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Rare Earth Elements in Moss in Sweden

Spatial Patterns and Temporal Comparisons

Master's thesis in Industrial Ecology

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Abstract

Rare earth elements (REEs) are increasingly used in modern technologies such as wind turbines, electric vehicles and electronics. Despite their growing importance, there is still limited knowledge about how these elements spread and behave in the environment. Mosses are often used as biomonitors of air pollution due to their ability to accumulate elements directly from atmospheric deposition. This thesis investigates temporal and spatial patterns of REEs in Swedish moss between 2015 and 2025, compares Swedish concentrations with those reported in international studies and evaluates correlations between REEs and selected metals in order to assess potential sources. The work was based on concentration data from moss samples collected within the Swedish national environmental monitoring programme. Samples from 2015 and 2025 were analysed using descriptive statistics, temporal comparisons and GIS-based spatial analysis. In addition, enrichment factor calculations and correlation analyses with aluminium (Al), lead (Pb) and antimony (Sb) were carried out to support interpretation of REE sources and behaviour. The results showed that REE concentrations in Swedish moss were generally low and followed the natural abundance pattern of the Earth's crust, with light REEs (LREEs) occurring at higher concentrations than heavy REEs (HREEs). Similar spatial distributions were observed in both 2015 and 2025, with somewhat elevated concentrations mainly in southern and central Sweden. Most REEs showed modest increases in concentration between 2015 and 2025, while the overall spatial patterns remained similar. Strong correlations between REEs and aluminium indicated that crustal material is an important contributor to the observed concentrations. However, local hotspots and enrichment patterns suggested that anthropogenic influences may occur in specific areas. Overall, the results suggest that REEs in Swedish moss are predominantly influenced by natural background sources, although the observed temporal increases and local enrichment indicate that continued environmental monitoring remains important.

Keywords: rare earth elements, moss biomonitoring, atmospheric deposition, spatial distribution, temporal trends, environmental monitoring, Sweden, anthropogenic sources.

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Table of Contents

List of Acronyms	x
List of Figures.....	xi
List of Tables	xii
1 Introduction	2
1.1 Background.....	2
1.2 Aim and research questions.....	3
1.3 Scope and limitations.....	3
2 Theory.....	4
2.1 Rare Earth Elements (REE): definition and classification.....	4
2.2 Environmental distribution and behaviour of REE	6
2.3 Anthropogenic sources of REE.....	8
2.3.1 Mining and mineral processing	8
2.3.2 Combustion and industrial emissions.....	9
2.3.3 Technological applications and the green transition	10
2.4 Moss as a biomonitor.....	10
2.4.1 Biological characteristics of moss.....	11
2.4.2 Moss uptake mechanisms	12
3 Methodology.....	14
3.1 Literature review	14
3.2 IVL moss sampling methodology and sample analysis.....	14
3.3 Data treatment and analysis.....	18
3.3.1 Data processing and temporal comparison.....	19
3.3.2 Spatial analysis and visualization.....	20
3.3.3 Comparative and interpretative analysis	20
3.3.4 Correlation analysis with selected metals	21
4 Results and discussion.....	23
4.1 Overall REE concentrations and descriptive statistics	23
4.2 Spatial distribution and temporal changes of REEs in Sweden (2015-2025)	25
4.3 Comparison with previous studies.....	34
4.4 Correlation analysis	40
4.5 Enrichment factor analysis.....	44
4.6 Overall interpretation of REE patterns and potential sources.....	47
5 Conclusion	50
References	51
Appendix	56

List of Acronyms

Below is the list of acronyms used in this thesis, listed in alphabetical order:

CLRTAP	Convention on Long-Range Transboundary Air Pollution
Dw	Dry weight
GIS	Geographic Information System
HREE	Heavy Rare Earth Elements
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP Vegetation	International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops
IDW	Inverse Distance Weighting
IQR	Interquartile Range
IVL	IVL Swedish Environmental Research Institute
LREE	Light Rare Earth Elements
NASC	North Americal Shale Composite
PM	Particulate Matter
PAAS	Post-Archean Australian shale
ppm	Parts per million
REE	Rare Earth Elements
REO	Rare Earth Oxides
UCC	Upper Continental Crust

List of Figures

FIGURE 1. PICTURES OF PLEUROZIIUM SCHREBERI AND HYLOCOMIUM SPLENDENS	12
FIGURE 2. ICP-MS AT THE IVL LABORATORY.	16
FIGURE 3. PREPARATION OF MOSS SAMPLES BEFORE DIGESTION	17
FIGURE 4. PICTURE OF THE TEFLON VESSELS AND THE THE MICROWAVE WITH THE VESSELS PUT INSIDE.....	18
FIGURE 5. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF CERIUM AND DYSPROSIUM, ..	26
FIGURE 6. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF ERBIUM AND EUROPIUM,	27
FIGURE 7. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF GADOLINIUM AND HOLMIUM,	28
FIGURE 8. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF LANTHANUM AND LUTETIUM,	29
FIGURE 9. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF NEODYMIUM AND PRASEODYMIUM,	30
FIGURE 10. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF SAMARIUM AND TERBIUM, .	31
FIGURE 11. SPATIAL DISTRIBUTION AND PERCENTAGE CHANGE OF THULIUM AND YTTERBIUM,	32
FIGURE 12. THE SUM AND COMPARISON OF REE CONCENTRATION IN MOSS ACROSS DIFFERENT COUNTRIES (WITH CHINA).	35
FIGURE 13. THE SUM AND COMPARISON OF REE CONCENTRATION IN MOSS ACROSS DIFFERENT COUNTRIES (EXCLUDING CHINA).	36
FIGURE 14. CORRELATIONS BETWEEN Σ REEs AND AL AND Pb FOR BACKGROUND SAMPLES IN 2015. (A) ALL SAMPLES. (B) OUTLIERS REMOVED USING IQR METHOD (11 FOR AL AND 10 FOR Pb). THE BLUE LINE REPRESENTS THE FITTED LINEAR REGRESSION AND THE SHADED AREA INDICATES THE 95% CONFIDENCE INTERVAL.	41
FIGURE 15. CORRELATIONS BETWEEN Σ REEs AND AL AND Pb FOR INDUSTRY/URBAN SAMPLES IN 2015. (A) ALL SAMPLES. (B) OUTLIERS REMOVED USING IQR METHOD (1 FOR AL AND 2 FOR Pb). THE BLUE LINE REPRESENTS THE FITTED LINEAR REGRESSION AND THE SHADED AREA INDICATES THE 95% CONFIDENCE INTERVAL.	42
FIGURE 16. CORRELATIONS BETWEEN Σ REEs AND AL, Pb AND Sb FOR BACKGROUND SAMPLES IN 2025. (A) ALL SAMPLES. (B) OUTLIERS REMOVED USING IQR METHOD (6 FOR AL, 8 FOR Pb AND 0 FOR Sb). THE BLUE LINE REPRESENTS THE FITTED LINEAR REGRESSION AND THE SHADED AREA INDICATES THE 95% CONFIDENCE INTERVAL.....	43
FIGURE 17. ENRICHMENT FACTOR PLOTTED IN BOXPLOTS FOR BACKGROUND SAMPLES (N = 86) AND INDUSTRY/URBAN SAMPLES (N = 20) FOR THE YEAR 2015.	45
FIGURE 18. ENRICHMENT FACTOR PLOTTED IN BOXPLOTS FOR BACKGROUND SAMPLES (N = 100) FOR THE YEAR 2025.....	46

List of Tables

TABLE 1. THE FOURTEEN NATURALLY OCCURRING LANTHANIDES WITH ATOMIC WEIGHTS (COMMISSION ON ISOTOPIC ABUNDANCES AND ATOMIC WEIGHTS, 2024).....	5
TABLE 2. NORMALIZATION CONCENTRATIONS, REFERENCE VALUES AND MEAN CRUSTAL ABUNDANCE (SAGER & WICHE, 2024; CHEN ET AL., 2025).....	7
TABLE 3. REEs IN MOSS SAMPLES COLLECTED IN BACKGROUND ENVIRONMENT IN SWEDEN, 2015 AND 2025 (MG/KG) (DANIELSSON ET AL., 2018; IVL, 2026).	24
TABLE 4. COMPARISON OF MEAN VALUES OF LIGHT REEs FROM DIFFERENT PARTS OF THE WORLD IN MOSSES (MG/KG).....	37
TABLE 5. COMPARISON OF MEAN VALUES OF HEAVY REEs FROM DIFFERENT PARTS OF THE WORLD IN MOSSES (MG/KG).....	38
TABLE A. 1. LIGHT EARTH ELEMENTS 2015 (MG/G) TS.	56
TABLE A. 2. HEAVY RARE EARTH ELEMENTS 2015 (MG/G) TS.	58
TABLE B. 1. LIGHT RARE EARTH ELEMENTS 2025 (MG/G) TS.	60
TABLE B. 2. HEAVY RARE EARTH ELEMENTS 2025 (MG/G) TS.	63

1 Introduction

This chapter gives an introduction to the project and aim to the research. It will present important background information, research questions and relevant limitations for the thesis.

1.1 Background

Since 1975, mosses have been used in Swedish national environmental monitoring as biomonitors of atmospheric deposition. The method is based on the ability of mosses to accumulate substances directly from the air, making them suited for detecting changes in environmental load and to identify spatial patterns of airborne pollutants. The moss surveys have been conducted every fifth year since 1975 for metals as a part of Sweden's environmental monitoring programme and the international ICP Vegetation network. In the Swedish moss survey, sampling is conducted across the whole country to represent regional background conditions. The moss species mainly used in Sweden are *Pleurozium schreberi* and *Hylocomium splendens* (IVL Swedish Environmental Research Institute, 2025).

Rare earth elements (REEs) are a group of chemically similar elements within the lanthanide family and the group consists of seventeen elements in the periodic table (Danielsson et al., 2018). This study will focus on the fourteen naturally occurring lanthanides. REEs are commonly divided into light rare earth elements (LREE) and heavy rare earth elements (HREE) based on their atomic weight and behaviour. They may therefore also differ in environmental mobility and behaviour. Although REEs are relatively abundant in the Earth's crust, they rarely occur in high exploitable concentrations that are economically favourable and are typically dispersed in mineral phases. In recent years, their importance has increased significantly due to their critical role in renewable energy technologies, electronics and other advanced applications.

Despite the growing importance in society, knowledge about their occurrence, distribution and environmental behaviour remains very limited. In contrast to many traditionally monitored metals, REEs are not routinely included in environmental monitoring programmes and therefore lack established environmental quality standards. As a result, there is a need for improved understanding of their behaviour in the environment and to investigate spatial distribution and temporal trends across countries.

In Sweden, REEs were analysed in moss samples for the first time in 2015 providing a national baseline for atmospheric deposition of these elements. In 2025 new moss samples were collected and analysed, which for the first time enabled a temporal comparison of REE concentration in Swedish moss during a 10-year period. To support interpretation of REE data, comparisons with selected traditionally monitored metals can provide valuable context. Similarities in spatial distribution or correlations in data analysis may indicate shared emission sources. Such comparative analysis can therefore contribute to a more robust understanding of REE behaviour in the environment.

1.2 Aim and research questions

The aim of this thesis is to investigate temporal and spatial patterns of rare earth elements in moss in Sweden between 2015 and 2025, and to compare potential correlations with those of selected other metals in order to support interpretation of REE trends and sources.

The thesis aims to address the following research questions:

- What temporal and spatial changes in rare earth element concentrations in Swedish moss can be observed between 2015 and 2025, and how do patterns differ between light and heavy REEs?
- How do concentrations of rare earth elements in moss in Sweden compared to those reported in other studies?
- How do rare earth elements correlate to other selected metals? Do they have common sources?

1.3 Scope and limitations

The thesis focuses on rare earth elements in moss samples collected within the Swedish national environmental monitoring programme. In addition, a set of selected other traditionally monitored metals is included for comparative and correlation purposes. The temporal analysis is limited to the years 2015 and 2025. The thesis aims to identify broad geographical patterns and gradients as well as individual point sources. Furthermore, the thesis does not aim to perform quantitative risk or toxicity assessments. Due to the lack of established guideline values for REEs, environmental implications are discussed primarily based on spatial patterns, temporal trends and correlation with other metals and previous studies.

2 Theory

This chapter provides the theoretical background for understanding the occurrence and behaviour of rare earth elements in moss. It introduces classification, potential sources and the environmental significance of REEs, as well as their increasing use in modern technologies. The chapter also described the use of moss as biomonitors for atmospheric deposition and moss uptake mechanism.

2.1 Rare Earth Elements (REE): definition and classification

The rare earth elements are a group of seventeen metallic elements, including the fifteen lanthanides together with scandium (Sc) and yttrium (Y) (The Geological Society of London, 2011). Although scandium and yttrium are not lanthanides, they are classified as REEs because they have similar chemical properties and commonly occur in the same mineral deposits as lanthanides. Due to their similar electronic configurational and chemical properties, REEs are often treated as a coherent group in environmental studies. In this thesis, the focus is on the fourteen naturally occurring lanthanides: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu), excluding promethium (Pm) as it does not occur naturally in significant amounts in the Earth's crust and is radioactive.

The lower atomic weight elements lanthanum (La) to samarium (Sm) are referred to as the light rare earth elements (LREE), while europium (Eu) to lutetium (Lu) are the heavy rare earth elements (HREE) (The Geological Society of London, 2011). The average abundance for REE in earth's crust is typically higher for LREE than for HREE. During magma crystallization, HREEs tend to be incorporated into early forming minerals, while LREEs remain in the melt and become enriched in a later stage, silica rich rocks (Sager & Wiche, 2024). The LREE concentrations often exceed HREE concentrations with a factor of 8-10 reflected in $\sum LREE / \sum HREE$ ratios observed in soils and moss (Berg & Steinnes, 1997; Rühling & Tyler, 2004).

Table 1. The fourteen naturally occurring lanthanides with atomic weights (Commission on Isotopic Abundances and Atomic Weights, 2024).

Name	Atomic number	Atomic weight (g/mol)	Chemical symbol	REE-group
Lanthanum	57	138.91	La	LREE
Cerium	58	140.12	Ce	LREE
Praseodymium	59	140.91	Pr	LREE
Neodymium	60	144.24	Nd	LREE
Samarium	62	150.36	Sm	LREE
Europium	63	151.96	Eu	LREE
Gadolinium	64	157.25	Gd	HREE
Terbium	65	158.93	Tb	HREE
Dysprosium	66	162.50	Dy	HREE
Holmium	67	164.93	Ho	HREE
Erbium	68	167.26	Er	HREE
Thulium	69	168.93	Tm	HREE
Ytterbium	70	173.05	Yb	HREE
Lutetium	71	174.97	Lu	HREE

REEs are widely distributed in rocks, soils and aquatic systems, and share similar ionic radii to the element Ca^{2+} (Sager & Wiche, 2024). Rare earth elements strongly interact with phosphate on negatively charged surfaces and forms cations similar to Ca^{2+} . In natural systems, REEs predominantly occur in the trivalent oxidation state (+3) and their biogeochemical behaviour resembles other trivalent metals, particularly Al^{3+} (Sager & Wiche, 2024). As atomic number increases from lanthanum (La) to lutetium (Lu) the ionic radii of the trivalent ions gradually decrease.

Despite their name, rare earth elements are not particularly rare but are widely distributed in the Earth's crust. The abundance of REE in the earth's crust varies from 0.5 mg/kg (Tm) to 66 mg/kg (Ce) with a mean value of 215 mg/kg (Dołęgowska & Migaszewski, 2013). However, REEs are rarely found in high concentrated ore bodies and are typically dispersed within silicate, carbonate, phosphate and other oxide minerals (Sager & Wiche, 2024). The dispersed occurrence complicates economically favourable extractions and increases the environmental footprint of mining and processing.

2.2 Environmental distribution and behaviour of REE

Rare earth elements occur naturally in several geological materials as well as in igneous, metamorphic rocks, pegmatites and granites (Tyler, 2004). Their environmental distribution is largely controlled by the characteristics of rocks and different weathering processes. In Scandinavian regions, REEs are primarily associated with granitic and metamorphic bedrock as well as certain alkaline igneous complexes.

During weathering, REEs are released from primary minerals and transferred into soils through both physical and chemical processes. Physical weathering generates fine particles that can be transported as soil dust, while chemical weathering releases REEs into soil water. However, REEs rarely remain in dissolved form for extended periods. Instead, they quickly bind to soil particles and organic matter, which limits their mobility (Sager & Wiche, 2024). Furthermore in soils, rare earth elements are mainly controlled by sorption processes. Sorption refers to the attachment of dissolved ions to the surface of minerals or organic materials. Iron (Fe) and manganese (Mn) oxides play an important role in controlling REE behaviour as they provide large reactive surface areas that strongly bind REE^{3+} ions. In addition, soil organic matter can form stable complexes with REEs, resulting in further reduction in their mobility (Sager & Wiche, 2024; Xu et al., 2022). As a result of these processes, REEs are usually not present in dissolved form in soil water but are predominantly bound to solid phases.

Soil pH also has a strong influence on REE behaviour. At low pH and acidic conditions, sorption to mineral and organic surfaces decreases and REEs become more soluble and mobile. At higher pH, REEs bind more strongly to these surfaces resulting in lower mobility (Sager & Wiche, 2024). Differences between light and heavy rare earth elements have also been observed. LREEs tend to be slightly more soluble, while HREEs form stronger and more stable complexes with organic matter. These differences may influence their behaviour and movement in soil (Sager & Wiche, 2024).

Even though REEs are not very mobile in dissolved form they can still be transported when associated with particulate matter (PM). Soil dust generated by weathering and erosion can carry rare earth elements into the atmosphere where they can be transported over longer distances. On top of that, industrial activities and combustion processes can contribute

releases of REE particles into the air (Bačeva Andonovska et al., 2023). Once airborne, these particles act as carriers for REEs and may be deposited onto terrestrial surfaces through both wet and dry deposition.

Table 2. Normalization concentrations, reference values and mean crustal abundance (Sager & Wiche, 2024; Chen et al., 2025).

