 030 °C and keeping the samples at this temperature for 15 minutes in a muffle furnace.

Total C and S

Total carbon and total sulphur were analysed at the laboratory of the Geological Survey of Norway using a LECO SC-444 instrument. The principle of the method is that all carbon and sulphur in the sample are burned in an oxygen atmosphere to CO_2 and SO_2, respectively, which are then detected using an IR-cell. Results are reported as wt.%.

Cation exchange capacity

Cation exchange capacity (CEC) was measured at the laboratory of the Slovak Geological Survey using the silver-thiourea method and it is reported in milliequivalent of hydrogen per 100 g (meq+/100 g, Reimann et al. 2011).

Total organic carbon

Total organic carbon (TOC) was determined according to ISO standard 10694 *Soil quality – determination of organic and total carbon after dry combustion*. The measurements were performed at the chemical laboratory of KIWA (former FUGRO), Berlin, Germany using a carbon analyser (ELTRA Helios).

pH $CaCl_2$

The pH of the soil samples was measured in 0.01 M $CaCl_2$ solution using a pH-meter equipped with a standard glass electrode at the laboratory of the Geological Survey of Norway.

Quality control

Analytical results for XRF show good quality. Analytical results for some elements are generally close to the detection limits (e.g. Sb, Bi, Ta, W, F, Hf, Sn and Cl), and here quality problems are observed. In all instances where poor precision was observed this was due to very low concentrations. The higher concentrations (upper outliers) are considered reliable even for these elements.

Analytical results following an aqua regia extraction (ICP-AES and ICP-MS) indicate an overall very good quality despite the fact that, for a number of elements, the majority of the analytical results are very close to the detection limits (e.g. Ge, Pt, Pd, Re, Ta, Te).

All quality control results are documented in detail in Reimann et al. (2009a, 2011). Both reports are available on the internet via the website of the Geological Survey of Norway (www.ngu.no).

Extractability of elements

A comparison of the analytical results from XRF (total analysis) with the results from an aqua regia extraction made it possible to calculate the extractability of each element analysed by the two methods. It is expected that the element concentrations are always lower for leached samples than for the same samples that are analysed for total concentrations with XRF. In the GEMAS dataset, the extractability varies from 1% (Hf, Zr, Na) up to over 80% (As, Co, P) for the arable soils. An extractability over 100% is calculated for Cu, which is an effect that is probably caused by differences in detection limits and precision of analyses. Therefore, the values for the extractability of any element should not be considered absolute. Instead the calculated extractability should be used as a tool to distinguish whether elements have high, intermediate or low extractability which is an effect of mineralogy. Elements originating in minerals resistant to chemical weathering have low extractability. Calculated values for extractability of the elements in European agricultural soil and grazing land are shown in Table 1.

Table 1. Extractability of the elements analysed by XRF (total concentrations) and by aqua regia extraction based on agricultural soil (Ap) and grazing land (Gr) in Europe.

Agricultural soil	Extractability (%)	Grazing land	Extractability (%)
Al	22	Al	22
As	81	As	85
Ba	17	Ba	19
Bi	10	Bi	12
Ca	61	Ca	66
Ce	53	Ce	52
Co	83	Co	82
Cr	34	Cr	34
Cs	23	Cs	21
Cu	115	Cu	118
Fe	72	Fe	73
Ga	32	Ga	32
Hf	1	Hf	1
K	8	K	8
La	69	La	63
Mg	55	Mg	56
Mn	80	Mn	81
Mo	41	Mo	40
Na	1	Na	1
Nb	4	Nb	5
Ni	79	Ni	79
P	83	P	83
Pb	77	Pb	83
Rb	21	Rb	20
Sb	9	Sb	13
Sc	29	Sc	28
Sn	33	Sn	42
Sr	19	Sr	21
Th	36	Th	26
Ti	3	Ti	3
U	38	U	52
V	40	V	41
W	3	W	4
Y	25	Y	28
Zn	74	Zn	75
Zr	1	Zr	1

INTERPRETATION OF MAPS

General remarks

The regional distribution of major and trace elements in agricultural soil and grazing land show results obtained from aqua regia extraction (ICP-MS and ICP-AES) and XRF-analyses visualised as growing dot maps. The size of the dots is proportional to the measured values of an element in the GEMAS dataset.

All element distribution maps show clear regional scale features and, for the majority of elements, anomalies can be explained by the occurrence of mineralisation, bedrock type and alterations.

Two main factors are often responsible for the occurrence of anomalies: the type of bedrock and the soil type (Fig. 5). Crystalline bedrock, especially the granitic domains, strongly influence the geochemistry of the overlying soils which is particularly seen in the higher median values (aqua regia) of Ag, Ce, Ge, Mo, Na, Nb, P, S, Ti and U in arable soils compared to soils where other rock types occur (appendix 1).

In Finland, the soil type was recorded for most of the samples on the field card. Clay soils showed high concentrations of aqua regia extractable potassium, iron and aluminium, and the concentrations of several trace elements (Ag, As, B, Ba, Be, Bi, Cd, Co, Cr, Cs, Cu, Ga, Ge, Hf, In, La, Li,

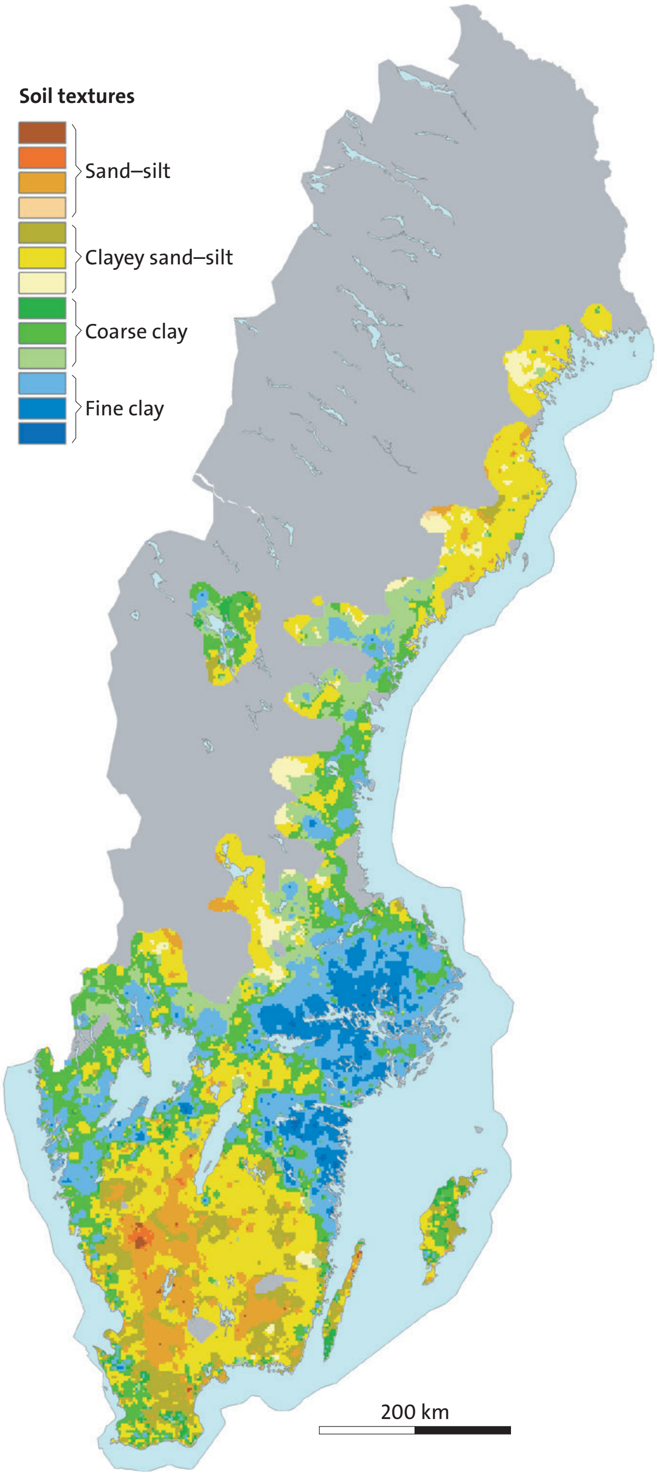


Figure 5. Geographical variation in the dominant mineral soil texture according to the Swedish classification system (n = 4 954, Eriksson et al. 2010).

Mg, Na, Nb, Rb, Sc, Th, Ti, Tl, V, Y, Zn and Zr) were relatively high in clay-rich soils (appendix 2). Biogenic (organic) soils showed elevated concentrations of S, Se and Hg (appendix 3).

Areas of anomalously high values were similar to those detected during the Baltic Soil Survey published in Agricultural Soils in Northern Europe: A Geochemical Atlas (Reimann et al. 2003). In the Baltic Soil Survey, organic soils were collected in eastern and northern Finland, while in the GEMAS data set small scale anomalies explained by biogenic soils were also found in south-eastern Finland where in general more minerogenic soils were sampled.

Central Scandinavian clay belt

Many element anomalies in central Scandinavia are related to the occurrence of postglacial clay-rich sediments and marine clays that cover the Mälaren region (Fig. 5) in central Sweden and large parts of southern and south-eastern Finland. For the purpose of discussion in this study we named this area the Central Scandinavian clay belt.

Ag (silver)

Ag shows elevated concentrations in the Central Scandinavian clay belt extending from the Lake Mälaren region in central Sweden to southern and south-eastern Finland. In this marine clay, under acidic conditions, Ag may substitute for K in clay minerals (Ure & Berrow 1982).

Otherwise Ag is strongly chalcophile and it is present in sulphide minerals, especially as a trace element in galena. Native Ag is rare.

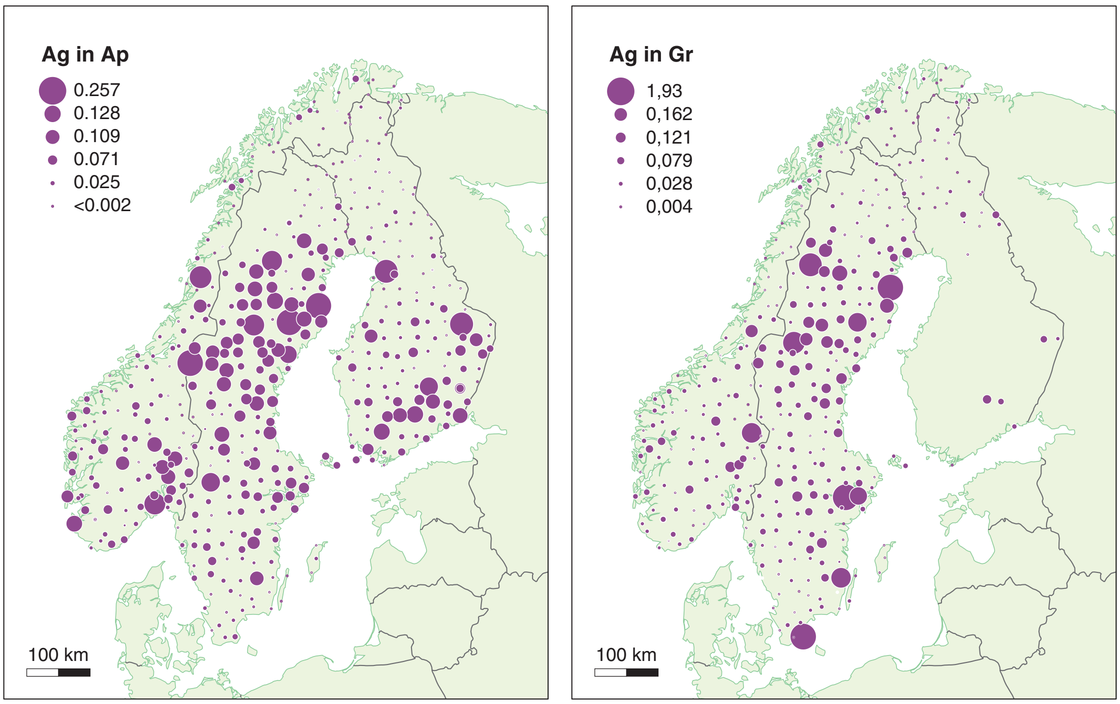
In general, samples with higher Al and K contents (clay-rich) show higher Ag concentrations. The contents of organic matter (TOC) in Ap samples also favour higher Ag contents. The highest median values occur in the Swedish samples (appendix 4).

Finland

Elevated Ag concentrations occur mostly in clay-rich soils and soils with high content of organic matter. Strong correlation occurs between Ag, K and TOC. In eastern Finland, high Ag concentrations correlate with numerous occurrences of polymetallic mineralisations. In northern Finland a large isolated anomaly is observed south of the large Kemi Cr and PGE ore deposits.

Norway

High Ag concentrations occur in the Oslo Rift where silver originates from vein type Ag-Zn deposits and Ag-bearing sulphides in alum shales. In south-western Norway and central Norway, silver anomalies point to the occurrence of further vein-type Ag-Zn-Pb deposits. Concentrations along the western coast are related to high precipitation and soils strongly enriched in organic matter.



Sweden

The Swedish samples have higher median Ag values (0.06 mg/kg), both in agricultural soils and in grazing land samples, than Norway and Finland. Knowing that almost 600 deposits with Ag occur in a variety of commodities situated all over the country, the dispersion patterns connect well to mineralisations.

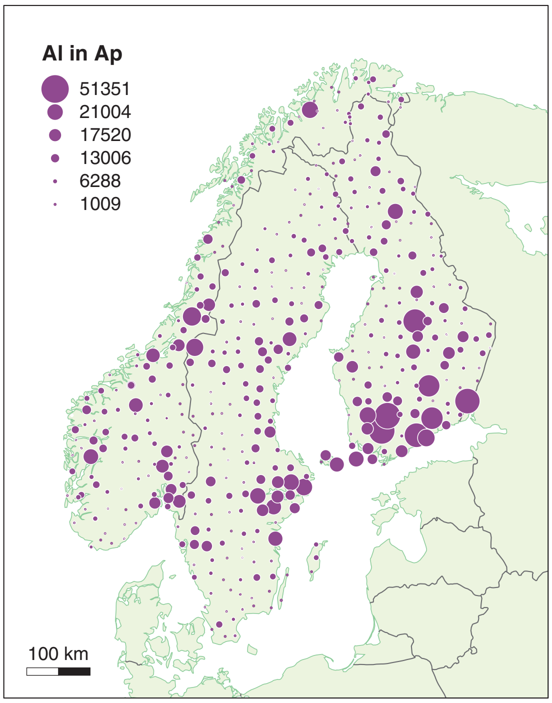
In the northern (Västerbotten), the upper central (Jämtland), and central (Dalarna) parts of Sweden, high Ag concentrations are related to sulphide or oxide mineralisations and alum shale occurrences. Anomalies following known Ag mineralisations in Västerbotten and northwards into the southern part of Norrbotten are often related to Ni, Cu, Co ore deposists located in mafic metavolcanic rocks.

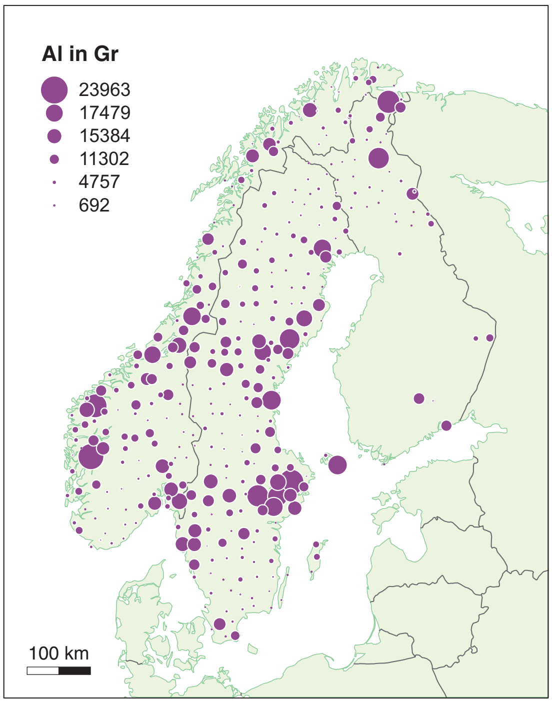
In central Sweden, Ag anomalies in Bergslagen and in the Mälaren region (Eskilstuna, Stockholm area) and in the south tip of Sweden (south-east Skåne) reflect Pb-Zn-Ag mineralisations in sedimentary rocks. In the western central part of the country (Värmland), concentrations of Ag relate to sulphide mineralisations or Cu-Au-Ag in quartz veins. Regions with Pb-Zn-Ag-Au ore deposits can also be recognised in the distribution patterns, such as in the southern interior.

Al (aluminium)

Unsurprisingly, the Central Scandinavian clay belt is clearly marked by high Al concentrations indicating the occurrence of clay-rich soils. The highest Al median occurs in Finland (agricultural soil). Generally, the abundance of Al is very high in crustal rocks and thus it is often difficult to define a source of anomalies for this element. Al occurs both in crystalline and sedimentary rocks, and is a major constituent of many rock-forming minerals (e.g. feldspar) and secondary clay minerals being products of weathering. This is the reason for the very good correlation with K.

Al is rather immobile but it can be transported into the surficial environment under acidic and highly alkaline conditions. The resulting extractability is not very high, 22% for both Ap and Gr samples. In aqua regia extraction maps, Al anomalies are mainly found in clay-rich areas where marine clay dominates. The map of total concentrations of Al shows slightly different patterns in grazing land with higher concentrations in soils in central and northern Sweden and in western





Norway, indicating occurrences of Palaeoproterozoic igneous rocks. In contrast, soils from regions with sedimentary rocks (e.g. Dala sandstones and metasedimentary rocks in the Bothnian Basin) have low Al concentrations.

Finland

High Al contents in southern Finland are related to clay-rich soils.

Norway

Elevated concentrations in the Oslo Rift are related to felsic volcanic rocks, rich in plagioclase and feldspar. None of the other anomalies is easily explained.

Sweden

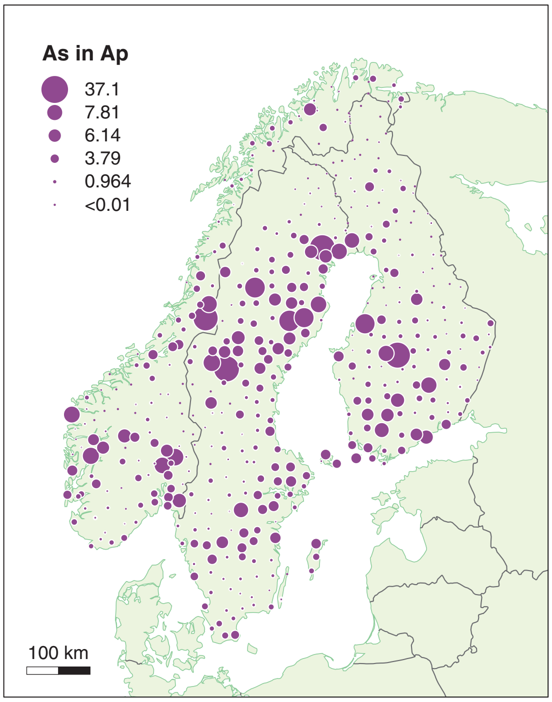
High Al concentrations occur in clay-rich soils in the Mälaren region (the Central Scandinavian clay belt) and along the eastern coast of the Baltic Sea. Locally, Al concentrations in samples collected along larger rivers, e.g. Lule river in southern Norrbotten, have been observed.

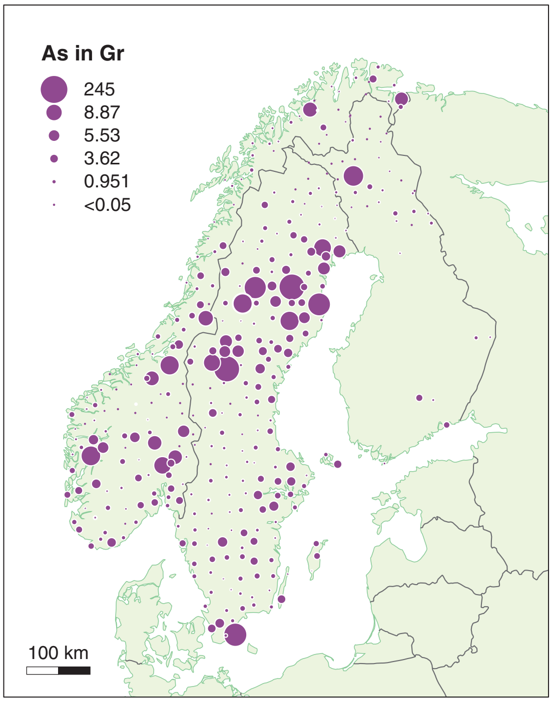
As (arsenic)

High As concentrations in Norway, Sweden and Finland are generally related to Cu-sulphide mineralisations. As is strongly chalcophile and forms a variety of sulphide and sulpharsenide minerals. Hydrothermal processes usually lead to an enrichment in arsenic.

The As extractability is very high, 81% for Ap and 85% for Gr samples. Samples with higher Al and K contents (clay-rich) generally show higher As concentrations. This trend shows that As preferentially concentrates into clay minerals. Correlation with pH and TOC is less pronounced. At low pH As is mobile but can easily be oxidised and adsorbed to clay minerals, Fe-Mn hydroxides and organic matter. Although high As concentrations in soils are often considered to be of anthropogenic origin, most of the anomalous As values are related to natural occurrences of base metal deposits.

The highest median values both in agricultural soils (2.6 mg/kg) and grazing land soils (2.5 mg/kg) samples occur in Sweden, while the lowest values have been observed in Finland. Note that the As con-





centrations in northern European soils are lower by a factor of 3 than As concentrations in central and southern European soils. This points at soil age and weathering playing an important role in the enrichment of As in soils over time.

Finland

High As contents in the soils occur in the "Tampere arsenic province". In northern Finland, As anomalies relate to sulphide mineralisations. However, the signal is masked by sandy soils which are generally characterised by low As concentrations.

Norway

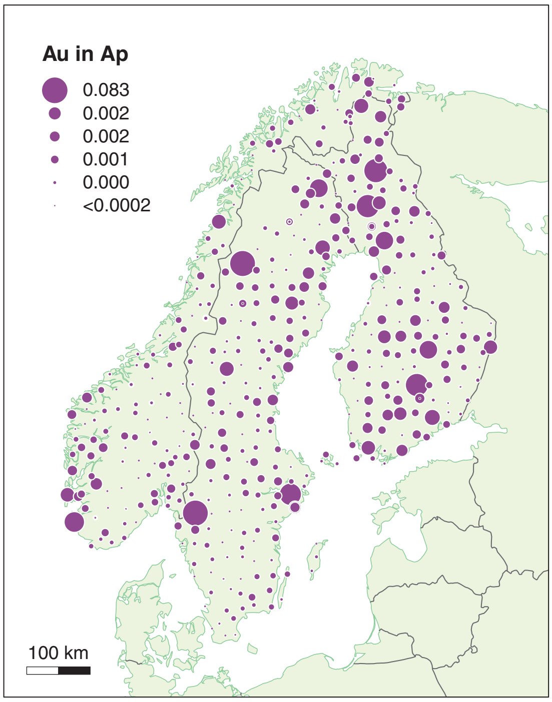
Elevated As concentrations in the soils in the Oslo Rift are related to sulphide mineralisations in Permian volcanic rocks and Early Palaeozoic black shale. In central Norway, As anomalies mark "the copper belt" of known sulphide mineralisations in the Caledonides.

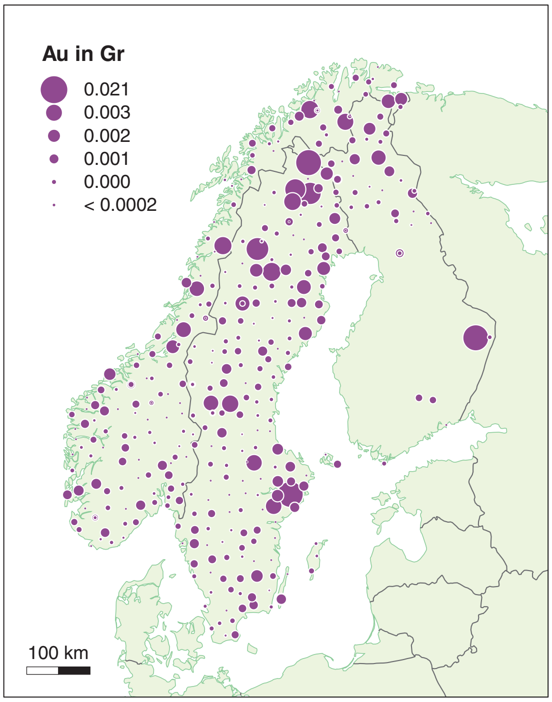
Sweden

High As contents correlate with sulphide mineralisations in Sweden: in Bergslagen, Jämtland (alum shale), Skellefte district (Västerbotten) and the Boden region (Norrbotten). Elevated As concentrations can be found in marine clay-rich soils in the Mälaren area and along the eastern coast from Gävle to Haparanda. High As concentrations in Cambrian alum shale from the south-east of Skåne are observed in grazing land soils.

Au (gold)

Au mainly occurs in soils in native form, and can be preconcentrated in fine-grained sediments. As a result, Au shows weak correlation with the Al content (clay-rich soils), while K concentrations, pH and TOC play a less significant role due to low activity of gold in solution. The highest median values are noted in Finland (Ap), while the maximum values occur in Sweden. Given the low density sampling it is surprising that well defined anomalies can be found in the maps. Most are, however, clearly related to known mineralised areas or ore deposits.





Finland

Au anomalies occur in the vicinity of known gold mineralisations, e.g. Suurikuusikko in northern Finland and Korpilampi-Pampalo in eastern Finland.

In the south-east, the anomalies occur in peaty soil samples. These anomalies are also associated with Ge, In, Se and Sb. There may be a connection with some minor skarn occurrences known in the same general area, but it remains an intriguing observation that the anomalous concentrations are observed only in peaty soils. This may point at a secondary process enriching gold in organic soils. Reimann et al. (2009b) described a similar phenomenon at the south coast of Norway in an area without any likely source of Au.

Norway

The Au anomalies are all related to occurrences of quartz-Au veins.

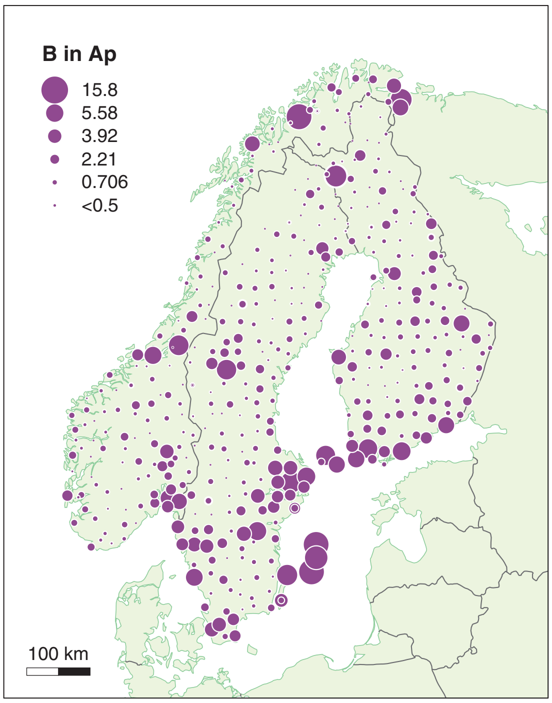
Sweden

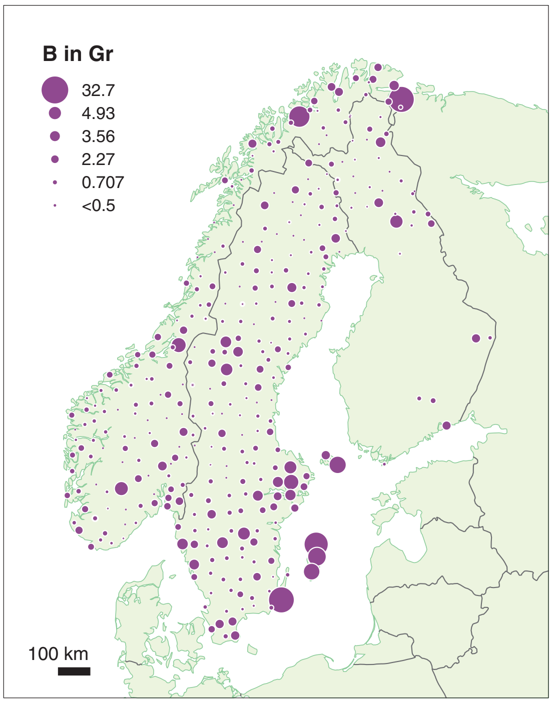
The high single spot in western Värmland to southern Dalsland is located in an area where Au-Cu-Pb deposits and other known Au occurrences are situated.

Anomalies in Västerbotten (e.g. in Arjeplog and Lycksele–Storuman) belong to the Gold Line mineralisations. In northern Norrbotten, large gold anomalies also point to known Au mineralisations. Anomalies in the Mälaren region reflect sulphide mineralisations, but high concentrations of Au seen in both agricultural and grazing land soils in the Stockholm area may have an anthropogenic source.

B (boron)

Boron results have to be viewed with care due to possible quality (analytical) problems due to generally low concentrations in soils. The primary B sources are late-stage magmatic rocks, especially pegmatites. Thus the main sources of B in Scandinavia are the Palaeoproterozoic intrusive rocks that are rich in pegmatites. Although B shows poor leachability from magmatic minerals (e.g. tourmaline), in soils it can be quite soluble and it is mainly adsorbed to clay minerals (e.g.





illite). Secondary B is concentrated in clays and carbonates, marine clays usually having higher B contents due to the primary concentrations of the element in the seawater. Evaporites also tend to have higher B contents, but they only occur sporadically in Scandinavia. B can be enriched in organic-rich soils, especially under low pH conditions.

In Norway, Sweden and Finland, there is a positive correlation between B concentrations and Al content, K content and pH values, which indicates strong enrichment in clay-rich soils, especially in the Central Scandinavian clay belt.

Finland

Elevated B concentrations occur in southern Finland in clay-rich soils of the Central Scandinavian clay belt and in northern Finland.

Norway

Elevated B concentrations can be observed within the Oslo Rift where it is enriched in Permian volcanic rocks. Larger anomalies with unidentified sources occur in central and northern Norway.

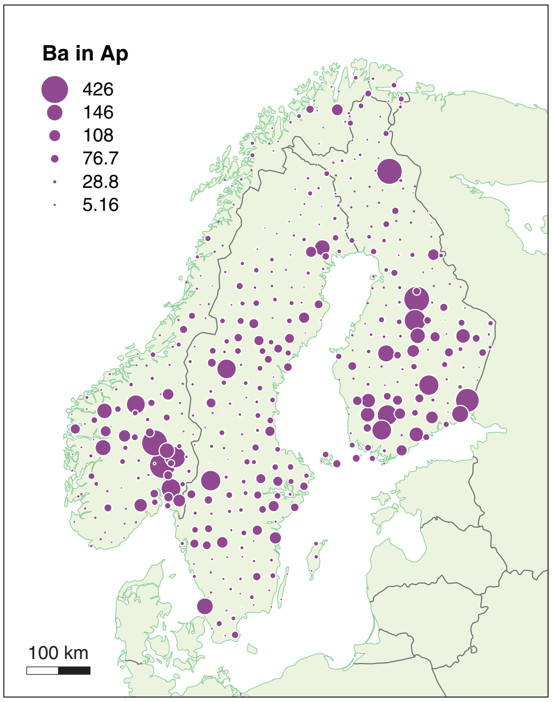
Sweden

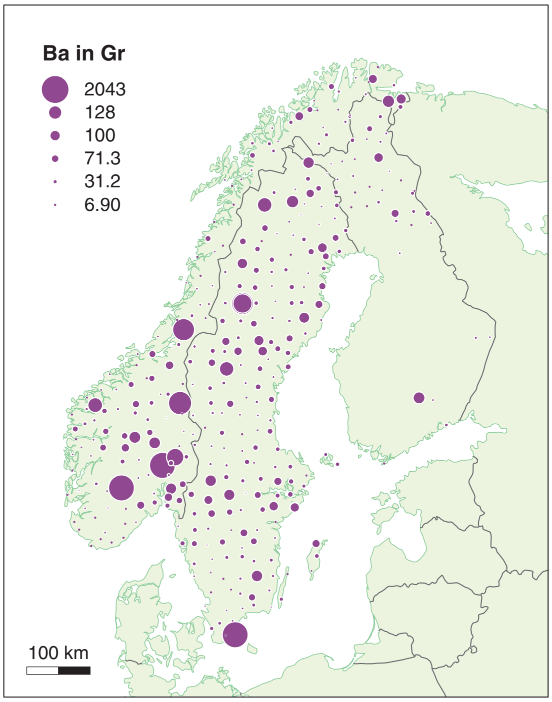
High B concentrations occur in black shale in Jämtland (alum shale), in clay-rich soils of the Mälaren region, along the western coast and in Skåne.

Surprisingly high B contents have been obtained from carbonate-rich soils on the large islands Gotland and Öland. These high levels are possibly related to the alkaline character of these soils. A certain percentage of B might also originate from input from fertilisers.

Ba (barium)

Barium is a common element in the soils of Norway, Sweden and Finland. Its low extractability (17–19%) is, however, responsible for differences in the elemental pattern between aqua regia extraction and total concentrations. Ba occurs in late-magmatic rocks, preferably alkaline, rich in K-feldspar and micas where it substitutes for K. Although Ba forms its own minerals,





common rock-forming minerals are the main source of the element, which can be seen in the positive correlation of Ba with Al and K in soil samples. Swedish samples show the highest Ba concentrations of the three countries with a median of 52 mg/kg (compared to the median of 47 mg/kg for all).

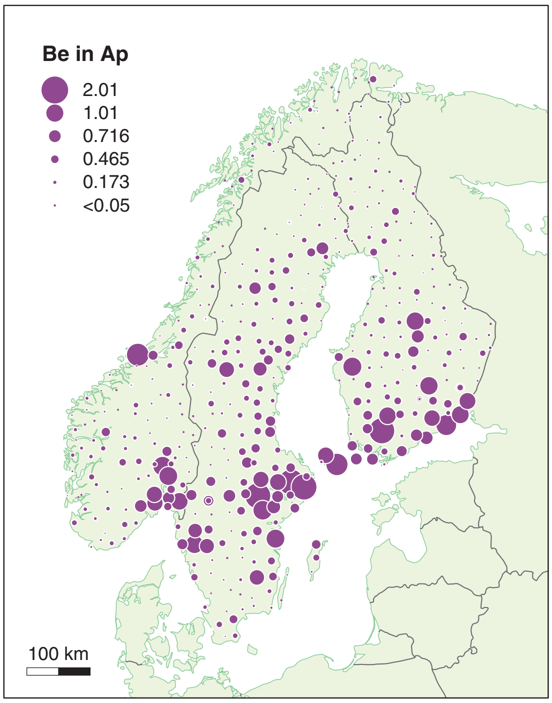
Finland
High Ba concentrations are indicative of clay-rich soils in southern and central Finland.

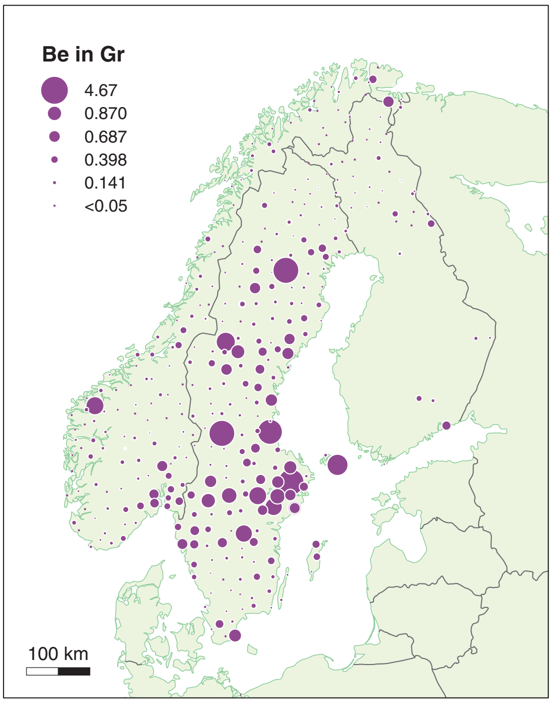
Norway
Elevated contents of Ba in soils occur in the Oslo Rift, composed mainly of felsic volcanic rocks, in the Caledonides and in Neoproterozoic sandstone (arcose) which is rich in K-feldspars. High Ba concentrations in soils north of Bergen and locally in southern Norway can be correlated with occurrences of Mesoproterozoic igneous rocks (Sveconorwegian and possibly older).

Sweden
In the Boden region in Norrbotten, the Ba concentrations in soils are derived from felsic metavolcanic rocks. In Jämtland, south of Östersund, the Ba content in the soils reflects Palaeozoic shale and Neoproterozoic arcose. In Värmland, the concentrations relate to the occurrences of granitic rocks. In south-east Skåne, the high Ba content occurs in soils overlying feldspar-rich Cambrian sandstone and shale.

Be (beryllium)

High Be concentrations occur in the Central Scandinavian clay belt, in pegmatites and in rapakivi granites, and is reflected in strong positive correlation with K and Al concentrations in the overlying soils. The highest Be concentrations in soils occur in Sweden (both in agricultural and grazing land soils). Be becomes mobile in acidic soils and precipitates with Fe-Mn hydroxides and humic acids at high pH.





Finland
High Be concentrations occur in southern Finland in clay-rich soils of the Central Scandinavian clay belt overlying old weathered crystalline rocks. Elevated Be contents also occur in soils underlain by metamorphic schist in southern Finland.

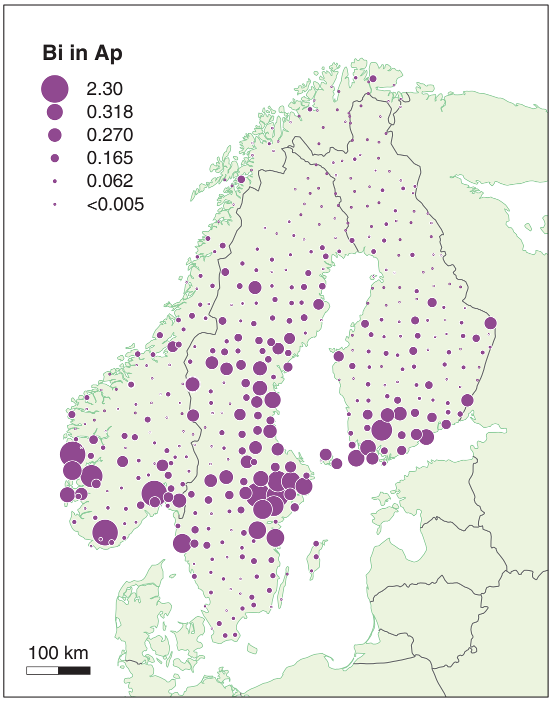
Norway
Anomalously high Be concentrations in the soils occur on Hitra island (pegmatites) and in the Oslo Rift (felsic volcanic rocks and other intrusions).

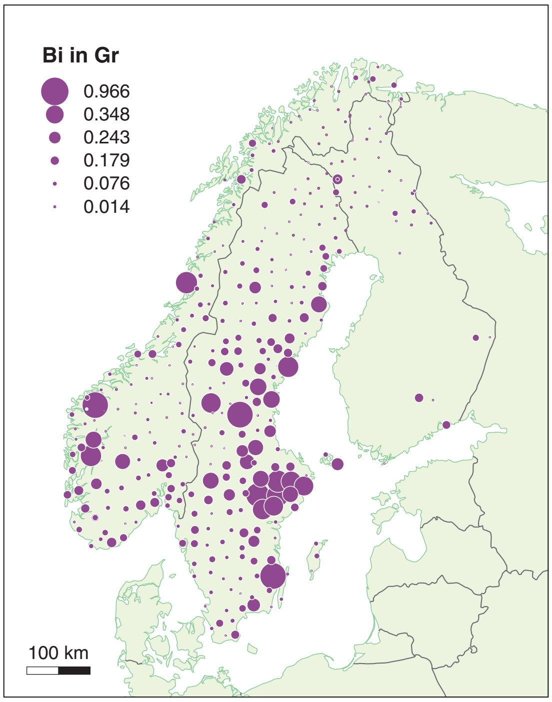
Sweden
High Be concentrations occur in mica-rich clays and in soils underlain by feldspar-rich granites, pegmatites and gneisses. The Be concentrations in soils from the Mälaren region have sources in the clays of the Central Scandinavian clay belt wich are rich in micas and secondary clays.

In Jämtland, elevated Be contents reflect Caledonian mica-rich shales and mudstones as well as old metamorphosed Palaeoproterozoic metasediments. Locally, high Be contents in soils are related to occurrences of granites, pegmatites and gneisses.

In the western central part of Sweden (Västra Götaland), Be anomalies in the soil reflect concentrations of Be in glacial and postglacial clays overlying intrusive, often metamorphosed, rocks.

Bi (bismuth)
Bi has a strong tendency to incorporate into sulphides and often substitutes for Pb in galena. Bi correlates well with Au and is often used as pathfinder element for gold during exploration. Secondary concentrations are common in fine-grained sediments and glacial clays. Bi therefore shows weak positive correlation with Al and K contents. The highest values are noted from Norway while the median values are highest in Swedish soils. Elevated Bi concentrations occur in the Central Scandinavian clay belt in southern Finland and central Sweden. Some of the anomalies can be linked to the occurrences of underlying felsic rocks.





Bi extractability is rather low (11%) which, to some extent, results in different elemental distributions in the aqua regia extraction and the total concentration (XRF) maps. Due to the relatively high detection limit for Bi by the XRF technique (>3 mg/kg), only the higher values from the XRF method are considered reliable. Leached Bi is enriched in soils from the Central Scandinavian clay belt in central Sweden and southern Finland, while high total contents of Bi correlate with occurrences of sulphide mineralisations.

Finland

Elevated Bi contents occur in clay-rich soils and soils overlying rapakivi granites.

Norway

High Bi concentrations occur in the Oslo Rift, the Kongsberg region (associated with felsic volcanic rocks and the well-known silver ore deposits) and in the Hardanger region. In south-west Norway and in the central Caledonides, Bi anomalies are linked to the occurrence of Pb-Zn ore deposits.

Sweden

High Bi concentrations in the soils occur in association with Cu-Zn deposits hosted by metamorphosed rocks (skarns) such as in the Åre–Storlien region (Jämtland). Some of the Bi concentrations observed in soils overlying Caledonian black shale are related to the presence of organic matter in the shale. Elevated Bi contents occur in central Sweden (north of Gävle) where the clay-rich soils are underlain by crystalline rocks (granites and pegmatites) of the Fennoscandian Shield.

In south-east Sweden, the Bi anomaly in grazing land correlates well with known Pb-Zn ore deposits and Bi, Au, Cu and pyrite mineralisations hosted by quartz-dolomite veins of hydrothermal origin.

Elevated concentrations of Bi by aqua regia leaching are observed in clay-rich soils (both in agricultural and grazing land soils) in the Mälaren region and along the eastern coast.

Ca (calcium)

As a consequence of the very limited presence of carbonates, northern Europe has relatively low Ca concentrations in soils compared to the remainder of Europe. Carbonate rocks mainly occur on the islands of Gotland and Öland in Sweden, within the Caledonian nappes, and as outliers on the Fennoscandian Shield. Older metamorphosed carbonate rocks (marbles) form thin layers within metamorphic units.

The Ca content in soils is thus to a large extent related to weathered mafic rocks containing Ca-bearing minerals such as pyroxene and amphibole. A significant anthropomorphic input also comes from the liming of agricultural soils.

Ca is highly mobile under acidic conditions and its extractability in aqua regia is quite high, 61% in agricultural soils and 66% in grazing land.

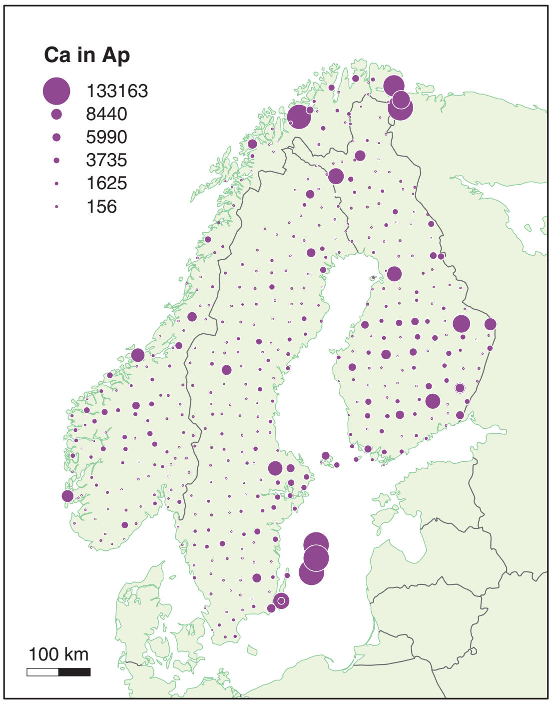
In the three Nordic countries, Ca correlates with TOC and shows, on a local scale, evidence of liming activities in peat-rich areas. The highest Ca concentrations are observed in Swedish soils.

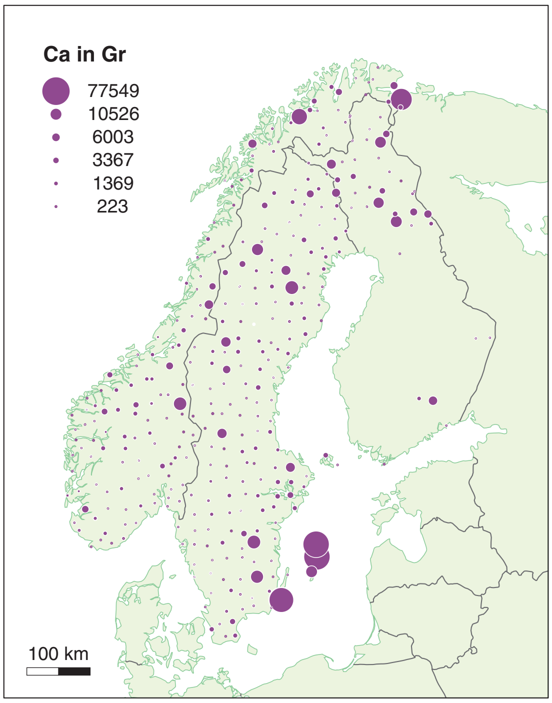
Finland

High Ca concentrations occur in agricultural soils in northern Finland where Ca originates from weathered mafic rocks of the "greenstone belts".

Norway

Elevated Ca concentrations in the soils occur across the country in higher level Caledonian nappes which consist of Neoproterozoic to Palaeozoic carbonates, marls and dolomites, often metamorphosed to marbles.





Sweden

Swedish soils generally have low content of Ca. Positive anomalies occur on Gotland (Silurian carbonates), slightly elevated values on Öland (Cambrian–Ordovician carbonates, marls, sandstones and shales), and in the Mälaren region (Palaeoproterozoic marble and secondary concentrations in marine clay). In northern Sweden, the Ca concentrations can be related to occurrences of mafic rocks containing relatively unstable pyroxene, amphibole and Ca-plagioclase. A smaller Ca anomaly in the eastern part of Bergslagen (Uppland) correlates with occurrences of limestone and dolomitic marble.

Cd (cadmium)

In comparison to the rest of Europe, soils in Norway, Sweden and Finland (apart from a few anomalies in Sweden and Norway) have relatively low Cd concentrations.

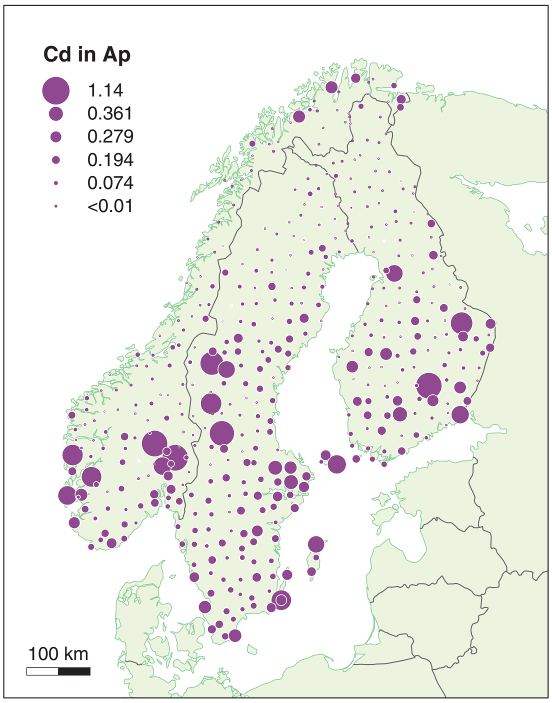
The main source of Cd is Zn-Pb-Cu ore deposits, where it substitutes into sulphides, predominantly galena and sphalerite. Additionally, Cd concentrations can be seen in soils associated with mafic rocks (gabbros, basalts) and fine-grained sedimentary rocks (shales).

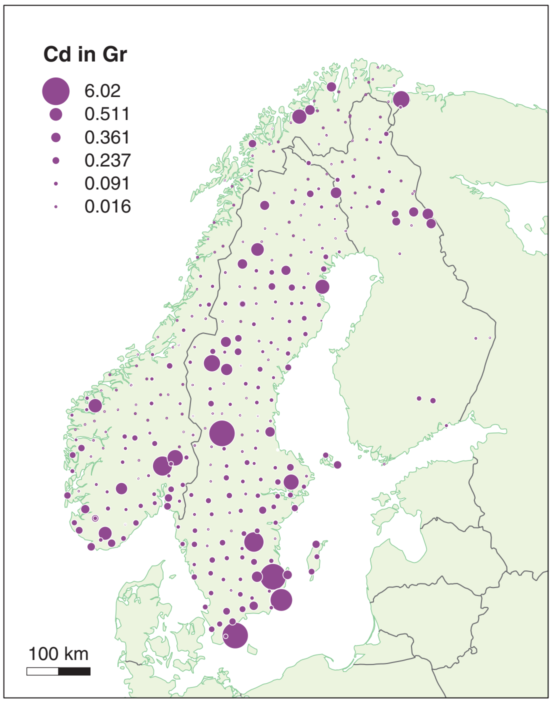
Cd has a strong affinity with organic matter and it is enriched in the organic layer in topsoils, in peat and in coal. An anthropogenic input of Cd can be related to fertilisers and the use of sewage sludge.

Cadmium shows weak positive correlation with Al and K contents, pH and TOC. Cd is mobile under oxidising conditions at a pH below 8 and moderately leached from sulphides in acidic environment. Under higher pH conditions, Cd precipitates together with carbonates. Clay minerals have a strong tendency to adsorb the element. On average, Swedish soils have higher Cd contents than soils from Norway and Finland.

Finland

Locally high Cd concentrations occur in organic-rich and clay-rich soils. On the Åland islands, elevated Cd contents in agricultural soils may have an anthropogenic origin (fertilisers).





Norway

High Cd contents in soils occur in the northern part of the Oslo Rift where the source is mainly black shales and mafic rocks. Along the coast of south-western Norway, the high precipitation and the related formation and build-up of organic-rich soils are responsible for the high Cd contents.

Sweden

Slightly elevated Cd concentrations occur in clay-rich soils of the Mälaren region. On Gotland, Cd might be concentrated both in the limestone and in the marine clay. In Jämtland, Cd in soils occurs in regions of Precambrian sandstone and alum shale related to Cu-Zn mineralisations. In Dalarna, the Cd concentrations correlate with Ag mineralisations (Älvdalen). In south-eastern Skåne, Cd reflects Cambrian sandstone where Zn and Ag mineralisations occur. Locally, an anthropogenic source (from fertilisers and natural sludge) of Cd must be considered (in the Mälardalen region, on Öland and in Skåne).

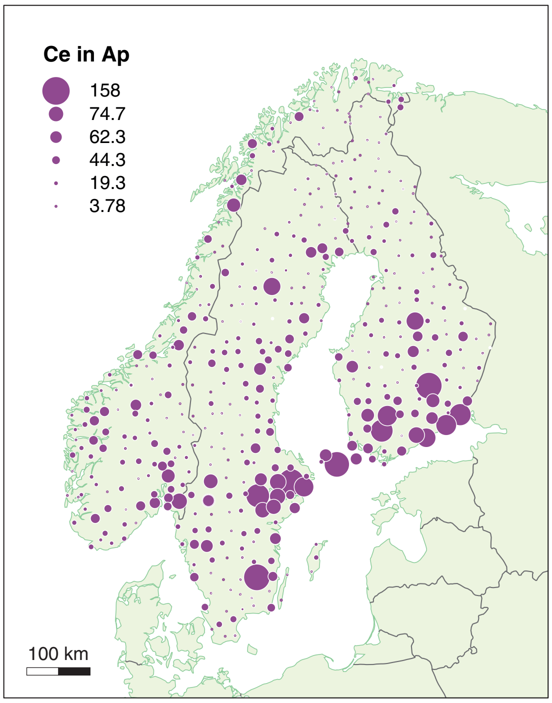
Ce (cerium)

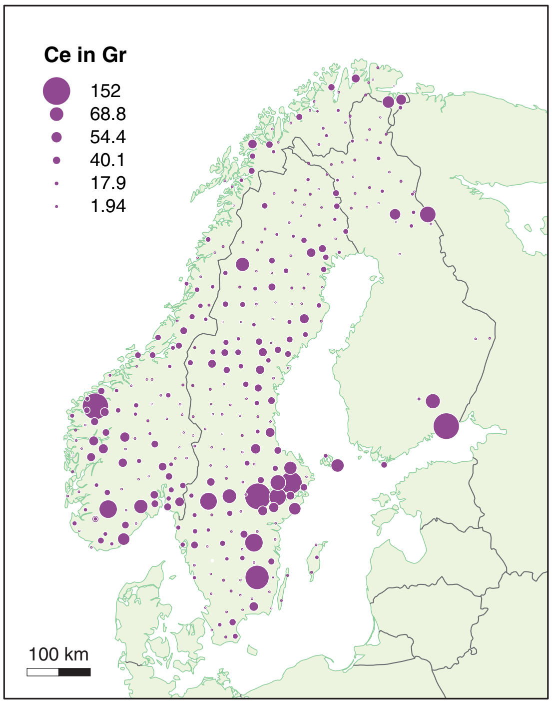
Ce is the most common of the rare earth elements (REEs). The primary source of Ce is accessory minerals in magmatic rocks, e.g. monazite, xenotime and allanite. Ce is not very mobile in the surficial environment and it is usually adsorbed to Fe oxides. Ce extractability is c. 52–53% due to its occurrence in resistant minerals.

In the three Nordic countries, soils have higher Ce contents compared with the rest of Europe. Relatively high values are observed in the Central Scandinavian clay belt and the clay-rich soils are enriched in Ce, reflected in the strong positive correlation with Al and K concentrations. The main sources of Ce in Scandinavian soils are granitoids, pegmatites and metamorphic rocks (paragneisses and migmatites).

Finland

High Ce concentrations occur in southern and central Finland, predominantly in clay-rich soils overlying granitoids with pegmatites.





Norway

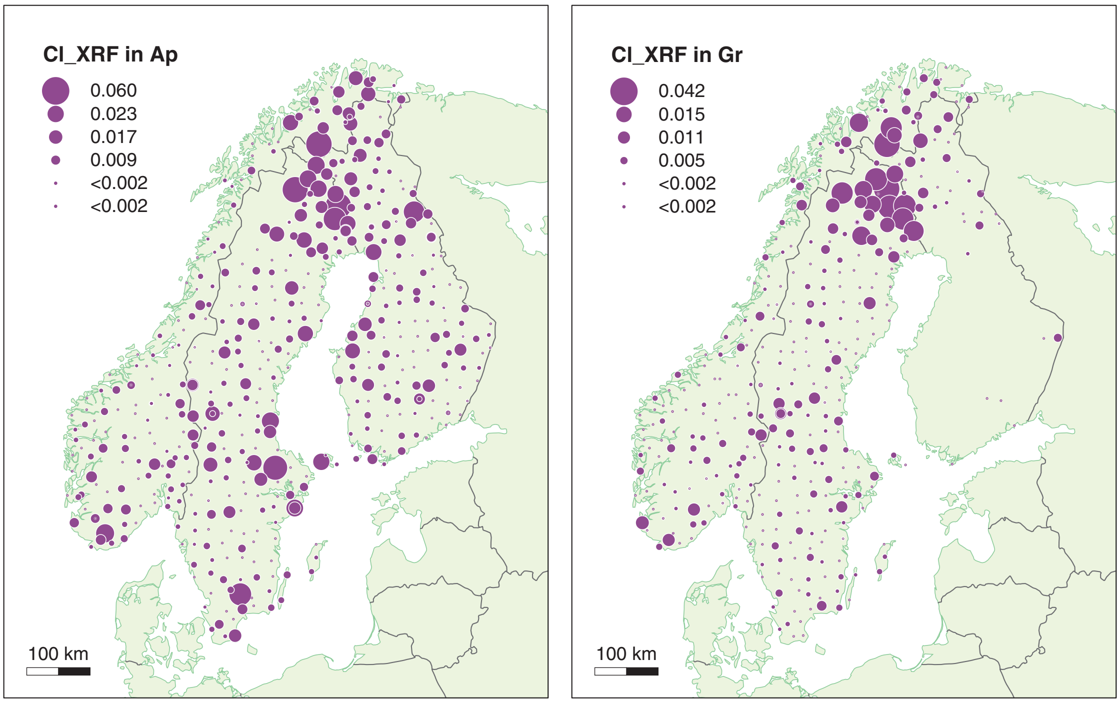
Elevated Ce oncentrations in the soils occur in the Oslo Rift, probably related to allanite-rich granitoids. Positive anomalies (especially on the XRF map) in southern, western and northern Norway are probably related to outcrops of Mesoproterozoic igneous rocks (Sveconorwegian and possibly older granitoids and pegmatites) which occur as tectonic windows within the Caledonides.

Sweden

High Ce contents occur in clay-rich soils in the Mälaren region. In Jämtland, Västernorrland, Västerbotten, the Boden region (Norrbotten), the southern inland (Småland) and Värmland–Dalsland, high Ce contents in soils originate from granitoids, pegmatites, paragneisses and migmatites underlying the soils and their weathering products.

Cl (chlorine)

Cl concentrations in both agricultural and grazing soils are very high in northern Scandinavia, especially in northern Sweden. This large Cl anomaly has been an enigma debated for a long time. There have been two main hypotheses about the origin of this large anomaly: the presence of old Precambrian evaporites (now eroded) and the scapolitisation of the mafic rocks. Cl is also an element which occurs in apatite and biotite, therefore weathering of apatite-bearing rocks and mica-rich metamorphic rocks in northern Sweden could have contributed Cl to the surface environment as well. Other potential sources of Cl from the crystalline basement are mafic minerals such as amphibole and sodalite, the only chloride occurring in igneous rocks. While sedimentary rocks can be cemented by Cl-rich brines, in arid areas or regions submerged under the sealevel for some geological time, sedimentary rocks in northern Scandinavia are highly metamorphosed and the primary cement components cannot be recognised. Additionally, Cl is very mobile due to its high solubility in water and only precipitates in extreme (evaporate) conditions, and is therefore rather rapidly transported via streams and rivers back to the sea. Any deposition of Cl during deglaciation is thus unlikely. Therefore the source of the enigmatic high Cl domain in the north still remains an open question.



Smaller, isolated Cl anomalies occur in the Mälaren region of Sweden where they can be directly related to Quaternary marine clay deposits and circulating salt brines in the groundwater system – a remnant left after sea level drop due to postglacial isostatic rebound. Small anomalies in the coastal areas of Norway are the result of high precipitation in the wet coastal climate and the steady input via marine aerosols, especially during winter storms.

Co (cobalt)

Cobalt is a common element occurring in sulphides and sulpharsenides. As a trace element it is present in mafic minerals such as olivine, pyroxene, amphibole and in Fe oxides. High Co concentrations therefore occur in soils derived from mafic and ultramafic rocks. Secondary concentrations of Co occur in clay-rich soils (strong positive correlation with the K and Al contents). In contrast, soils rich in organic matter (high TOC) are usually depleted in Co.

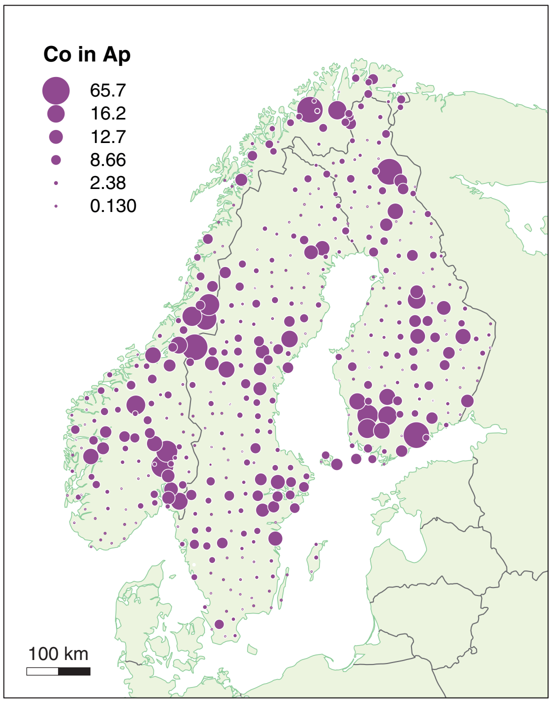
The element is quite mobile under acidic conditions and precipitates rapidly together with Fe-Mn oxides and hydroxides when the pH increases. Extractability of Co is high, 82–83% in this study. In comparison with the rest of Europe, the soils have relatively low Co content. The highest Co values are noted in Norway.

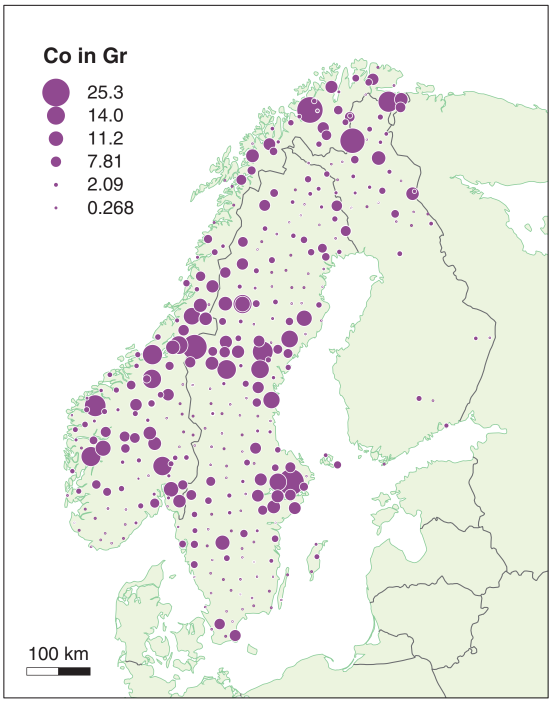
Finland

The highest Co concentrations occur in agricultural soils in northern Finland, within the greenstone belt. The Co concentrations in southern Finland occur in clay-rich soils which are underlain by schists.

Norway

High concentrations of Co in soils in central Norway are related to Zn, Pb, Cu, Ni and PGE mineralisations in mafic and ultramafic rocks. For example, metamorphosed ultramafic rocks rich in talc-soapstone are also enriched in Co. Co mineralisations which coincide with Co anomalies in soils are known from Brattbaken, east of Steinkjer and in northern Norway (Vaddas, Kåfjord). In the Oslo Rift in southern Norway, volcanic rocks and black shale correlate with high Co concentrations in soils.





Sweden

Elevated Co concentrations occur in clay-rich soils in the Mälaren region. In central Jämtland, Co anomalies correlate with occurrences of ultramafic rocks (soapstone in Handöl) and with Cu-Zn mineralisations in the Caledonides. Alum shale is another source of Co in the foreland of the mountain chain. To the east, high Co concentrations in soils have their source in Palaeoproterozoic mafic and ultramafic intrusions.

Cr (chromium)

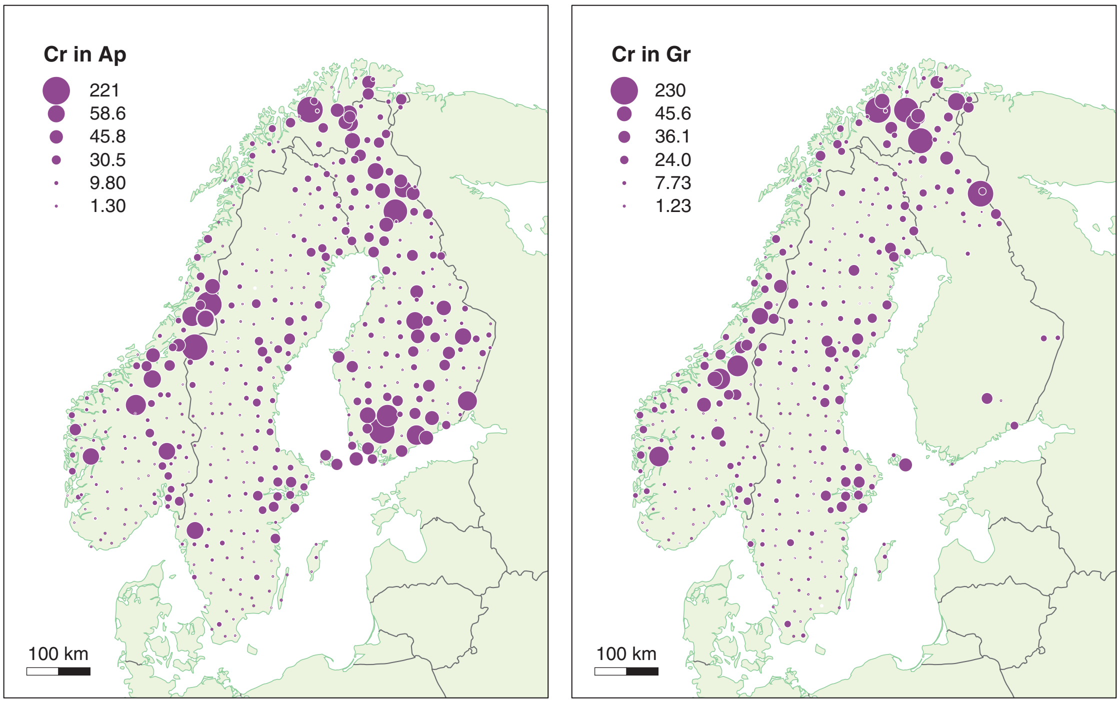
Cr is a common element in mafic and ultramafic rocks where it occurs as chromite or as a trace element in amphibole, pyroxene, spinel, mica and garnet. It shows a strong correlation with Ni. Cr has rather low mobility and a low extractability of 34%, but it is usually found in sediments and soils overlying mafic and ultramafic rocks. Cr is preferentially concentrated in clays, reflected in strong positive correlation with K and Al. The highest Cr contents occur in soils of northern Finland and northern Norway, with a strong affinity to the presence of mafic and ultramafic rocks (the greenstone belts).

Finland

In southern Finland, Cr shows high contents in clay-rich soils of the Central Scandinavian clay belt. In northern Finland, Cr anomalies are related to the occurrence of mafic and ultramafic rocks (greenstone belts).

Norway

High Cr contents occur in the soils in central Norway (ophiolite rocks in the Caledonides, soapstone) and in northern Norway (greenstone belts). Smaller Cr anomalies occur on the western coast of southern Norway (unknown origin) and in the Oslo Rift (mafic volcanic rocks and shales).



Sweden

Elevated concentrations of Cr occur in clay-rich soils in the Mälaren region. In central Jämtland, in the Handöl area, elevated Cr concentrations reflect the mafic and ultramafic rocks of the Köli Nappe (ophiolites, soapstone). Elevated Cr values in the coastal region occur in clay-rich soils and correlate with mafic and ultramafic intrusions located in the area.

Cs (caesium)

Most Cs in Scandinavian soils originates from weathered crystalline rocks rich in K-bearing minerals (K-feldspars and micas) where Cs commonly substitutes. These rocks are represented by granitoids and related pegmatites. Secondary Cs has a strong tendency to be adsorbed to clay minerals, especially in marine fine-grained sediments and soils. Cs is therefore enriched in clay-rich soils of the Central Scandinavian clay belt.

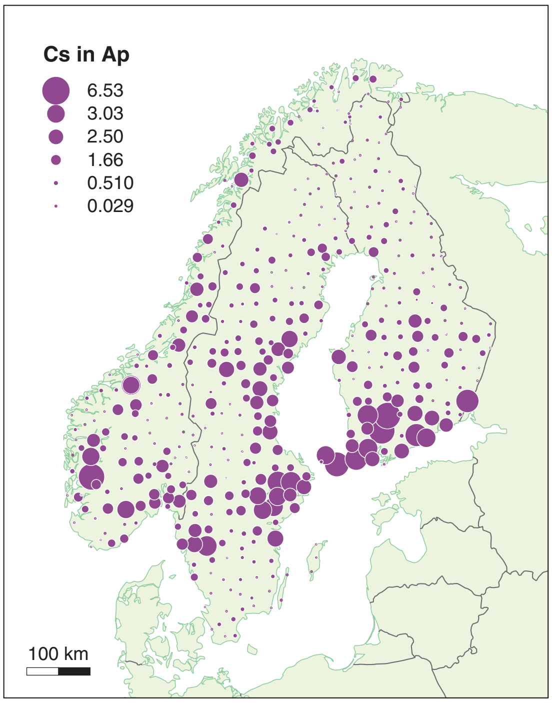
The affinity of Cs to clay minerals is also reflected in a strong correlation with Al and K contents. When released through weathering, Cs is rapidly adsorbed onto clay minerals. Organic-rich soils are usually depleted in Cs. The extractability is low (23% in Ap and 21% in Gr), but the general elemental pattern on maps for aqua regia solution and total concentrations (XRF) are similar.

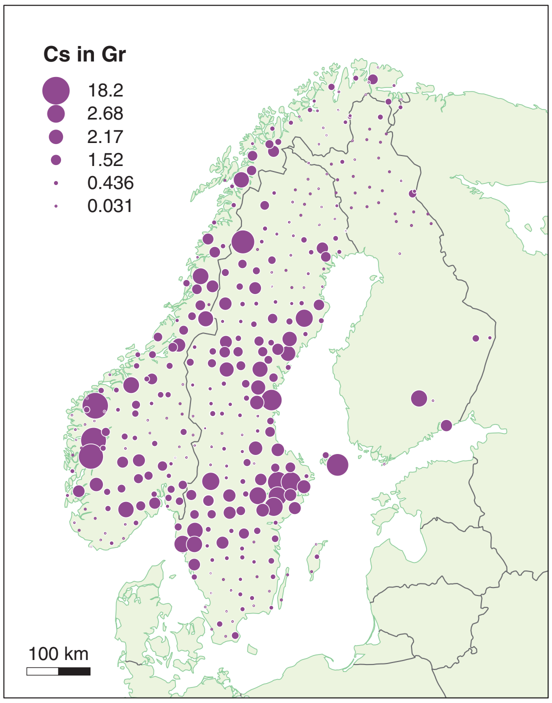
Finland

High Cs concentrations occur within the Central Scandinavian clay belt in southern Finland.

Norway

Interestingly, high Cs concentrations in soils correlate with Zn mineralisations in central Norway. Some of the Cs anomalies can be related to the outcrops of granitoids and pegmatites which are both Sveconorwegian and Caledonian in age. The contents of Cs in soils within the Oslo Rift originate from sedimentary rocks (shale) and felsic igneous intrusions.





Sweden

Elevated Cs contents in soils of the Mälaren region and along the eastern coast are related to the occurrence of clays. In central Jämtland, Cs concentrations are related to the occurrence of fine-grained metasedimentary rocks (Palaeozoic shale). Very low values are characteristic of the Dala sandstone.

Cu (copper)

Cu mainly occurs in sulphide form. As a trace element it can be found in micas, pyroxene and amphibole, and it is thus more abundant in mafic rocks. Fine-grained sediments are usually enriched in Cu and the element therefore shows a positive correlation with Al and K contents, which indicates a strong preference to bind in clay-rich soils.

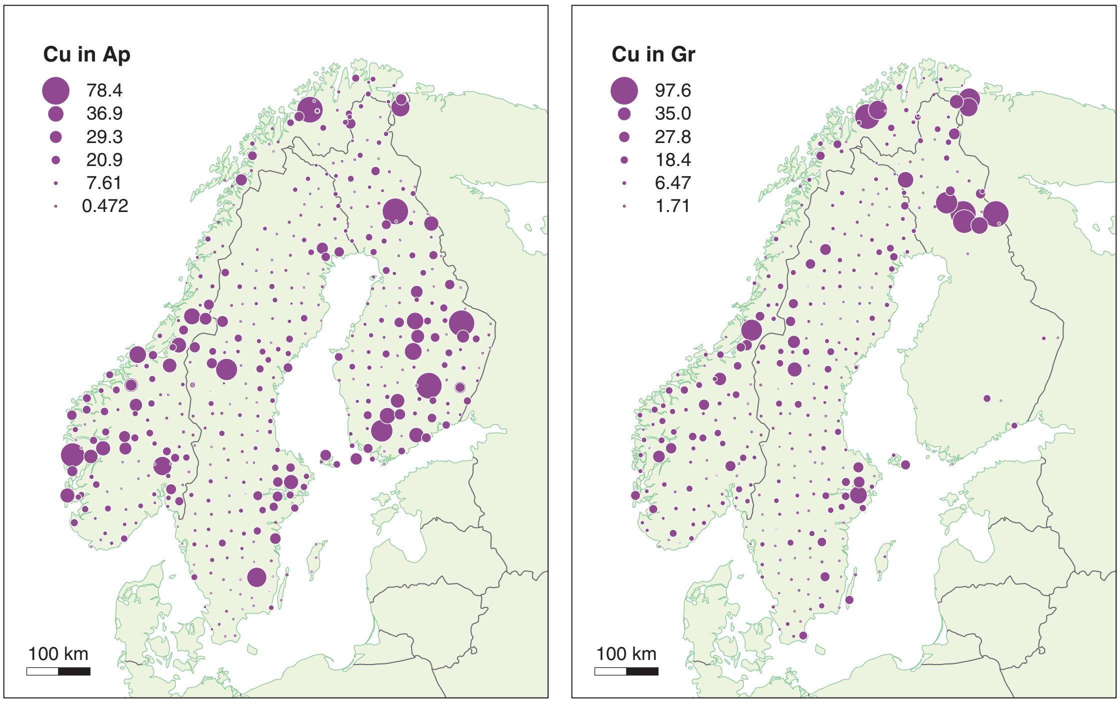
Cu is mobile under slightly acidic conditions and precipitates together with Zn and Fe hydroxides. In organic-rich soils, Cu precipitation is often controlled by microbial activity. Cu mobility increases during hydrothermal activity and low-grade metamorphism. It is a base metal of high economic importance.

Extractability of Cu is very high, nearly 100% of Cu can be leached from the sample by Aqua Regia. The low Cu contents in the soils are caused by intensive leaching under acidic conditions in the relatively wet climate.

Norwegian and Finnish soils have higher Cu contents than Swedish soils. Elevated Cu concentrations occur over the Central Scandinavian clay belt.

Finland

High Cu concentrations occurring in Finnish Lapland are related to the presence of Cu-clay-rich soils overlying polymetallic mineralisations and layered intrusions. In central Finland, high Cu concentrations occur in soils overlying schists and black shale. The Lapland greenstone belt does not show up well with respect to Cu contents – the anomalies are hidden due to the organic-rich nature of the soil (peat-rich samples). In contrast to Hg, Pb and Se, Cu does not show a tendency to enrich with organic material but is somewhat depleted in such soils.



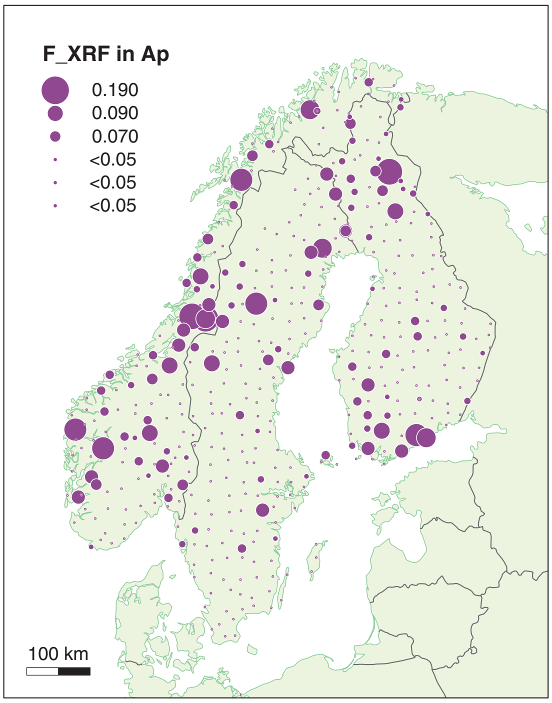
Norway
Elevated Cu concentrations in Norwegian soils are mainly related to known polymetallic ore deposits (VMS deposits) in central and northern Norway. Rather high Cu concentrations also occur on the Hitra Island and in the Oslo Rift.

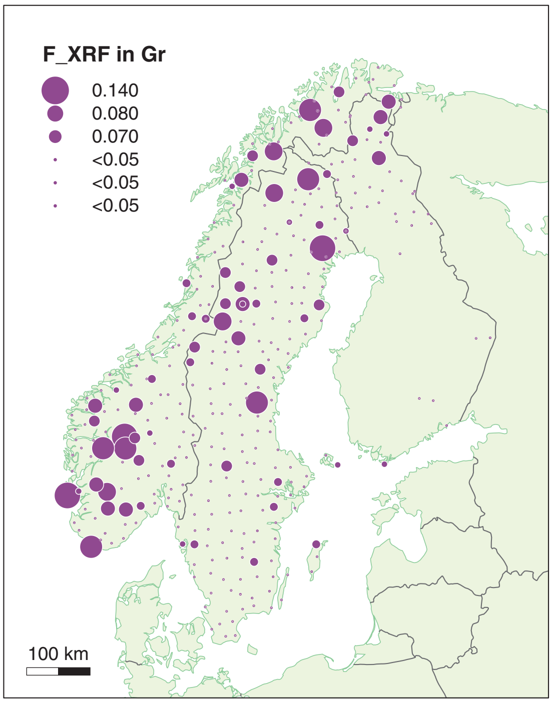
Sweden
Elevated Cu concentrations occur in clay-rich soils of the Mälaren region. In Jämtland and southern Sweden, Cu anomalies correlate with known polymetallic mineralisations. As a peculiarity, no clear Cu anomalies can be found in regions with large base-metal ore deposits such as the Skellefte mining district and Bergslagen.

F (fluorine)
F is a common minor element in igneous and sedimentary rocks where it forms primary minerals (fluorite, topaz) and occurs as F-anions in common rock-forming and accessory minerals (apatite, amphiboles and micas). Both igneous and sedimentary mica-rich rocks are the main source of F. The detection limit for F with XRF is rather high and thus the lower values should be treated with some caution.

F concentrations in soils are generally low. A few anomalies are thought to correlate with the fluorite, apatite, mica and amphibole enrichment in soils. F released from these minerals can be adsorbed to the clay minerals.

Finland
High F concentrations occurring in soils in northern and southern Finland probably originate from underlying granites and pegmatites containing minerals rich in F (fluorite, apatite, mica). The large F anomaly located close to the Koitelainen Fe-V ore deposits in the north can be related to the specific composition of this layered mafic intrusion hosting mineralisation.





Norway

Some of the higher values of F occur on the western coast of Norway and might originate from the steady input of marine aerosols. Alternatively, they could be related to Al-smelters.

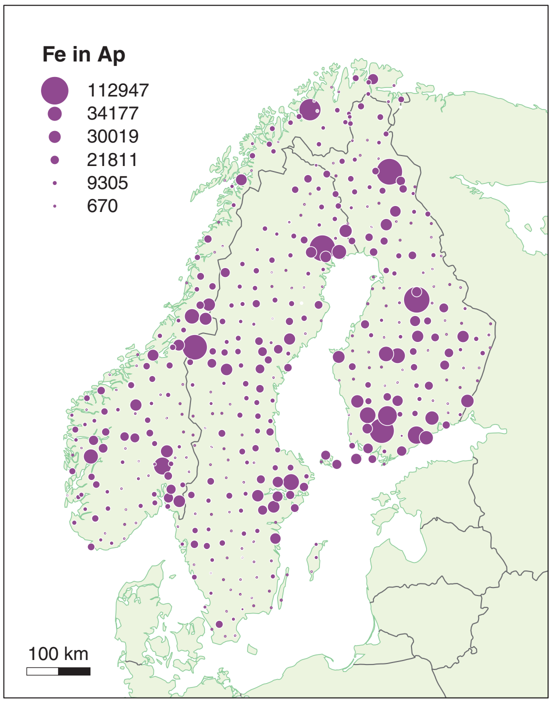
Sweden

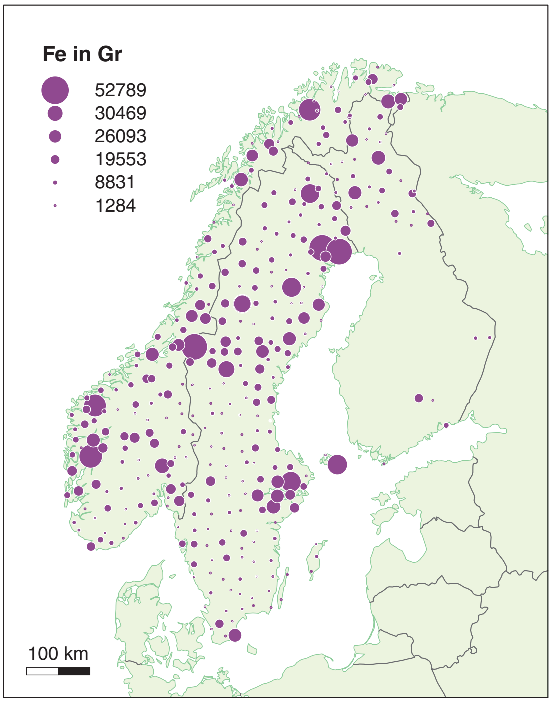
In Sweden, elevated concentrations of F in Västerbotten may relate to occurrences of fluorite-W-Mo-Cu mineralisations in granite and fluorite in sandstone. F anomalies in grazing land samples from northernmost Sweden can be related to the occurrence of the apatite-iron Kiruna type deposits and to occurrences of fluorite.

Fe (iron)

Fe is a very common element and occurs in many forms: as sulphides, oxides and as a major component of a variety of common silicate and aluminosilicate rock-forming minerals. High Fe contents are typical of mafic and ultramafic rocks, but sedimentary rocks can also contain substantial amounts, sometimes reaching concentrations of economical value, e.g. banded-iron formation (BIF) ore deposits. Fe compounds are soluble under acidic conditions and precipitate under oxidising and alkaline conditions. In general, the geochemical properties of Fe depend to a large extent on the element speciation, e.g. Fe^{2+} is more mobile than Fe^{3+}. Extractability of Fe in aqua regia is relatively high (72%).

Soils in Norway, Sweden and Finland locally have quite high Fe contents due to outcrops of mafic and ultramafic rocks, and the presence of significant iron ore deposits. Slightly elevated concentrations occur in the Central Scandinavian clay belt and other clay-rich soils, indicated by a positive correlation with Al and K. In clays and metasediments, Fe often occurs as Fe hydroxides and Fe coatings.





Finland

High Fe concentrations occur in central and northern Finland in the vicinity of known Fe deposits. In southern Finland, the Fe contents occur in the clay-rich soils of the Central Scandinavian clay belt.

Norway

Elevated Fe concentrations occur in soils in the Oslo Rift (associated with outcrops of mafic to intermediate volcanic rocks), and along the west coast between Bergen and Trondheim. There is a correlation between high Fe content in soils and known Cu-Zn deposits. Local, isolated anomalies can be related to the presence of mafic and ultramafic rocks and their weathering products. The Fe content along the coast can be related to the precipitation of Fe-Mn oxides and hydroxides.