Element	PAAS (mg/kg dw)	NASC (mg/kg dw)	EUS (mg/kg dw)	UCC (ppm)
La	44.6	32	44.3	39
Ce	88.2	73	88.5	78
Pr	10.1	7.9	10.6	9.1
Nd	37.3	33	39.5	35
Sm	6.88	5.7	7.30	6.8
Eu	1.21	1.24	1.48	1.34
Gd	6.04	5.2	6.34	6.0
Tb	0.89	0.85	0.94	0.95
Dy	5.32	5.8	5.86	5.5
Ho	1.05	1.04	1.17	1.13
Er	3.07	3.4	3.43	3.3
Tm	0.45	0.5	0.49	0.49
Yb	3.01	3.1	3.26	3.2
Lu	0.44	0.48	0.49	0.49

Rare earth element concentrations in rocks, soils and other biological materials are commonly interpreted through comparison with established geochemical reference systems. These include chondritic materials as well as different shale-based standards that represent the composition of the upper continental crust. Table 2 shows the most commonly used shale standards which includes the Post-Archean Australian shale (PAAS), the North American Shale Composite (NASC) and the European shale (Sager & Wiche, 2024). Normalization of REE concentrations involves dividing measured values by those of a selected reference dataset. This approach helps to analyse the fraction patterns between different elemental groups (e.g. LREE and HREE), anomalies and distinction between natural and anthropogenic sources. The PAAS dataset is based on nine Australian shale samples, NASC is based on 40

shale samples (including 20 from the United States) and the European shale originates from a Phanerozoic shale reference established in 1935 (Sager & Wiche, 2024). These normalization frameworks are very useful when interpreting REE concentrations in biological indicators such as moss. Since mosses primarily accumulate elements from atmospheric deposition and surface interactions, comparing with shale derived reference compositions enables the differentiation between background crustal inputs and anthropogenic enrichment. Table 2 also shows the mean crustal abundance for the Upper Continental Crust (UCC) of the Earth, as another commonly used reference system (Chen et al., 2025).

2.3 Anthropogenic sources of REE

The increasing demand for REEs are driven by their new and critical role in the green transition such as renewable energy technologies and advanced electronics. The emerging demand in this sector the past few years have contributed to the pressure of extracting rare earth metals at higher rates, thereby increasing the risk that rare earth metal extraction becomes an important anthropogenic source.

2.3.1 Mining and mineral processing

China has dominated the global REE production in recent decades and accounts for more than 95% of the global supply between 2000 and 2010, and approximately 60-70% between 2010 and 2020 (Sager & Wiche, 2024). Globally the resources of REE are unevenly distributed and are estimated at 43% in China, 17% in Russia and 12% in USA, as well as additional deposits in Australia, India, Brazil and Greenland.

Mining and processing of REE ores represent important sources of environmental emission. During extraction and refining, REEs may be released into the surrounding environment through dust pollution, tailings and wastewater from ore processing or chemical separation steps. These emissions can contribute to elevated REE concentrations in nearby environment in both soils and atmospheric particles, which can be transported and deposited over longer distances. Although REEs are not volatile, they can be transported through the atmosphere when bound to particulate matter. Airborne PM can be a carrier of many trace elements including rare earth elements. However, REEs are typically present at very low concentrations in air and are not routinely included in conventional air quality monitoring programmes. Monitoring atmospheric REE deposition using conventional air sampling methods, such as

particulate matter collection on filters often requires specialised equipment. In contrast, biomonitoring using mosses provides a much more practical and cost-effective alternative to determine and measure atmospheric deposition for REEs.

Within Europe there have been several significant sources of REE identified, although large scale mining activity remains limited. In Sweden, there have been large discoveries of REE deposits including the Per Geijer mine in Kiruna, northern Sweden. The discovery includes over one million tons of rare earth elements in the form of rare earth oxides (REO), which is used for the production of REEs (LKAB, 2023). There have also been notable discoveries in Norra Kärr (Jönköping) and Olserum (Västervik). Despite these findings, large scale extraction has not yet been implemented in Sweden. However, interest in REE resources has increased in recent years driven by the growing demand for critical raw minerals within the European Union and the desire to reduce dependence on external supply chains.

2.3.2 Combustion and industrial emissions

In addition to mining activities, several other industrial processes such as coal combustion can contribute to anthropogenic emissions of REEs. Coal naturally contains trace amounts of REEs bound to different mineral phases (Sager & Wiche, 2024). During combustion these elements are not destroyed but instead become concentrated in residues such as ash. Because combustion ash consists of fine particles, it can be emitted into the atmosphere and transported over longer distances. As a result, coal combustion can contribute to the atmospheric load of rare earth elements, particularly in regions where intensive energy production and industrial activity occur (Aničić Urošević et al., 2020).

Industrial processes such as metal smelting and waste incineration can also contribute to REE emissions (Jovan et al., 2024). Solid waste incineration has been identified as a potential source of atmospheric trace elements through both stack emissions and the release of fine particles (dust). Particulate matter plays a central role in the environmental transport of REEs from combustion and industrial sources. Rather than existing in gaseous form, REEs are typically associated with solid particles. These fine particles that are generated during combustion and other processes can remain suspended in the atmosphere and be transported over longer distances before deposition occurs.

2.3.3 Technological applications and the green transition

Rare earth elements have become essential components in our modern society due to their important role in advanced technologies and the ongoing transition towards low carbon energy systems. Their unique properties include magnetic strength, luminescence and catalytic characteristics, which makes them usable in a wide range of technology applications (Sager & Wiche, 2024). As a result, the demand for REEs has increased significantly in recent years and is driven by the rapid expansion of renewable energy technologies and electronics. One of the most important technological applications of REEs are in permanent magnets used in wind turbines and electric vehicles. Elements such as neodymium (Nd), praseodymium (Pr), cerium (Ce) and samarium (Sm) are essential for producing these high-performance magnets with strong magnetic properties and thermal stability (Sager & Wiche, 2024).

In addition to energy applications, REEs are widely used in electronic devices and communication technology. They are essential components in telephones (neodymium, Nd), computer hard drives (terbium, Tb) and flat screen monitors (europium, Eu) (Aničić Urošević et al, 2020). Rare earth elements are also used in lasers, guidance systems and other defence technologies such as radar and sonar systems. Another important application area is in the medical field where gadolinium (Gd) is widely used as a contrast agent in magnetic resonance imaging (MRI) (Sager & Wiche, 2024).

The rapid growth of REE consumption has also resulted in increased electronic waste, which represents another important source of REEs to the environment. Electronic devices contain numerous of REE components and improper disposal or inefficient recycling processes can lead to further release of these elements into soils, water systems and atmospheric particulate matter. Despite their high economic value, the recycling rates of REEs remain relatively low due to technical challenges with separation and recovery (Binnemans et al., 2013).

2.4 Moss as a biomonitor

Mosses are widely used as biomonitors of atmospheric pollution due to their ability to accumulate trace elements directly from the atmosphere (Rühling & Tyler, 2004). Unlike other vascular plants, mosses lack a developed root system and obtain most of their nutrients from wet and dry atmospheric deposition. This characteristic makes them particularly suitable for monitoring airborne pollutants such as heavy metals and rare earth elements. Moss

biomonitoring has therefore become a widely applied method in environmental monitoring programmes for assessing spatial and temporal patterns of atmospheric deposition (ICP Vegetation, 2020).

The moss monitoring method has been implemented across Europe through the International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation). This programme uses moss species to assess atmospheric deposition of heavy metals, nitrogen and other organic pollutants across large geographical regions. The method is an easy and cost-effective approach towards environmental monitoring and allows researchers to identify long term trends in atmospheric pollution (Bačeva Andonovska et al., 2023). In Sweden, mosses have been used as a biomonitor since the 1970s as a part of the national environmental monitoring programme. Repeated studies have been conducted every five years to evaluate the accumulation of metals in mosses across the country (Danielsson et al., 2021).

2.4.1 Biological characteristics of moss

Mosses belong to the group of non-vascular plants known as bryophytes. They differ from vascular plants in several ways that make them particularly suitable for biomonitoring studies. One key feature as mentioned is the absence of a well-developed root system. Instead of absorbing nutrients from roots, mosses rely primarily on atmospheric deposition and surface water for nutrient uptake. Carpet forming mosses, such as *Pleurozium schreberi* and *Hylocomium splendens* are not rooted in a substrate (such as soils), and their uptake of elements from the ground is therefore considered insignificant or negligible (Rühling & Tyler, 2004). Another important characteristic of mosses is the absence of a protective waxy cuticle on the surface of their leaves. In vascular plants, the cuticle acts as a barrier that reduces the absorption of external substances. Since mosses lack this protective layer, water and dissolved ions can more easily penetrate their tissue. This makes mosses highly sensitive to environmental changes and allows them to accumulate substances directly from precipitation and atmospheric particles (Xu et al., 2022). Mosses also have a high surface area to volume ratio which enhances their ability to capture airborne particles and dissolved substances from precipitation. The cell walls of moss tissues contain negatively charged sites that bind positively charged metal ions through cation exchange processes. Together these characteristics enables mosses to efficiently accumulate trace metals from the atmospheric deposition (Xu et al., 2022).



Figure 1. Pictures of *Pleurozium schreberi* and *Hylocomium splendens*
(Ohio Moss and Lichen Association, n.d.; BioPix, n.d.).

Another important characteristic of mosses used in biomonitoring is their segmented growth structure. Moss shoots typically consist of annual growth segments, which allows researchers to distinguish different growth periods. The upper segments of moss plants represent approximately two to three years of growth and therefore reflects the atmospheric deposition over this period of time (Rühling & Tyler, 2004).

2.4.2 Moss uptake mechanisms

The accumulation of elements in mosses occurs primarily through atmospheric deposition rather than through uptake from soil. This is largely due to their lack of a developed root system and protective cuticle. Instead, elements are absorbed directly from the moss surface via several mechanisms including wet deposition, dry deposition and particle entrapment.

Wet deposition refers to the transfer of atmospheric substances to surfaces through precipitation such as rain, snow, fog or dew. Trace elements that are present in the atmosphere may dissolve in precipitation water that eventually deposits onto moss surfaces. When precipitation reaches the moss canopy, dissolved ions can be absorbed directly by the moss tissue through passive diffusion and ion exchange. Since mosses lack the protective cuticle and possess a high surface to volume ratio, they are particularly efficient at absorbing dissolved metals and other elements (Xu et al. 2022; Sager & Wiche, 2024). Dry deposition on the other hand involves the direct settling of airborne particles onto surfaces in absence of precipitation. Atmospheric particulate matter, which often contains trace elements such as REEs, can be deposited onto moss surfaces. Once deposited, these particles can remain attached to the moss surface and gradually release components that can be absorbed by the

moss tissue. Dry deposition is common in areas influenced by industrial emissions or combustion industries where airborne particulate matters are released in the air.

Particle entrapment refers to the physical retention of airborne particles on the moss surface. The structural characteristics of moss, enhances its ability to intercept and retain particulate matter. As air passes over the moss, particles of various sizes can be captured within the shoots and leaves. Once trapped particles can either remain on the surface or become incorporated in the tissue over time (Tyler, 1990).

3 Methodology

The thesis was conducted as a combination of literature review and data treatment. In addition, methodological insights were obtained through documentation provided by IVL Swedish Environmental Research Institute and through study visits to the IVL laboratory. The information was gathered from scientific articles, reports and books accessed through different databases such as Google Scholar, ScienceDirect and Chalmers Library. Moreover, official IVL protocols, manuals and internal documentation were used to ensure that the methodology described reflects current practices in Swedish environmental monitoring.

3.1 Literature review

Initially a comprehensive literature review was conducted to establish a theoretical foundation for the study. The review focused on rare earth elements, their environmental occurrence and the use of mosses as bioindicators of atmospheric deposition. Additional reports and datasets were provided by IVL, including previous moss surveys conducted in Sweden. Keywords used during the literature search included: *rare earth elements*, *moss uptake mechanism*, *atmospheric deposition*, *moss used as a bioindicator* and *moss sampling*.

The literature review also included methodological documentation related to moss monitoring programs. In particular, the ICP Vegetation monitoring manual was used to understand international standards for moss sampling. This included site selection, sampling density and sample handle procedures (Hayes et al., 2024).

3.2 IVL moss sampling methodology and sample analysis

To gain a detailed understanding of the practical aspects of moss monitoring, both IVLs and ICP vegetation official sampling protocols and laboratory procedures were studied. These protocols were used in the national moss monitoring program in Sweden. According to IVLs sampling instructions, moss samples were collected in background environments, typically located at least 300 meters from major roads and at least 100 meters from smaller roads or buildings (IVL, 2025). For REEs, there were 100 samples collected throughout Sweden in the summer months of 2025. Sampling was carried out using two different moss species, primarily *Pleurozium schreberi* and second *Hylocomium splendens*. The sampling sites were typically located in forested areas, preferably near closed forest stands, but not directly under spruce trees as throughfall may influence deposition patterns. At each sampling site, 2-3 litres

of moss was collected, and multiple subsamples (typically 5-10) was collected within a defined area (IVL, 2025). To avoid contamination during sampling, strict handling procedures were followed. The use of nitriles gloves was required, and moss samples were cleaned (not washed) from soil, litter and other prior to storage. Only the upper green part (approximate 2-3 cm) of the moss was used for analysis as it represents the most recent growth and therefore most relevant for assessing atmospheric deposition. The samples were placed in double 5 litre plastic bags that are labelled with sampling date, name of sampler, ID number, altitude above sea level, topography, moss species and the number of subsampling points. After collection, the samples were sent to IVL for review and cataloguing. The samples were later sent to the National Museum of Natural History for further manual cleaning (remove dead material and litter) and drying at room temperature. The amount of cut shoots from the moss was estimated to weigh at least 4 g dry weight at room temperature per sample. The National Museum of Natural History keeps the moss samples stored in the Environmental Specimen Bank and sends small bag samples with 4 g of moss to IVLs laboratory where samples get prepared for analysis.

The analytical method used for determining elemental concentrations at IVL was inductively coupled plasma mass spectrometry (ICP-MS), which is a technique that combines a high energy plasma source with mass spectrometers to analyse isotopic and elemental compositions with high sensitivity and accuracy (Hills & Fisher, 2017). The ICP-MS instrument used at the IVL lab were a Thermo.Scientific ICAP Qc (Segura Roux et al., 2025).



Figure 2. ICP-MS at the IVL laboratory.

Before the ICP-MS analysis, the samples were prepared with nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). About 0.3 g of moss material was digested with the mixture of 7ml HNO_3 and 1 ml H_2O_2 .



Figure 3. Preparation of moss samples before digestion
with 0.3 g of moss material.

The solution was afterwards put in closed Teflon vessels using microwave assisted digestion. The microwave oven was equipped with a 2000 MHz microwave power supply of 0-1800 W output, resistant up to 200 psi and 210°C (Segura Roux et al., 2016). The temperature increased to 200°C within 20 minutes with the power of 1800 W. After, the vessels cooled for 60 minutes before being diluted with ultrapure water to the final volume of 50 ml.

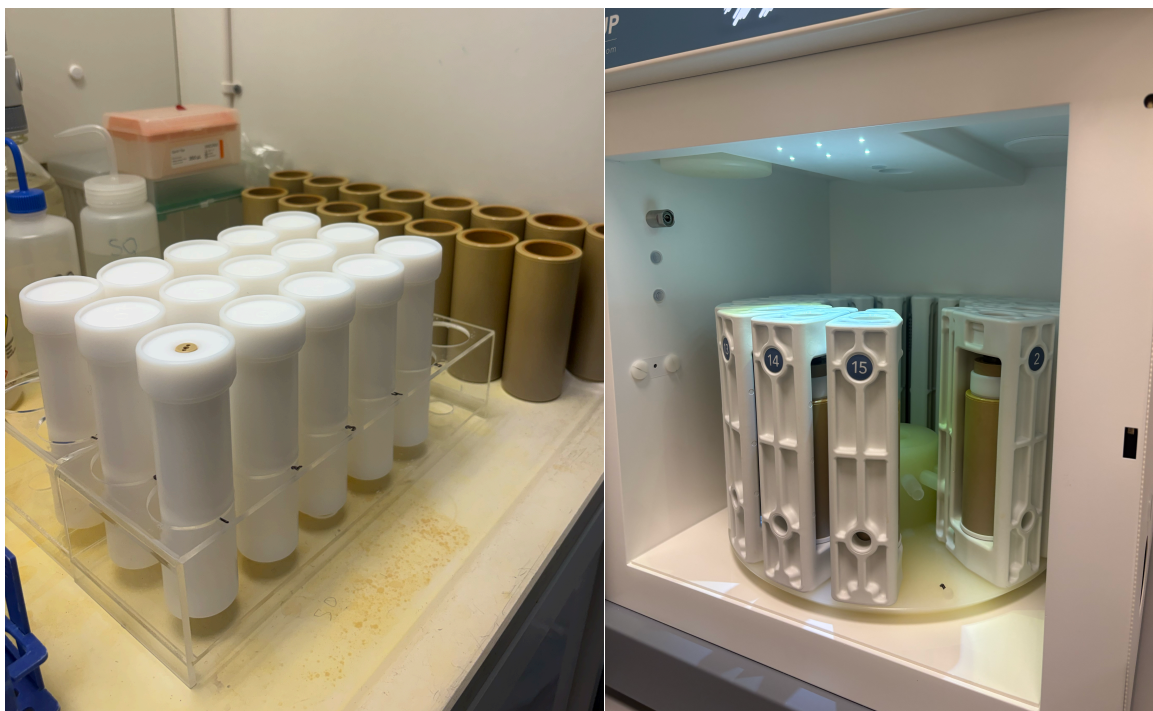


Figure 4. Picture of the Teflon vessels and the the microwave with the vessels put inside.

To ensure analytical accuracy and method validation, certified reference materials were included in each batch. Two reference materials, M2 and M3, were used and originates from the European moss survey under the Convention on Long-Range Transboundary Air Pollution (CLRTAP). These reference materials were originally developed by the Finnish Environmental Institute (SYKE) (Danielsson et al., 2018).

3.3 Data treatment and analysis

The analytical part of the thesis was based on concentration data for rare earth elements measured in moss samples collected within the Swedish national moss monitoring programme for the years 2015 and 2025. The analytical approach included descriptive statistics, temporal comparisons, spatial visualization, comparative literature-based analysis, correlation analysis and enrichment factor calculations. In addition to the REE dataset, selected other metals from the moss monitoring programme were included in parts of the analysis in order to assess whether REE displayed correlations or similar patterns in distribution. These metals were aluminium (Al), lead (Pb) and antimony (Sb). The chose of these metals will be explained further in chapter 3.3.4.

3.3.1 Data processing and temporal comparison

The dataset was compiled and organized in a structured format in Excel to easier enable and access further analysis between the different years and elements. The dataset was organized according to “background”, “urban/industry” and “all” for 2015, and only “background” for 2025 since no urban or industry samples were taken. A background sample includes samples originated in background environments, for example in forests where there is little to no effects from humans. Urban and industry samples include samples collected close to cities or near different industries such as metallurgy and mining. The “all” dataset includes all samples, both background and urban/industry. In addition, summary variables such as the sum of total REEs and ratios between LREE and HREE were prepared and used later in the analysis. Because environmental concentration data are commonly irregular and easily influenced by elevated observations, the analysis did not only rely on mean values alone but also included medians and distribution-based visualisations in the form of GIS maps. This is particularly relevant for elements and sites influenced by a small number of high-concentration observations, where means can be strongly affected by these extreme values.

Descriptive statistics were calculated for each rare earth elements in order to summarize concentration levels and variability among the moss samples. For each element and sampling year the mean, median, minimum, maximum and standard deviation were calculated. The mean provides an estimate of the overall concentration across all sampling sites, whereas the median provides a measure of central tendency in the presence of skewed data and outliers. Minimum and maximum values show the full range of concentrations, while standard deviation was used to describe the spread of data and the extent of variability. For 2015 there were a total of 106 samples, where 20 of them were from industry and urban environments, and 2025 had a total of 100 samples from background environments. These summary statistics were used to provide an overall view and description of concentration ranges and later comparison between 2015 and 2025. The order of REEs based on their concentration levels were also examined. This makes it possible to assess whether the Swedish moss samples show the same general sequence of abundance as previous Swedish and international moss studies.

To investigate temporal changes of REE in moss, the 2015 and 2025 datasets were compared using both descriptive and graphical approaches. The temporal comparison focused on

whether the concentration levels had increased, decreased or remained similar over the ten-year period and whether there were changes across all REEs or between individual elements.

3.3.2 Spatial analysis and visualization

Spatial analysis aimed to investigate geographical patterns in REE concentrations across Sweden. To visualize the spatial distribution, geographic information system (GIS) based maps were created by Jonas Ljungqvist at IVL using sampling coordinates and measured concentration data. These maps were used to identify broad national gradients, regional differences and local hotspots, here referring to sampling locations with high absolute concentrations relative to the other sampling sites. The spatial interpolation of concentrations between sites were based on inverse distance weighting (IDW). One map was created for each of the rare earth elements for both 2015 and 2025. In addition, a third map was created for each element to show the percentual difference between the years to easier identify changes.

3.3.3 Comparative and interpretative analysis

To place the Swedish moss concentrations in a broader context, the results were compared with other published REE concentrations in moss from other countries and regions. This comparative analysis was based on mean values reported in previous studies identified through the literature review. The comparison was organized in tables and plots based on light and heavy REEs as well as the sum of REE concentrations.

To assess the extent to which measured REE concentrations may reflect natural crustal inputs or possible enrichment from other sources, the enrichment factor (EF) was calculated to evaluate whether the concentration of an element is higher than expected based on the natural composition of the Earth's crust. To determine the enrichment factor of rare earth elements, the following equation was used according to Michel et al. (2025):

$$EF = \frac{\frac{M_x}{M_{Fe}}}{\frac{S_x}{S_{Fe}}} \quad (1)$$

In this equation, the concentration of element X in moss is normalized to iron (Fe) since Fe is predominantly of crustal origin and is commonly used as a reference element. The soil values used for comparison come from average upper continental crust (UCC) data that are presented

in table 2. An EF value close to 1 indicates that the element mainly comes from natural sources, whereas higher EF values (>10) indicate that the element is enriched in the moss and may come from other sources, such as human activities or atmospheric pollution (Michel et al., 2025). In the UCC dataset from Chen et al. (2025), iron is commonly reported as total iron oxide (FeO). Therefore, the Fe concentration was calculated from FeO using a conversion factor based on molecular weights, since the fraction of Fe in FeO is $55.85/71.85 \approx 0.777$. Therefore, Fe concentrations were obtained using:

$$Fe = FeO \times 0.777 \quad (2)$$

Using the UCC value of 5.3 wt% FeO, the corresponding Fe concentration is:

$$Fe = 5.3 \times 0.777 \approx 4.12 \text{ wt\%} \quad (3)$$

This value is equivalent to 41200 ppm and was used as the reference Fe concentration in the EF calculations. The EF results were presented through boxplots in order to show enrichment patterns differences between the elements and years. The boxplots and comparison plots with other countries were created in Excel and Python.

3.3.4 Correlation analysis with selected metals

To investigate whether REEs share similar source characteristics with other elements, a correlation analysis was carried out between REEs and other selected monitored metals (Al, Pb, Sb). The purpose was to analyse if the REEs show similar patterns as elements known to be associated with natural crustal material or anthropogenic sources. The Pearson correlation coefficient (r) was used to quantify the strength of linear relationships between variables. Aluminium (Al) represents a typical crustal element and antimony (Sb) is commonly used as a tracer of anthropogenic pollution, according to Aničić Urošević et al. (2020). As Sb was not available in the 2015 moss dataset, lead (Pb) was selected as an alternative indicator of anthropogenic influence. The analysis was complemented by graphical visualization using scatterplots, which were generated in Python. The scatterplots were used to illustrate relationships between the sum of REEs and Al, Sb or Pb. A strong correlation has a r value greater than 0.80, which indicates a high degree of association between variables (Aničić Urošević et al., 2020).

To improve the interpretation of the relationships an additional analysis was performed in which outliers were removed. This was done using the interquartile range (IQR) method described by Tukey (1977). In this approach the middle 50% of the data is identified using the first (Q1) and the third (Q3) quartiles, and the spread between them ($IQR = Q3 - Q1$) is used to identify what can be considered normal values. Data points that fell outside this range were classified as outliers and therefore excluded from the analysis. A factor of $k = 2.0$ was chosen to apply a relative conservative filtering approach. This means only the most extreme values were removed, reducing the risk of excluding data points that represent natural environmental variation rather than true anomalies or errors. This can be important for environmental datasets that often show natural variability and uneven distributions.

4 Results and discussion

This chapter presents the findings from the literature review and data analysis, followed by a discussion of their implications. The results are organised into subchapters, and each section includes an interpretation of the findings, to lastly finish with an overall synthesis at the end relating to the research questions.

4.1 Overall REE concentrations and descriptive statistics

Table 3 presents descriptive statistics (mean, median, minimum, maximum and standard deviation) for REEs in moss samples collected in Sweden 2015 and 2025. Overall, most REEs showed comparable or slightly higher mean and median concentrations in 2025 compared to 2015. In contrast, maximum values decreased for several elements between the two sampling years. For example, Ce decreased from 2.3 to 1.4 mg/kg and Nd from 1.0 to 0.53 mg/kg. The lower maximum concentrations observed for several REEs in 2025 may indicate that fewer isolated hotspots were present during the later sampling year. However, differences in exact sampling locations between the years and the influence of extreme values may also contribute to these differences. Median values are consistently lower than mean values for most elements in both years, indicating positively skewed distributions. This means that most sampling sites had relatively low REE concentrations, while a smaller number of sites with high concentrations increased the overall mean values.

Table 3. REEs in moss samples collected in background environment in Sweden, 2015 and 2025 (mg/kg) (Danielsson et al., 2018; IVL, 2026).

2015 (n=86)						2025 (n=100)				
	Mean	Median	Minimum	Maximum	Standard Deviation	Mean	Median	Minimum	Maximum	Standard Deviation
La	0.16	0.12	0.022	1.1	0.14	0.20	0.16	0.033	0.81	0.16
Ce	0.31	0.23	0.041	2.3	0.29	0.38	0.31	0.065	1.4	0.30
Pr	0.035	0.025	0.0047	0.26	0.035	0.043	0.036	0.0074	0.15	0.034
Nd	0.13	0.096	0.018	1.0	0.13	0.16	0.13	0.027	0.53	0.12
Sm	0.023	0.017	0.0034	0.16	0.024	0.028	0.023	0.0048	0.092	0.022
Eu	0.0035	0.0027	0.00038	0.027	0.0036	0.0052	0.0045	0.00095	0.016	0.0035
Gd	0.021	0.015	0.0031	0.14	0.020	0.024	0.019	0.0041	0.083	0.019
Tb	0.0028	0.002	0.0001	0.019	0.0028	0.0034	0.0027	0.00036	0.012	0.0026
Dy	0.017	0.012	0.0025	0.11	0.016	0.019	0.016	0.0031	0.069	0.015
Ho	0.0031	0.0022	0.00046	0.019	0.0029	0.0036	0.0029	0.00053	0.013	0.028
Er	0.0089	0.0064	0.0014	0.054	0.0082	0.01	0.0082	0.0016	0.042	0.0082
Tm	0.0012	0.00084	0.00011	0.0073	0.0011	0.0013	0.0011	0.000045	0.0056	0.0011
Yb	0.0078	0.0055	0.0008	0.046	0.0072	0.009	0.0072	0.0014	0.038	0.0074
Lu	0.0011	0.00076	0.00016	0.0068	0.0010	0.0013	0.00095	0.000095	0.0059	0.0011

Standard deviations are generally similar between 2015 and 2025 which suggests that the variability of the data has remained relatively stable. The overall pattern of REEs is similar in both years, with Ce, La and Nd showing the highest concentrations while heavier elements such as Tm and Lu occur at much lower levels. The general concentrations of REEs in Sweden are at very low levels.

The concentration order of REEs in Swedish background moss samples in 2025 was similar to the one observed in 2015 (Danielsson et al., 2018) and followed the sequence:

Ce>La>Nd>Pr>Sm>Gd>Dy>Er>Yb>Eu>Ho>Tb>Tm>Lu. Where Ce remained the most abundant REE, while Tm and Lu showed the lowest concentrations. The abundance order of REEs followed the natural crustal abundance pattern with LREEs occurring at higher concentrations than HREEs. This distribution is consistent with REEs geochemical behavior in the Earth's crust and suggests that mineral particles and material are important contributors to the concentrations of REES that can be observed in moss.

4.2 Spatial distribution and temporal changes of REEs in Sweden (2015-2025)

Rare earth elements have received increasing attention in environmental studies due to their widespread use in modern technologies (Sager & Wiche, 2024). Understanding their spatial distribution and how concentrations change over time is useful for identifying patterns as well as potential anthropogenic influences. This chapter presents a visual presentation of the spatial distribution of background samples from REEs across Sweden in 2015 and 2025 in the form of GIS maps. To allow a more accurate comparison, only sampling sites from 2015 and 2025 located within 2 km of each other were included in the percentage change map, as not all samples were collected from the exact same location over the 10-year period. The 14 REEs are presented across seven different figures. Figure 5 shows Ce and Dy, Figure 6 shows Er and Eu, Figure 7 shows Gd and Ho, Figure 8 shows La and Lu, Figure 9 shows Nd and Pr, Figure 10 shows Sm and Tb and Figure 11 shows Tm and Yb. Most figures show one LREE with one HREE, however some figures also show within the same group to provide a more comprehensive overview. Overall, most REEs displayed highly similar spatial distributions across Sweden characterised by relatively low concentrations in northern regions and somewhat elevated concentrations in the south and central parts. Moderate increases between 2015 and 2025 were observed at many sites for most elements, while decreases were generally less frequent and more spatially scattered (see Figure 5-11 below).

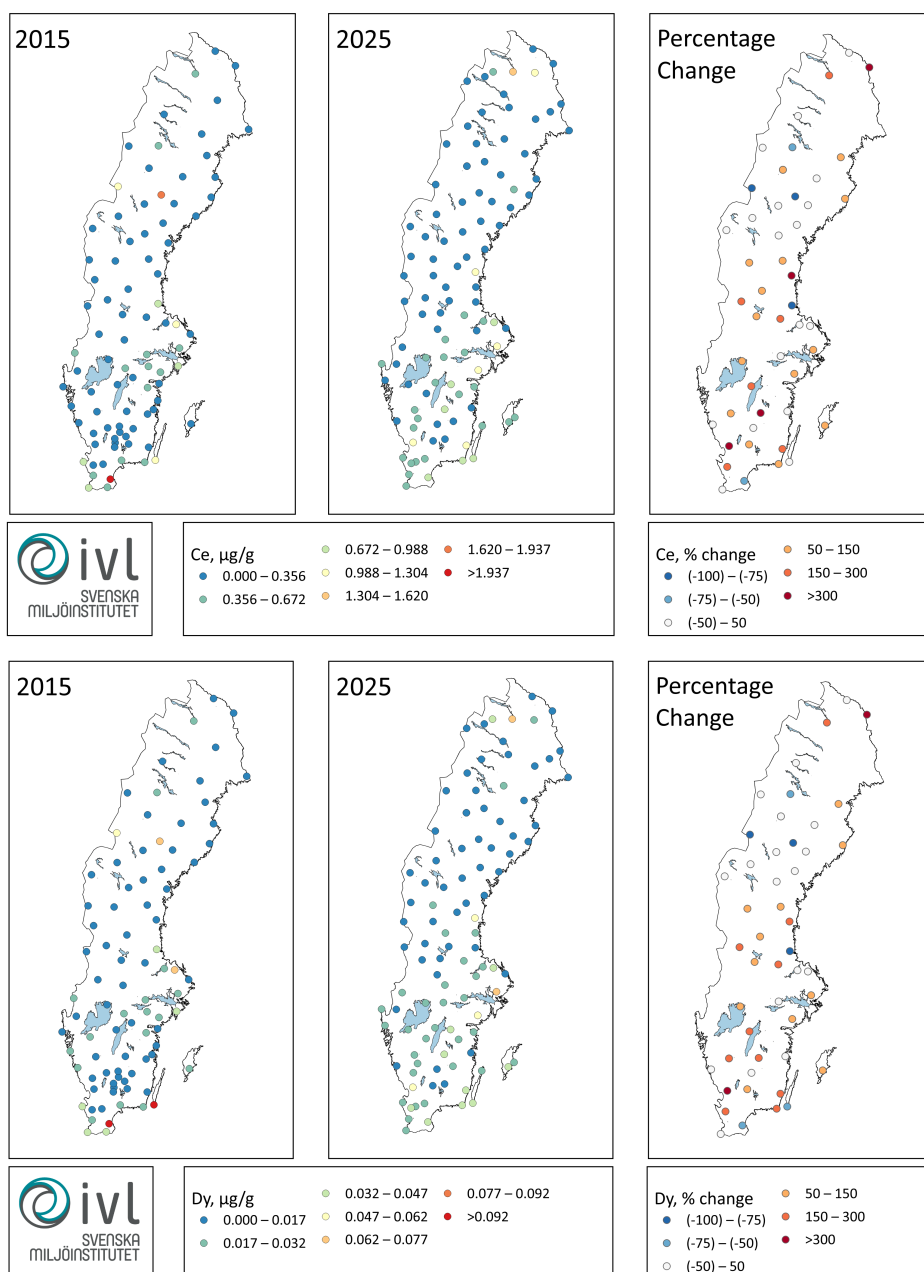


Figure 5. Spatial distribution and percentage change of cerium and dysprosium, Ce at the top and Dy at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

The spatial distributions of Ce and Dy across Sweden in 2015 and 2025, together with their percentage changes over the period, are shown in Figure 5. Ce displayed the highest concentrations amongst the analysed REEs, while Dy occurred at lower levels, likely reflecting the stronger dominance of LREEs in crustal materials. Both elements showed several local increases between 2015 and 2025, particularly at sites in the south and eastern Sweden.