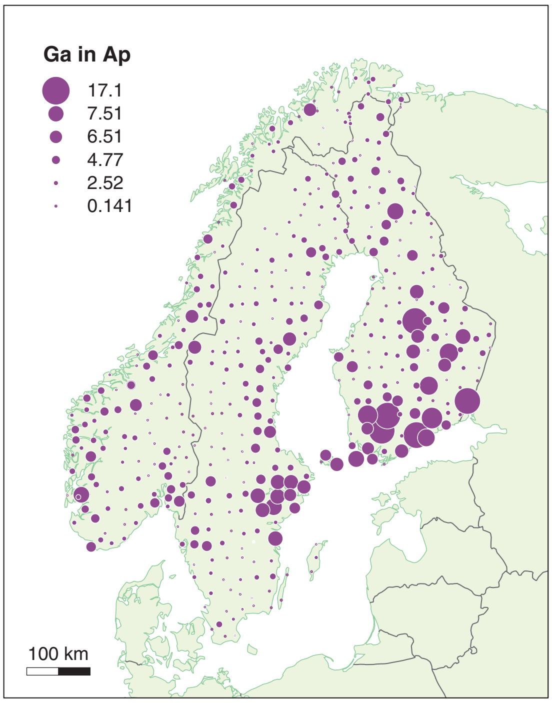
Sweden

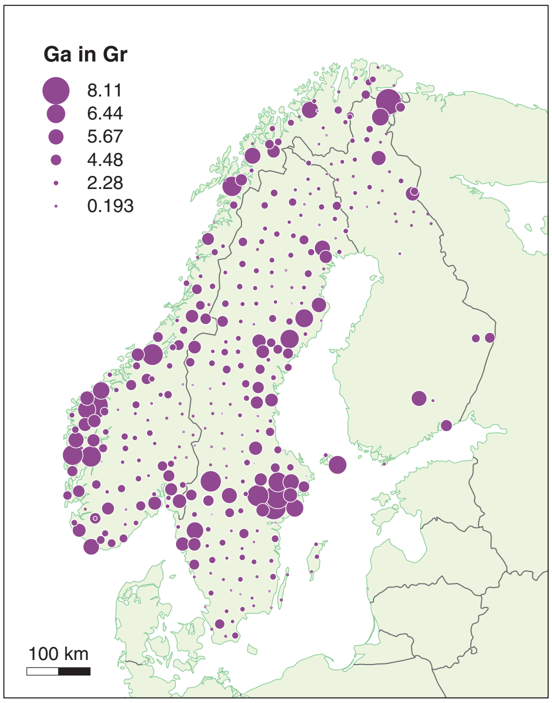
High Fe concentrations in soils occur in central Jämtland (amphibolites, ultramafic rocks), in Norrbotten (the Boden–Haparanda region associated with mafic and ultramafic intrusions) and in clay-rich soils of the Mälaren region. The Kiruna ore deposits in northern Sweden do not, however, show large Fe anomalies in the overlying soils due partly to the deep-seated nature of the ore deposits and partly because of the low pH in the surficial environment.

Ga (gallium)

Concentrations of Ga in agricultural soils in Norway, Sweden and Finland are relatively high in comparison with the rest of Europe. Ga is a rather rare element occurring as substitutions in Zn minerals (sphalerite), in some silicates (amphibole, feldspar, mica) and in clay minerals.

Ga concentrates in fine-grained sediments and clay-rich soils (the Central Scandinavian clay belt) and correlates strongly with Al and K. The highest Ga values are observed in soils in southern Finland. Ga tends to have higher concentrations in soils overlying alkaline intrusive rocks (e.g. syenites) and in Al-rich metasediments (e.g. shale and greywacke). Locally, it may show higher





concentrations in organic soils and soils with Fe-Mn hydroxides. Ga is mobile under acidic conditions but its extractability is rather low in aqua regia, 32% in this study.

Finland

High Ga concentrations occur in southern Finland in the clay-rich soils of the Central Scandinavian clay belt. The high Ga concentrations in central Finland can be related to the presence of sulphide mineralisations.

Norway

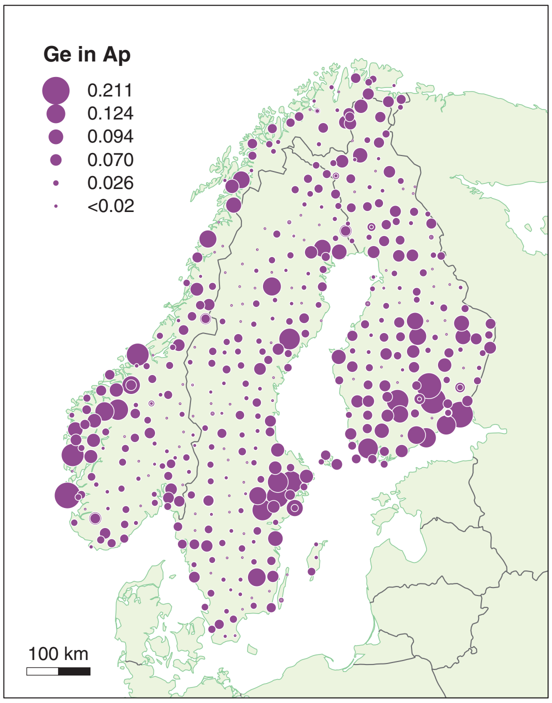
Elevated Ga concentrations are observed in the Oslo Rift (alkaline intrusions) and, especially for the grazing land samples, along the west coast. The latter is possibly related to specific weathering condititions.

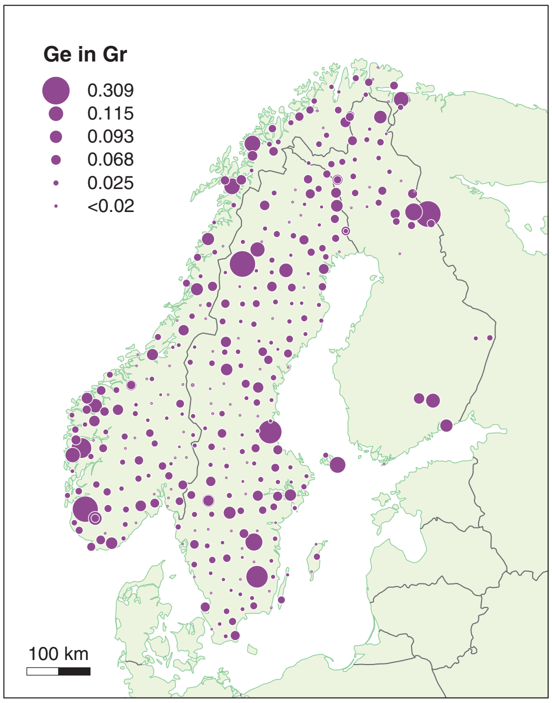
Sweden

High Ga concentrations occur in the clays of the Mälaren region and along the eastern coast of the Baltic Sea. Anomalies of total concentrations of Ga are higher than leachable Ga in northern Sweden which indicates its residence in resistant minerals, e.g. K-feldspars and micas.

Ge (germanium)

Concentrations of Ge in soils in Norway, Sweden and Finland are relatively high on a European scale. High Ge concentrations occur in soils of the Central Scandinavian clay belt. Ge occurs in fine-grained sediments, e.g. shales, where it is fixed as Ge hydroxides by clay minerals. Ge thus shows a strong positive correlation with Al and K. It tends to be enriched in organic-rich soils and sediments. In rocks, it mainly occurs as sulphide and as a trace element in micas, garnets and topaz from late-stage magmatic rocks, i.e. granites and pegmatites. The highest Ge concentrations in soils occur in Finland and the lowest are found in Sweden.





Finland

High Ge values are observed in southern Finland in the clay-rich soils of the Central Scandinavian clay belt. Ge anomalies in peat soil samples in south-eastern Finland follow known Au mineralisations.

Norway

A striking pattern of high Ge values occurs along the entire west coast of Norway. We do not currently have a good explanation for this enrichment. A comparatively minor Ge anomaly occurs on the eastern flank of the Oslo Rift, especially in the agricultural soil samples.

Sweden

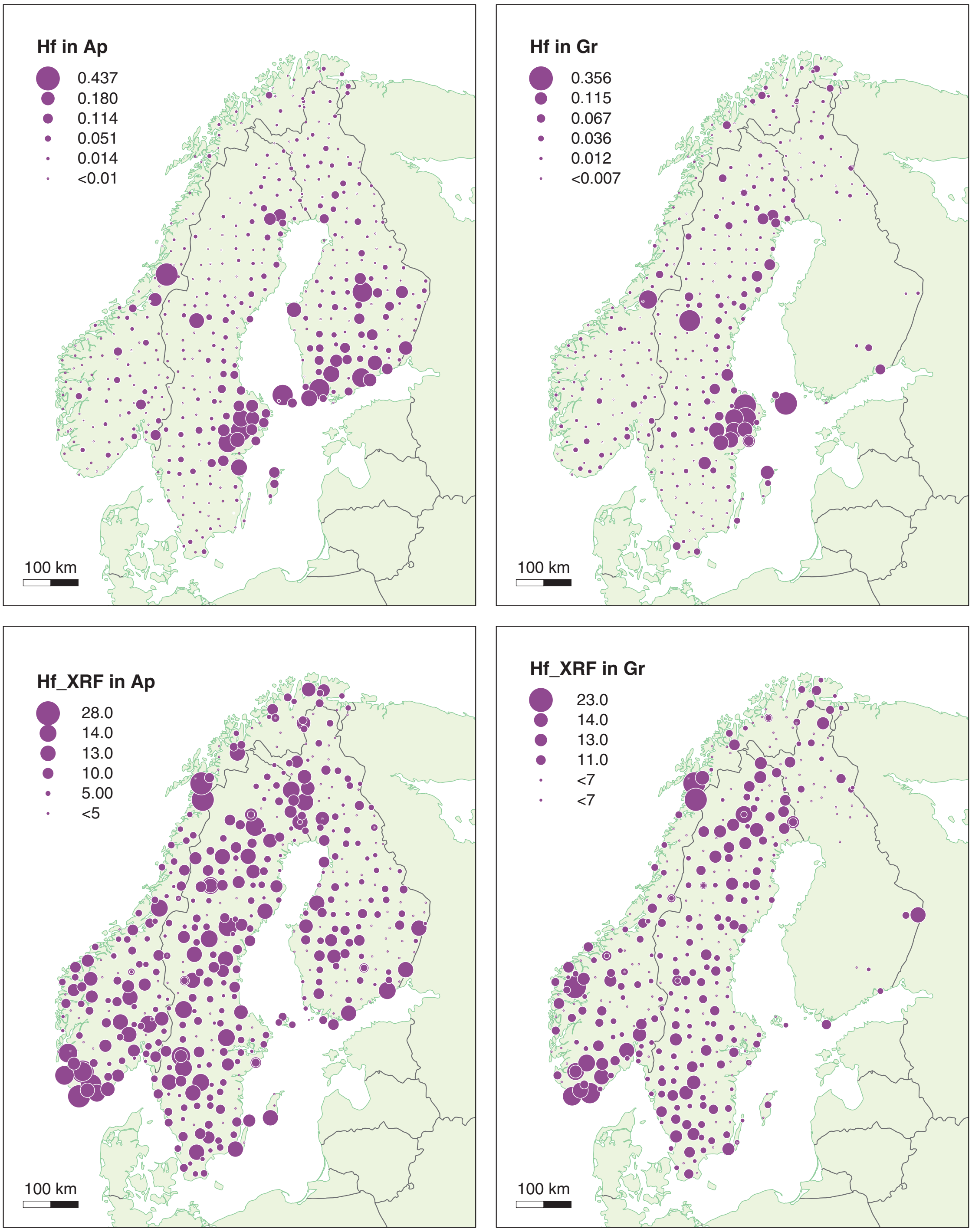
Elevated Ge concentrations occur in agricultural clay-rich soils in the Mälaren region and, to some extent, along the east coast of Sweden. Ge concentrations in Västerbotten correlate with Ag, Cd, Bi and sulphide mineralisations.

Hf (hafnium)

Primary sources of Hf are felsic igneous rocks, especially alkaline rocks where the Hf resides in resistant accessory minerals such as zircon. The extractability of Hf is therefore very low (1%) in aqua regia. Subordinate amounts of Hf occur in rock-forming minerals, e.g. pyroxene and amphibole. Secondary enrichments of Hf can occur in clay-rich soils (leachable Hf), which is indicated by strong positive correlation with Al and K content, and pH. The Swedish and Finnish soils are richer in soluble Hf than Norwegian soils (high Hf concentrations in the Central Scandinavian clay belt).

Finland

High Hf concentrations occur in clay-rich soils of the Central Scandinavian clay belt in the south. Some of the larger isolated anomalies in central Finland can be related to the presence of alkaline intrusions and their weathering products.



Norway
Hf total concentrations are high in Norwegian soils, especially in areas underlain by alkaline intrusive rocks, e.g. the Rogaland Anorthosite Province in southern Norway.

Sweden
High Hf concentrations occur in clay-rich soils from the Mälaren region, in Jämtland (fine-grained sediments such as Palaeozoic shale) and in southern Norrbotten (the Boden region, fine-grained sediments overlying mafic rocks). Total contents (XRF) of Hf show many local anomalies which

can be related to the presence of Zr-Hf-bearing resistant minerals in the soils, such as zircon, and the presence of Hf-enriched felsic intrusions in the bedrock.

Hg (mercury)

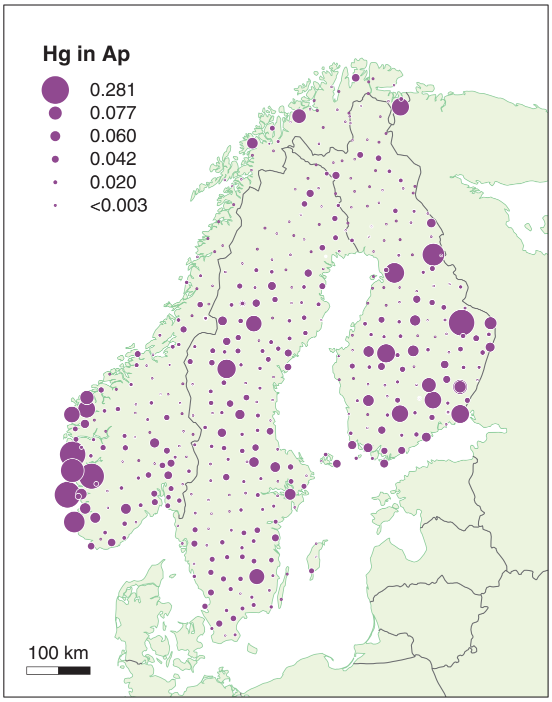
Hg occurs mainly in sulphide form in hydrothermally altered volcanic and volcaniclastic rocks. Secondary enrichments occur in fine-grained sedimentary rocks, especially in black shales. Hg shows an exceptionally strong affinity to organic matter (TOC) and pH, and is often bound to clay minerals. Coal can show high Hg concentrations, and coal-fired power plants are arguably seen as the most important contributor of Hg to the environment. On a local scale, waste incinerators, crematories and hospitals are prominent sources of anthropogenic Hg contamination. In mineral exploration, Hg is often used as pathfinder for Au, Ag and Sb ore deposits. The highest median values of Hg occur in Swedish soils, while the maximum concentrations are observed in Norway.

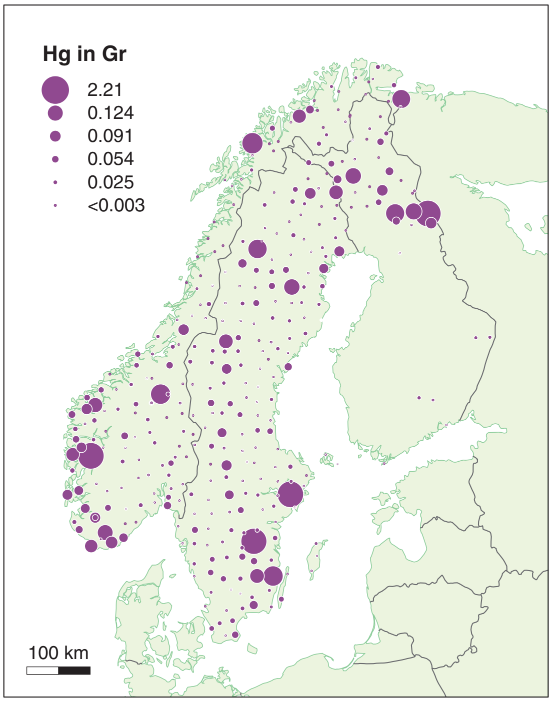
Finland

Local high Hg concentrations are clearly related to the occurrence of organic-rich soils (peat).

Norway

High Hg concentrations along the south-west coast of Norway are related to the climatic conditions. A wet and cold climate leads to the build-up of organic-rich soils (see also Se, S and P), which provide a good trap for Hg, independent of source. The observed anomaly occurs around the city of Bergen and the Zn-smelter at Odda, both potential anthropogenic sources of Hg, but is thought to be primarily related to natural sources. Some slightly elevated values in the Oslo and Hamar area (Ap) are related to the occurrence of black shales. Some anomalies in central and northern Norway mark known mineralisations.





Sweden

The Hg concentrations in central Jämtland occur in soils overlying Caledonian (Cambrian–Ordovician) black shale with high organic matter content and sulphides. Isolated Hg anomalies in northern Sweden and the Stockholm area overlap to some extent with known gold mineralisations.

In grazing land, samples with high Hg concentrations occur in the Stockholm area. The source is thought to be anthropogenic.

In (indium)

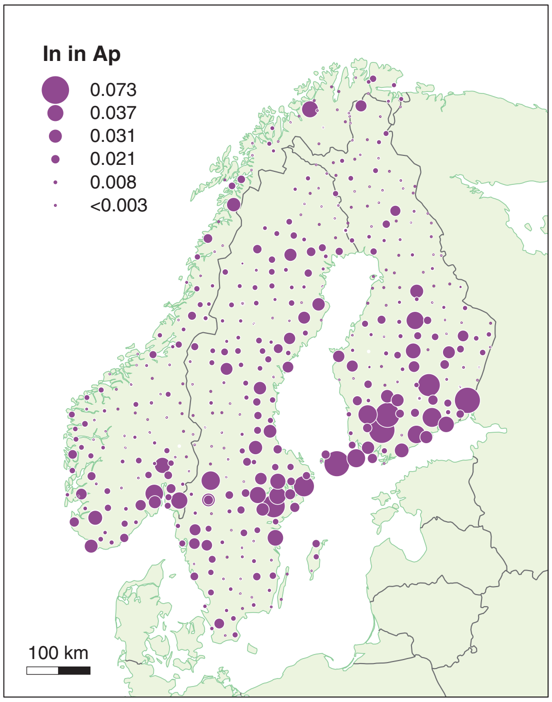
Primary In can be found in sulphides, especially in chalcopyrite and sphalerite. It is found in sulphide ores (especially Zn-Pb-Cu) and tin mineralisations associated with cassiterite. The element has a strong preference to concentrate in clay-rich soils (strong positive correlation with K and Al). Slightly elevated In concentrations occur at higher pH (binding to carbonates and Fe oxides) and in organic-rich soils (sulphide forms). The highest In concentrations in Norway, Sweden and Finland occur in clay-rich soils of the Central Scandinavian clay belt. The highest median values have been noted in Swedish soils and the maximum values are observed in Finland.

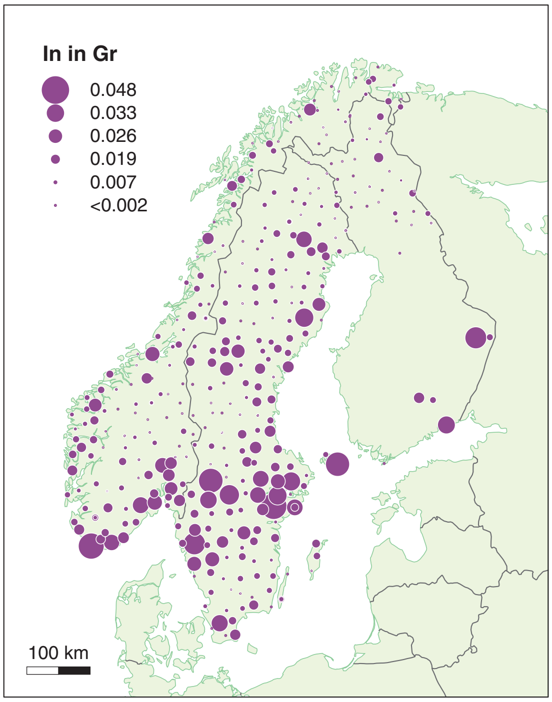
Finland

High In concentrations occur in clay-rich soils of the Central Scandinavian clay belt in southern Finland. These large anomalies overlap with Zn-Cu ore deposits, e.g. Salo-Issakka in the south-east and Ni-Cu-Co ores in the south-west, e.g. Vammala. In central Finland, the In contents in the soils coincide with numerous Zn-Cu-Ag deposits, e.g. Pyhäsalmi.

Norway

Elevated In concentrations occur in soils from the Oslo Rift (sulphide mineralisations and black shale) and associated with ore deposits from the Kongsberg region. The large anomaly in southernmost Norway (Gr samples) occurs in the vicinity of V-Fe-Ti ore deposits, e.g. the world class Tellnes anorthosite-hosted Ti deposits. The southern tip of Norway is, however, also the site of





a strong climatic gradient and it cannot be excluded that In is enriched due to special climatic conditions (see Reimann et al. 2009b). In northern Norway, In contents correlate with Cu-Co mineralisations.

Sweden

Elevated In concentrations occur in clay-rich soils of the Central Scandinavian clay belt in the Mälaren region and along the eastern coast. In Värmland, high In values correlate with sulphide mineralisations. In Jämtland, the In concentrations might originate from Caledonian metasedimentary rocks, black shales rich in organic matter and sulphides, or known Cu-Zn mineralisations within the Caledonian mountain chain (e.g. Storsjö) and within the Fennoscandian Shield (e.g. Tjärnberget). Slightly elevated In concentrations in the Skellefte region correlate with Cu-Zn VMS deposits. Elevated In concentrations in Dalarna and in coastal eastern Sweden may also correlate with Sn mineralisations (e.g. in the Sollefteå region).

K (potassium)

In Norway, Sweden and Finland, K concentrations are relatively high compared with in continental Europe. K is a common alkali metal element, occurring in large concentrations in felsic, alkaline and metamorphic rocks rich in K-feldspar and micas. Secondary K is a major component of clay minerals such as illite in sedimentary rocks. Although K, once released from the mineral structure, is very soluble and mobile, its extractability in aqua regia is very low (8%). This indicates that primary K resides in minerals which are resistant to chemical weathering (e.g. K-feldspar). The elemental pattern on the map for leachable K shows almost exclusively K anomalies associated with the presence of clay-rich soils, while XRF results (total concentrations) show variable concentrations of K in soils reflecting the types of underlying bedrock.

K is a major component of clay-rich soils (together with Al), and high K concentrations occur over the Central Scandinavian clay belt. K correlates positively with pH and is depleted in organic-rich soils. On average, Norwegian soils show higher K contents than soils from Sweden and Finland while the highest K concentrations occur in clay-rich soils in Finland. Soils underlain by Proterozoic crystalline rocks of the Fennoscandian Shield tend to have higher K concentrations than soils from the Caledonides and from Archaean domains. Elevated K concentrations may occur in areas where granitic and alkaline rocks, rich in K-feldspar (and micas) show higher degrees of weathering. Climate and rainfall therefore have a significant influence on K behaviour.

Finland

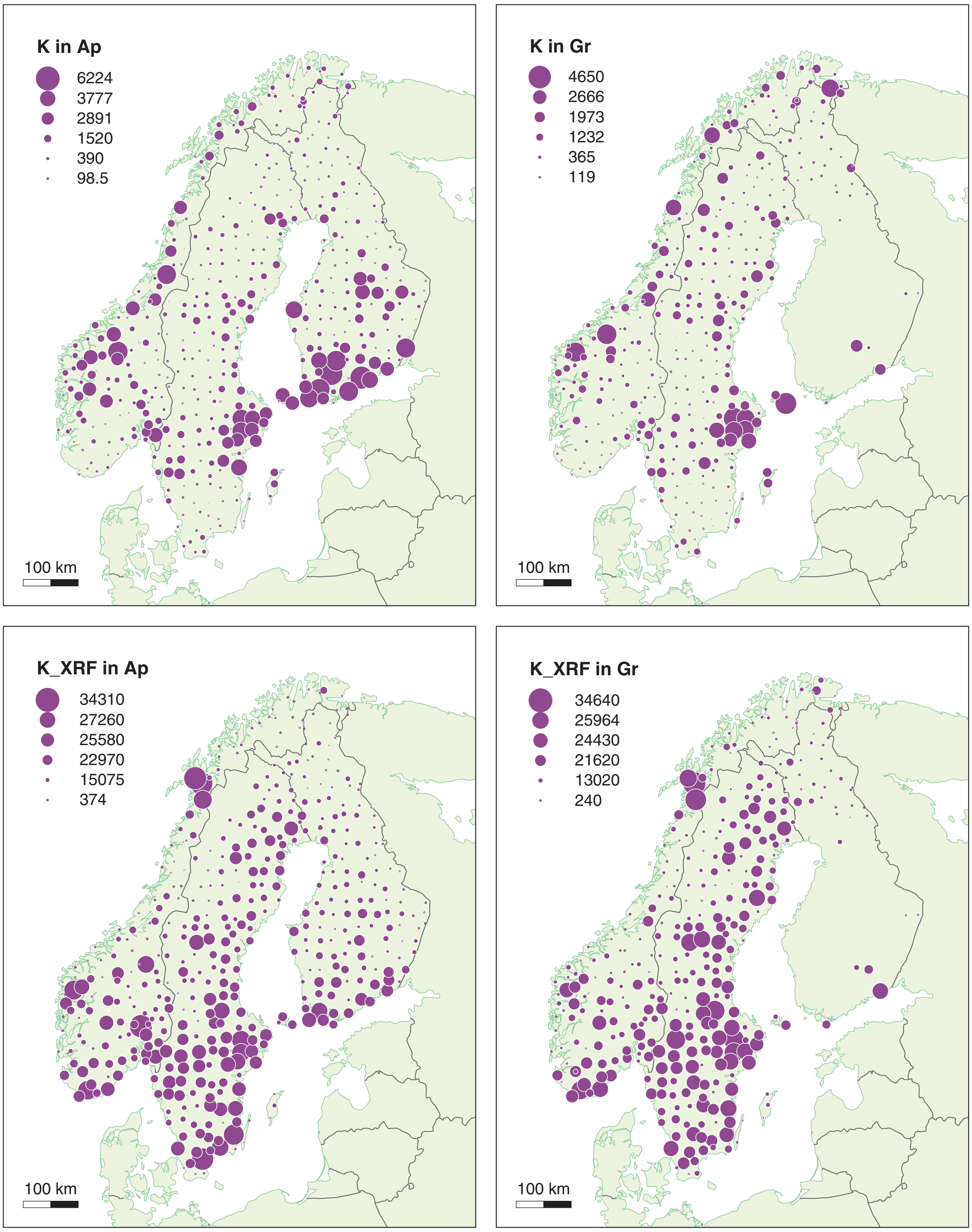
High K concentrations (both leachable K and total concentrations) occur in clay-rich soils overlying granites (rapakivi granites) in southern Finland.

Norway

High K concentrations in the soils occur along the coast and in the Oslo Rift (felsic volcanic rocks rich in K-feldspar and micas). Large anomalies in the XRF results occur in northern Norway (Lofoten region) and correlate with metamorphosed felsic igneous rocks rich in K feldspar and micas.

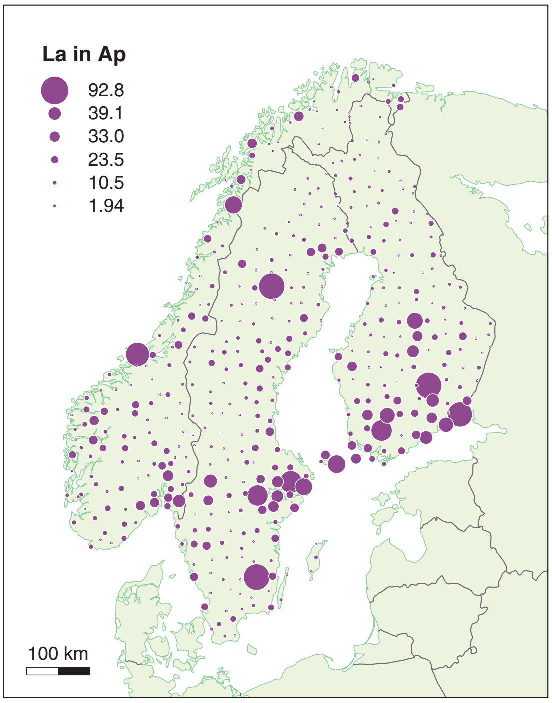
Sweden

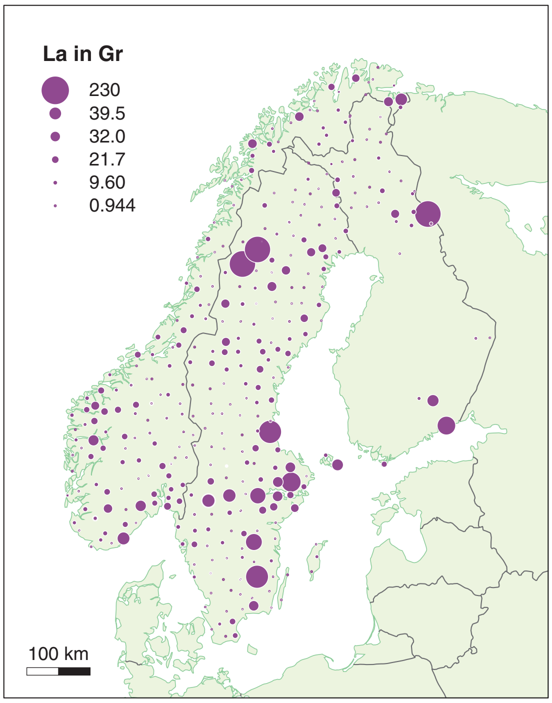
High concentrations of K in soil occur in the Mälaren region (within the Central Scandinavian clay belt), in Värmland, Dalsland and in Jämtland. Total concentrations of K are relatively high within the Fennoscandian Shield in Sweden and correlate with the high clay content in soils overlying feldspar and mica-rich felsic rocks (intrusive, alkaline, volcanic and highly metamorphosed).



La (lanthanum)

La is one of the REEs and occurs mainly in accessory minerals and as a trace element in rock-forming minerals in felsic rocks and the leucosomes of high metamorphic grade migmatites. In sedimentary rocks, La resides in heavy minerals and, during weathering, enters the clay minerals. In Norway, Sweden and Finland, La is concentrated in fine-grained sediments (leachable La) and clays (the Central Scandinavian clay belt) which is reflected in its positive correlation with Al and K. The main sources of La are granites and pegmatites. Organic-rich soils may have enhanced La contents.





La is not very mobile in the surficial environment. Intermediate extractability by aqua regia of La (69% in agricultural soil and 63% in grazing land soil) is responsible for the similar elemental pattern in leachable La and XRF results. The only difference can be observed in Norway where the XRF map shows larger La anomalies in the south and in the west.

Finland
High La concentrations occur in southern Finland, in clay-rich soils of the Central Scandinavian clay belt overlying granites (rapakivi granites). A large anomaly in grazing land (aqua regia and XRF method) samples from north-eastern Finland coincides with the presence of Nb, Co, Au and Fe mineralisations.

Norway
Elevated La values in soils have been observed on Hitra island (felsic intrusions and pegmatites) and in the Oslo Rift (felsic volcanic and intrusive rocks, shale and clay-rich soils), and in soils overlying basement rocks of western Norway and in the Lofoten region.

Sweden
High concentrations of La occur in the Mälaren region (in clay-rich soils), in Värmland, Dalsland, south-east Sweden (anomalies together with Cu, Cd, Ag, Ba, Ca), in Jämtland, in Västerbotten and in Norrbotten. The large La anomaly in south-eastern Sweden correlates with W mineralisation hosted by granite (1.86–1.84 Ga). In Bergslagen and in the Mälaren region, elevated La concentrations might be related to the underlying marine clay and metasedimantary rocks including greywacke and sandstone. The La anomaly in Jädersbruk (western part of the Mälaren region) coincides with W, Pb, Zn and Cu mineralisations and the occurrence of calc-silicate skarn. At the border to Norway, some anomalies are related to the Sveconorwegian younger granite (1.27–1.15 Ga) and with some W-Fe skarn mineralisation (e.g. in Soliden).

A large La anomaly (both aqua regia and XRF methods) in Västerbotten coincides with U ore deposits in the Arjeplog–Arvidsjaur–Sorsele uranium province in the Fennoscandian Shield (e.g. Björklund, Virka, Långträsk). In the Norrbotten county, La anomalies overlap with outcrops of intrusive rocks (granite, quartz-monzonite) hosting W-scheelite mineralisation.

Li (lithium)

Li is a lithophile element which only rarely forms its own minerals (in pegmatites) but commonly occurs as a trace element in a large variety of silicates from pyroxene to K-feldspar. In clay minerals (e.g. illite) it substitutes for K, Na and Mg. The highest Li contents are found in alkaline igneous rocks, tungsten ore deposits and fine-grained marine sediments. Li is not very mobile but it can be released from the host minerals during weathering and under very low pH conditions.

Li is preferentially accumulated in clay-rich sediments and soils where it becomes relatively stable in adsorbed form. Li therefore shows strong correlation with both K and Al concentrations but organic-rich soils tend to be depleted in Li. Apart from the Central Scandinavian clay belt, Li concentrations in Norwegian, Swedish and Finnish soils are lower than in the rest of Europe with the maximum concentrations occuring in Finland.

Finland

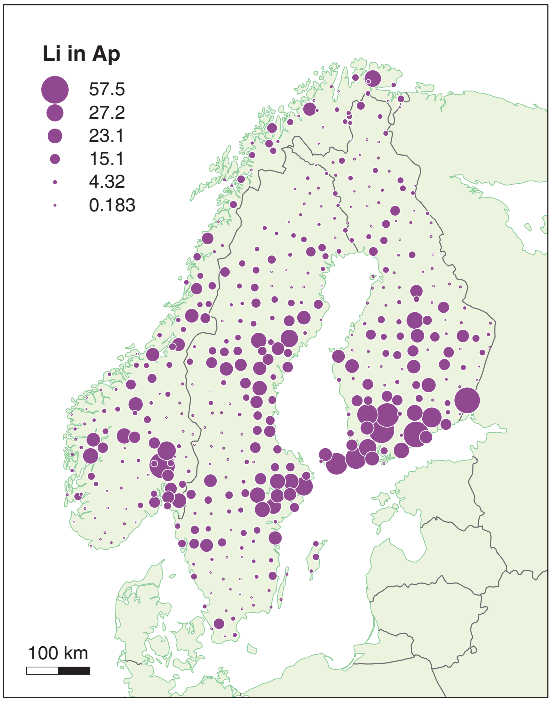
High Li concentrations occur in clay-rich soils of the Central Scandinavian clay belt in southern Finland. Locally (e.g. in central Finland), Li has been released from mafic minerals vulnerable to weathering.

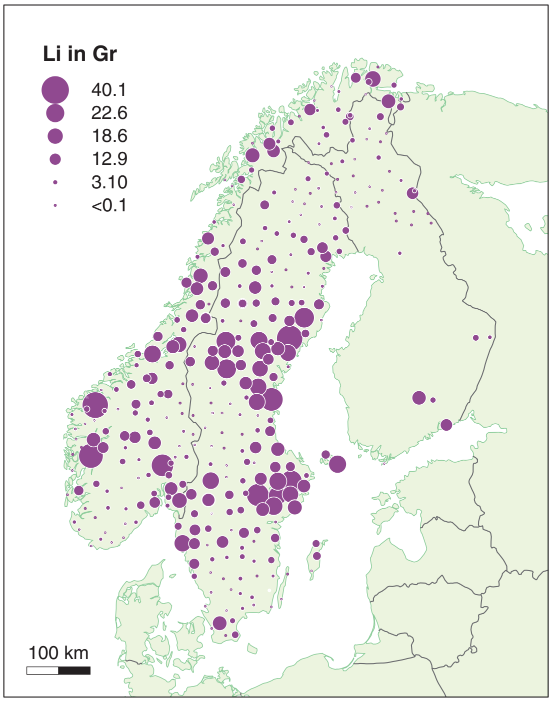
Norway

Elevated Li concentrations in the soils occur in the Oslo Rift (alkaline intrusions). Rather high Li contents in soils along the coast can in part be explained by weathering conditions but are quite often also related to the occurrence of intrusive rocks (granites and pegmatites).

Sweden

In agricultural soils, Li shows elevated values in clay-rich soils of the Mälaren region and in the eastern part of central Sweden (Västernorrland and Gävleborg). The trend is similar for grazing





land. Elevated Li concentrations occur also in Värmland, Dalsland and Jämtland. In Jämtland, Li occurs in soils overlying Palaeozoic fine-grained metasediments. In the Sollefteå region (Västernorrland), some Li anomalies correlate with Sn, Ta, Nb mineralisations and mafic intrusions (leachable Li from mafic minerals).

Mg (magnesium)

Mg is a major constitutent of many minerals but the main source of Mg is the breakdown of mafic to ultramafic rocks and minerals. Secondary Mg concentrations occur in clays and fine-grained sediments (the Central Scandinavian clay belt), reflected in a strong positive correlation with Al and K concentrations. The highest Mg concentrations in soils occur in Norway and the lowest in Sweden.

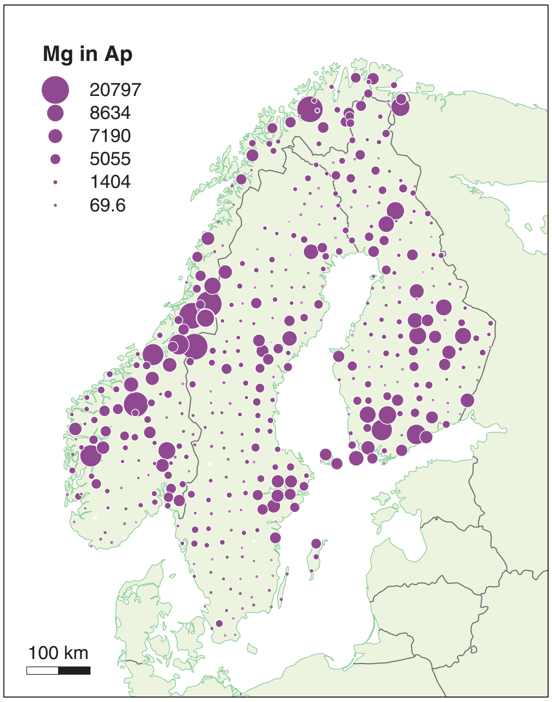
Although the extractability in aqua regia is not very high (55–56%), Mg is generally considered to be a very mobile and soluble element.

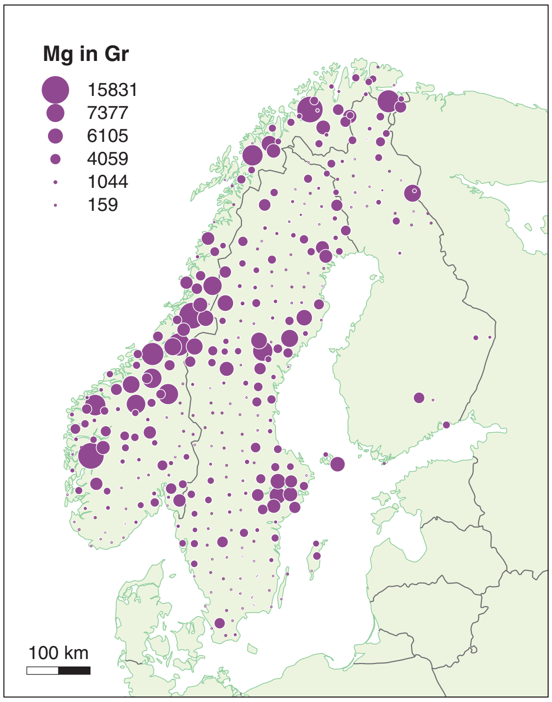
Finland

Elevated concentrations of leachable Mg occur in the southern part of Finland related to clay-rich soils of the Central Scandinavian clay belt, and in the central and northern parts of the country related to occurrences of mafic rocks (greenstone belts). Locally, expected Mg anomalies in the soils overlying Mg-rich bedrock are not visible. The explanation is that the soils are peaty and the element is not taken up into organic matter. XRF results show high Mg contents in soils from northern Finland underlain by mafic rocks and amphibolites.

Norway

High Mg concentrations occur in soils from central and northern Norway that are underlain by mafic and ultramafic rocks and their metamorphic counterparts (e.g. amphibolites). Slightly elevated Mg concentrations (aqua regia extraction) occur in agricultural soils in the Oslo Rift region and can be explained by the presence of mafic volcanic rocks.





Sweden

Moderate Mg concentrations (aqua regia method) occur in the Mälaren region (clay-rich soils of the Central Scandinavian clay belt and gabbro intrusions), Jämtland (mafic and ultramafic rocks) and eastern Norrbotten (the Boden-Haparanda area with mafic intrusions). XRF results only show elevated Mg contents in Jämtland and northern Sweden, and these correlate with the occurrences of mafic and ultramafic rocks.

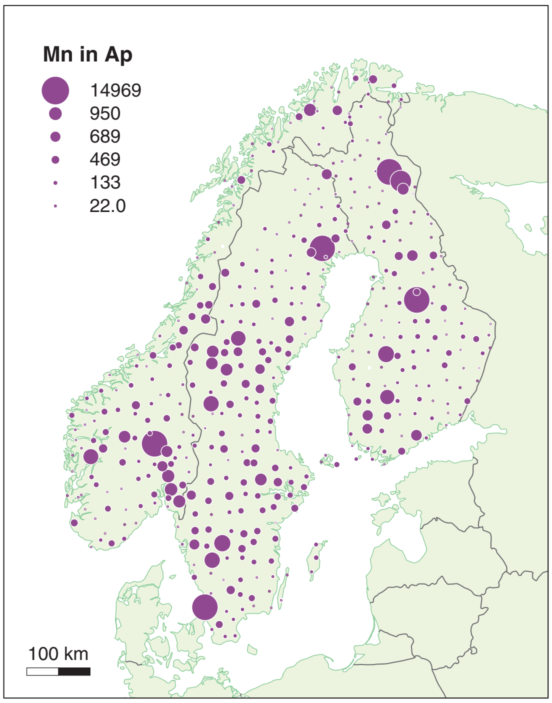
Mn (manganese)

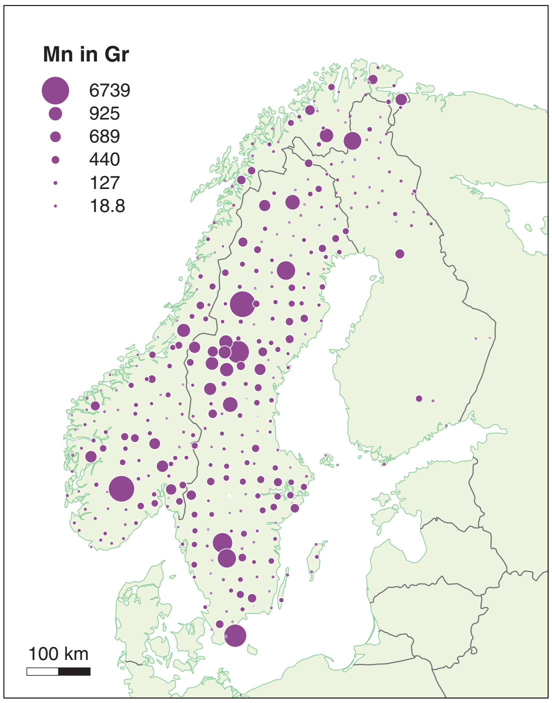
Mn is a very abundant element which forms a variety of minerals (oxides, hydroxides, carbonates, silicates), and occurs as a minor and accessory element in many rock-forming minerals, e.g. garnet, pyroxene, amphibole, olivine. Mn^{2+} substitutes for Fe^{2+} and Mg^{2+} in magmatic ferromagnesian minerals, and is therefore more abundant in mafic rocks. In sedimentary rocks and sediments, Mn forms secondary Mn oxides that occur as small concretions or coatings on detrital grains. Mn shows weak positive correlation with K and Al and negative correlation with TOC, which indicates Mn enrichment in clay minerals under oxidised conditions. Mn is mobile at low pH but Mn compounds (hydrous oxides) are not very soluble. Due to the high extractability of Mn (80–81%), maps with leachable Mn and total concentrations of the element show the same elemental pattern.

The highest median values occur in Swedish soils while the maximum concentrations are observed in agricultural soils from Norway and Finland.

Finland

High concentrations of Mn in soils occur as isolated anomalies in central and northern Finland (Central Lapland Area). These anomalies correlate with Mn mineralisations where Mn occurs as oxide, carbonate and sulphide in low-grade metamorphic rocks. The anomalies also coincide with Fe-V and even Mn deposits (the Porkonen-Pahtavaara Fe-Mn zone) hosted by manganiferous iron formations.





Norway

Elevated Mn contents occur in soils of the Oslo Rift (Ap samples). In the Bergen area, the Mn concentrations in soils correlate with outcrops of Sveconorwegian intrusive rocks.

Sweden

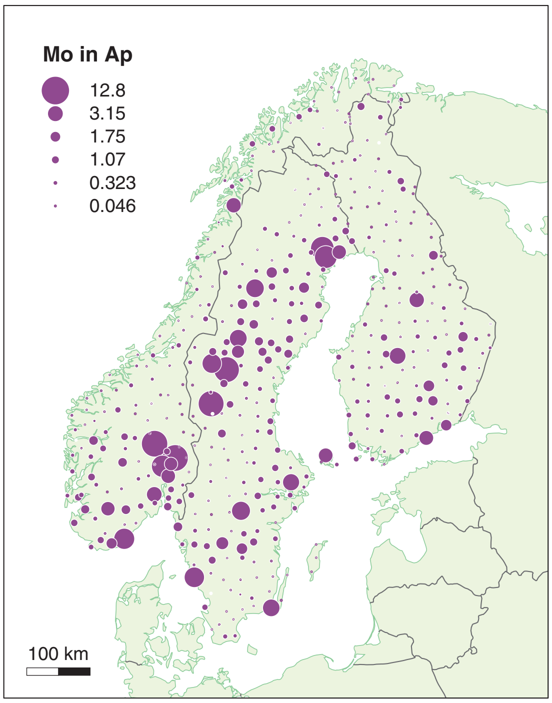
High Mn concentrations occur in grazing land sampled along the Caledonian front in Jämtland, Västerbotten and Västra Götaland. These anomalies originate from the underlying black shale.

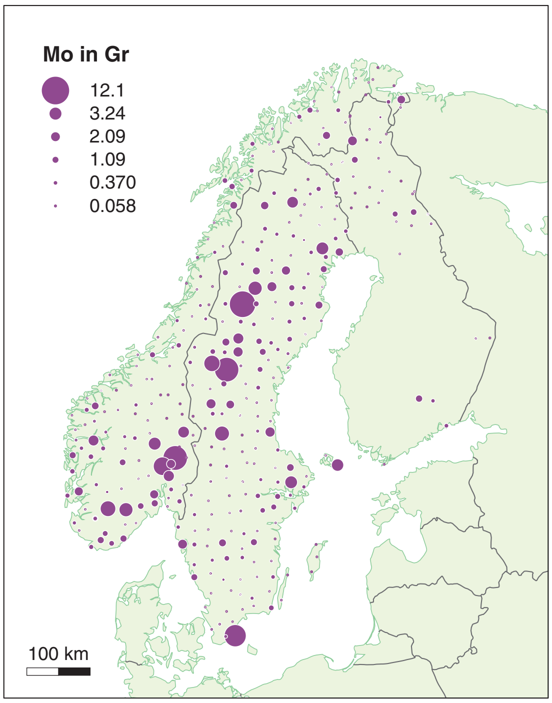
In Bergslagen, the Mn concentrations correlate with known Mn mineralisations that accompany the Fe and sulphide mineralisations. High Mn concentrations in soils in Norrbotten (the Boden region) may originate from underlying mafic intrusions and their weathering products. Smaller anomalies in grazing land samples from the Kiruna mining district and the Junosuando region reflect the location of iron ores. In south-eastern Skåne, Mn concentrations may originate from fine-grained sediments (Cambrian shale), and in south-western Skåne (agricultural soil) most likely from dolerite and gneiss.

Mo (molybdenum)

Mo shows high concentrations in soils in Norway, Sweden and Finland compared to the rest of Europe. It mainly occurs as sulphide and shows a weak correlation with K, Al and TOC, which indicates its affinity to clay-rich and organic soils (which are also sulphide-rich). Mo minerals can degrade under acidic conditions to very small particles. The extractability of Mo is 40–41% and the element is mobile at high pH. Under alkaline conditions, Mo forms secondary minerals which can be found in fine-grained sediment.

The highest median Mo concentrations are observed in Sweden and the lowest in Finland. Most of the Mo anomalies correlate with sulphide mineralisations (Cu, Bi, Pb, Zn, Co, Fe, Sb) and Fe, W, U, Au and Ag. Alum shale in Sweden is also a major source rock for Mo.





Finland

Smaller isolated Mo anomalies occur in agricultural soils in southern and central Finland. In central Finland, anomalies follow Mo mineralisations at Saviselkä and Mätäsvaara (the only Mo ore mined). The small anomaly in southern Lapland close to the Russian border overlaps with the Archaean hosted Aittojätvi Mo ore deposit.

Norway

High Mo concentrations occur in soils of the Oslo Rift with a source in the felsic volcanic rocks and fine-grained sedimentary rocks, e.g. black shale, and in the Kongsberg region (polymetallic ore deposits). The large Mo anomaly north of Oslo correlates with the Mo ore deposit in Nordli near Hurdal. This is an untouched porphyry Mo ore deposit which is one of the largest known, unmined deposits in the world. The other anomaly in southern Norway correlates with Mo mineralisation in Knaben, a mining district where Mo was exploited from 1885 to 1973.

Sweden

High Mo concentrations occur in Jämtland (alum shale in Myrviken) and Västerbotten (felsic volcanic rocks, limestone) and correlate with sulphide mineralisations (Cu-Zn), Au and U occurring by the Caledonian mountain front.

In Västerbotten, Mo soil anomalies follow occurrences of sulphide mineralisations with Mo and Cu, but also W, Au and fluorite. In southern Norrbotten (the Boden region), Mo anomalies coincide with Mo, Cu and Au mineralisations. Enhanced Mo contents in soils follow Fe and sulphide ore deposits in the Kiruna region. In western Bergslagen, a larger anomaly in agricultural soils is located close to the large Zn-Pb-Ag Zinkgruvan mine. In south-east Skåne, high Mo contents in soils originate from Cambrian alum shale.

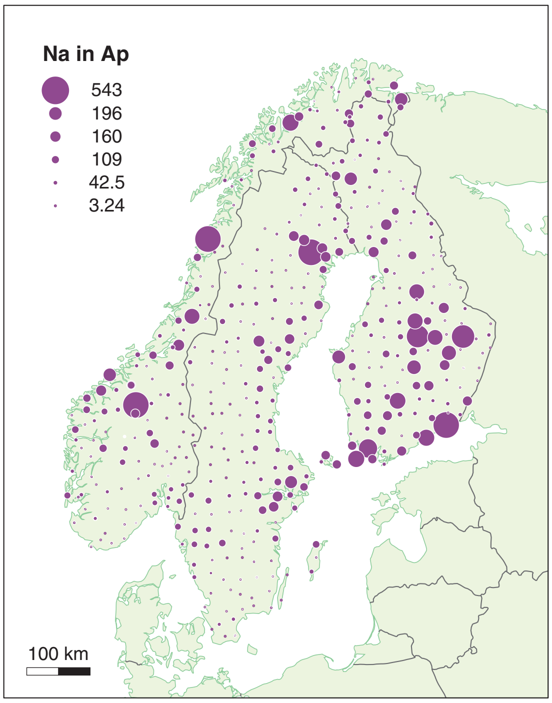
Na (sodium)

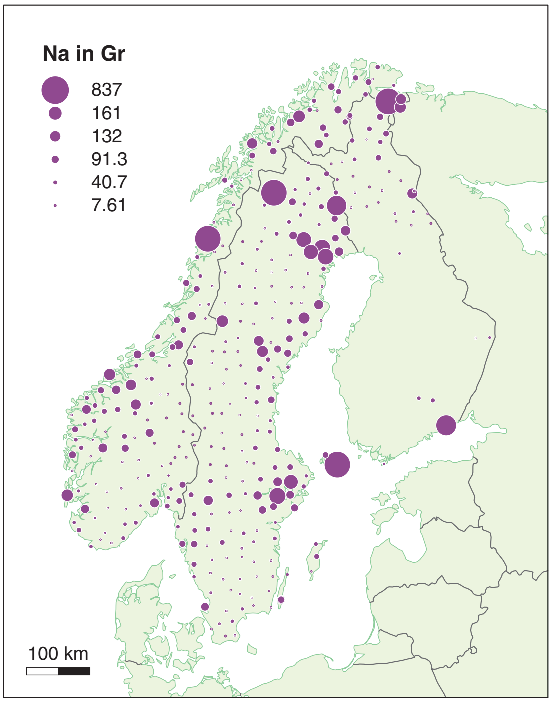
Norway, Sweden and Finland show high Na concentrations in soils compared with the rest of Europe. Crystalline bedrock and less weathered soils are the main cause of this discrepancy. Na in solution tends to remain in dissolved form, and can thus readily adsorb to clay minerals with high cation-exchange capacity. Na (aqua regia method) shows correlation with K and Al which indicates affinity to clay-rich soils. In areas previously covered by the sea, Na may remain in brines in the groundwater system (e.g. in the Mälaren region in central Sweden).

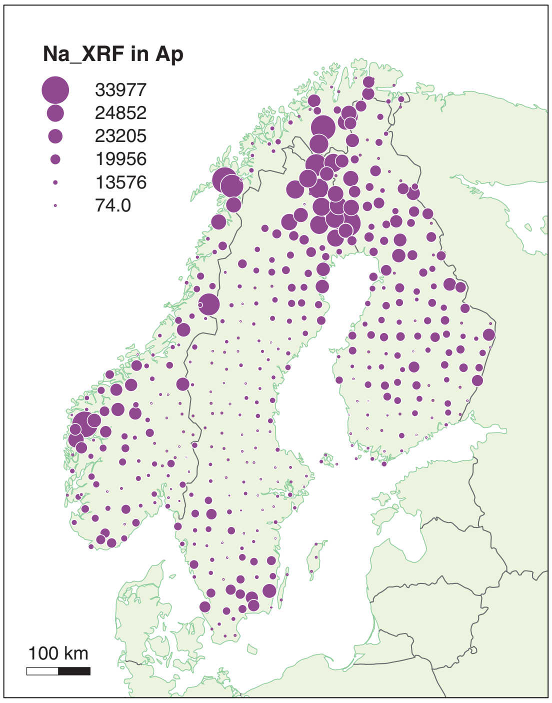
Fine-grained soils derived from felsic intrusive rocks are the most common source of Na. Very low extractability for Na (1%) and different elemental patterns on maps for aqua regia extraction and XRF methods indicate high mineralogical effects on the dispersion pattern. The map of leachable Na (aqua regia method) shows where the element originates from minerals susceptible to weathering, predominantly micas and mafic minerals. The XRF method commonly reflects where Na is bound in plagioclase in the soil. However, the most characteristic feature of the geochemical pattern is the large Na anomaly in the north that can be seen on the XRF map. These anomalously high Na concentrations in soils have been attributed to hydrothermal alteration of the bedrock with recycled elements. Na, originating primarily from plagioclase, has been enriched in minerals like scapolite and halite. The widespread scapolitisation of mafic rocks and the possible presence of old evaporites (subsequently eroded and removed) have left this high geochemical Na signal, together with a high Cl content, in the soils.

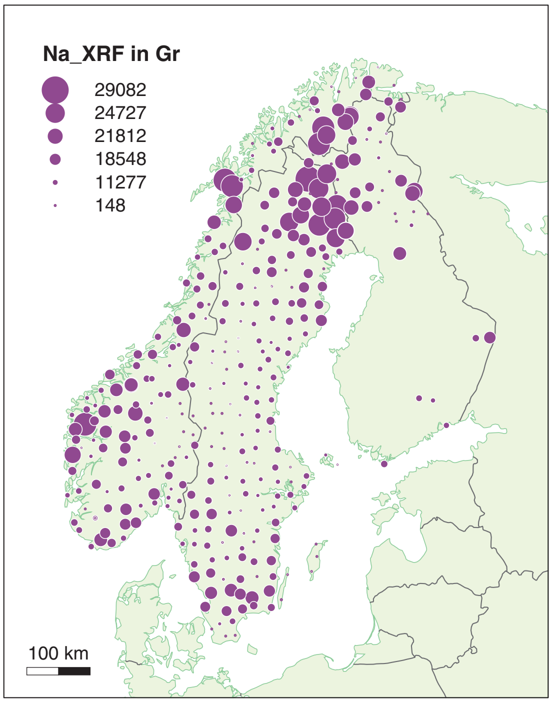
Finland

Relatively high concentrations of Na are spread throughout Finland where fine-grained soils, felsic intrusions and granites with albite are the source of the element.









Norway

Locally high concentrations of Na in soils can be observed (XRF method), e.g. in the Bergen area associated with Palaeoproterozoic igneous rocks and in the Lofoten region associated with crystalline rocks. Single anomalies of leachable Na probably indicate a high clay content in soil samples or the presence of marine clays.

Sweden

Agricultural soils in Sweden have the lowest median value. Elevated Na contents occur in clay-rich soils in the lake Mälaren region and along the eastern coast in the north. This may be the reason why the Na concentrations in the Lule river basin are enhanced and this Na is probably derived from fine-grained particles (albite, scapolite) in till. The pattern of Na in grazing land is similar to agricultural soils, with an extreme concentration of Na observed in Nikkaluokta in north-west Sweden (there are no samples from agricultural soil in this area).

Nb (niobium)

Concentrations of Nb are very high in Norway, Sweden and Finland compared with the rest of Europe and the highest median values are found in Sweden. Nb is enriched in soils overlying the crystalline bedrock of the Fennoscandian Shield and depleted in soils from the Caledonides. High concentrations of Nb are typical for felsic igneous rocks and shales. Common minerals are pyrochlore and columbite–tantalite. Nb can also be incorporated into biotite, rutile, ilmenite, sphene, cassiterite and zircon. Among these minerals, biotite is the most soluble and a common source for Nb in the aqua regia extraction method.

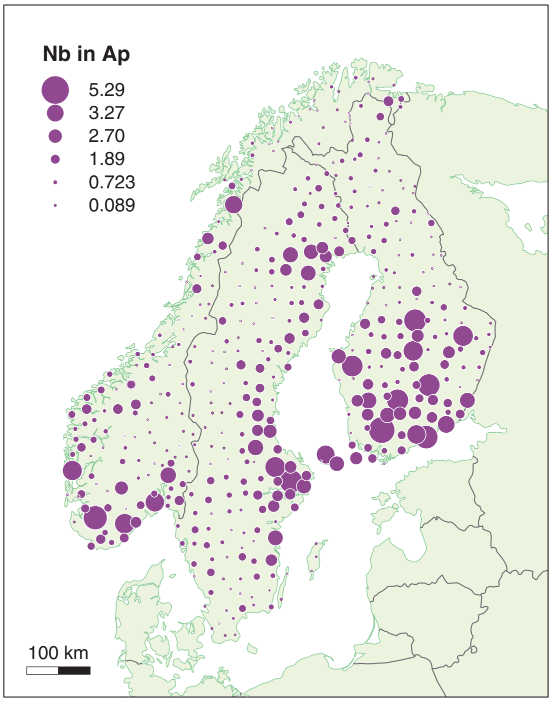
Low extractability of Nb (4–5%) shows that the element is not very mobile and occurs in minerals resistant to weathering. Nb is not a common constituent of clay minerals, but tends to be enriched in fine-grained soils overlying granites and pegmatites.

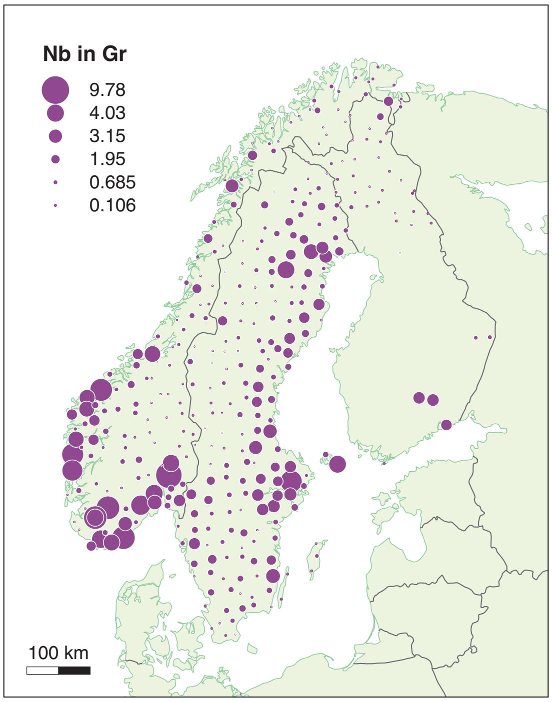
Finland

High concentrations of Nb occur in fine-grained soils overlying granites and pegmatites. In central Finland, Nb anomalies point to known mineralisations, e.g. the Nb-REE mineralisations in Katajakangas.

Norway

High concentrations of Nb occur within the Oslo Rift and associated with the basement rocks in southern Norway. The main sources of Nb are Be-REE-rich alkaline Proterozoic granites and pegmatites, e.g. the Nb-Zr mineralisations in Sæteråsen. A high value in Northern Norway (Tysfjord) is probably related to the occurrence of a carbonatite. The high values on the west coast and at





the southern tip of Norway may be related to the occurrence of pegmatites but could also indicate that the element may have a tendency to enrich in organic soils.

Sweden

Elevated Nb contents occur in soils overlying crystalline rocks of the Fennoscandian Shield. The leachable Nb is enriched in clay-rich soils overlying pegmatites in the Mälaren region (the Central Scandinavian clay belt) and along the eastern and western coasts. Smaller anomalies correlate with Nb-REE mineralisations, e.g. in Gävleborg (Mosisjön) and Västernorrland. High Nb concentrations (XRF) in northern and central Sweden correlate with occurrences of evolved granites and pegmatites. Intermediate Nb concentrations (XRF) occur in the Köli nappe of the Caledonides.

Ni (nickel)

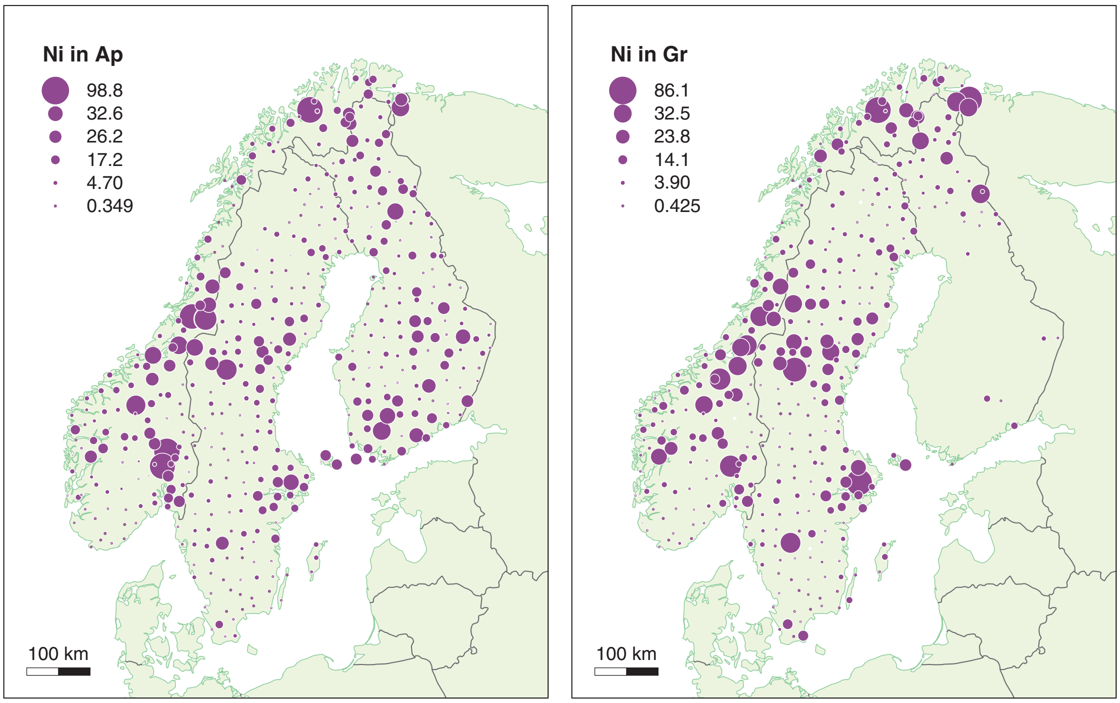
Concentrations of Ni are low in Norway, Sweden and Finland compared with the rest of Europe. The main sources of Ni are mafic and ultramafic rocks. The extractability of 79% (agricultural and grazing land soils) indicates a high solubility of Ni-bearing minerals. Secondary concentrations occur in clays and fine-grained sediments (the Central Scandinavian clay belt) which is reflected in strong positive correlation with the Al and K contents. Ni does not accumulate in organic matter but shows, rather unusually, low concentrations in organic-rich (peaty) soils.

Finland

Elevated concentrations of Ni occur in clay-rich soils (the Central Scandinavian clay belt) and in northern Finland associated with the greenstone belt mafic and ultramafic rocks. The strong signal from mafic rocks is often masked by peat samples rich in organic matter (and low in Ni). Ni deposits can be traced by Ni anomalies in soils.

Norway

In general, the occurrence of greenstones (mafic and ultramafic rocks) is marked by a number of pronounced Ni anomalies in the soils of Norway. Interestingly the Kongsberg and Oslo Rift areas



are also marked by a number of Ni anomalies which may be due to polymetallic mineralisation and enhanced Ni concentrations in the black shales know from this area.

Sweden

High Ni concentrations in the soils can be observed in central Jämtland reflecting outcrops of alum shale and mafic to ultramafic rocks, e.g. the soapstone in the Handöl region. Intermediate concentrations of Ni in soil are related to serpentinite, nickel deposits or sulphide mineralisations occuring within the Caledonides and in mafic rocks in Västernorrland. Ni concentrations in the Mälaren region relate to clay-rich soils (the Central Scandinavian clay belt), and occurrences of mafic intrusions and sulphide mineralisations. In Skåne and at Billingen, alum shales are the main source of Ni anomalies.

P (phosphorus)

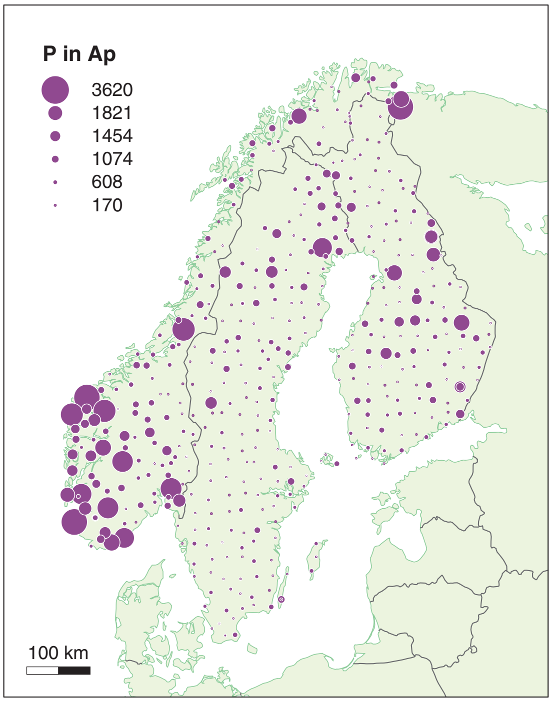
Norway, Sweden and Finland have rather high values of P due to the fact that the bedrock is rich in apatite and that P enriches strongly in organic soils. Apatite weathers easily and, in solution, P tends to bind to organic matter. In arable soils, P is highly extractable in aqua regia (83%). In nature the element is most soluble around pH 7. P is a macro nutrient and an important component of fertilisers. Hot spots of P on the maps can therefore reflect the use of fertilisers on arable land.

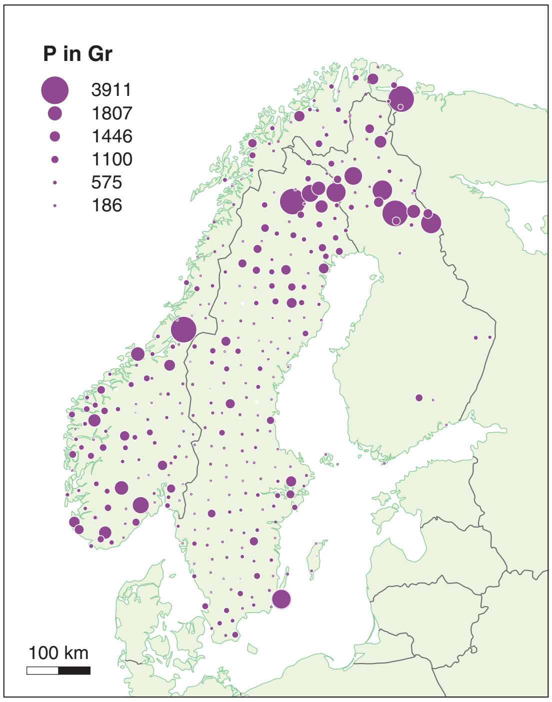
Finland

Elevated concentrations of P occur in the central part of Finland and mainly correlate with organic-rich soils and the presence of Fe, Co, Ni and Cu ore deposits hosted by mafic and ultramafic rocks.

Norway

The coastal soils in south-west Norway have very high concentrations of P which is thought to reflect the organic-rich soils and is therefore a climatic effect. The main primary sources of P in the south are mafic intrusive rocks rich in apatite (Rogaland anorthosite province) and hosting Fe-V-Ti mineralisations (Egersund region, e.g. Teksevatn), and alkaline, carbonatitic rocks (Føn Complex





in the Oslo Rift). North of Bergen, by the coast, large P anomalies overlap with the largest rutile ore deposits in Norway hosted by eclogite (Ti ore Engebøfjellet). In central and northernmost Norway, large P anomalies correlate with Fe ore deposits (Fosdalen west of Steinkjer and Bjørnevatn south of Kirkenes).

Sweden

In Sweden, P has no obvious correlation with organic matter in Ap. Arable soils overlying till display the highest values and are situated in the northern part of the country. Grazing land samples show high P values in the north (the Kiruna mining district), in the central eastern part, and on Öland in south. Here, some of the concentrations are found in organic-rich soils. In northern Sweden, grazing land with elevated concentrations of P are related to the apatite-iron ore deposists, local alkaline rocks (lamprophyres) and carbonatites. On Öland, the anomaly in grazing land may be of anthropogenic origin from the use of fertilisers.

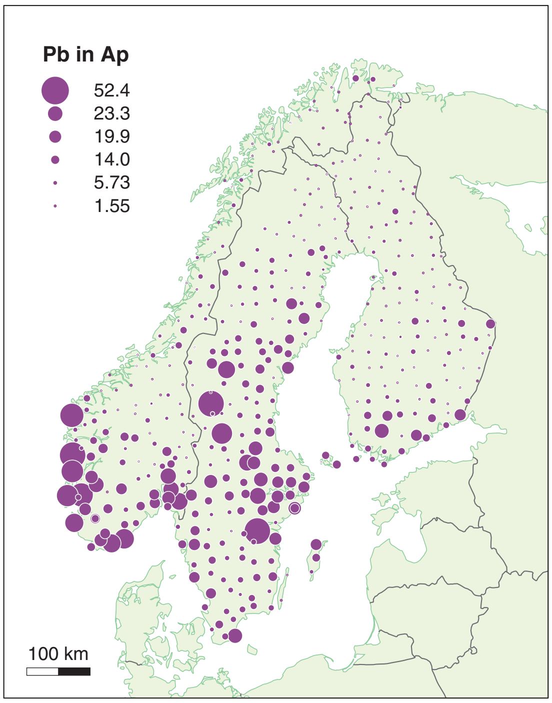
Pb (lead)

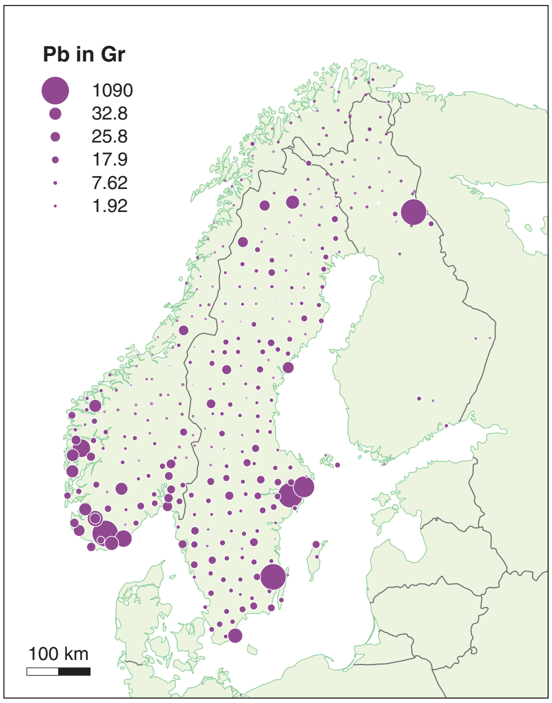
Soils in Norway, Sweden and Finland have rather low concentrations of Pb in comparison with the rest of Europe (on average a factor of 2 lower). The sources of Pb are silicate minerals in crystalline rocks, mainly K-feldspars and micas, and polymetallic mineral deposits (e.g. Pb-Zn-Ag) where Pb occurs as galena, cerrusite and anglesite. Shales and coal can have very high concentrations of Pb due to Pb binding strongly to organic matter. During weathering, Pb is preferentially adsorbed onto clay minerals and Fe-Mn oxyhydroxides, or bound to organic matter.

The extractability of Pb is high (77% in Ap, 83% in Gr in aqua regia), indicating that Pb in arable soils occurs predominantly in relatively soluble minerals.

Finland

In southern Finland, the highest concentrations of Pb were found in clayey and organic (peaty) soils mainly overlying K-rich granitoids. Locally, Zn-Pb deposits contribute to the high Pb contents in soils.





Norway

High Pb concentrations occur along the south-west coast of Norway (organic-rich soils, high precipitation) and in the Oslo Rift (skarn type mineralisation). Comparable elemental distributions can be observed for Cd, Hg, P and Se. The pronounced Pb anomaly at the southern tip of Norway was originally interpreted as a result of long range atmospheric transport. However, Reimann et al. (2009b) recently demonstrated that it is purely related to a natural build-up of Pb in organic-rich soils near the coast and that the observed concentration gradient closely follows a climatic gradient from coast to inland.

Sweden

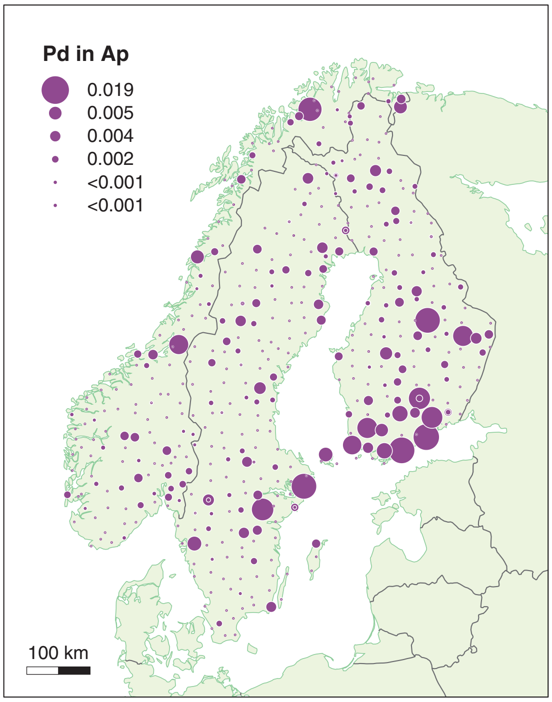
Sweden has higher median values of Pb than Norway and Finland. High contents in the soils correspond to felsic igneous rocks and to regions with mineralisations where Pb is present mostly as galena. The anomalous zone stretches from the southern part of the Caledonian mountains, via the Bergslagen mining district to the Mälardalen region in the south-east. Pb anomalies are seen in areas where mineralisations occur in the vicinity of Stockholm (Pb, Zn and Ag in breccia), Åtvidaberg (Pb, Zn and Cu in felsic volcanic rocks), in south-eastern Skåne (alum shale and galena in Cambrian sandstone) and south of the Skellefte mining district.

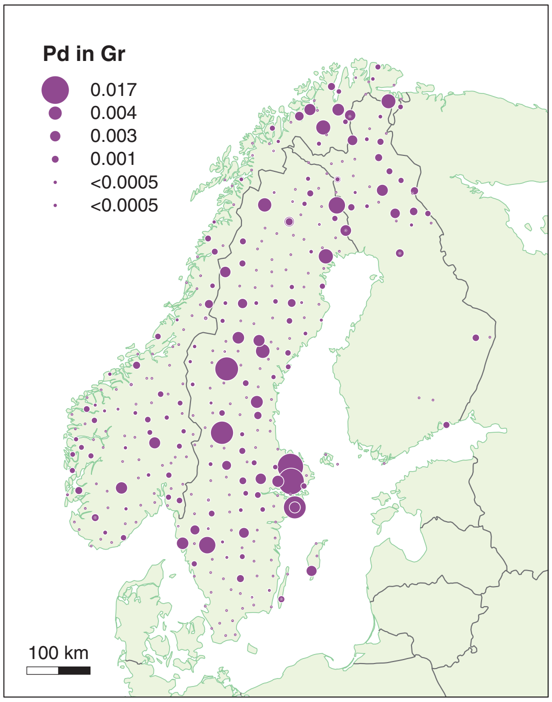
Platinum group elements (palladium, platinum)

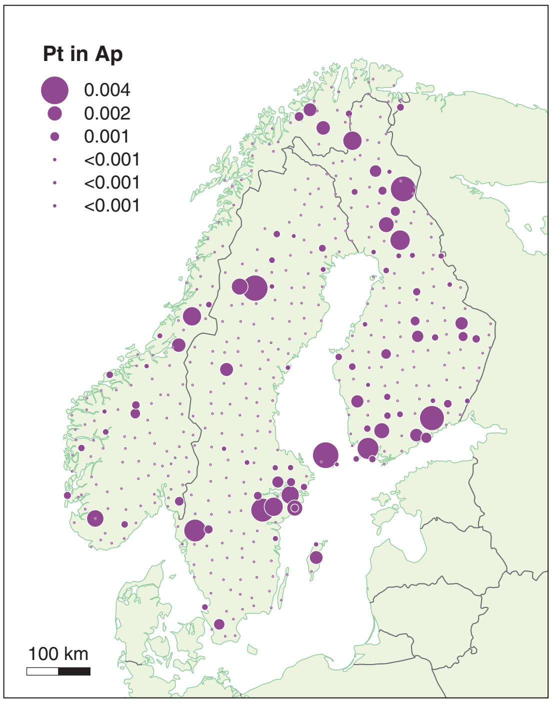
Compared with the rest of Europe, Norway, Sweden and Finland have low median values of the Platinum group elements, PGEs (Pd, Pt).

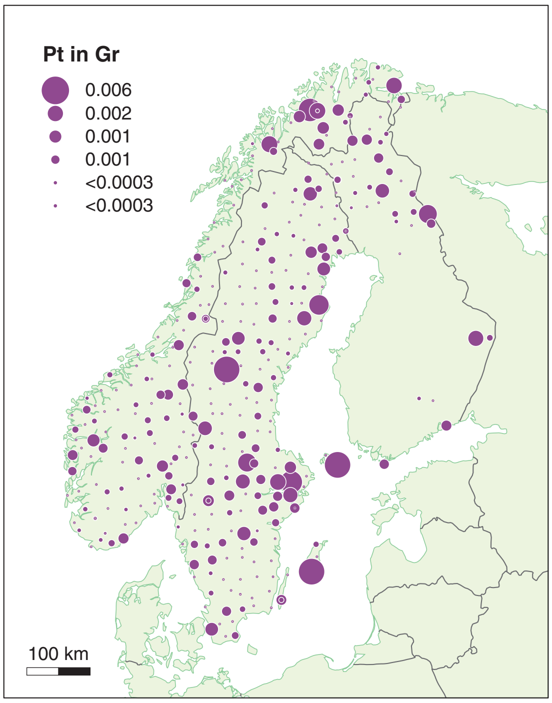
Finland

Finnish soils have somewhat higher concentrations of Pd and Pt than Norway and Sweden. Pd and Pt originate mainly from mafic and ultramafic rocks, often hosting Fe-V, Ni and Cr mineralisations. Additionally, the Central Scandinavian clay belt in southern Finland is clearly visible pointing to clay-rich soils that are enriched in the PGE metals.









Norway

The few high values in central and northern Norway are related to the occurrence of ultramafic intrusions.

Sweden

The concentrations of PGE in the soils correlate with known PGE-Ni-Au mineralisations, for example Kukkola (PGE, Cr, Au) in the north, Notträsk (Au, PGE) at the north-east coast and at Kläppsjö (PGE, Au) in central Sweden. The presence of clay-rich soils does not affect the concentration of PGEs in Sweden.

Rb (rubidium)

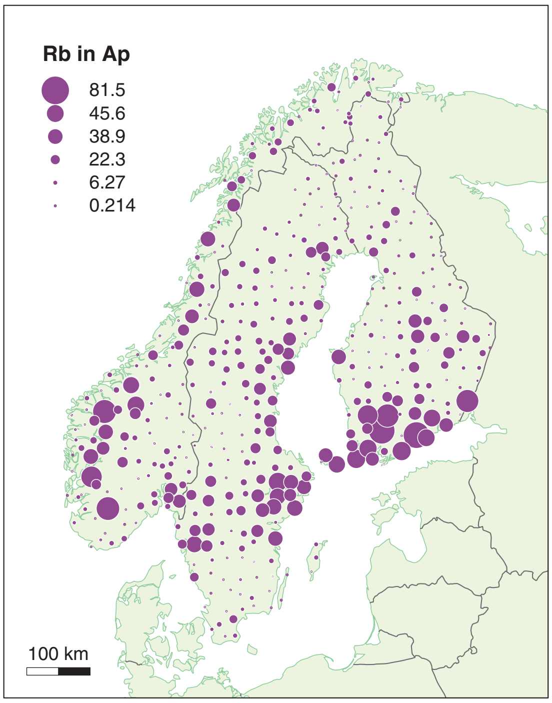
Concentrations of Rb in Norway, Sweden and Finland are relatively low compared to the rest of Europe. Rb is common in minerals rich in K and replaces this element in many potassium silicates, including feldspar and mica. Granites and shales have high concentrations of the element. Rb is easily released by weathering processes and, like K, binds to clay minerals. High Rb concentrations in the Central Scandinavian clay belt make the element a good indicator of clay-rich soils. Rb correlates well with K and Al. The extractability of Rb is 20% which, to some extent, gives different patterns of the element in the southern part of Norway depending on the choice of analytical method (XRF vs. aqua regia).

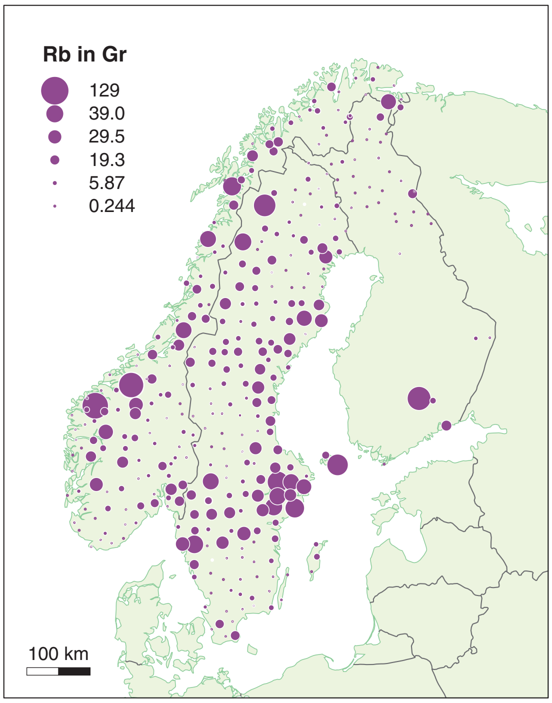
Finland

The distribution of Rb is similar to K. High Rb concentrations were measured in clayey soils.

Norway

In general, the soils along the south-western coast of Norway appear somewhat enriched in Rb with a belt of high Rb concentrations observed slightly inland. The pattern is similar to Cs and K.