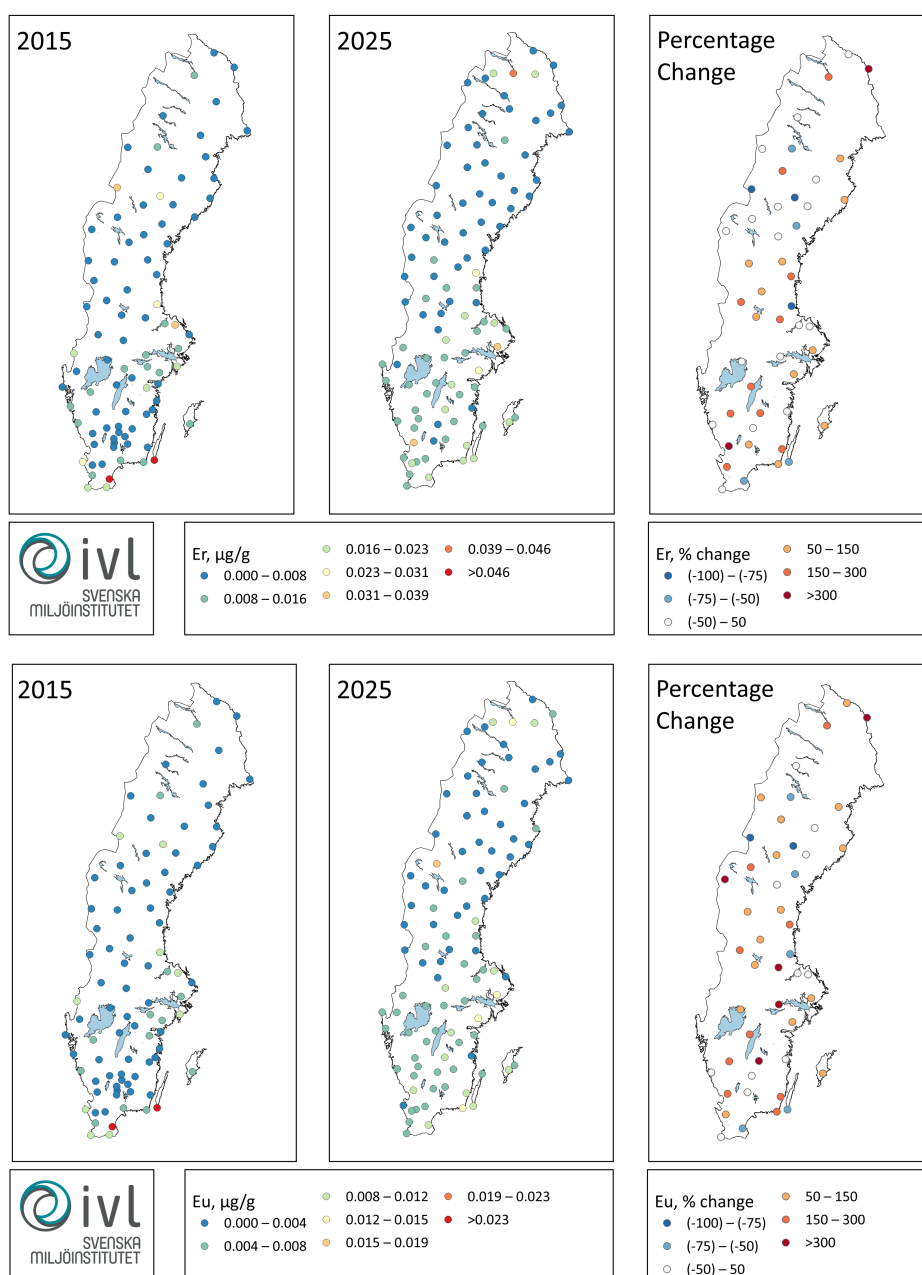


Figure 6. Spatial distribution and percentage change of erbium and europium, Er at the top and Eu at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

Er and Eu in Figure 6 showed relatively similar spatial behaviour between 2015 and 2025, although Eu occurred at lower concentrations. Several of the sites displayed moderate to strong increases during the 10-year time period, while only a limited number of sites showed a decrease in concentrations. The similarity in spatial distribution and temporal trend between Er and Eu indicates comparable deposition patterns and potentially common sources and transport pathways.

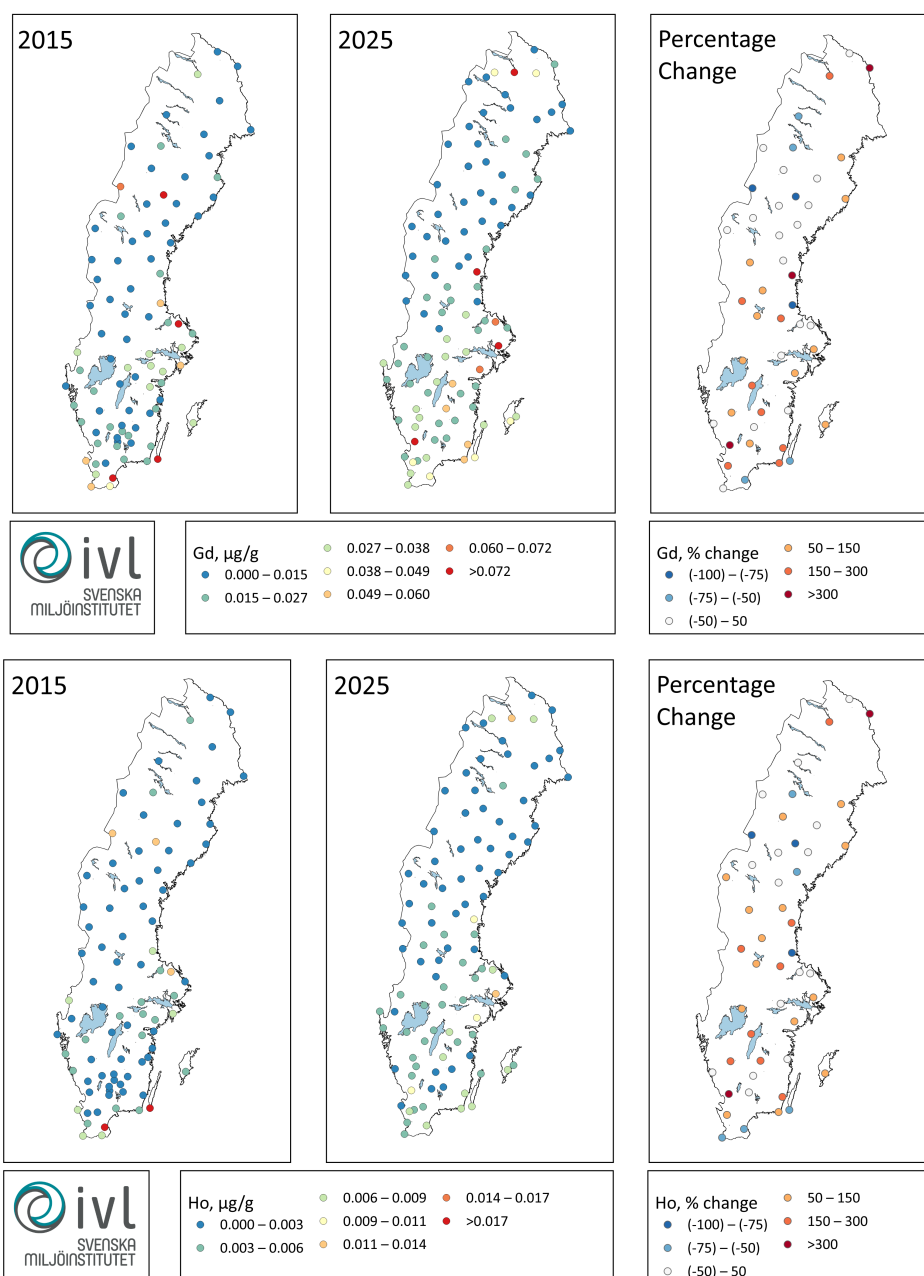


Figure 7. Spatial distribution and percentage change of gadolinium and holmium, Gd at the top and Ho at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

Gd and Ho (Figure 7) displayed comparable geographical patterns, although Gd showed somewhat greater spatial variability. Several sites showed increasing concentrations between 2015 and 2025. The elevated Gd concentrations are notable given the potential association with anthropogenic sources such as medical wastewater. One particular hotspot for Gd occurs around big city areas like Stockholm along the east coast, however no direct source attribution can be made solely from these maps.

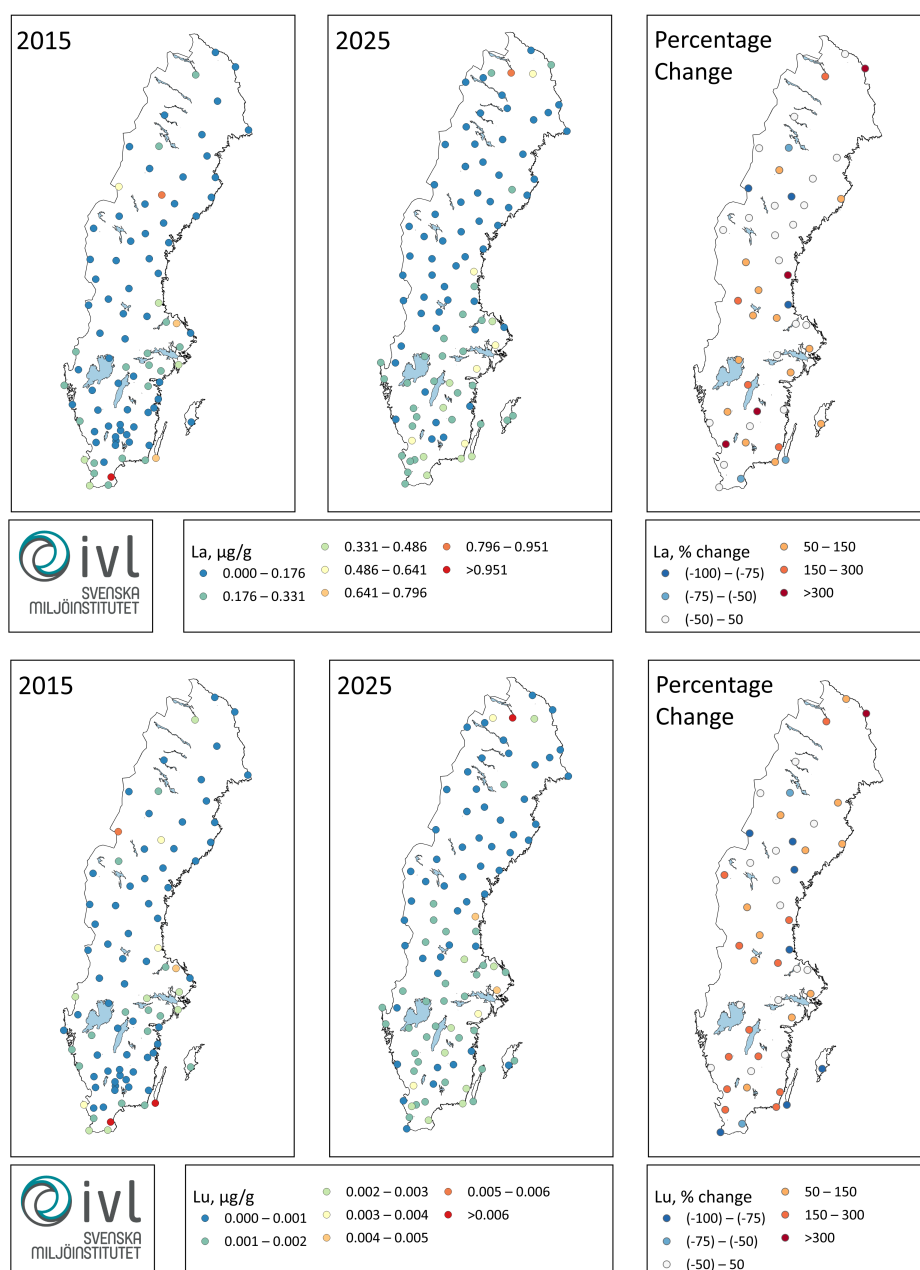


Figure 8. Spatial distribution and percentage change of lanthanum and lutetium, La at the top and Lu at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

La in Figure 8 occurred at substantially higher concentrations than Lu, reflecting the dominance of LREEs over HREEs. Both elements showed increasing concentrations at several sites between 2015 and 2025, although Lu remained consistently low across most of Sweden.

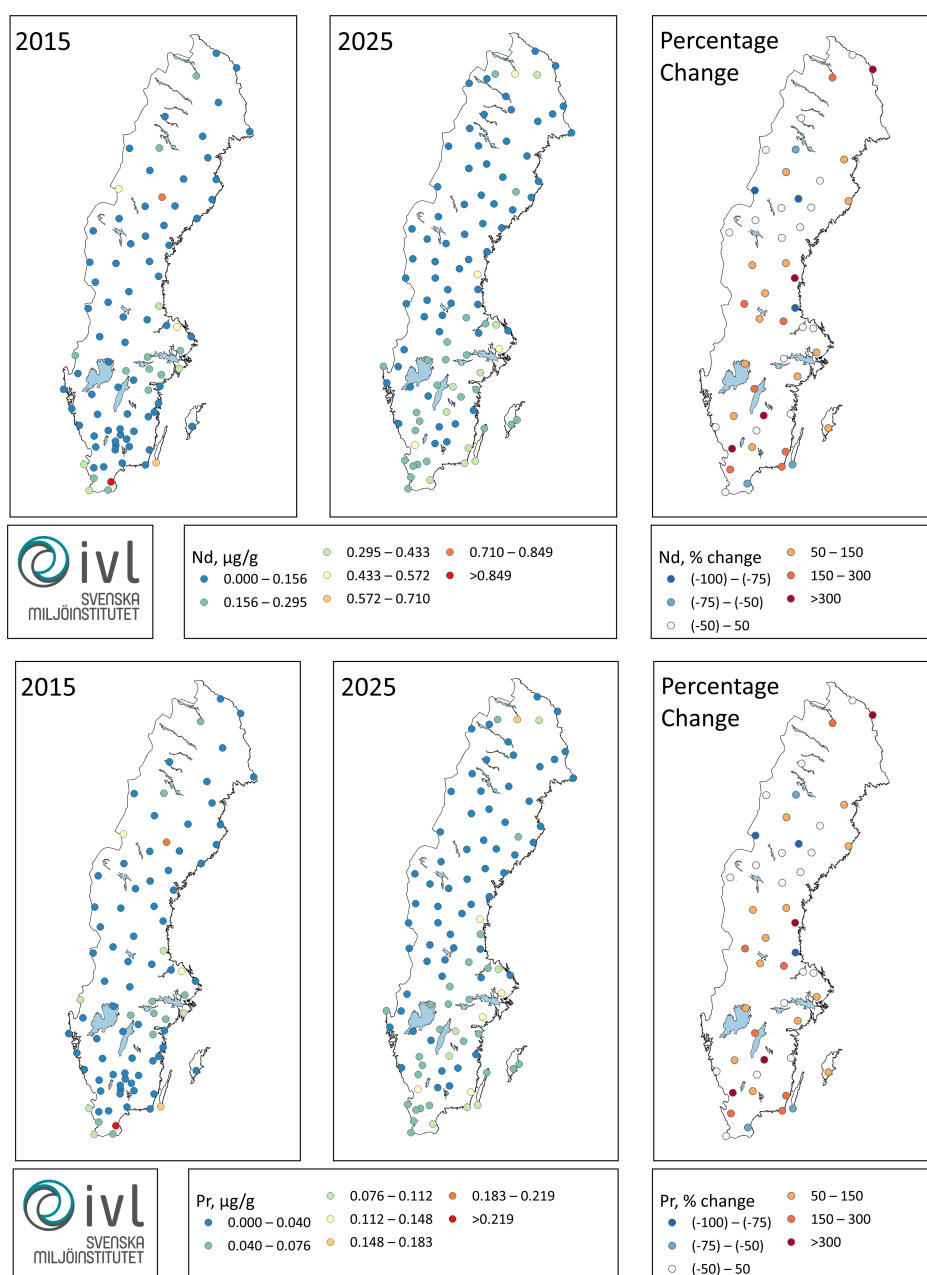


Figure 9. Spatial distribution and percentage change of neodymium and praseodymium,

Nd at the top and Pr at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

Nd and Pr (Figure 9) showed highly similar spatial patterns and temporal behaviour. Nd occurred at higher concentrations, while both elements showed several local increases between 2015 and 2025, particularly in southern and eastern Sweden.

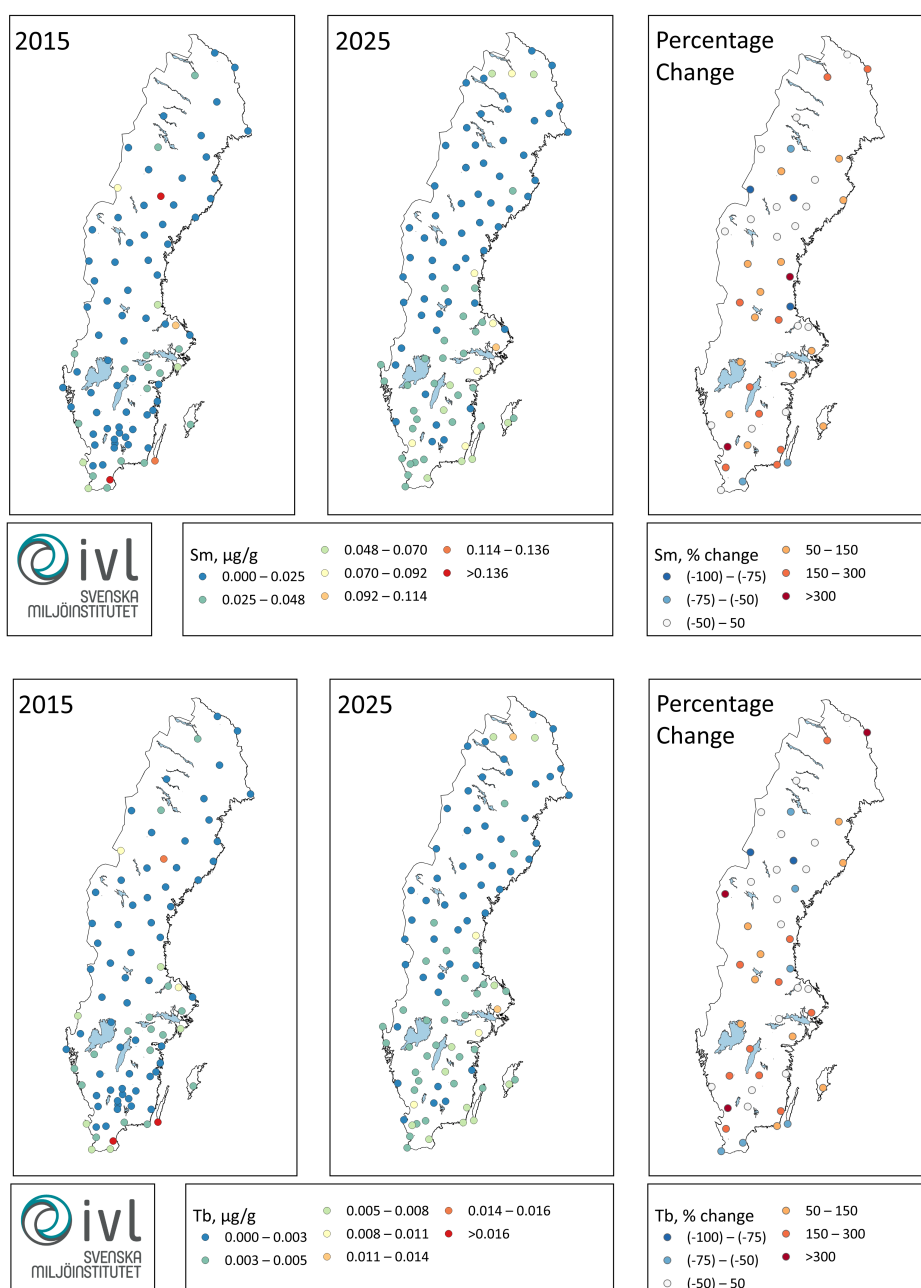


Figure 10. Spatial distribution and percentage change of samarium and terbium, Sm at the top and Tb at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

Sm and Tb (Figure 10) showed comparable spatial distributions, although Sm occurred at higher concentrations than Tb. Several sites displayed moderate increases over time, while decreases remained relatively limited.