Sweden
Arable soils are enriched in Rb in the clay-rich Mälaren region (the Central Scandinavian clay belt) and northwards along the coast. The highest values of Rb in grazing land are found in till soil in northern Sweden. Positive Rb anomalies are indicative of the presence of K-bearing rock-forming minerals and clay minerals.

S (sulphur)

Norway, Sweden and Finland have relatively high concentrations of S compared with the rest of Europe. S occurs commonly in the sulphide form (e.g. pyrite, sphalerite, galena, pyrrhotite) and as sulphates (e.g. barite, gypsum, anhydrite). The main sources of S in soil are mafic and ultramafic rocks, fine-grained sedimentary rocks, carbonates and evaporites. Shales with high S concentrations are usually rich in organic matter. During weathering, S is very mobile. Under low pH conditions, S can be reduced to sulphide form (together with many other metals). Another common form is the sulphate ion which can occur in large concentrations in water. Mobilisation of S is hampered by uptake into organic matter (S has strong correlation with TOC). Therefore the highest S concentrations can be observed in peat soils and soils overlying black shales. S is an important component of fertilisers, although the need for S in agricultural soils in Norway, Sweden and Finland is considered to be negligible. S can also be added to the environment by acid rain. When oxidised (e.g. when drained), soils with high concentrations of sulphides can release large amounts of toxic metals. These so called acid sulphate soils are very acidic, and toxic elements can be transported with runoff into lakes and groundwater.

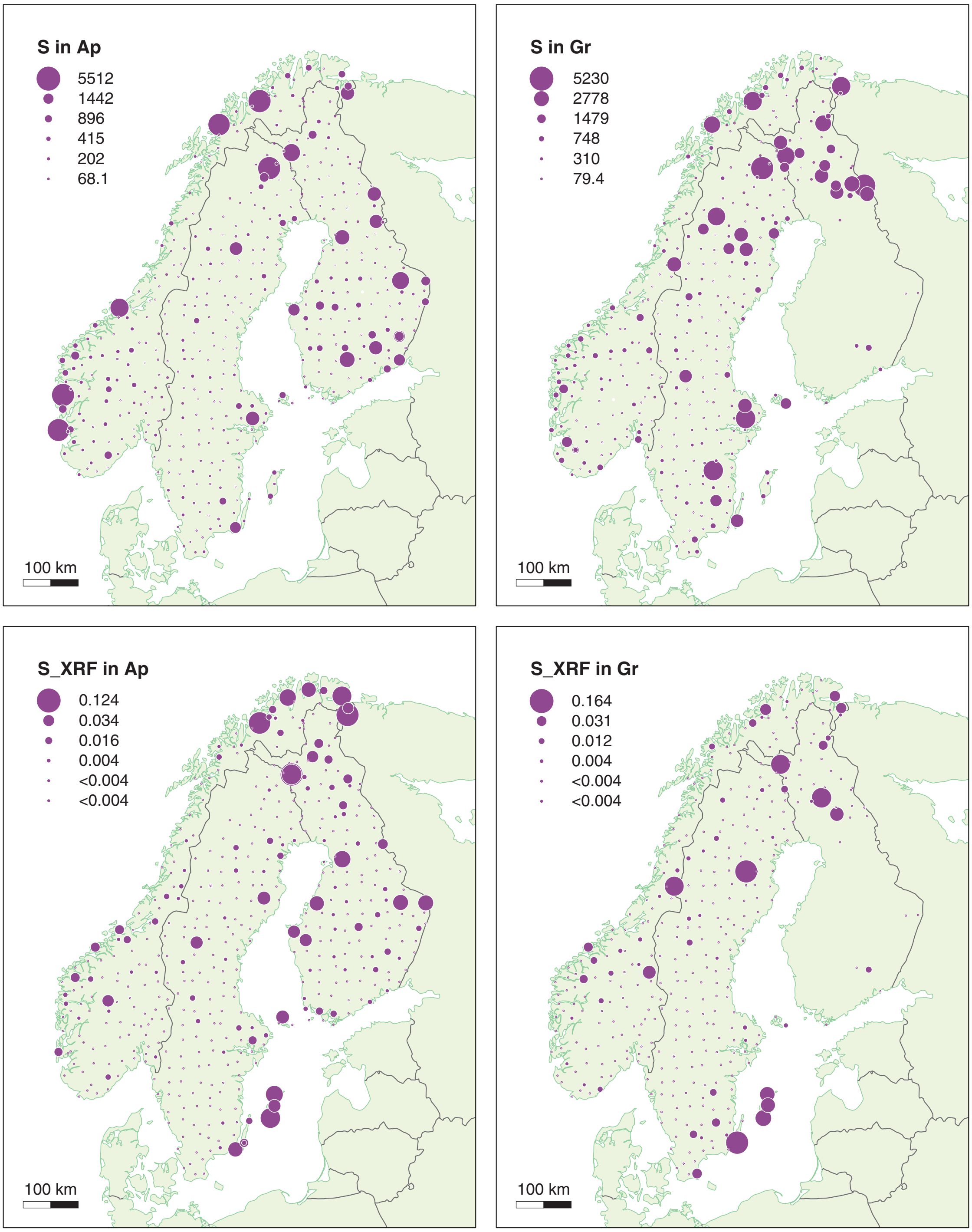
Finland
Organic-rich soils and acid sulphate soils show high concentrations of S.

Norway
Norway has the highest median S concentrations among the three Nordic countries. The high S concentrations in arable land are mostly a result of coastal effect, i.e. high precipitation and the

presence of organic-rich soils. Locally, high S concentrations correlate with Cu-Zn-Pb and Fe mineralisations (south-western and northern Norway).

Sweden

Total element concentrations of S correlate well with Ca. When extracted in aqua regia, S has a strong correlation with the TOC and cation exchange capacity (e.g. the major cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, H^{+} and NH^{4+}) , but not with Ca. Grazing land has higher concentrations of S than agricultural soils, but it is in farmed peat land that the highest values are found, such as near Vit-



tangi in Norrbotten. The large islands Gotland and Öland have high total concentrations of S in soils composed of Cambro-Silurian sedimentary rocks. The maps based on aqua regia show high concentrations of S reflecting mineralised regions like Malmberget–Vittangi, the Skellefte district, the Caledonian mountain range with small mineralisations, shales and sulphides in Jämtland, and ferrous and base metal districts in eastern Bergslagen etc.

Sb (antimony)

Concentrations of Sb in soils in Norway, Sweden and Finland are very low. Sb is strongly chalcophile and rarely forms its own minerals (e.g. stibnite). Commonly, Sb occurs as a trace element in sulphides (e.g. galena, sphalerite and pyrite) but also in ilmenite and olivine. Sb is, together with As and Bi, used as pathfinder element for gold mineralisations. Shales, mudstones and argillaceous rocks can be enriched in Sb. In soils, the Sb content correlates with the presence of organic matter. Sb can also be adsorbed to Fe hydroxides and clay minerals.

Finland

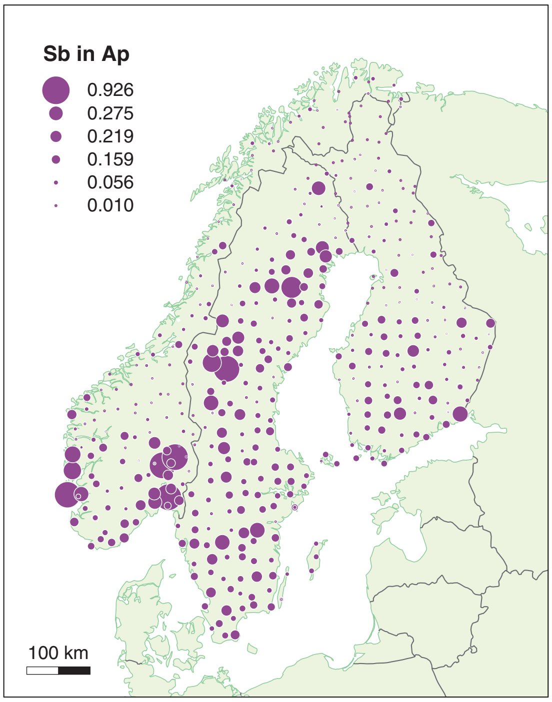
Finland has the lowest median values of Sb in Europe.

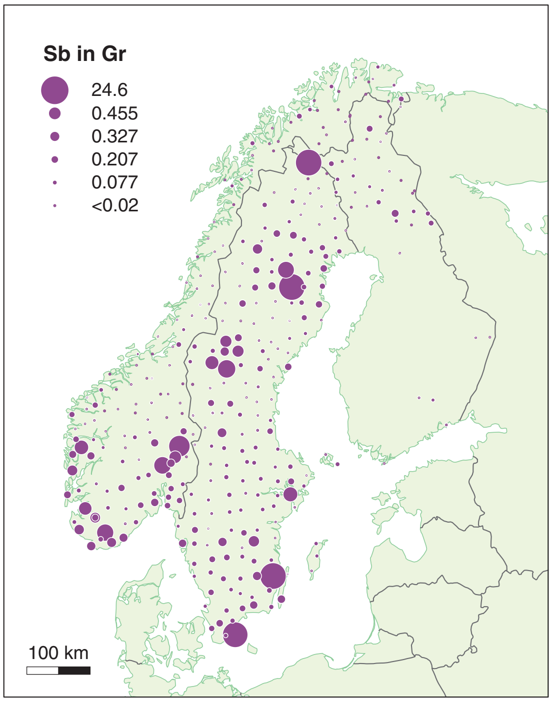
Norway

High concentrations of Sb in the soils occur in the Oslo Rift and in the coastal region. The Sb anomalies correlate with occurrences of Pb-Zn vein mineralisations and the presence of organic-rich soils with a high amount of sulphides.

Sweden

Sweden has higher median values of Sb than Norway and Finland. Low values of Sb analysed with XRF are not considered reliable, but higher values in the soils correlate well with some mineralised regions. Locally, high concentrations are found in the vicinity of alum shale in Jämtland and in relation to Pb-Zn-Cu mineralisations. High concentrations of the element are found in the Skel-





lefte mining district. North-west of Luleå, both XRF and aqua regia extraction results point to a region with known mineralisations of Sb, Bi, Au and As. In southern Sweden, concentrations of Sb in soil reflect outcrops of alum shale and mineralisations with Pb. The soil type does not play an important role for Sb in Sweden. Sb from aqua regia extraction shows a similar elemental pattern to the patterns for As and Mo.

Sc (scandium)

Soils in Norway, Sweden and Finland have relatively low concentrations of Sc. It occurs as a trace element in a variety of minerals where it can replace elements such as Fe, Mg, Cr and Ti in mineral lattices. Mafic rocks have higher concentrations of Sc than granitoids. High values can be found in hydrothermal deposits and pegmatites. Rarely, Sc can form its own minerals e.g. thorveitite ($Sc_2Si_2O_7$) which is found in Norway.

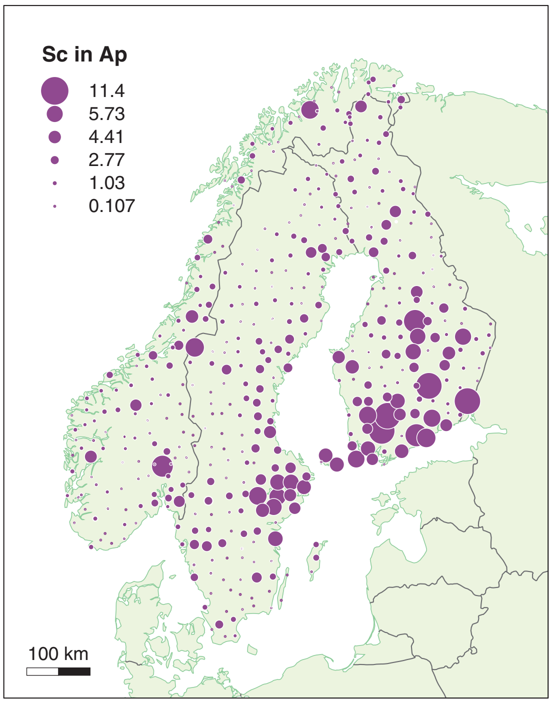
Sc has a low extractability in aqua regia (28%). It shows different dispersion patterns depending on analytical method due to the element concentrating in both soluble and rather resistant minerals. During weathering, released Sc adsorbs to clay minerals. The concentrations of Sc extracted in aqua regia are higher in clay-rich soils creating the anomalous dispersion pattern observed in the Central Scandinavian clay belt. Total concentrations of the element (by XRF) show weak anomalies in the Central Scandinavian clay belt, while higher Sc levels are seen in the Caledonian mountain range. Organic-rich soils often show exceptionally low Sc concentrations.

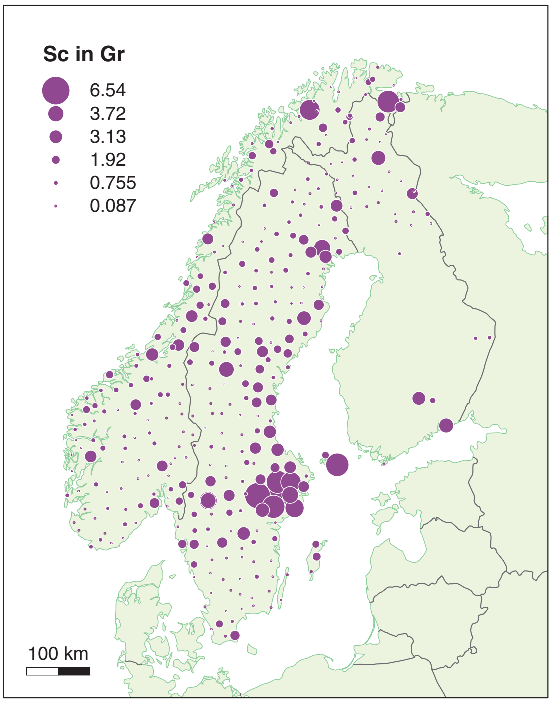
Finland

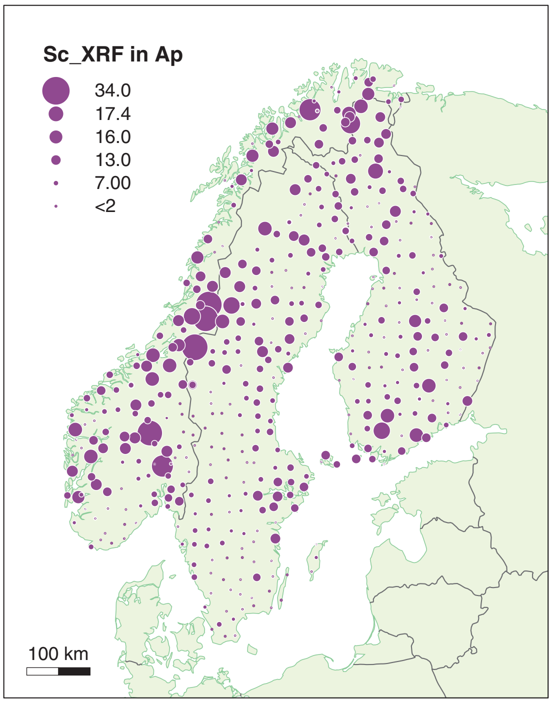
The concentrations of Sc are high in clay-rich soils and in areas with mafic and ultramafic rocks (greenstone belts).

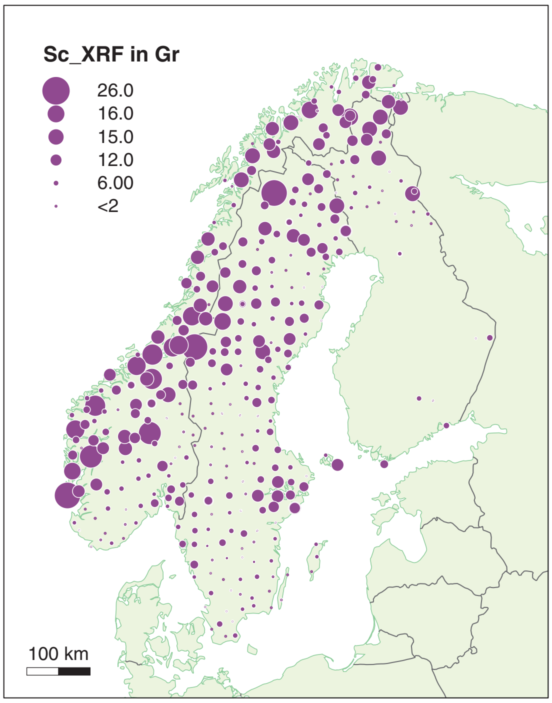
Norway

Elevated Sc concentrations occur in soils of the Oslo Rift (alum shale and volcanic rock related) and soils overlying mafic and ultramafic rocks in the central parts of the country.









Sweden

Clayey soils in the Mälaren region and along the eastern coast have moderate concentrations of extractable Sc. Elevated concentrations occur in the Caledonides (overlying mafic and ultramafic rocks, e.g. soapstone in Handöl, Jämtland). Total concentrations of Sc in river valleys west of Jokkmokk are observed. West of Kiruna, grazing land has elevated Sc concentrations. North of Kiruna, there is a known mineralisation of Sc and REEs. West-north-west of Skellefteå, there is another known mineralisation (Varuträsk) with Sc in pegmatite, weakly reflected in both agricultural soil and grazing land soil.

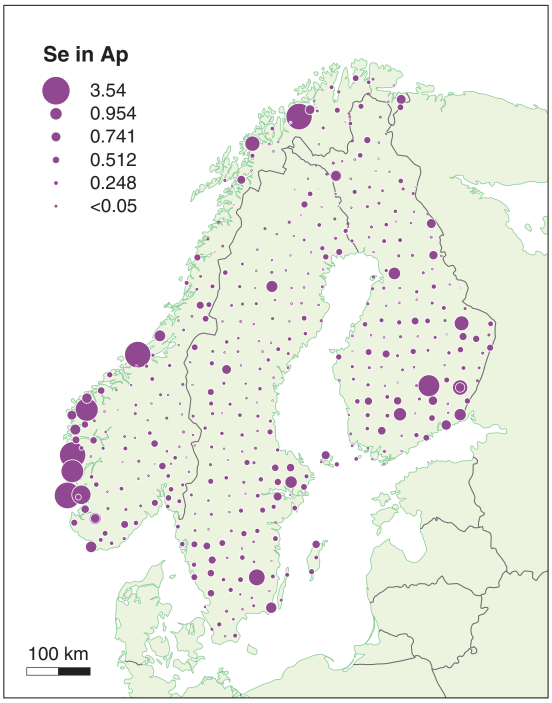
Se (selenium)

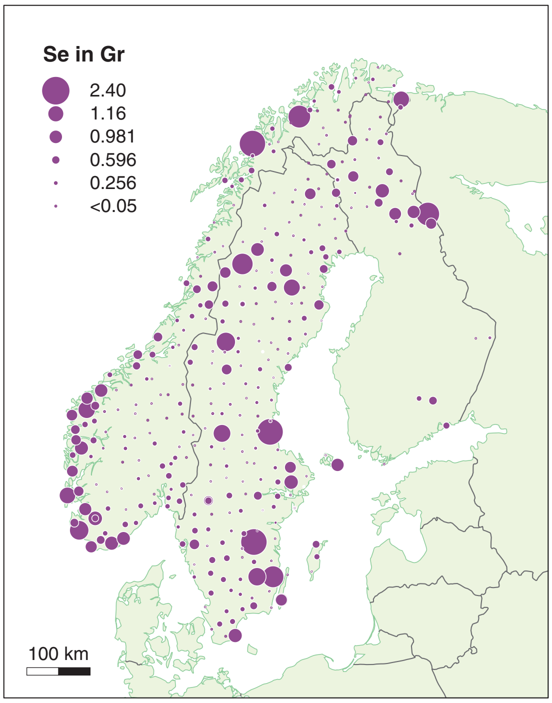
The content of Se in soils in Norway, Sweden and Finland is rather low compared to the rest of Europe. Mafic rocks and sulphide minerals may have high contents of Se. Se binds strongly to organic matter and is thus often enriched in shales and coal. Se is quite mobile under oxidising conditions and its mobility decreases with decreasing pH. Se compounds can be adsorbed to Fe oxyhydroxides, clays or organic matter.

Se is an essential element for human and animal health and it is often added to animal food and fertilisers.

Finland

High concentrations of Se occur in organic-rich soils. In some areas, Se anomalies are an effect of fertilising; Finland is in general Se deficient and Se was for many years added to the fertilisers. Due to the strong binding of Se to organic matter this led to a strong enrichment of Se in the peaty soils, an effect that is clearly seen in the Baltic Soil Survey (Reimann et al. 2003). In the south-eastern part of Finland, Se correlates with Ge, In, Sb and Au in peat soils.





Norway

The south-western coast of Norway shows high levels of Se due to concentration in organic-rich soils and input of Se via marine aerosols. In some cases, the presence of polymetallic mineralisations contribute to the high Se contents in the overlying soils.

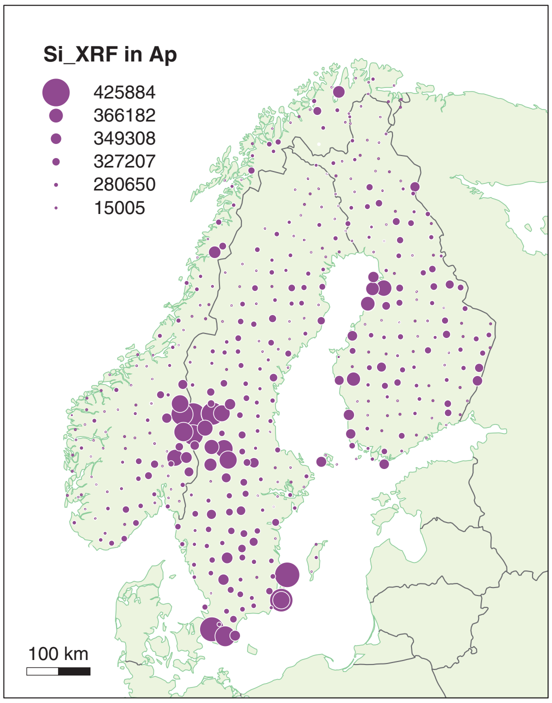
Sweden

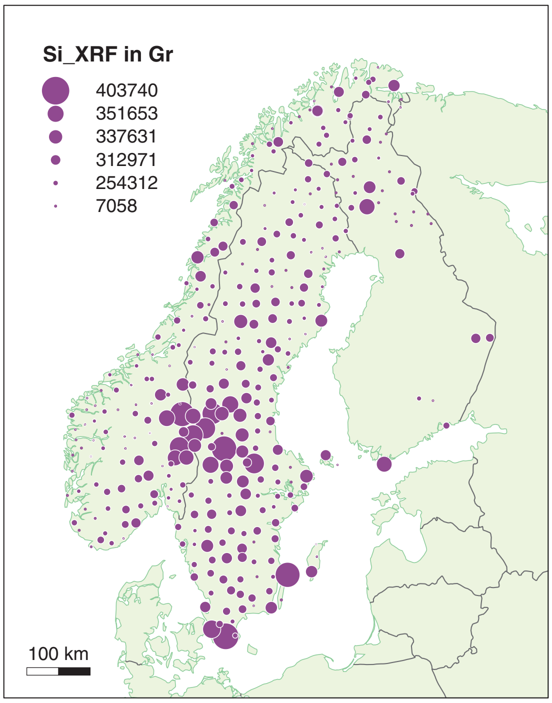
Slightly elevated Se concentrations occur in organic-rich agricultural soils in the Mälaren region and on the west coast. Se correlates with CEC, which is usually high in humic-rich soils. Se anomalies often follow sulphide mineralisations, seen in the elemental pattern in grazing land in the north (the Skellefte mining district) and in the southern part of the country. Soils underlain by shales in Jämtland and south-eastern Skåne have concentrations of Se. The highest values of Se in grazing land are found in areas where horses, sheep and cattle graze the fields. In Sweden, Se is often added to the food for livestock and especially for breeding animals. Concentrates including Se (as hydrosoluble powder) is often given to the animals in the fields. It is therefore likely that Se is of anthropogenic origin in other form than added to fertilisers.

Si (silicon)

High Si values indicate the presence of quartz-rich, and often quite coarse-grained soils. Silicon is a major component of rock-forming minerals like silicates. Acidic rocks have high contents of Si while mafic rocks contain less. Sandstones can have very high concentrations of Si and limestones have very low concentrations.

Arable soils overlying sandstones (Dala sandstones), conglomerates and granites tend to dominate the distribution pattern of total Si (XRF) in central Sweden and Norway (note that this area is marked by a pronounced “low” for many other elements). In the south-western part of Skåne, Si concentrations are high in soils overlying Phanerozoic sedimentary rocks like sandstones and siltstones. On Öland, high Si contents occur in soils overlying fine-grained calcareous sandstones and siltstones.





Sn (tin)

Sn is a relatively rare metal. Cassiterite (SnO_2) is the main Sn ore mineral and occurs in hydrothermal veins, pegmatites and placer deposits. Sn occurs as a trace element in rock-forming minerals and accessory minerals such as micas, amphiboles, sphene, rutile, ilmenite, magnetite etc. High Sn concentrations are known from felsic igneous rocks, metamorphic schists, shales and coal. Sn is mobile under very acidic conditions and precipitates together with Fe and Al hydroxides. Sn may form both soluble and insoluble complexes with organic compounds.

Finland

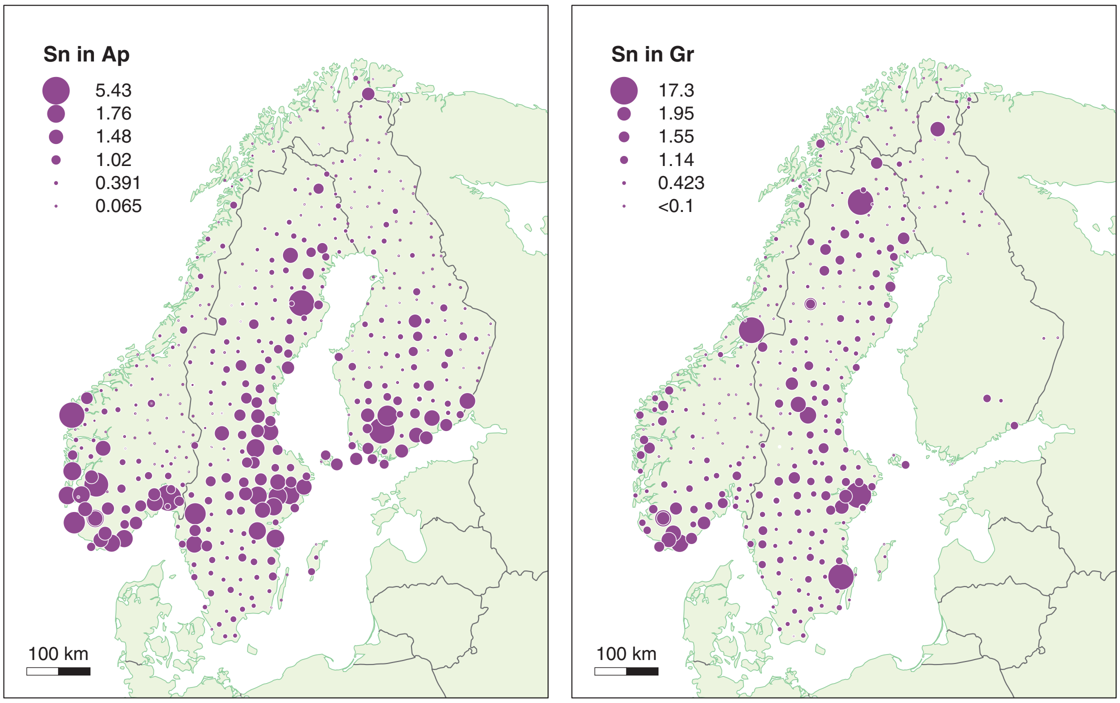
High Sn contents occur in clay-rich soils overlying granites (the Central Scandinavian clay belt). In south-eastern Finland, Sn anomalies can be related to known Sn deposits on the Russian side of Finlands eastern border, which have been mined during 1910–1920.

Norway

Elevated Sn concentrations occurring along the coast in southern Norway and in the Oslo Rift correlate with both the soil type (organic-rich) and numerous vein mineralisations.

Sweden

Sweden has the highest concentrations of Sn compared to Norway and Finland, although the values are not particularly high compared with the rest of Europe. High values are found preferably in sandy soils due to the presence of resistant cassiterite. Elevated concentrations of Sn in the Mälaren region and along the eastern coast correlate with fine-grained and clay-rich soils overlying granites, pegmatites and highly metamorphosed rocks. In Bergslagen and Värmland (Bengtsfors), Sn anomalies correlate with the younger generation of Mesoproterozoic granites and pegmatites. In central Sweden, Sn anomalies coincide with known Sn mineralisations in Gävleborg (e.g. Mosisjön), in the Stockholm area (Norrskogen) and in cassiterite-bearing greisen veins.



Sr (strontium)

Sr is a relatively common element which substitutes for Ca, Ba and K in rock-forming minerals, including feldspars, plagioclase, gypsum, calcite and dolomite. Intermediate to mafic rocks tend to be enriched in Sr. Sr minerals (strontianite and celestite) occur in hydrothermal veins. Together with Ba and Mg, Sr is a common element in calcareous rocks. During weathering, Sr is very mobile and it is usually adsorbed to clay minerals and bound to organic matter.

The Sr extractability is low (c. 20%) and therefore the dispersion pattern differs depending on the analytical method used. The highest values of Sr occur in Norway while Swedish soils have the lowest concentrations.

Finland

The concentrations of Sr in the south relate to clay-rich soils overlying granites and alkaline rocks. In northern Finland, leachable Sr originates from mafic volcanic rocks of the greenstone belts.

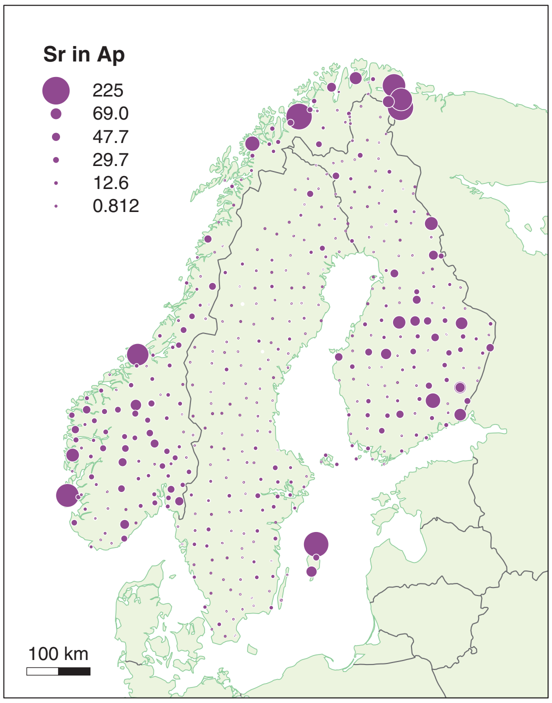
Norway

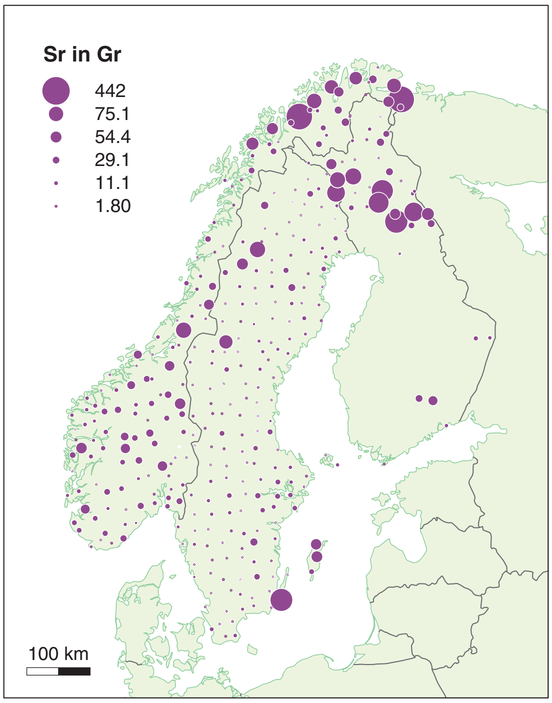
In Norway, the highest total concentrations of Sr occur on the west coast (metamorphic rocks in the Western Gneiss Region), while the highest aqua regia extractable concentrations are observed in the north (mafic rocks and Fe ore deposits).

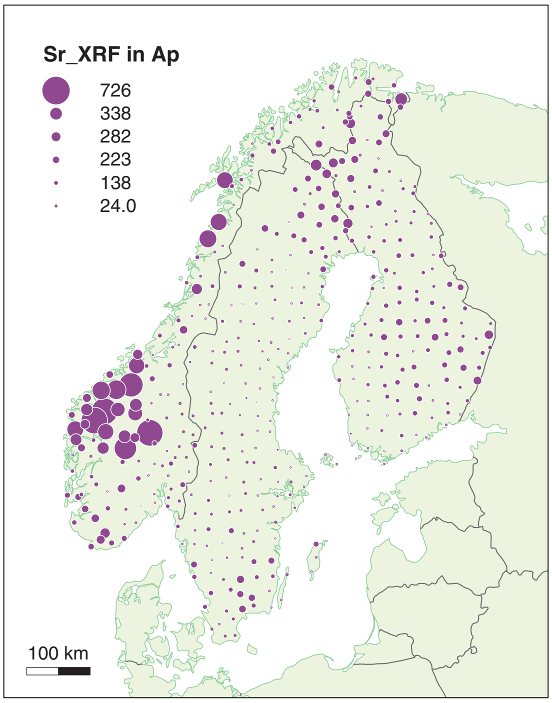
The concentrations of leachable Sr occurring along the coast in southern Norway can be attributed to input from marine aerosols. Sr concentrations in soils from the Oslo Rift and northern Norway indicate the presence of volcanic and alkaline rocks, respectively.

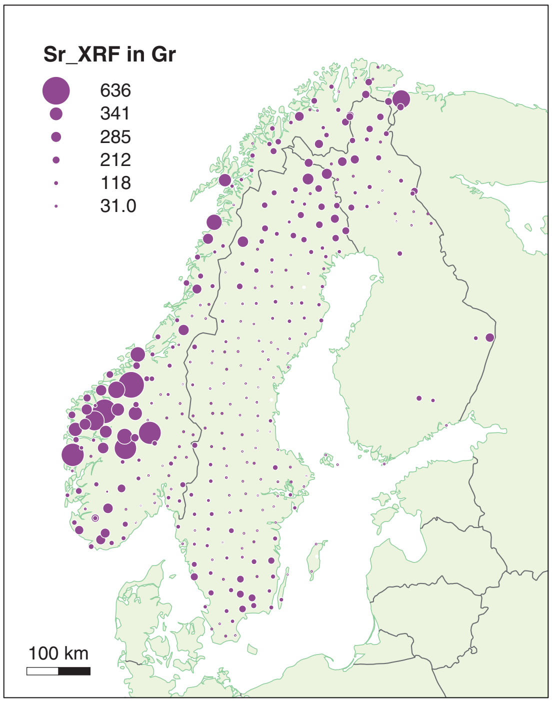
Sweden

Swedish soils have very low concentrations of Sr. Total concentrations of Sr (XRF) correlate with Al, Ba and K indicating the presence of feldspars in underlying crystalline rocks. Leachable Sr (aqua regia) correlates strongly with Ca, B and to some extent with CEC. The highest concentrations of leachable Sr are found in calcareous till on Gotland.



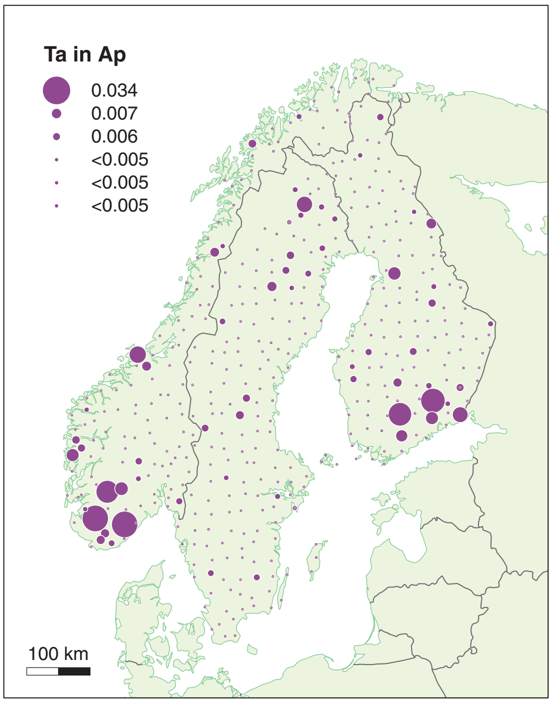


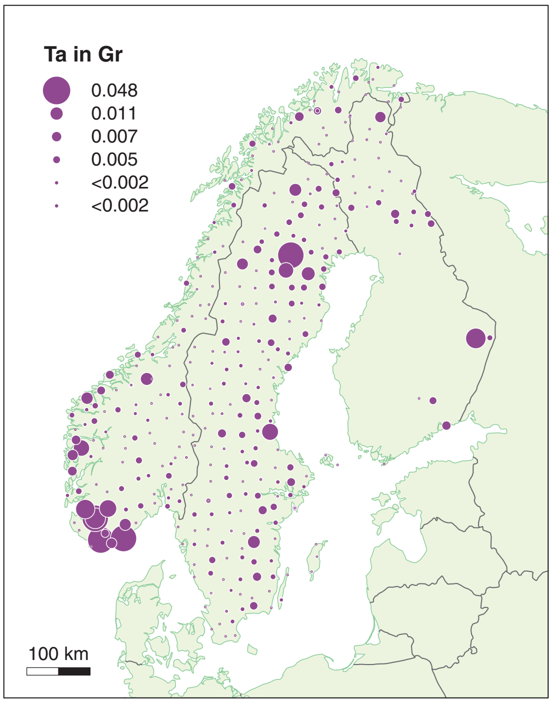




Ta (tantalum)

Ta is a lithophile element which occurs mainly as an oxide (tantalite). Ta can be found as a trace element in rock-forming minerals (biotite, pyroxene, amphibole) and in accessory minerals such as sphene, ilmenite and zircon where it often substitutes for Ti, Y and REEs. Ta occurs with Nb in granites, pegmatites and alkaline rocks. High values can also be found in Sn-greisen and veins. Tantalite and pyrochlore are the main Ta-bearing minerals in ore deposits. Minerals containing Ta are resistant to weathering, therefore, the element is rather immobile. Secondary Ta enrichments can be found in heavy mineral deposits (placers).





Finland

Locally in southern Finland there are some high concentrations of Ta which can be related to the occurrence of pegmatitic veins that are also rich in Li, Sn, W, Be and Au, e.g. the Sn-Ta-Li mineralisation in Kietyönmäki hosted by a spodumen-rich pegmatitic dyke. A larger anomaly in a grazing land sample in central-eastern Finland probably correlates with Au deposits and ilmenite-rich Fe mineralisations.

Norway

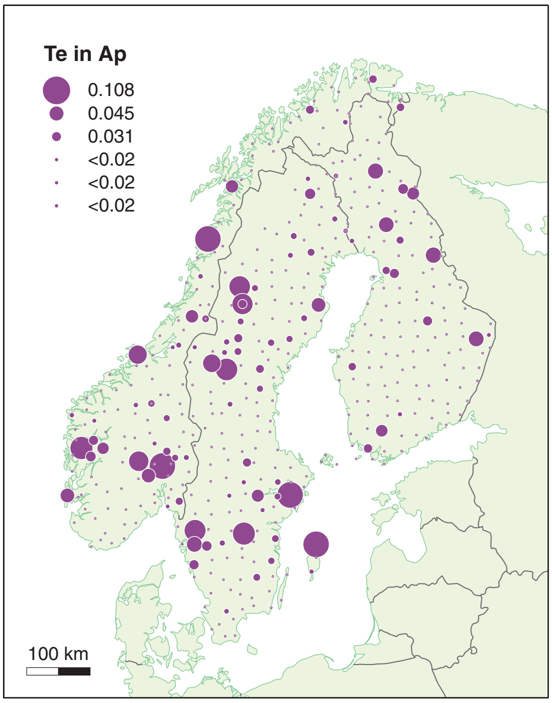
High concentrations of Ta occur in southern Norway and on the Hitra island. High values of Ta in soils are mainly related to the occurrence of Sveconorwegian felsic igneous rocks (granites and pegmatites), ilmenite-rich mafic rocks (e.g. norite in the Rogaland anorthosite province) and high-grade metamorphic rocks (e.g. eclogites).

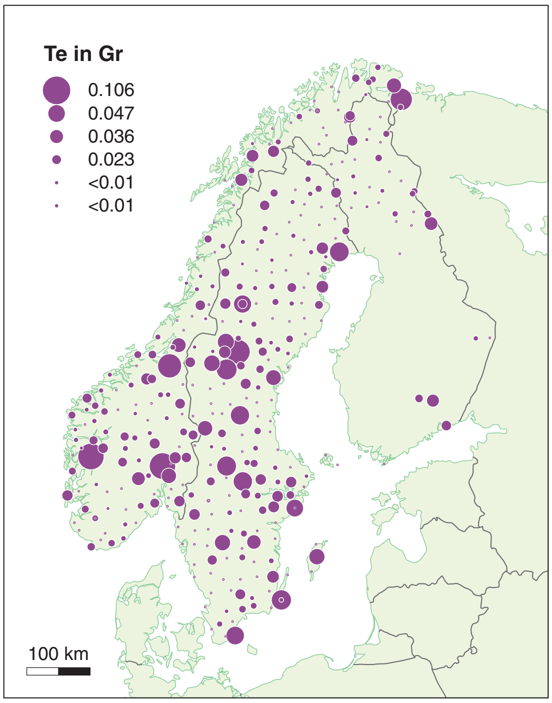
Sweden

Elevated Ta concentrations can be seen in soils underlain by crystalline and metamorphic rocks of the Fennoscandian Shield. The main sources of Ta are highly differentiated granites, pegmatites and alkaline rocks. Ta occurs with Nb, Sn, W, Au, U and REEs in many ore deposits throughout the country. Larger Ta anomalies in northern Sweden probably originate from ilmenite-rich apatite-iron ore deposits.

Te (tellurium)

Te is a rare metalloid of chalcophile nature and occurs mainly in mesothermal to epithermal vein formations. It forms tellurides, among which tellurides of gold and silver are important from the economical point of view. Te is therefore sometimes used as a pathfinder element for gold deposits. Apart from gold mineralisation, pyrite, Cu and Mo deposits may exhibit high Te concentrations. Concentrations of Te in magmatic and sedimentary rocks are low with the exception of shales, which can show some enrichment of the element. In the surficial environment, Te is





soluble at low pH and it is adsorbed to Fe hydroxides. Te can also be added to the environment by the burning of coal. Soils in Norway, Sweden and Finland display low values of Te compared with the rest of Europe. Very low values of leachable Te, near the detection limit, result in some analytical problems.

Finland
A few local hot spots of Te coincide with gold deposits, e.g. in Satulinmäki (southern Finland), Korpilampi-Pampalo and Pahkalampi (central-eastern Finland), and various Au mineralisations within the Palaeoproterozoic Central Lapland Greenstone Belt in northern Finland, with the biggest mine Suurikuusikko.

Norway
High Te concentrations occur in southern Norway (the Oslo Rift, Kongsberg, Bergen) and in central Norway (in the Caledonides). These local elevated Te contents coincide with known Au and Ag mineralisations, e.g. Eidsvold (the Oslo Rift), Kongsberg, Nygruva (Zn-Cu-Au ore deposits located south-west of Bergen) and Mannfjell (Zn-Cu-Au ore deposits in the Caledonides). In northern Norway, near Kirkenes, Te anomalies in grazing land are related to the Russian Au ore deposits at Braginskoe.

Sweden
The dispersion pattern reflects areas with alum shale in the Caledonides as well as in the southern parts of Sweden. Some mineralisations with gold and silver are known from Värmland-Dalsland (e.g. Harnäs), Bergslagen (Zinkgruvan, Saxberget), the Skellefte district and the Gold line where elevated concentrations of Te occur in the soils. Enigmatic anomalies from the islands Gotland (Ap) and Öland (Gr) are explained as secondary concentrations of Te in soils overlying carbonate rocks. Similar anomalies are known from karstic soils in Greece and Slovenia. In general, sandy soils tend to have higher concentrations of Te than clay-rich soils.

Th (thorium)

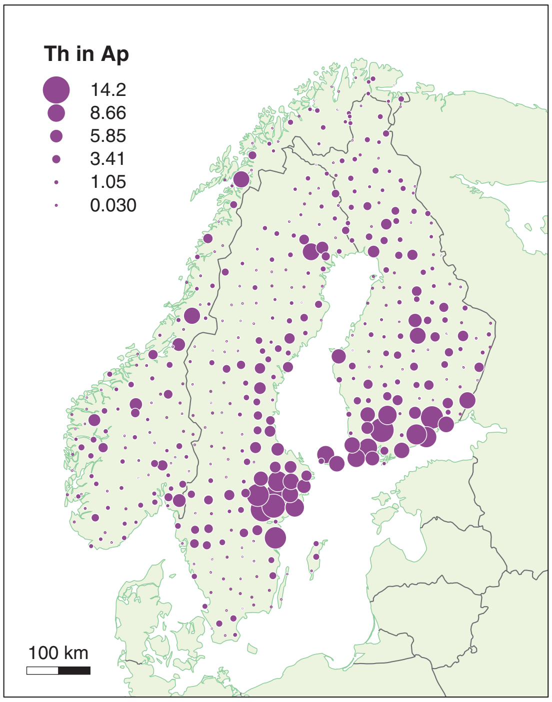
Apart from the Central Scandinavian clay belt, Th shows rather low values in soils in Norway, Sweden and Finland compared with the rest of Europe. Th is an incompatible element in most crustal processes and therefore concentrates in more evolved igneous rocks, such as granites and pegmatites, and their metamorphic derivatives. Th occurs in one oxidation state in nature (4+) and often follows U in crustal processes. One significant difference compared to U is the lack of a more oxidised (6+) state. While Th can form oxides and silicates, it is more commonly found as a minor element in minerals such as monazite, allanite and biotite. Chemically, Th often follows Ca and as such can occur as a significant trace element in limestones.

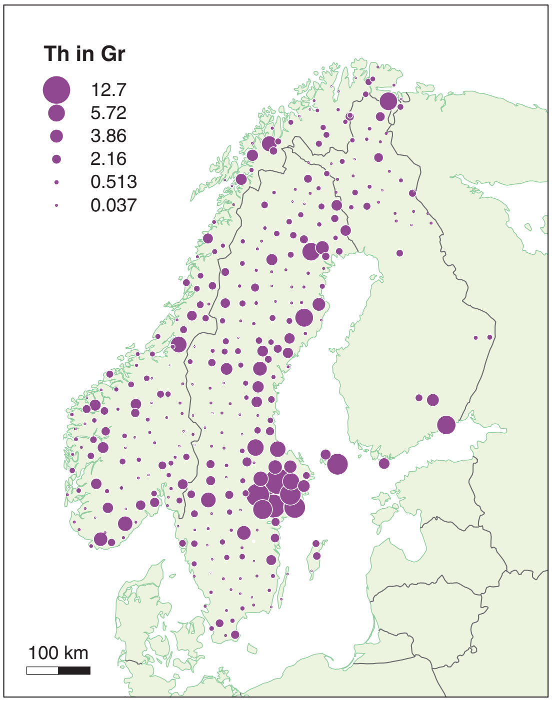
Like U, Th is oxidised during weathering and redeposited in reducing environments. While both are strongly bound to clay minerals, Th has been shown to have a proportionally greater affinity for organic complexing than U, but not to the extent that Th is enriched in organic-rich soils, but rather is generally strongly depleted. Overall, in rocks, the concentration of Th is approximately three times the concentration of U, but in the GEMAS dataset it is usually seen in lower absolute concentrations for a given sample site. This points to weathering and related processes in the secondary environment playing a major role in the redistribution of these two elements in soils.

Agricultural soils have higher concentrations of Th than grazing land and the extractability (European) in arable soils differs (36% in agricultural soils vs. 26% in grazing land).

Finland

High concentrations of Th occur in southern Finland were clay-rich soils (the Central Scandinavian clay belt) overlie granitic rocks, e.g. rapakivi granites. Intermediate Th values in central and northern Finland coincide with outcrops of Archaean intrusive rocks (orthogneisses and migmatites). The Th anomaly in central Finland along the Baltic coast overlaps with the presence of an open pit mine in Korsnäs where Pb and REEs were exploited until 1972.





Norway
In the Oslo Rift and in central Norway, the concentrations of Th are at intermediate levels in the soils. Locally, small anomalies occur in relation to mineralised pegmatites and quartz veins (with Au, Ag). The large Th anomaly in the total XRF data located south-west of Oslo is probably derived from the famous alkaline intrusion – the Fen Complex.

Sweden
The highest concentrations of Th in Sweden occur in the Mälaren region where clays and fine-grained soils of the Central Scandinavian clay belt overlie granites and pegmatites. These high values correlate with similar high values on Åland and in southern Finland in clay-rich soils of the Central Scandinavian clay belt. Elevated concentrations of Th can also be seen in soils overlying the same rock types in Värmland and Dalsland, Västergötland, and in Norrbotten, e.g. in the Lule river basin. A large area of slightly elevated Th concentrations along the coast from Gävle to Västerbotten reflect clay-rich soils overlying crystalline and often highly metamorphosed rocks of the Fennoscandian Shield.

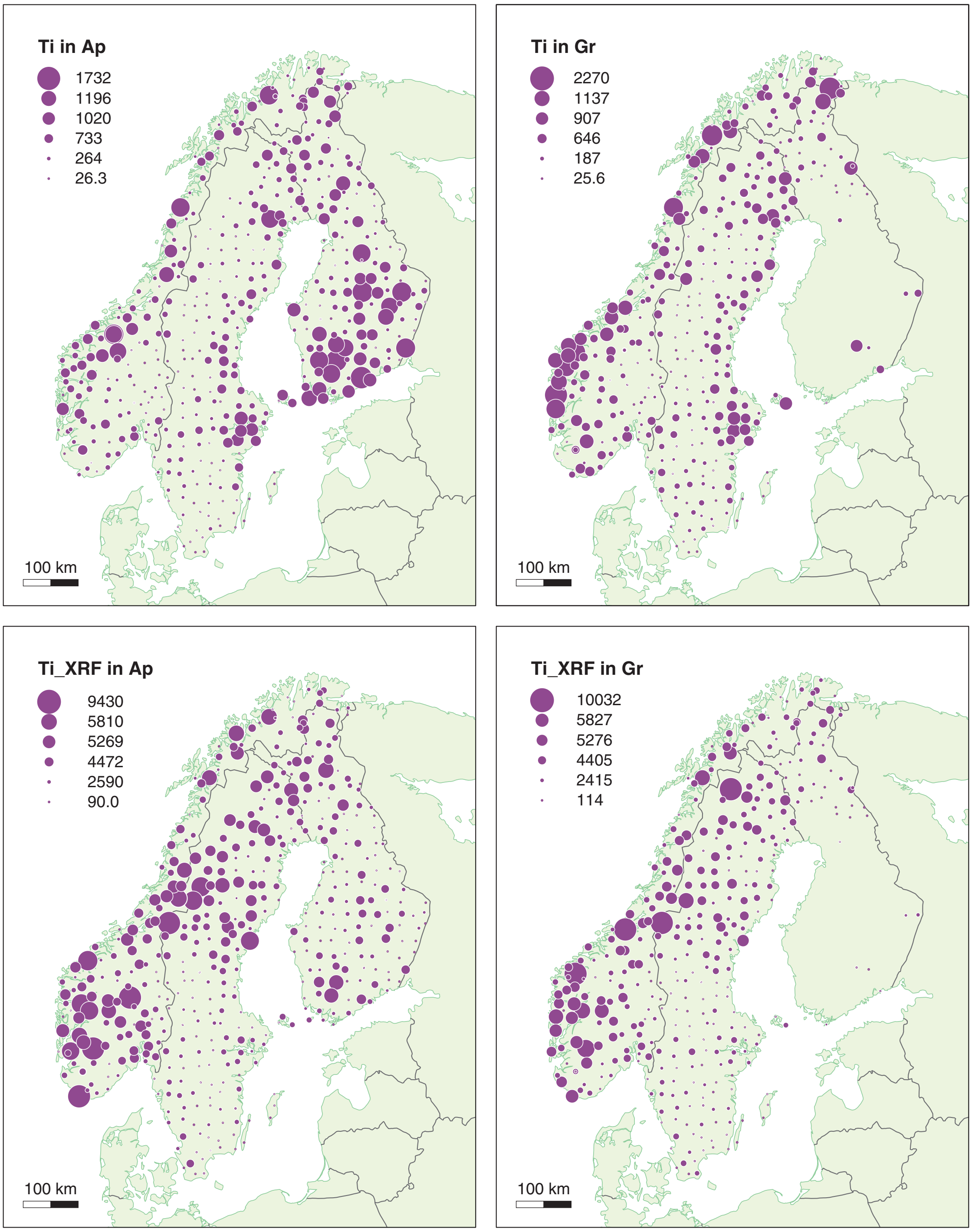
Ti (titanium)
Ti is a common element which forms several minerals, including ilmenite, rutile and sphene, that are resistant to weathering. Ti can also substitute for Mg and Fe in rock-forming silicates like pyroxenes, amphiboles and micas. Mafic and ultramafic rocks can have high concentrations of Ti and the element is enriched in shales. During weathering, Ti is largely immobile and remains in resistant minerals. Ti can, however, be released during weathering of Fe-Mg-silicates from mafic rocks. In solution, the element is adsorbed to clay minerals.

Soils in Norway, Sweden and Finland have very high Ti concentrations in comparison to central and southern Europe. The elemental pattern correlates well with the geology of the crystalline rocks of the Fennoscandian Shield. Ti shows a very low extractability; only 3% of the total concentrations are extracted in aqua regia. The dispersion patterns thus differ depending on the analytical method. The Central Scandinavian clay belt can be seen in the dispersion patterns of leachable Ti, while it is completely missing on the map of the total concentrations of Ti.

Finland
High contents of Ti (XRF) in soils correlate well with occurrences of crystalline rocks, especially mafic rocks. The content of leachable Ti in clay-rich soils in the Central Scandinavian clay belt is discernible, especially in the aqua regia map.

Norway
High concentrations of Ti occur along the coast. The combination of geology and weathering processes results in a secondary concentration of the element. Many Fe-Ti-V mineralisations occur in Norway, both in the basement rocks (south-western and northern Norway) and in the central Caledonides. Ti anomalies occur in soils overlying mafic and ultramafic rocks rich in ilmenite and high-grade metamorphic rocks rich in rutile (e.g. eclogite). Another source of Ti in soils underlain by metamorphic rocks is sphene, a common mineral occurring in metasedimentary rocks in the Caledonides.

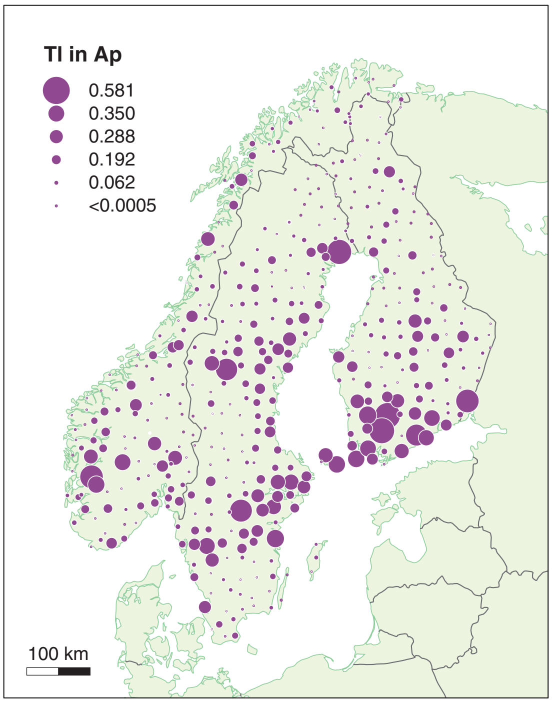
Sweden
Elevated concentrations of leachable Ti (aqua regia extraction) occur in clay-rich soils of the Mälaren region (the Central Scandinavian clay belt) and along the eastern coast. In Västerbotten and in Norrbotten, Ti contents originate from mafic rocks. Concentrations of Ti are higher in regions

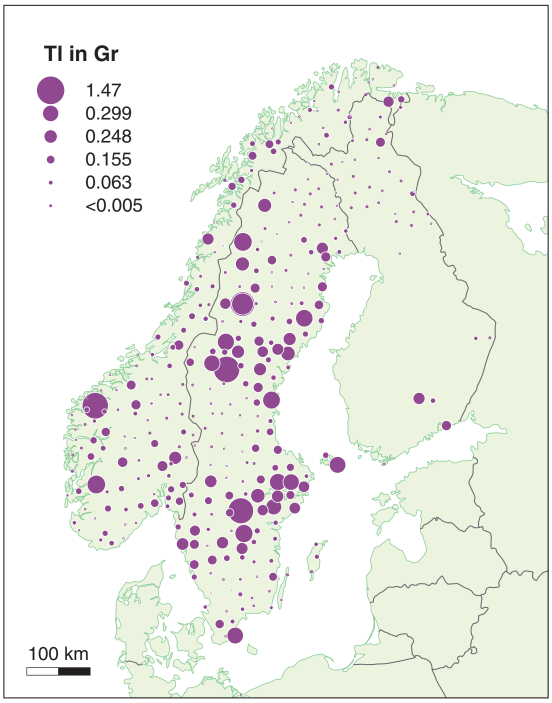


with Fe-Ti mineralisations, especially in Västerbotten and Norrbotten. High concentrations of total Ti in soils (XRF) in the Caledonides in Jämtland and Västerbotten are the result of the presence of mafic and ultramafic rocks and the high content of minerogenic material in soils due to intensive physical weathering.

Tl (thallium)

Tl is a minor element which forms minerals in hydrothermal environments (e.g. lorandite). Tl occurs as a trace element in various sulphides (galena, sphalerite) and silicates (K-feldspar and micas). The highest concentrations of Tl are found in granites, shales and coal. Tl can be enriched





in pegmatites and in Zn-Pb mineralisations with galena and sphalerite, and is used as a pathfinder element for gold. Tl is easily released during weathering and it is adsorbed to clay minerals and Fe-Mn oxides or is bound to organic matter. Plants can easily accumulate Tl (probably in place of the major nutrient K). The metal is highly toxic. Tl is enriched in clay-rich soils of the Central Scandinavian clay belt, in regions with shales and in Cu-Zn-Pb ore deposits.

Finland

The Tl content is high in clay-rich soils in southern Finland (the Central Scandinavian clay belt) overlying crystalline felsic rocks (e.g. rapakivi granites) and black shale. Otherwise, Tl concentrations correlate well with occurrences of polymetallic mineralisations (mainly Zn-Pb).

Norway

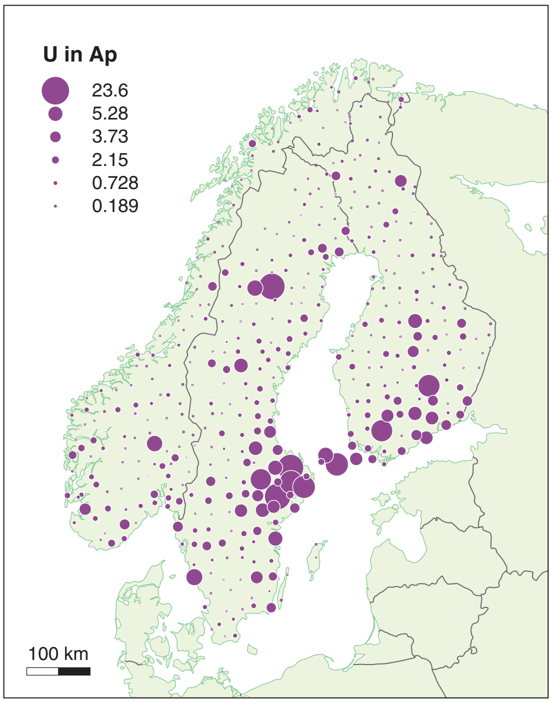
Elevated concentrations of Tl in soils occur in the Oslo Rift (alum shale) and locally along the west coast. Tl anomalies correlate with various polymetallic sulphide mineralisations.

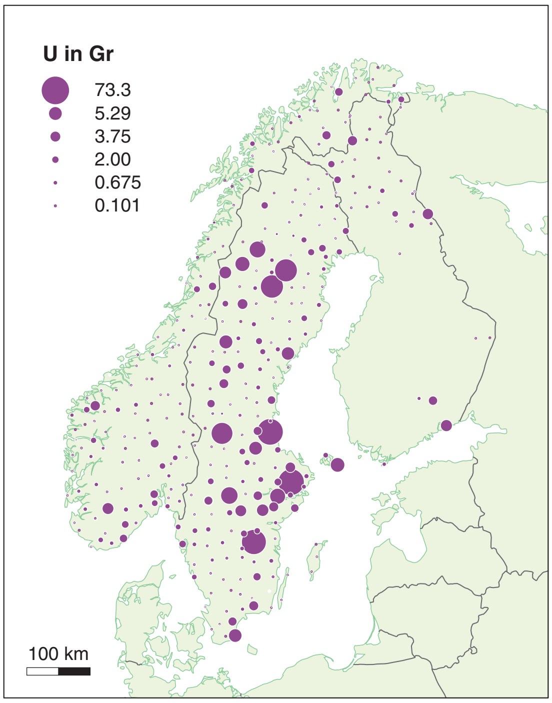
Sweden

Tl concentrations are relatively high in clay-rich soils in the Mälaren region (the Central Scandinavian clay belt) and along the coast. In Jämtland and southern Norrbotten, Tl follows sulphide mineralisations (Cu-Zn) and black shale occurrences. In the southern part of Sweden, Tl concentrations in soils reflect occurrences of Palaeozoic fine-grained sedimentary rocks and Zn-Pb mineralisations.

U (uranium)

Norway, Sweden and Finland has the highest concentrations of U in Europe due to granitic bedrocks of the Fennoscandian Shield. In younger granites, pegmatites and shales, the content of U can be particularly high. High concentrations of U in soils occur in the Central Scandinavian clay belt. U forms its own minerals (e.g. uraninite), and substitutes into apatite, zircon, allanite, monazite and minerals with Nb-Ta. Most U-bearing minerals are resistant to weathering. When





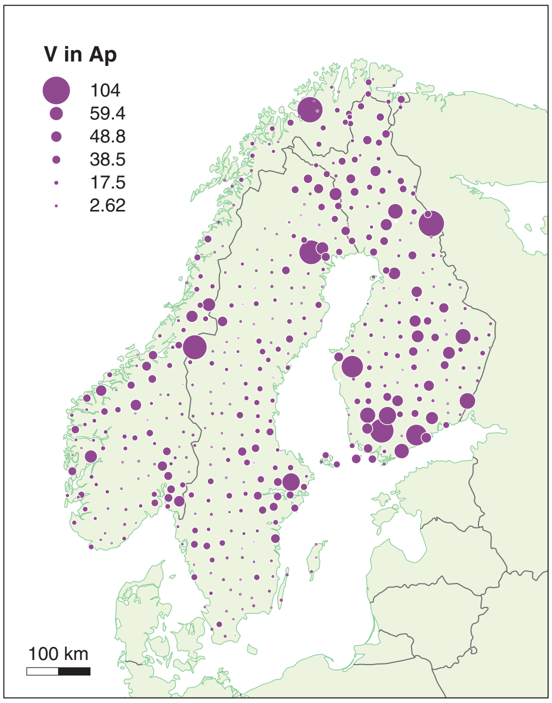
released (e.g. from apatite), U adsorbs to clays, organic matter and iron oxides, and also binds to phosphates. Northern Europe hosts some of Europe's most important U ore deposits and Sweden, for example, had up to 1981 a number of operational test-mines. The extractability of U is not very high, 38% in agricultural soils (in Europe) and 52% in grazing land.

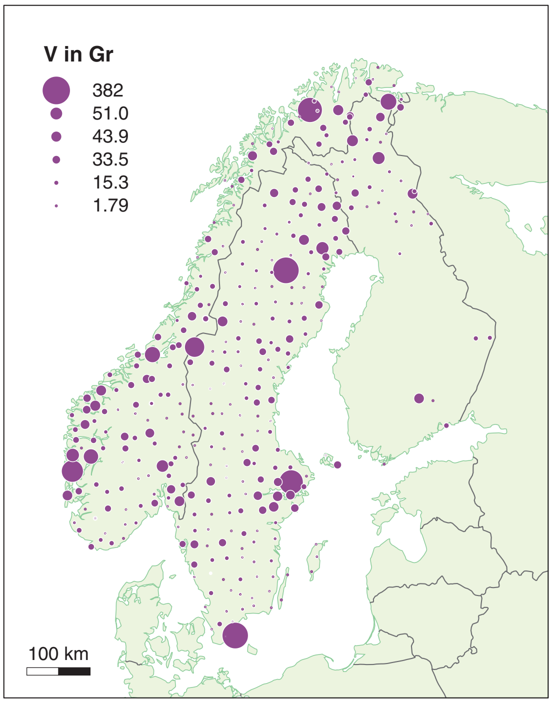
Finland
The elevated concentrations of U occur in clay-rich soils of the Central Scandinavian clay belt in southern Finland, which overlie younger granites and, locally, black shale. In central and northern Finland, U anomalies follow known U ore deposits and V-Zn mineralisations.

Norway
Moderate U concentrations in soils occur in the Oslo Rift region and are related to the occurrence of black shales.

Sweden
Compared with Norway and Finland, Sweden has the highest median values of U. Elevated concentrations are seen in association with known ore deposits including the Arjeplog–Arvidsjaur epigenetic mineralisations and the Caledonian black-shale deposits. Although there is no strong correlation with clay elements like Al and K, U is enriched in the Mälaren region where fine-grained sediments overlie granites and pegmatites. These high values correlate with similar high values on Åland and in southern Finland in clay-rich soils of the Central Scandinavian clay belt. High concentrations of U occur in Jämtland (alum shale and granites), in Norrbotten and Västerbotten (granites, volcanic rocks, gneiss), in the south-east, and along the west coast (younger granites with high gamma radiation in Bohuslän).

V (vanadium)
The geochemical behavior of V resembles that of Fe. V occurs in Fe-bearing minerals such as magnetite, chromite and ulvöspinel, and it can substitute for Fe in Fe-Mg silicates (amphiboles,





pyroxenes, micas). As a trace element, V occurs in accessory minerals, e.g. apatite, rutile and sphene. Mafic rocks are usually enriched in V, and the content can also be high in shales and coal due to the element's affinity to organic matter. V is easily released during weathering processes, and it is highly mobile under oxidising conditions. V is relatively immobile at low pH and during metamorphism. It adsorbs to Fe- and Mn-oxy-hydroxides, clays and organic matter. V extractability is intermediate, 40% in arable soils.

Leachable V (aqua regia extraction) is enriched in clay-rich soils of the Central Scandinavian clay belt. Total concentrations correlate with the occurrence of mafic rocks.

Finland

Relatively high V concentrations are seen throughout the country where the element occurs in clay-rich soils (the Central Scandinavian clay belt in southern Finland) and in areas overlying mafic and ultramafic rocks (greenstone belts). In general, V also follows known Fe(-V-Ti) deposits.

Norway

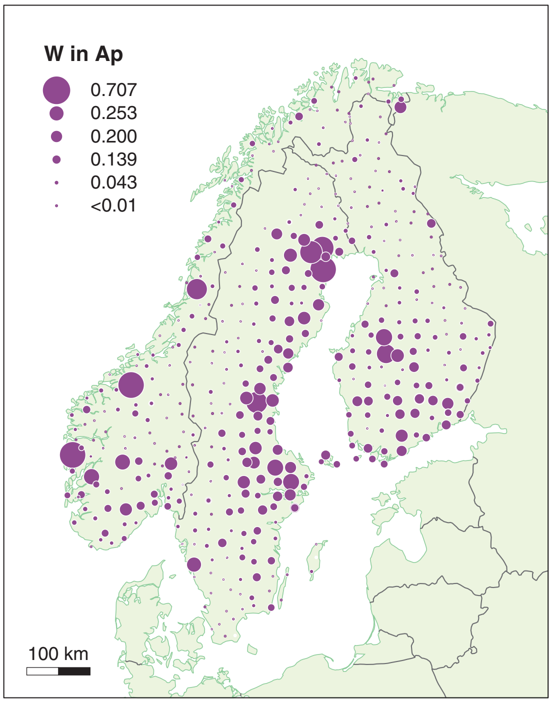
Elevated V concentrations in soils occur in the Oslo Rift (volcanic rocks and alum shale) and in those parts of the Caledonides underlain by mafic and ultramafic rocks.

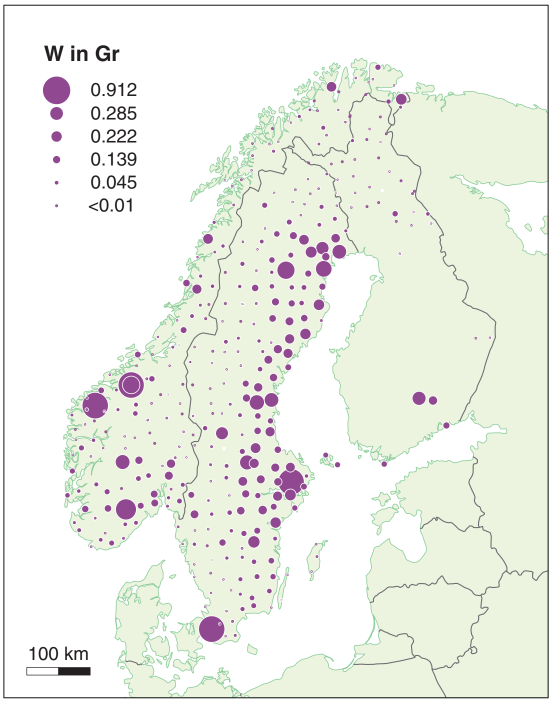
Sweden

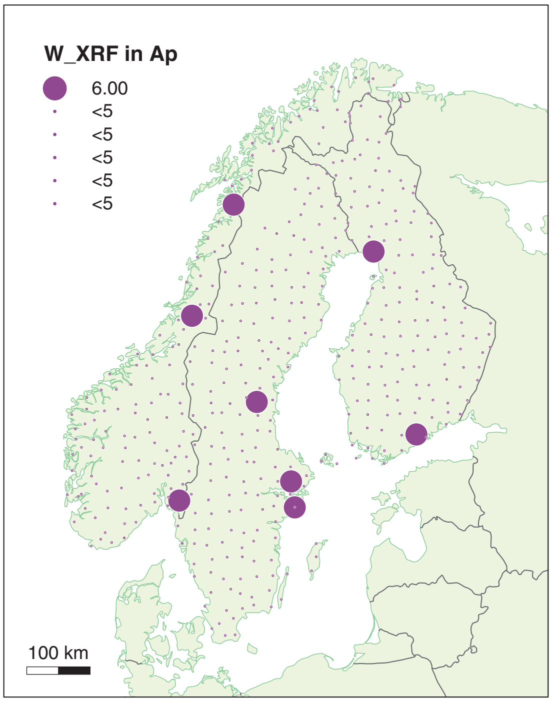
High V concentrations occur in the clays of the Mälaren region (the Central Scandinavian clay belt) and along the eastern coast. High concentrations of V are observed in relation to outcrops of mafic and ultramafic rocks, e.g. Handöl in Jämtland (ophiolites with soapstone) and in the Haparanda and Pajala regions in Norrbotten. Known polymetallic mineralisations are indicated by V anomalies in Västerbotten, Jämtland (near Östersund) and south-eastern Skåne. Enrichment of V in soils can also be caused by a high content of organic matter and by Fe-Mn oxides.

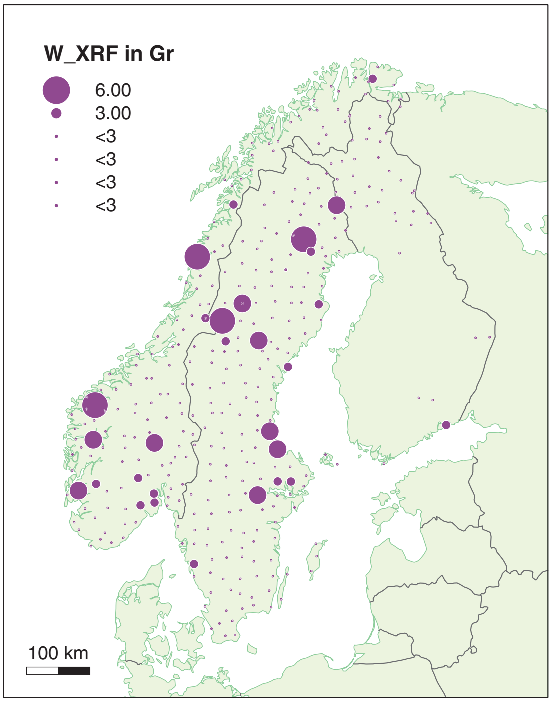
W (tungsten)

W is a relatively rare element occurring in granites, graphitic schists, phyllites and shales. It forms the minerals scheelite and wolframite, which are the economic source of W and mainly found in quartz veins, pegmatites and skarn deposits. W minerals are often accompanied by cassiterite and fluorite. The geochemical behavior of W resembles that of Mo. In altered granites near W deposits, the element can be enriched in micas. The element is used as a pathfinder element both for its own deposits and for gold deposits. W has very low extractability (3–4%) and W minerals are generally insoluble under acidic conditions. When released during weathering, W is mobile in alkaline waters and tends to adsorb to Mn oxides and to clays.









Finland

The W anomalies in the soils of south-eastern Finland correlate with U mineralisations and the occurrence of pegmatites. W anomalies in central Finland might correlate with the occurrence of Au, Ag and Li mineralisations in pegmatites and quartz-rich veins.

Norway

A few isolated W anomalies may originate from underlying pegmatites and metamorphic rocks containing wolframite and scheelite. Locally, anomolies correlate with Au mineralisations, e.g. Reppen and Kolsvik in central Norway.

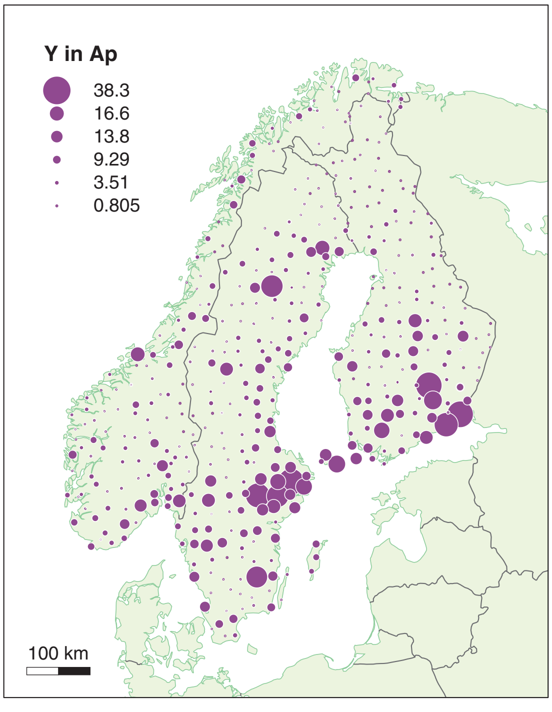
Sweden

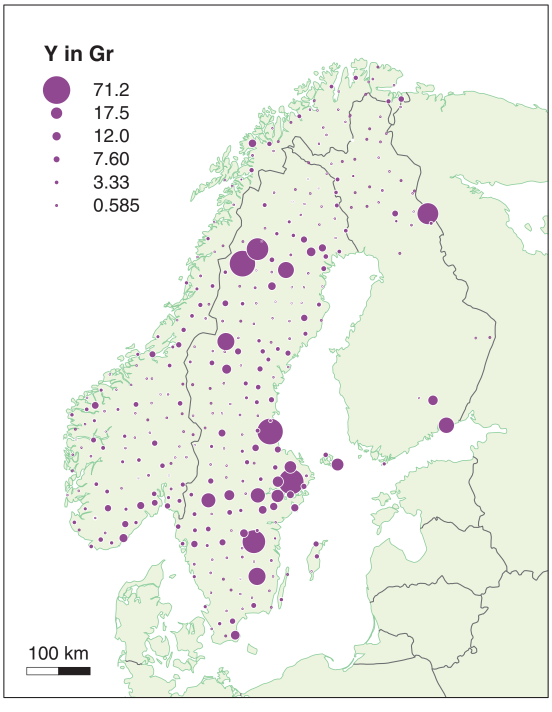
Sweden has higher median values of W than Norway and Finland. In Sweden, the highest concentrations of leachable W (aqua regia) occur along the eastern coast from the Mälaren region to the northern Bothnian Gulf in clay-rich soils overlying granites and pegmatites of the Fennoscandian Shield. Dispersion patterns show elevated concentrations of W in Norrbotten, Bergslagen and along the central coastline. These anomalies follow known W mineralisations occurring within granitic rocks (together with U and Au). In the Caledonides of northern Jämtland, in the Gäddede region, high W concentrations (Gr, XRF) in soils correlate with U-fluorite-hematite mineralisations hosted by cataclastic breccias within fractured granitic rocks.

W from aqua regia extraction correlates with Na, Nb and Ti, but not with elements that normally occur in clays.

Y (yttrium)

Y occurs in many types of rocks, but preferentially in granites, pegmatites and shales. The element forms accessory minerals, e.g. xenotime, monazite and bastnäsite, all of which are resistant to weathering. Y can enter lattices of common rock-forming minerals such as apatite, biotite, pyroxenes, amphiboles, garnets and feldspars. Its geochemical behavior is similar to the rare earth elements, therefore these elements can be found together in evolved felsic rocks. Y can be mobile





during hydrothermal processes. Y is released to the surficial environment through weathering of rock-forming minerals but the element has a strong tendency to be adsorbed to Fe oxyhydroxides and to clay minerals. Although the extractability of Y in European arable soils is only 25%, the elemental dispersion patterns for aqua regia extraction and XRF are very similar.

Finland

Elevated Y concentrations occur in clay-rich soils of the Central Scandinavian clay belt in southern Finland. Local high Y concentrations in southern Finland are related to occurrences of granitic rocks (e.g. rapakivi granite) and pegmatites. The large Y anomaly in grazing land soil in north-eastern Finland coincides with Nb-Ta-REE mineralisations occurring on the Russian side of the border.

Norway

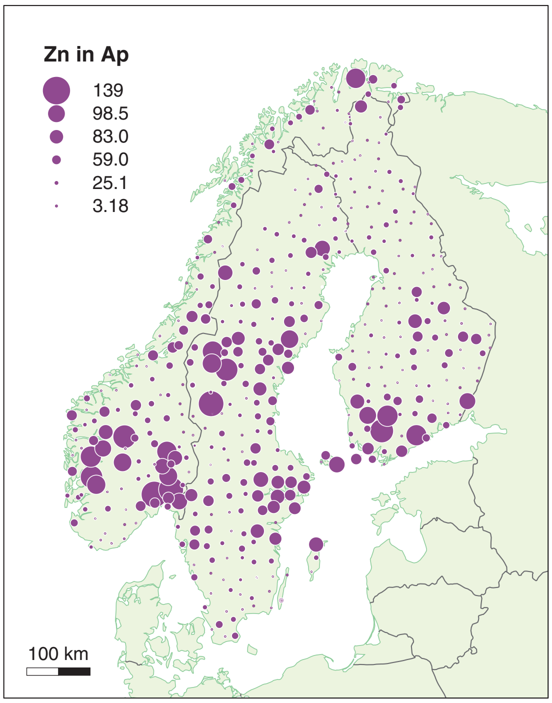
Locally, intermediate Y concentrations occur in soils that overlie granites and pegmatites.

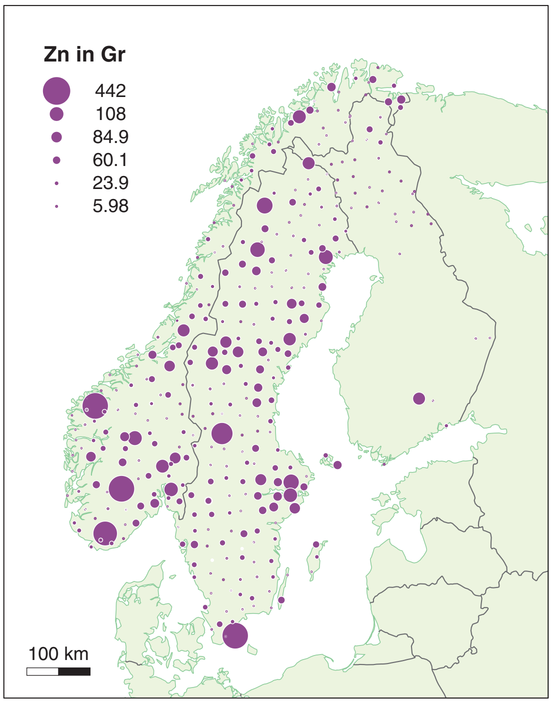
Sweden

Y concentrations are relatively high in the Mälaren region where clays of the Central Scandinavian clay belt overlie granites and pegmatites. The mine of Ytterby, situated south of Stockholm, is the location where Y was first discovered. The soils have local high contents of Y in Småland (close to the Ädelfors Au mine), in Värmland reflecting mineralised regions (e.g. the Harnäs Au-Pb ore deposits), in Jämtland (in soils overlying black shale and granites) and in Västerbotten where they coincide with the U, Au, Ag, W and REE mineralisations (Sorsele-Arjeplog region).

Zn (zinc)

Zn is a strongly chalcophile element which forms economically important ore deposits with the Zn ore mineral sphalerite. Sphalerite is often accompanied by galena and other sulphides. Zn also forms Zn carbonate (smithsonite) and Zn oxide (zincite). As a trace element, Zn occurs in minerals such





as magnetite, pyroxenes, amphiboles, biotite and garnets, and tends to be enriched in mafic rocks and in shales. In sedimentary rocks, Zn occurs in clay minerals, carbonates and detrital magnetite. Zn released during weathering is co-precipitated with Fe-Mn oxyhydroxides or it adsorbs to clay minerals and organic matter. The extractability in European arable soil is 75%.

The dispersion pattern of Zn is clearly affected by clay-rich soils in the Central Scandinavian clay belt. The elemental distribution of Zn is to some extent similar to that of Mn, Mo, Ag, As and Sb.

Finland

High concentrations of Zn occur in southern Finland (the Central Scandinavian clay belt) and in the central part of the country in correlation with clay-rich soils and Zn-Pb-Cu mineralisations.

Norway

High Zn concentrations in soils are observed in the Oslo Rift and in south-western and central Norway. The large Zn anomaly in south-western Norway marks the location of the Odda Zn smelter. Based on observations from most other elements, this anomaly appears to be too large for a purely anthropogenic origin and follow-up work in this area is justified. Other Zn anomalies correlate very well with numerous Zn-Pb-Cu-Ag mineralisations.

Sweden

Elevated Zn concentrations occur in the clay-rich soils in the Mälaren region (the Central Scandinavian clay belt) and along the eastern coast. Zn anomalies follow sulphide mineralisations in many places, including northern Dalarna (e.g. Vassbo), Jämtland (e.g. Tjärnberget), Västernorrland (e.g. Rockliden), Bergslagen and Värmland (e.g. Dingelvik). The large Zn anomaly (and Cd) in grazing land in south-eastern Skåne corresponds to mineralisation with galena in Cambrian sandstone. Unexpectedly high Zn concentrations have been noted on northern Gotland. This anomaly possibly has an anthropogenic source as Zn can originate from fertilisers (manure) or it may indicate historical pollution related to brass (zinc-copper alloy) manufacture. Significant amounts of Zn (together with Cd, Pb and other metals) have been found in marine sediments in the Gotland Basin.

Zr (zirconium)

Zr is a common trace element enriched in granitic and alkaline rocks. Zr forms minerals such as zircon and baddeleyite, and it substitutes for Ti in ilmenite, sphene and rutile. As a trace element, Zr occurs in rock-forming minerals such as pyroxene, amphibole, garnets and micas. The amount of Zr in sedimentary rocks depends on the contribution of the heavy mineral fraction. Secondary Zr can be adsorbed to clay minerals.

Zr shows poor leachability, and its extractability in arable soil is only 1%. Most Zr in arable soils is immobilised in resistant minerals. Leachable Zr occurs almost exclusively in clay-rich soils of the Central Scandinavian clay belt. The elemental patterns displayed on the maps for XRF and aqua regia extraction differ significantly.