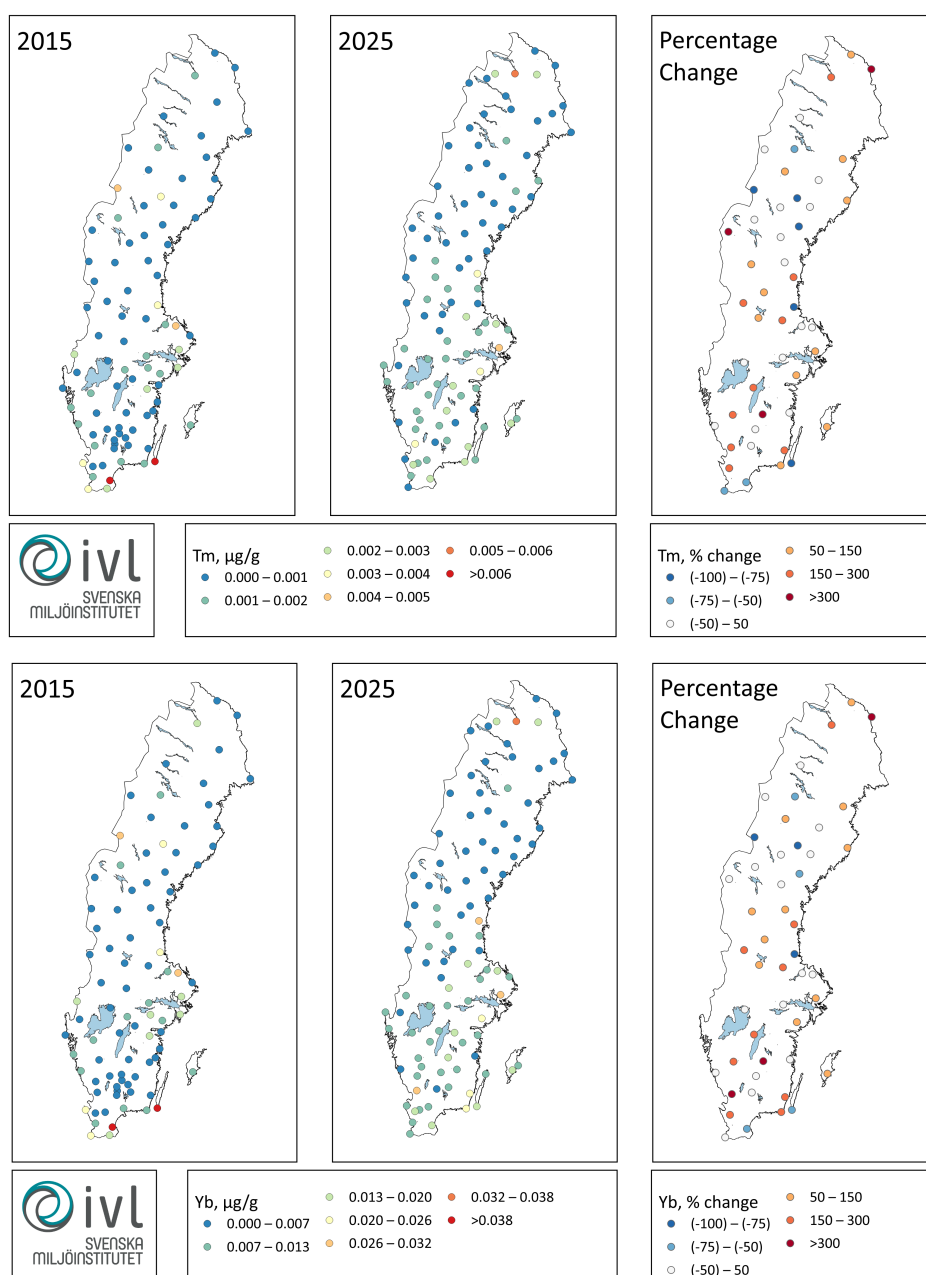


Figure 11. Spatial distribution and percentage change of thulium and ytterbium, Tm at the top and Yb at the bottom in Sweden from 2015 to 2025 (IVL, 2026).

Figure 11 with Tm and Yb occurred at generally low concentrations across Sweden in both years. Despite the low concentrations, several sites showed increasing values between 2015 and 2025.

The 14 REEs together showed a broadly consistent spatial pattern across Sweden. Overall, the measured concentrations were low compared with those reported in many published moss studies from other countries (see Section 4.3). Some locations showed percentage increases

exceeding 300%, however, these changes often originated from low absolute concentrations in 2015. Consequently, relatively small increases could produce large percentage changes. The observed percentage changes therefore indicate relative temporal changes rather than necessarily high levels of environmental contamination. Across all elements, the clearest spatial feature was a north-south gradient with generally lower concentrations in northern Sweden and higher concentrations in southern Sweden. This pattern was observed for both LREEs and HREEs. LREEs consistently occurred at higher concentrations than HREEs, which is consistent with their greater average abundance in reference crustal materials such as the Upper Continental Crust (Table 2).

In southern Sweden, more sites showed moderate and higher concentration of REEs, both 2015 and 2025, while northern Sweden had the lowest concentrations. This suggests that REE deposition or accumulation in moss is not randomly distributed but can be influenced by regional differences in atmospheric deposition, population density, long range transport and soil dust inputs. Visual inspection of the spatial maps suggested a north–south gradient for the more abundant REEs, particularly Ce, La, Nd and Pr with generally higher concentrations in southern Sweden and lower concentrations in the north. The HREEs (Ho, Er, Tm, Yb and Lu) occurred at considerably lower absolute concentrations than the LREEs making the geographical pattern less distinct. Nevertheless, their spatial distributions were broadly similar with relatively higher concentrations more frequently observed in southern and central Sweden.

The percentage change maps indicates that concentrations increased at many comparable sampling sites between 2015 and 2025 for most REEs. Many sites showed increases in the range of 50–150%, while several sites showed increases of 150–300% or more than 300%. Sites with negative changes were also present but appeared less frequent and more spatially scattered. These percentage changes should be interpreted as relative changes between comparable sampling locations in 2015 and 2025, rather than as evidence of high absolute environmental contamination. Despite differences in the magnitude of the changes between individual elements, the overall temporal patterns were broadly similar across most REEs.

The sampling sites with percentage increase above 300% were not identical for all REEs, but several recurring sites were visible. A repeated hotspot appeared in the far north or northeastern part of Sweden for many elements. This region is close to one of Sweden’s major northern mining districts, including Kiruna and Gällivare/Malmberget and their surrounding

ore fields. Kiruna and Gällivare are regions that have central mining areas in northern Sweden and most of the Swedish mines are located in these three main regions: Norrbotten, Skelleftefältet and Bergslagen. This northern hotspot could therefore be relevant in relation to mining and mineral dust sources. Kiruna is especially important because of the identified Per Geijer deposit, containing iron ore, phosphorus and high levels of REEs. It is however important to note that potential influences related to mining should not be interpreted as limited to Swedish sources, since mining and metallurgical activities in neighbouring countries may also contribute through regional atmospheric transport.

Another group of hotspots appears in central and south Sweden where several sites had elevated REE concentrations, particularly in areas corresponding to the Bergslagen region near Stockholm and Vällentuna. Industries such as iron and steel manufacturers are also located here together with other industries, which could increase these regions industrial or geogenic inputs. Several strong increases also occurred in southern Sweden, and these were visible among many elements. One of them was in Skåne, Tomelilla. Unlike the northern hotspot, no obvious source related to mining has been identified for this area. The elevated concentrations may therefore reflect local geological conditions, diffuse atmospheric deposition or smaller scale anthropogenic sources. Other regions and cities with higher maximum values of La, Ce and Nd were Kalmar, Halmstad and Åsele, see Table 3 and appendix for 2015 and 2025.

Southern Sweden has higher population density, greater road traffic and more industrial sources than northern Sweden. Furthermore, southern Sweden is more strongly influenced by air masses originating from continental Europe in comparison with northern Sweden. Long-range atmospheric transport therefore likely contributes to the higher REE concentrations observed in the south. REEs are often associated with fine particles and dust and can be transported together with other airborne pollutants. Similar north-south gradients linked to atmospheric deposition has previously been observed for other trace metals in Scandinavian moss monitoring studies (Danielsson et al., 2021).

4.3 Comparison with previous studies

As an outcome of the literature review, a comparison with other countries was carried out to analyse 2015 and 2025 samples from Sweden in a broader context. The total rare earth

element concentrations (ΣREE) in moss varied among the studied countries and sampling years seen in Figure 12. China showed remarkably higher ΣREE concentrations ($\sim 90 \mu g/g$) compared to other countries where values ranged between $0.7 \mu g/g$ and $7.7 \mu g/g$. The included studies represent different sampling environments. Samples from Sweden, Norway, Serbia, Russia and Albania were collected at background sites, whereas studies from China, Poland and North Macedonia included sites influenced by mining, urban or industrial environments. Consequently, the comparison should be regarded as qualitative rather than a direct quantitative comparison between countries.

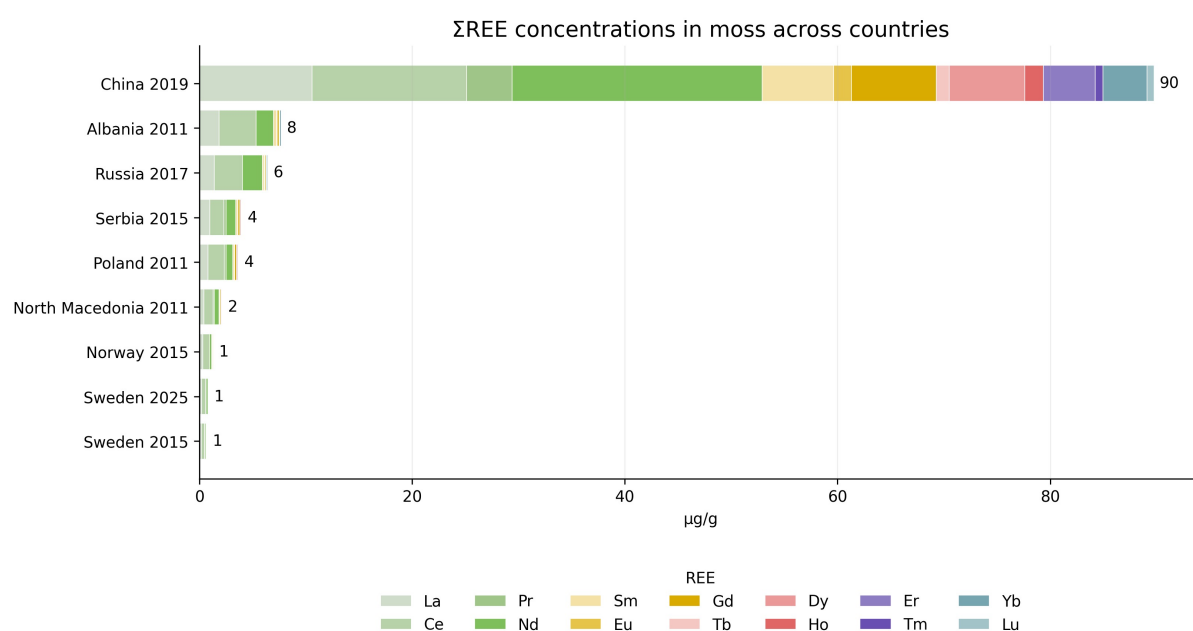


Figure 12. The sum and comparison of REE concentration in moss across different countries (with China).

When excluding China (Figure 13), Albania and Russia showed the highest ΣREE levels ($\sim 7.7 \mu g/g$ and $\sim 6.4 \mu g/g$) followed by Serbia and Poland ($\sim 4.0 \mu g/g$ and $\sim 3.7 \mu g/g$). The lowest concentrations were observed in North Macedonia ($\sim 2.2 \mu g/g$), Norway ($\sim 1.3 \mu g/g$) and Sweden ($\sim 0.7 - 0.9 \mu g/g$). Although, the Swedish moss surveys in 2015 and 2025 showed a slight increase, the Swedish concentrations of REEs does however remain among the lowest in terms of overall REE accumulation compared to the other countries collected in background environments. Across all sites, the REE patterns were dominated by light rare earth elements (La-Eu) shown in green and yellow colours.

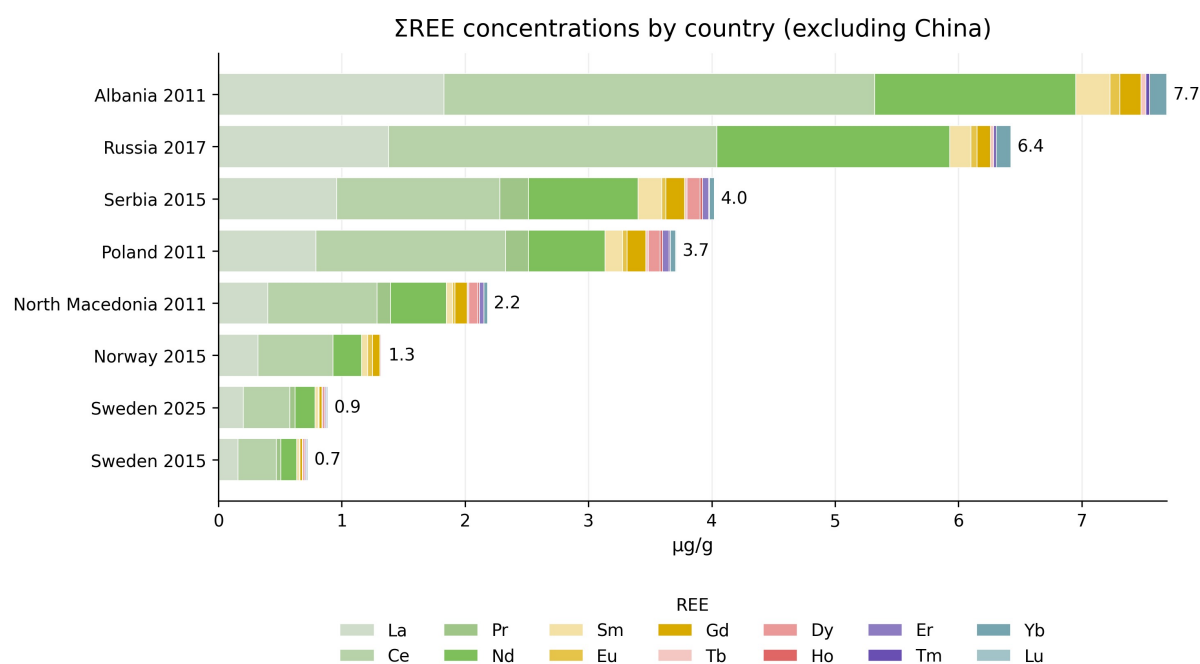


Figure 13. The sum and comparison of REE concentration in moss across different countries (excluding China).

Table 4 and 5 show all data found in the literature review for LREEs and HREEs, even those from earlier years compared to the figures that only show the most recent years. China (Guizhou province, 2019) shows exceptionally high concentrations for both LREE and HREE with La (10.6 mg/kg), Ce (14.5 mg/kg), Nd (23.5 mg/kg) and Gd (7.98 mg/kg) dominating the overall ΣREE . The European countries display much lower concentrations in comparison.

Table 4 and 5 also show moss samples collected in the southern parts of Sweden in the year 2000. This year the REE concentrations were consistently low with LREEs at La (0.190 mg/kg), Ce (0.360 mg/kg) and Nd (0.280 mg/kg). HREE were present in very low concentrations, Gd (0.028 mg/kg), Yb (0.009 mg/kg).

Table 4. Comparison of mean values of light REEs from different parts of the world in mosses (mg/kg).

Country	Region/city	Moss species	La	Ce	Pr	Nd	Sm	Eu	Collection year	References
Poland	Kielce	<i>P.schreberi</i>	0.789	1.540	0.183	0.624	0.141	0.038	2011	Dołęgowska et. al (2013)
Sweden	Southern	<i>P.schreberi</i>	0.190	0.360	0.041	0.280	0.025	0.010	2000	Rühling & Tyler (2004)
Norway	Birkenes, Nordmoen, Svanvik	<i>P.schreberi</i> , <i>H.splendens</i>	0.255	0.488	0.060	0.221	0.034	0.012	1993-1995	Berg & Steinnes (1997)
Poland	Niepolomice	<i>P.schreberi</i>	0.52	--	--	--	0.069	--	1998	Grodzińska et. al (2005)
Slovakia	--	<i>P.schreberi</i> , <i>H.splendens</i>	2.5	3.9	--	--	0.4	--	2000	Maňkovská et al. (2003)
China	Guizhou providence	<i>P.flexuosa</i>	10.6	14.5	4.31	23.5	6.74	1.66	2019	Xu et al. (2022)
France	Ardennes, Vosges	<i>P.schreberi</i> , <i>H.cupressiforme</i> , <i>S.purum</i>	0.774	1.470	0.167	0.647	0.124	0.027	1873	Agnan et al. (2014)
Serbia	--	<i>H.cupressiforme</i>	0.96	1.323	0.23	0.89	0.19	0.036	2015	Anicic Urosevic et al. (2020)
Russia	Ryazan	<i>P.schreberi</i> , <i>H.splendens</i> , <i>H.cupressiforme</i>	1.38	2.66	--	1.89	0.17	0.05	2017	Blinova et al. (2024)
Norway	--	<i>H.splendens</i>	0.48	0.93	0.090	0.37	0.070	0.050	2015	Steinnes et al. (2016)
Albania	--	<i>H.cupressiforme</i>	1.83	3.49	--	1.63	0.28	0.08	2010-2011	Allajbeu et al. (2015)
North Macedonia	Allchar locality	<i>H.cupressiforme</i>	0.40	0.887	0.11	0.45	0.050	0.022	2011	Andonovska et al. (2023)

Note. -- indicates no data

Table 5. Comparison of mean values of heavy REEs from different parts of the world in mosses (mg/kg).