Finland

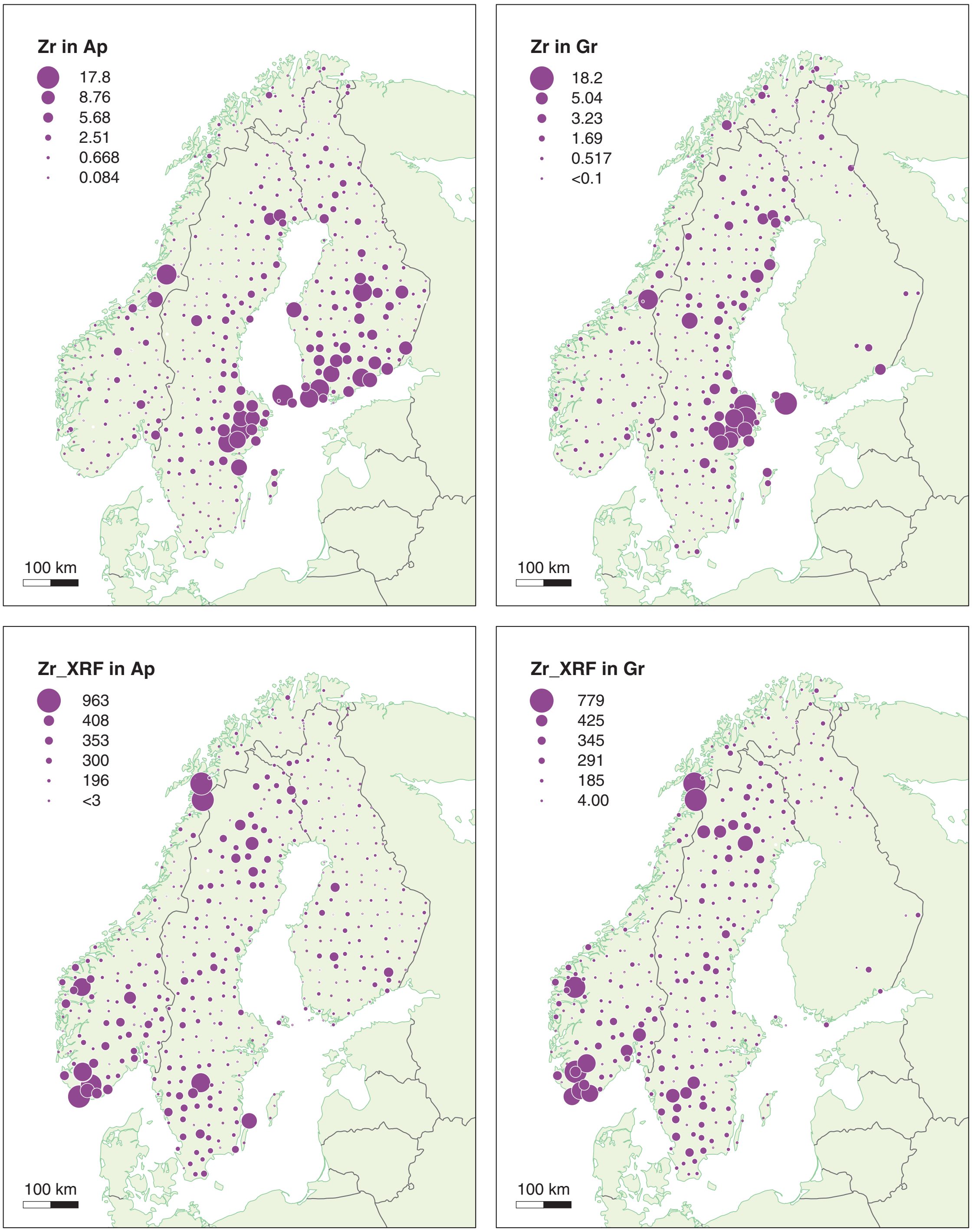
High Zr contents (aqua regia extraction) occur in clay-rich soils in southern Finland (the Central Scandinavian clay belt) and in central Finland.

Norway

High concentrations in soils of extractable Zr occur in central Norway and correlate with the presence of ilmenite-rutile-bearing metamorphic rocks. The total Zr (XRF) shows high concentrations in the soils of southern Norway, north of Bergen and in the Lofoten region. These anomalies occur in soils overlying crystalline basement rocks and high-grade metamorphic rocks (eclogites of the Western Gneiss Region) and coincide with Fe-Ti mineralisations where Zr substitutes Ti in ilmenite, rutile and sphene.

Sweden

High concentrations of extractable Zr occur in clay-rich soils in the Mälaren region (the Central Scandinavian clay belt) and along the eastern coast. In central Jämtland, elevated Zr concentrations originate from black shales outcropping along the mountain front. High total concentrations of



Zr in south-western and northern Sweden originate from underlying crystalline rocks (granites and pegmatites). The anomaly on the northern tip of Öland (XRF) is probably related to a sandy sample containing a relativly high percentage of heavy minerals.

pH

The soil acidity, measured as pH, is strongly influenced by precipitation, altitude, rock type, vegetation, clay content, organic matter etc. The distribution pattern of pH in the arable soils in Norway, Sweden and Finland shows low (acidic) values that mainly reflect the absence of carbonate rocks in Fennoscandia. Most of the low pH values indicate peaty soils, rich in humic acids. High pH values are very scarce and correlate with rare occurrences of limestone and marble.

Finland

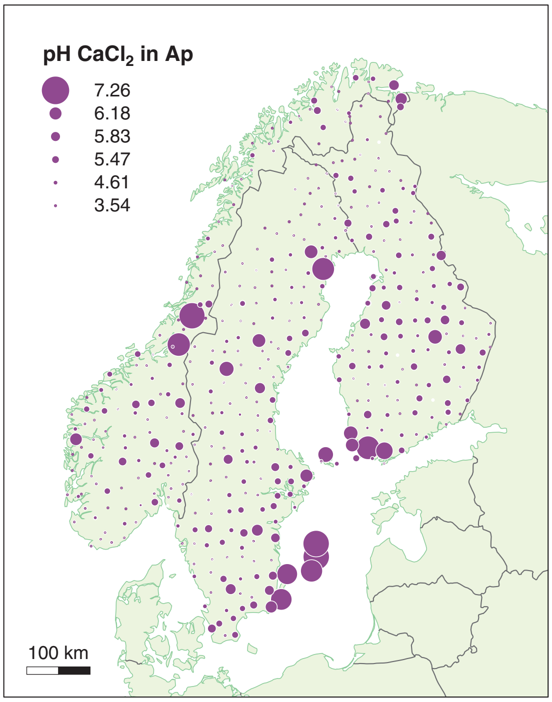
Low pH values occur in northern Finland where many samples are exceptionally rich in organic matter (peat). In southern and central Finland, the observed high pH in the soils is probably a result of liming.

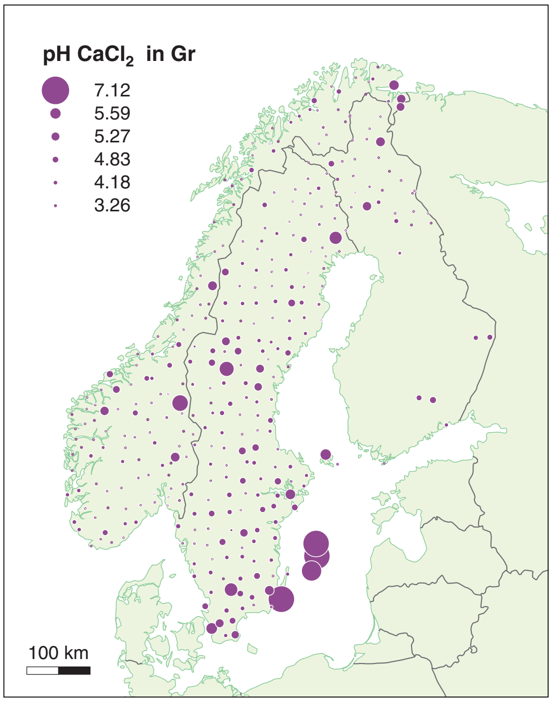
Norway

Low pH values are present in most of the country and indicate high organic matter content in soils, and high precipitation. Single anomalies with high pH in central Norway correlate with outcrops of carbonates in the higher nappes of the Caledonides.

Sweden

The lowest pH values are found in organic-rich soils, often collected in peat bog areas. The pH values are neutral to alkaline on Gotland, Öland and in Jämtland where Cambro-Silurian carbonates and marls occur. At the north-eastern coast, some high concentrations may reflect mafic rocks containing easily weathered minerals, e.g. Ca-plagioclase, pyroxene and amphibole.





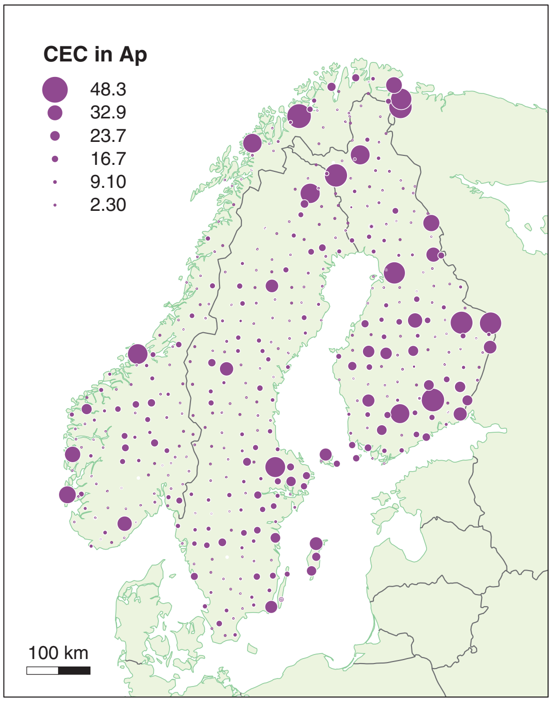
Cation exchange capacity

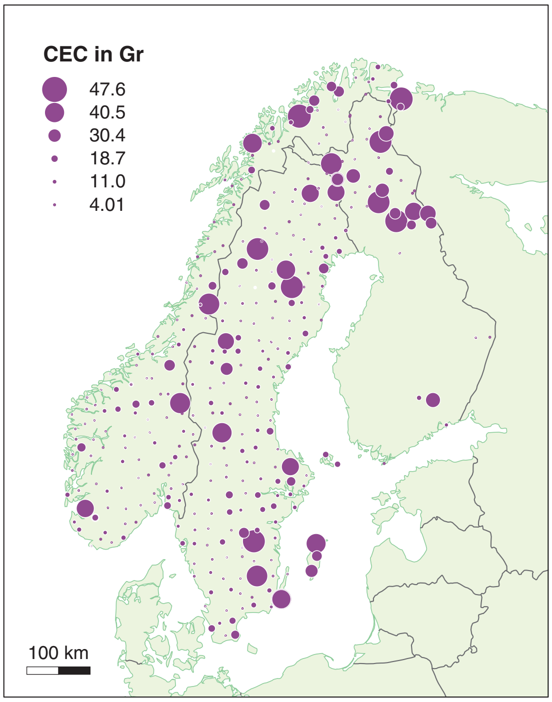
At a given pH value the cation exchange capacity (CEC) is the maximum quantity of total cations that a soil is capable of holding for exchange with the soil solution. CEC is measured in milliequivalent of hydrogen per 100 g (meq+/100g), and for agricultural soils values between 10 and 30 meq are usually reported. The CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from contamination. Clay, silt and humus have electrostatic surface charges that attract the ions in solution and hold them. This holding capacity varies for the different clay types and clay blends occurring in soil, and is very dependent on the proportions of clay, silt and humus that are present in a particular soil. For example, humus-rich soils usually have a high CEC.

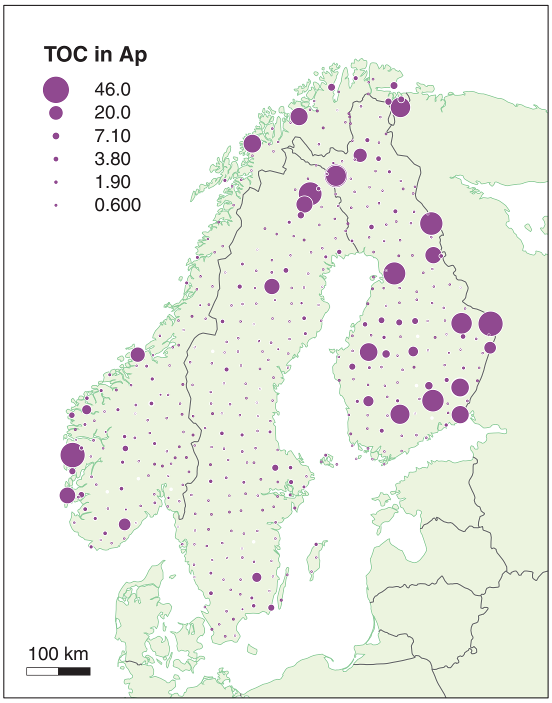
In Norway, Sweden and Finland, the measured values of CEC are highest when arable land has a high content of organic matter (TOC). CEC is also high where concentrations of extractable K and Al are high, as in clays. In soils where TOC is low and the CEC is high, the pH levels are relatively high, reflecting soils with a high capacity of holding cations. This is shown by the dispersion patterns of CEC, pH and TOC in central Norway, south-west Finland, Åland, Öland and Gotland, assuming good soil quality (fertile, i.e. nutrient-rich and free of acidification and toxic elements).

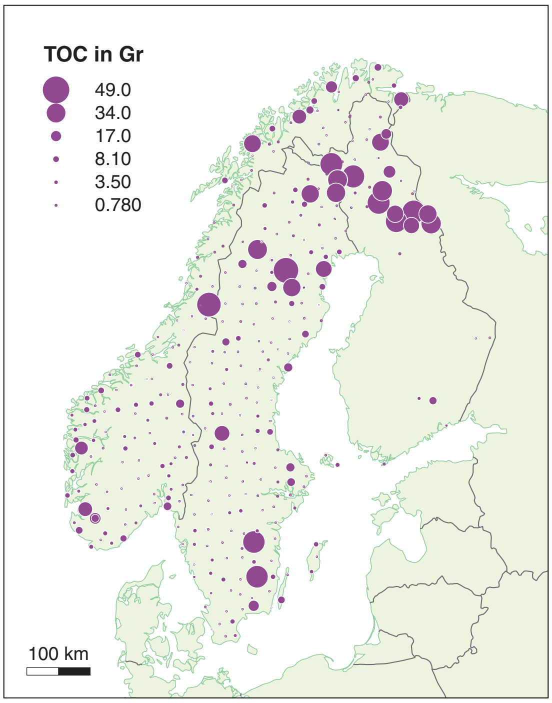
Total organic carbon

The contribution of organic matter to soils is a normal soil-forming process and the content of total organic carbon (TOC) increases with increasing soil maturity (but can be dramatically decreased due to agriculture). The content of organic matter also depends strongly on climate: warm and dry conditions will result in low TOC, wet and cold conditions in high TOC. In the studied soils, there is a strong positive correlation between sulphur and TOC resulting from the tendency of sulphur to bind to organic matter. There is also a weaker correlation between CEC and TOC. The cation exchange capacity is high when the content of TOC is high. High TOC values are accompanied by high CEC and low pH values.









Finland

Local enrichment occurs in soils rich in organic matter collected in peat bog areas. Lower values can be a result of liming.

Norway

The high content of TOC along the coast in south-west Norway occurs due to the cold and wet climate, resulting in the build-up of organic matter in soils.

Sweden

In Sweden, TOC varies from 0.8% to 49%. Concentrations are highest in the northern part of the country, especially in peat bog areas. In the southern part of the country, the high contents of TOC are observed in grazing land rich in organic material.

SUMMARY

The geochemical mapping of agricultural soil and grazing land (GEMAS project) in Norway, Sweden and Finland provides an exceptional opportunity to constrain regional geochemical trends in arable soils. When looking at the European dataset as a whole, Norway, Sweden and Finland stand out as geochemically “different” and it is thus justified to study this dataset as a separate entity. The data define the soil sample archive in Norway, Sweden and Finland in the year of collection 2008. All the samples have been collected in a standarised manner.

All samples were analysed in carefully chosen laboratories in order to guarantee the coherent results which can be used across the country borders. Rigorous quality control protocols have been applied to ensure that the information obtained from the elemental patterns is reliable and reflects the true geochemical situation.

The results from aqua regia extractions show very good overall quality. For a number of elements in the aqua regia ICP-MS and in the XRF methods, the majority of the analytical results are very close to the detection limits, e.g. Ge, Pt, Pd, Re, Ta, Te (aqua regia extraction) and Sb, Bi, Ta, W, F, Hf, Sn and Cl (XRF), and as such these results have to be considered to be less reliable. In all instances, where poor precision was observed, it was due to very low element concentrations. The high values (upper outliers) are, however, reliable, even for the above mentioned elements, and reflect true anomalies. As all samples were randomised prior to analysis, multi-sample anomalies are always reliable, even for problematic elements. Within the XRF results, Sb, Bi, Ta, W, F, Hf, Sn and Cl must be viewed with caution. The main (and well-known) problem with XRF analyses is the rather high detection limits of the method for many such trace elements.

The agricultural soil (Ap) samples often show somewhat better (less noisy) results than the grazing land (Gr) samples. An explanation for this feature is that ploughing homogenises soils over many years, and the samples may be more weathered and finer grained.

The complex interpretation of the elemental patterns presented on the maps and with the help of the statistical tools (box plots, cumulative probability plots) indicates several groups of factors influencing the observed trends in the geochemical picture of Norway, Sweden and Finland:

1. The sample type and its compositions.
2. Sample density.
3. The bedrock geology.
4. The presence of mineralisations and mining centres.
5. Quaternary history.
6. Climate.
7. Human activity.

The sample type and its compositions

In the soil sample archive of Norway, Sweden and Finland, several sample types appear: clay-rich soils, sandy soils, till-rich soils, minerogenic soils and organic-rich (peaty) soils. The dominant soil component (clay, sand, organic) often has a significant influence on the observed distribution of the elements. For many metals (e.g. Ag, Al, As, B, Ba, Be, Bi, Ce, Co, Cr, Cs, Ga, Ge, Hf, In, K, La, Li, Mg, Na, Ni, Rb, Sc, Sn, Sr, Th, Ti, Tl, U,V, W, Y, Zn, Zr) clay-rich soils (e.g. the Central Scandinavian clay belt and along the eastern coast of Sweden where clays dominate) are the main cause of observed anomalies. Several elements (e.g. As, Cd, Hg, Pb, Se) tend to adsorb to organic matter and therefore peaty soils have higher levels of many of these potentially toxic elements. Sandy soils usually have low concentrations of metals and often mask the geological nature of the underlying bedrock as well as any mineralisation. In areas with intense physical erosion and very thin soil cover, e.g. in the Caledonides, certain elemental anomalies are strengthened due to higher concentrations of lithic clasts and primary minerals (rock-forming and accessory minerals) in minerogenic soils. In sandy soils collected in river valleys, a higher fraction of heavy minerals also influences the elemental distribution pattern.

Sample density

The GEMAS project is based on a low sampling density (1 site per 2 500 km^2). Thus certain anomalous areas in Norway, Sweden and Finland could have been missed, i.e. local mineralisations or even mining sites (e.g. in the Skellefte mining district in Västerbotten in Sweden). The choice of sampling site carries a certain subjectivity burden which is difficult to avoid. However, due to the scale of the project, this personal factor is thought to be negligible and the big picture still gives reliable information.

The bedrock geology

Bedrock geology is the major factor that can be recognised in the geochemical pattern of soils in Norway, Sweden and Finland. Large scale differences can be seen in areas underlain by crystalline rocks of the Fennoscandian Shield, the Archaean domain and the Caledonides. Lithological variations are also mirrored in the geochemistry, e.g. crystalline rocks vs. siliciclastic and carbonate sedimentary rocks. Mafic rocks (intrusions, dykes, greenstone belts) have an especially strong imprint on the soil geochemistry due to distinct elemental differences (Cr, Ni, Mg, Co). The presence of pegmatites can be mapped using e.g. Li, Nb, Ta, Mo and W. Several bedrock age domains can be recognised in the soil geochemistry, e.g. Archaean in the northern and north-eastern parts of Scandinavia, Late Mesoproterozoic (Sveconorwegian) units in southern Sweden and Norway, Palaeozoic on Gotland and Öland and in the Caledonides, and Mesozoic in southern Sweden. Some tectonic borders can also be seen, e.g. the major tectonic boundary between the Proterozoic and Archaean domain in the Fennoscandian Shield in the Boden region.

The presence of mineralisations and mining centres

Scandinavia is often considered to be Europe's biggest repository for iron, base metals and high-tech metals. The soil geochemistry clearly reflects the numerous mineralisation sites and ore deposits mined historically and through to the present day. Several mining districts and famous ore fields can be recognised, e.g. the Kiruna mining district in northernmost Sweden, the Skellefte mining district with base metals, the Gold Line in northern Sweden, the Bergslagen district in central Sweden, the Outokumpu mining district in central Finland and the Kongsberg region in southern Norway. They are marked by especially prominent anomalies.

Quaternary history

Surficial deposits (till, gravel, soil) in Norway, Sweden and Finland are largely the result of the latest Quaternary history with its periods of glaciation and deglaciation. Melting of the ice cap and resulting isostatic rebound have a pronounced influence not only on the topography but also on the types of the Quaternary deposits. Erosion processes were very intense during the glaciation. Ice movement is responsible for the till formation and its transport. Glacial meltwaters and the retreating sea (due to landrise) have also influenced the uppermost cover leaving behind thick layers of freshwater sediments, sands and gravels, and postglacial and marine clays. All these features can be recognised in the soil characteristics (composition, texture and geochemistry). For example, marine clays cover vast areas, from the Mälaren region in central Sweden east into southern Finland, the eastern coast of the Baltic Sea and, locally, inland. The marine influence on the soils can be recognised up to the altitude of 290 m a.s.l. in Sweden, c. 210 m a.s.l. in north-western Finland and up to c. 200 m a.s.l. in Norway near Trondheim. The presence of salty brines in the groundwater systems and their influence on the surficial deposits can also be of local importance. Ice movement and activity of glacial waters are responsible for a shift and dilution of some geochemical anomalies, although the transport distance is usually not large, up to 5–10 km on average in northern Scandinavia.

Climate

Climate is an important factor during both chemical and physical weathering. In Norway, Sweden and Finland, several different climate zones can be recognised: wet and warm in southern and south-western Norway, continental in central Sweden and Finland, arctic in northern Scandinavia, and alpine in the mountains. In our study, the most prominent impact of climate on geochemical patterns can be observed in Norway, where high precipitation and a large quantity of marine aerosols in the air contribute to the high metal contents in organic-rich coastal soils.

Human activity

Anthropogenic impact on soils is to be expected in every geochemical survey. In Norway, Sweden and Finland, however, human activity seems to only have a minor influence on soil geochemistry in both agricultural and grazing land. Identified geochemical anomalies related to anthropogenic contamination are very small and scarce in our study. In mining regions, with a natural signal from the mineralisation, it is often difficult to discriminate between the original natural anomaly and any anthropogenic contamination signal. Areas in Norway, Sweden and Finland where anthropogenic contamination becomes visible are: the Stockholm area, southern Sweden and Finland (fertilising, liming activities), the Zn-smelter at Odda near Bergen in Norway, Öland and Gotland (fertilising, historical iron and brass manufacturer), and the Skellefte mining district (mining-related contamination).

A certain number of geochemical anomalies remain unexplained due to insufficient information about the local geological situation, the presence of mineralisations and other factors that might influence the soil chemistry.

In general, arable soil is an especially suitable sample material for this sort of large scale geochemical mapping exercise. The data now awaits application in form of research publications and this report provides basic information for the continental European summary in the final book and atlas available in December 2013.

ACKNOWLEDGEMENTS

The GEMAS project is a cooperation project of the EuroGeoSurveys Geochemistry Expert Group with a number of outside organisations, among them the Norwegian Forest and Landscape Institute.

All colleagues organising sampling in their countries, as well as the many field teams, are acknowledged for the work they have put into this project: in Finland Timo Tarvainen, Mikael Eklund, in Norway Clemens Reimann, Rolf Tore Ottesen, Tore Volden, Ola A. Eggen, Arnold Arnoldussen, in Sweden Madelen Andersson, Anna Ladenberger, Erland Sellersjö.

Eurometaux is thanked for its financial support and continued interest in the project. The analytical work was partly financed by the following organisations: Eurometaux, Cobalt Development Institute (CDI), European Copper Institute (ECI), Nickel Institute, Europe, European Precious Metals Federation (EPMF), International Antimony Association (i2a), International Manganese Institute (IMnI), International Molybdenum Association (IMoA), ITRI Ltd. (on behalf of the REACH Tin Metal Consortium), International Zinc Association (IZA), International Lead Association (ILA-Europe), European Borates Association 33 (EBA), the (REACH) Vanadium Consortium (VC) and the (REACH) Selenium and Tellurium Consortium.

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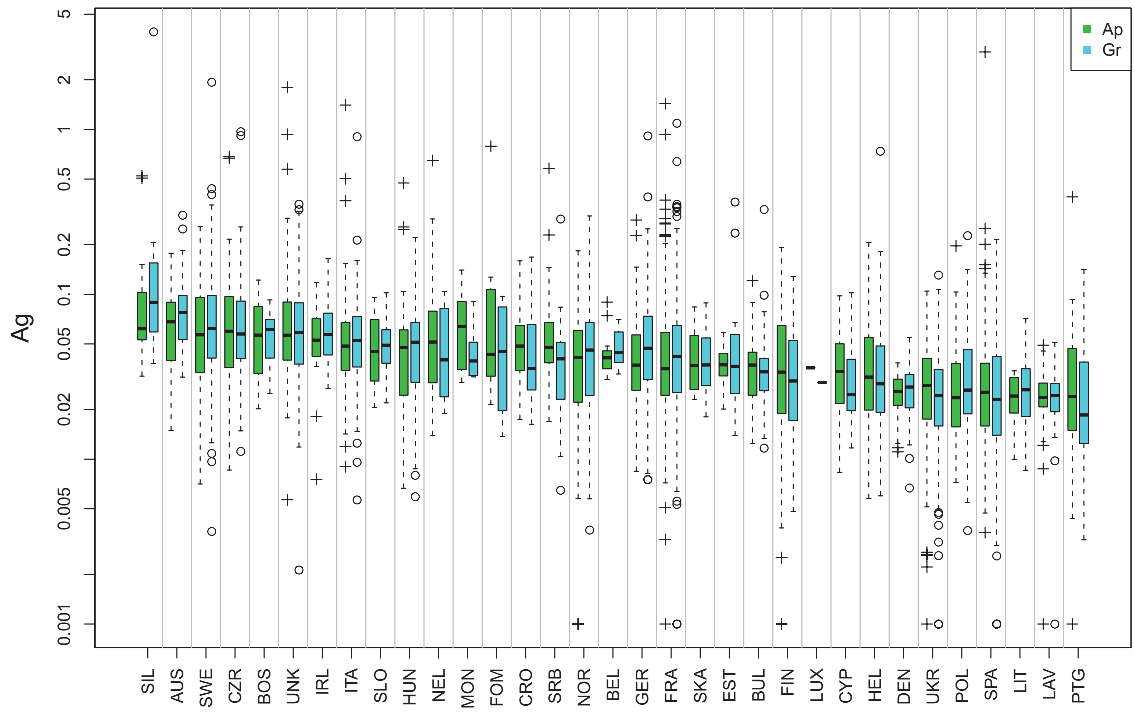
APPENDIX 1

Boxplot comparison for agricultural (Ap) and grazing land (Gr) soils in the GEMAS dataset for Europe

Results from aqua regia extraction. The boxplots are sorted according to the median values from highest to lowest. The countries taking part in the geochemical mapping are abbreviated as shown in the list below.

AUS	Austria	FRA	France	NOR	Norway
BOS	Bosnia	GER	Germany	POL	Poland
BEL	Belgium	HEL	Greece	PTG	Portugal
BUL	Bulgaria	HUN	Hungary	SIL	Switzerland
CRO	Croatia	IRL	Ireland	SKA	Slovakia
CYP	Cyprus	ITA	Italy	SLO	Slovenia
CZR	Czechia	LAV	Latvia	SPA	Spain
DEN	Denmark	LIT	Lithuania	SRB	Serbia
EST	Estonia	LUX	Luxembourg	SWE	Sweden
FOM	Macedonia	MON	Montenegro	UKR	Ukraine
FIN	Finland	NEL	Netherlands	UNK	United Kingdom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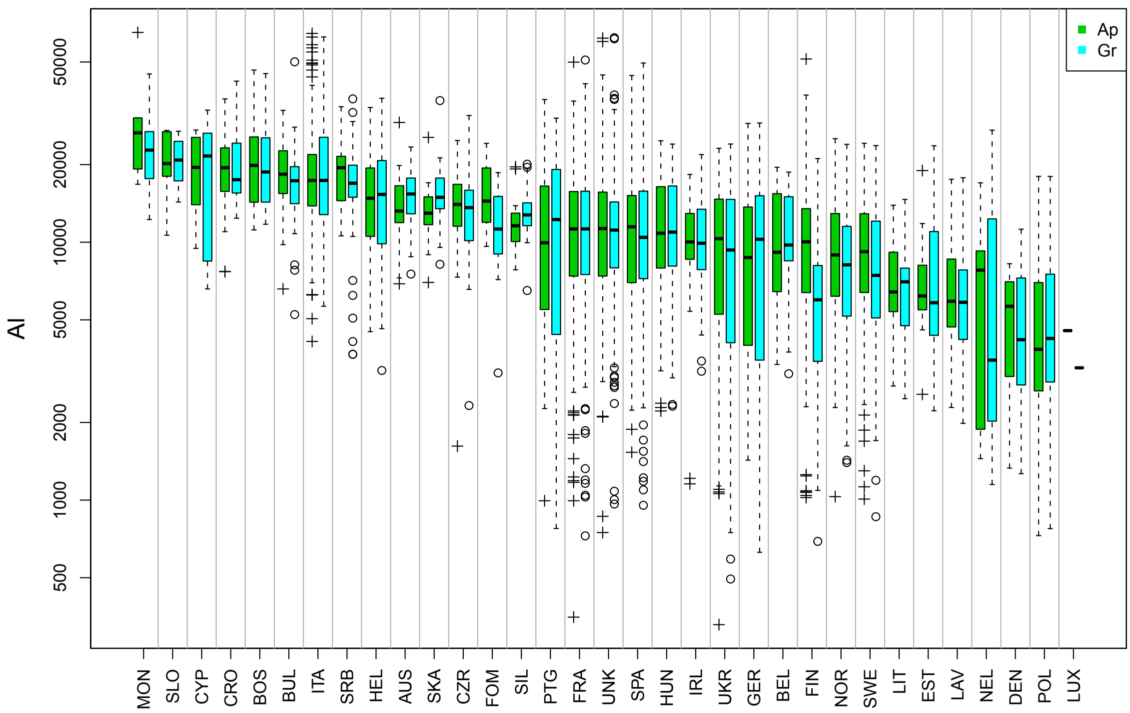
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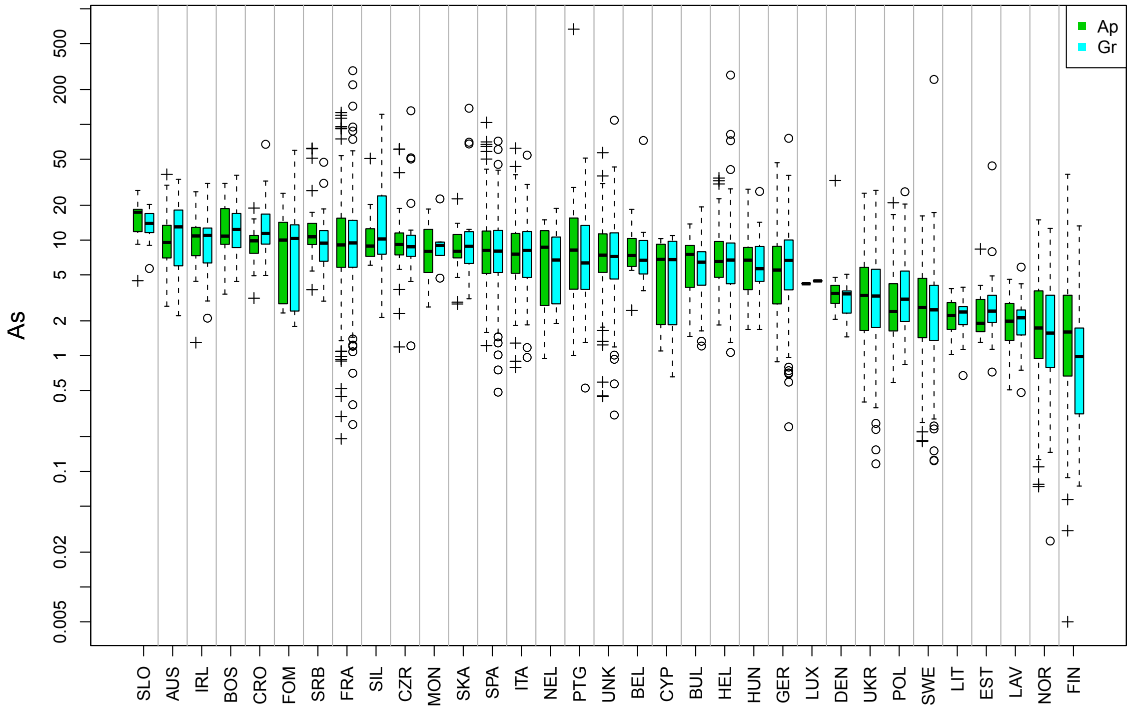
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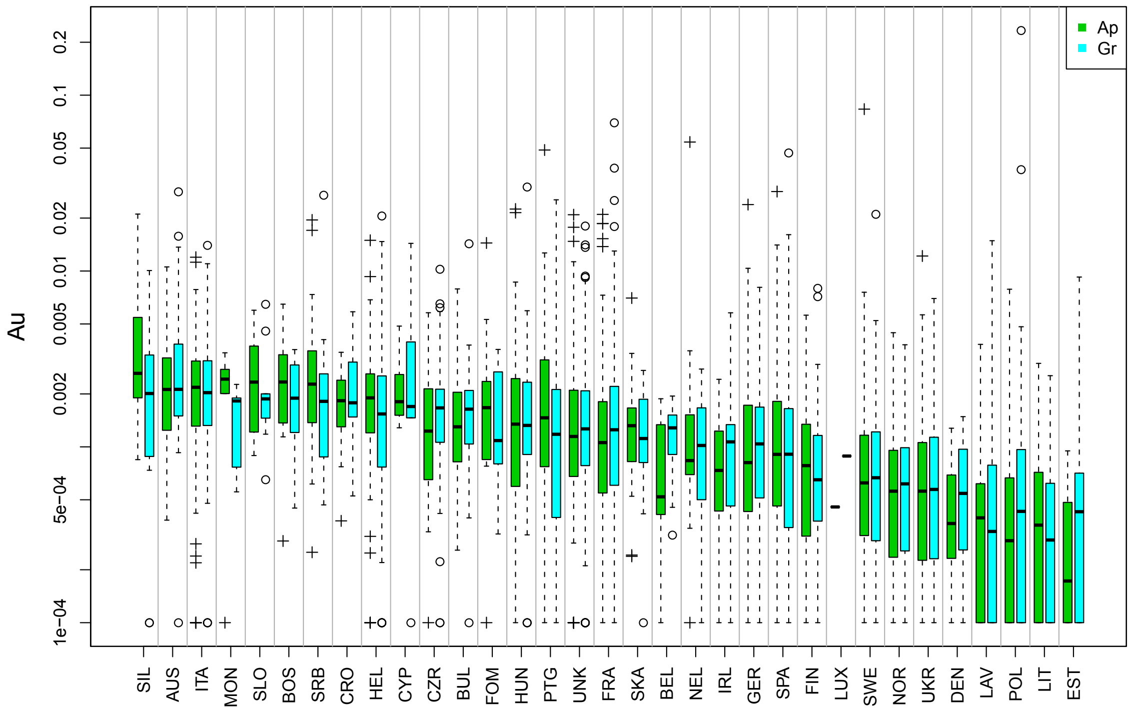
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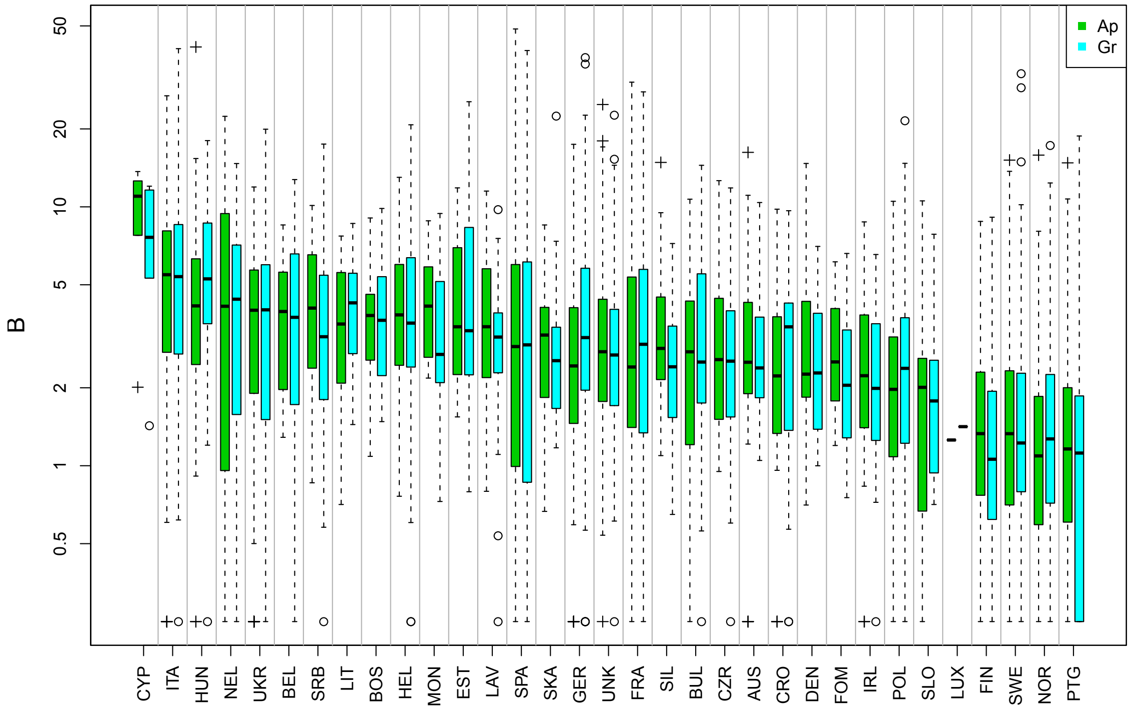
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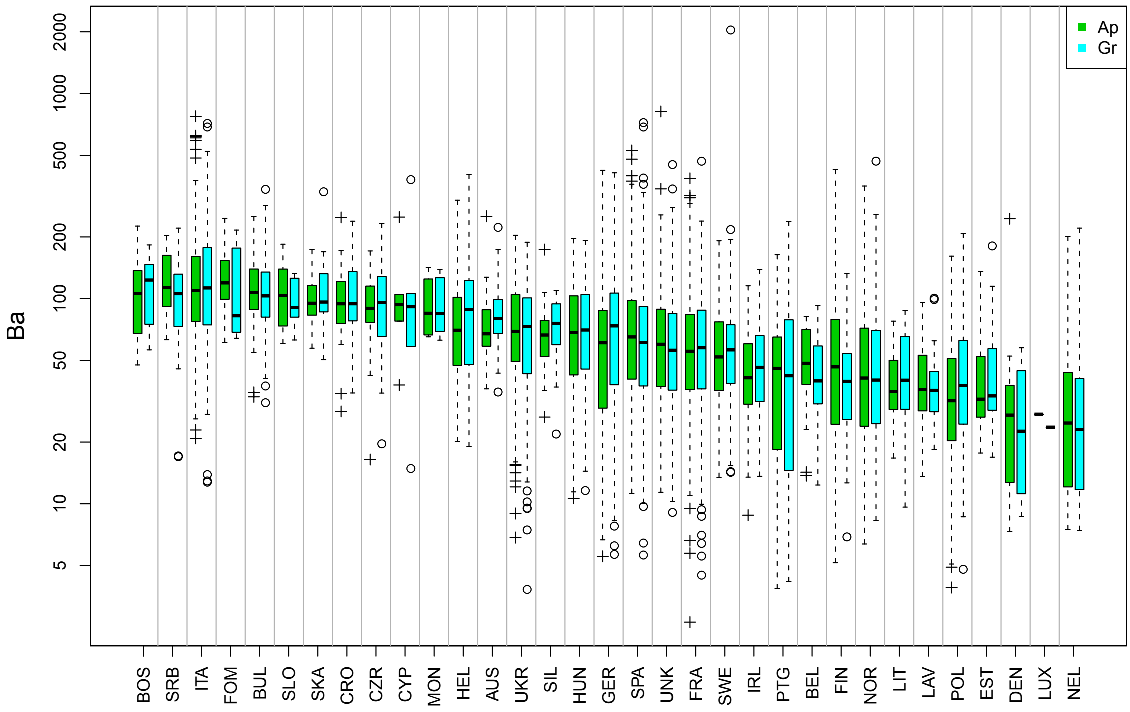
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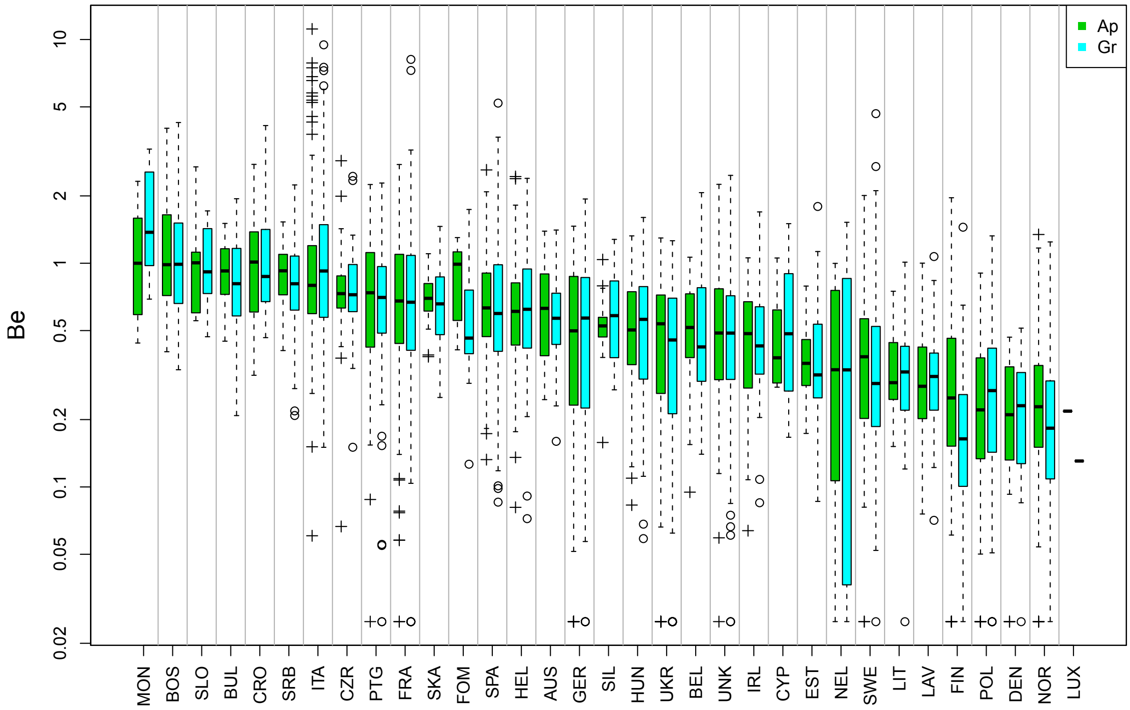
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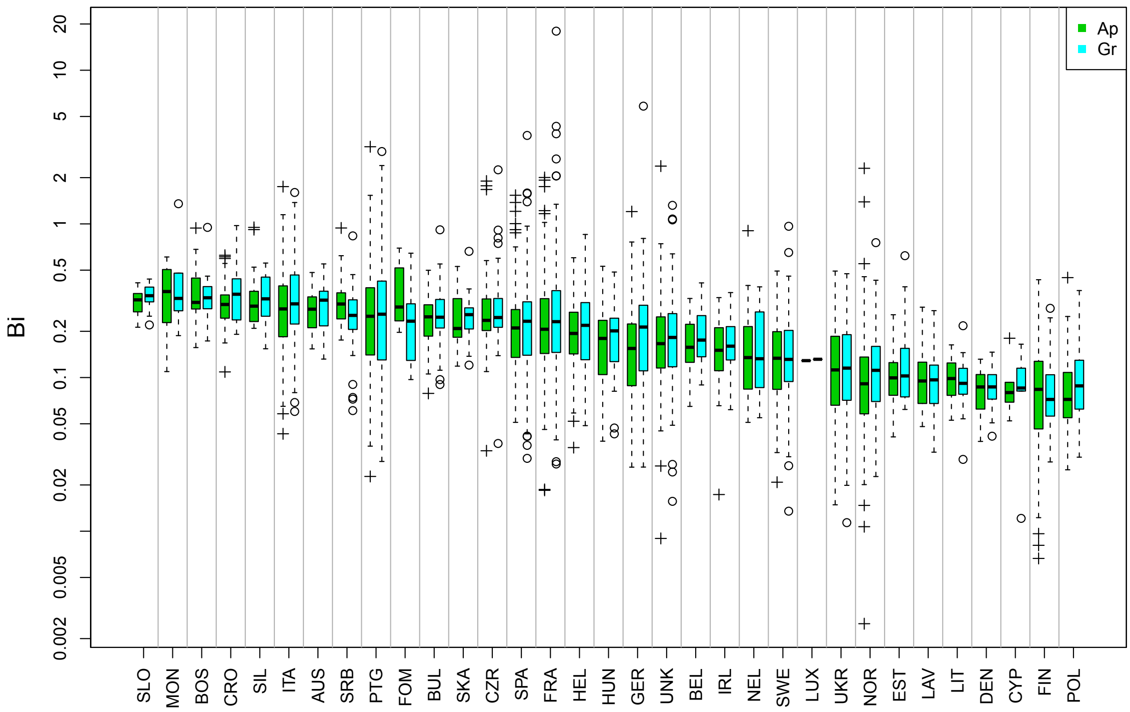
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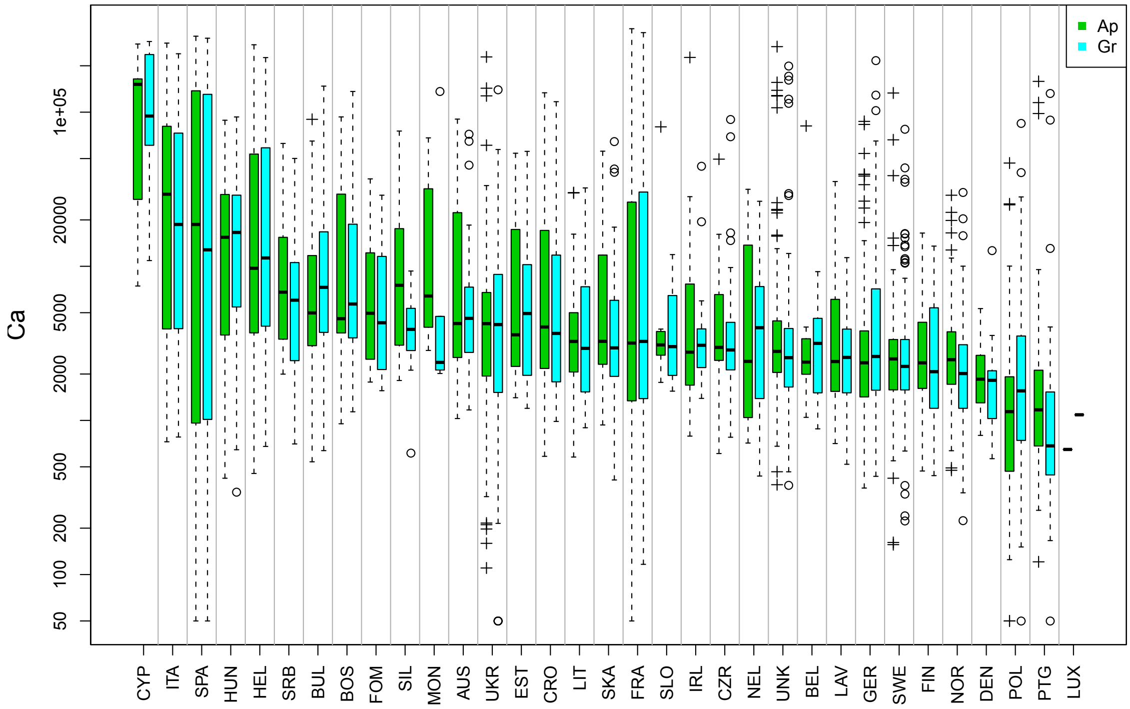
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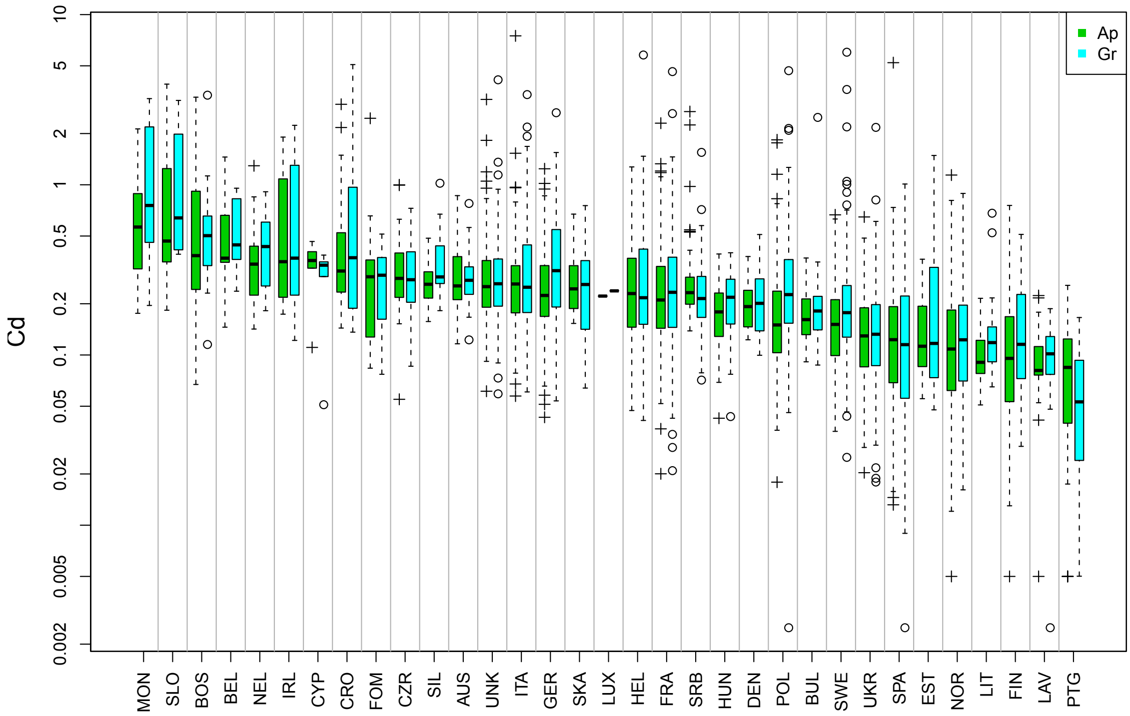
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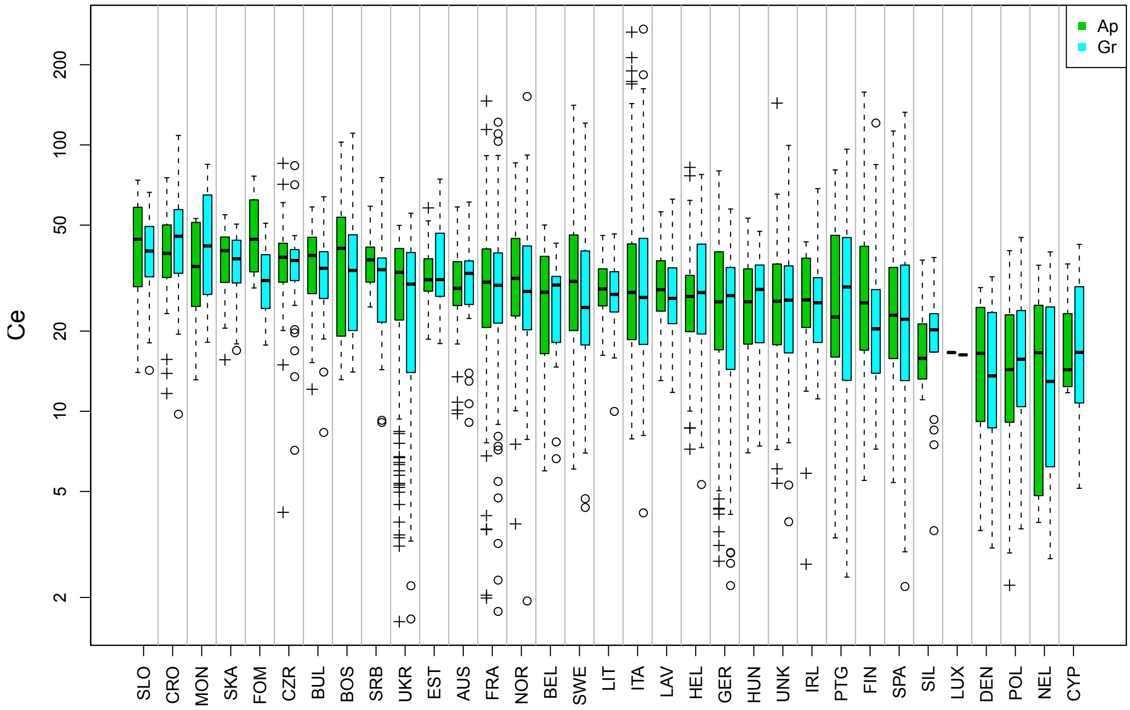
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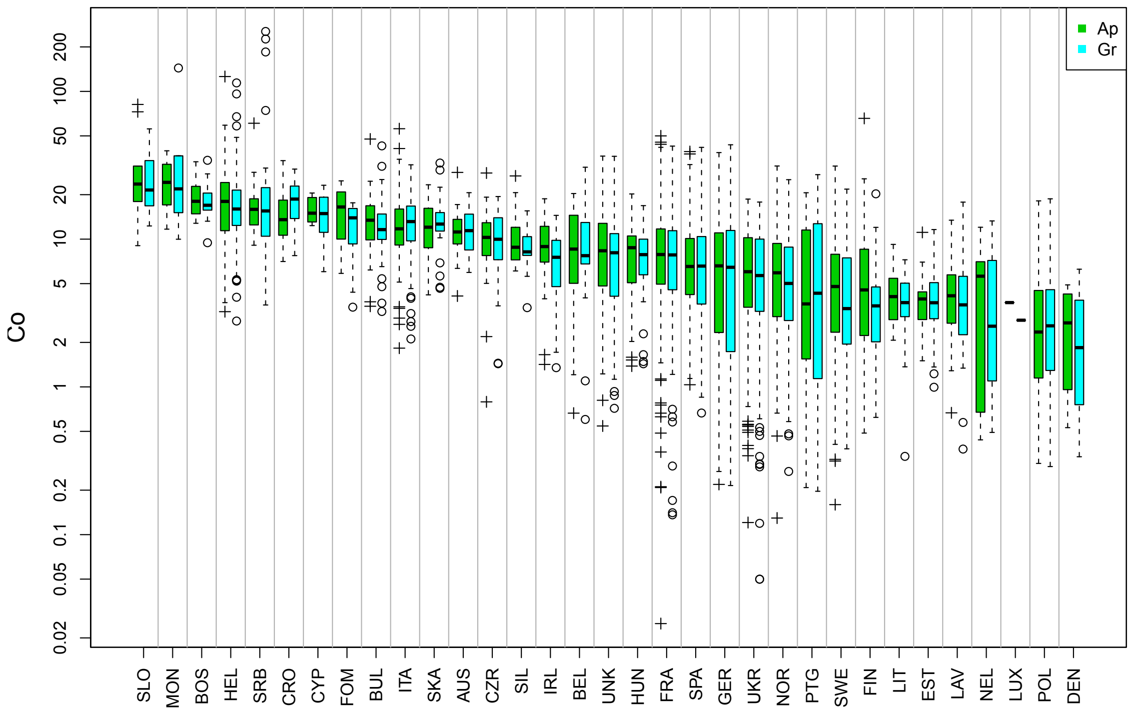
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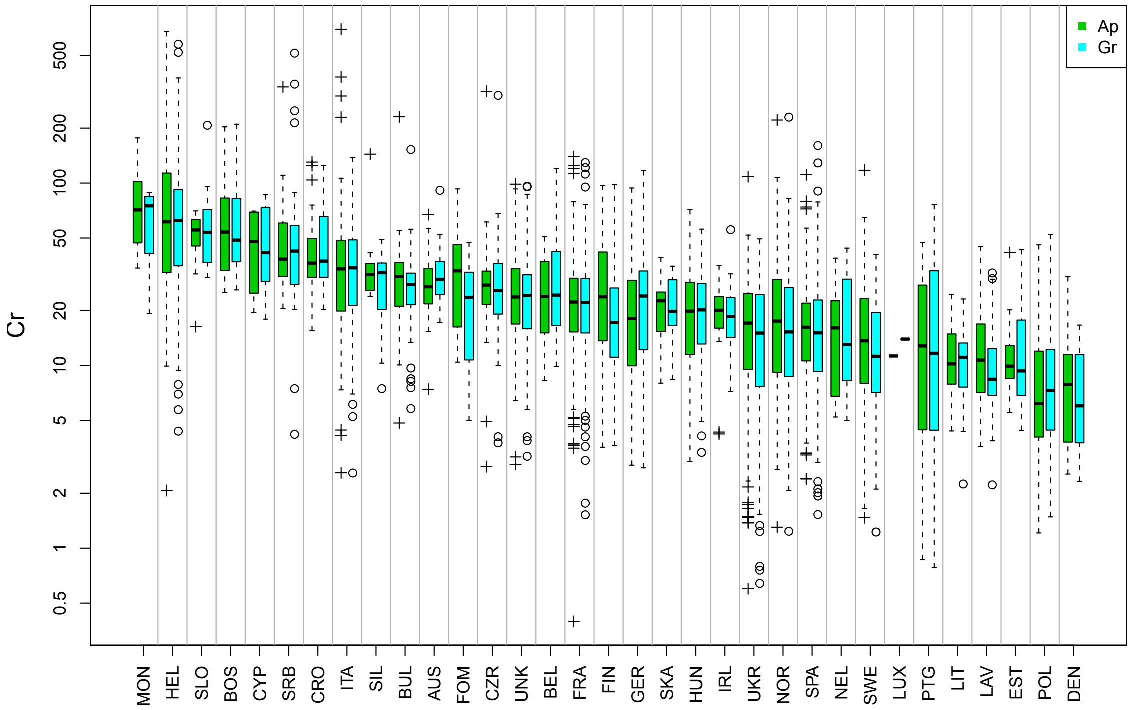
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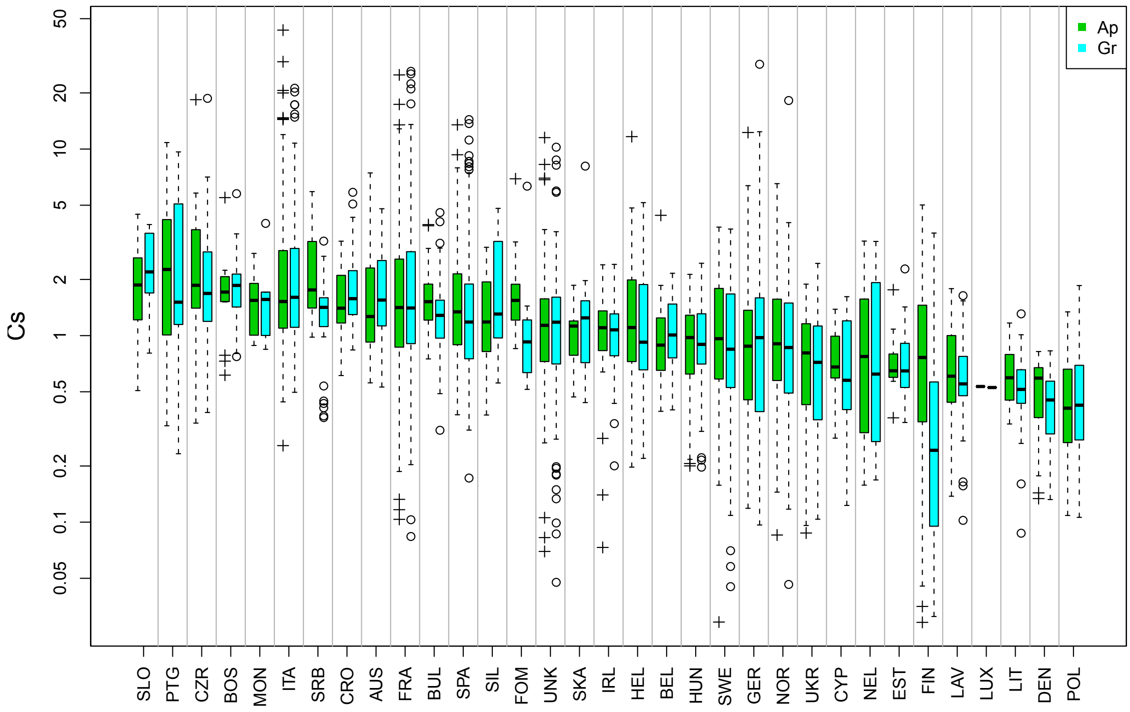
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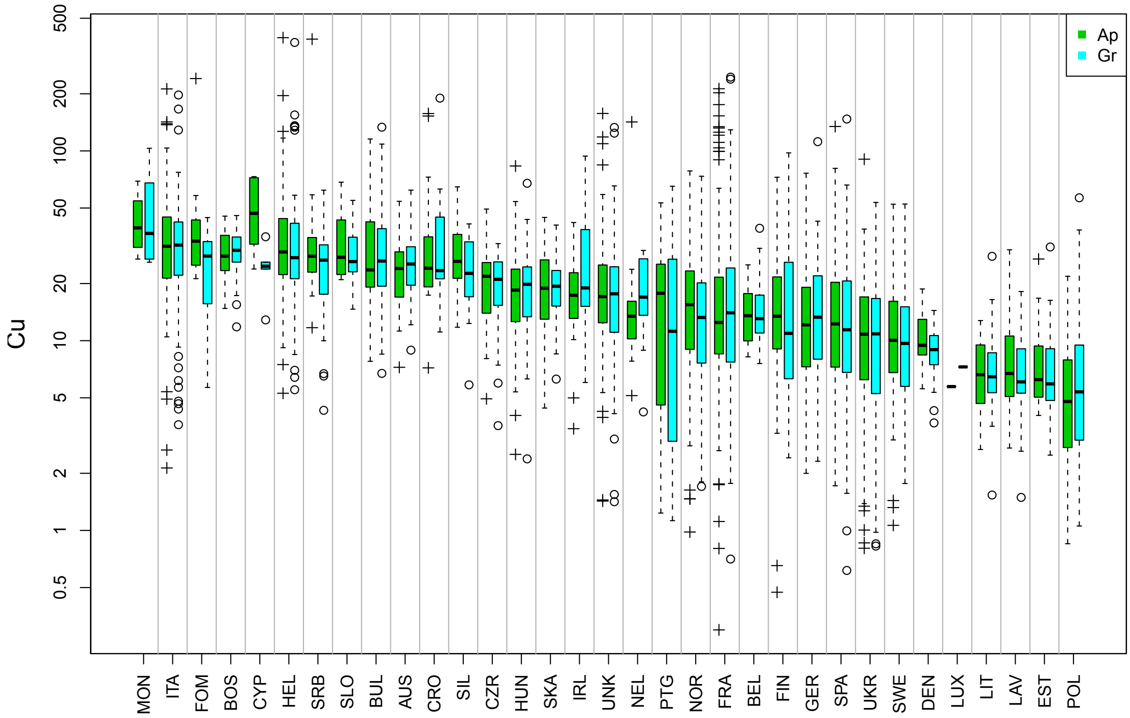
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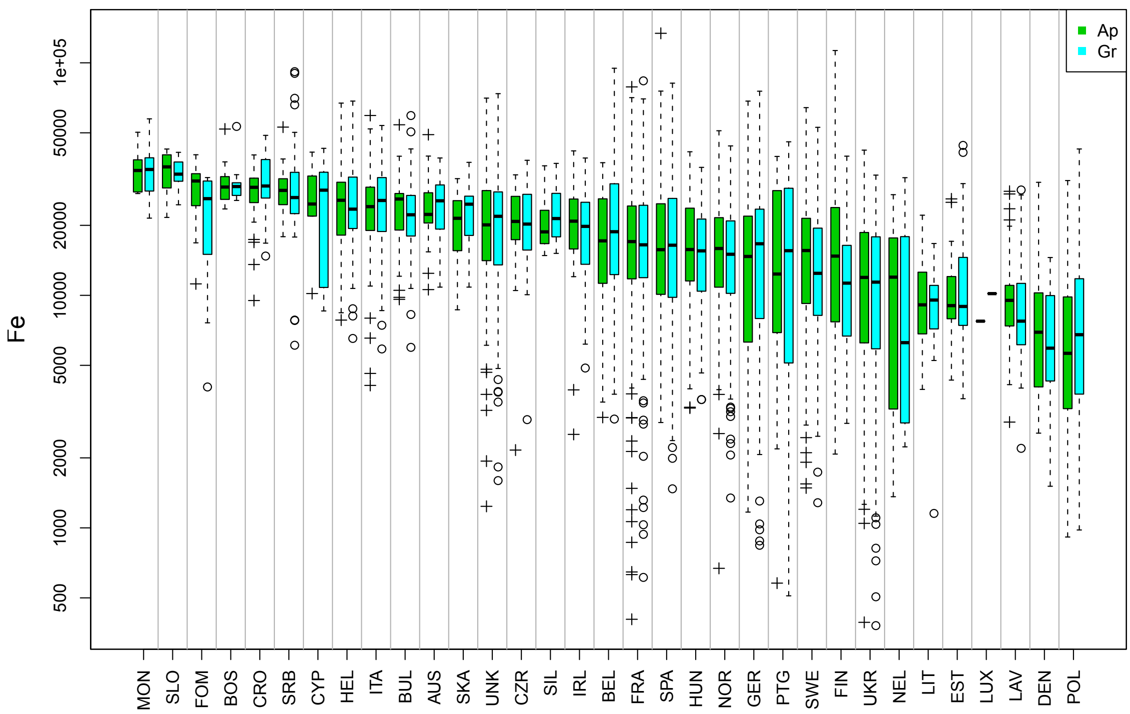
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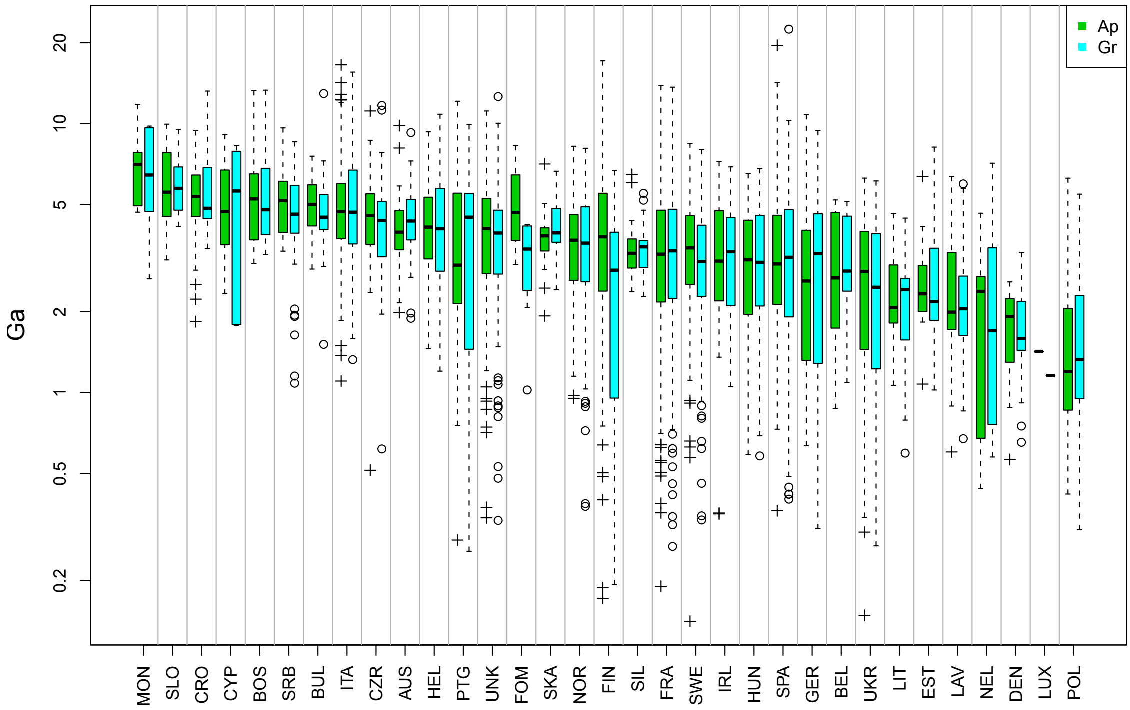
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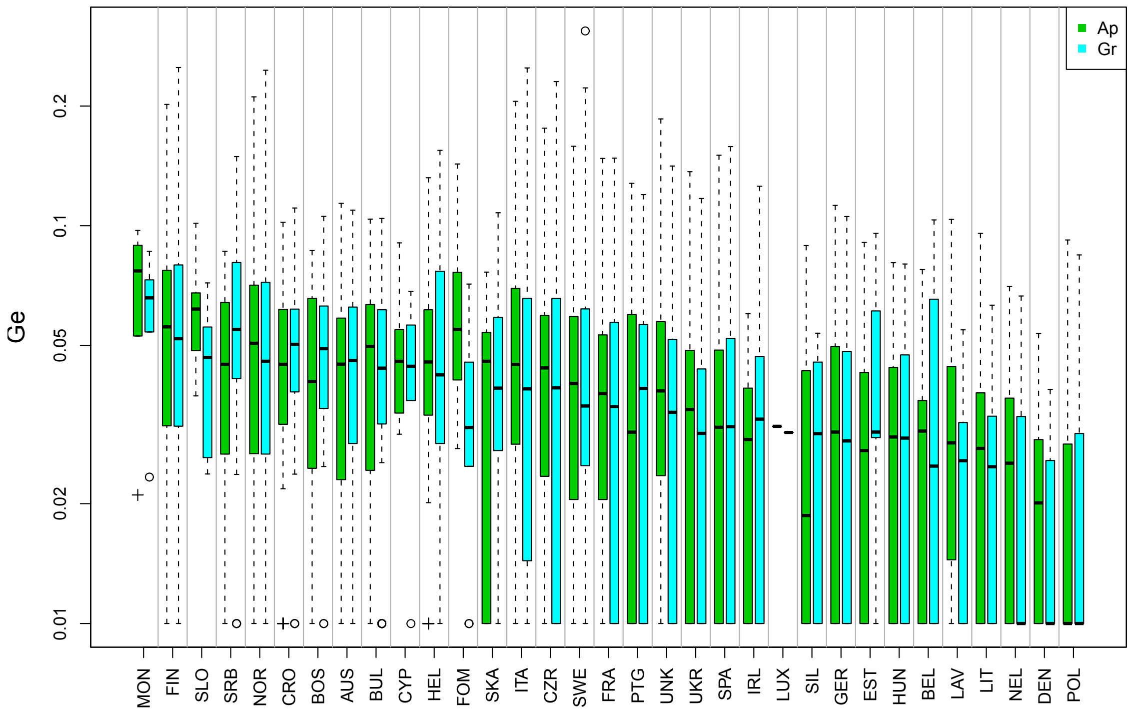
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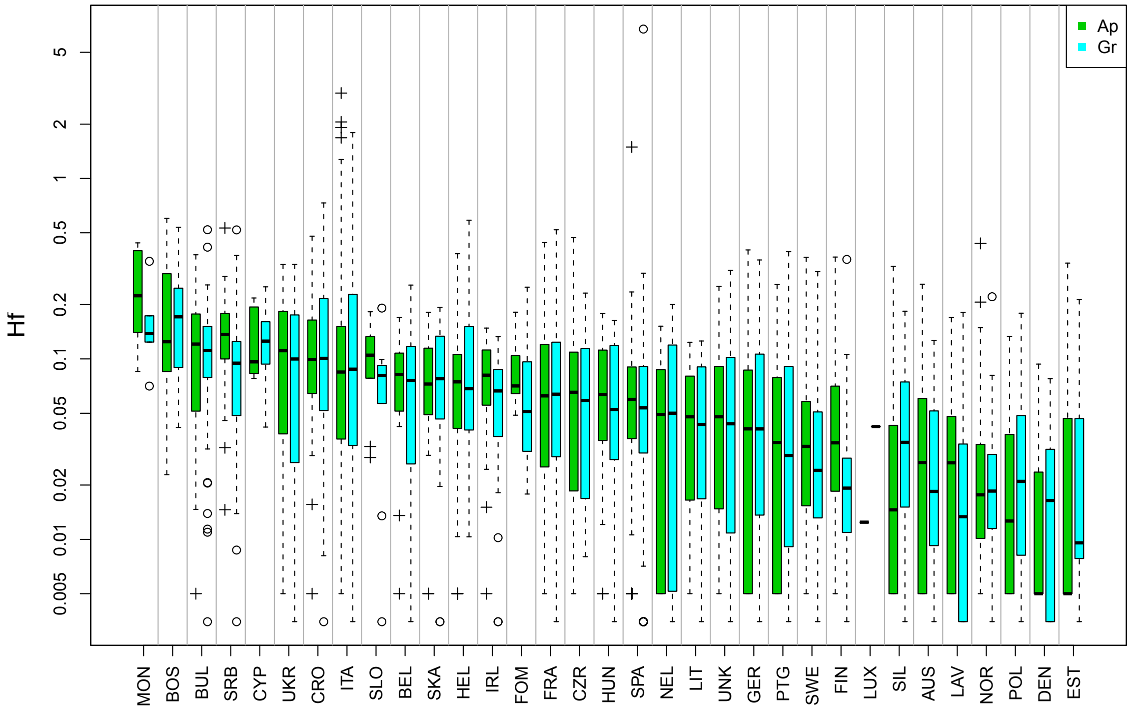
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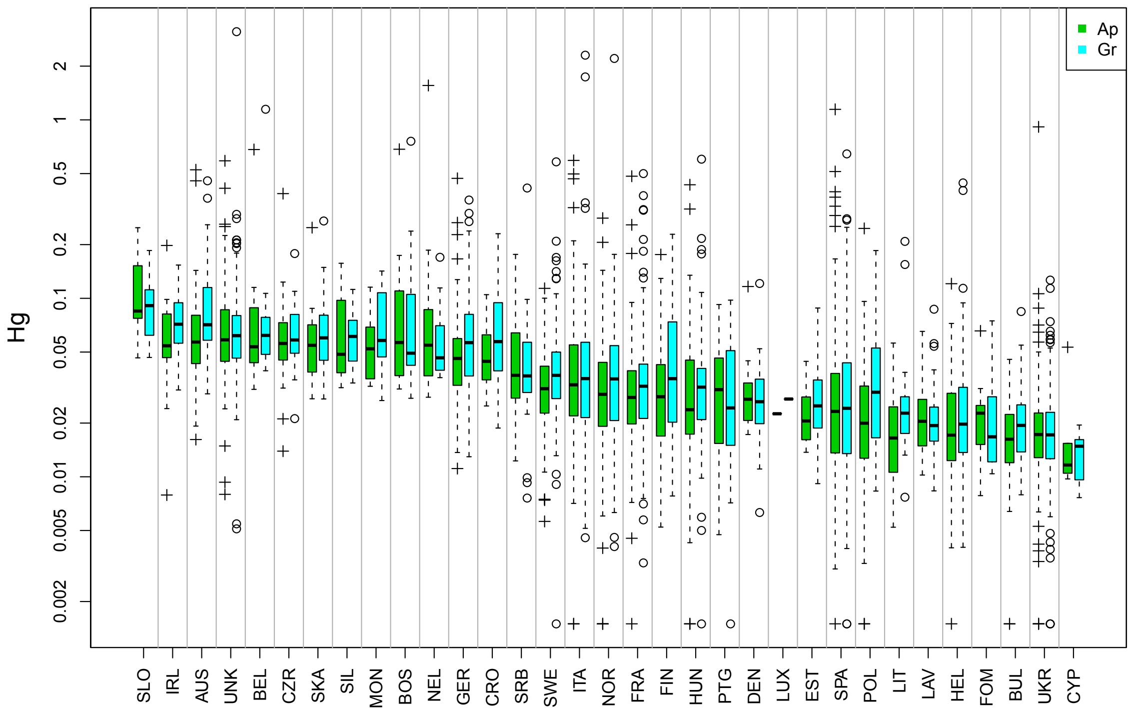
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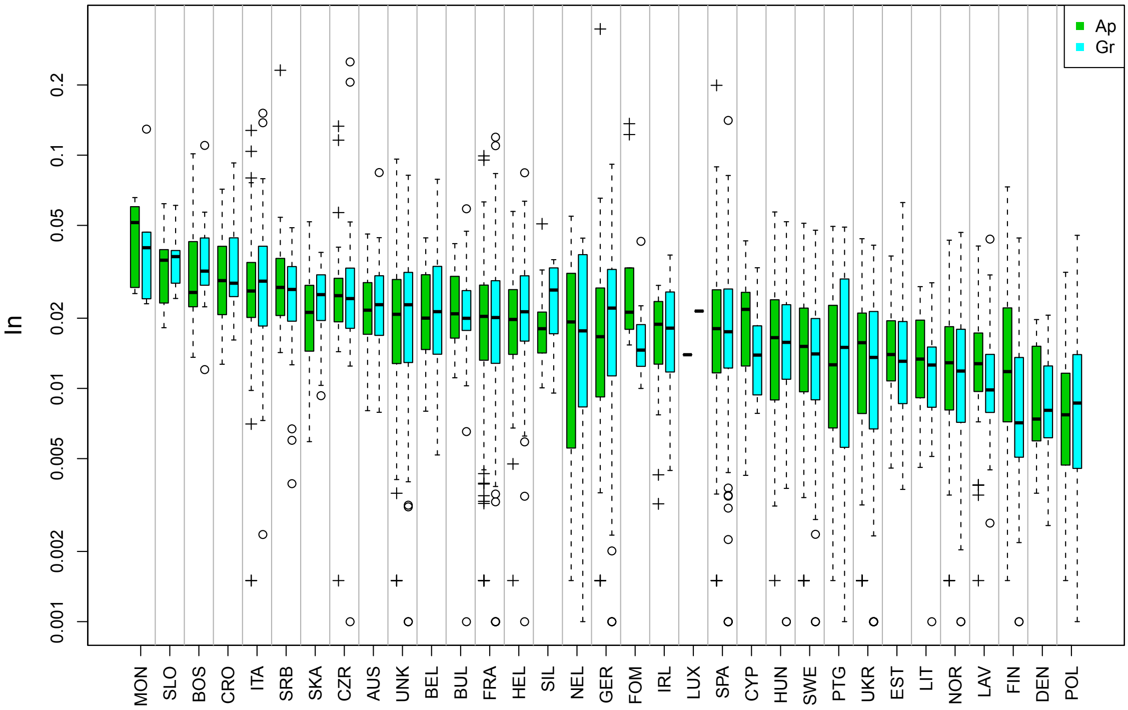

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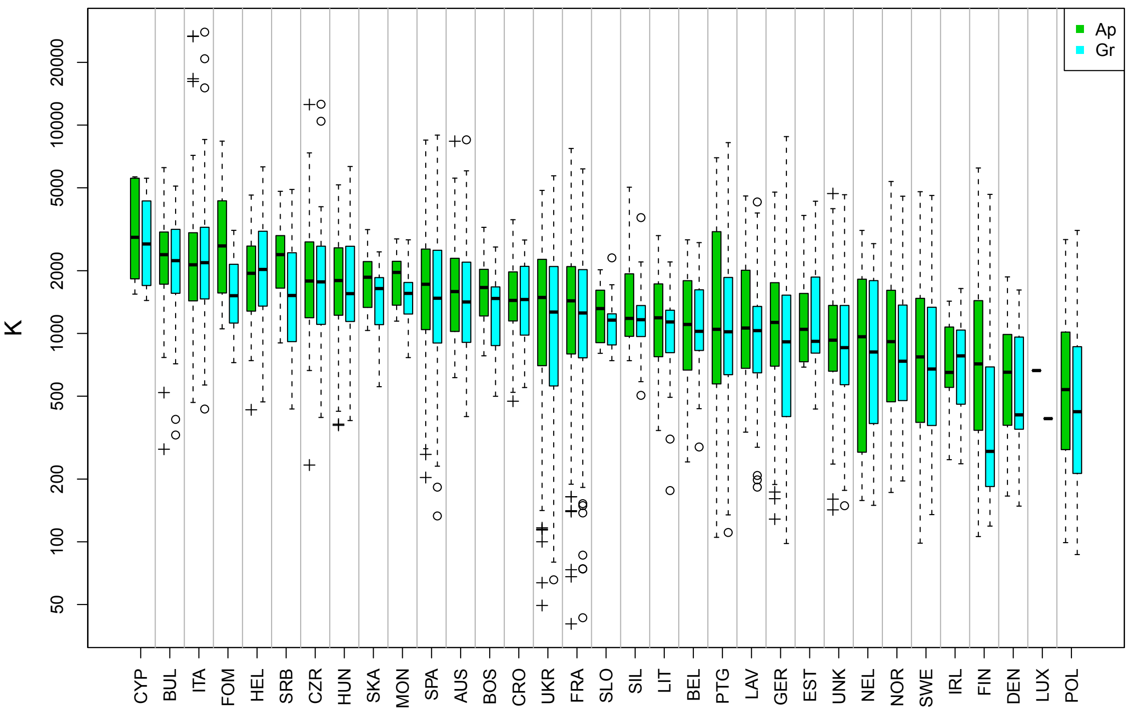

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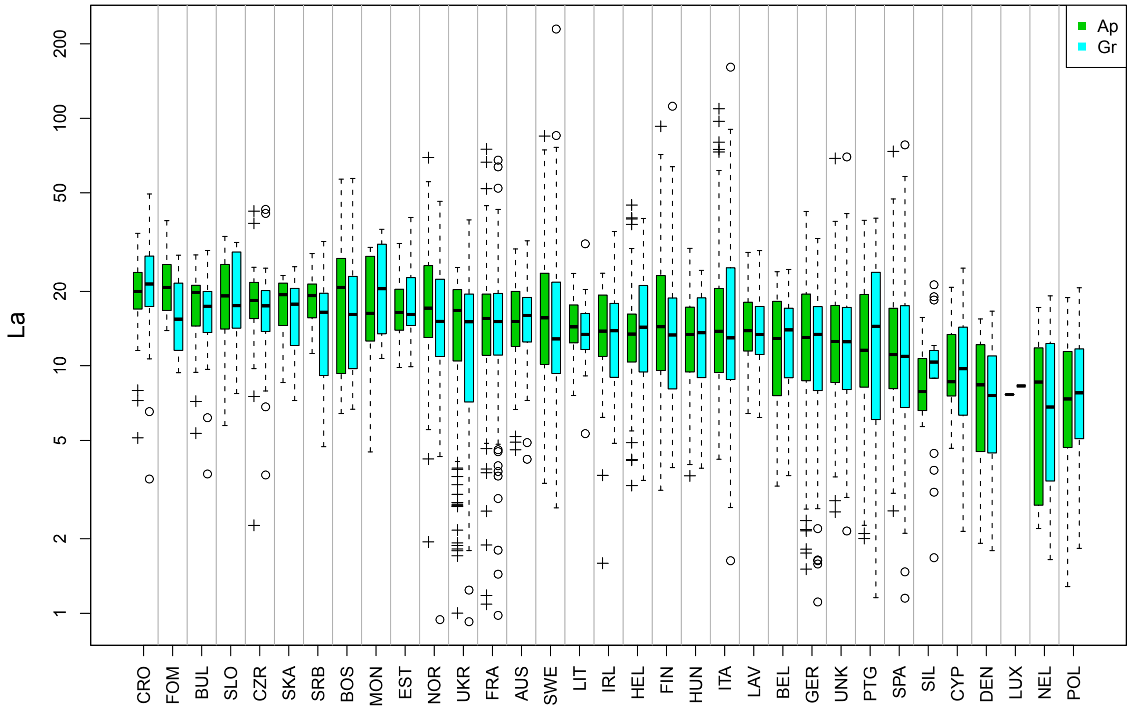
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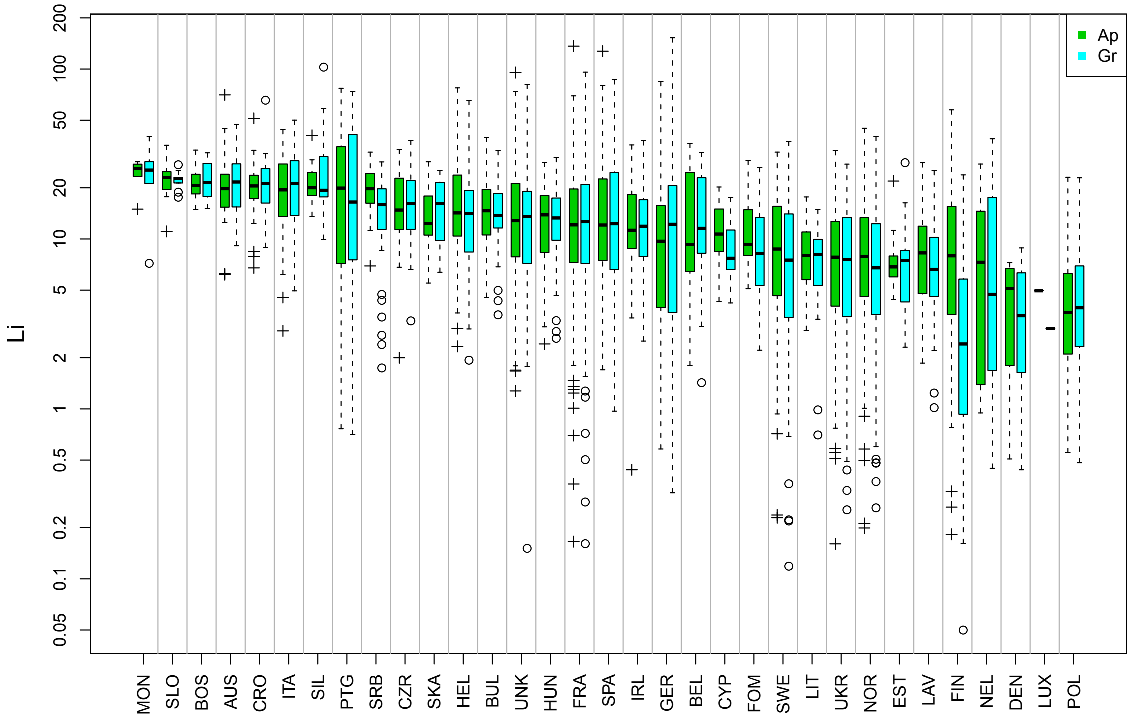
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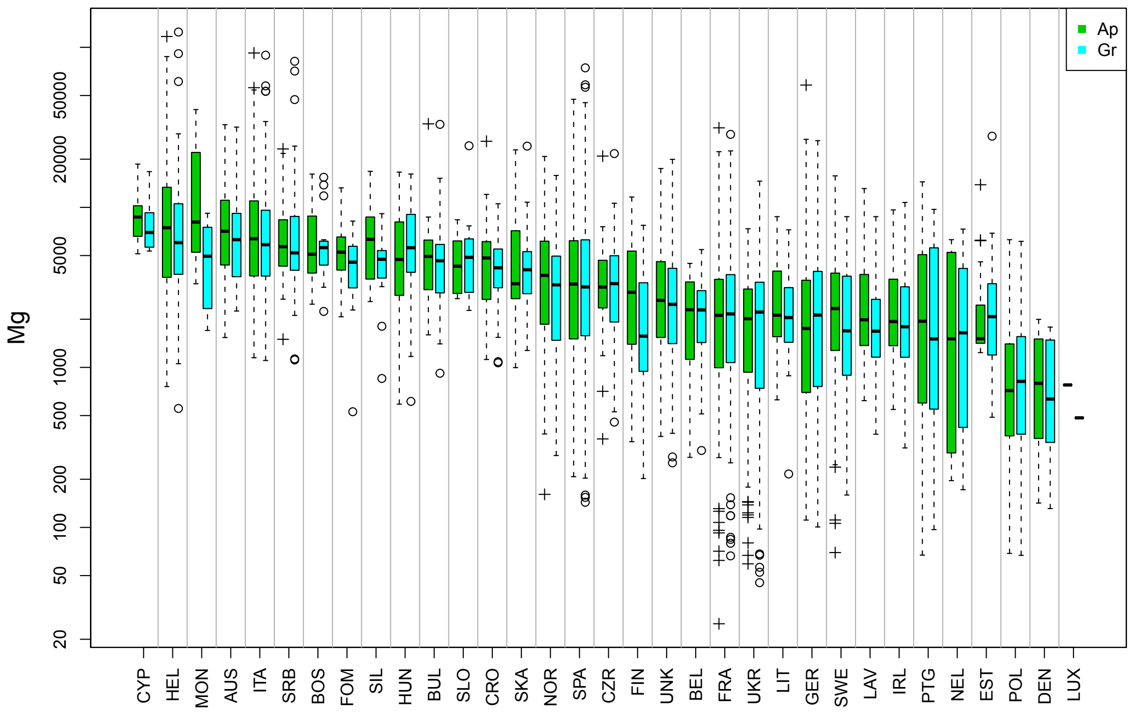
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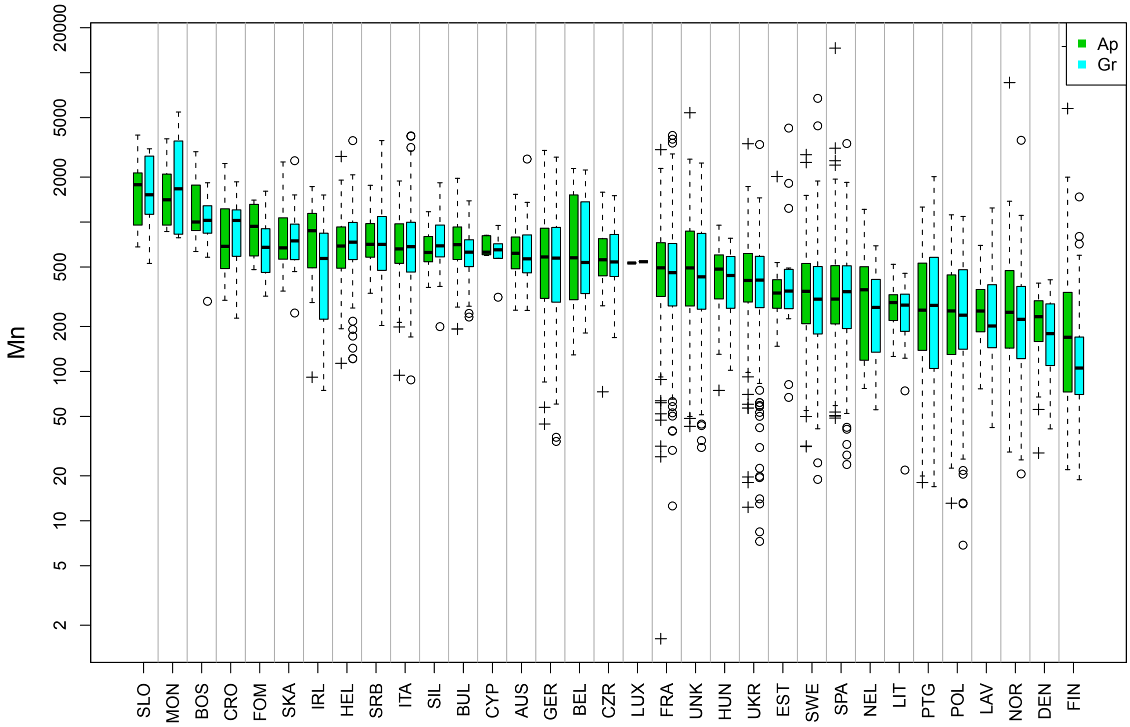
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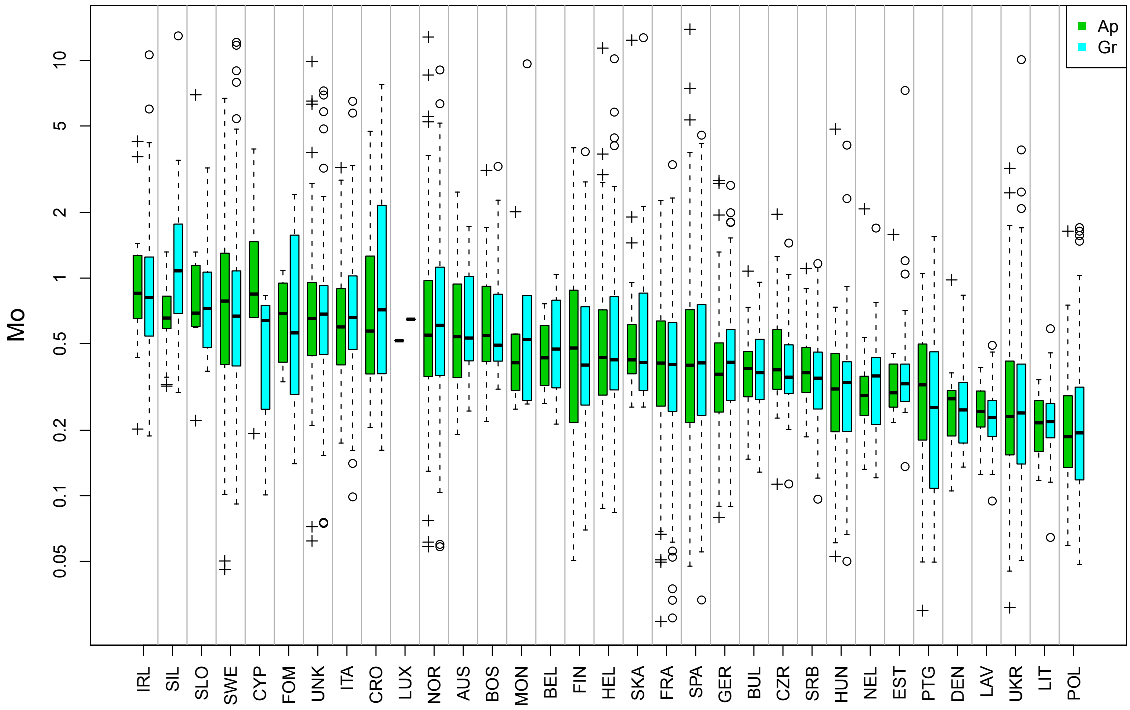
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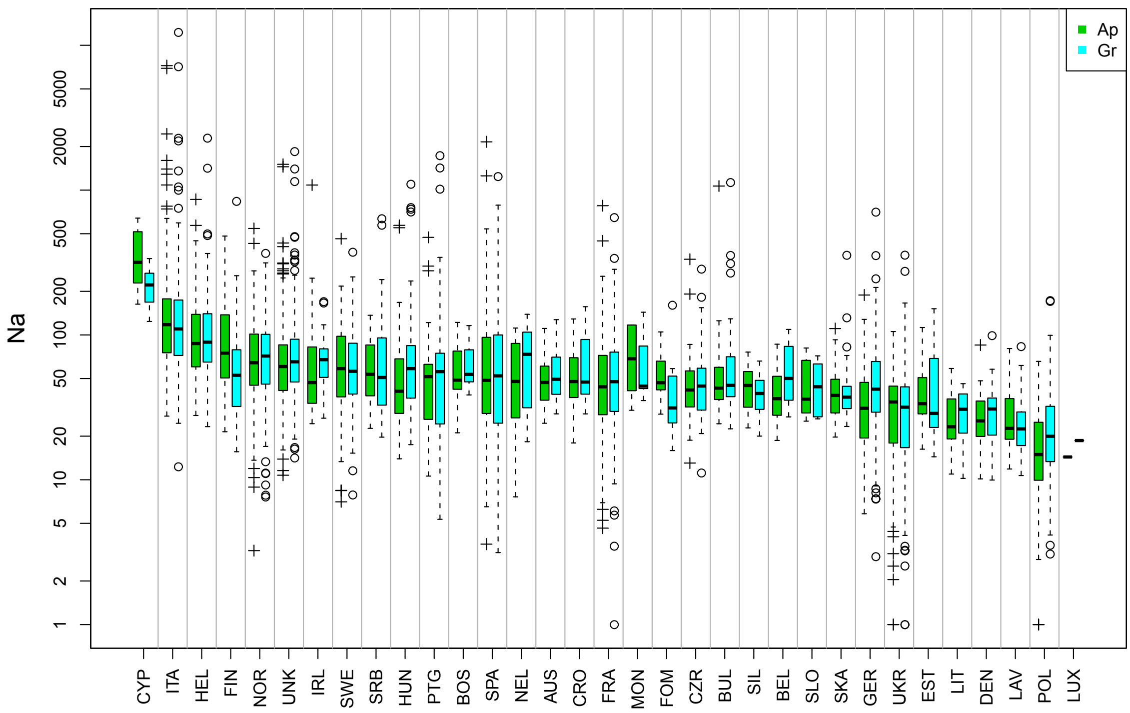
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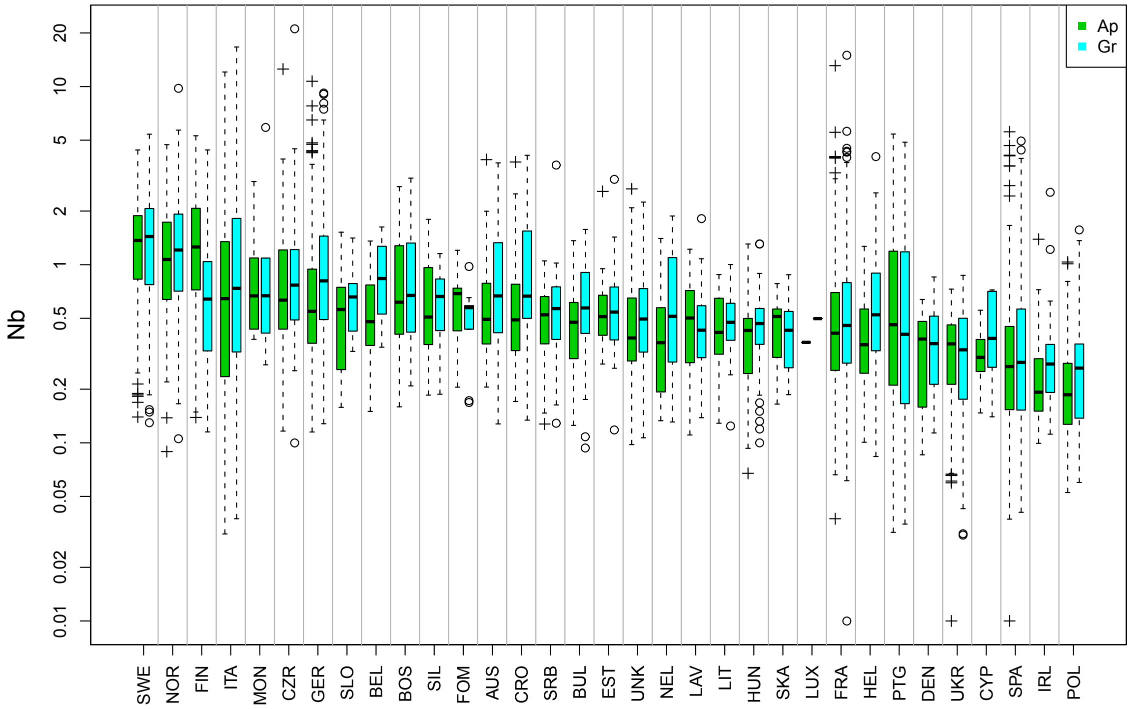
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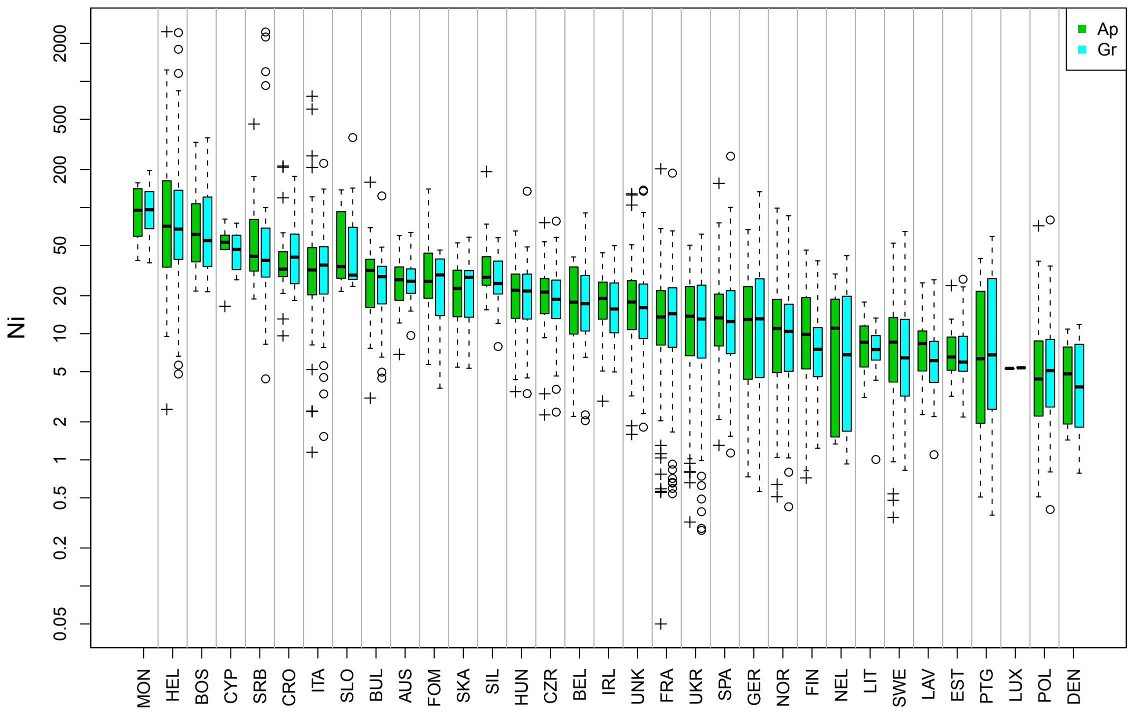
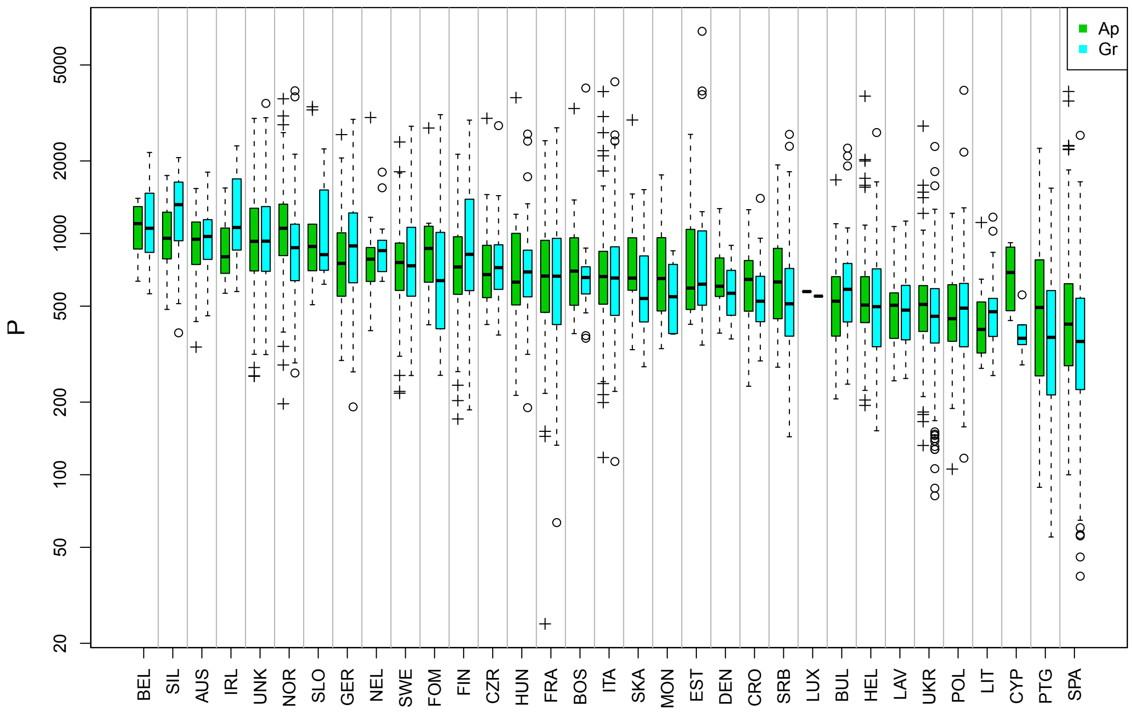
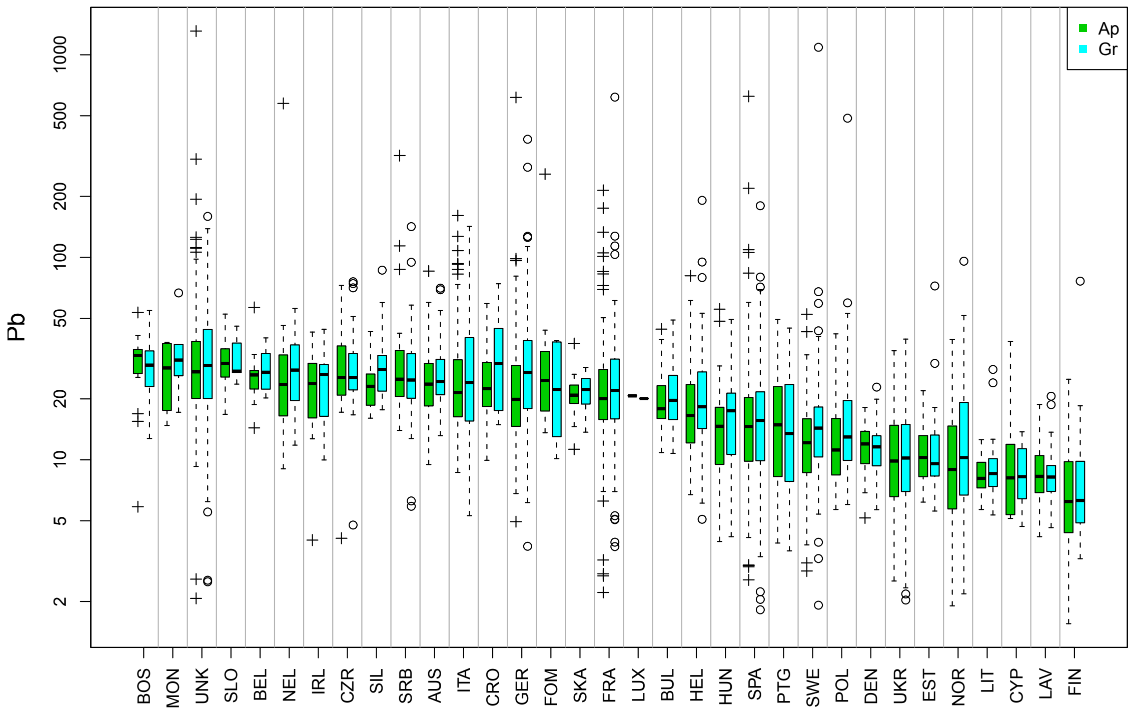
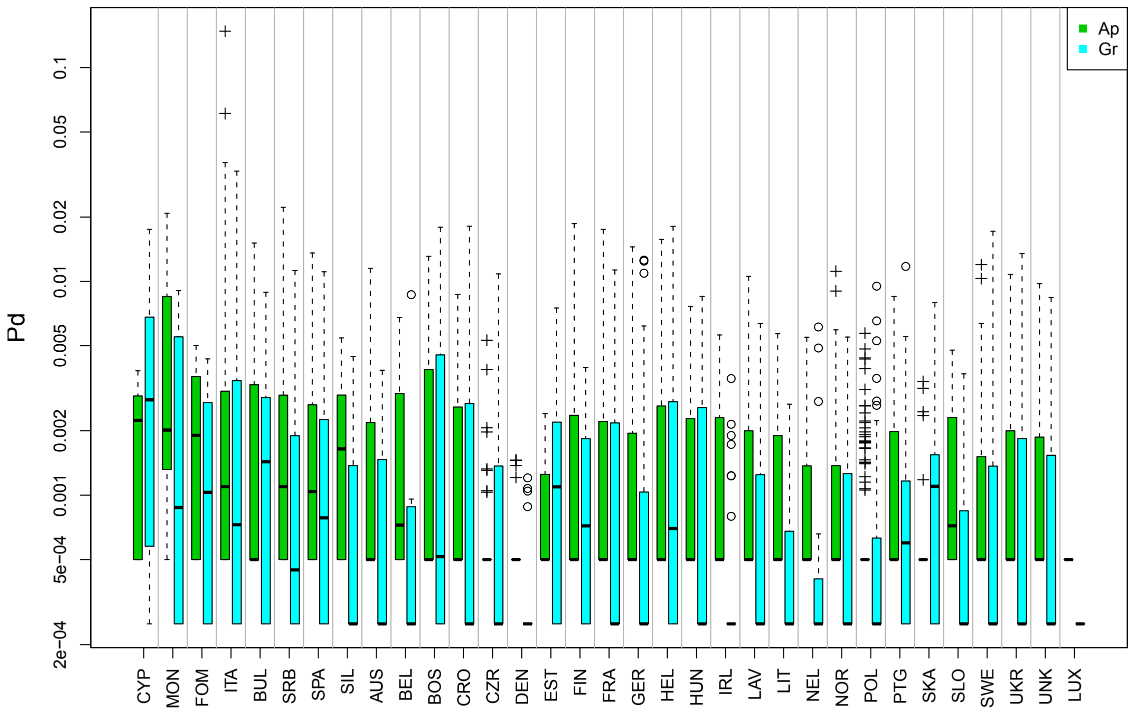
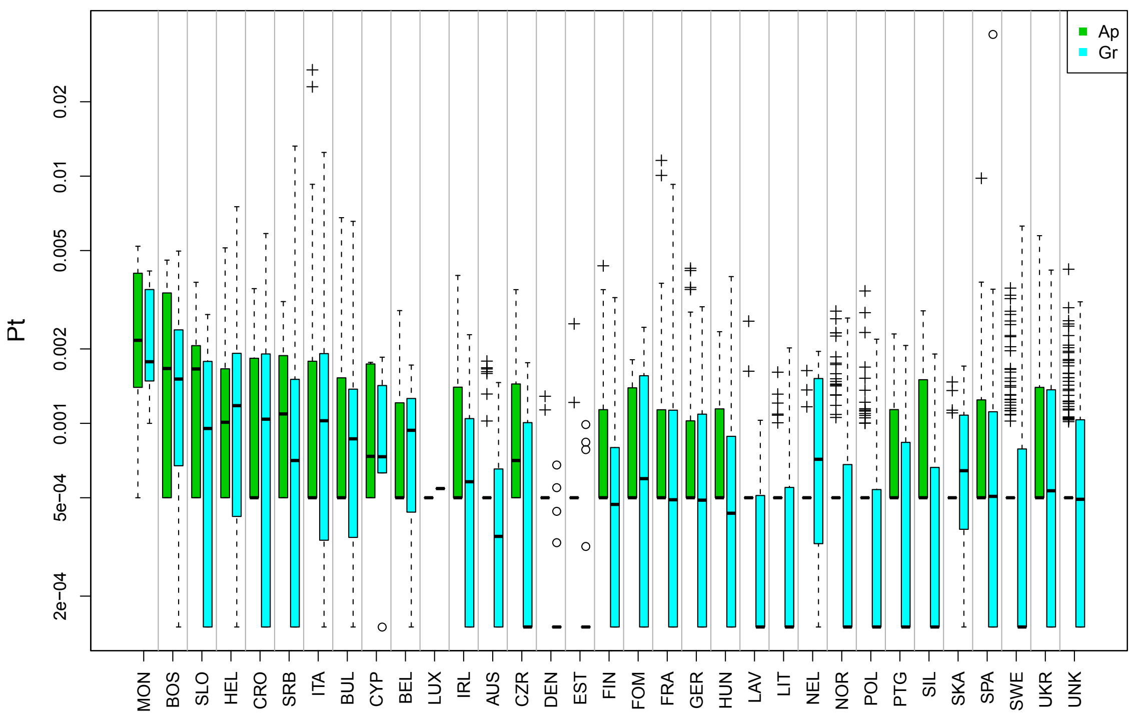
2
5
10
20
Ap
Gr
SWE NOR FIN ITA MON CZR GER SLO BEL BOS SIL FOM AUS CRO SRB BUL EST UNK NEL LAV LIT HUN SKA LUX FRA HEL PTG DEN UKR CYP SPA IRL POL

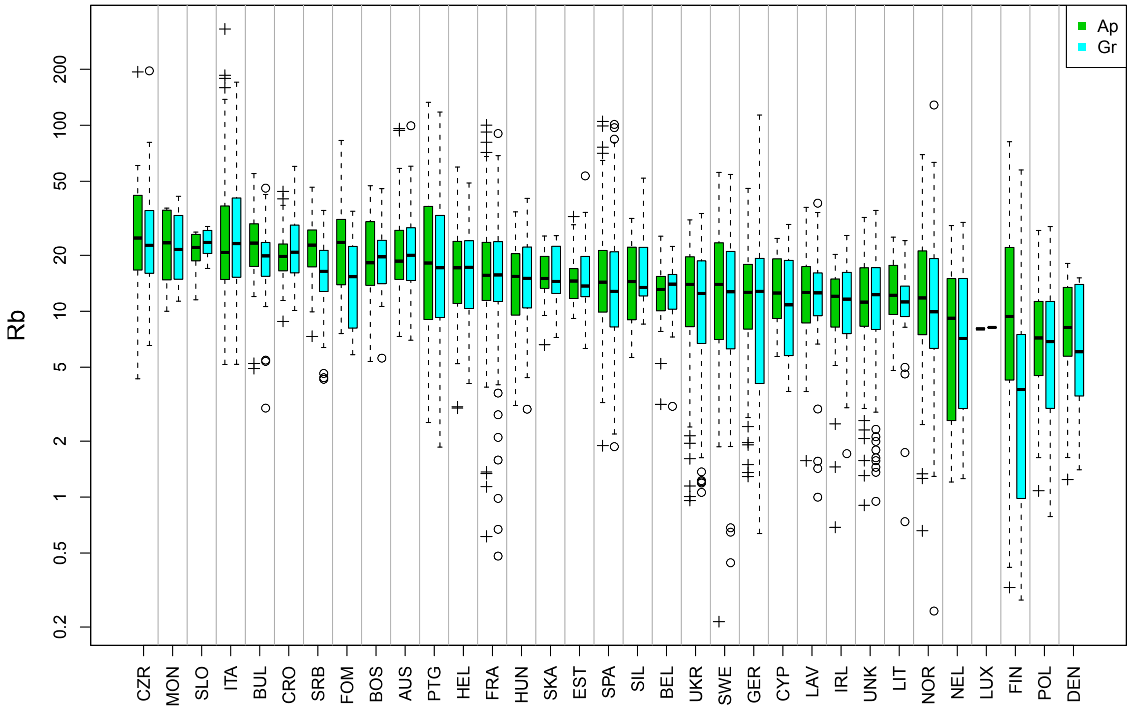

Ni
0.05
0.2
0.5
1
2
5
10
20
50
200
500
2000
Ap
Gr
MON HEL BOS CYP SRB CRO ITA SLO BUL AUS FOM SKA SIL HUN CZR BEL IRL UNK FRA UKR SPA GER NOR FIN NEL LIT SWE LAV EST PTG LUX POL DEN

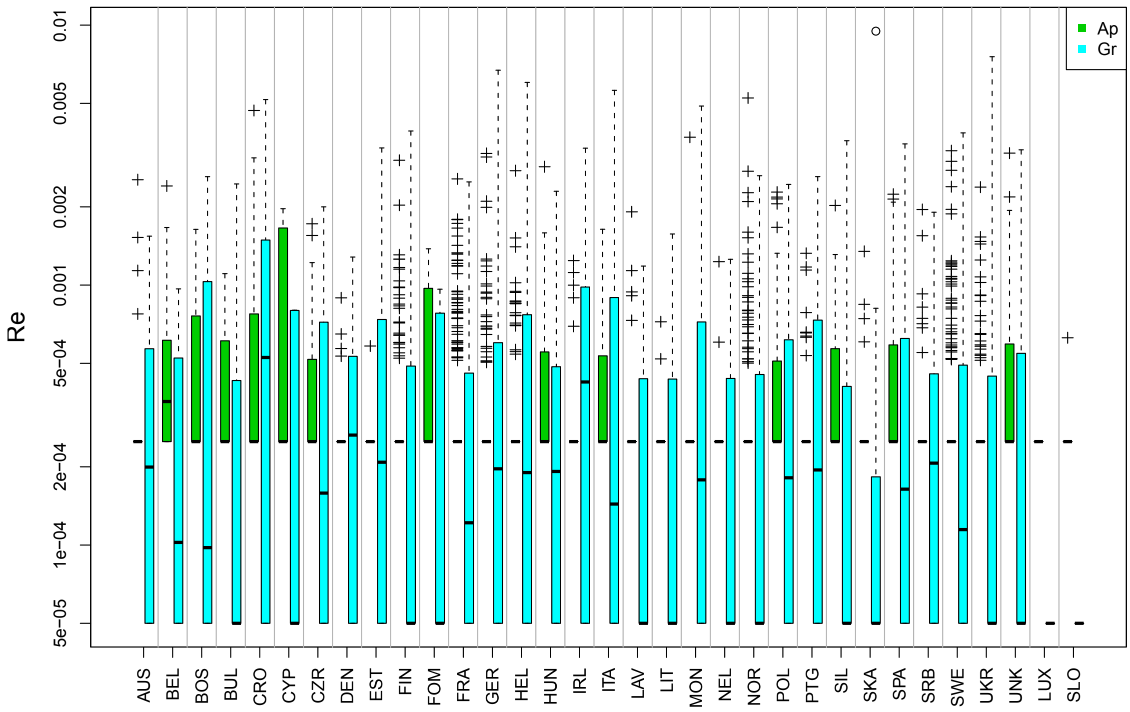

P
20
50
100
200
500
1000
2000
5000
Ap
Gr
BEL SIL AUS IRL UNK NOR SLO GER NEL SWE FOM FIN CZR HUN FRA BOS ITA SKA MON EST DEN CRO SRB LUX BUL HEL LAV UKR POL LIT CYP PTG SPA


Pb
2
5
10
20
50
100
200
500
1000
Ap
Gr
BOS MON UNK SLO BEL NEL IRL CZR SIL SRB AUS ITA CRO GER FOM SKA FRA LUX BUL HEL HUN SPA PTG SWE POL DEN UKR EST NOR LIT CYP LAV FIN


Pd
0.1
0.05
0.02
0.01
0.005
0.002
0.001
5e−04
2e−04
Ap
Gr
CYP MON FOM ITA BUL SRB SPA SIL AUS BEL BOS CRO CZR DEN EST FIN FRA GER HEL HUN IRL LAV LIT NEL NOR POL PTG SKA SLO SWE UKR UNK LUX


Pt
0.02
0.01
0.005
0.002
0.001
5e−04
2e−04
Ap
Gr
MON BOS SLO HEL CRO SRB ITA BUL CYP BEL LUX IRL AUS CZR DEN EST FIN FOM FRA GER HUN LAV LIT NEL NOR POL PTG SIL SKA SPA SWE UKR UNK


Rb
Ap
Gr
200
100
50
20
10
5
2
1
0.5
0.2
CZR
MON
SLO
ITA
BUL
CRO
SRB
FOM
BOS
AUS
PTG
HEL
FRA
HUN
SKA
EST
SPA
SIL
BEL
UKR
SWE
GER
CYP
LAV
IRL
UNK
LIT
NOR
NEL
LUX
FIN
POL
DEN


Re
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Gr
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0.005
0.002
0.001
5e−04
2e−04
1e−04
5e−05
AUS
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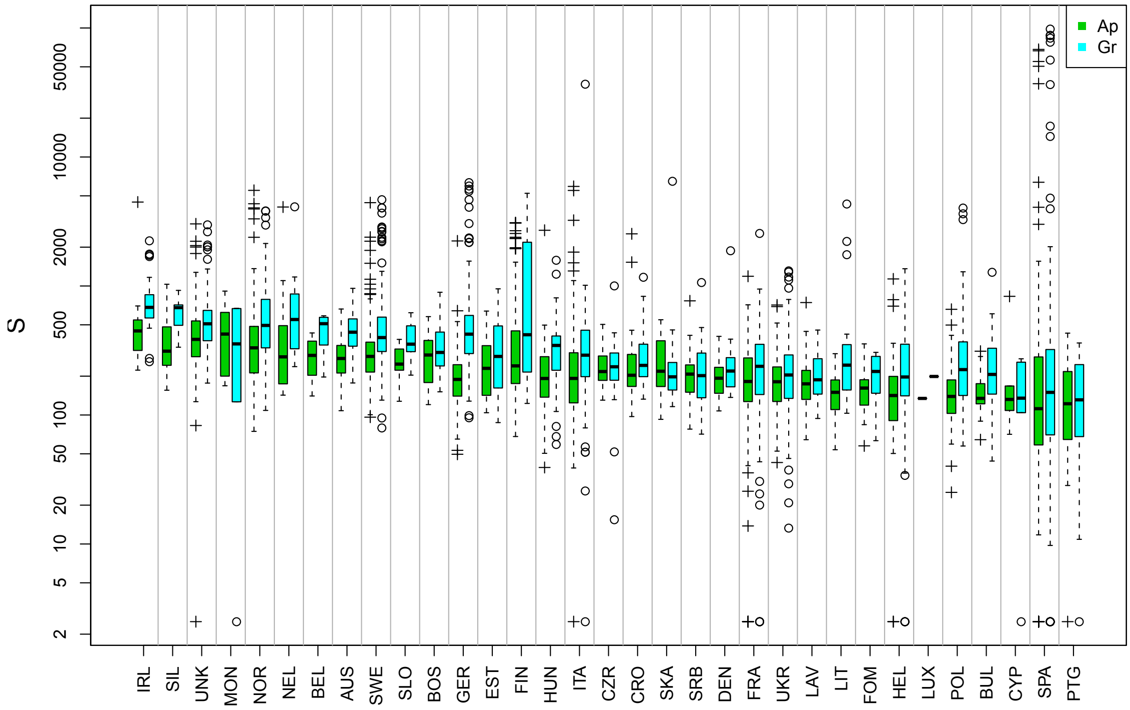
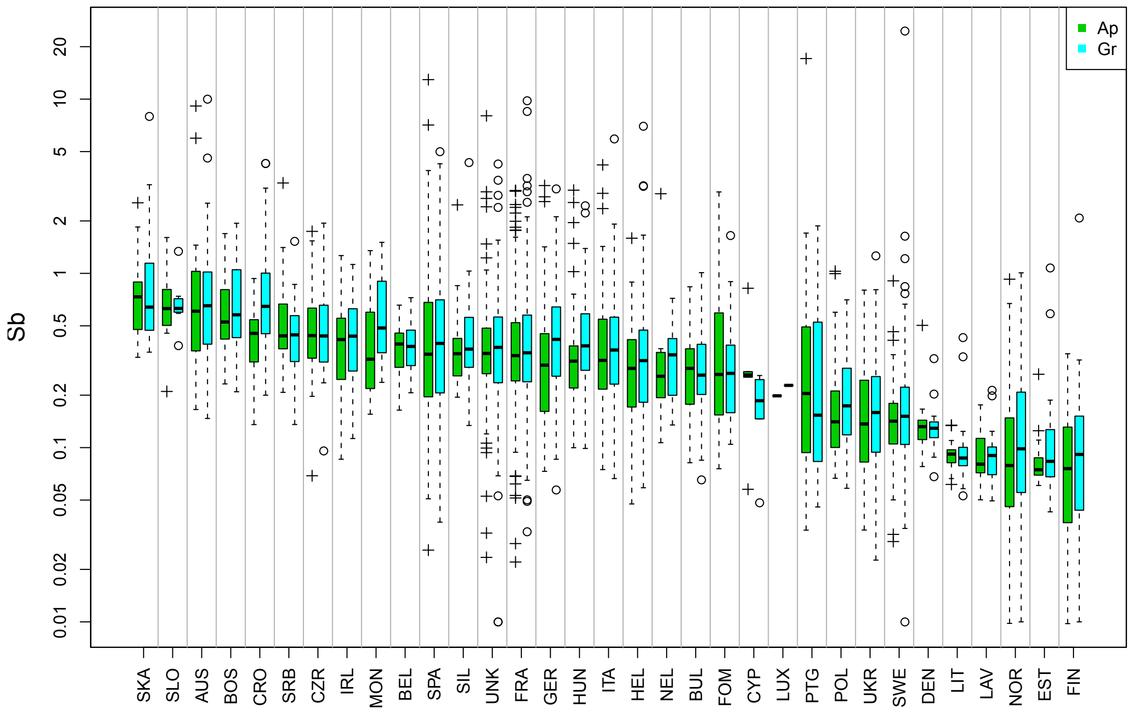
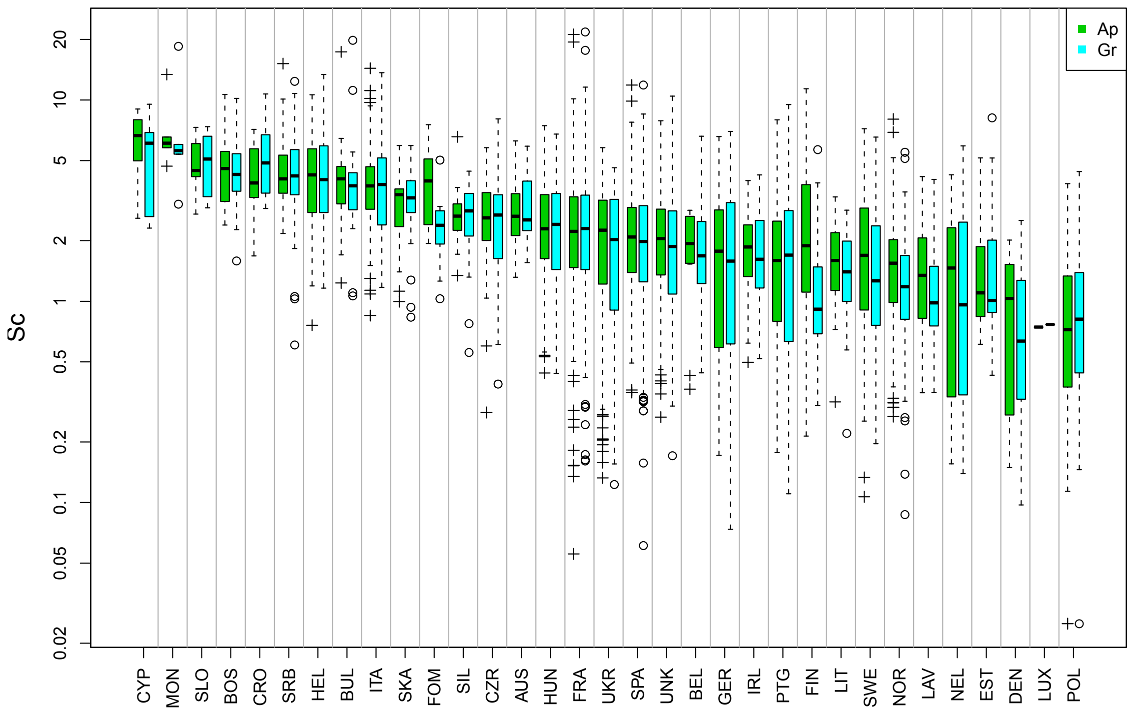
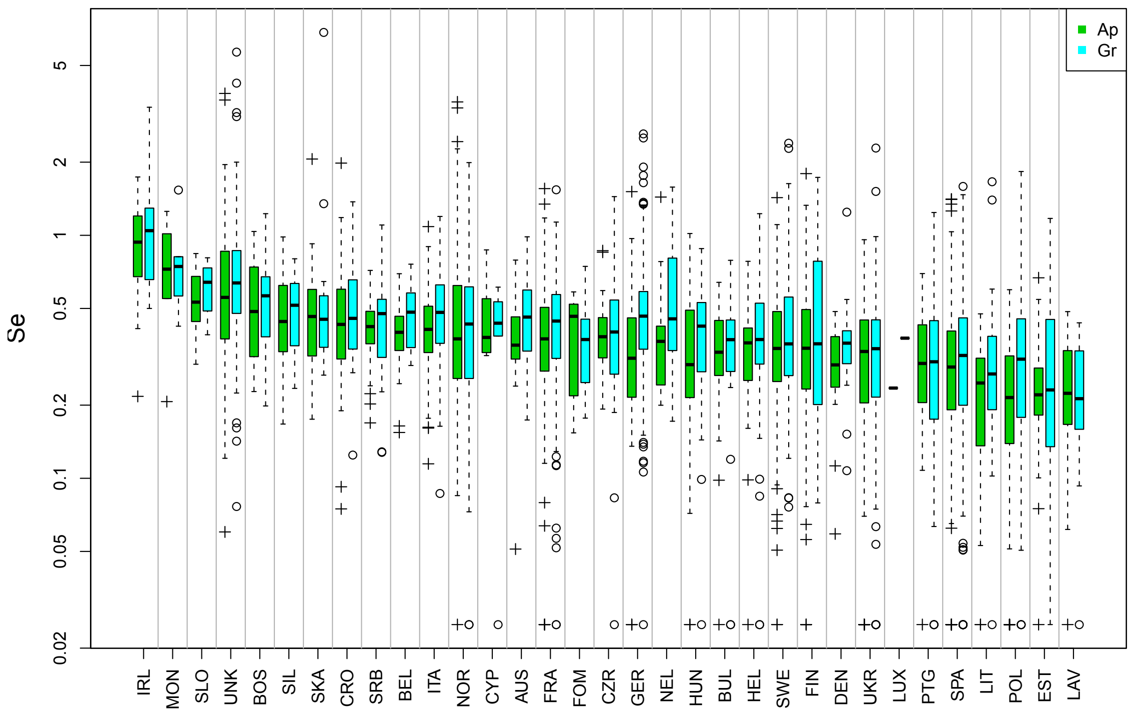
BOS
BUL
CRO
CYP
CZR
DEN
EST
FIN
FOM
FRA
GER
HEL
HUN
IRL
ITA
LAV
LIT
MON
NEL
NOR
POL
PTG
SIL
SKA
SPA
SRB
SWE
UKR
UNK
LUX
SLO


S
50000
10000
2000
500
100
50
20
10
5
2
Ap
Gr
IRL SIL UNK MON NOR NEL BEL AUS SWE SLO BOS GER EST FIN HUN ITA CZR CRO SKA SRB DEN FRA UKR LAV LIT FOM HEL LUX POL BUL CYP SPA PTG


Sb
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
Ap
Gr
SKA SLO AUS BOS CRO SRB CZR IRL MON BEL SPA SIL UNK FRA GER HUN ITA HEL NEL BUL FOM CYP LUX PTG POL UKR SWE DEN LIT LAV NOR EST FIN


Sc
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
Ap
Gr
CYP
MON
SLO
BOS
CRO
SRB
HEL
BUL
ITA
SKA
FOM
SIL
CZR
AUS
HUN
FRA
UKR
SPA
UNK
BEL
GER
IRL
PTG
FIN
LIT
SWE
NOR
LAV
NEL
EST
DEN
LUX
POL


Se
5
2
1
0.5
0.2
0.1
0.05
0.02
Ap
Gr
IRL
MON
SLO
UNK
BOS
SIL
SKA
CRO
SRB
BEL
ITA
NOR
CYP
AUS
FRA
FOM
CZR
GER
NEL
HUN
BUL
HEL
SWE
FIN
DEN
UKR
LUX
PTG
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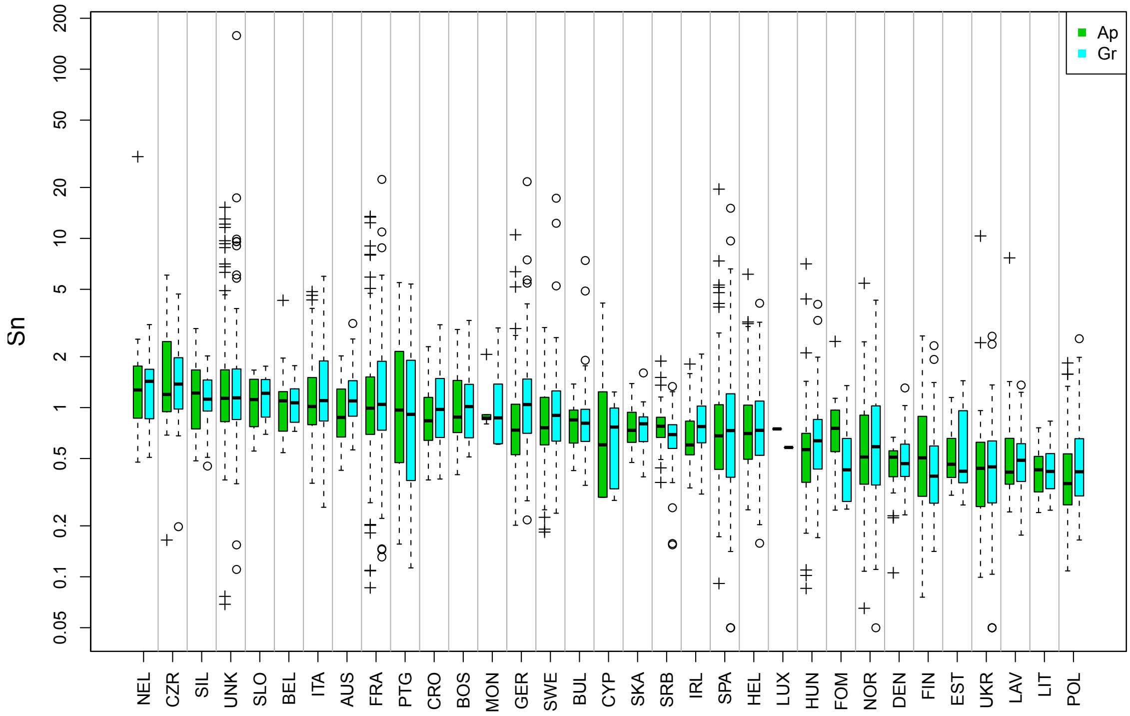
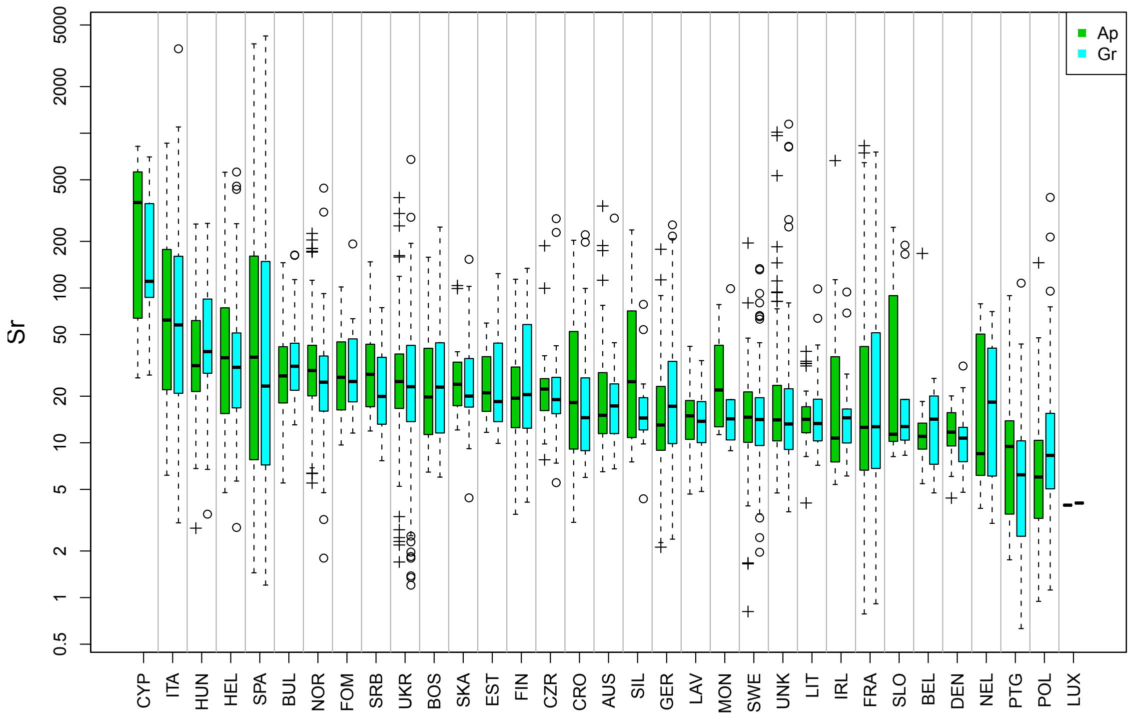
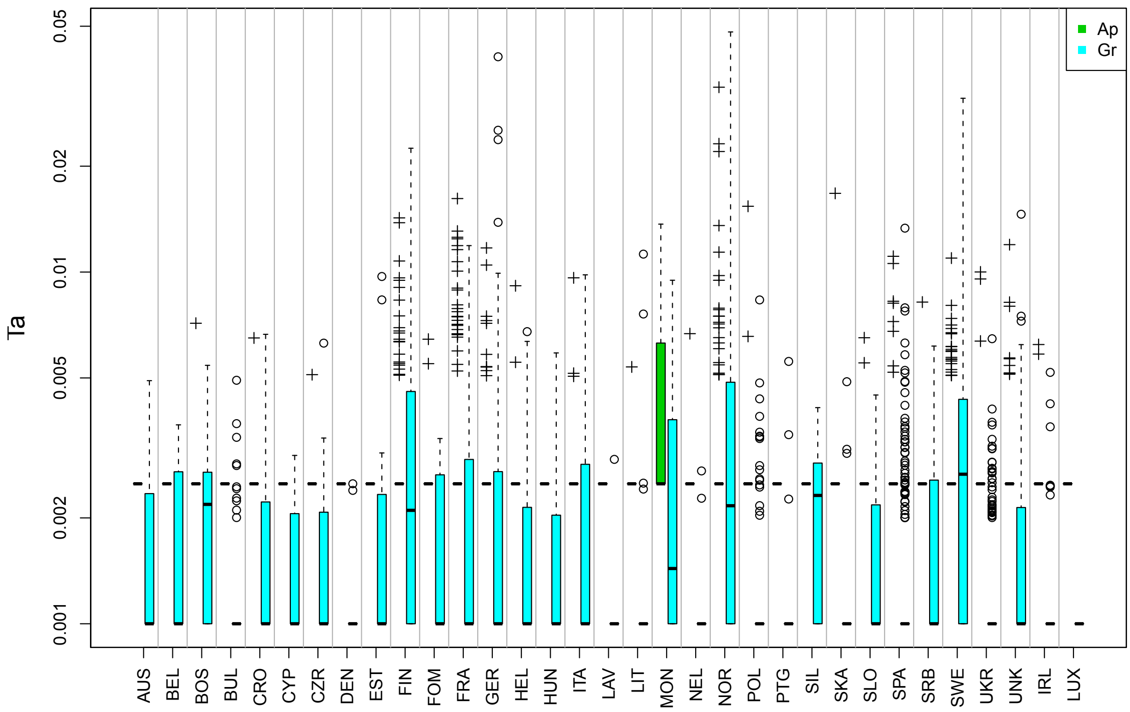
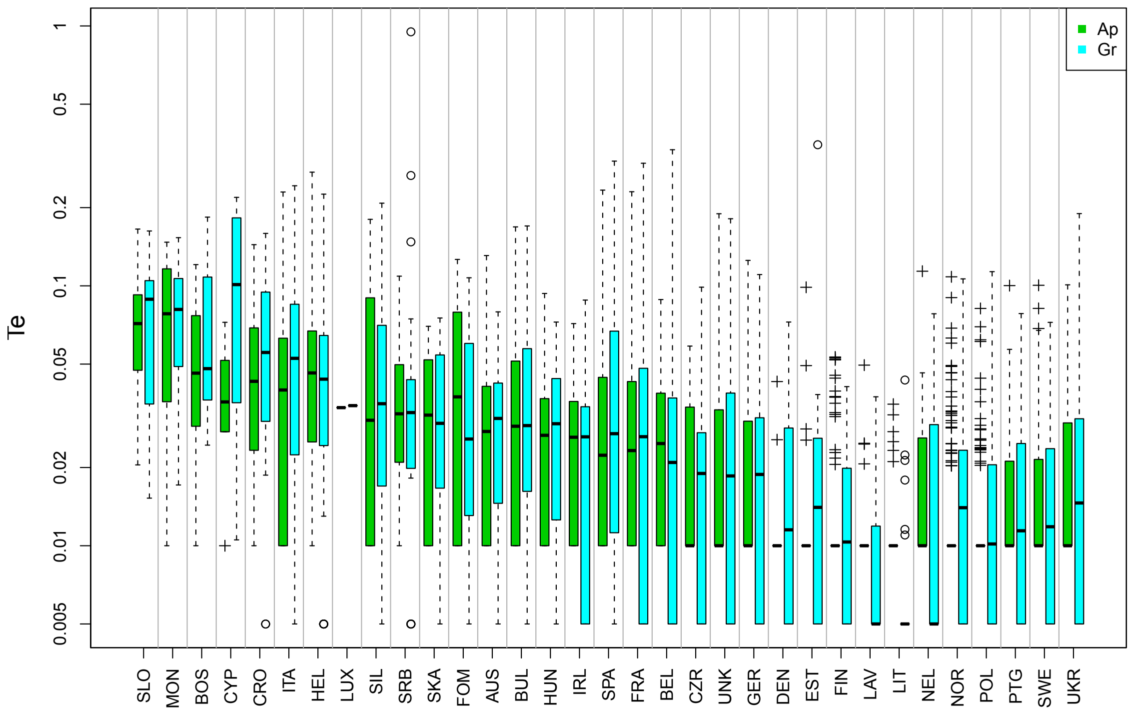
LIT
POL
EST
LAV


Sn
Ap
Gr
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
NEL
CZR
SIL
UNK
SLO
BEL
ITA
AUS
FRA
PTG
CRO
BOS
MON
GER
SWE
BUL
CYP
SKA
SRB
IRL
SPA
HEL
LUX
HUN
FOM
NOR
DEN
FIN
EST
UKR
LAV
LIT
POL


Sr
Ap
Gr
0.5
1
2
5
10
20
50
100
200
500
2000
5000
CYP
ITA
HUN
HEL
SPA
BUL
NOR
FOM
SRB
UKR
BOS
SKA
EST
FIN
CZR
CRO
AUS
SIL
GER
LAV
MON
SWE
UNK
LIT
IRL
FRA
SLO
BEL
DEN
NEL
PTG
POL
LUX


Ta
Ap
Gr
0.05
0.02
0.01
0.005
0.002
0.001
AUS
BEL
BOS
BUL
CRO
CYP
CZR
DEN
EST
FIN
FOM
FRA
GER
HEL
HUN
ITA
LAV
LIT
MON
NEL
NOR
POL
PTG
SIL
SKA
SLO
SPA
SRB
SWE
UKR
UNK
IRL
LUX


Te
Ap
Gr
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
SLO
MON
BOS
CYP
CRO
ITA
HEL
LUX
SIL
SRB
SKA
FOM
AUS
BUL
HUN
IRL
SPA
FRA
BEL
CZR
UNK
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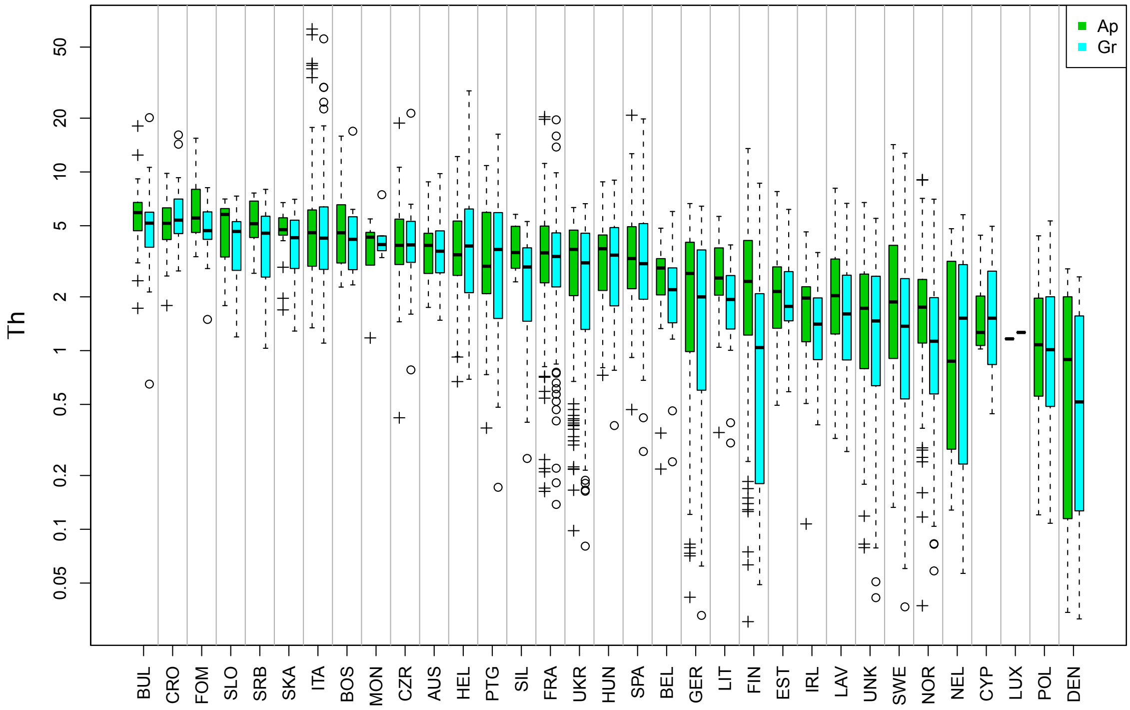
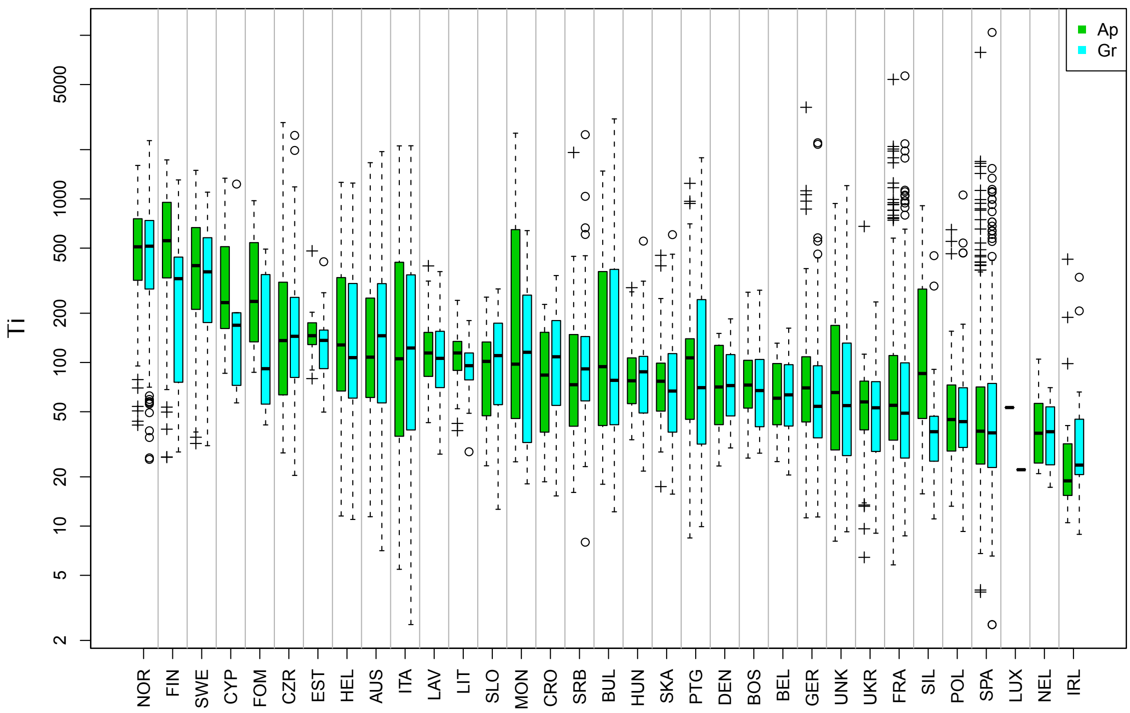
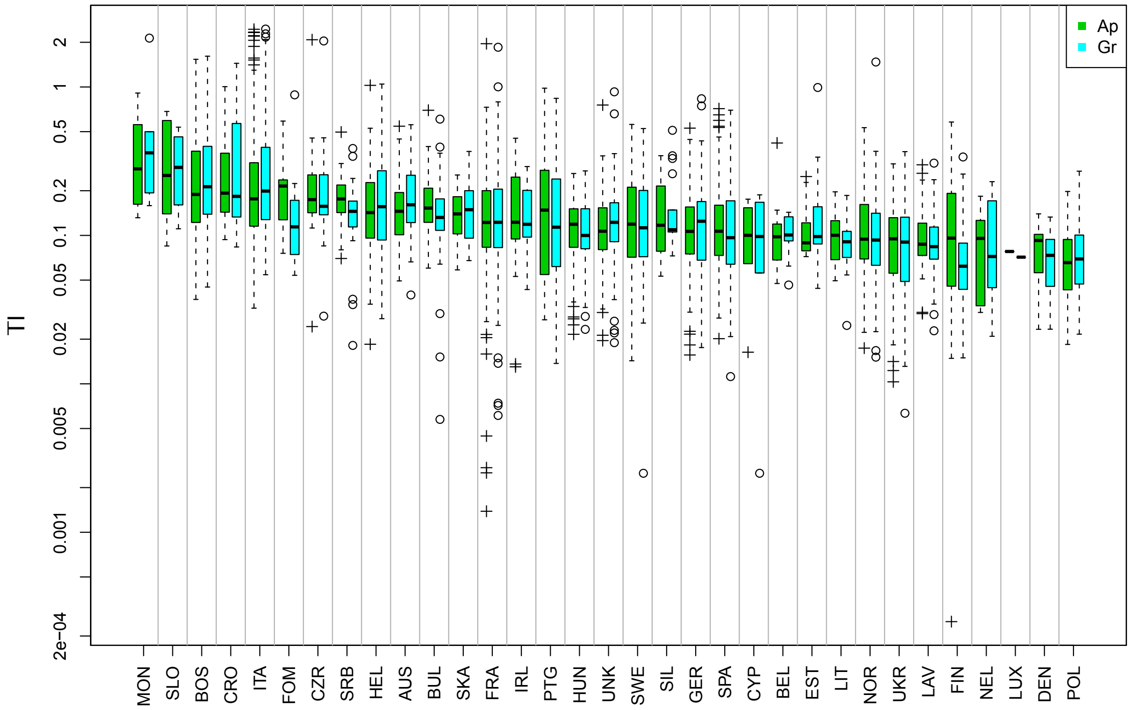
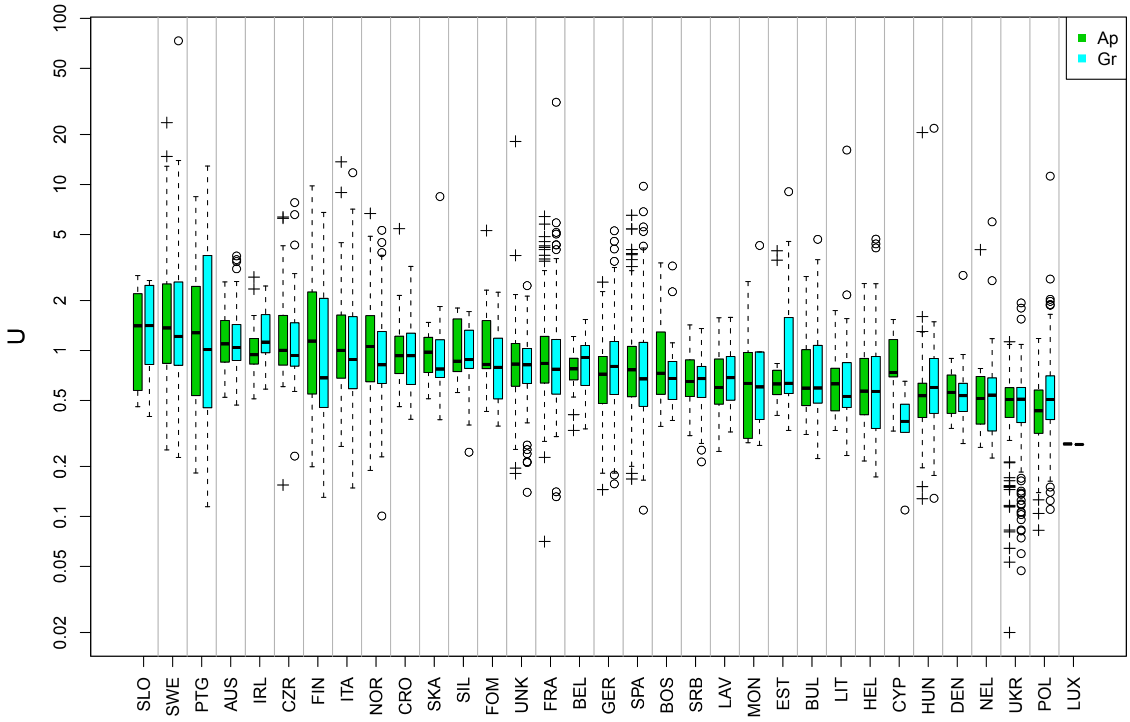
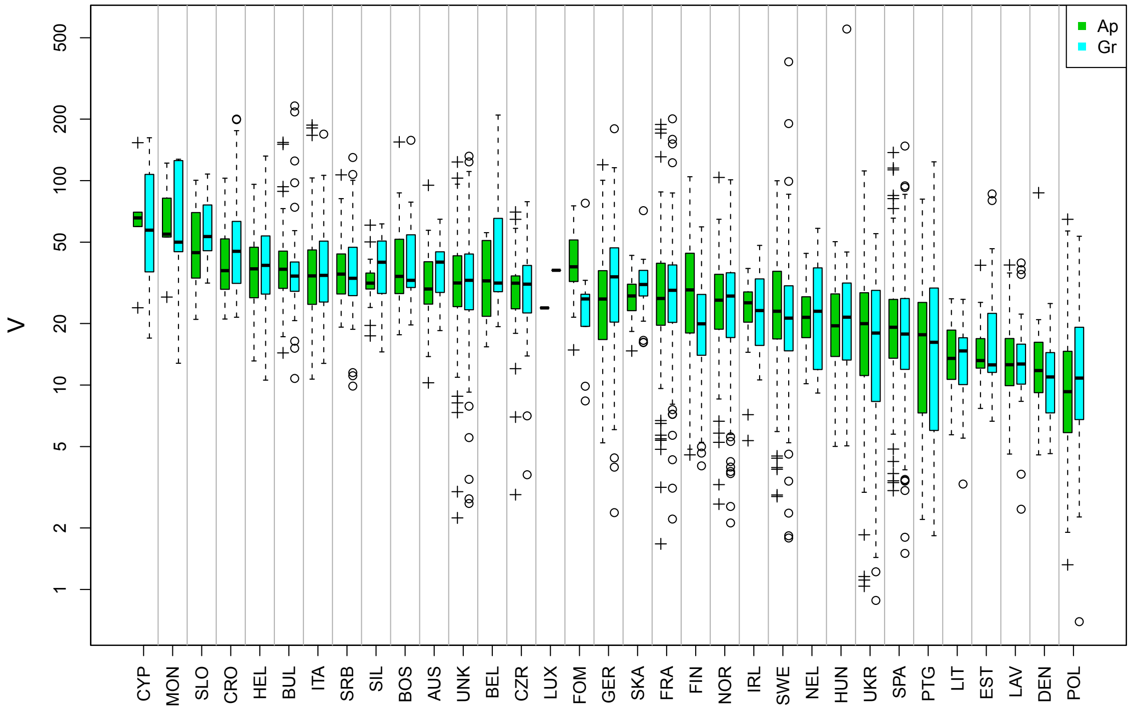
DEN
EST
FIN
LAV
LIT
NEL
NOR
POL
PTG
SWE
UKR

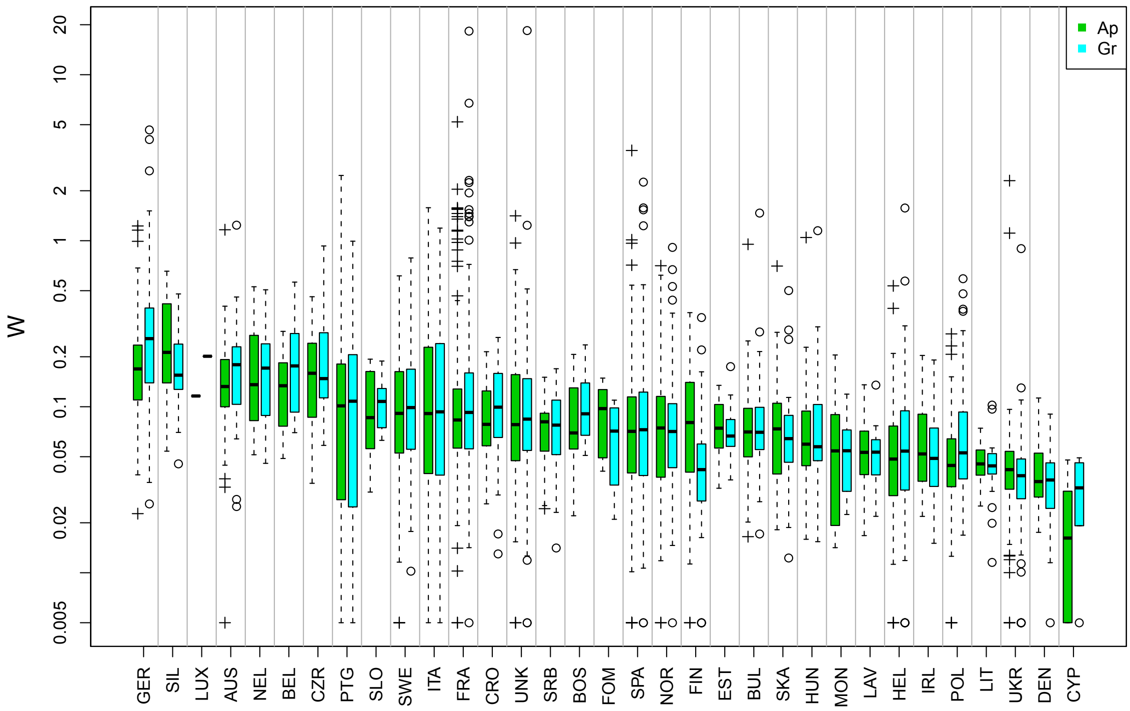

Th
50
20
10
5
2
1
0.5
0.2
0.1
0.05
Ap
Gr
BUL CRO FOM SLO SRB SKA ITA BOS MON CZR AUS HEL PTG SIL FRA UKR HUN SPA BEL GER LIT FIN EST IRL LAV UNK SWE NOR NEL CYP LUX POL DEN

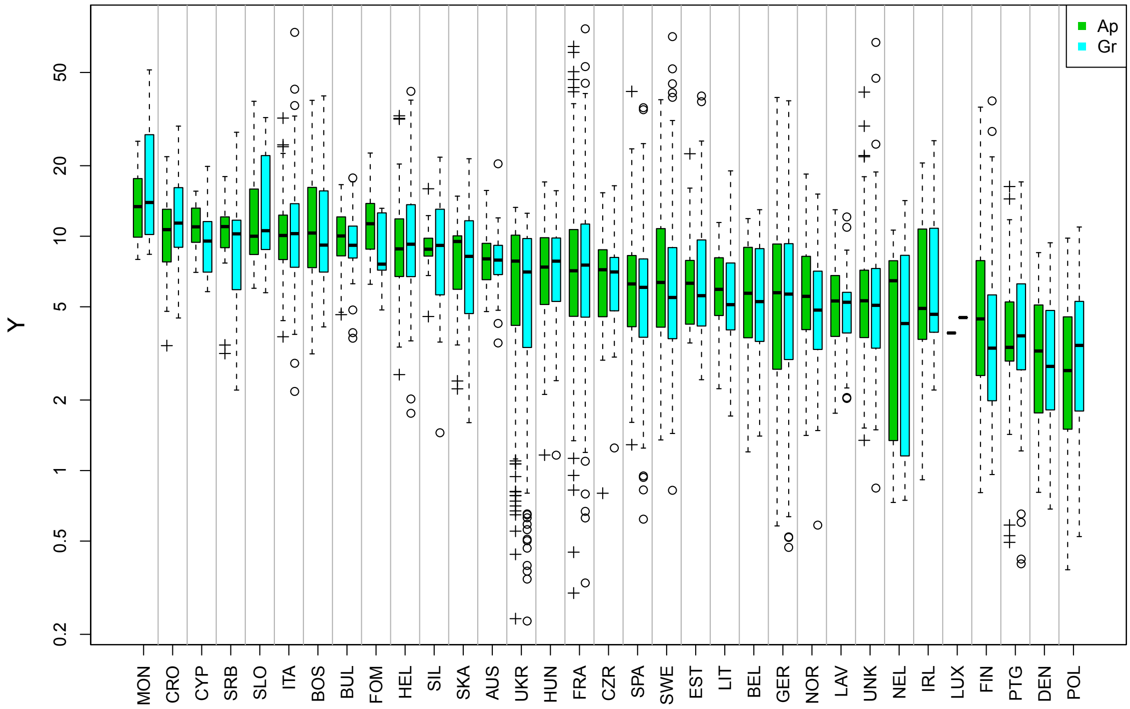

Ti
5000
1000
500
200
100
50
20
10
5
2
Ap
Gr
NOR FIN SWE CYP FOM CZR EST HEL AUS ITA LAV LIT SLO MON CRO SRB BUL HUN SKA PTG DEN BOS BEL GER UNK UKR FRA SIL POL SPA LUX NEL IRL

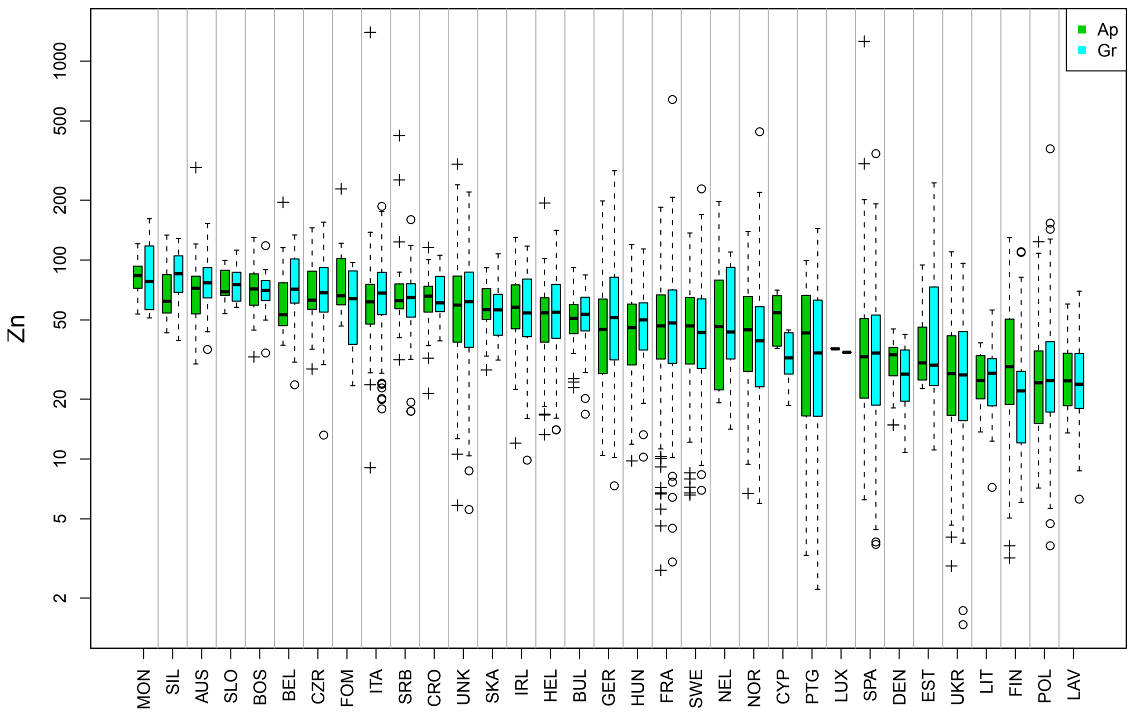

Ap
Gr
Tl
2e−04
0.001
0.005
0.02
0.05
0.1
0.2
0.5
1
2
MON
SLO
BOS
CRO
ITA
FOM
CZR
SRB
HEL
AUS
BUL
SKA
FRA
IRL
PTG
HUN
UNK
SWE
SIL
GER
SPA
CYP
BEL
EST
LIT
NOR
UKR
LAV
FIN
NEL
LUX
DEN
POL

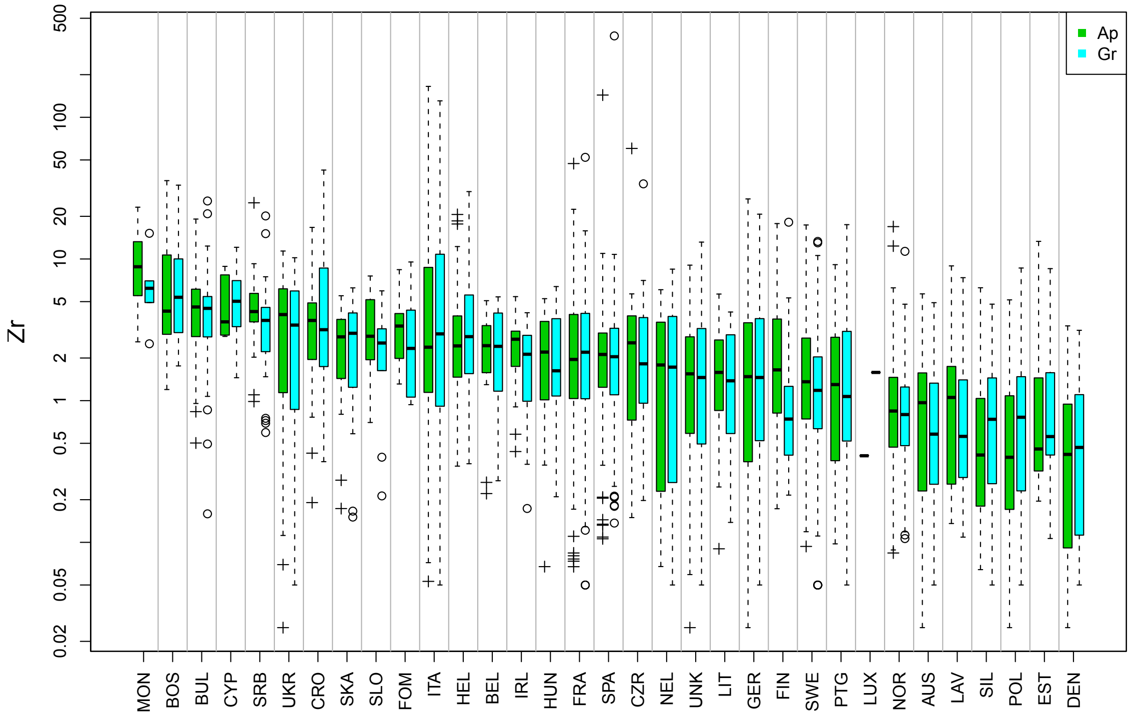

Ap
Gr
U
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
SLO
SWE
PTG
AUS
IRL
CZR
FIN
ITA
NOR
CRO
SKA
SIL
FOM
UNK
FRA
BEL
GER
SPA
BOS
SRB
LAV
MON
EST
BUL
LIT
HEL
CYP
HUN
DEN
NEL
UKR
POL
LUX


V
500
200
100
50
20
10
5
2
1
Ap
Gr
CYP MON SLO CRO HEL BUL ITA SRB SIL BOS AUS UNK BEL CZR LUX FOM GER SKA FRA FIN NOR IRL SWE NEL HUN UKR SPA PTG LIT EST LAV DEN POL


W
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.005
Ap
Gr
GER SIL LUX AUS NEL BEL CZR PTG SLO SWE ITA FRA CRO UNK SRB BOS FOM SPA NOR FIN EST BUL SKA HUN MON LAV HEL IRL POL LIT UKR DEN CYP


Ap
Gr
Y
MON CRO CYP SRB SLO ITA BOS BUL FOM HEL SIL SKA AUS UKR HUN FRA CZR SPA SWE EST LIT BEL GER NOR LAV UNK NEL IRL LUX FIN PTG DEN POL

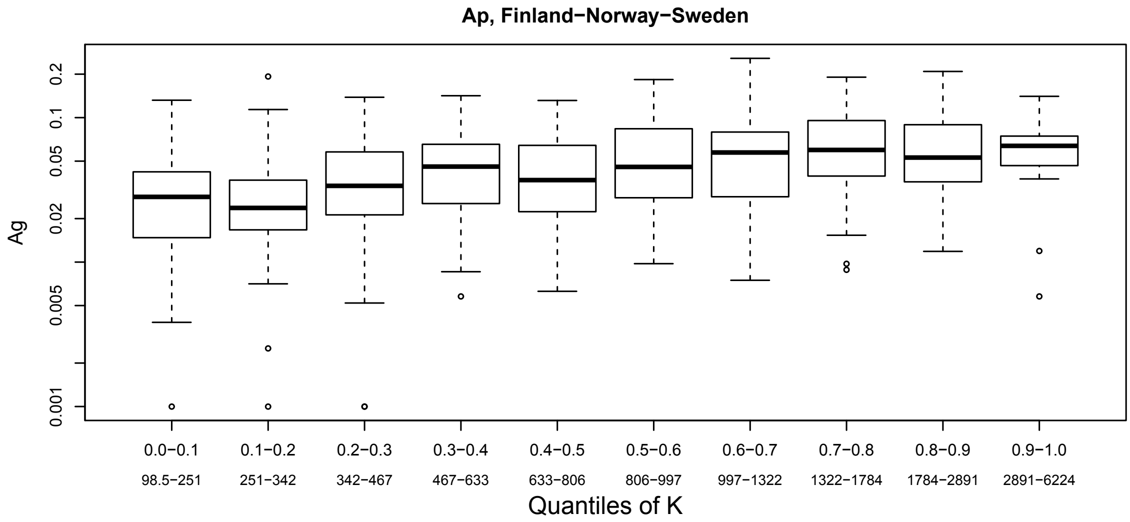

Ap
Gr
Zn
MON SIL AUS SLO BOS BEL CZR FOM ITA SRB CRO UNK SKA IRL HEL BUL GER HUN FRA SWE NEL NOR CYP PTG LUX SPA DEN EST UKR LIT FIN POL LAV

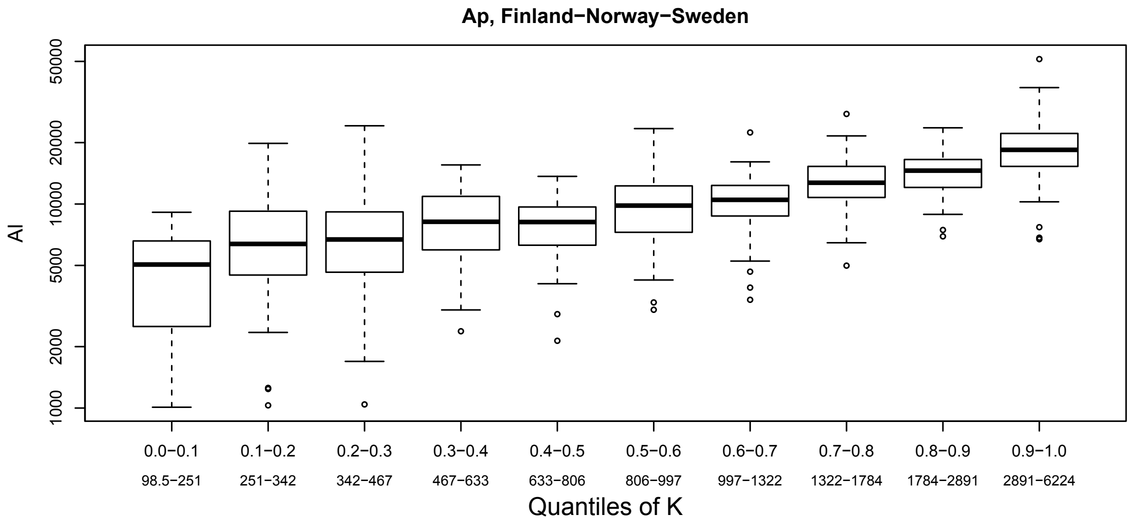


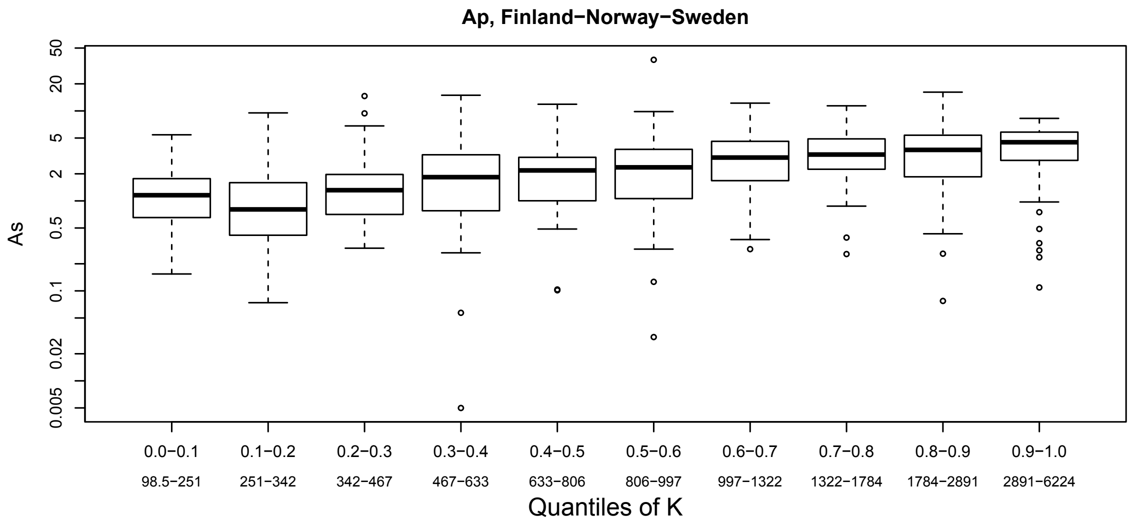
Ap
Gr
Zr
500
100
50
20
10
5
2
1
0.5
0.2
0.05
0.02
MON
BOS
BUL
CYP
SRB
UKR
CRO
SKA
SLO
FOM
ITA
HEL
BEL
IRL
HUN
FRA
SPA
CZR
NEL
UNK
LIT
GER
FIN
SWE
PTG
LUX
NOR
AUS
LAV
SIL
POL
EST
DEN

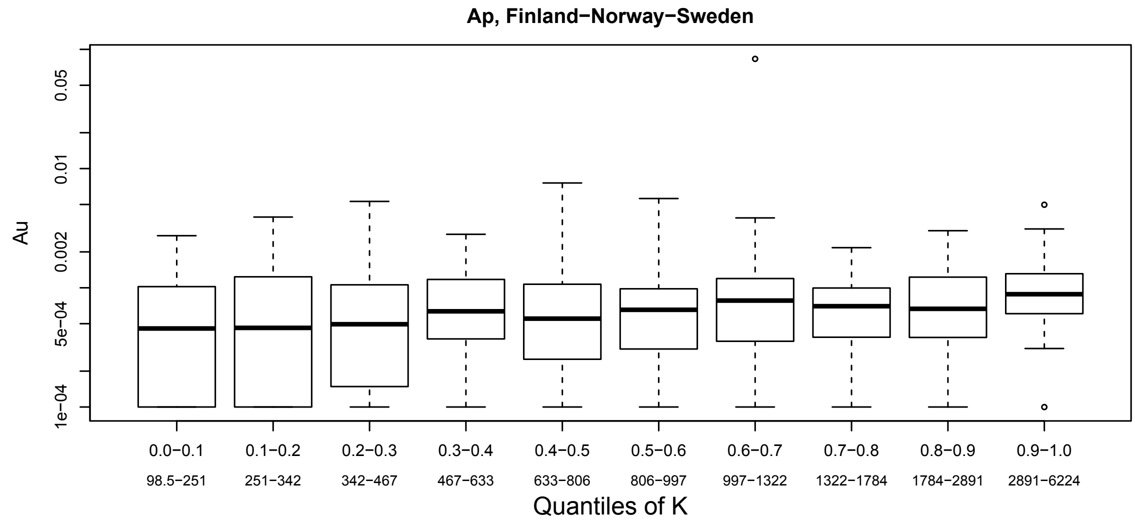
APPENDIX 2

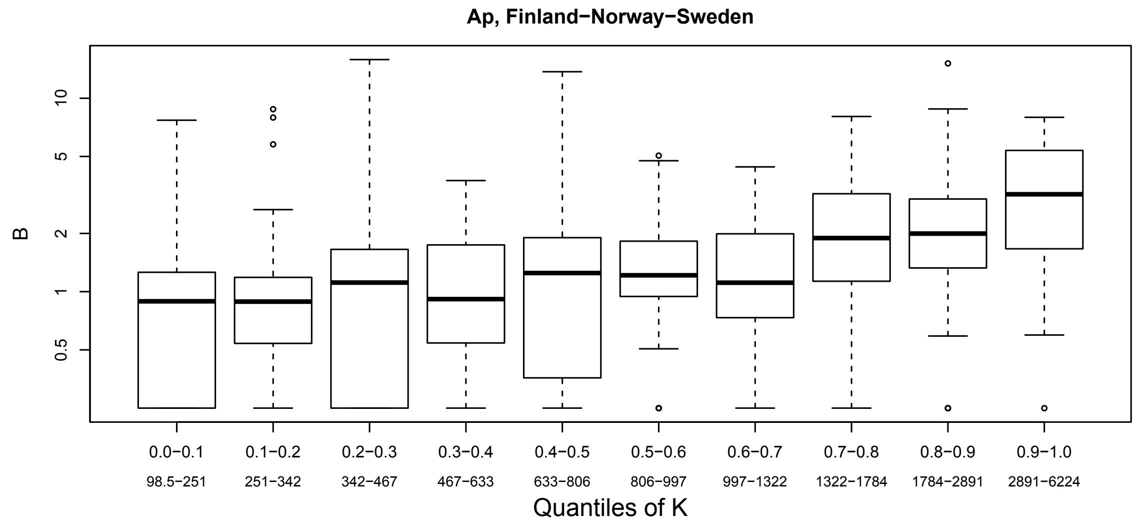
Boxplots for major and trace elements in agricultural soils (Ap) defined by quantiles of K
Results from aqua regia extraction.