Country	Region/city	Moss species	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Collection year	References
Poland	Kielce	<i>P.schreberi</i>	0.152	0.020	0.095	0.020	0.053	0.008	0.044	0.007	2011	Dołęgowska et. al (2013)
Sweden	Southern	<i>P.schreberi</i>	0.028	0.004	0.019	0.019	0.011	0.001	0.009	0.0014	2000	Rühling & Tyler (2004)
Norway	Birkenes, Nordmoen, Svanvik	<i>P.schreberi</i> , <i>H.splendens</i>	0.044	0.006	0.035	0.035	0.018	0.001	0.014	0.002	1993- 1995	Berg & Steinnes (1997)
Poland	Niepolomice	<i>P.schreberi</i>	--	0.008	--	--	--	--	--	--	1998	Grodzińska et. al (2005)
Slovakia	--	<i>P.schreberi</i> , <i>H.splendens</i>	--	0.1	--	--	--	--	0.3	--	2000	Maňková et al. (2003)
China	Guizhou providence	<i>P.flexuosa</i>	7.98	1.23	7.10	1.75	4.85	0.730	4.15	0.680	2019	Xu et al. (2022)
France	Ardennes, Vosges	<i>P.schreberi</i> , <i>H.cupressiforme</i> , <i>S.purum</i>	0.117	0.019	0.082	0.015	0.044	0.006	0.040	0.006	1873	Agnan et al. (2014)
Serbia	--	<i>H.cupressiforme</i>	0.15	0.020	0.106	0.019	0.050	0.00593	0.040	0.004	2015	Anicic Urosevic et al. (2020)
Russia	Ryazan	<i>P.schreberi</i> , <i>H.splendens</i> , <i>H.cupressiforme</i>	0.11	0.028	--	--	--	0.02	0.116	--	2017	Blinova et al. (2024)
Norway	--	<i>H.splendens</i>	0.090	0.020	0.050	0.008	0.040	0.0040	0.004	0.020	2015	Steinnes et al. (2016)
Albania	--	<i>H.cupressiforme</i>	0.17	0.040	--	--	--	0.03	0.14	--	2010- 2011	Allajbeu et al. (2015)
North Macedonia	Allchar locality	<i>H.cupressiforme</i>	0.098	0.013	0.072	0.014	0.036	--	0.031	--	2011	Andonovska et al. (2023)

Note. -- indicates no data

The results demonstrate a substantial variation in REE concentrations in moss across different countries and time periods. The elevated concentrations observed in China are likely the result of a combination of anthropogenic and natural factors. China is a global center for rare earth element mining and processing as the country stands for around 70% of the global production in the world. Emissions associated with these activities can contribute to elevated REE levels. In addition, certain regions of China such as the Guizhou province black shales, are naturally enriched in REE due to local geological conditions (Xu et al., 2022). In contrast, European countries show considerably lower REE concentrations but do however still display spatial variability between the countries. Albania and Russia show the highest ΣREE values followed

by Serbia and Poland, while North Macedonia, Norway and Sweden have the lowest concentrations. This difference can likely be attributed to a combination of local pollution sources and geological backgrounds. However, it is important to consider that REEs can be transported over long distances in the atmosphere meaning that even regions with limited local sources may receive measurable inputs from distant emissions sources.

A consistent pattern observed across all sites is the dominance of light rare earth elements, which contribute the largest fraction to the total REE concentration. The heavy rare earth elements are present at lower concentrations. The dominance by LREE can be explained by their higher natural abundance in the Earth's crust, as well as their greater mobility and availability during weathering.

In addition to the present datasets from 2015 and 2025, published Swedish moss data from 2000 (Rühling & Tyler, 2004) provide a longer term perspective on REE concentrations. The comparison between samples from 2000, 2015 and 2025 shows that REE concentrations remained generally low over time, with small differences between sampling years. A slight decrease is observed between 2000 and 2015 for certain elements, followed by a slight increase between 2015 and 2025. When considering the full period between 2000 and 2025 the data suggest a small overall increase in REE concentrations. This pattern was observed for both LREEs and HREEs. One possible explanation is the growing global use of REEs in modern technologies such as electronics, renewable energy systems and batteries, which may lead to increased emissions. However, it is important to acknowledge that the dataset for the year 2000 is limited both in terms of samples and spatial coverage as it represents only southern Sweden rather than the entire country (in contrast to 2015 and 2025). This difference makes the direct comparisons between years more uncertain and limits the strength of conclusions. Nevertheless, the available data still provide useful insight into how REE concentrations in Swedish moss may have evolved over time.

When interpreting the comparison with previous studies, several methodological differences should be considered. One important factor is the use of different moss species across studies. The studies included in Tables 4 and 5 used species such as *Pleurozium schreberi*, *Hylocomium splendens*, *Hypnum cupressiforme* and *Pohlia flexuosa*, which may differ in their capacity to accumulate REEs. Because relatively few studies have investigated REE accumulation in different moss species it remains unclear to what extent accumulation of specific species influences the reported concentrations. Consequently, all available studies

were included to provide a broader overview of REE concentrations in moss despite differences in moss species. In addition, the same moss species do not occur uniformly across all geographical regions, making the inclusion of multiple species necessary for broader comparisons. The studies also span a wide time period, from 1873 to 2025, during which environmental conditions, atmospheric deposition and anthropogenic emissions have changed considerably. These methodological differences should therefore be taken into account when interpreting the comparisons presented in this section.

4.4 Correlation analysis

The relationship between Σ REEs and selected elements (Al, Pb and Sb) are shown in Figures 14-16 below for background (2015), industry/urban (2015) and background (2025). The top rows (a) in each figure show the correlation analysis including all values, whereas the bottom rows (b) show the analysis after removal of outliers to get a more comprehensive and deeper perspective of the data. The outliers were identified using the IQR method described in Section 3.3.4. The blue line in the plots represents the linear regression trend line showing the overall relationship between REE concentrations and the compared element. The shaded blue area indicates the 95% confidence interval of the regression showing the uncertainty around the estimated trend. Narrower intervals suggest a more reliable relationship, whereas wider intervals indicate greater variability in the data. The correlations between Σ REEs and the selected elements help to understand where the REEs are coming from and how they behave in the environment.

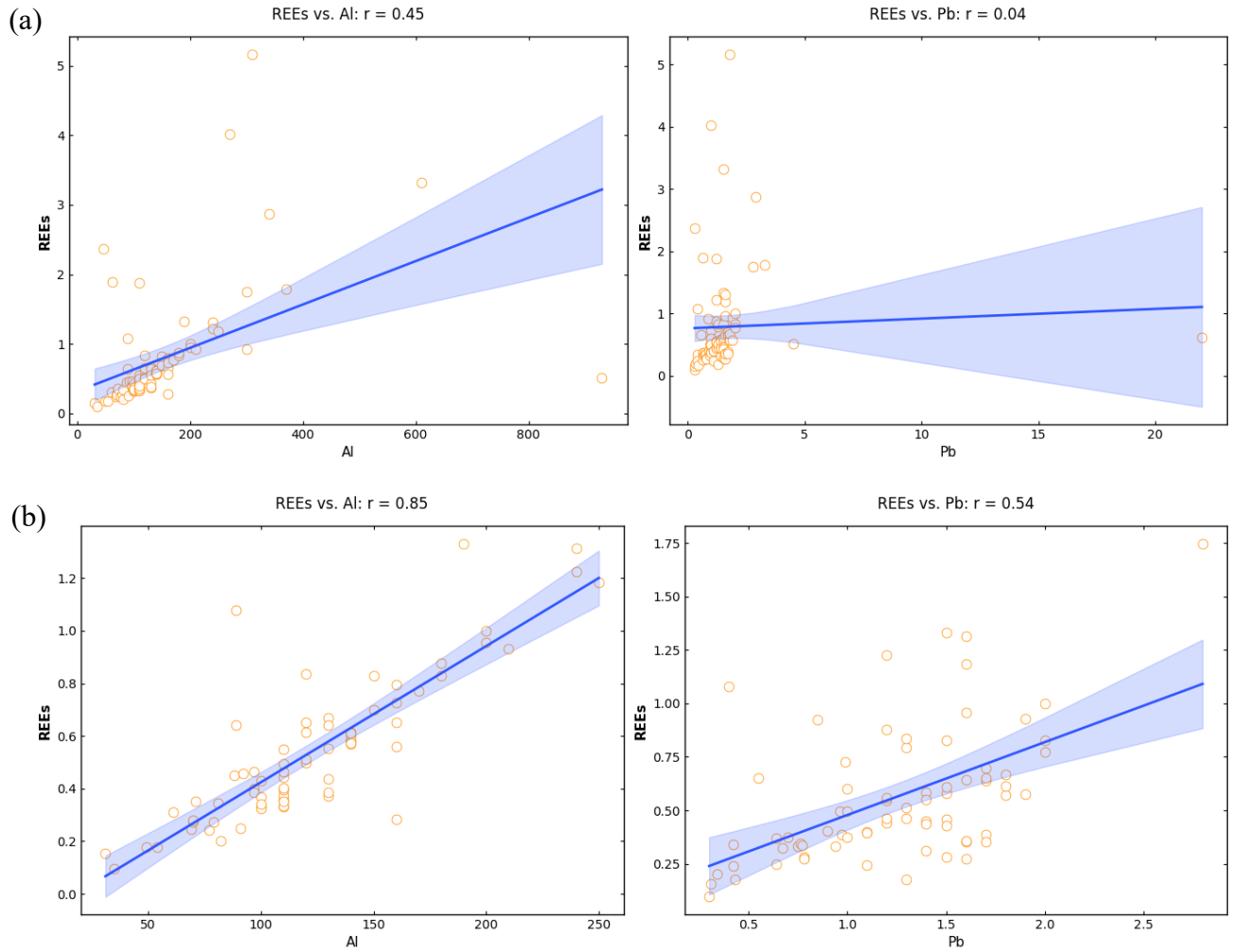


Figure 14. Correlations between Σ REEs and Al and Pb for background samples in 2015. (a) All samples. (b) Outliers removed using IQR method (11 for Al and 10 for Pb). The blue line represents the fitted linear regression and the shaded area indicates the 95% confidence interval.

For background samples in 2015, Σ REEs showed a moderate correlation with Al ($r = 0.45$), suggesting little association with crustal materials. In contrast, the relationship between Σ REEs and Pb was negligible ($r = 0.04$). After removal of outliers, the correlation between Σ REEs and Al increased substantially to $r = 0.85$ showing a much stronger linear relationship. The correlation with Pb also increased but does not indicate a strong relationship, as $r < 0.80$ (Aničić Urošević et al., 2020).

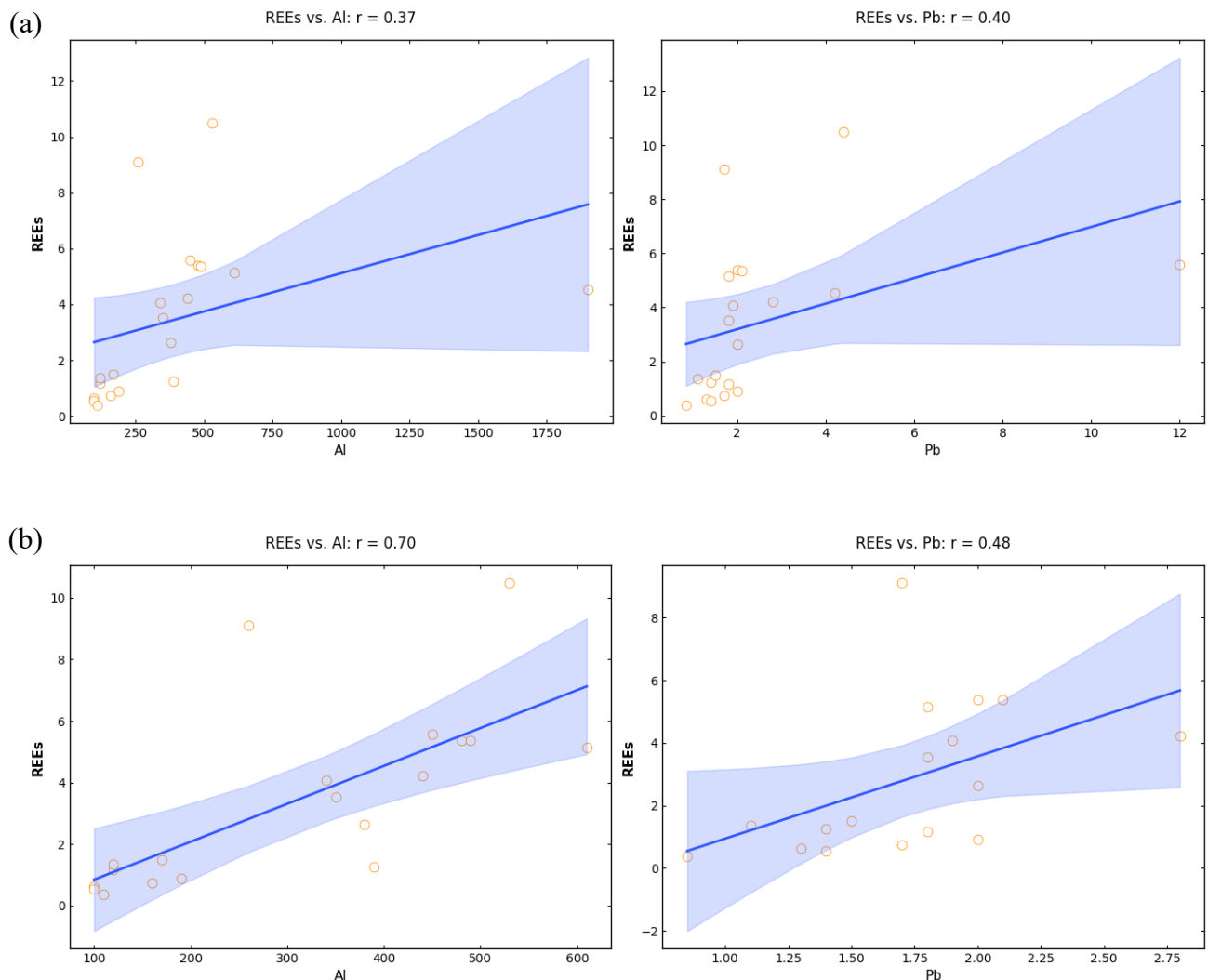


Figure 15. Correlations between Σ REEs and Al and Pb for industry/urban samples in 2015. (a) All samples. (b) Outliers removed using IQR method (1 for Al and 2 for Pb). The blue line represents the fitted linear regression and the shaded area indicates the 95% confidence interval.

For industry and urban samples in 2015 (Figure 15), Σ REEs showed a weak correlation with Al ($r = 0.37$) and Pb ($r = 0.40$). After outlier removal the correlations strengthened to $r = 0.70$ for Al and $r = 0.48$ for Pb, indicating clearer trends for Al when extreme values were excluded. However, not a strong relationship.

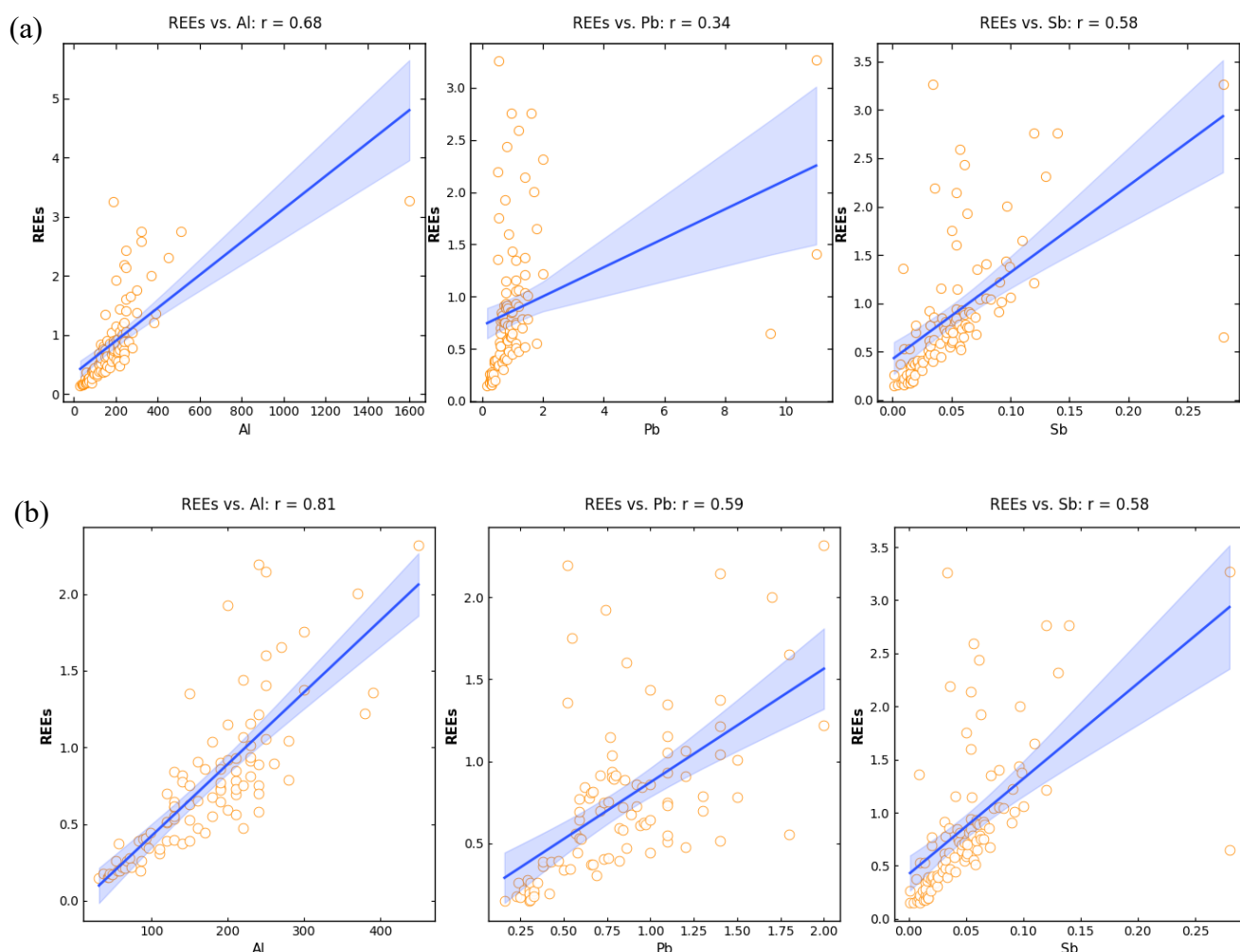


Figure 16. Correlations between Σ REEs and Al, Pb and Sb for background samples in 2025. (a) All samples. (b) Outliers removed using IQR method (6 for Al, 8 for Pb and 0 for Sb). The blue line represents the fitted linear regression and the shaded area indicates the 95% confidence interval.