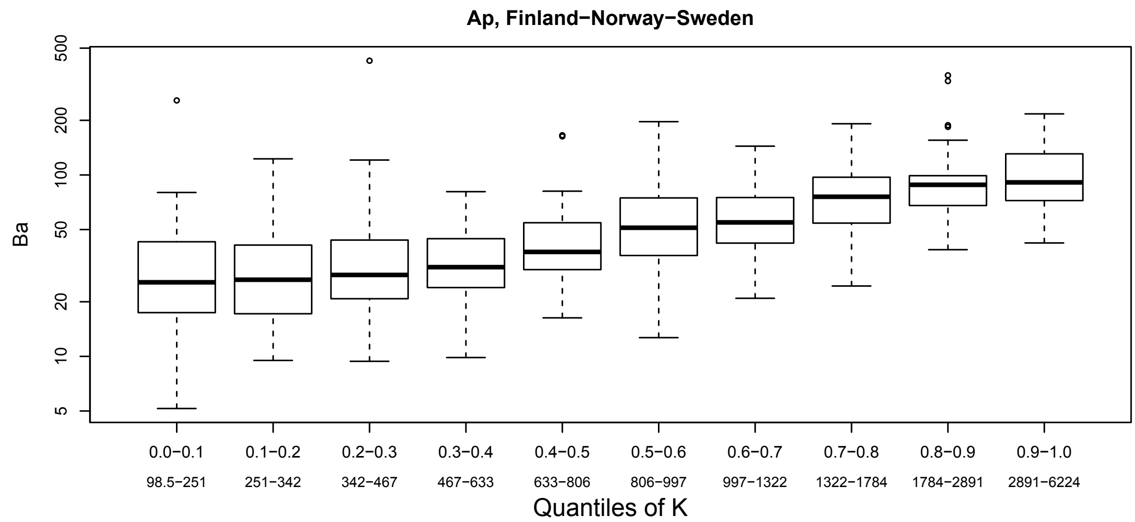


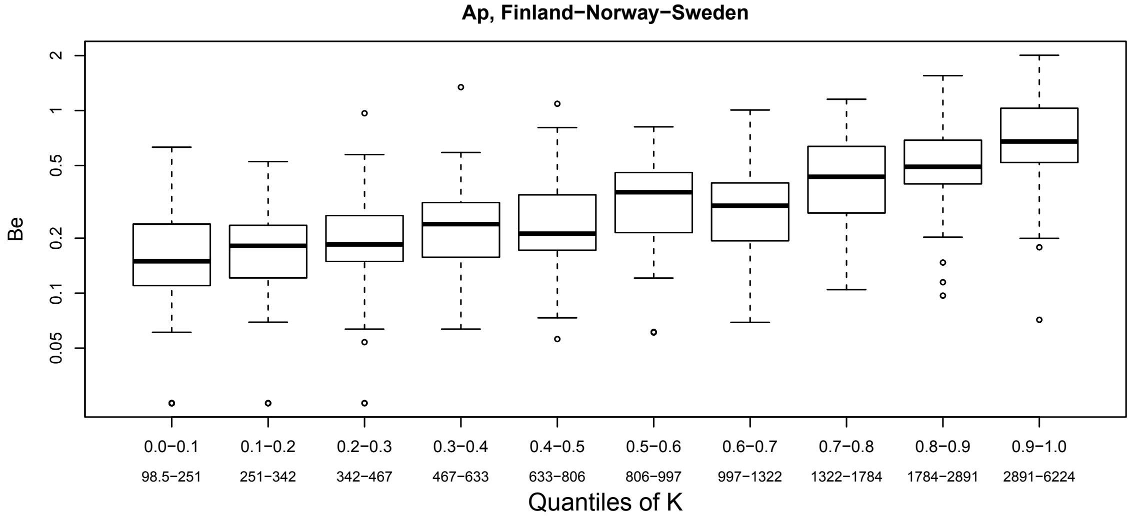


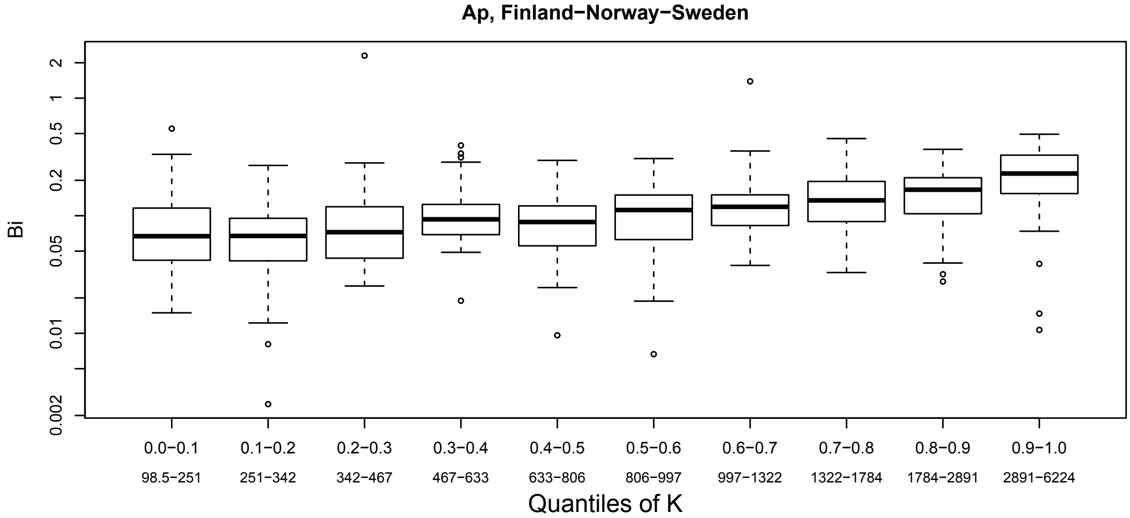


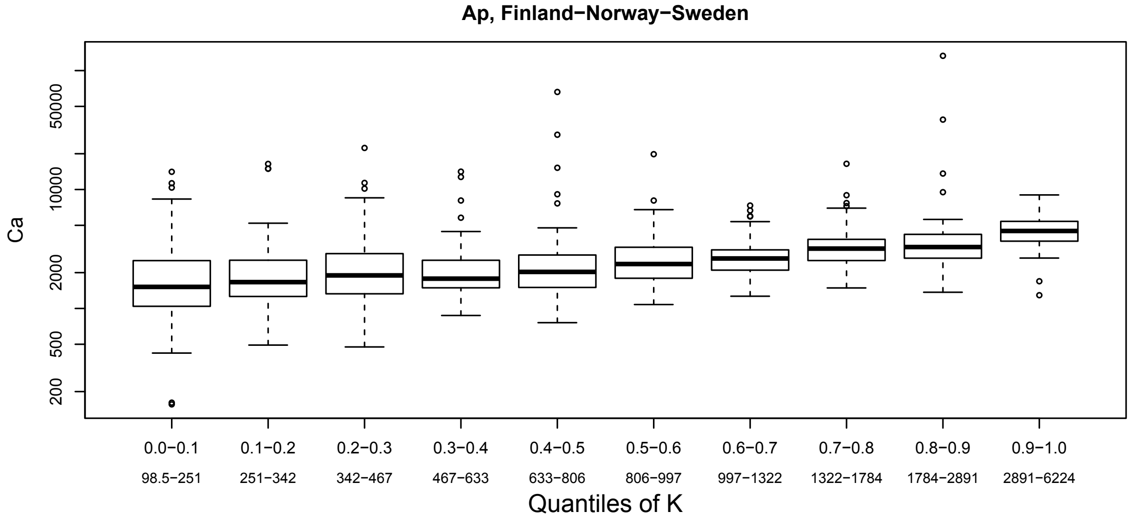

Ap, Finland−Norway−Sweden
Au
0.05
0.01
0.002
5e−04
1e−04
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

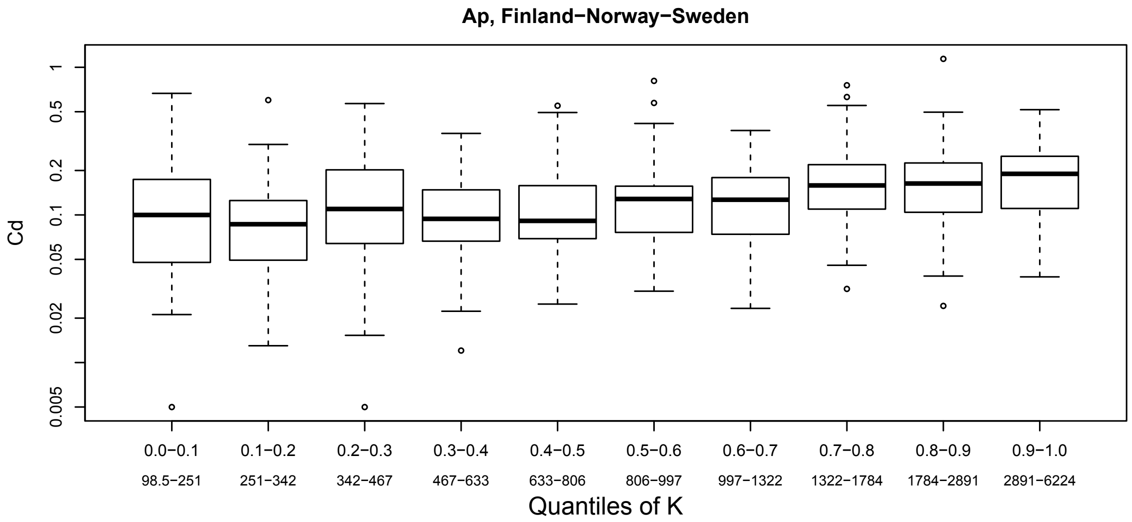

Ap, Finland−Norway−Sweden
B
10
5
2
1
0.5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

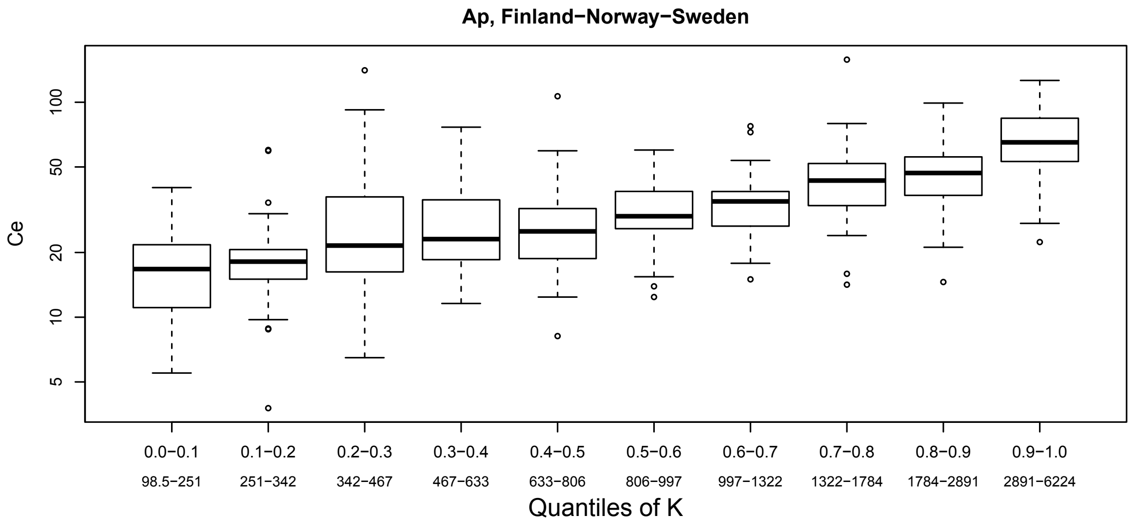

Ap, Finland−Norway−Sweden
Ba
500
200
100
50
20
10
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

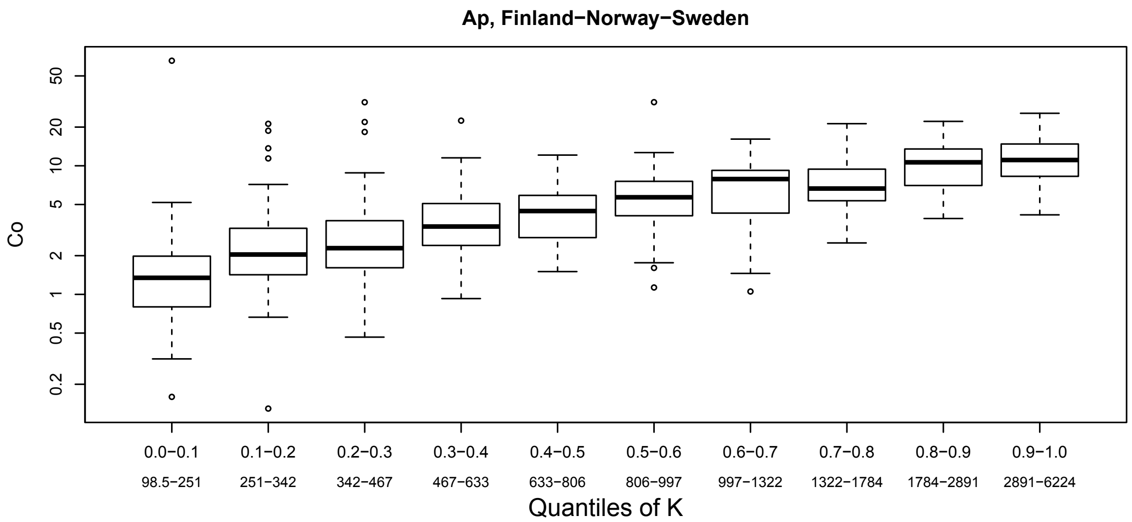

Ap, Finland−Norway−Sweden
Be
2
1
0.5
0.2
0.1
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

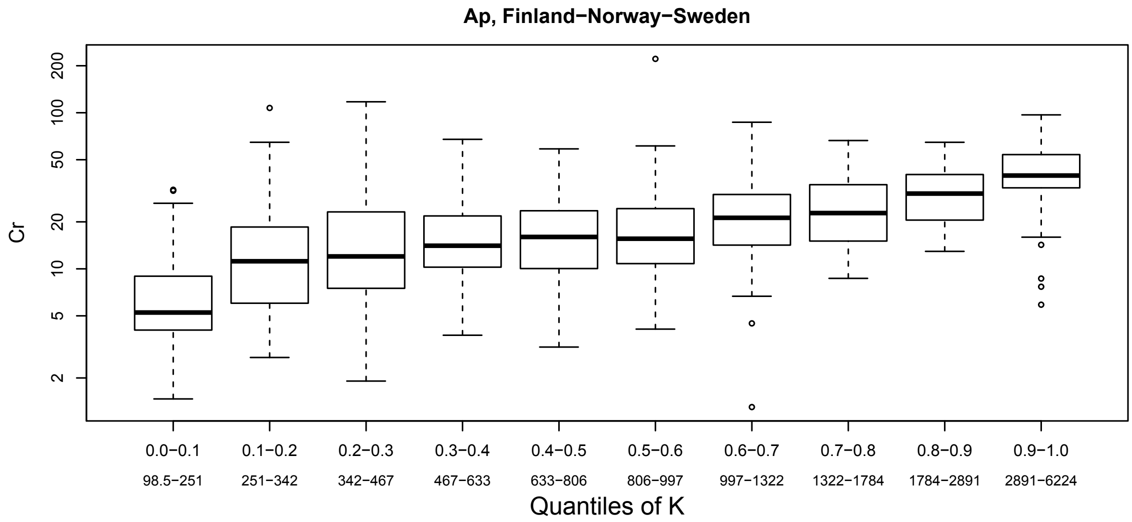

Ap, Finland−Norway−Sweden
Bi
2
1
0.5
0.2
0.05
0.01
0.002
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Ca
50000
10000
2000
500
200
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Cd
1
0.5
0.2
0.1
0.05
0.02
0.005
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Ce
100
50
20
10
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Co
50
20
10
5
2
1
0.5
0.2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K



Ap, Finland−Norway−Sweden
Cr
2
5
10
20
50
100
200
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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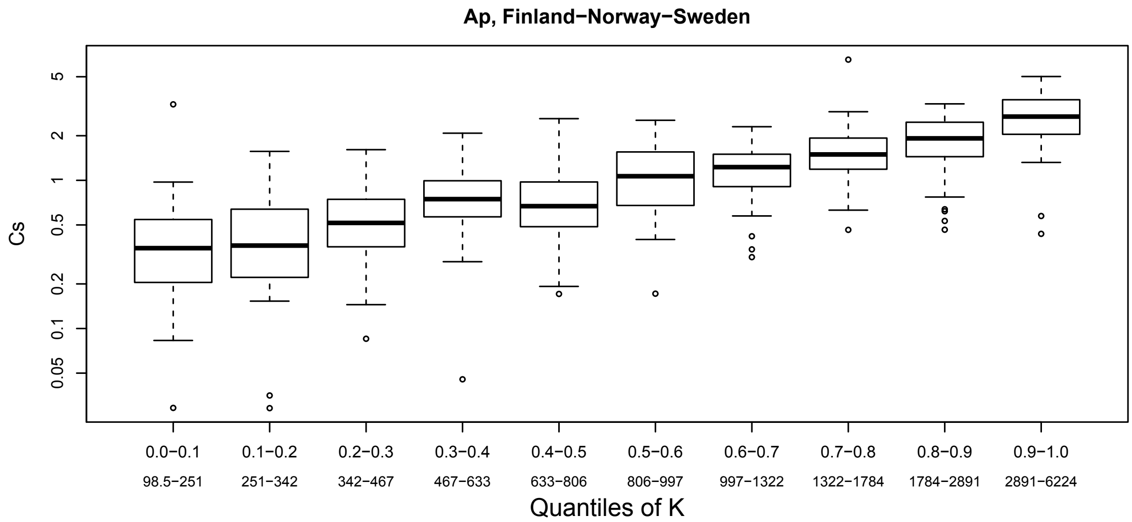
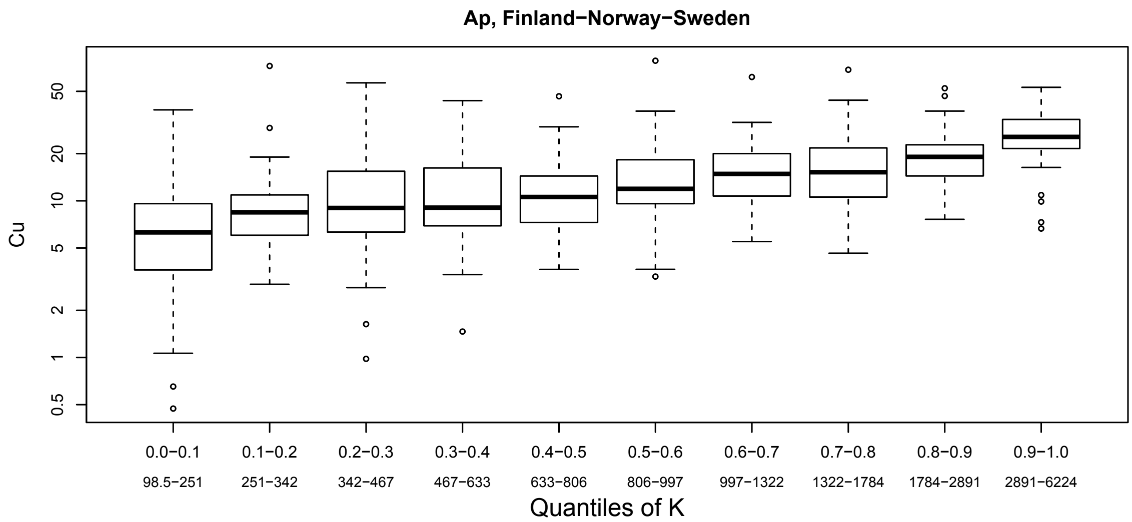
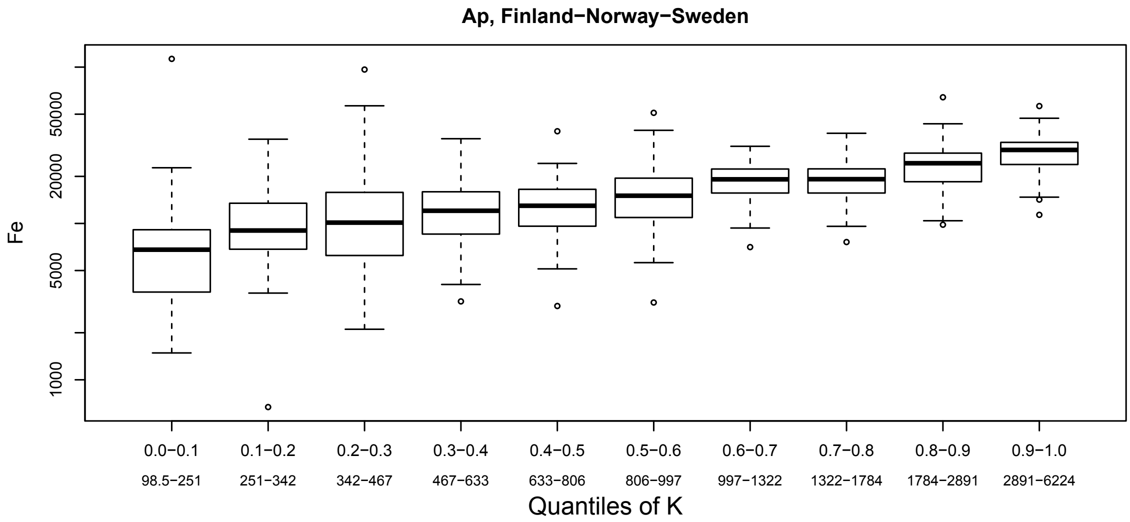
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

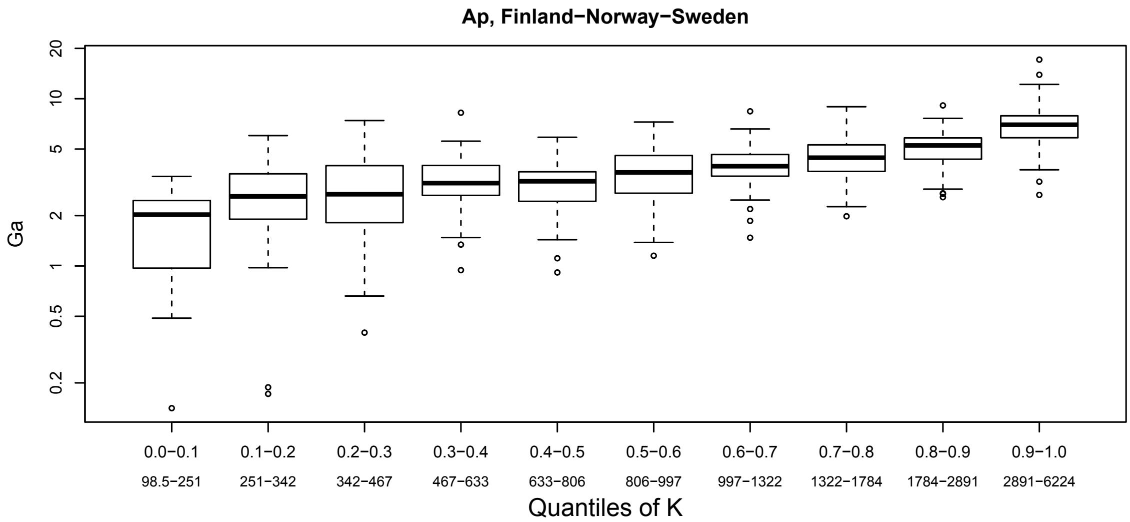


Ap, Finland−Norway−Sweden
Cs
0.05
0.1
0.2
0.5
1
2
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K



Ap, Finland−Norway−Sweden
Cu
0.5
1
2
5
10
20
50
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Fe
1000
5000
20000
50000
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Ga
0.2
0.5
1
2
5
10
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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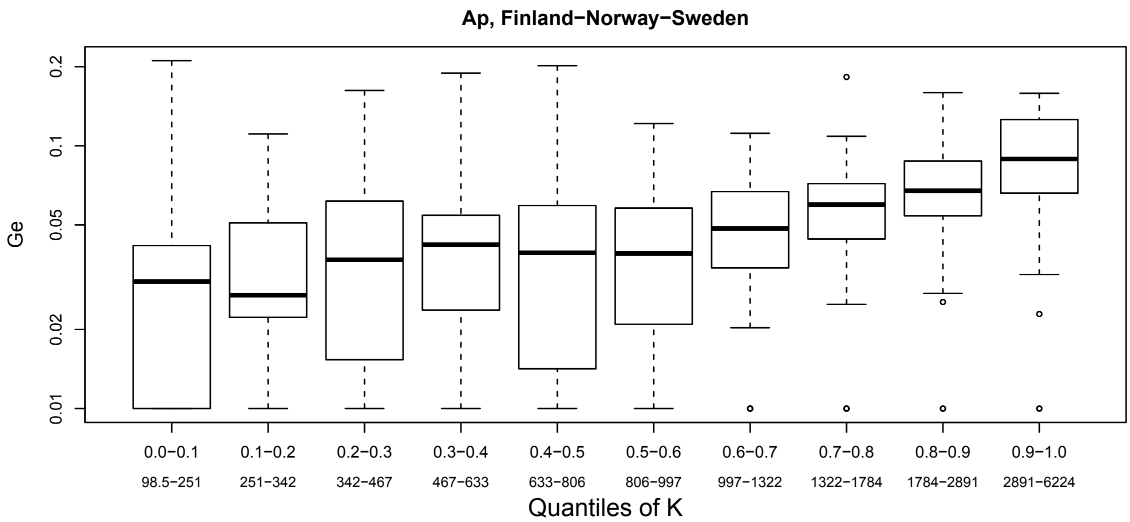
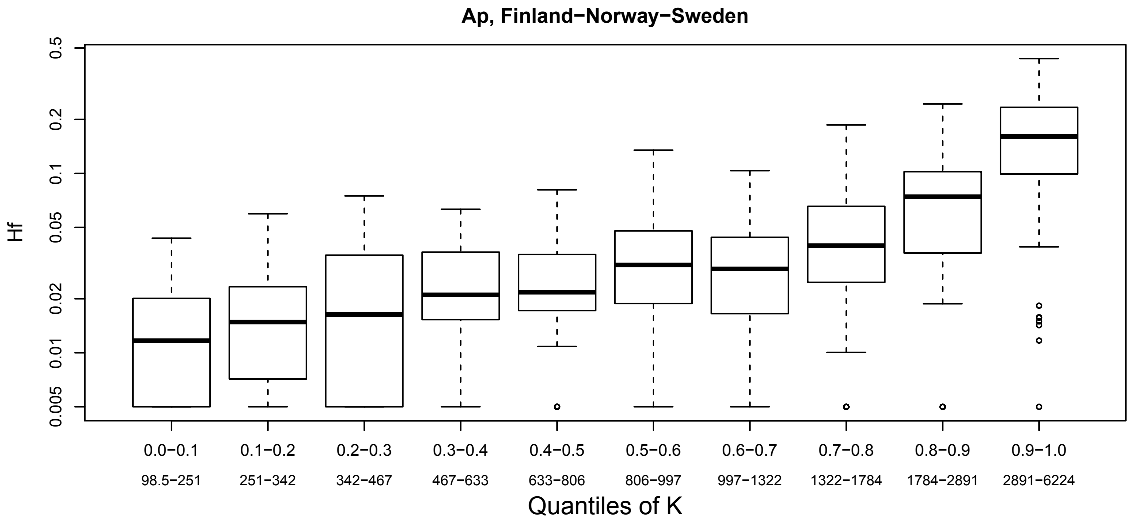
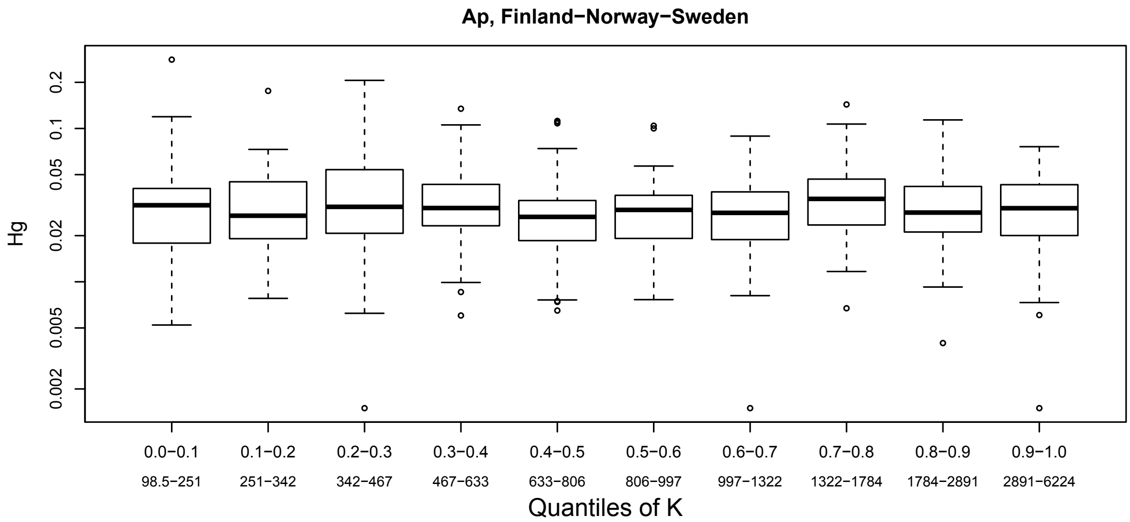
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Ge
0.01
0.02
0.05
0.1
0.2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Hf
0.005
0.01
0.02
0.05
0.1
0.2
0.5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Hg
0.002
0.005
0.02
0.05
0.1
0.2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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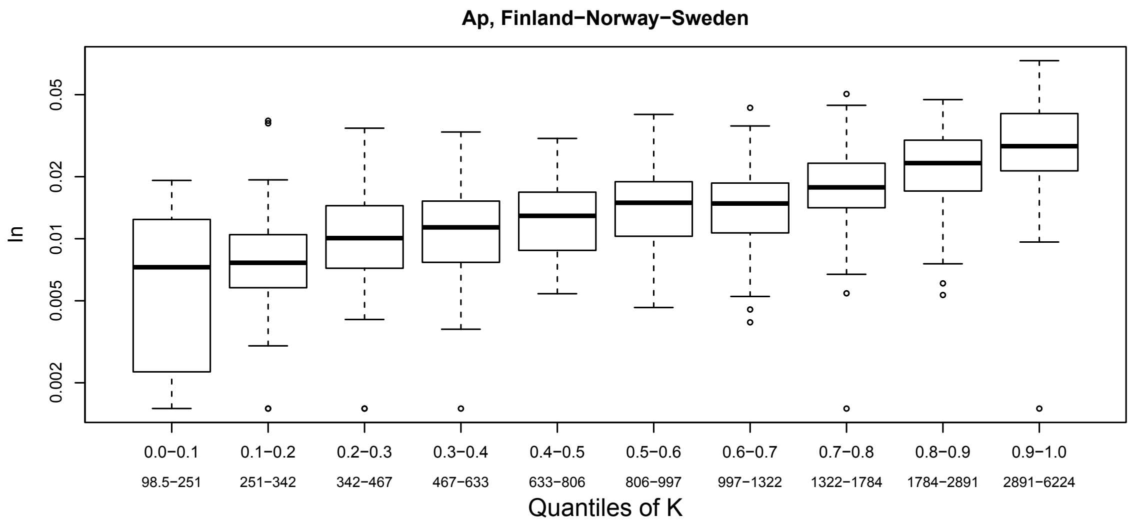
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
In
0.002
0.005
0.01
0.02
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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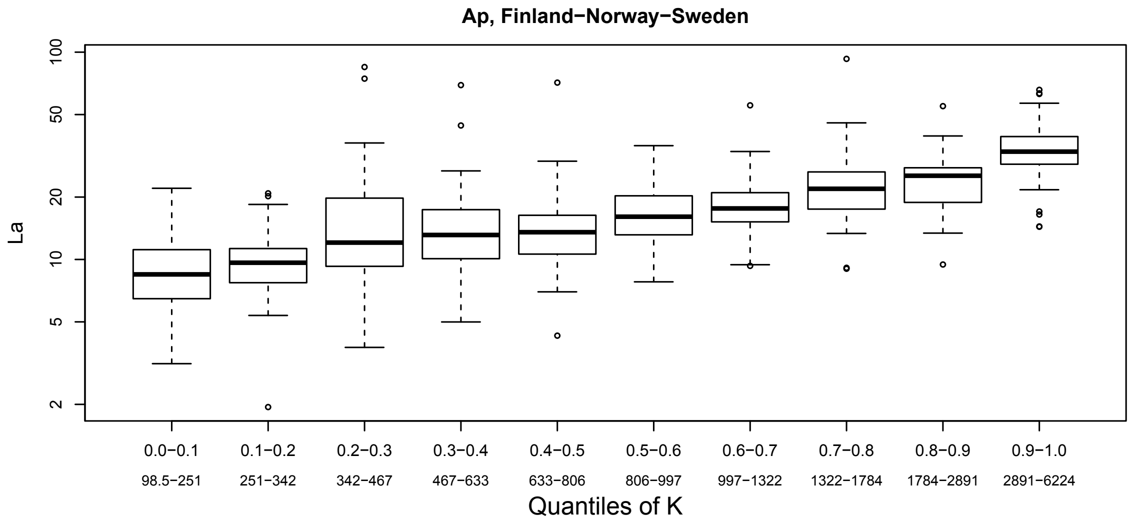
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
La
100
50
20
10
5
2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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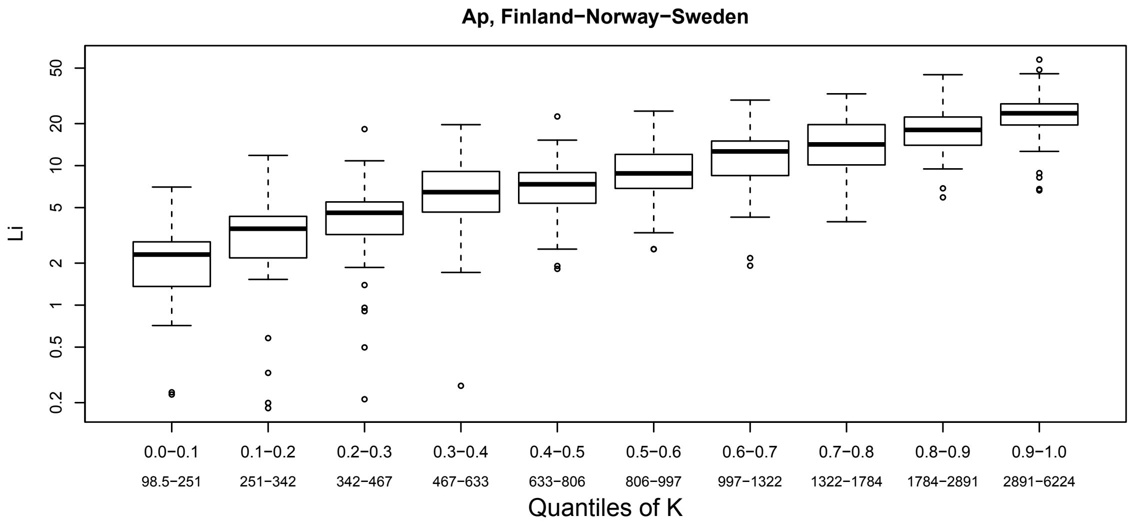
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Li
50
20
10
5
2
1
0.5
0.2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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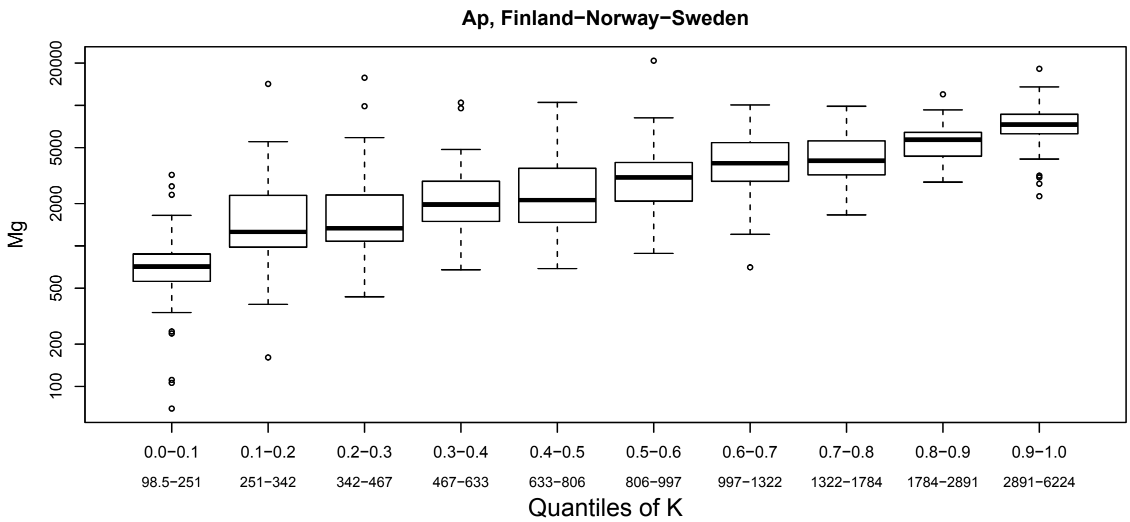
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Mg
20000
5000
2000
500
200
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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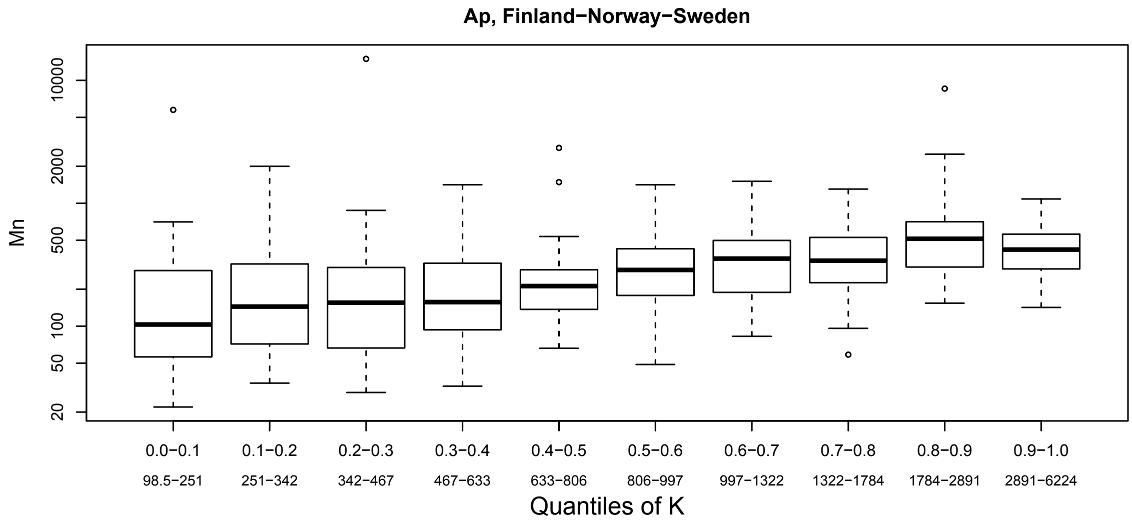
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Mn
10000
2000
500
100
50
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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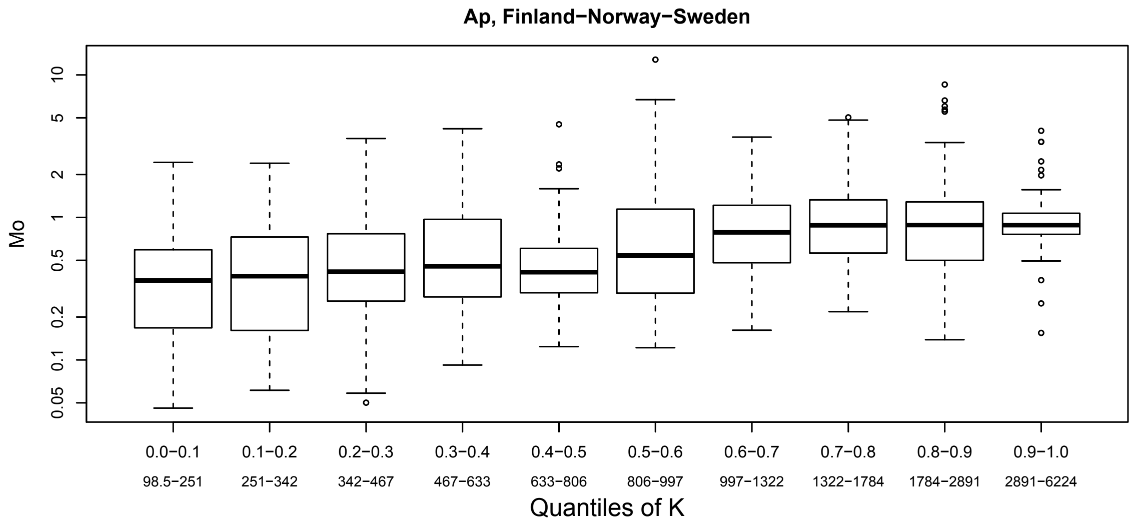
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Mo
10
5
2
1
0.5
0.2
0.1
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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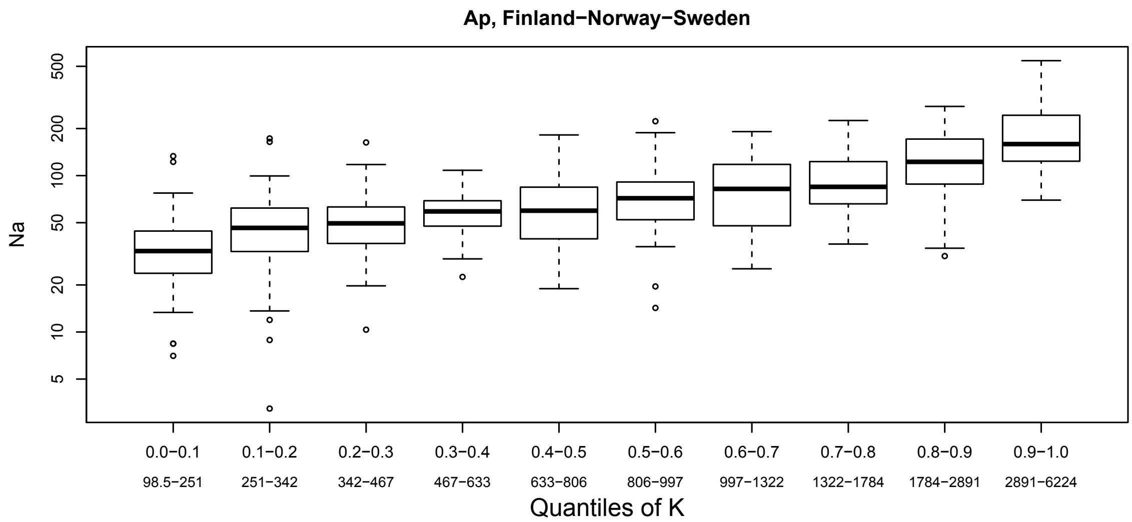
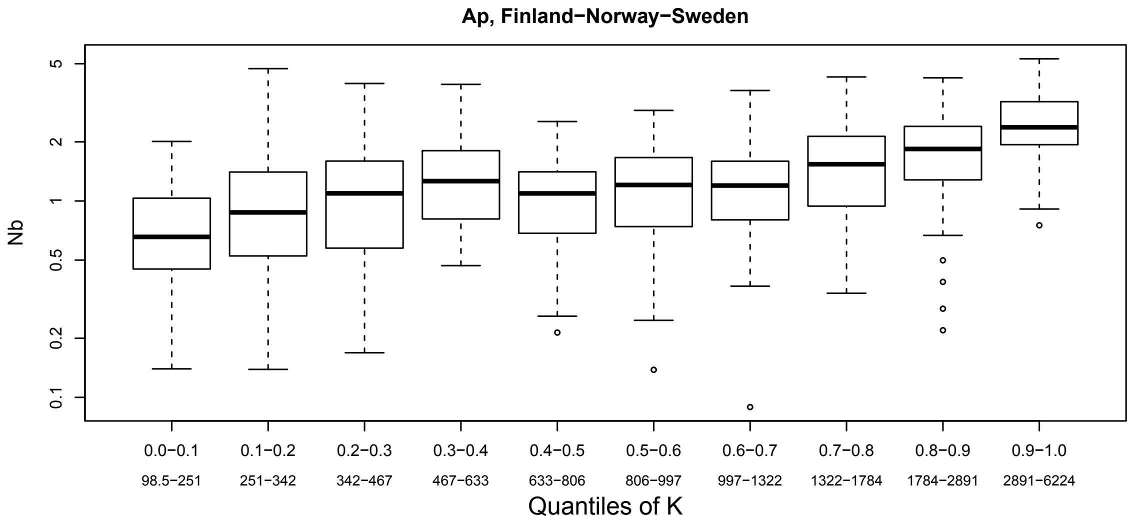
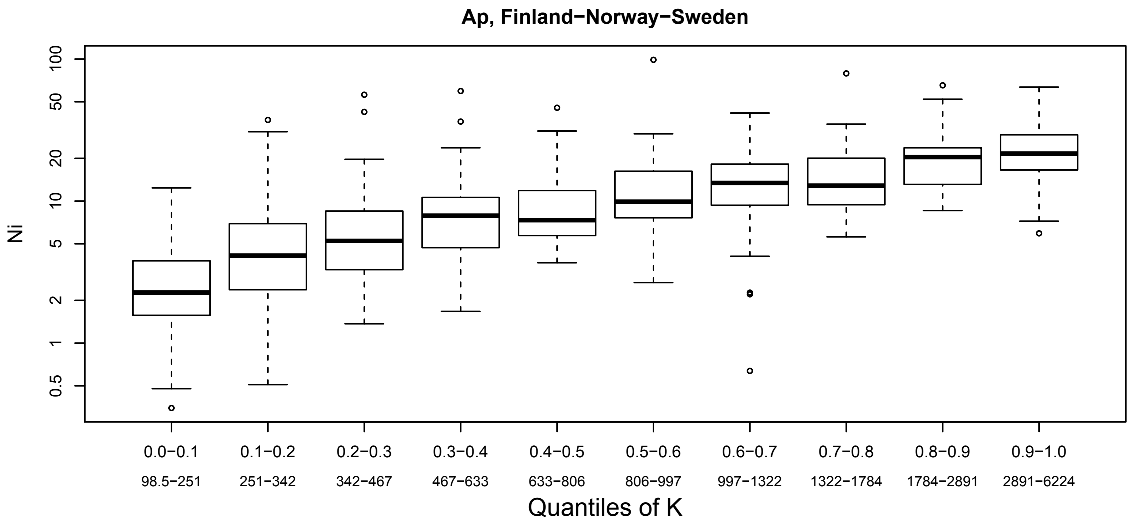
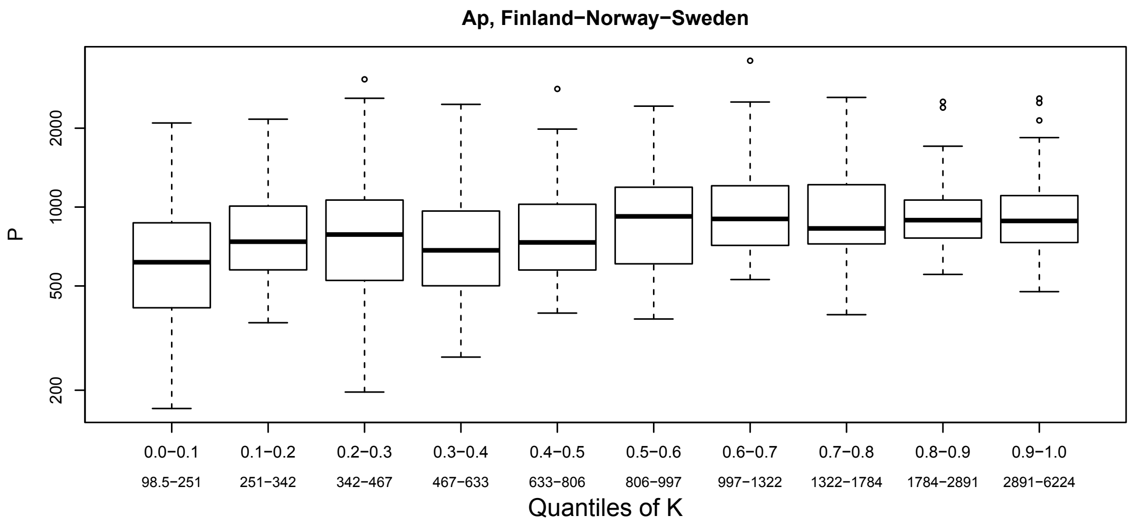
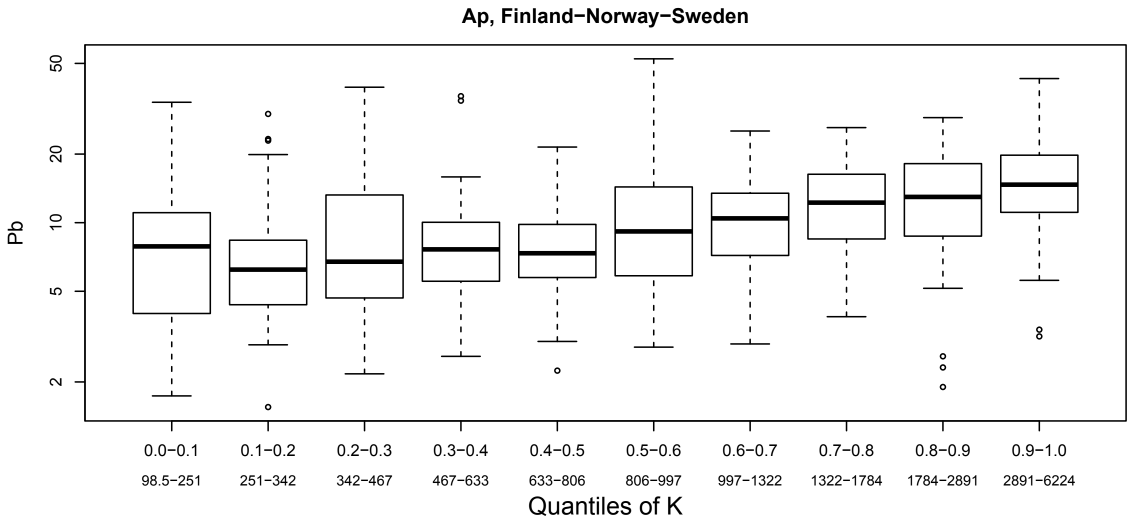
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

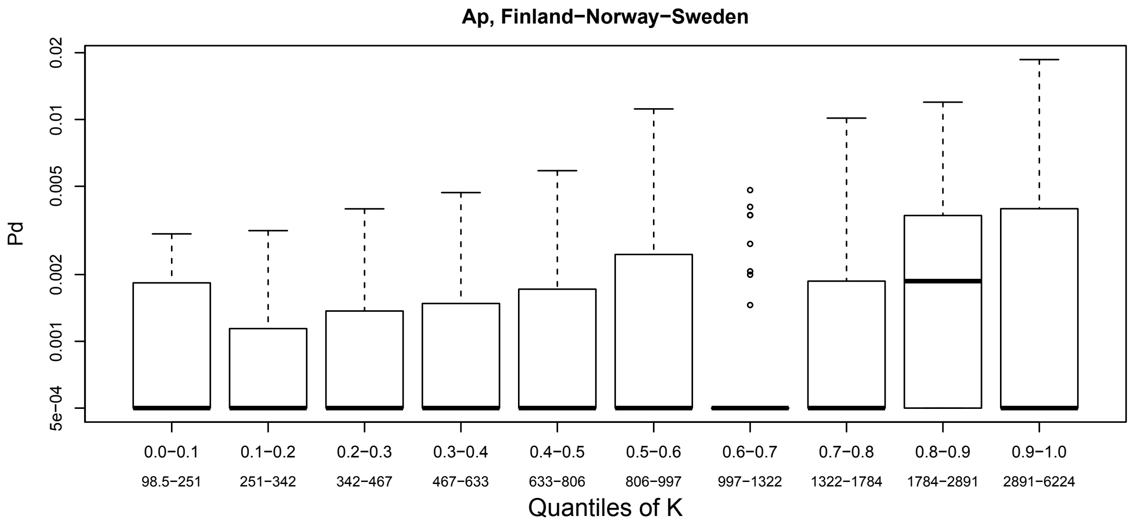

Ap, Finland−Norway−Sweden
Na
500
200
100
50
20
10
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

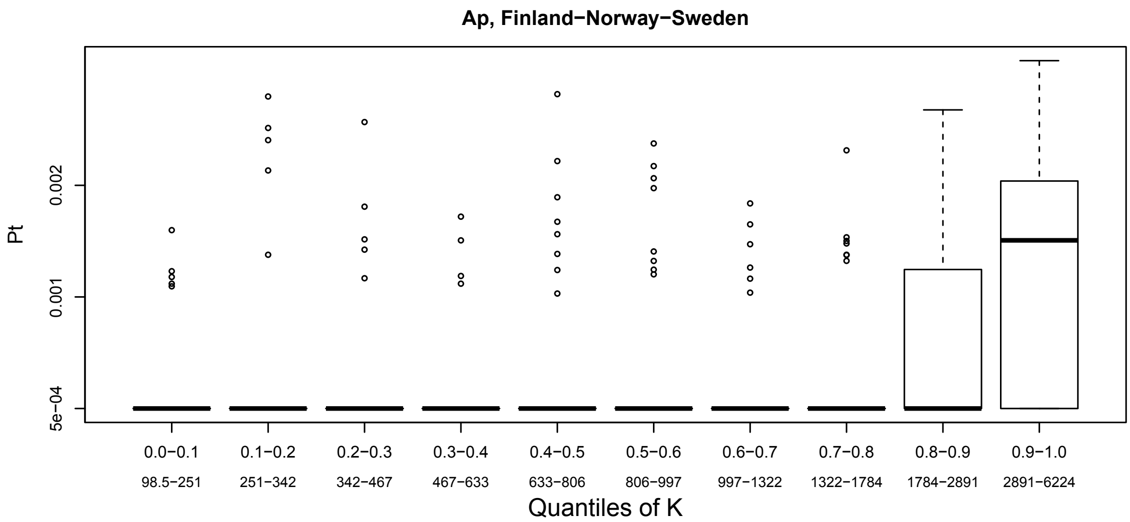

Ap, Finland−Norway−Sweden
Nb
0.1
0.2
0.5
1
2
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

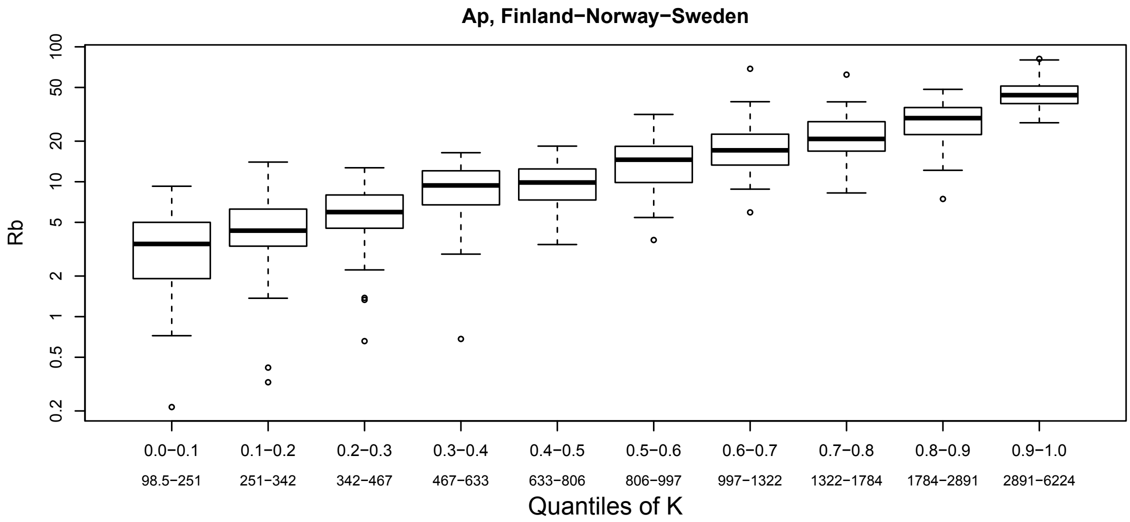

Ap, Finland−Norway−Sweden
Ni
0.5
1
2
5
10
20
50
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

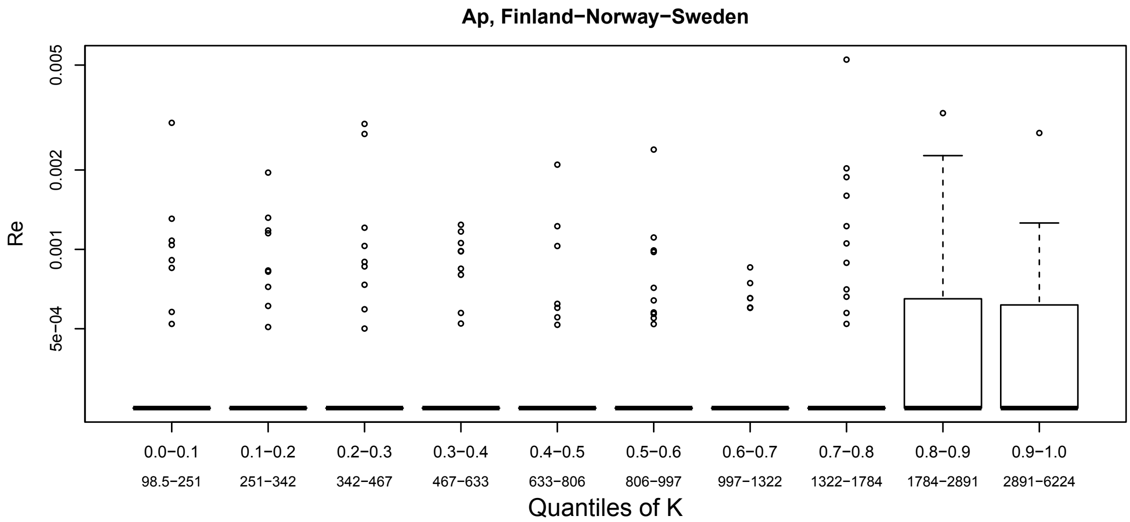

Ap, Finland−Norway−Sweden
P
200
500
1000
2000
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

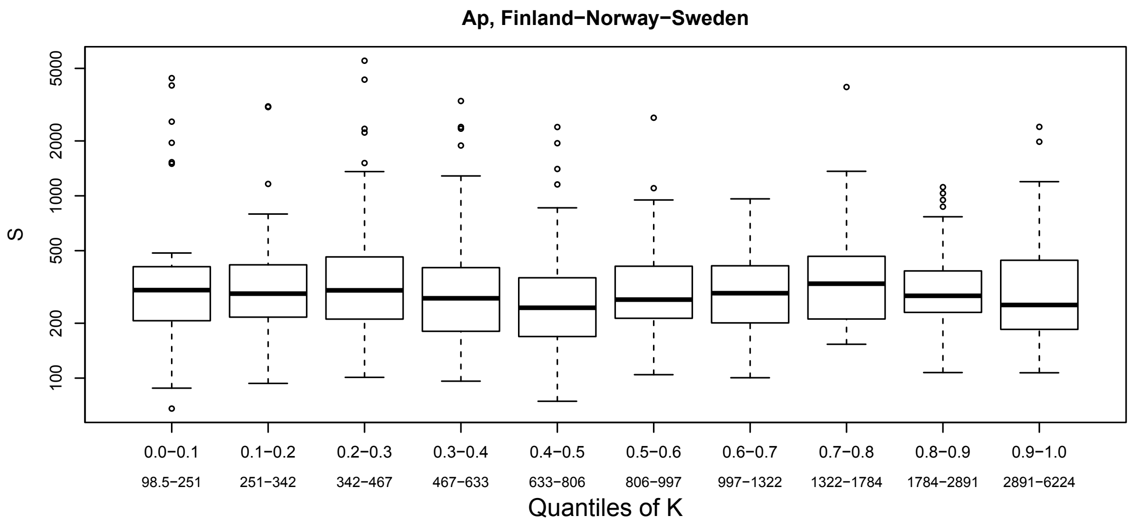

Ap, Finland−Norway−Sweden
Pb
50
20
10
5
2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

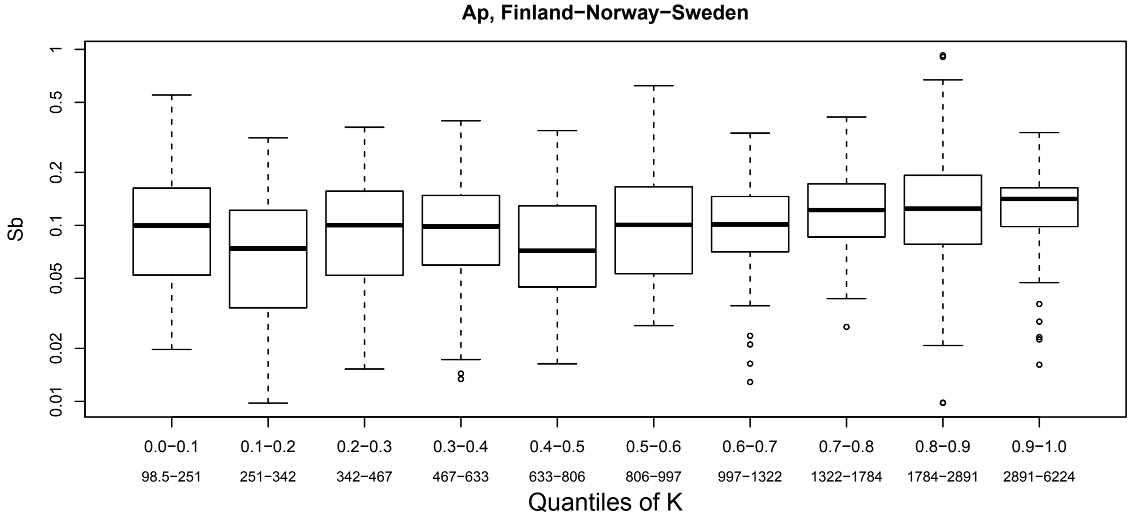

Ap, Finland−Norway−Sweden
Pd
0.02
0.01
0.005
0.002
0.001
5e−04
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Pt
0.002
0.001
5e−04
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Rb
100
50
20
10
5
2
1
0.5
0.2
0.0−0.1 0.1−0.2 0.2−0.3 0.3−0.4 0.4−0.5 0.5−0.6 0.6−0.7 0.7−0.8 0.8−0.9 0.9−1.0
98.5−251 251−342 342−467 467−633 633−806 806−997 997−1322 1322−1784 1784−2891 2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Re
0.005
0.002
0.001
5e−04
0.0−0.1 0.1−0.2 0.2−0.3 0.3−0.4 0.4−0.5 0.5−0.6 0.6−0.7 0.7−0.8 0.8−0.9 0.9−1.0
98.5−251 251−342 342−467 467−633 633−806 806−997 997−1322 1322−1784 1784−2891 2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
S
5000
2000
1000
500
200
100
0.0−0.1 0.1−0.2 0.2−0.3 0.3−0.4 0.4−0.5 0.5−0.6 0.6−0.7 0.7−0.8 0.8−0.9 0.9−1.0
98.5−251 251−342 342−467 467−633 633−806 806−997 997−1322 1322−1784 1784−2891 2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Sb
0.01
0.02
0.05
0.1
0.2
0.5
1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
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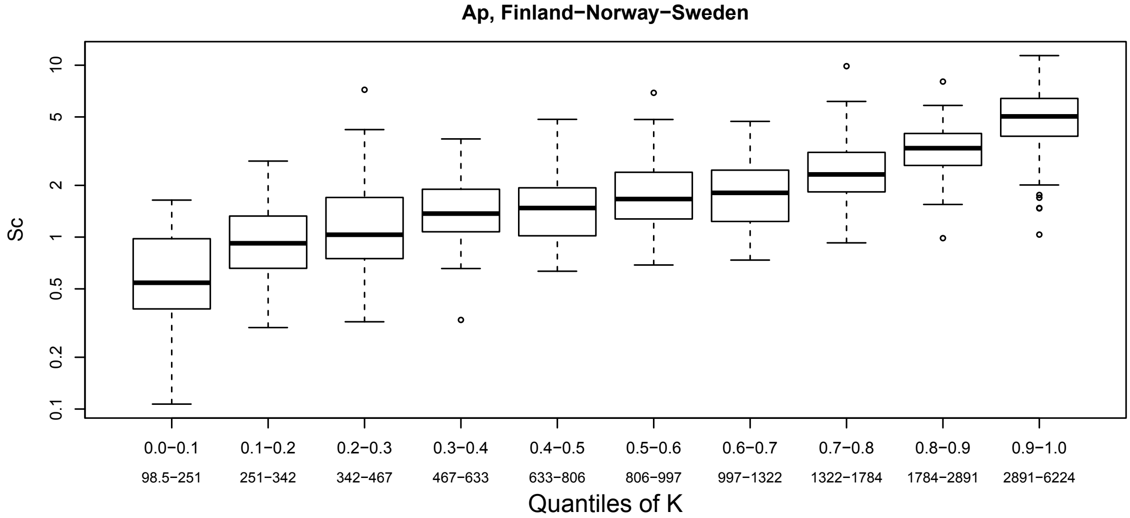
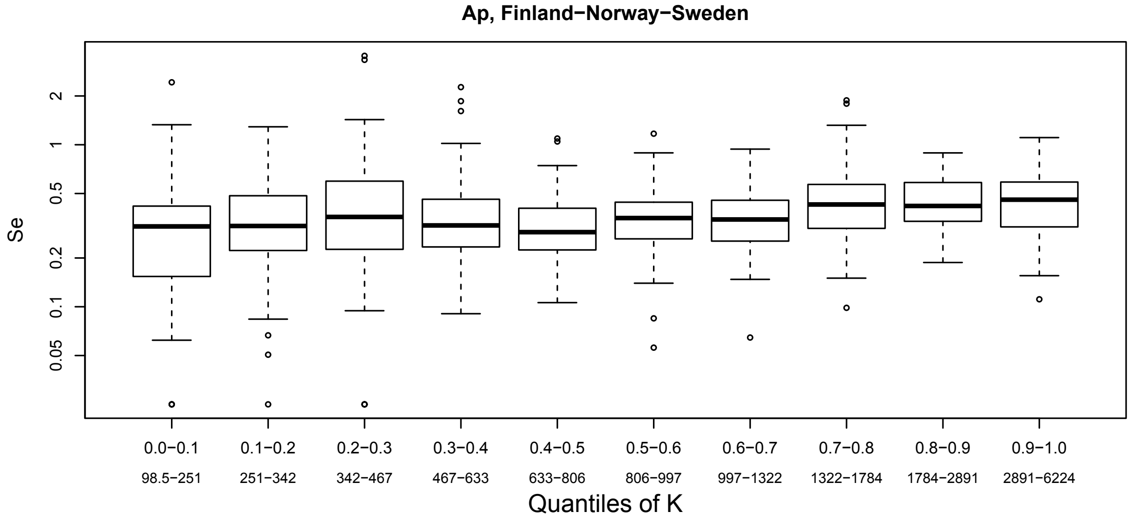
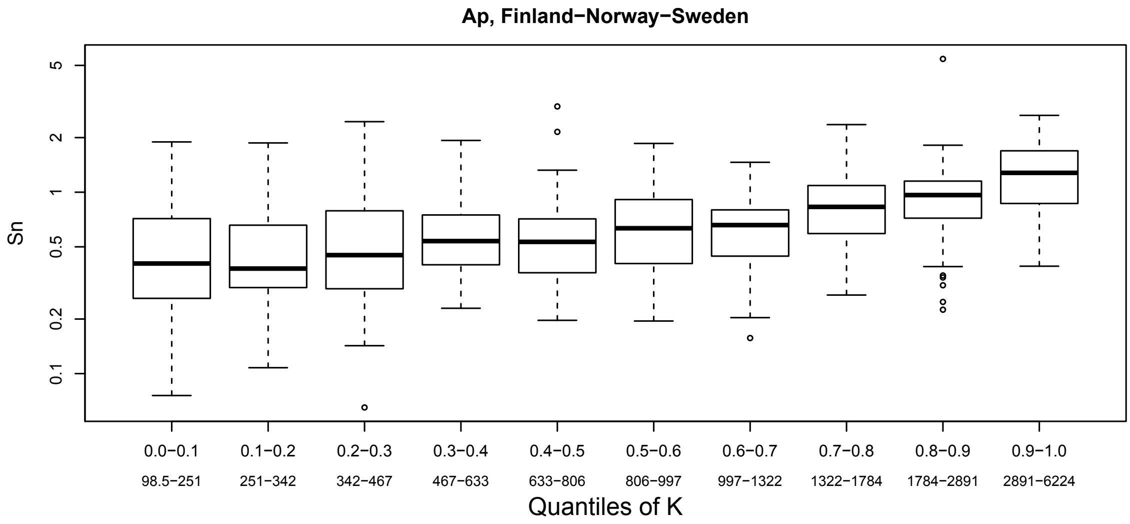
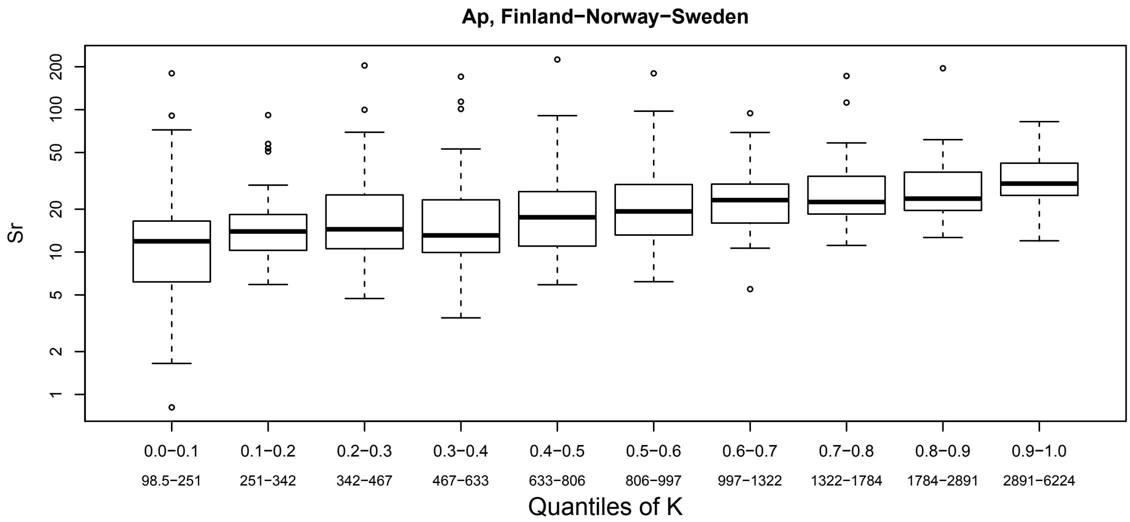
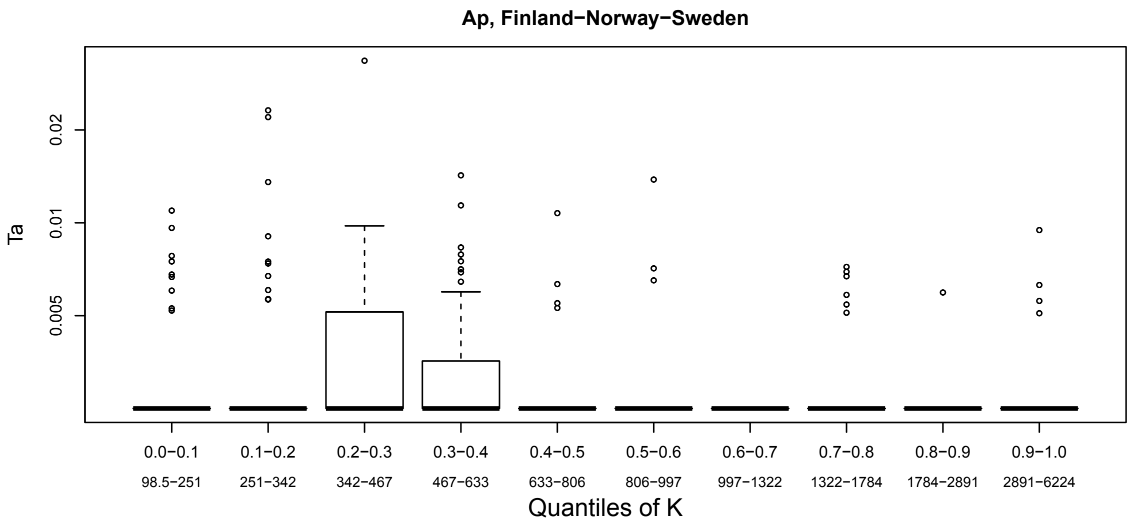
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