For background samples in 2025 (Figure 16), Σ REEs showed moderate correlations with Al ($r = 0.68$), Pb ($r = 0.34$) and Sb ($r = 0.58$). After filtering outliers the correlation with Al increased to $r = 0.81$ showing a strong association, while correlations with Pb ($r = 0.59$) and Sb ($r = 0.58$) remained fairly low.

The consistently strong relationship between Σ REEs and Al, especially after outlier removal, indicates that REEs measured in Swedish moss samples are largely associated with crustal or lithogenic material rather than anthropogenic sources. The removal of outliers using the IQR method had a clear effect on the result. Environmental data often include extreme values due to measurement variability or nearby industries such as mining. Removing outliers provides a clearer picture of the dominant relationships within the dataset. However, the excluded

observations may also represent locations affected by local anthropogenic sources or other site specific processes and should therefore not be regarded as unimportant. Rather, the filtered analysis was used to complement the analysis of the complete dataset.

Aluminium is commonly used as an indicator of natural and crustal material such as soil and mineral dust. The strong relationship therefore suggests that REEs are mainly coming from natural sources. In contrast, lead (Pb) shows weaker and more variable correlations with Σ REEs. In the unfiltered background dataset from 2015 there was almost no correlation ($r = 0.04$), which suggest that Pb and REEs do not share the same main source. Pb is often linked to human activities such as traffic, industrial emissions and combustion. The increase in correlation after removal of the outliers suggests that a limited number of observations influenced the relationship between Σ REE and Pb. These observations may reflect local processes affecting Pb concentrations rather than the general behaviour of REEs.

For the industry and urban samples in 2015 the results show a more mixed pattern. The correlation with Al is weaker than in background samples, while the correlations with Pb are slightly stronger. In urban environments, where both natural sources and emissions from industries occur, it can be expected that both dust from soil and emissions from human activities can influence the samples.

The addition of antimony (Sb) in the 2025 dataset provides further information about anthropogenic influence since Sb is often associated with traffic emissions (Hjortenkrans et al., 2006). The moderate correlation between Σ REEs and Sb ($r = 0.58$) suggests that the elements don't have a high association with each other. The correlation in 2025 is the strongest with Al showing that natural sources remain the dominant contributor since 2015.

4.5 Enrichment factor analysis

The distribution of enrichment factors (EF) for REEs is shown in Figure 17 and 18. The boxplots illustrate how the EF values are spread for each element. The box represents the interquartile range (25th-75th percentile) meaning it contains the middle 50% of the data, while the line inside the box indicates the median. The whiskers extend to the minimum and maximum values within 1.5 times the interquartile range from the lower and upper quartiles, representing the spread of the majority of the data. Points outside the whiskers are shown as outliers. In this dataset most EF values are concentrated within a relatively narrow interval,

while fewer observations occur at much higher or lower values. This results in more narrow boxes combined with long whiskers and some outliers reflecting a skewed distribution, mainly towards lower EF values. This type of distribution is common for environmental data.

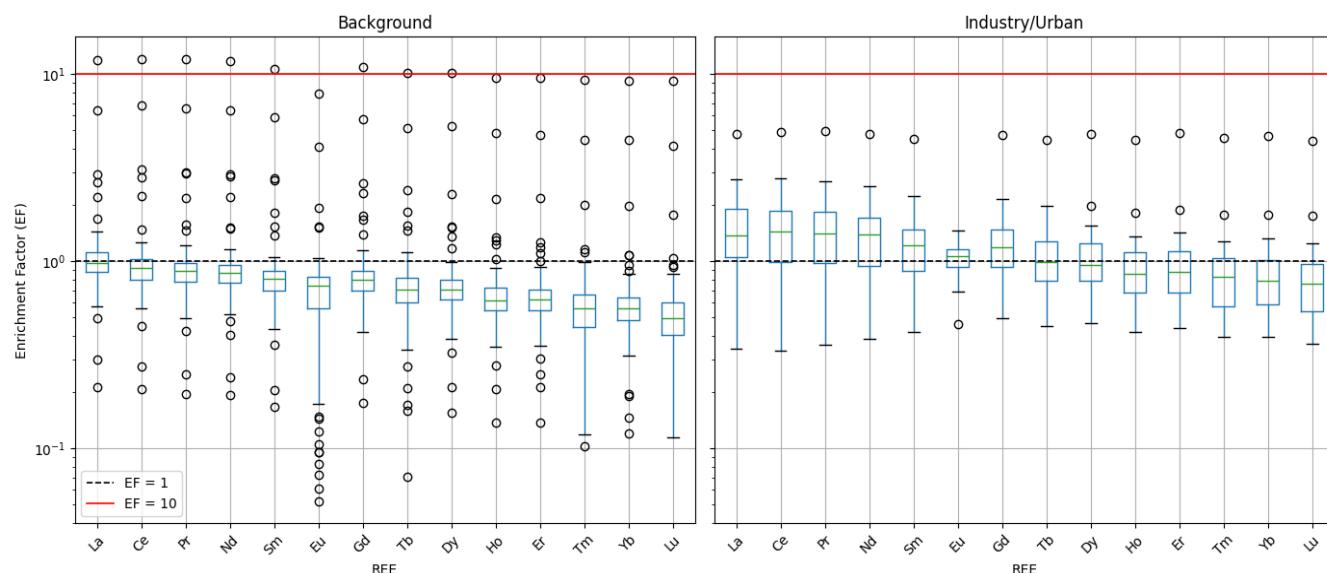


Figure 17. Enrichment factor plotted in boxplots for background samples ($n = 86$) and industry/urban samples ($n = 20$) for the year 2015.

Enrichment factors for REEs in moss samples from 2015 are presented in Figure 17 for both background and industry/urban environments. In background areas, median EF values are all close to 1 indicating that the observed concentrations mainly reflect natural levels and are controlled by lithogenic sources. Samples from industry and urban environments show somewhat higher median EF values for some elements as well as slightly larger interquartile ranges, indicating a broader spread within the central portion of the data. At the same time, several background samples display longer whiskers and more extreme outliers showing that the overall range can still be considerable despite relatively narrow interquartile ranges. The larger variation observed for the background samples is likely related to the substantially larger number of sampling sites and their wider geographical distribution compared with the urban/industrial dataset. However, most EF values in both environments remain close to $EF \approx 1$ –2 and only a few observations reach higher values. Values near or above $EF = 10$ are rare suggesting that strong enrichment is uncommon. Nevertheless, these elevated values may represent locations influenced by local anthropogenic sources or site specific geological conditions and could therefore be interesting to investigate further.

Across both environmental types, a similar pattern is observed along the REE series, with a gradual decrease in EF from LREEs to HREEs. This consistent trend suggests that the overall distribution is mainly controlled by natural geochemical processes rather than by specific anthropogenic sources. The slightly broader distribution within the central part of the industry and urban datasets may reflect minor contributions from local emissions or human activities. However, the absence of consistently elevated EF values indicates that these influences are limited.

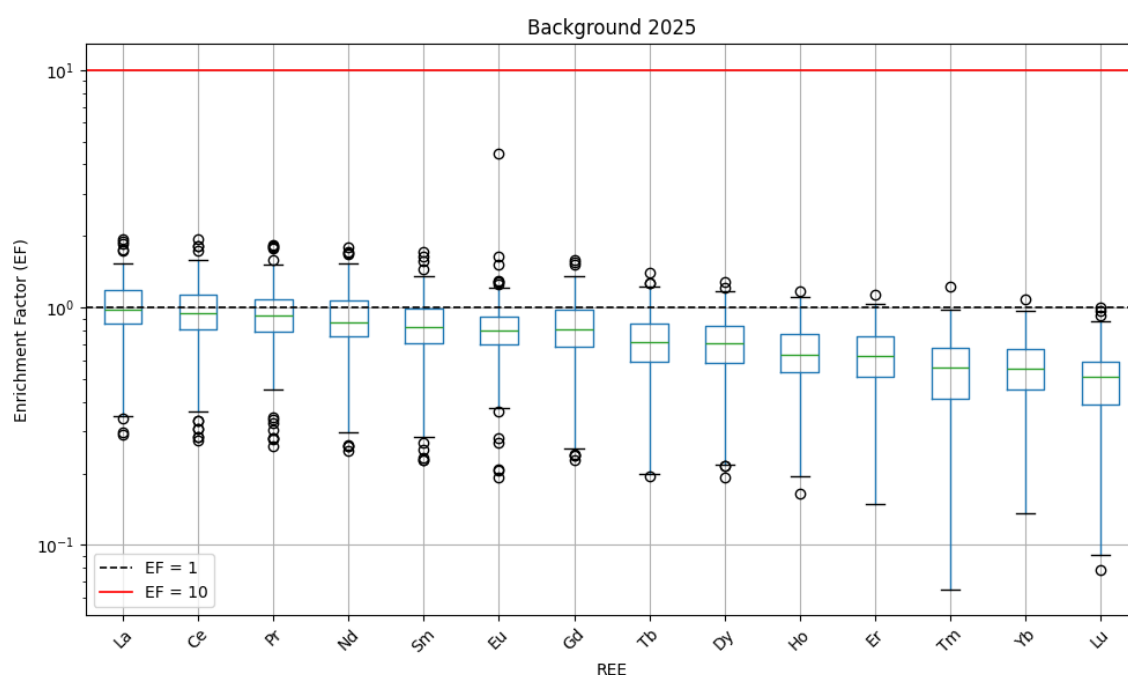


Figure 18. Enrichment factor plotted in boxplots for background samples (n = 100) for the year 2025.

The EF distribution for background samples in 2025 (Figure 18) shows a pattern very similar to the background data from 2015. Compared with 2015, the 2025 background dataset contained fewer extreme enrichment factors. Most EF values remained below 10 in 2025, whereas several elements displayed isolated higher values in 2015. The reasons for this difference cannot be determined from the present dataset. Median EF values remain close to unity for all REEs, indicating natural sources. Just as in 2015 the boxes are relatively small showing that most values are clustered within a narrow range. At the same time, long whiskers and some outliers are still present. These represent values that are higher or lower than most samples but they do not dominate the dataset. Instead, it reflects natural variability. A similar decreasing trend from LREE to HREE is also observed in 2025. For the background

samples, this further supports the interpretation that REE patterns are mainly controlled by natural geochemical processes.

Taken together, the enrichment factor analysis indicates that most REEs exhibited EF values close to 1 in both background and urban/industrial samples, suggesting that crustal material is the dominant source of REEs in Swedish moss. Although the urban/industrial samples displayed slightly greater variation for some elements, enrichment remained generally low.

4.6 Overall interpretation of REE patterns and potential sources

The combined results from the spatial analysis, temporal comparison, enrichment factor analysis and correlation analysis indicate that REE concentrations observed in Swedish moss are mainly controlled by natural crustal and geogenic sources rather than strong anthropogenic contamination. Although some local hotspots and moderate increases were observed between 2015 and 2025, the overall REE patterns remain relatively stable and consistent throughout the country. One of the findings throughout the study was the strong similarity in behavior between different REEs. Both LREEs and HREEs displayed comparable spatial distributions characterized by low concentrations in northern Sweden and somewhat elevated concentrations in the south regions. This north-south gradient was visible for nearly all elements and remained similar between 2015 and 2025, which could suggest influence by near environment such as cities or long-range transport mechanisms. Southern Sweden is more densely populated and have more roads, industrial activities and urban areas in comparison to the north. Also, southern Sweden is more strongly influenced by long-range atmospheric transportation from Europe so these factors likely contributed to increased deposition of airborne particles and mineral dust. At the same time, some local hotspots were identified in mining and industrial regions particularly in northern Sweden and parts of Bergslagen, which probably contributed to elevated REE concentrations through emissions.

The spatial distributions, descriptive statistics and correlation analysis all showed strong similarities between the REEs. Both LREEs and HREEs showed broadly the same geographical patterns as mentioned, while the concentration order remained the same between 2015 and 2025. At the same time, LREEs occurred at higher concentration levels than HREEs. This pattern agrees with the natural abundance distribution of REEs in the Earth's crust and is further supported by the strong correlations observed between REEs and aluminum, particularly after removal of outliers. In contrast, the correlations between REEs

and anthropogenic tracer metals, such as lead and antimony, were weaker. This indicates that REEs do not follow the same environmental behavior as typical pollution related metals. Since aluminum is commonly associated with crustal material, the correlation results strengthen the interpretation suggested by both the maps and descriptive statistics that crustal inputs are important contributors to REE accumulation in moss.

The enrichment factor analysis and spatial maps also support each other well. The maps showed broad regional gradients rather than highly concentrated hotspots, while most enrichment factors remained relatively low and close to crustal reference values. Together, these findings suggest that the REE concentrations mainly reflect diffuse background deposition and natural sources rather than strong anthropogenic enrichment. Although some local hotspots and elevated enrichment values were identified near mining and industrial regions, these areas were relatively limited and did not dominate the overall national pattern.

The temporal comparison between 2015 and 2025 showed that concentrations of most REEs increased slightly over the 10-year period. However, the increases were moderate and occurred consistently across many elements rather than being restricted to specific REEs. This broad increase may partly reflect the growing global use of REEs in modern technologies and increased atmospheric circulation of REE containing particles. Nevertheless, the overall magnitude of the increase was relatively small and the spatial patterns remained unchanged during these years. The stability of the REE pattern suggests that the dominant environmental controls have remained similar and that no major shift towards anthropogenic emission increase or contamination has occurred. The comparison with international studies further supports this interpretation. Swedish moss samples showed substantially lower REE concentrations compared to other countries with intensive mining activity, industrial emission or naturally REE enriched environments such as in China and Albania. Instead, Sweden showed concentration levels more similar to Norway and North Macedonia. The relatively low Swedish concentrations likely reflect the absence of active large-scale extraction of REEs in mining today, as well as the country's lower population density and lower levels of atmospheric pollution compared to other countries and regions.

Overall, the spatial patterns, temporal trends, correlation analysis and enrichment factor analysis suggest that REEs in Swedish moss are primarily associated with natural crustal material, combined with atmospheric transport processes. Anthropogenic influences may

contribute locally in some specific regions, but do not appear to dominate the overall national REE patterns observed between 2015 and 2025. Together, these findings demonstrate the usefulness of moss as a biomonitor for detecting spatial and temporal variation in REE deposition. They also highlight that both natural geological conditions and anthropogenic activities contribute to the observed REE patterns, although their relative importance varies between regions.

5 Conclusion

The findings of this thesis indicate that REE concentrations in Swedish moss are predominantly controlled by natural crustal and geogenic sources, although modest temporal increases and some local hotspots were observed between 2015 and 2025. Despite these increases, the overall spatial patterns remained similar over the study period. Both LREEs and HREEs showed higher concentrations in southern Sweden and lower concentrations in the north. The higher concentrations and larger increases observed in southern Sweden may be related to long-range atmospheric transport and the greater presence of industrial activities in this part of the country. In comparison with previous studies from other countries, Swedish background moss generally contained lower REE concentrations. However, these comparisons should be interpreted with some caution because the included studies differed in sampling strategy, environmental setting and moss species. Nevertheless, the Swedish results indicate relatively low atmospheric inputs of REEs compared with many previously published studies. The strong correlations between REEs and aluminium, together with generally low enrichment factors, suggest that REEs in Swedish moss primarily originate from crustal and geogenic sources rather than anthropogenic emissions. This interpretation is further supported by the observed abundance pattern, where LREEs consistently occurred at higher concentrations than HREEs, reflecting the natural distribution of REEs in the Earth's crust. While some local hotspots may be linked to industrial activities or mining, anthropogenic sources do not appear to be the main driver of REE concentrations at the national scale. Overall, the results suggest that REEs are not currently a widespread environmental pollution issue in Sweden and demonstrate that moss biomonitoring is a useful approach for assessing atmospheric deposition and spatial trends for REEs. The results provide an important baseline for further monitoring of REEs in Sweden, particularly since the global use of these elements continues to increase in connection with the green transition and the growing demand for modern technologies.

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Appendix

The appendix presents information and data from samples analysed and collected between 2015 and 2025. Due to privacy restrictions, data from industry and urban samples from 2015 cannot be disclosed and are therefore not included. The tables are organised according to county code and name.

A. Complete results 2015

Table A. 1. Light earth elements 2015 (µg/g) TS.