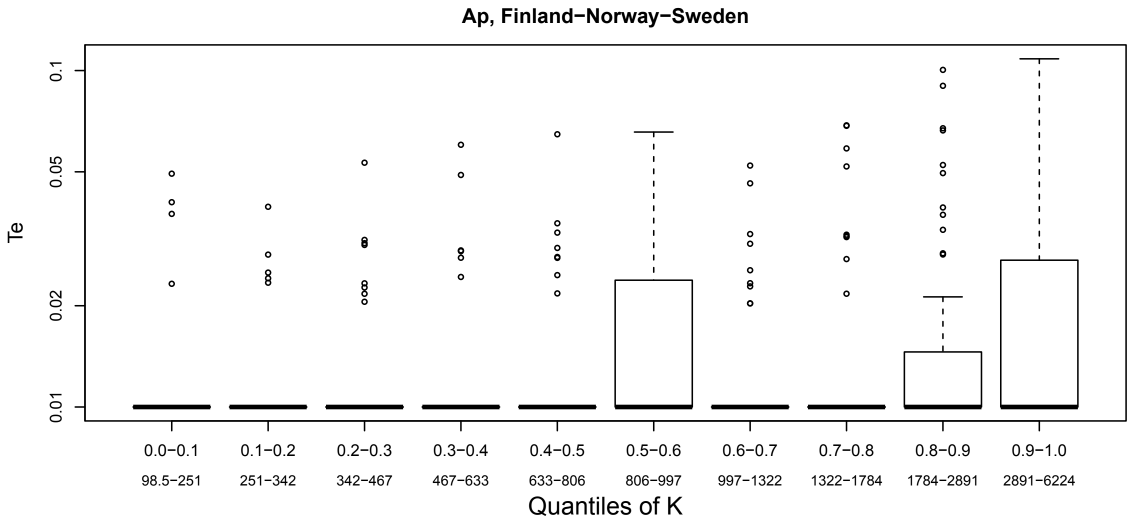

Ap, Finland−Norway−Sweden
Sc
0.1
0.2
0.5
1
2
5
10
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

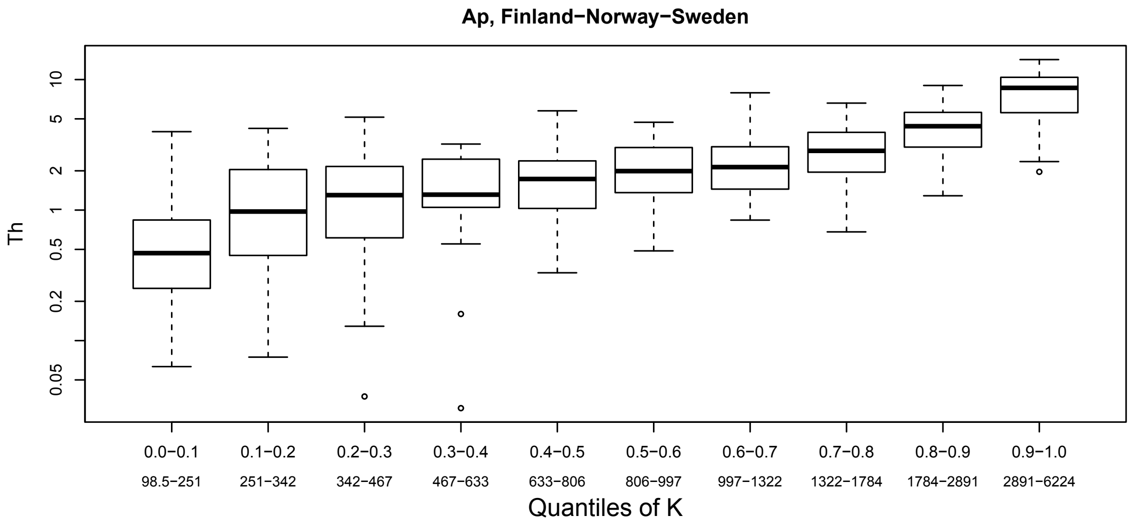

Ap, Finland−Norway−Sweden
Se
0.05
0.1
0.2
0.5
1
2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

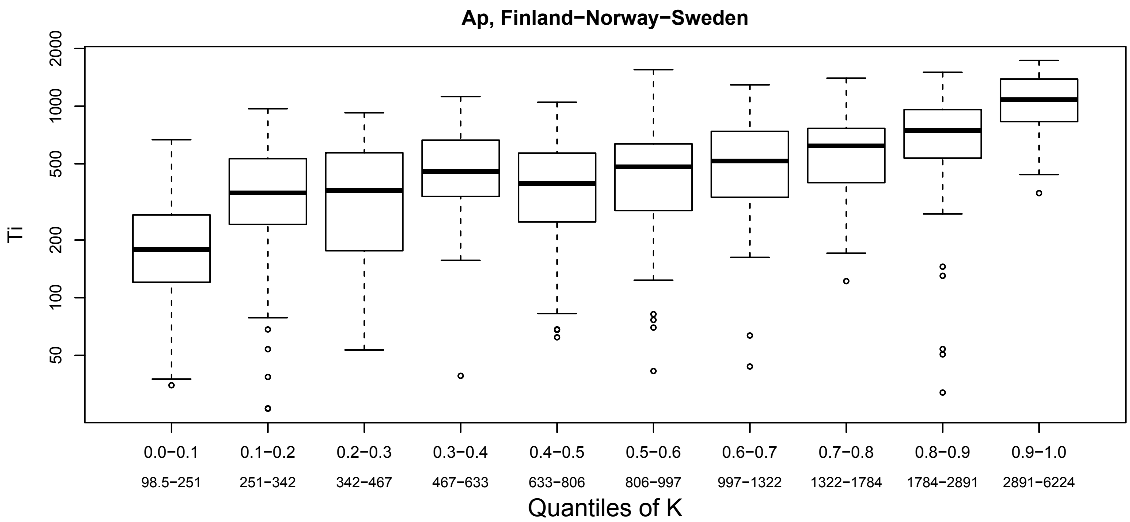

Ap, Finland−Norway−Sweden
Sn
0.1
0.2
0.5
1
2
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

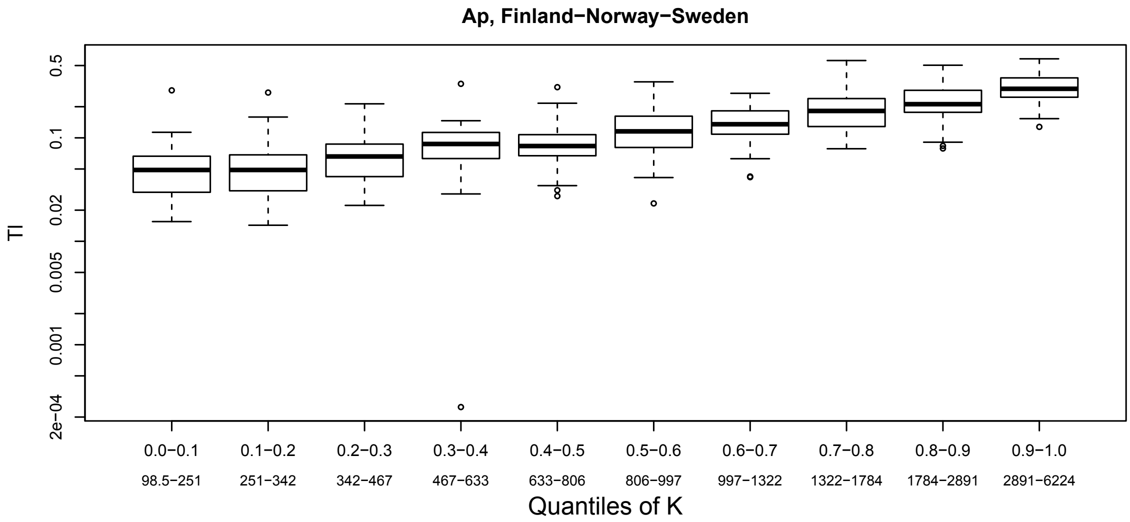

Ap, Finland−Norway−Sweden
Sr
1
2
5
10
20
50
100
200
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

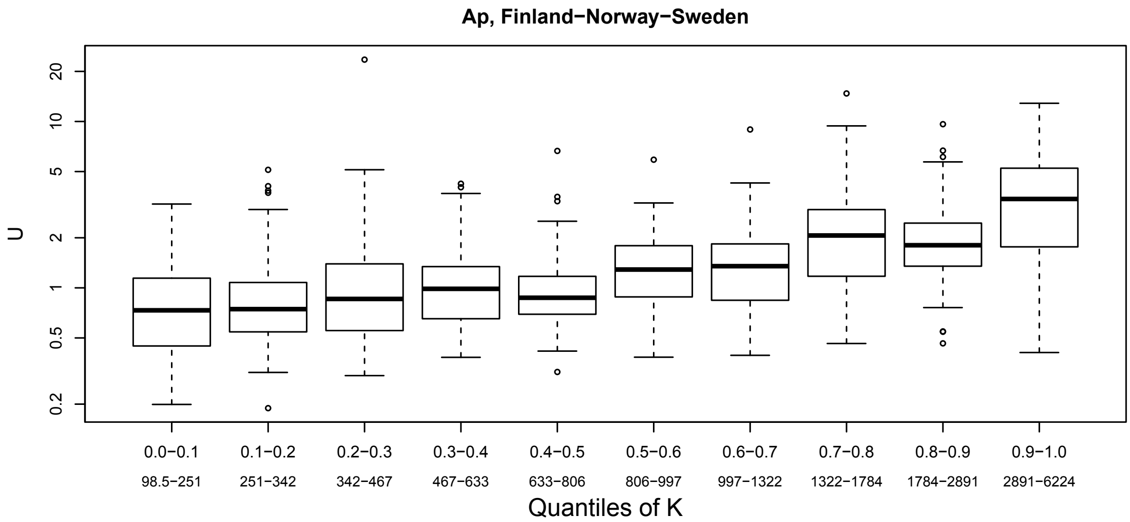

Ap, Finland−Norway−Sweden
Ta
0.005
0.01
0.02
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

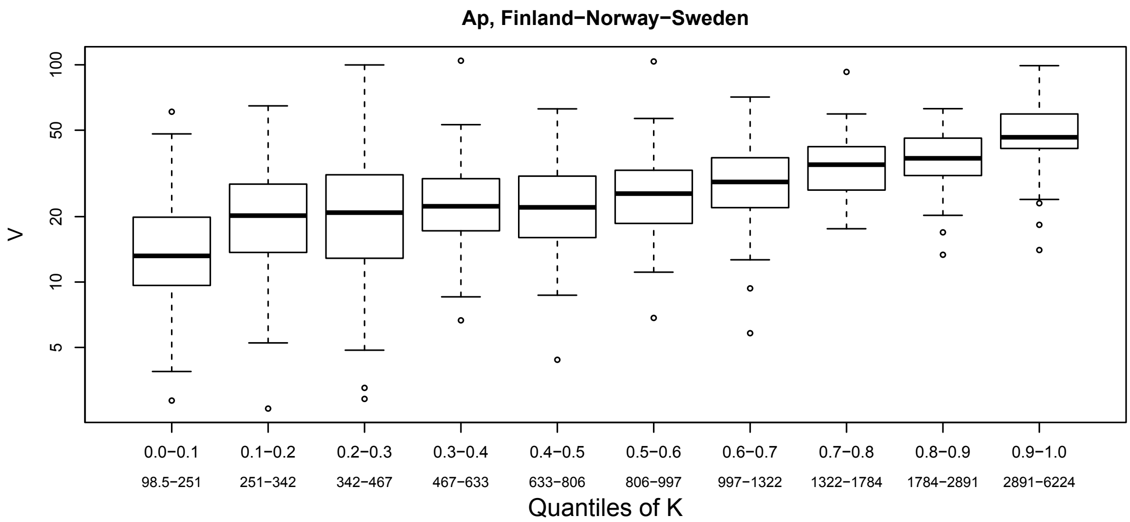

Ap, Finland−Norway−Sweden
Te
0.01
0.02
0.05
0.1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

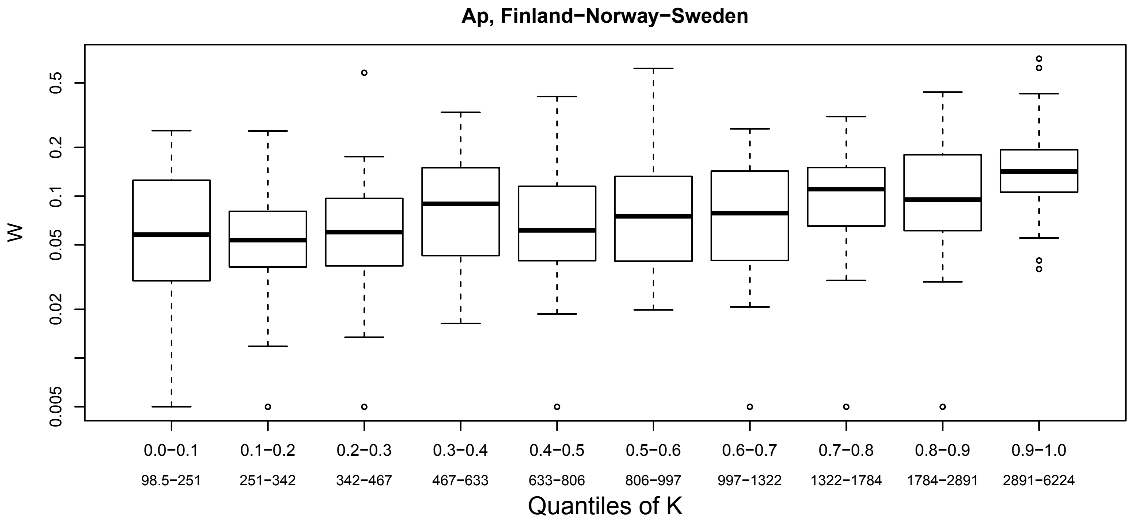

Ap, Finland−Norway−Sweden
Th
0.05
0.2
0.5
1
2
5
10
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

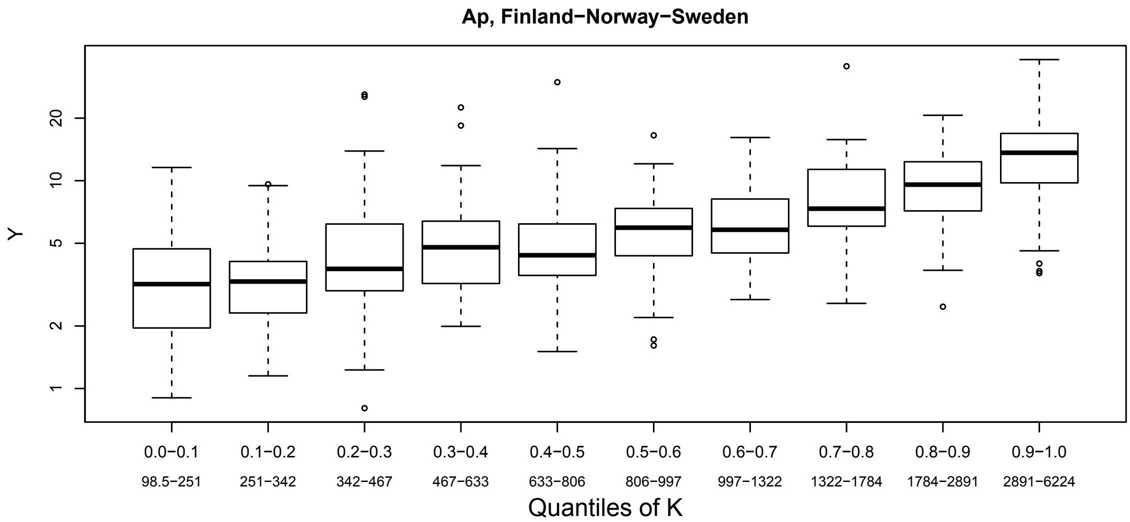

Ap, Finland−Norway−Sweden
Ti
50
100
200
500
1000
2000
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

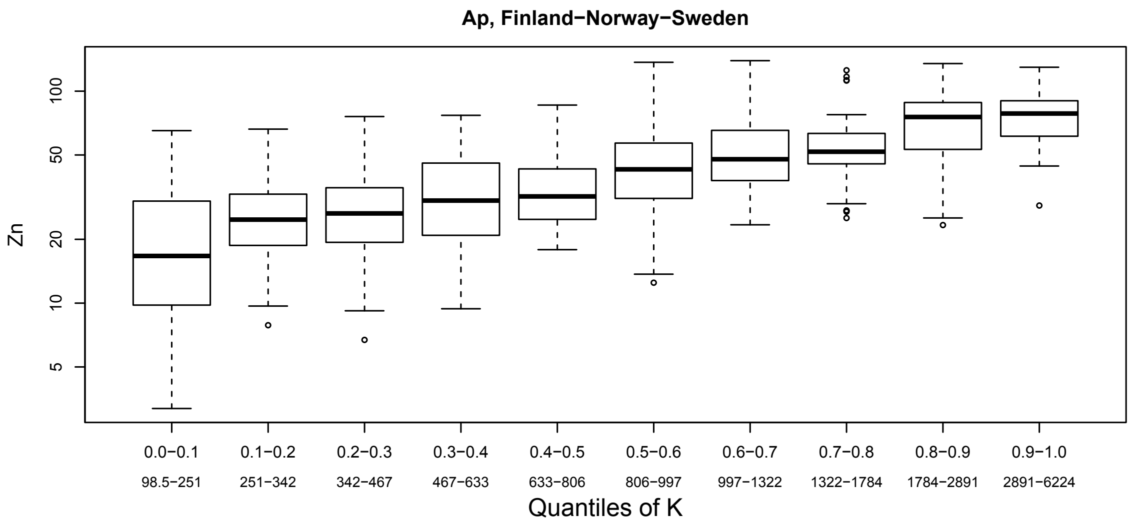

Ap, Finland−Norway−Sweden
TI
0.5
0.1
0.02
0.005
0.001
2e−04
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

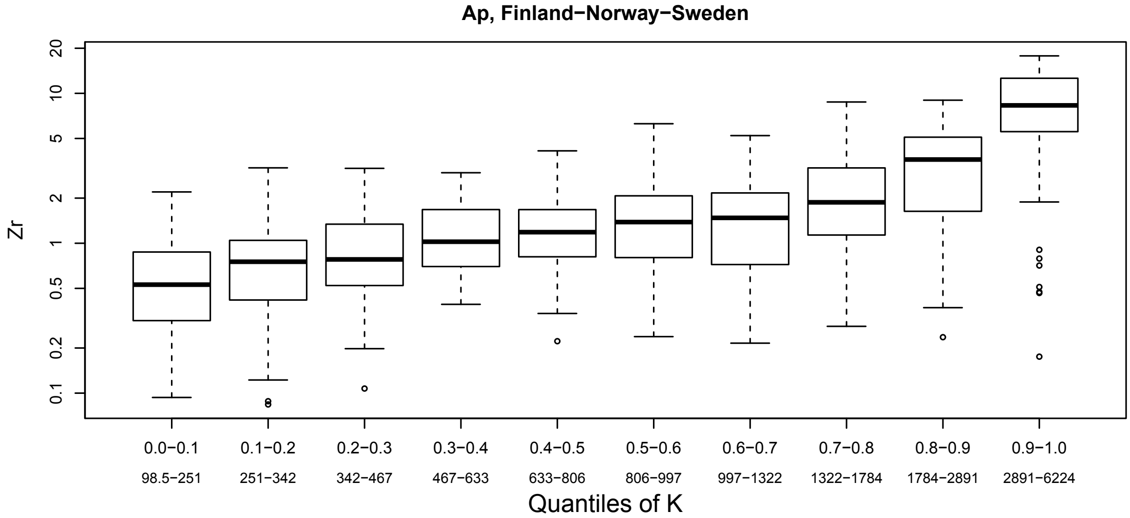

Ap, Finland−Norway−Sweden
U
20
10
5
2
1
0.5
0.2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

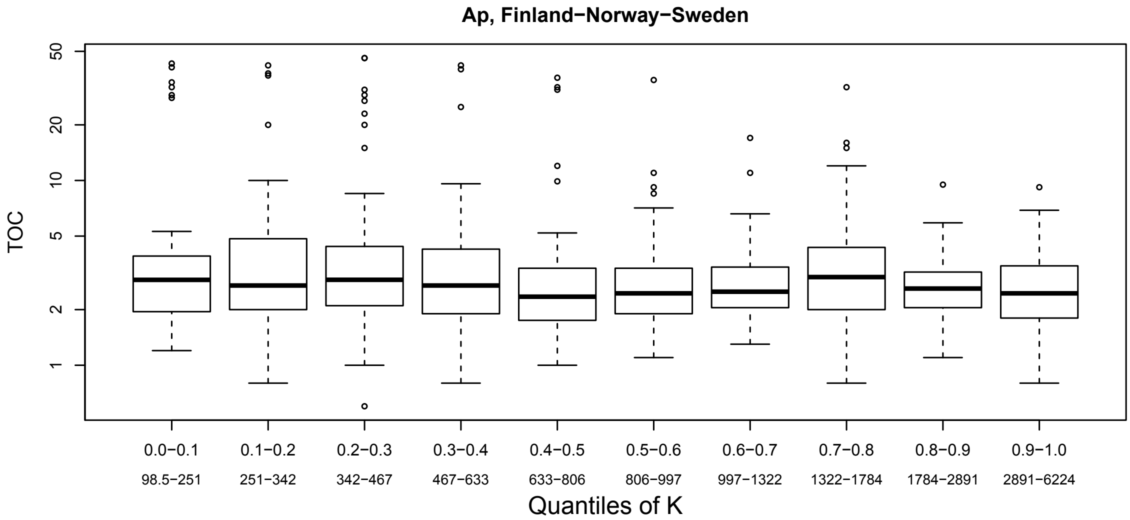

Ap, Finland−Norway−Sweden
V
100
50
20
10
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

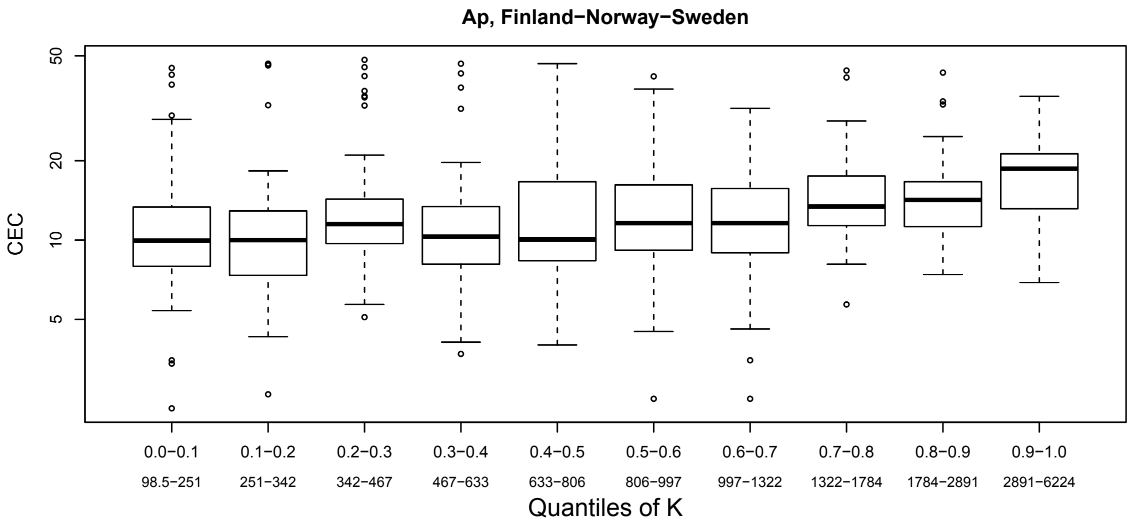

Ap, Finland−Norway−Sweden
W
0.005
0.02
0.05
0.1
0.2
0.5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

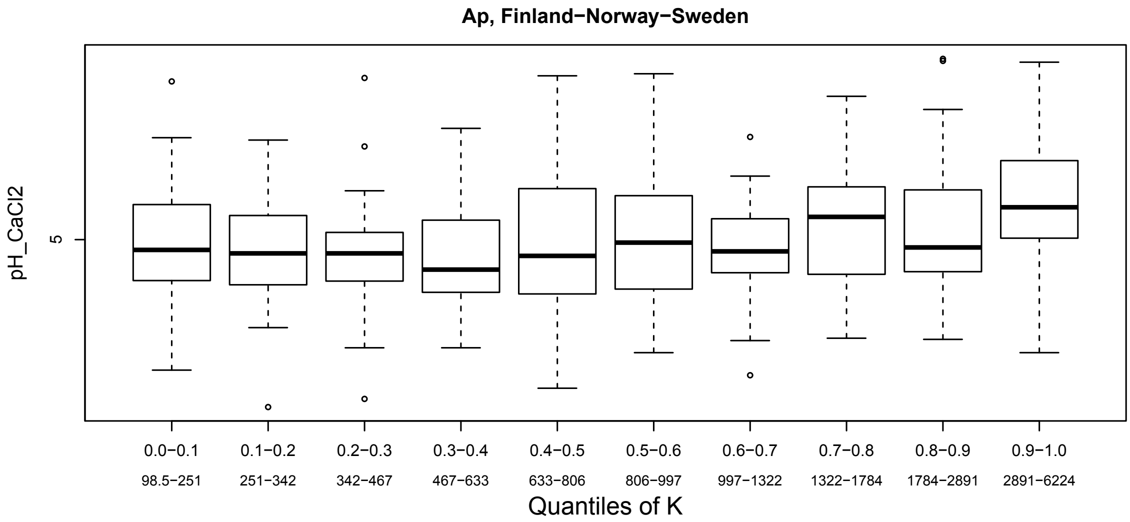

Ap, Finland−Norway−Sweden
Y
1
2
5
10
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Zn
5
10
20
50
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K


Ap, Finland−Norway−Sweden
Zr
0.1
0.2
0.5
1
2
5
10
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

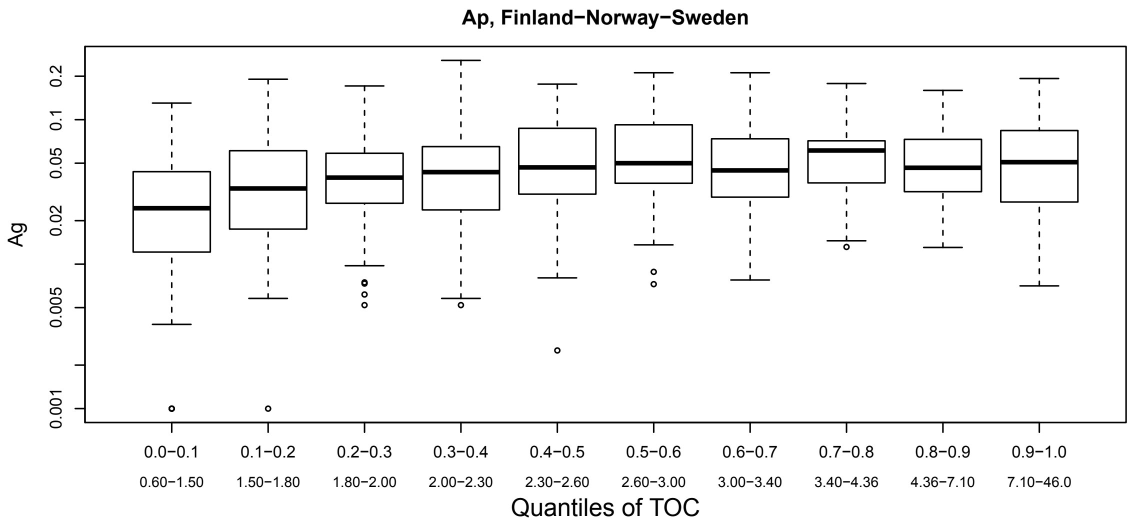

Ap, Finland−Norway−Sweden
TOC
1
2
5
10
20
50
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

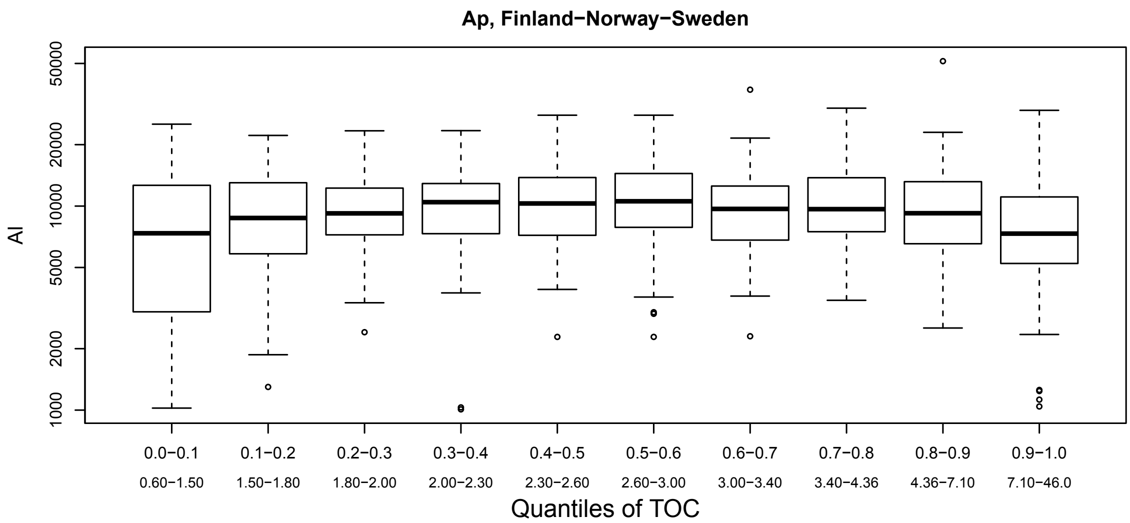

Ap, Finland−Norway−Sweden
CEC
5
10
20
50
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

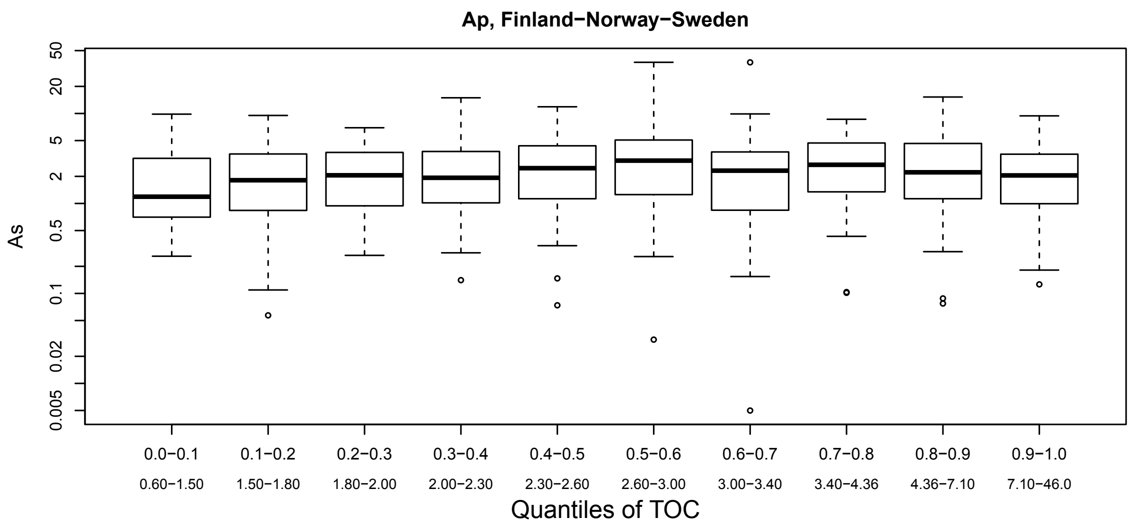

Ap, Finland−Norway−Sweden
pH_CaCl2
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
98.5−251
251−342
342−467
467−633
633−806
806−997
997−1322
1322−1784
1784−2891
2891−6224
Quantiles of K

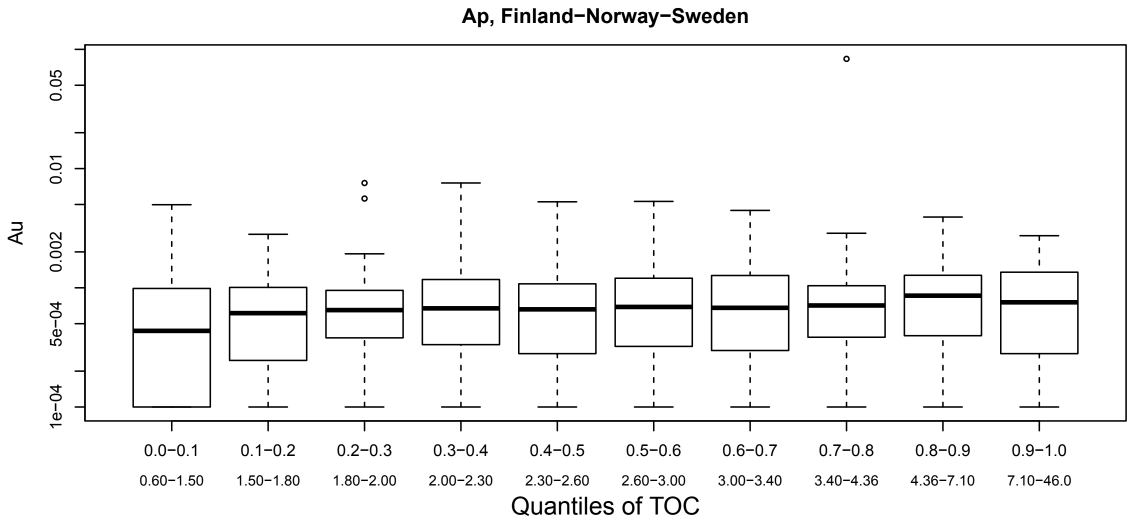
APPENDIX 3

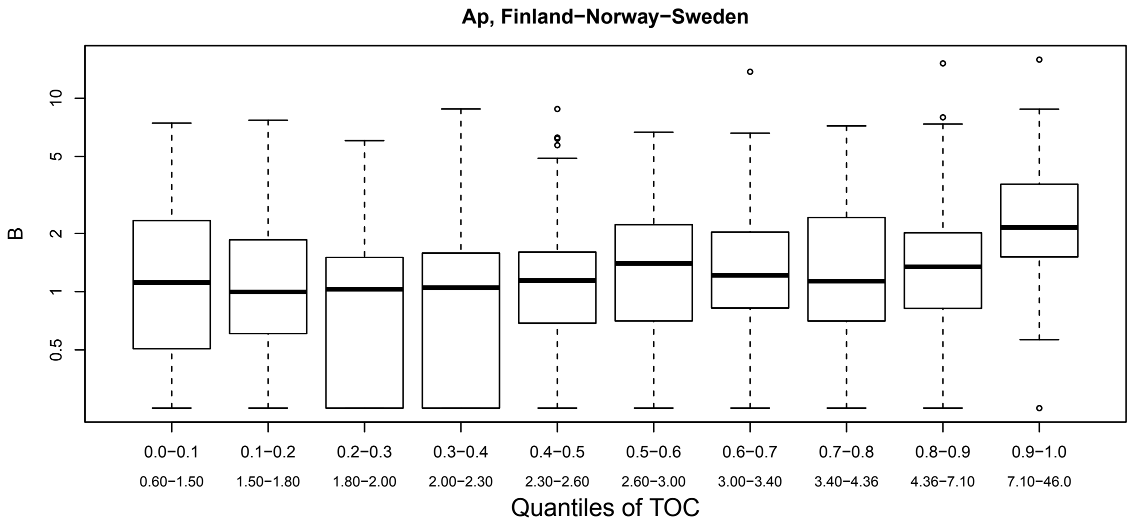
Boxplots for major and trace elements in agricultural soil (Ap) defined by quantiles of TOC
Results from aqua regia extraction.

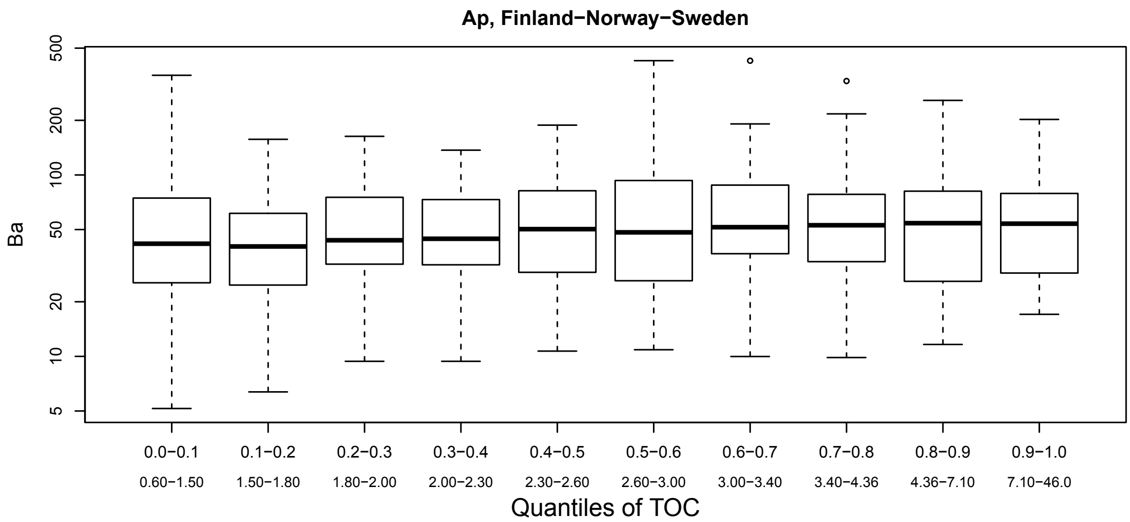


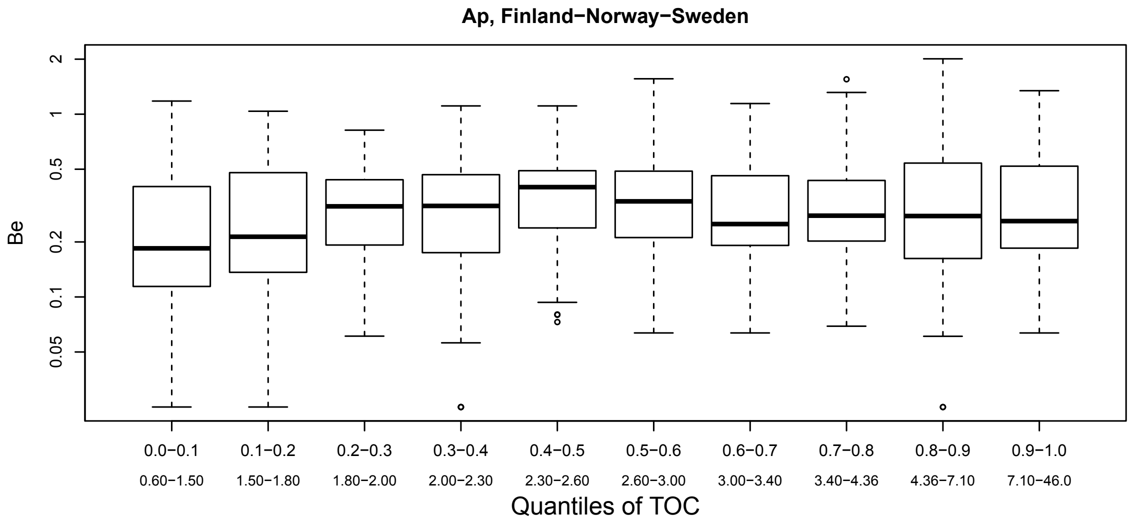


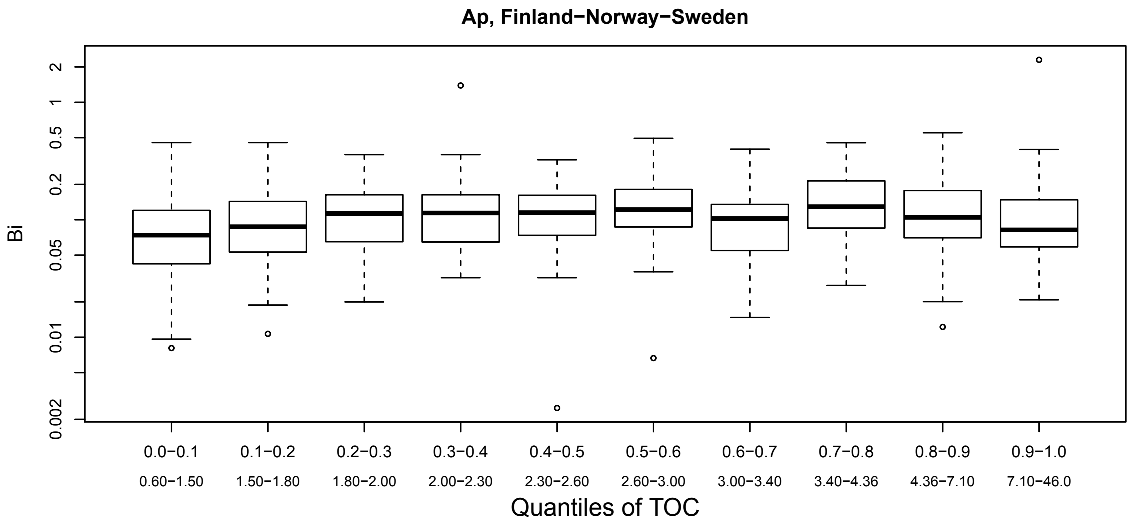


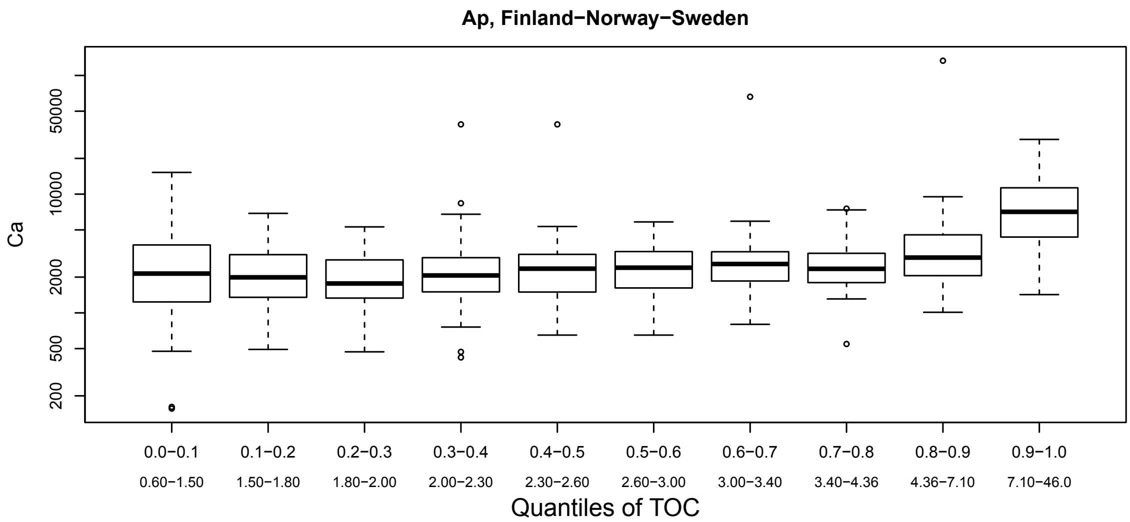

Ap, Finland−Norway−Sweden
Au
1e−04
5e−04
0.002
0.01
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

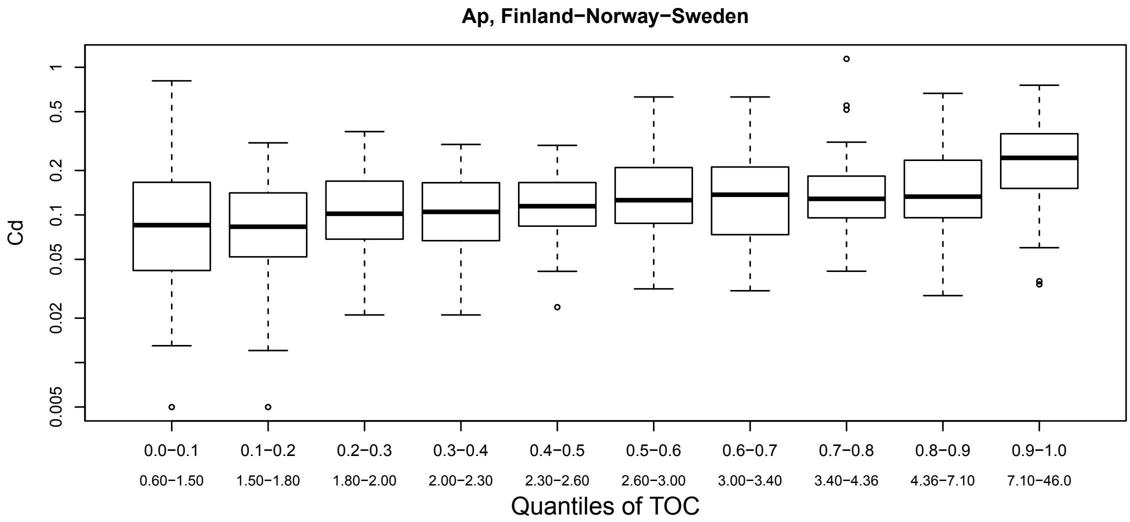

Ap, Finland−Norway−Sweden
B
0.5
1
2
5
10
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

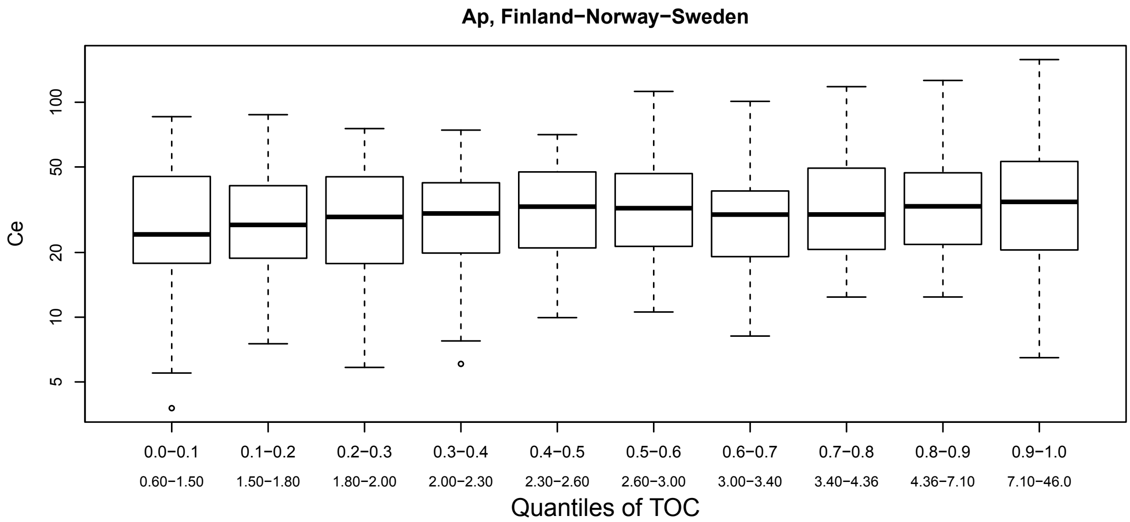

Ap, Finland−Norway−Sweden
Ba
5
10
20
50
100
200
500
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

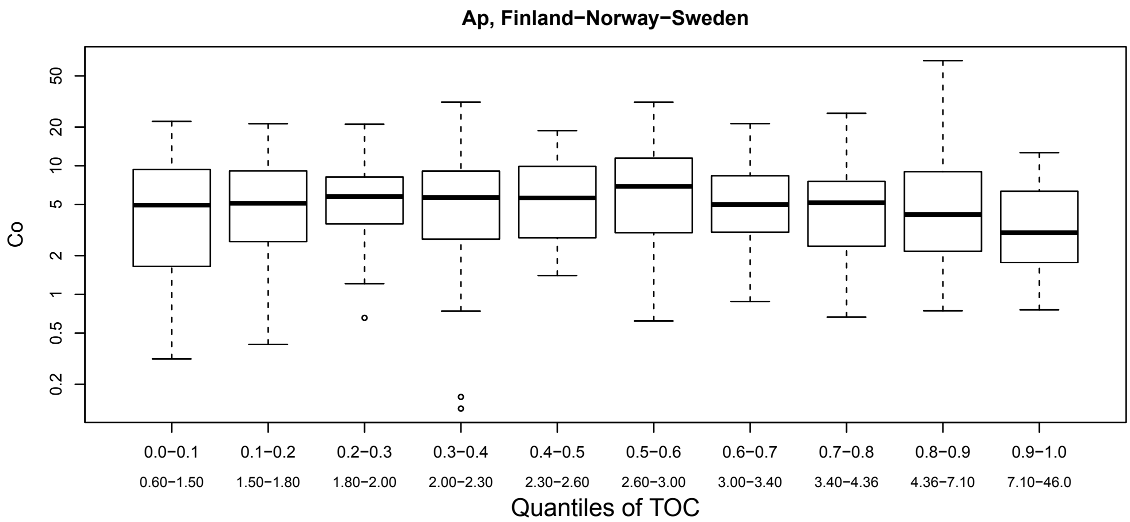

Ap, Finland−Norway−Sweden
Be
0.05
0.1
0.2
0.5
1
2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Bi
0.002
0.01
0.05
0.2
0.5
1
2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Ca
200
500
2000
10000
50000
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Cd
0.005
0.02
0.05
0.1
0.2
0.5
1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Ce
5
10
20
50
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Co
0.2
0.5
1
2
5
10
20
50
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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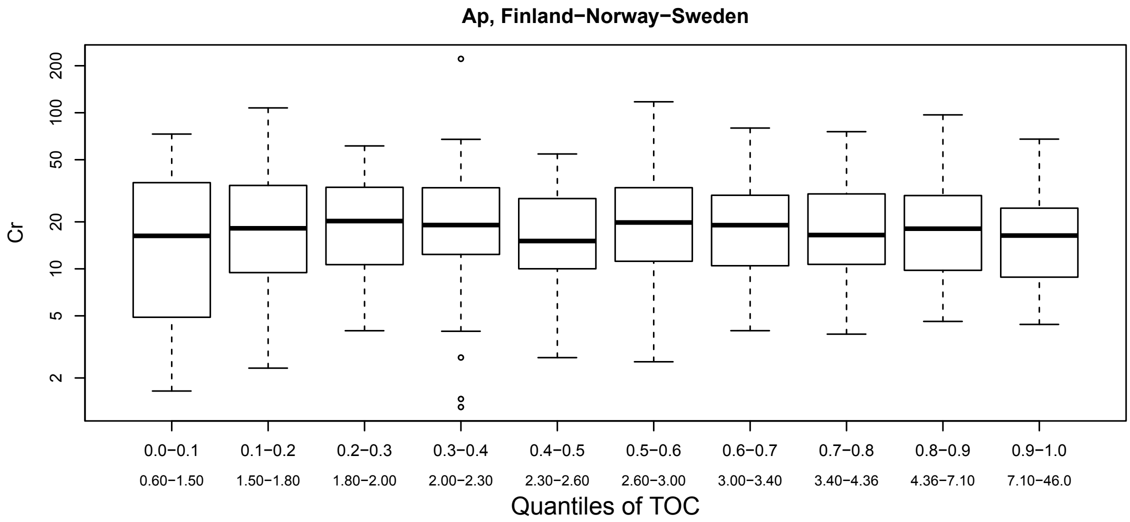
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Cr
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5
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100
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0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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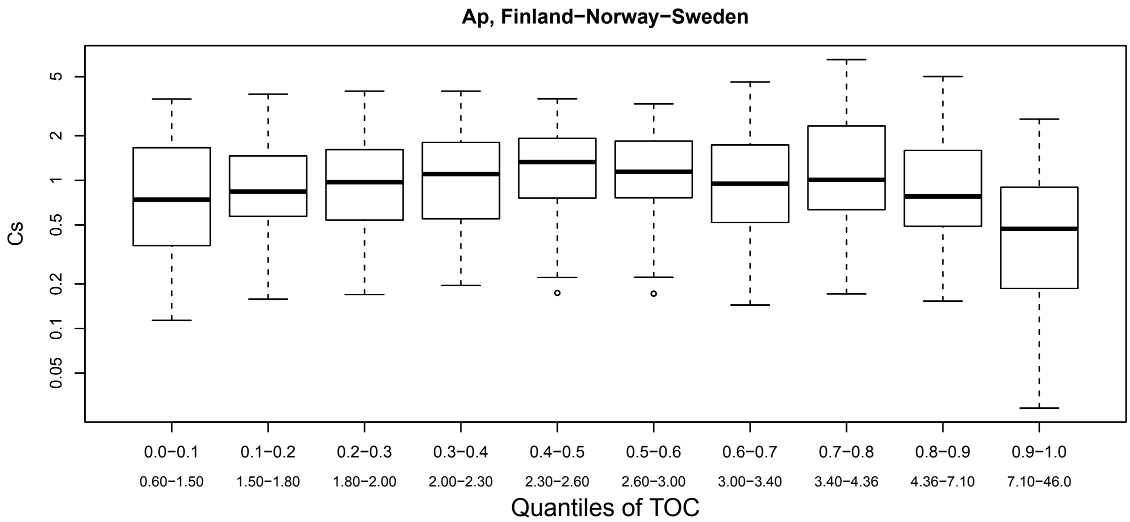
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Cs
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0.2
0.5
1
2
5
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0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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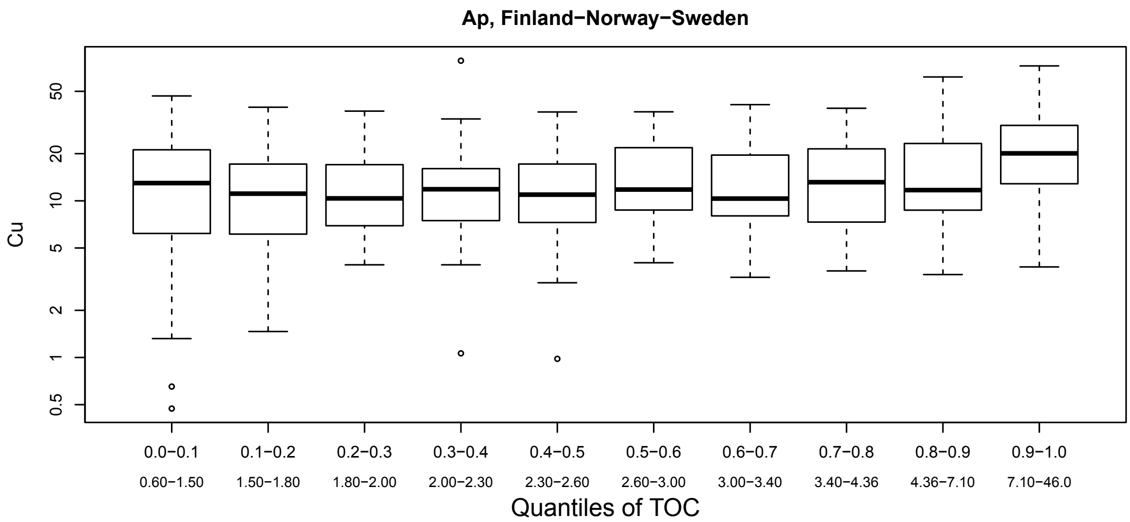
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Cu
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1
2
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10
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0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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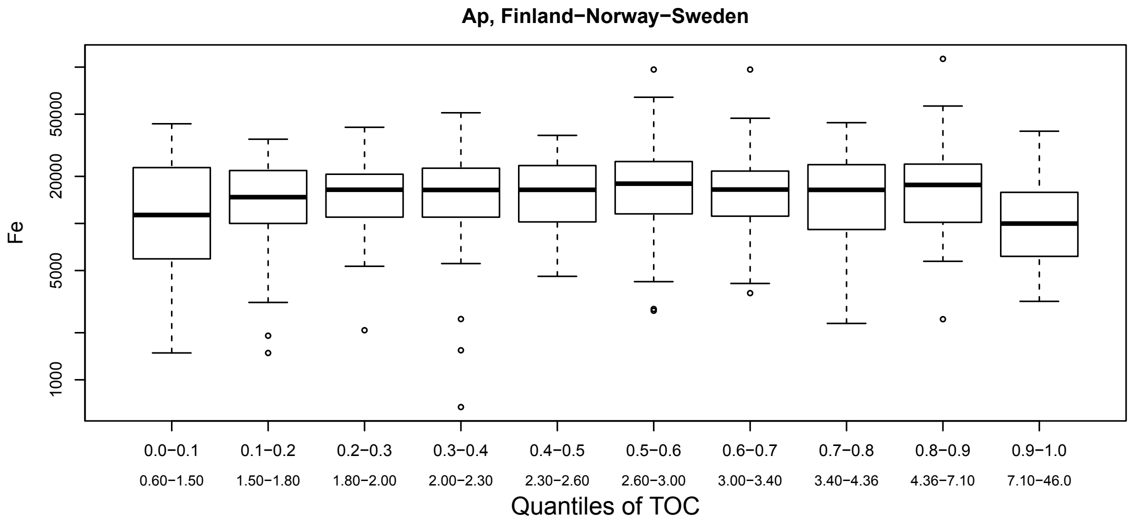
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Fe
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5000
20000
50000
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0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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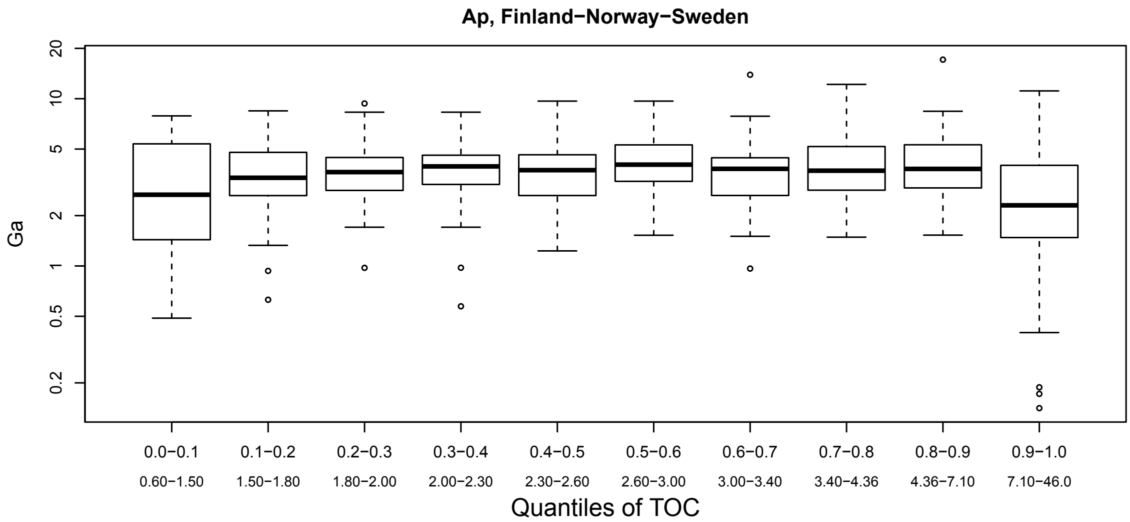
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Ga
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0.5
1
2
5
10
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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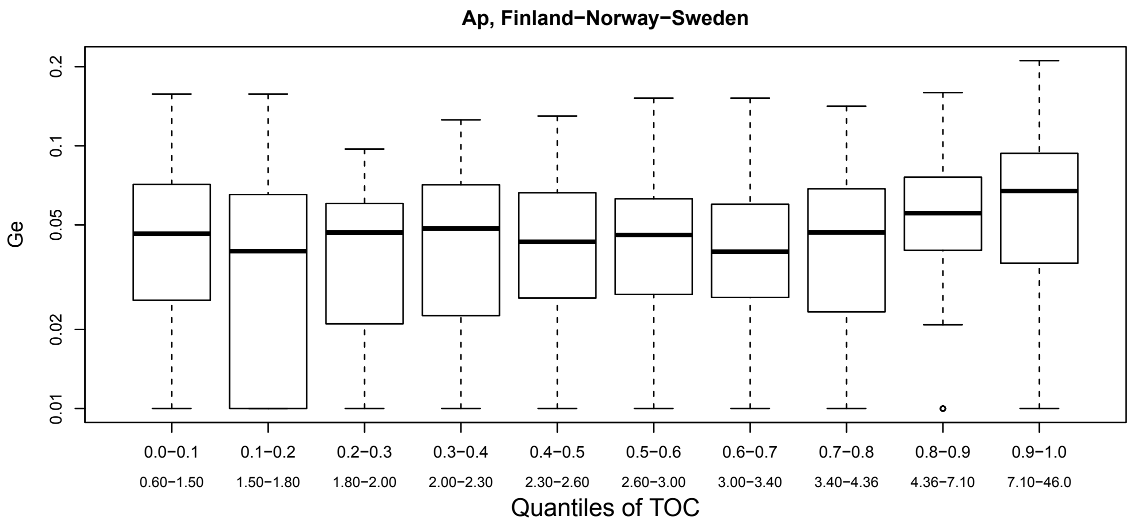
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Ge
0.01
0.02
0.05
0.1
0.2
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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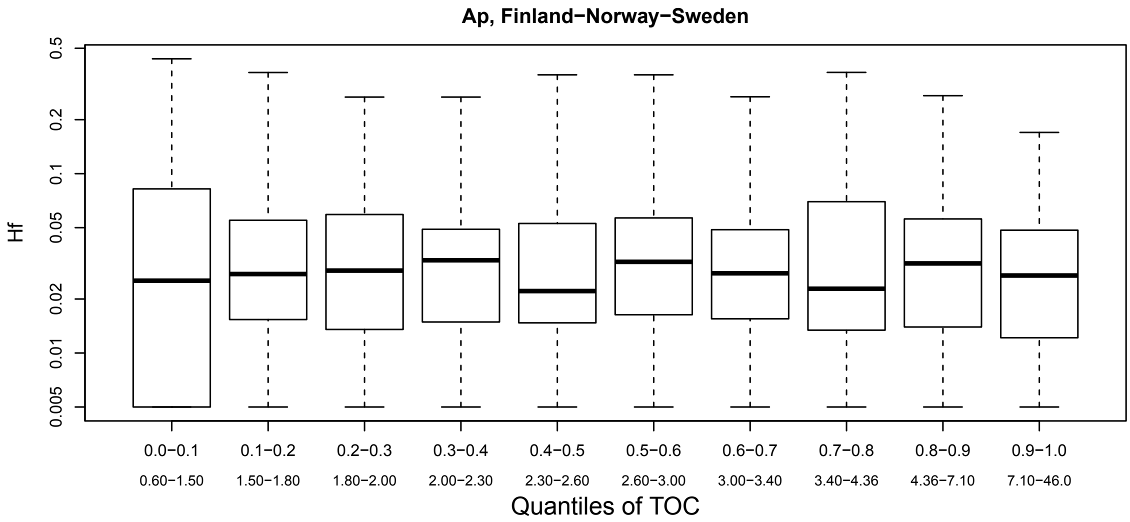
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Hf
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0.01
0.02
0.05
0.1
0.2
0.5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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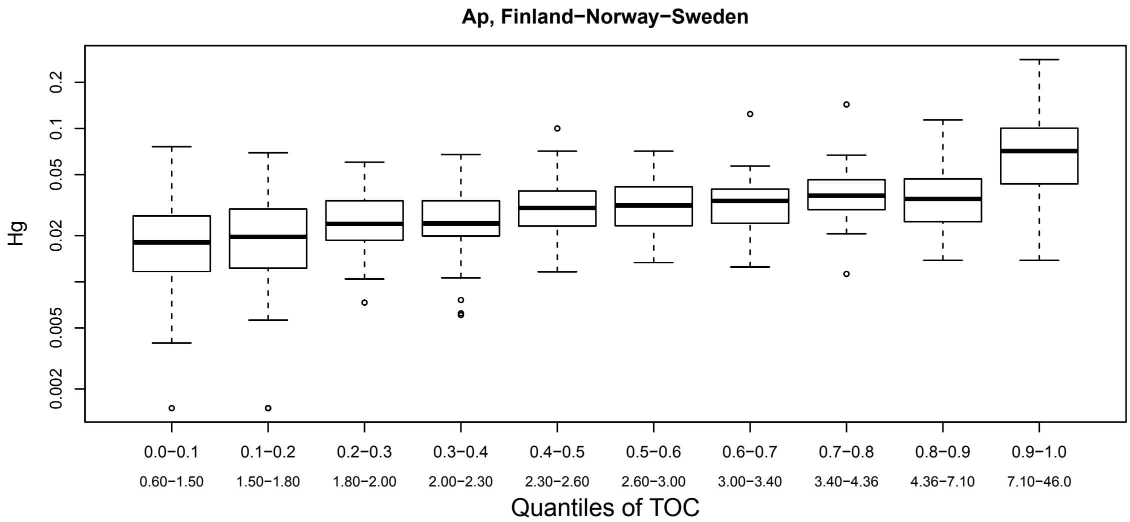
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Hg
0.002
0.005
0.02
0.05
0.1
0.2
0.0−0.1
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0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
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4.36−7.10
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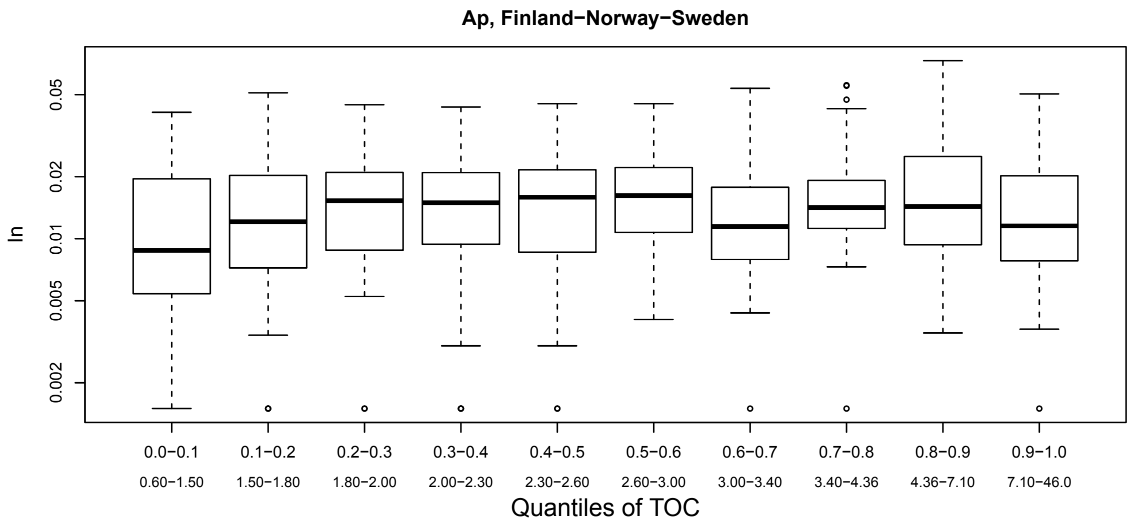
Quantiles of TOC


Ap, Finland−Norway−Sweden
In
0.002
0.005
0.01
0.02
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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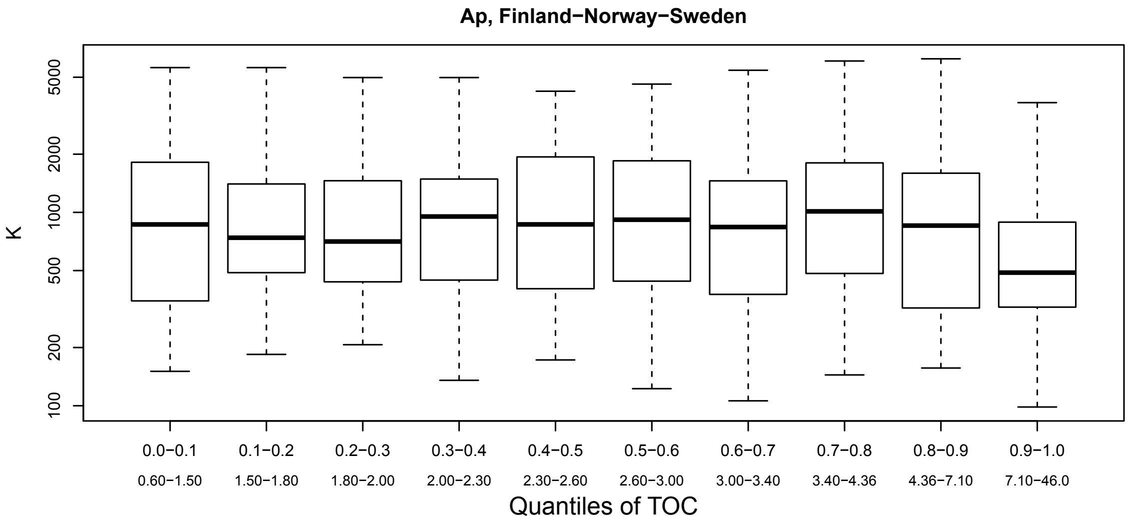
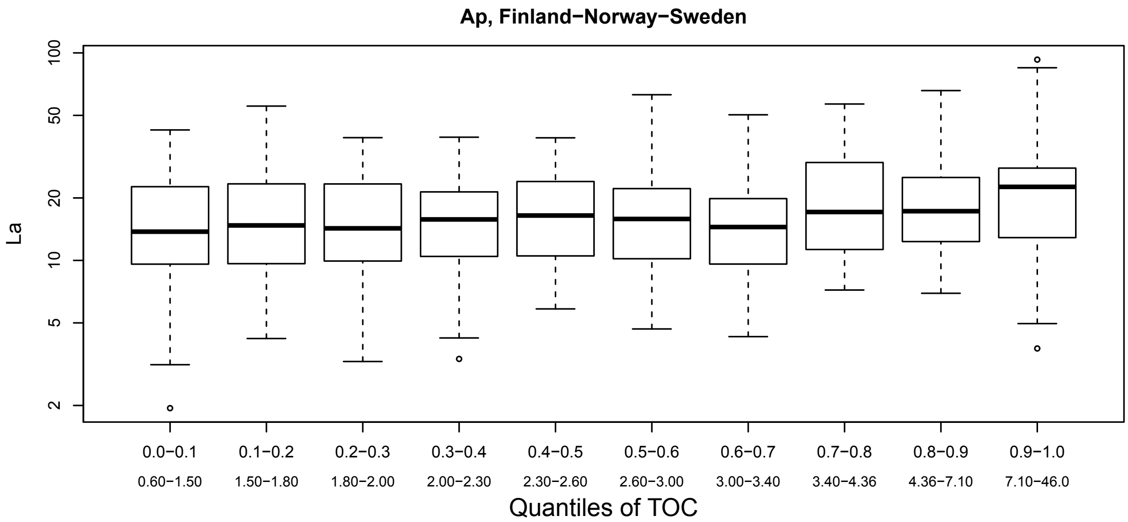
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC



Ap, Finland−Norway−Sweden
K
100
200
500
1000
2000
5000
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC



Ap, Finland−Norway−Sweden
La
2
5
10
20
50
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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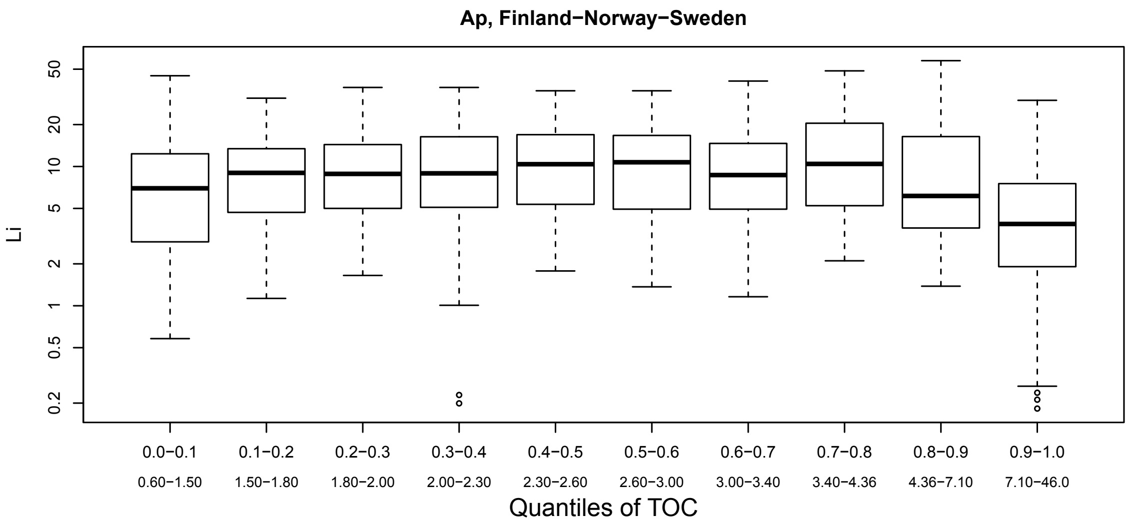
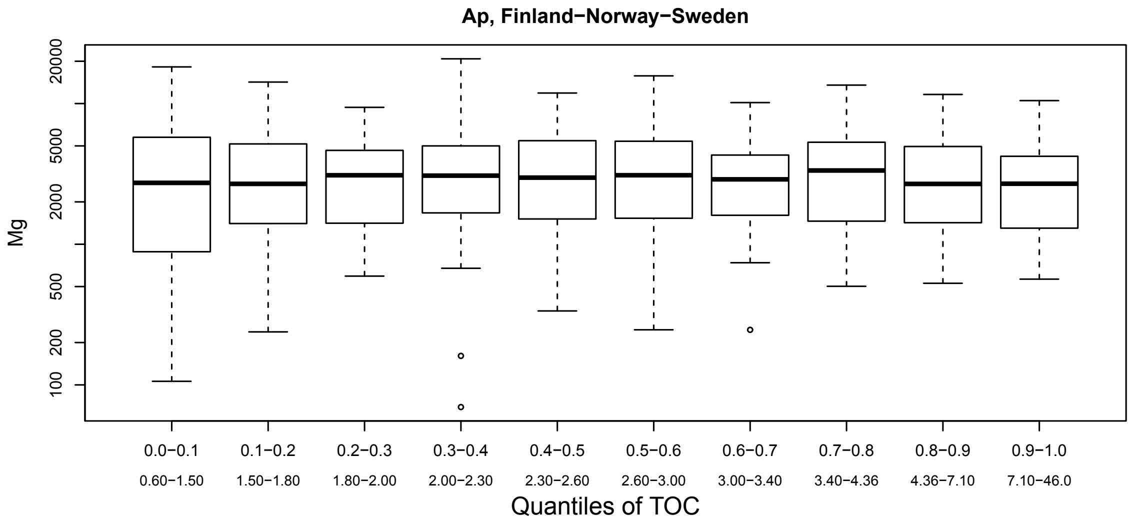
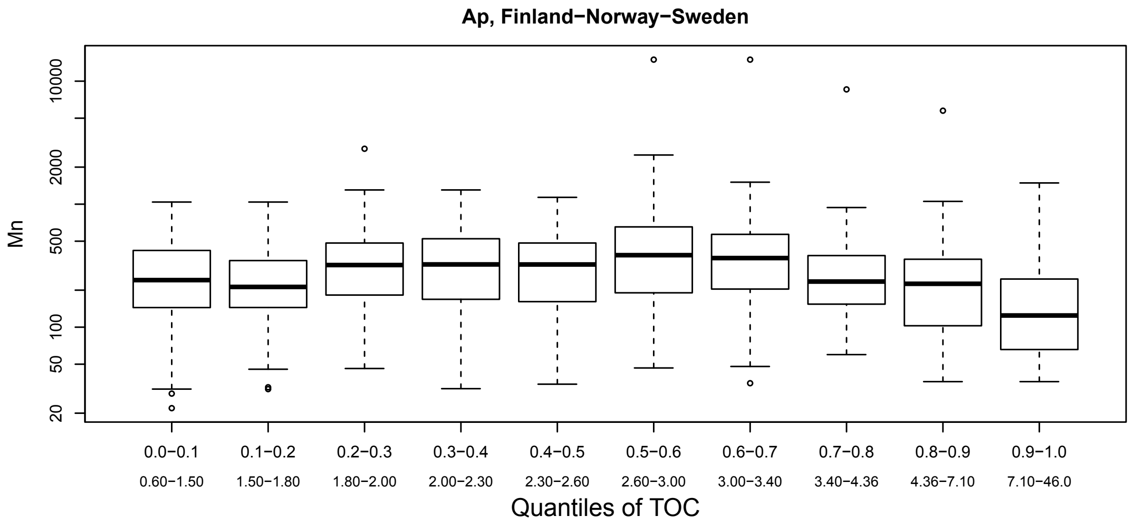
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC



Ap, Finland−Norway−Sweden
Li
0.2
0.5
1
2
5
10
20
50
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Mg
20000
5000
2000
500
200
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Mn
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2000
500
100
50
20
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0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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2.60−3.00
3.00−3.40
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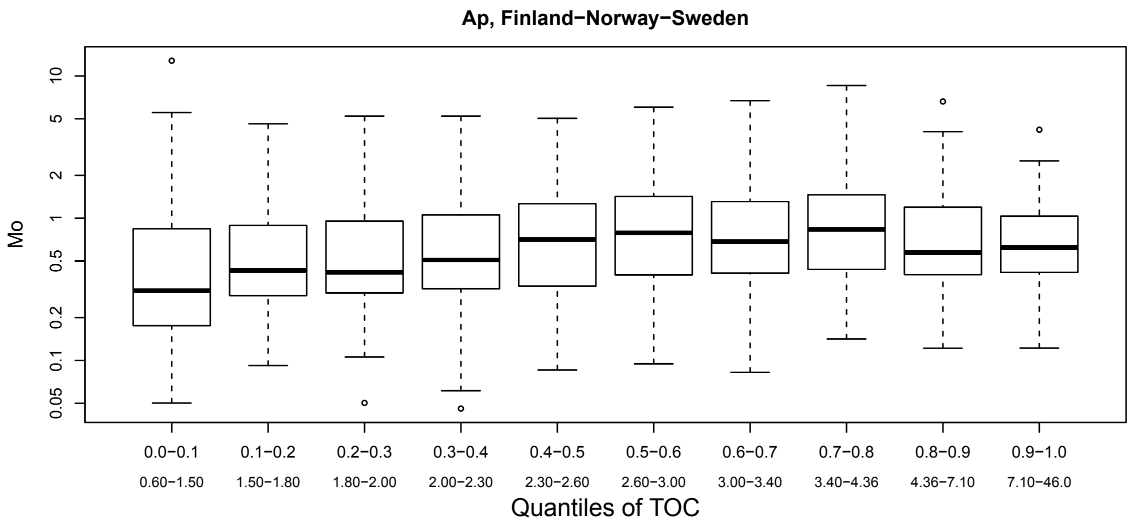
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Mo
10
5
2
1
0.5
0.2
0.1
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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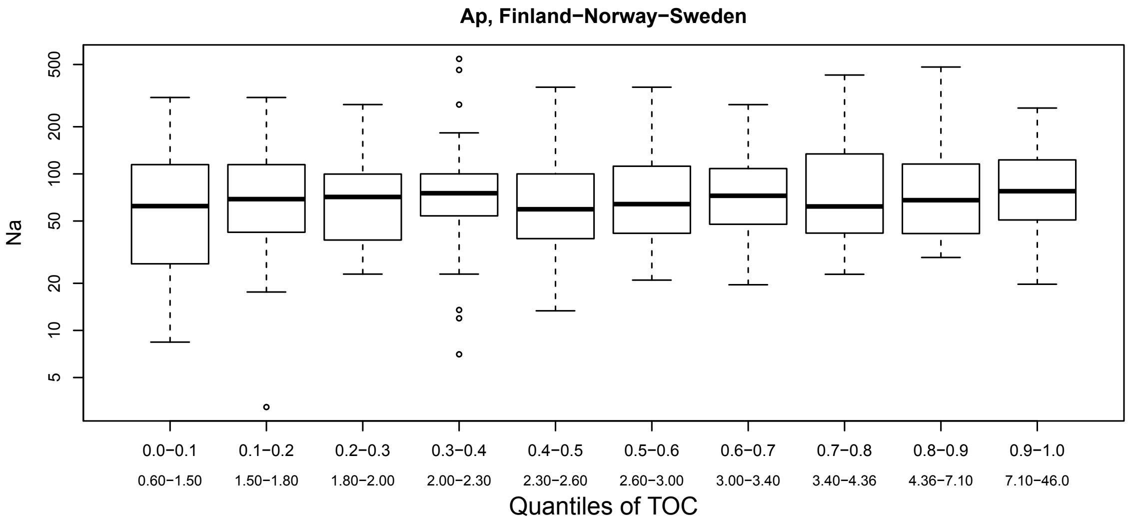
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Na
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0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
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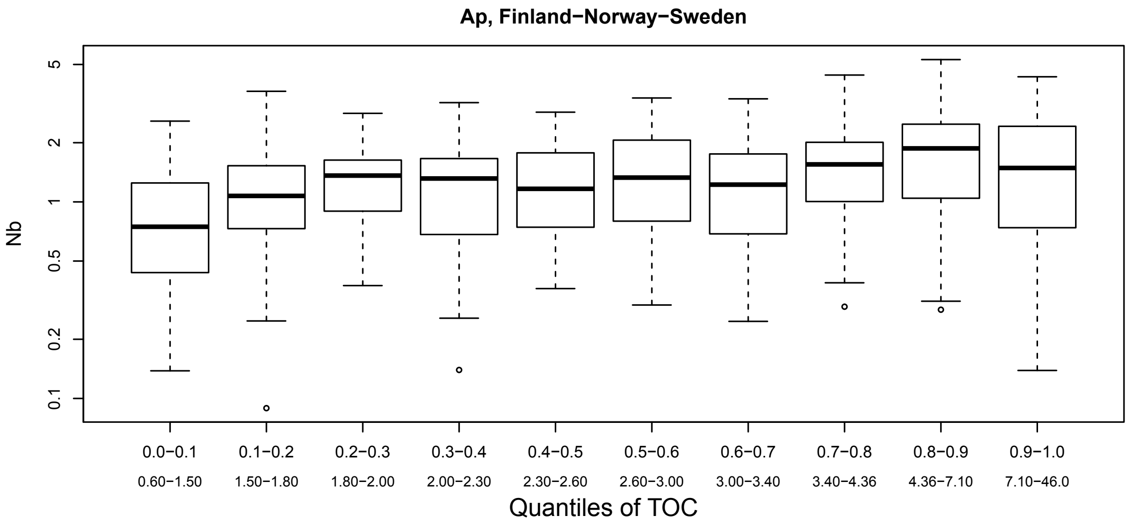
Quantiles of TOC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Nb
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0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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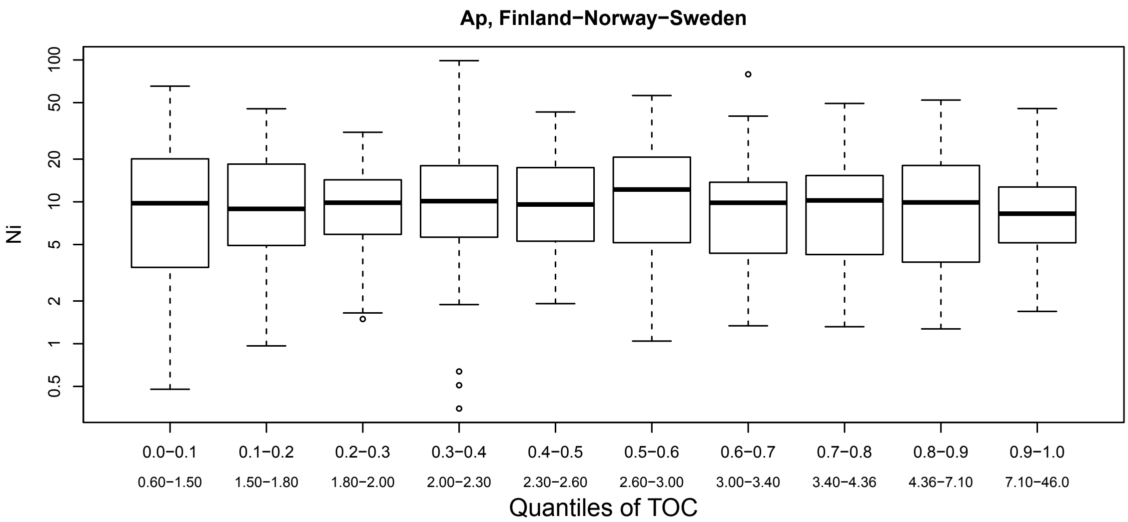
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Ni
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50
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0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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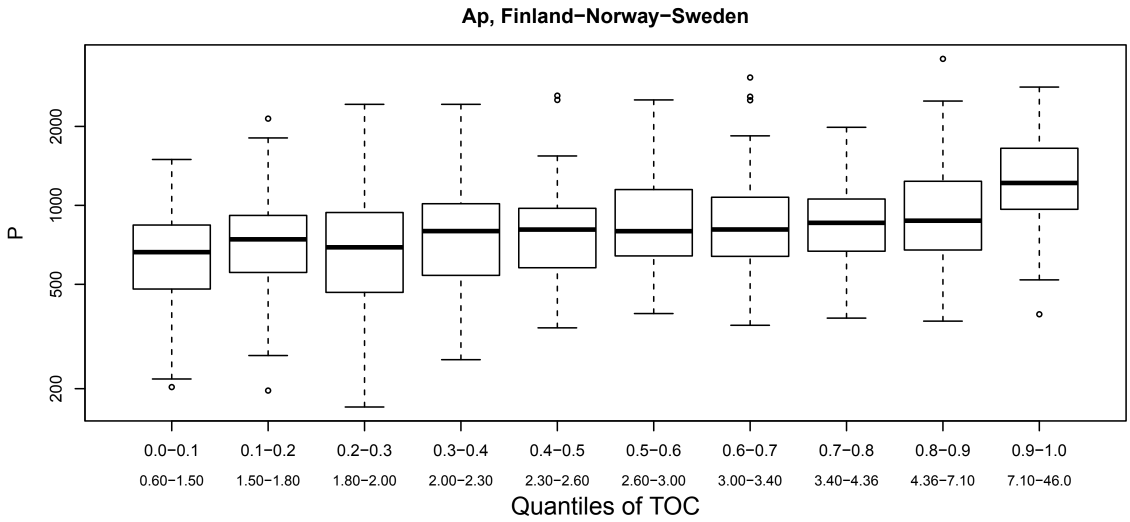
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC



Ap, Finland−Norway−Sweden
P
200
500
1000
2000
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0.1−0.2
0.2−0.3
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0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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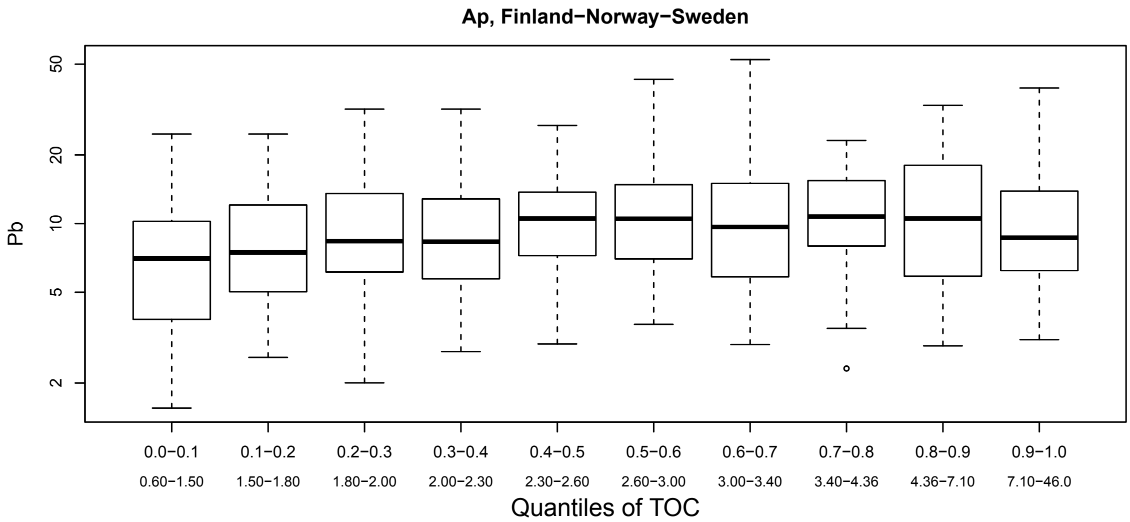
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC



Ap, Finland−Norway−Sweden
Pb
2
5
10
20
50
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0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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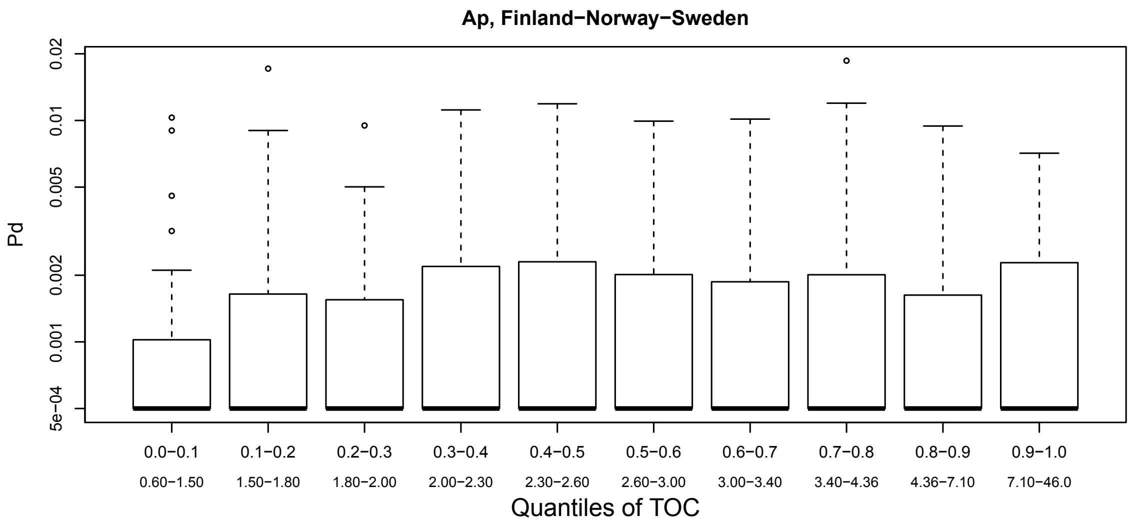
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC



Ap, Finland−Norway−Sweden
Pd
5e−04
0.001
0.002
0.005
0.01
0.02
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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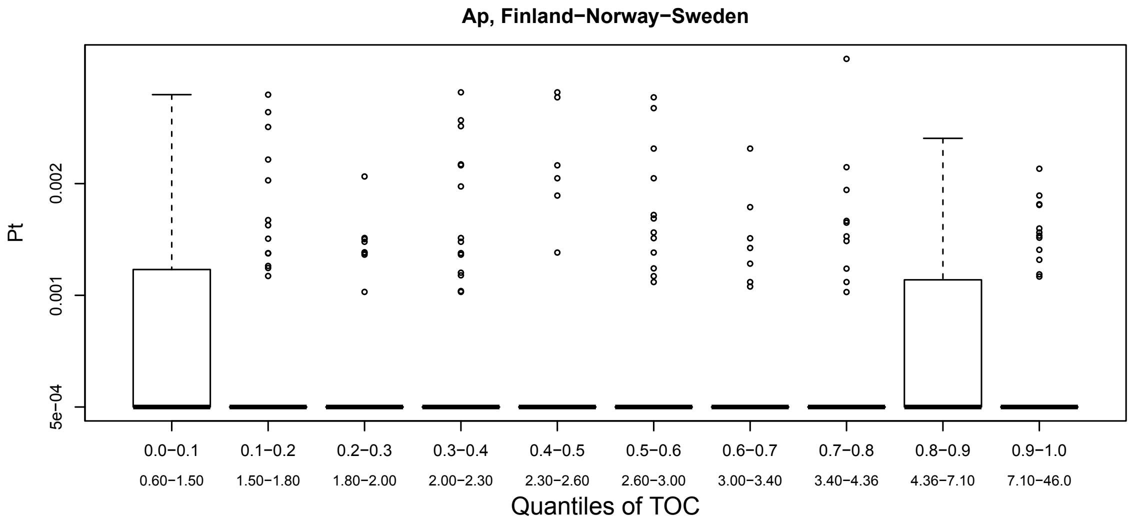
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Pt
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0.002
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0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
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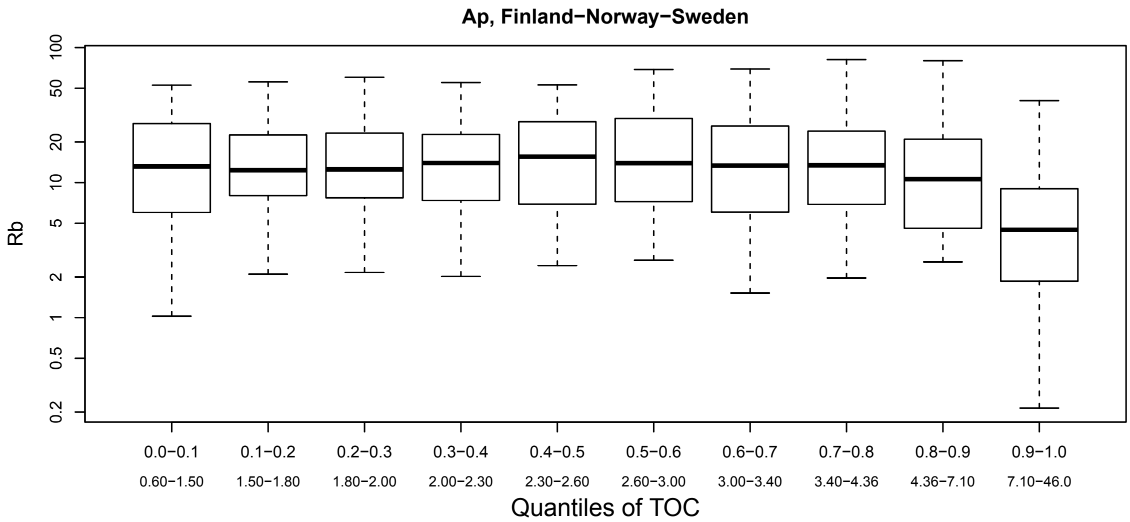
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Rb
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0.5
1
2
5
10
20
50
100
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0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
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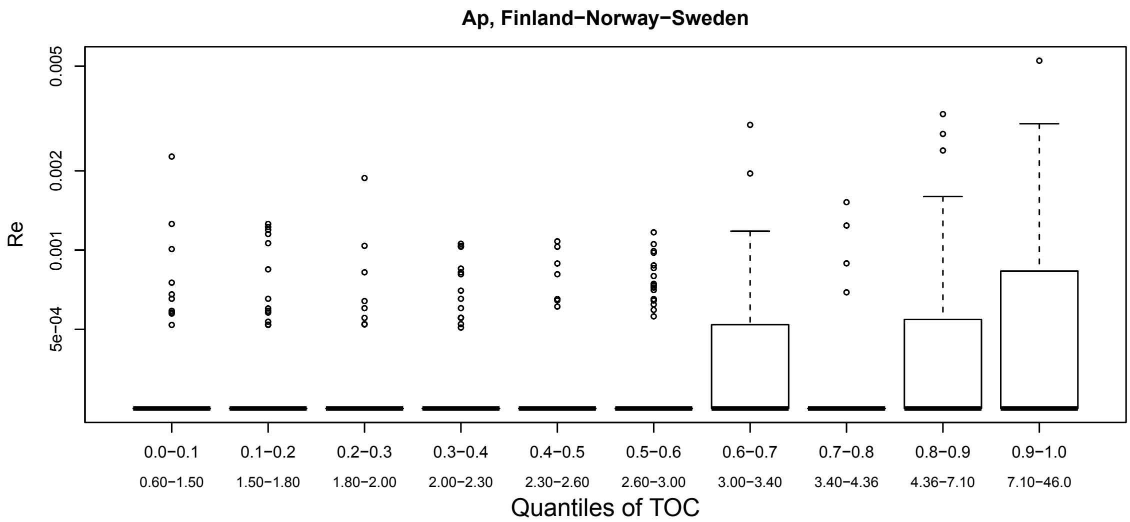
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Re
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0.002
0.005
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0.3−0.4
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0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
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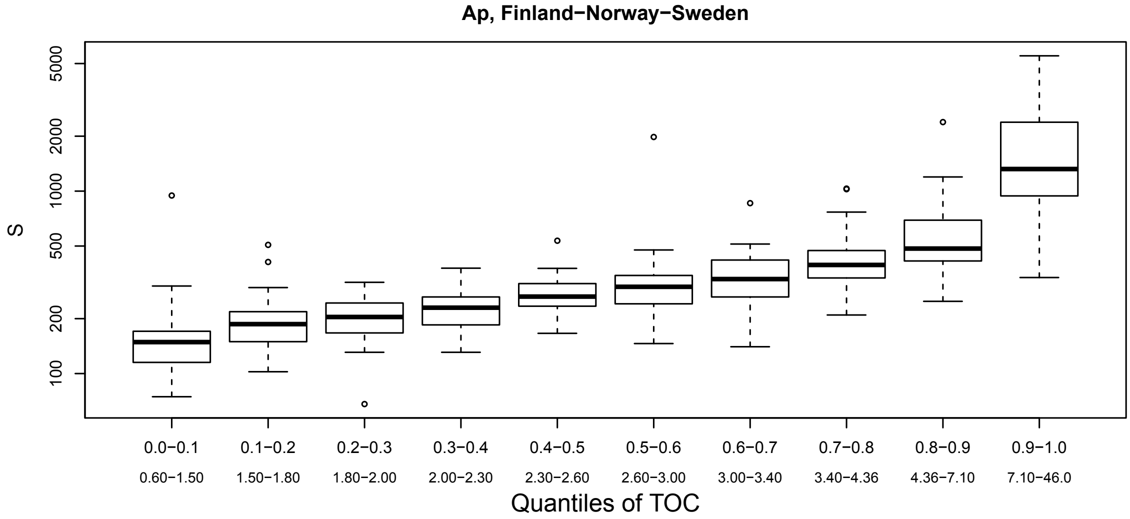
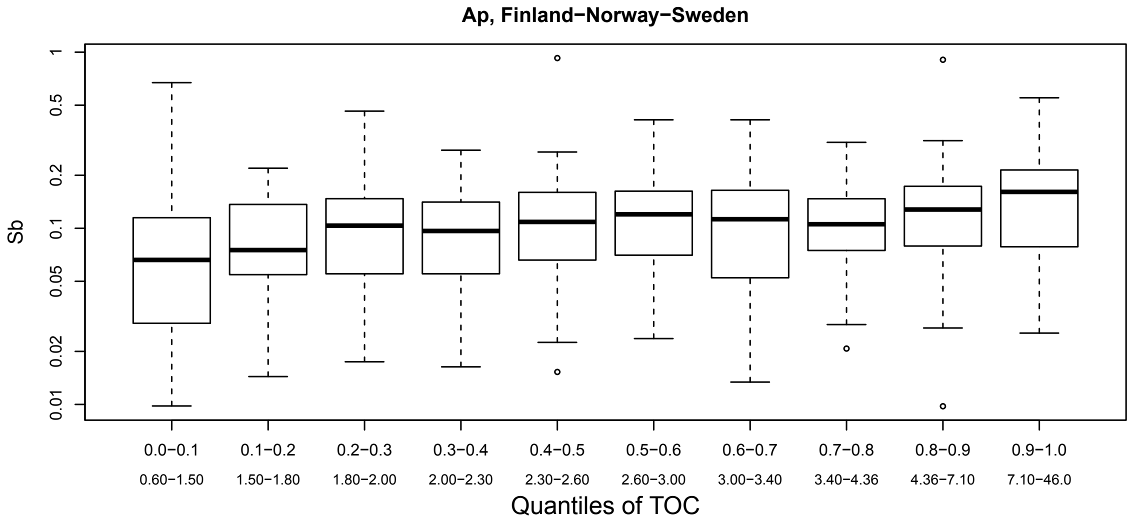
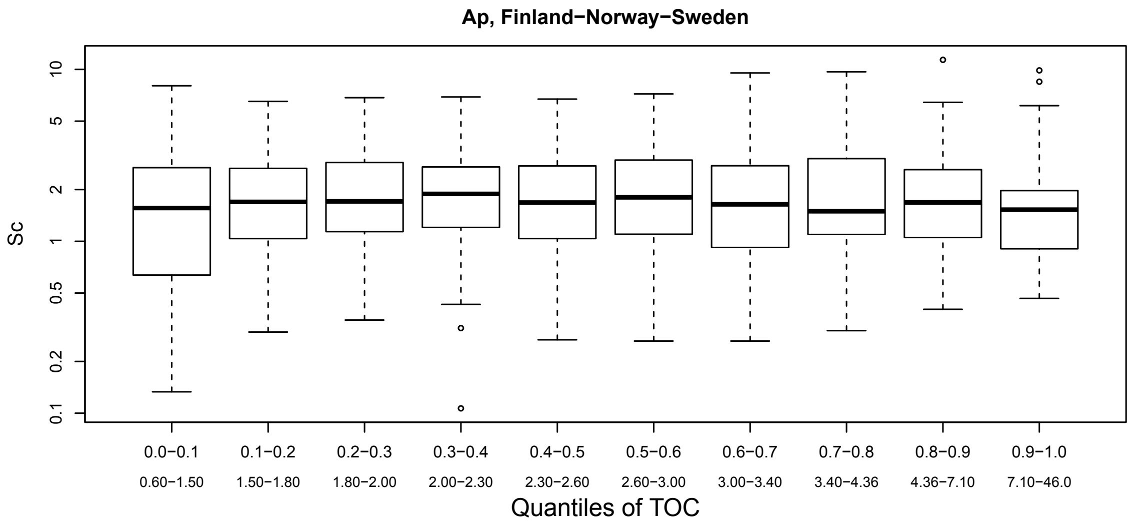
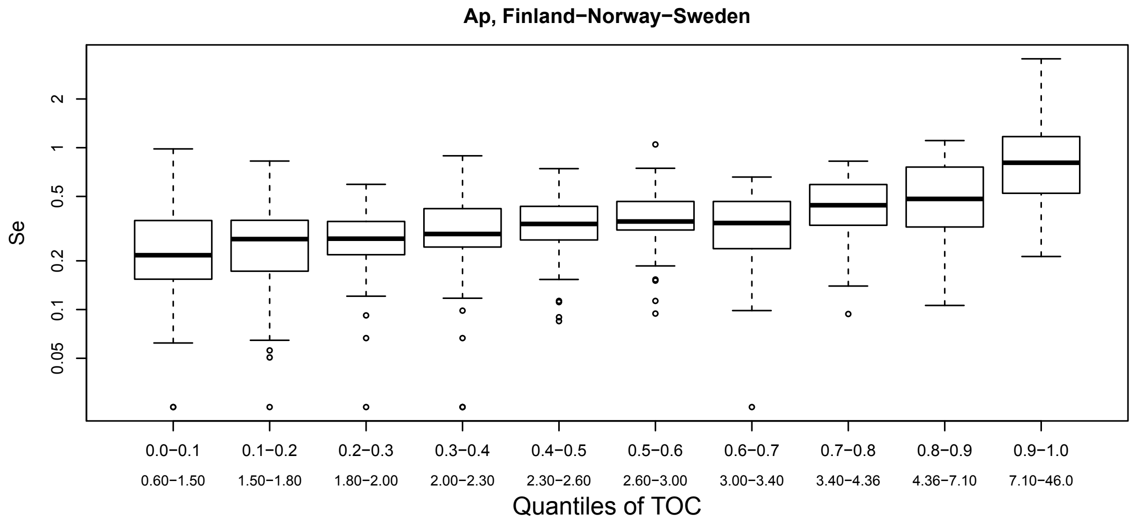
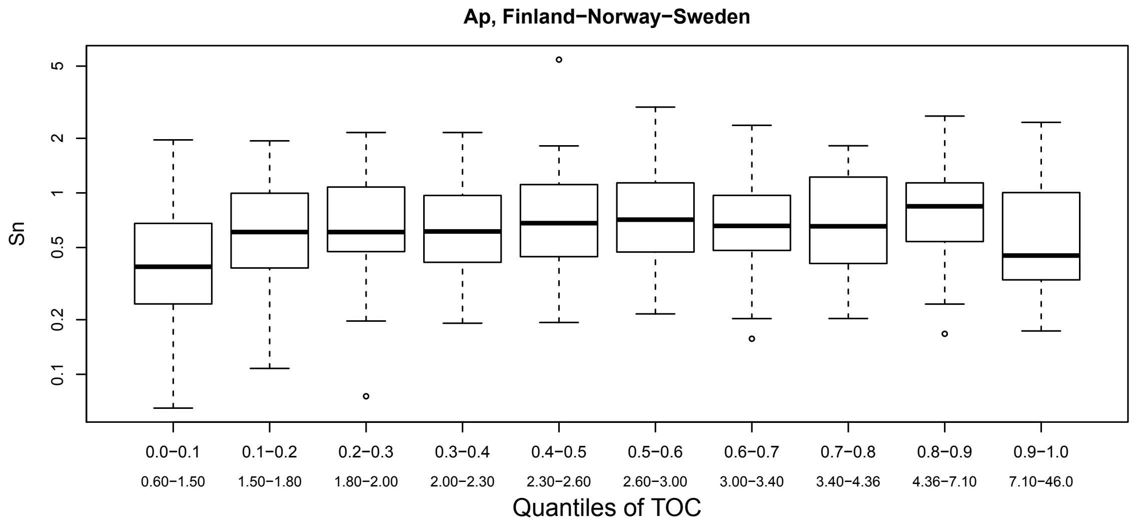
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

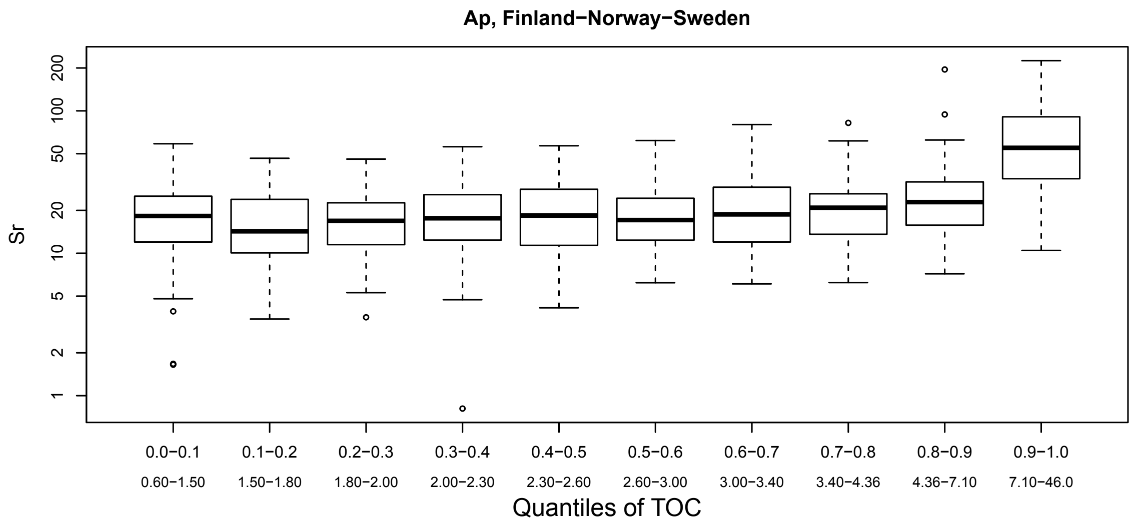

Ap, Finland−Norway−Sweden
S
5000
2000
1000
500
200
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

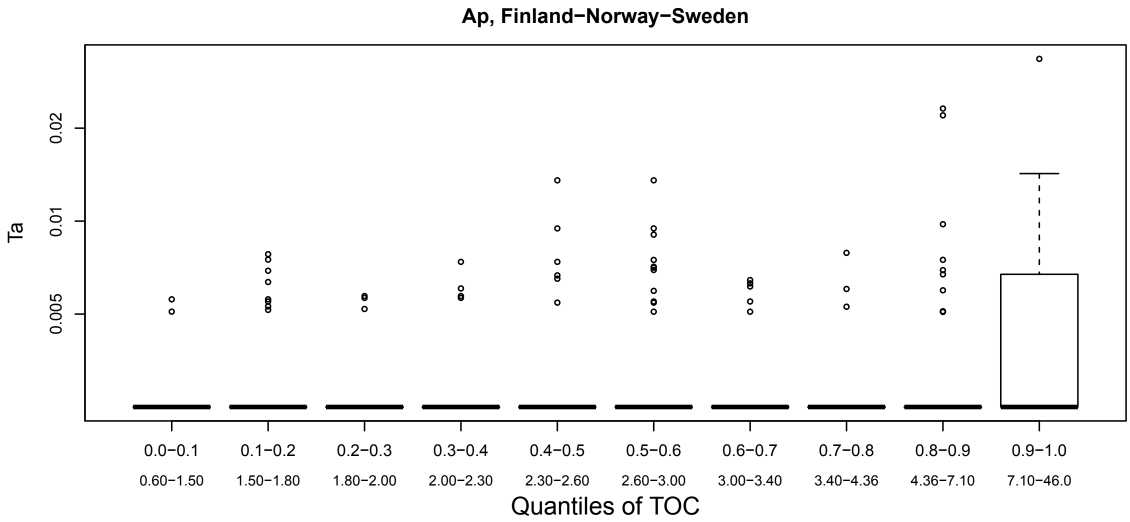

Ap, Finland−Norway−Sweden
Sb
1
0.5
0.2
0.1
0.05
0.02
0.01
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

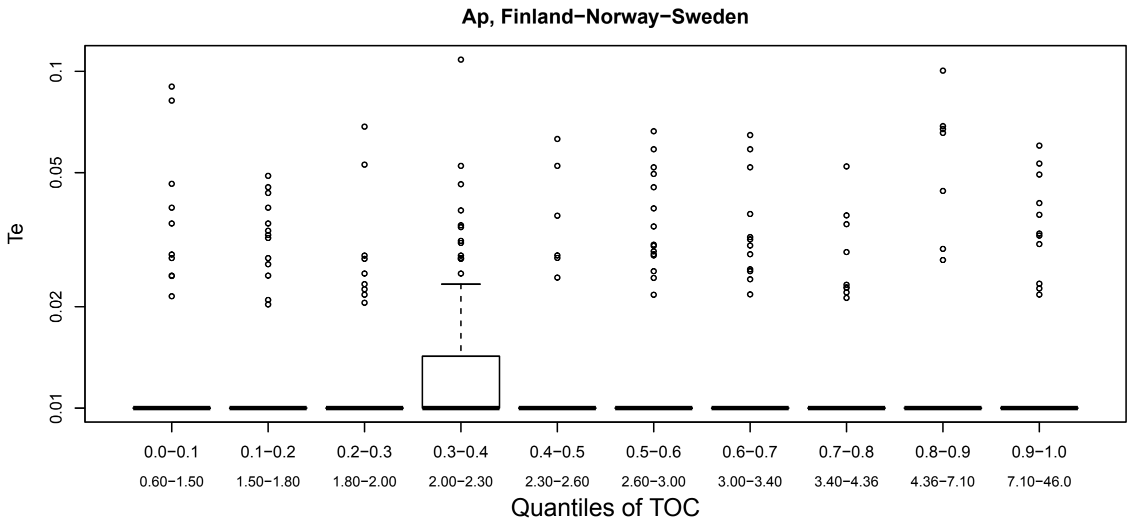

Ap, Finland−Norway−Sweden
Sc
10
5
2
1
0.5
0.2
0.1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

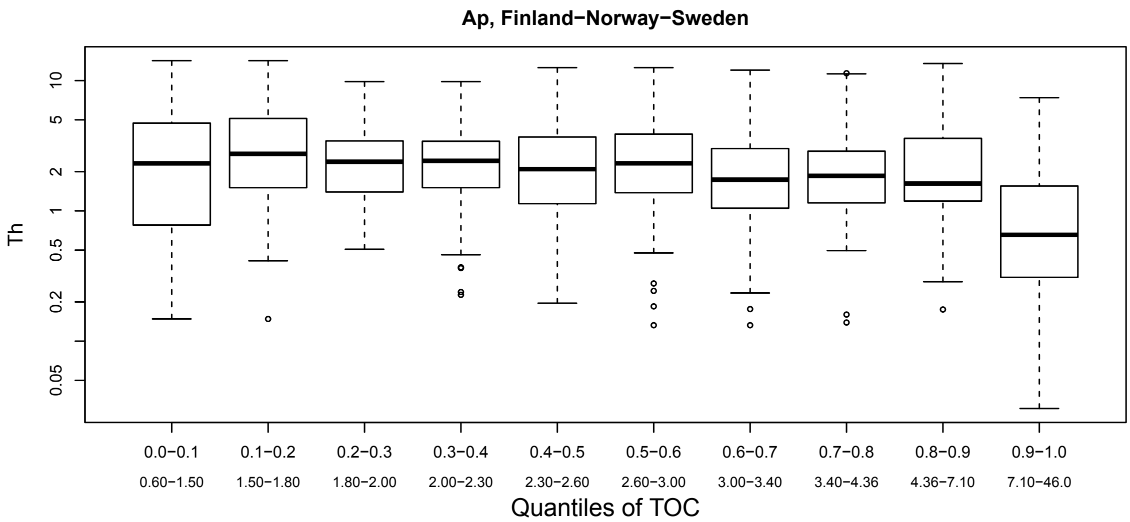

Ap, Finland−Norway−Sweden
Se
2
1
0.5
0.2
0.1
0.05
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

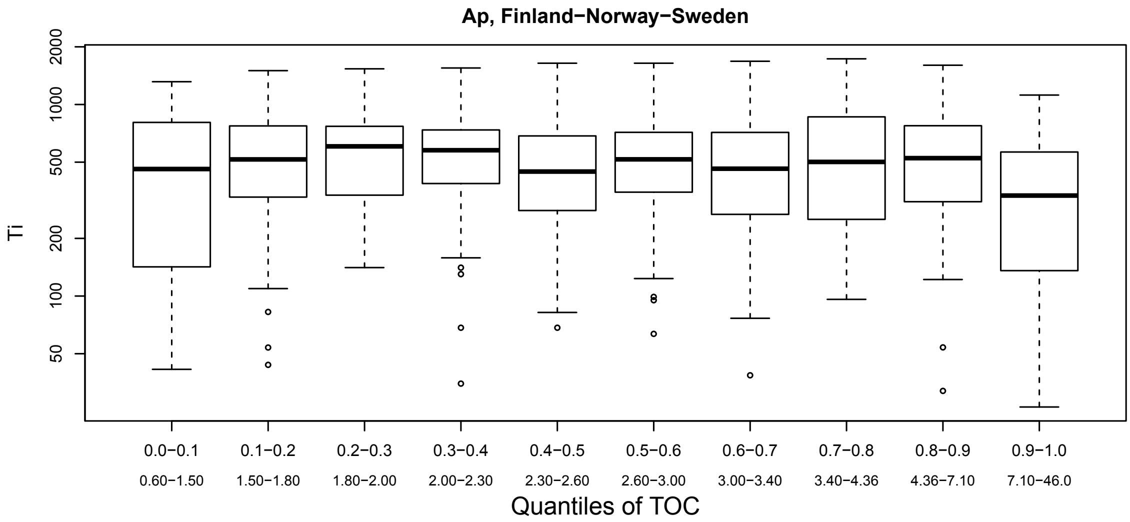

Ap, Finland−Norway−Sweden
Sn
5
2
1
0.5
0.2
0.1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

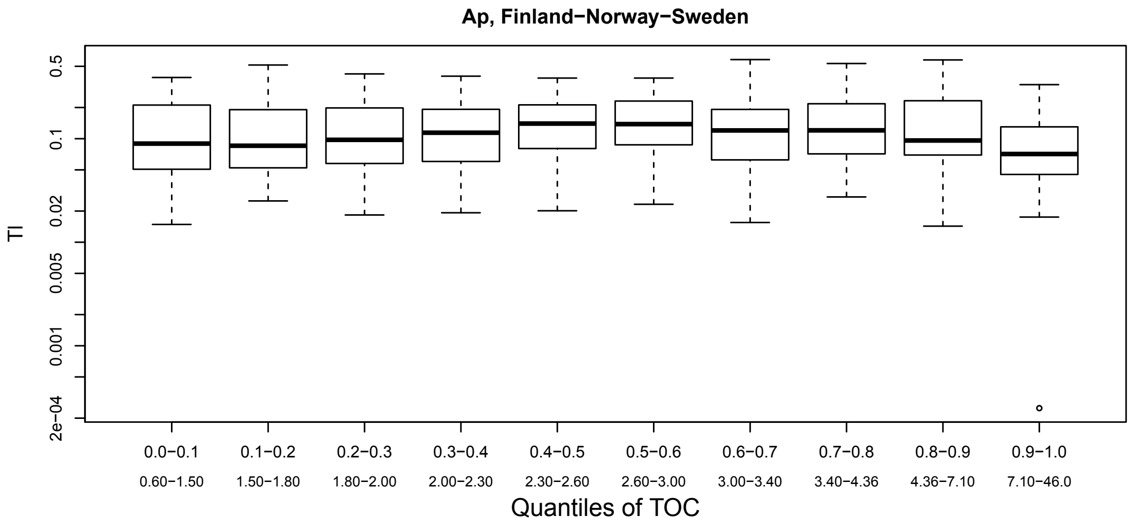

Ap, Finland−Norway−Sweden
Sr
200
100
50
20
10
5
2
1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

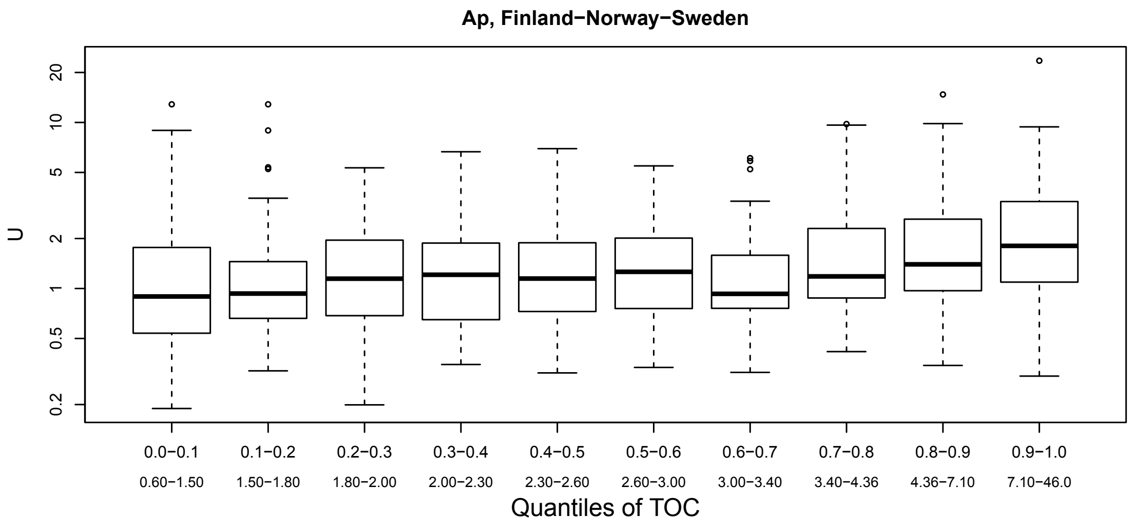

Ap, Finland−Norway−Sweden
Ta
0.005
0.01
0.02
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

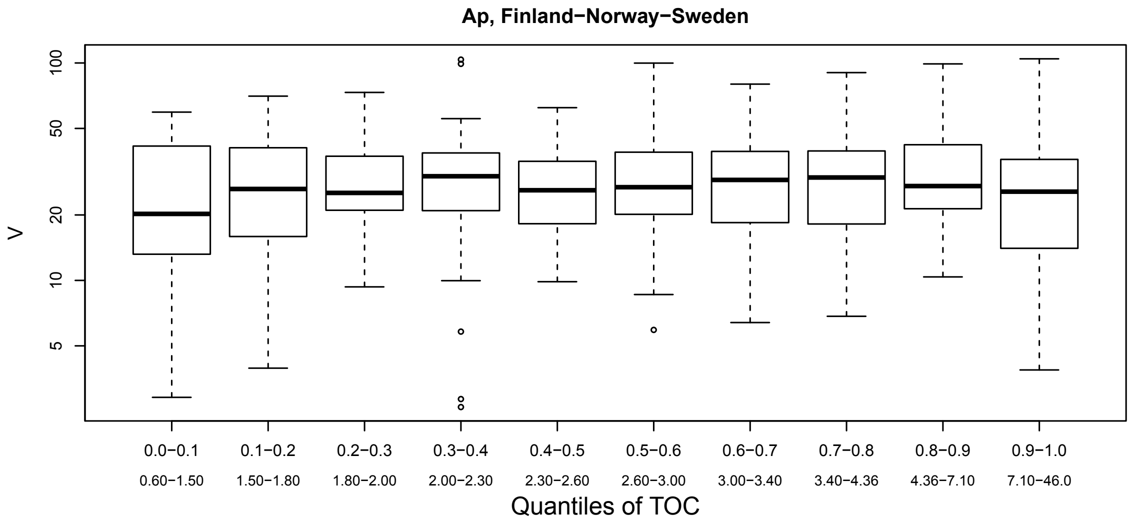

Ap, Finland−Norway−Sweden
Te
0.01
0.02
0.05
0.1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

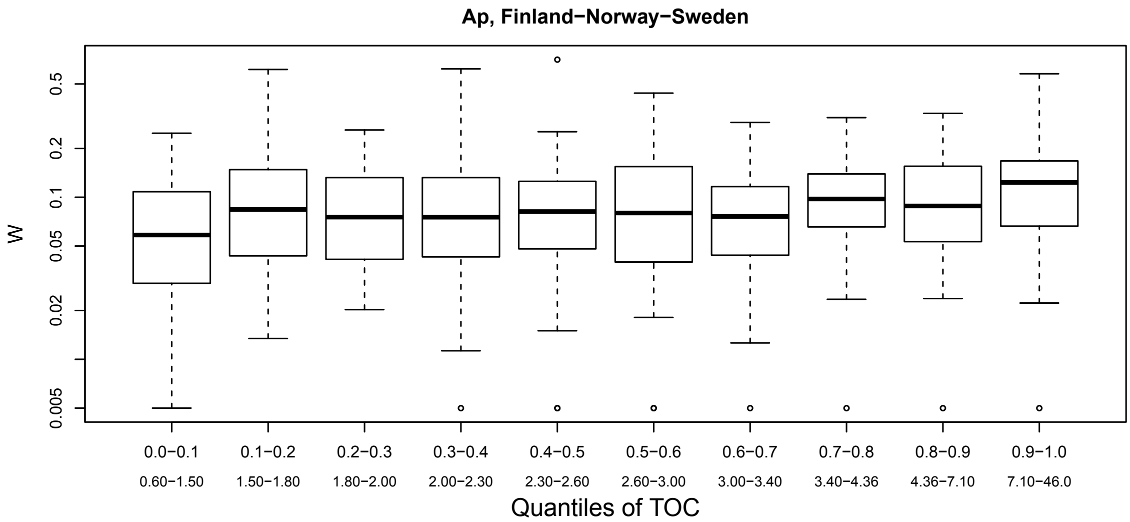

Ap, Finland−Norway−Sweden
Th
0.05
0.2
0.5
1
2
5
10
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

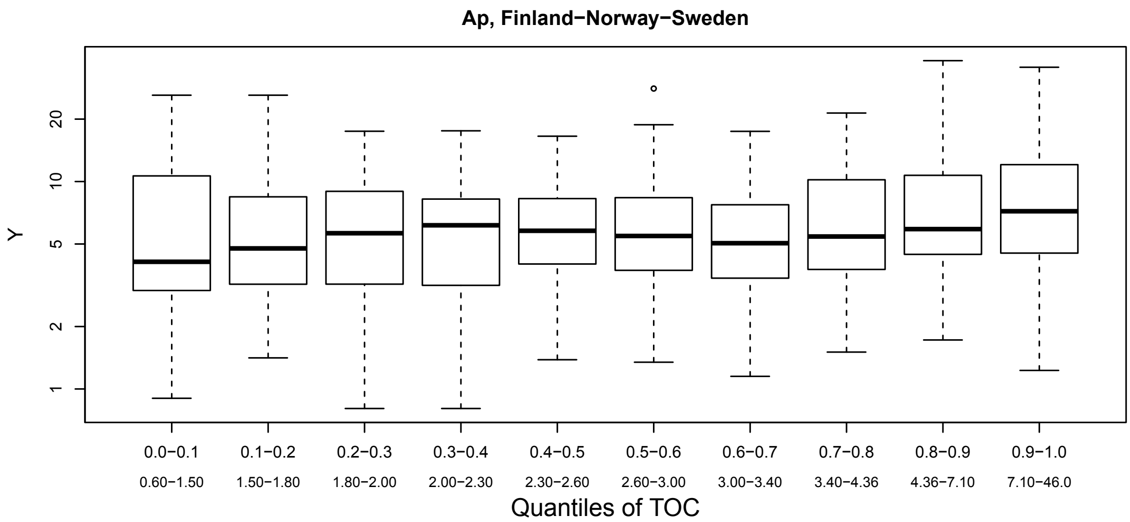

Ap, Finland−Norway−Sweden
Ti
50
100
200
500
1000
2000
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

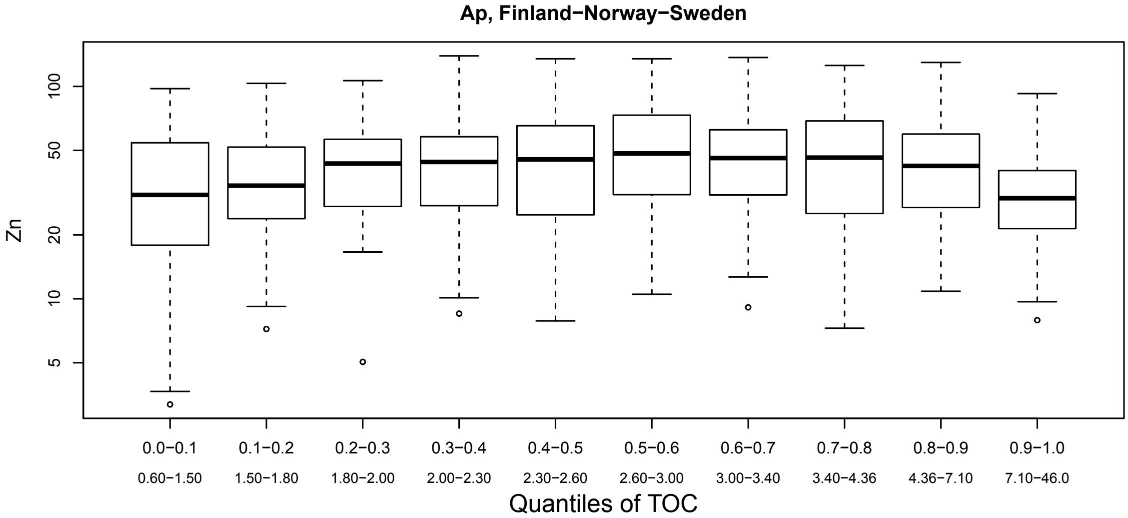

Ap, Finland−Norway−Sweden
Tl
2e−04
0.001
0.005
0.02
0.1
0.5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

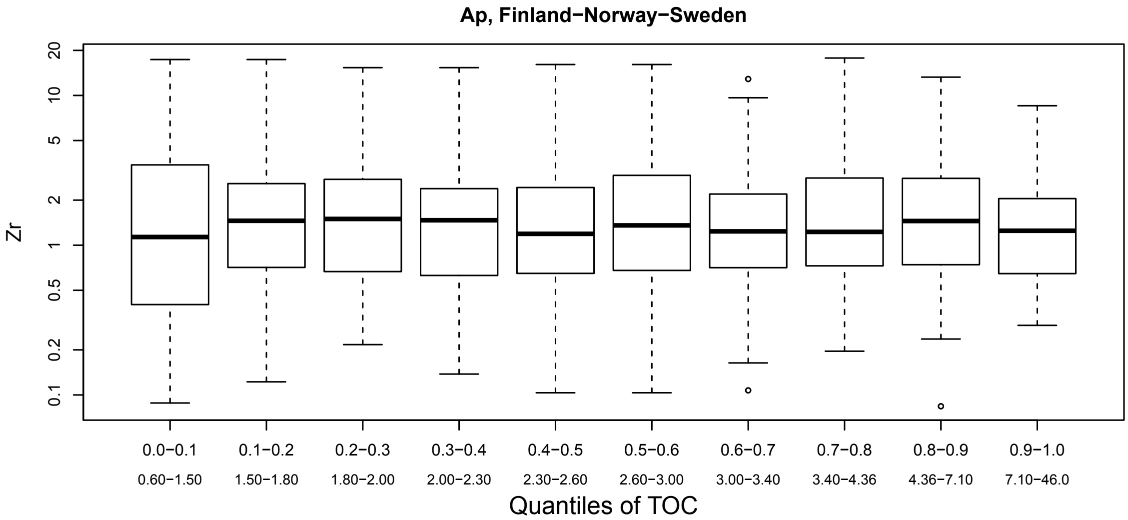

Ap, Finland−Norway−Sweden
U
0.2
0.5
1
2
5
10
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

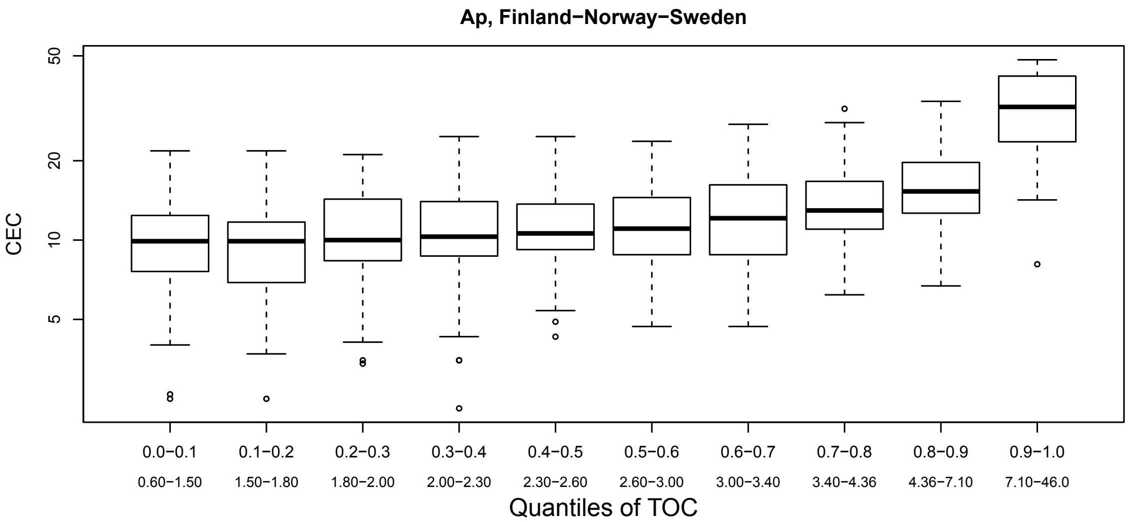

Ap, Finland−Norway−Sweden
V
100
50
20
10
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

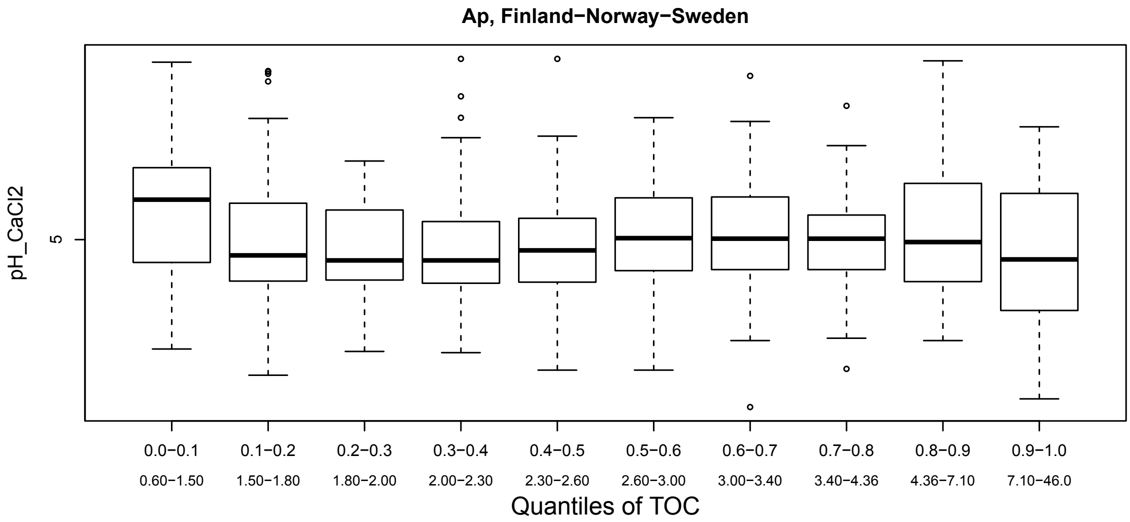

Ap, Finland−Norway−Sweden
W
0.5
0.2
0.1
0.05
0.02
0.005
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Y
20
10
5
2
1
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Zn
5
10
20
50
100
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
Zr
0.1
0.2
0.5
1
2
5
10
20
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC


Ap, Finland−Norway−Sweden
CEC
5
10
20
50
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

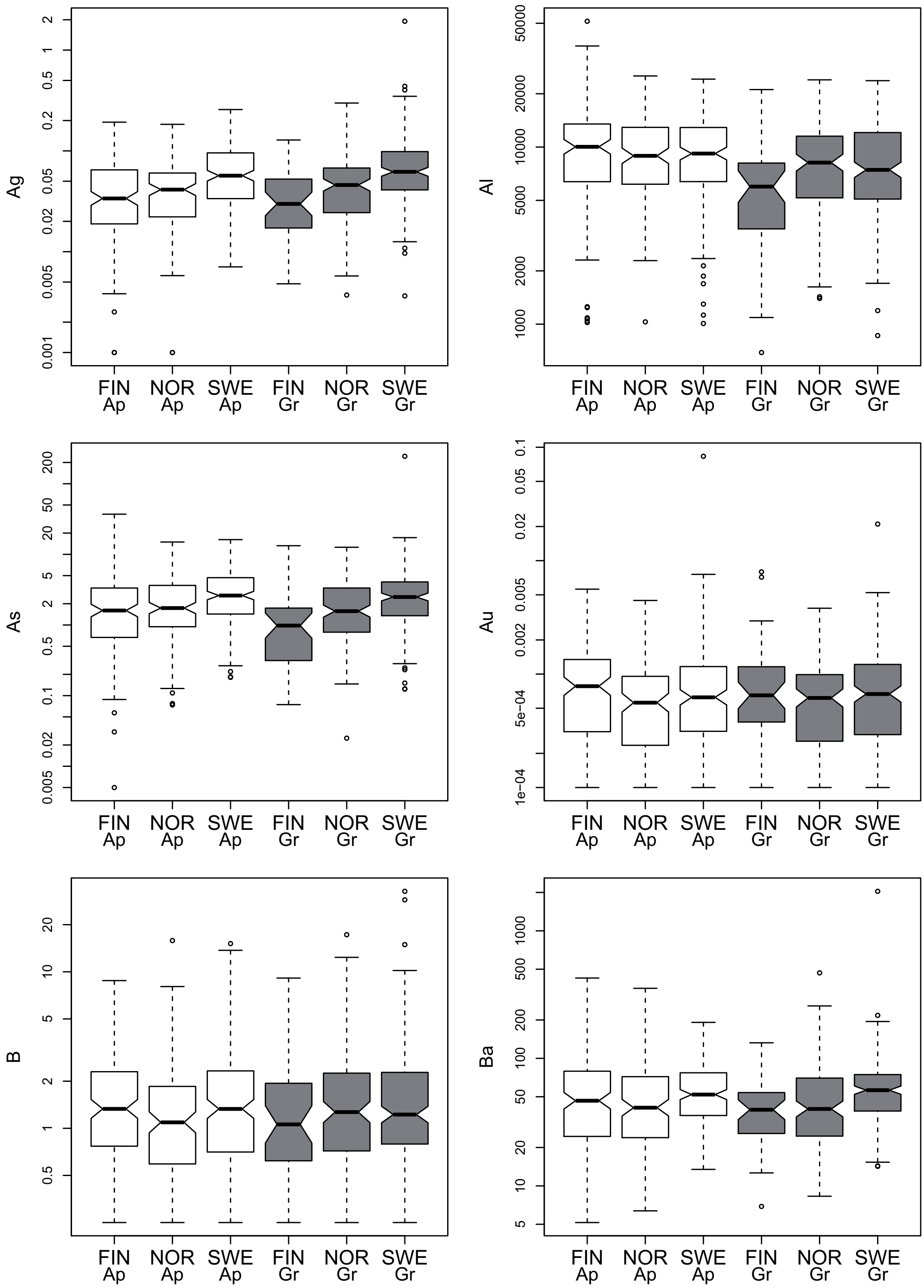


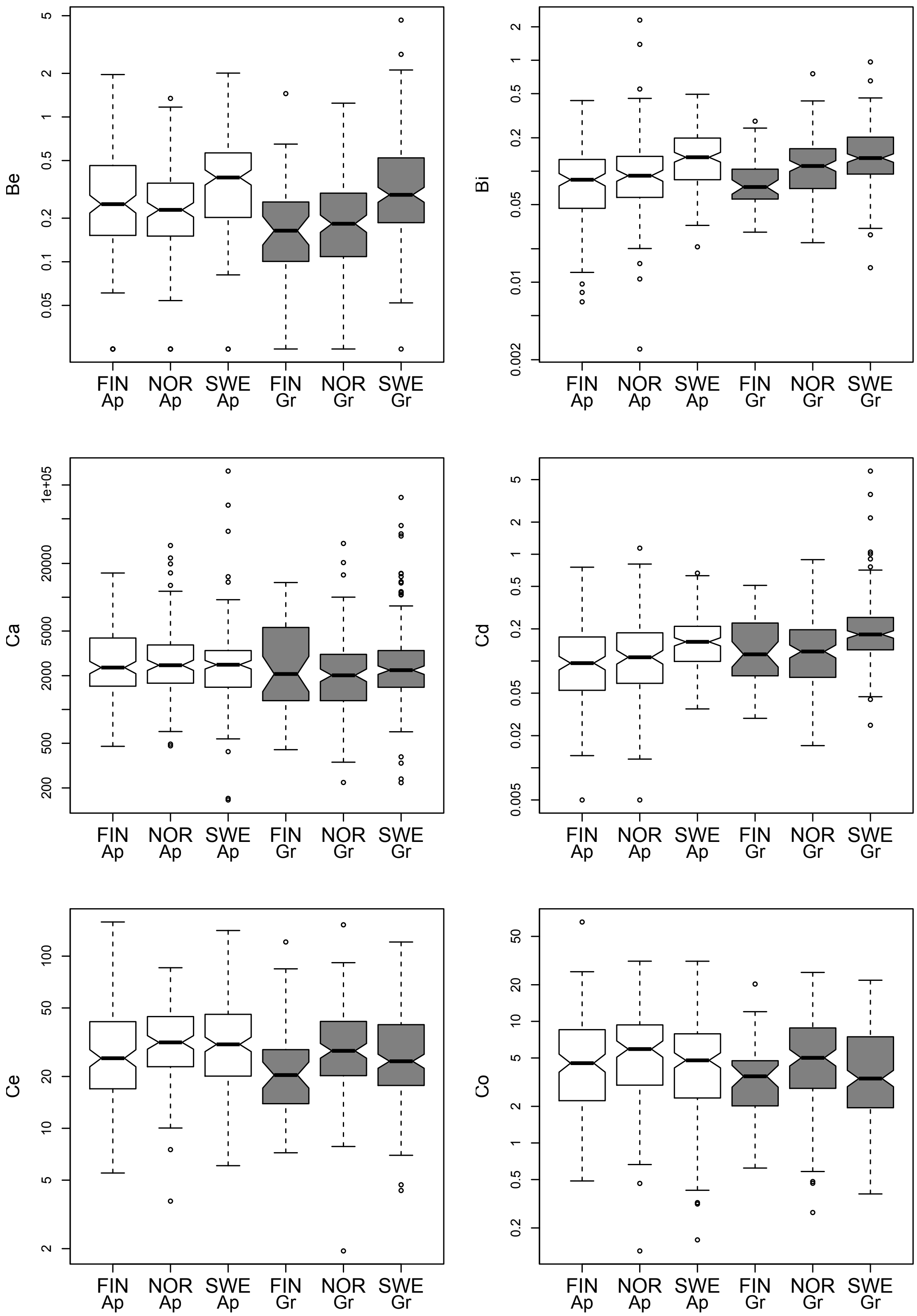
Ap, Finland−Norway−Sweden
pH_CaCl2
5
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
0.5−0.6
0.6−0.7
0.7−0.8
0.8−0.9
0.9−1.0
0.60−1.50
1.50−1.80
1.80−2.00
2.00−2.30
2.30−2.60
2.60−3.00
3.00−3.40
3.40−4.36
4.36−7.10
7.10−46.0
Quantiles of TOC

APPENDIX 4

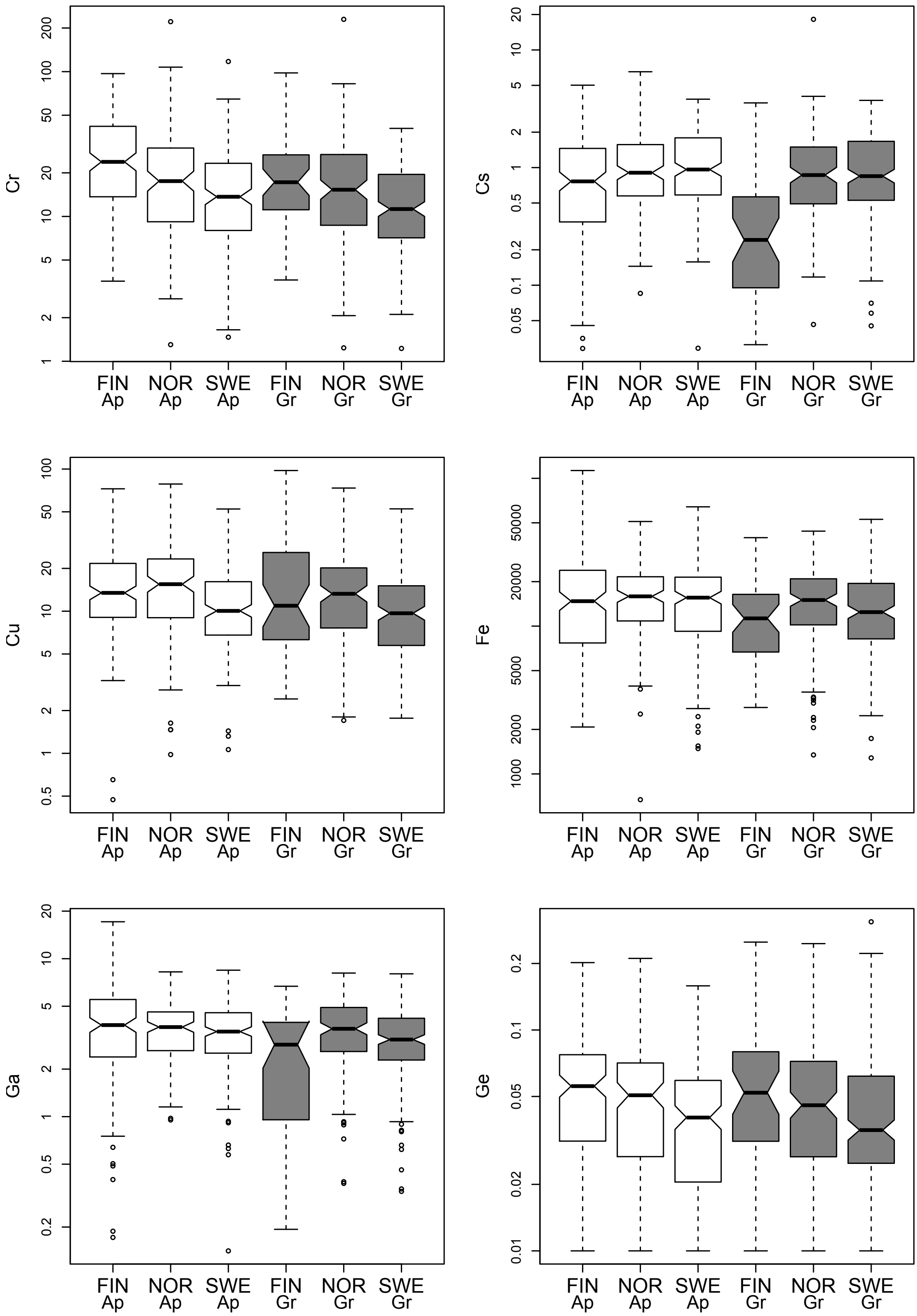
Boxplot comparison for agricultural (Ap) and grazing land (Gr) soils in the GEMAS data-set for Finland, Norway and Sweden

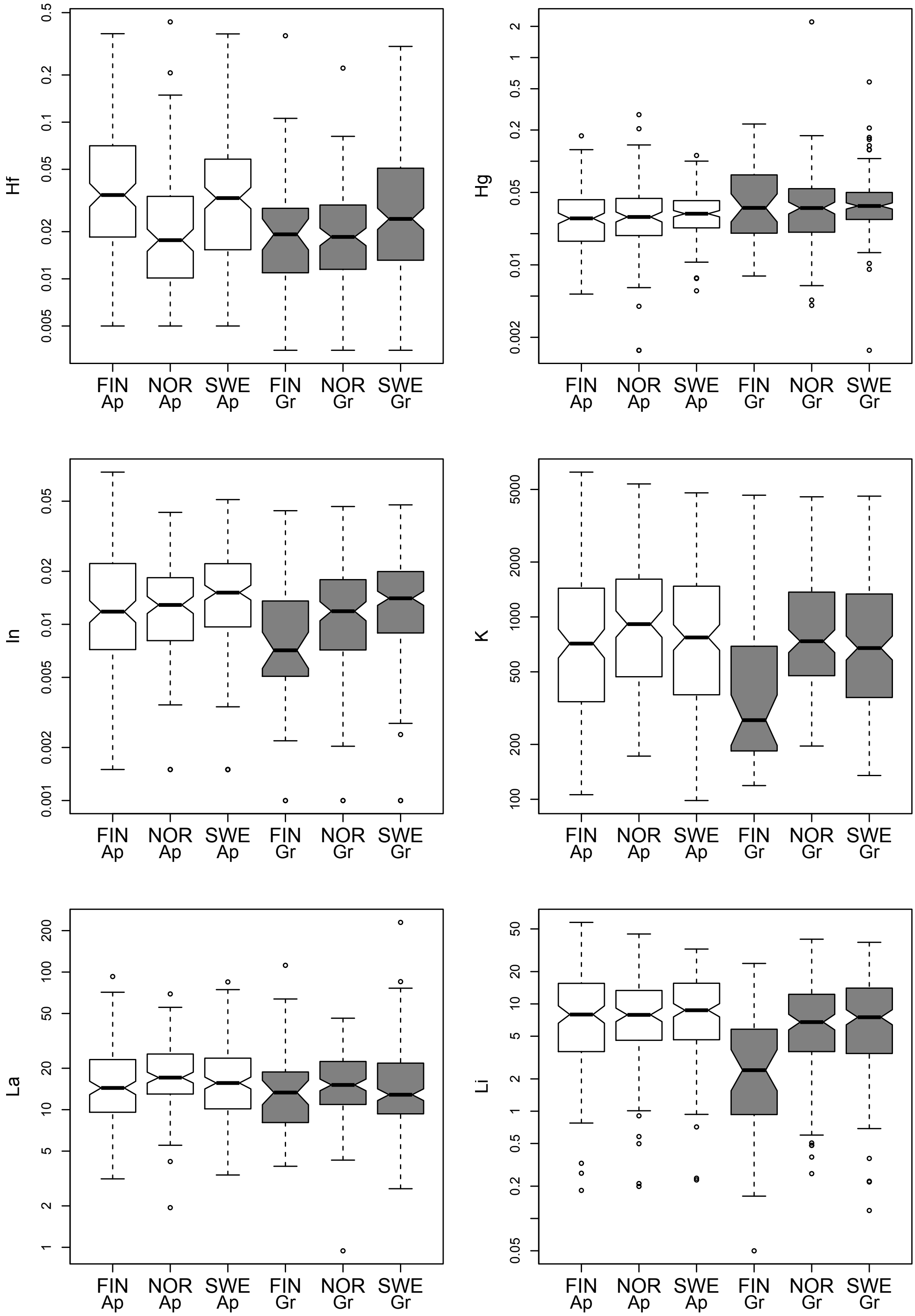
Results from aqua regia extraction.

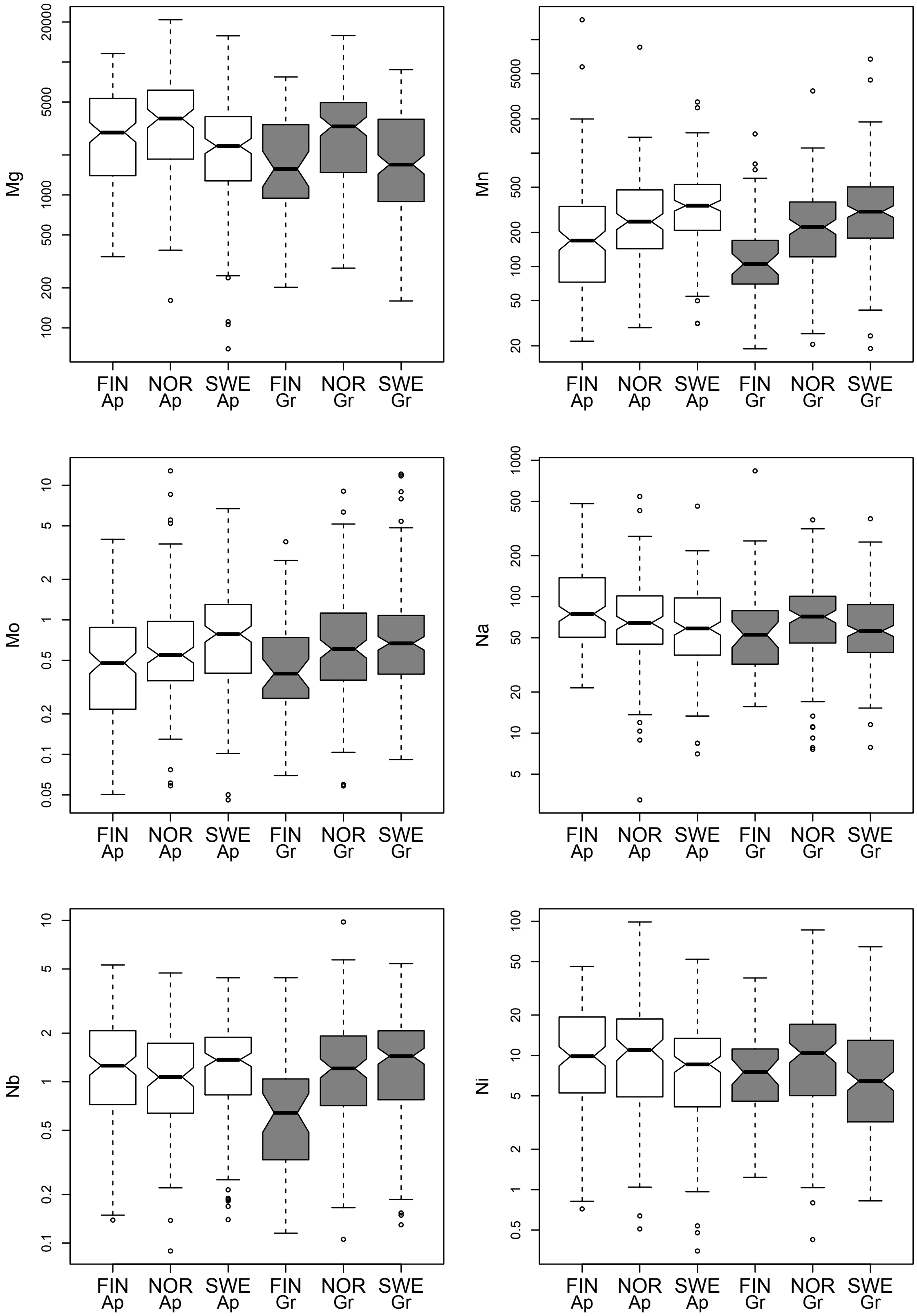


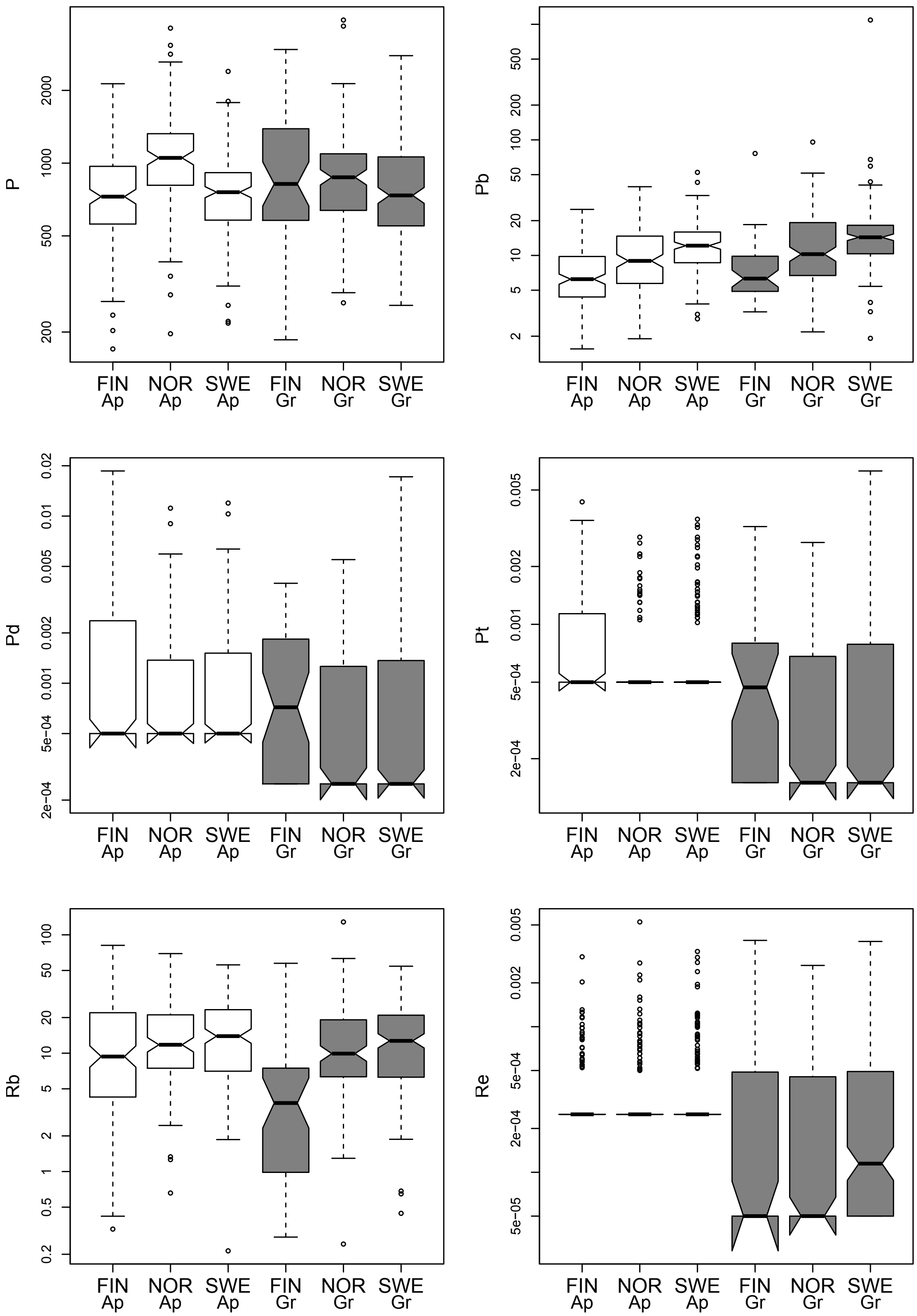


Be
5
2
1
0.5
0.2
0.1
0.05
Bi
2
1
0.5
0.2
0.05
0.01
0.002
Ca
1e+05
20000
5000
2000
500
200
Cd
5
2
1
0.5
0.2
0.05
0.02
0.005
Ce
100
50
20
10
5
2
Co
50
20
10
5
2
1
0.5
0.2
FIN Ap
NOR Ap
SWE Ap
FIN Gr
NOR Gr
SWE Gr

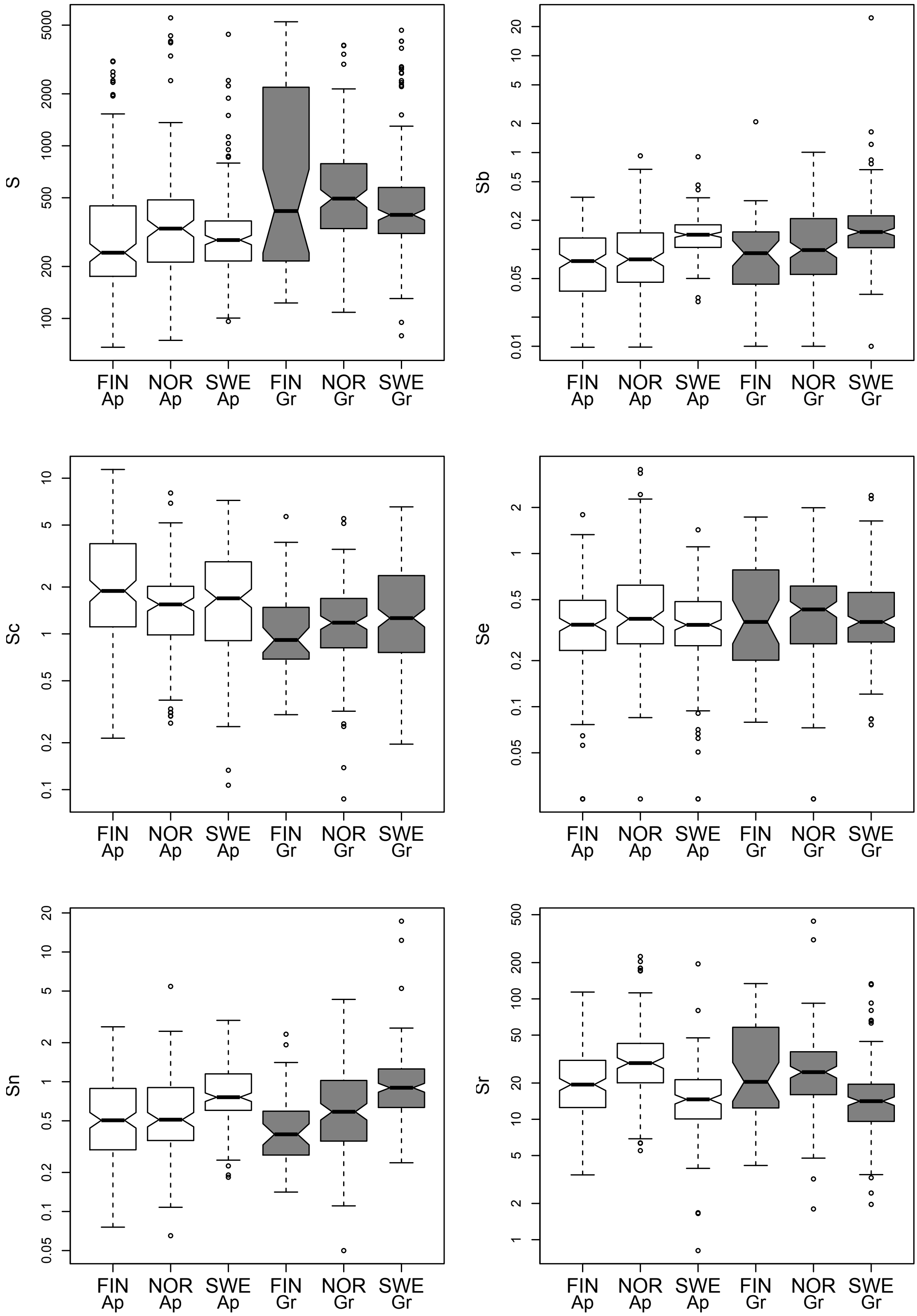

Cr
Cs
Cu
Fe
Ga
Ge
FIN Ap
NOR Ap
SWE Ap
FIN Gr
NOR Gr
SWE Gr

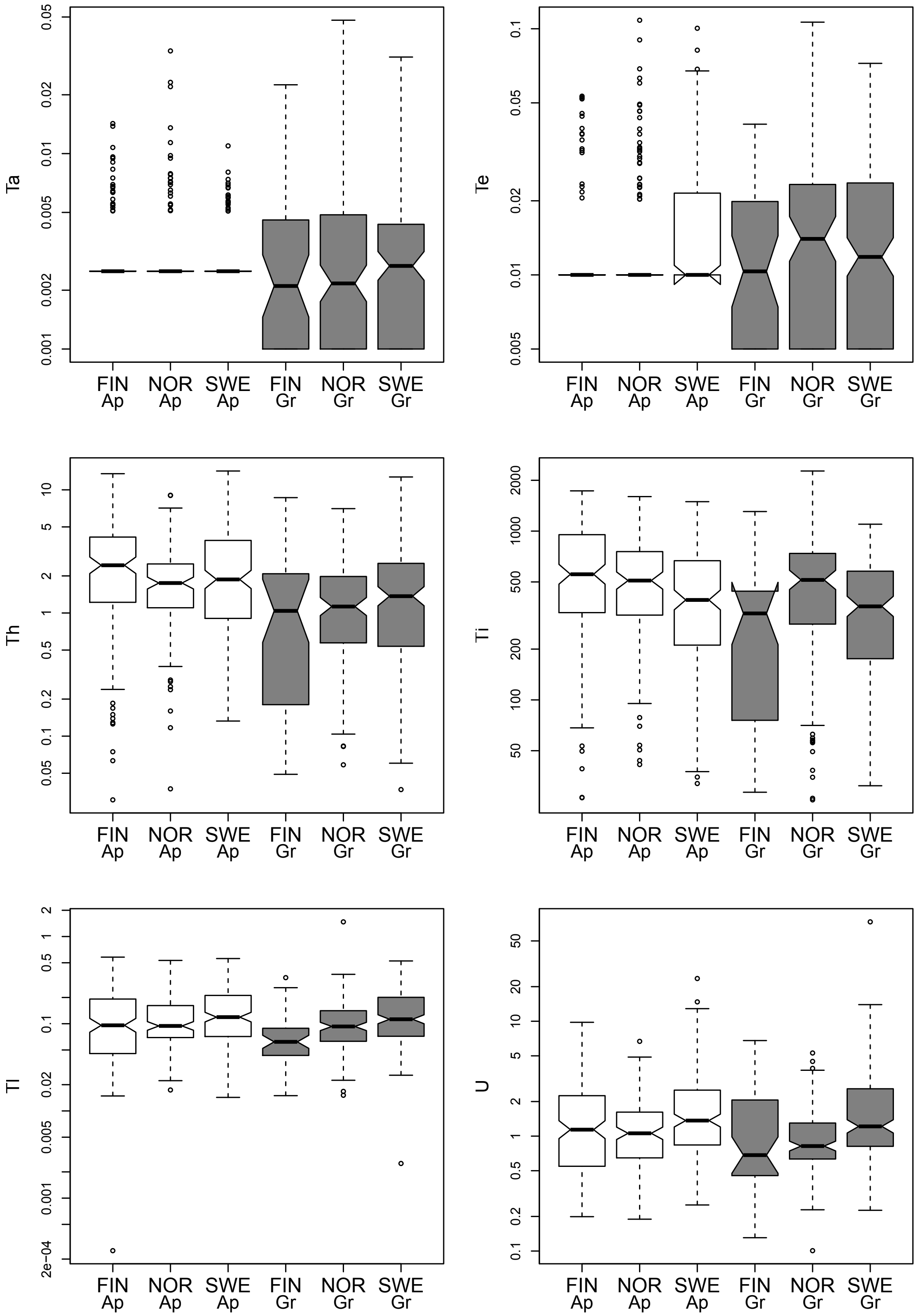

Hf
0.5
0.2
0.1
0.05
0.02
0.01
0.005
Hg
2
1
0.5
0.2
0.05
0.01
0.002
In
0.05
0.02
0.01
0.005
0.002
0.001
K
5000
2000
1000
500
200
100
La
200
100
50
20
10
5
2
1
Li
50
20
10
5
2
1
0.5
0.2
0.05
FIN Ap
NOR Ap
SWE Ap
FIN Gr
NOR Gr
SWE Gr


Mg
Mn
Mo
Na
Nb
Ni
FIN Ap
NOR Ap
SWE Ap
FIN Gr
NOR Gr
SWE Gr



P
200
500
1000
2000
Pb
2
5
10
20
50
100
200
500
Pd
2e−04
5e−04
0.001
0.002
0.005
0.01
0.02
Pt
2e−04
5e−04
0.001
0.002
0.005
Rb
0.2
0.5
1
2
5
10
20
50
100
Re
5e−05
2e−04
5e−04
0.002
0.005
FIN Ap
NOR Ap
SWE Ap
FIN Gr
NOR Gr
SWE Gr


S
100
200
500
1000
2000
5000
Sb
0.01
0.05
0.2
0.5
1
2
5
10
20
Sc
0.1
0.2
0.5
1
2
5
10
Se
0.05
0.1
0.2
0.5
1
2
Sn
0.05
0.1
0.2
0.5
1
2
5
10
20
Sr
1
2
5
10
20
50
100
200
500
FIN Ap
NOR Ap
SWE Ap
FIN Gr
NOR Gr
SWE Gr



Ta
0.05
0.02
0.01
0.005
0.002
0.001
Te
0.1
0.05
0.02
0.01
0.005
Th
10
5
2
1
0.5
0.2
0.1
0.05
Ti
2000
1000
500
200
100
50
Tl
2
1
0.5
0.1
0.02
0.005
0.001
2e−04
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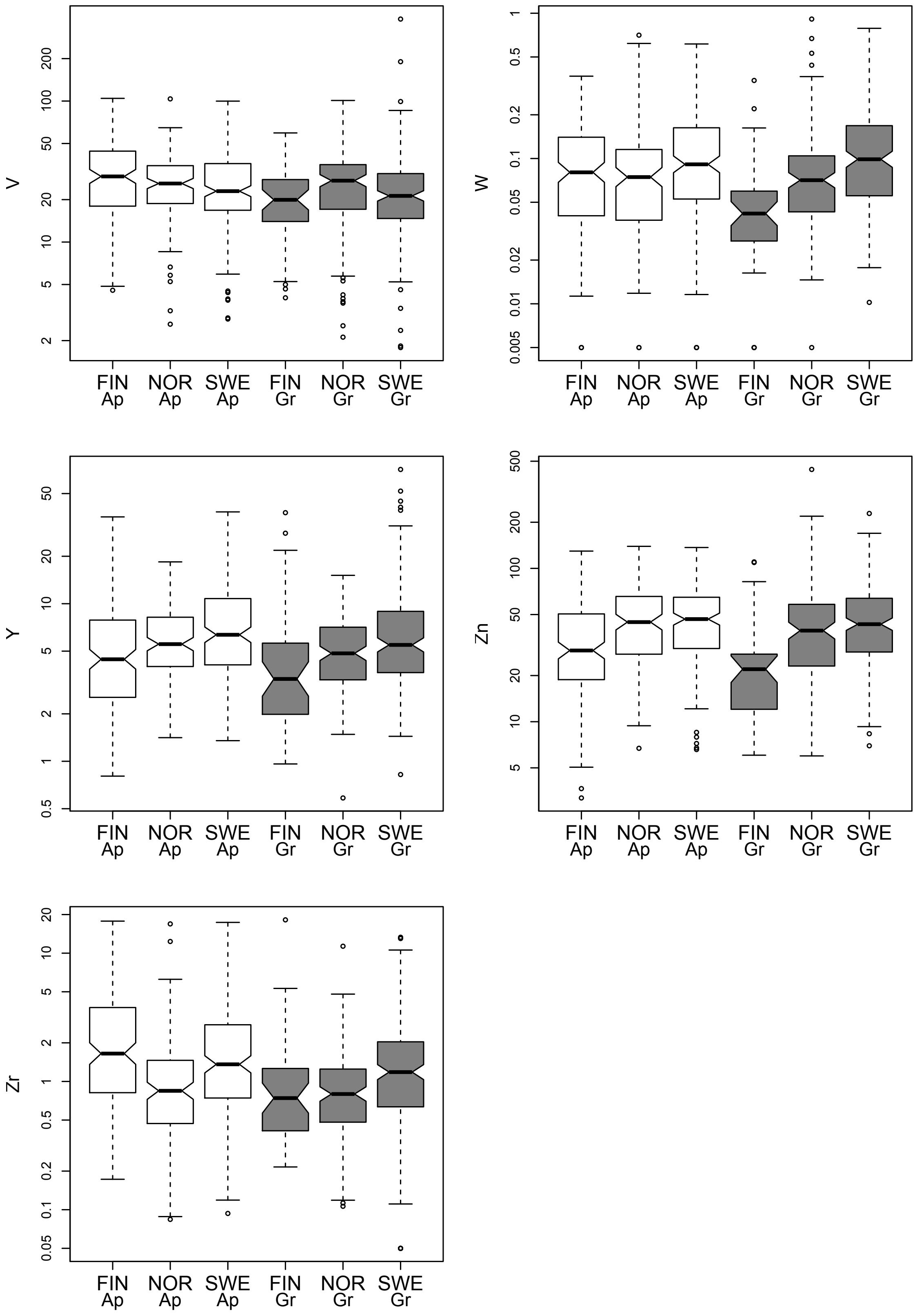
V
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