Municipality name	Municipality code	La	Ce	Pr	Nd	Sm	Eu
Dals-Ed	1438	0.14	0.24	0.026	0.098	0.021	0.0035
Hedemora	2038	0.10	0.19	0.019	0.078	0.014	0.00038
Kungsör	1960	0.19	0.37	0.042	0.16	0.030	0.00038
Hallsberg	1861	0.22	0.42	0.047	0.18	0.034	0.00038
Nässjö	682	0.11	0.20	0.022	0.085	0.016	0.00038
Norrköping	581	0.13	0.25	0.029	0.11	0.020	0.00038
Kristinehamn	1781	0.11	0.21	0.024	0.087	0.017	0.0028
Västervik	883	0.13	0.24	0.027	0.10	0.018	0.0034
Tierp	360	0.18	0.34	0.038	0.14	0.025	0.0047
Ljungby	781	0.11	0.20	0.022	0.079	0.014	0.0030
Åsele	2463	0.82	1.8	0.21	0.79	0.15	0.0092
Åsele	2463	0.092	0.17	0.019	0.073	0.014	0.0023
Krokom	2309	0.14	0.29	0.032	0.12	0.021	0.0041
Nynäshamn	192	0.39	0.74	0.086	0.31	0.060	0.0080
Värnamo	683	0.13	0.26	0.030	0.11	0.019	0.0037
Norrtälje	188	0.13	0.24	0.027	0.10	0.018	0.0038
Hässleholm	1293	0.13	0.24	0.027	0.10	0.019	0.0032
Pajala	2521	0.043	0.075	0.0084	0.031	0.0060	0.0011
Olofström	1060	0.18	0.36	0.040	0.15	0.026	0.0042
Älvdalen	2039	0.061	0.11	0.013	0.052	0.0083	0.0019
Leksand	2029	0.080	0.15	0.017	0.063	0.012	0.0021
Karlsborg	1446	0.079	0.15	0.016	0.061	0.010	0.0019
Piteå	2581	0.091	0.14	0.016	0.060	0.010	0.0019
Sorsele	2422	0.19	0.42	0.042	0.16	0.030	0.0055
Arjeplog	2506	0.061	0.11	0.013	0.048	0.0087	0.0020
Strömsund	2313	0.074	0.14	0.016	0.064	0.012	0.0019
Lycksele	2481	0.089	0.16	0.018	0.070	0.013	0.0025
Uppvidinge	760	0.097	0.22	0.020	0.073	0.013	0.0027
Växjö	780	0.13	0.25	0.028	0.10	0.019	0.0036
Värnamo	683	0.097	0.18	0.021	0.076	0.014	0.0030

Torsby	1737	0.090	0.17	0.021	0.070	0.013	0.0029
Årjäng	1765	0.28	0.54	0.079	0.24	0.044	0.0079
Sunne	1766	0.13	0.21	0.025	0.092	0.014	0.00085
Älmhult	765	0.14	0.28	0.032	0.12	0.020	0.0019
Hällefors	1863	0.11	0.19	0.021	0.078	0.012	0.00038
Vimmerby	884	0.088	0.16	0.018	0.068	0.0086	0.00038
Åre	2321	0.055	0.11	0.012	0.043	0.0058	0.00038
Bräcke	2305	0.075	0.15	0.017	0.061	0.011	0.00038
Tierp	360	0.67	1.2	0.15	0.54	0.095	0.012
Sotenäs	1427	0.19	0.28	0.030	0.11	0.018	0.00038
Ockelbo	2101	0.39	0.82	0.092	0.35	0.062	0.0086
Mörbylånga	840	0.68	1.2	0.17	0.68	0.13	0.026
Valdemarsvik	563	0.083	0.16	0.018	0.066	0.011	0.0022
Åstorp	1277	0.20	0.22	0.024	0.097	0.016	0.0031
Höganäs	1284	0.39	0.82	0.092	0.35	0.063	0.0088
Halmstad	1380	0.14	0.29	0.030	0.11	0.019	0.0030
Strömsund	2313	0.49	1.0	0.12	0.44	0.078	0.011
Ånge	2260	0.057	0.10	0.012	0.044	0.0077	0.0014
Kungsbacka	1384	0.19	0.36	0.039	0.15	0.027	0.0046
Älvdalen	2039	0.064	0.12	0.013	0.051	0.0099	0.0018
Nyköping	480	0.25	0.47	0.054	0.20	0.035	0.0056
Älvsbyn	2560	0.036	0.064	0.0073	0.027	0.0051	0.0012
Alvesta	764	0.15	0.28	0.031	0.11	0.020	0.0041
Vallentuna	115	0.28	0.52	0.058	0.21	0.038	0.0061
Vilhelmina	2462	0.021	0.040	0.0045	0.018	0.0032	0.00084
Storuman	2421	0.044	0.090	0.0089	0.033	0.0058	0.0014
Gällivare	2523	0.077	0.14	0.015	0.058	0.0092	0.0022
Kiruna	2584	0.25	0.46	0.049	0.18	0.030	0.0057
Kiruna	2584	0.037	0.067	0.0074	0.027	0.0044	0.0010
Haparanda	2583	0.091	0.15	0.016	0.060	0.011	0.0022
Skellefteå	2482	0.14	0.25	0.030	0.12	0.019	0.0035
Nordmaling	2401	0.060	0.10	0.011	0.044	0.0072	0.0015
Härnösand	2280	0.042	0.073	0.0082	0.032	0.0053	0.0011
Härjedalen	2361	0.077	0.14	0.016	0.058	0.0096	0.0025
Härjedalen	2361	0.086	0.15	0.017	0.064	0.012	0.0023
Ragunda	2303	0.12	0.22	0.025	0.093	0.016	0.0032
Sollefteå	2283	0.078	0.14	0.015	0.059	0.011	0.0023
Robertsfors	2409	0.075	0.13	0.015	0.054	0.0098	0.0018
Orsa	2034	0.090	0.17	0.018	0.070	0.013	0.0025
Hudiksvall	2184	0.13	0.23	0.025	0.096	0.019	0.0030
Motala	583	0.065	0.12	0.013	0.048	0.0082	0.0017
Söderköping	582	0.26	0.50	0.057	0.21	0.039	0.0068
Vara	1470	0.16	0.31	0.035	0.13	0.024	0.0043

Växjö	780	0.12	0.24	0.026	0.098	0.017	0.0033
Kalmar	880	0.15	0.28	0.030	0.11	0.019	0.0033
Sävsjö	684	0.11	0.21	0.023	0.091	0.016	0.0032
Borås	1490	0.10	0.19	0.021	0.080	0.015	0.0027
Katrineholm	483	0.21	0.40	0.046	0.17	0.031	0.0053
Kungälv	1482	0.16	0.29	0.033	0.12	0.022	0.0035
Hylte	1315	0.089	0.16	0.018	0.067	0.012	0.0024
Karlskrona	1080	0.19	0.36	0.040	0.14	0.026	0.0047
Gotland	980	0.16	0.31	0.037	0.14	0.028	0.0058
Kävlinge	1261	0.20	0.39	0.045	0.17	0.031	0.0059
Vellinge	1233	0.39	0.78	0.084	0.31	0.059	0.0099
Ystad	1286	0.28	0.56	0.063	0.24	0.044	0.0079
Tomelilla	1270	1.1	2.3	0.26	0.99	0.16	0.026

Table A. 2. Heavy rare earth elements 2015 (µg/g) TS.

Municipality name	Municipality code	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Dals-Ed	1438	0.016	0.0023	0.013	0.0024	0.0064	0.00089	0.0054	0.00093
Hedemora	2038	0.012	0.0017	0.010	0.0019	0.0059	0.00071	0.0049	0.00066
Kungsör	1960	0.027	0.0038	0.022	0.0038	0.012	0.0017	0.011	0.0021
Hallsberg	1861	0.031	0.0042	0.026	0.0049	0.013	0.0019	0.013	0.0019
Nässjö	682	0.014	0.0018	0.011	0.0019	0.0053	0.00064	0.0040	0.00062
Norrköping	581	0.017	0.0024	0.014	0.0027	0.0074	0.00095	0.0060	0.00095
Kristinehamn	1781	0.015	0.0022	0.013	0.0025	0.0068	0.00096	0.0059	0.00092
Västervik	883	0.015	0.0021	0.012	0.0021	0.0065	0.00081	0.0054	0.00084
Tierp	360	0.022	0.0032	0.019	0.0036	0.0096	0.0013	0.0088	0.0013
Ljungby	781	0.012	0.0017	0.0098	0.0018	0.0050	0.00067	0.0045	0.00056
Åsele	2463	0.11	0.014	0.068	0.012	0.029	0.0039	0.025	0.0034
Åsele	2463	0.012	0.0016	0.0094	0.0018	0.0050	0.00065	0.0039	0.00044
Krokom	2309	0.019	0.0026	0.015	0.0028	0.0080	0.0011	0.0075	0.0011
Nynäshamn	192	0.052	0.0073	0.039	0.0071	0.019	0.0026	0.016	0.0022
Värnamo	683	0.017	0.0026	0.015	0.0030	0.0076	0.0011	0.0065	0.00084
Norrtälje	188	0.016	0.0024	0.014	0.0026	0.0072	0.00099	0.0062	0.00073
Hässleholm	1293	0.015	0.0022	0.013	0.0026	0.0071	0.00010	0.0062	0.00089
Pajala	2521	0.0044	0.00055	0.0031	0.00054	0.0017	0.00011	0.00080	0.00016
Olofström	1060	0.024	0.0035	0.019	0.0036	0.011	0.0016	0.0010	0.0015
Älvdalen	2039	0.0081	0.0011	0.0060	0.0011	0.0035	0.00044	0.0029	0.00042
Leksand	2029	0.010	0.0013	0.0081	0.0014	0.0043	0.00058	0.0036	0.00049
Karlsborg	1446	0.0097	0.0015	0.0080	0.0014	0.0042	0.00049	0.0034	0.00049
Piteå	2581	0.0098	0.0012	0.0072	0.0013	0.0042	0.00050	0.0033	0.00052
Sorsele	2422	0.024	0.0035	0.021	0.0040	0.011	0.0014	0.0091	0.0012
Arjeplog	2506	0.0085	0.0012	0.0069	0.0011	0.0033	0.00041	0.0028	0.00033
Strömsund	2313	0.0099	0.0012	0.0074	0.0013	0.0039	0.00042	0.0034	0.00045

Lycksele	2481	0.011	0.0020	0.0093	0.0016	0.0049	0.00063	0.0042	0.00063
Uppvidinge	760	0.012	0.0015	0.0090	0.0018	0.0048	0.00063	0.0043	0.00046
Växjö	780	0.016	0.0024	0.014	0.0025	0.0071	0.00094	0.0062	0.00092
Värnamo	683	0.012	0.0016	0.0092	0.0018	0.0051	0.00064	0.0046	0.00065
Torsby	1737	0.011	0.0015	0.0086	0.0015	0.0043	0.00056	0.0043	0.00058
Årjäng	1765	0.037	0.0056	0.031	0.0061	0.018	0.0024	0.018	0.0026
Sunne	1766	0.013	0.00095	0.010	0.0016	0.0050	0.00042	0.0050	0.00046
Älmhult	765	0.018	0.0018	0.015	0.0024	0.0082	0.00084	0.0070	0.00093
Hällefors	1863	0.012	0.00085	0.010	0.0014	0.0052	0.00040	0.0048	0.00048
Vimmerby	884	0.0094	0.00059	0.0080	0.0010	0.0041	0.00011	0.0037	0.00041
Åre	2321	0.0069	0.00013	0.0054	0.00078	0.0030	0.00011	0.0023	0.00016
Bräcke	2305	0.0091	0.00031	0.0076	0.0011	0.0041	0.00011	0.0038	0.00035
Tierp	360	0.085	0.011	0.066	0.012	0.034	0.0042	0.028	0.0038
Sotenäs	1427	0.014	0.0013	0.011	0.0017	0.0063	0.00038	0.0048	0.00056
Ockelbo	2101	0.053	0.0076	0.045	0.0086	0.024	0.0034	0.022	0.0031
Mörbylånga	840	0.13	0.019	0.11	0.019	0.054	0.0073	0.045	0.0060
Valdemarsvik	563	0.011	0.0015	0.0090	0.0018	0.0045	0.00075	0.0044	0.00058
Åstorp	1277	0.016	0.0021	0.012	0.0031	0.0063	0.00081	0.0054	0.00076
Höganäs	1284	0.053	0.0077	0.043	0.0083	0.024	0.0033	0.022	0.0029
Halmstad	1380	0.016	0.0023	0.014	0.0026	0.0068	0.0011	0.0061	0.00095
Strömsund	2313	0.070	0.010	0.060	0.012	0.034	0.0049	0.032	0.0048
Ånge	2260	0.0074	0.0011	0.0060	0.0011	0.0030	0.00042	0.0024	0.00043
Kungsbacka	1384	0.023	0.0033	0.017	0.0033	0.0094	0.0013	0.0079	0.0012
Älvdalen	2039	0.0085	0.0012	0.0070	0.0012	0.0034	0.00045	0.0028	0.00044
Nyköping	480	0.032	0.0048	0.026	0.0051	0.015	0.0020	0.013	0.0018
Älvsbyn	2560	0.0042	0.00057	0.0034	0.00069	0.0020	0.00030	0.0019	0.00016
Alvesta	764	0.019	0.0024	0.013	0.0025	0.0072	0.00010	0.0060	0.00096
Vallentuna	115	0.033	0.0045	0.027	0.0052	0.016	0.0022	0.014	0.0020
Vilhelmina	2462	0.0029	0.00047	0.0024	0.00045	0.00066	0.00011	0.00080	0.00016
Storuman	2421	0.0053	0.00084	0.0046	0.00093	0.0027	0.00039	0.0024	0.00033
Gällivare	2523	0.0093	0.0013	0.0068	0.0013	0.0039	0.00055	0.0035	0.00049
Kiruna	2584	0.030	0.0043	0.025	0.0051	0.015	0.0021	0.014	0.0021
Kiruna	2584	0.0039	0.00060	0.0030	0.00056	0.0015	0.00011	0.00080	0.00016
Haparanda	2583	0.0093	0.0013	0.0078	0.0015	0.0042	0.00058	0.0036	0.00054
Skellefteå	2482	0.017	0.0026	0.015	0.0027	0.0075	0.0010	0.0066	0.00095
Nordmaling	2401	0.0066	0.00096	0.0054	0.0010	0.0029	0.00039	0.0024	0.00035
Härnösand	2280	0.0055	0.00069	0.0039	0.00077	0.0022	0.00031	0.0019	0.00016
Härjedalen	2361	0.0098	0.0014	0.0079	0.0015	0.0044	0.00060	0.0037	0.00052
Härjedalen	2361	0.011	0.0015	0.0086	0.0016	0.0047	0.00063	0.0047	0.00057
Ragunda	2303	0.015	0.0021	0.012	0.0021	0.0062	0.00085	0.0053	0.00078
Sollefteå	2283	0.0095	0.0014	0.0083	0.0016	0.0044	0.00061	0.0038	0.00053
Robertsfors	2409	0.0086	0.0012	0.0061	0.0011	0.0031	0.00041	0.0026	0.00036
Orsa	2034	0.011	0.0018	0.0097	0.0018	0.0052	0.00074	0.0049	0.00066

Hudiksvall	2184	0.017	0.0025	0.015	0.0027	0.0079	0.0011	0.0070	0.00099
Motala	583	0.0085	0.0013	0.0072	0.0013	0.0040	0.00055	0.0036	0.00048
Söderköping	582	0.037	0.0051	0.028	0.0055	0.016	0.0022	0.014	0.0019
Vara	1470	0.021	0.0031	0.018	0.0034	0.0010	0.0014	0.0087	0.0012
Växjö	780	0.015	0.0021	0.012	0.0022	0.0064	0.00090	0.0055	0.00076
Kalmar	880	0.016	0.0021	0.011	0.0021	0.0062	0.00088	0.0056	0.00080
Sävsjö	684	0.014	0.0020	0.011	0.0021	0.0061	0.00081	0.0051	0.00069
Borås	1490	0.014	0.0019	0.011	0.0020	0.0056	0.00080	0.0048	0.00069
Katrineholm	483	0.030	0.0045	0.026	0.0049	0.014	0.0020	0.013	0.0019
Kungälv	1482	0.021	0.0031	0.018	0.0034	0.0095	0.0013	0.0084	0.0012
Hylte	1315	0.011	0.0016	0.0092	0.0018	0.0054	0.00079	0.0051	0.00075
Karlskrona	1080	0.022	0.0032	0.017	0.0032	0.0092	0.0013	0.0079	0.0011
Gotland	980	0.028	0.0040	0.023	0.0042	0.012	0.0016	0.010	0.0014
Kävlinge	1261	0.027	0.0040	0.023	0.0043	0.013	0.0018	0.011	0.0016
Vellinge	1233	0.052	0.0073	0.042	0.0079	0.023	0.0032	0.020	0.0028
Ystad	1286	0.041	0.0060	0.035	0.0069	0.020	0.0029	0.019	0.0027
Tomelilla	1270	0.13	0.018	0.096	0.018	0.051	0.0070	0.045	0.0066

B. Complete results 2025

Table B. 1. Light rare earth elements 2025 (µg/g) TS.

Municipality name	Municipality code	La	Ce	Pr	Nd	Sm	Eu
Åsele	2463	0.056	0.11	0.014	0.052	0.010	0.00095
Lycksele	2481	0.091	0.15	0.019	0.068	0.012	0.0021
Vilhelmina	2462	0.040	0.076	0.0089	0.032	0.0057	0.0015
Vilhelmina	2462	0.045	0.076	0.0084	0.028	0.0049	0.0013
Sorsele	2422	0.067	0.12	0.013	0.047	0.0085	0.0019
Storuman	2421	0.046	0.076	0.0094	0.036	0.0066	0.0024
Sorsele	2422	0.078	0.14	0.017	0.061	0.011	0.0027
Arvidsjaur	2505	0.15	0.32	0.028	0.10	0.021	0.0054
Arjeplog	2506	0.038	0.065	0.0074	0.027	0.0048	0.0014
Arjeplog	2506	0.033	0.065	0.0074	0.027	0.0050	0.0011
Jokkmokk	2510	0.093	0.16	0.018	0.063	0.011	0.0022
Gällivare	2523	0.051	0.091	0.010	0.038	0.0068	0.0015
Jokkmokk	2510	0.056	0.11	0.013	0.048	0.0085	0.0019
Gällivare	2523	0.12	0.23	0.026	0.093	0.015	0.0038
Gällivare	2523	0.27	0.54	0.067	0.27	0.052	0.011
Kiruna	2584	0.81	1.4	0.15	0.53	0.090	0.015
Kiruna	2584	0.040	0.072	0.0080	0.030	0.0057	0.0017
Älvdalen	2039	0.045	0.084	0.0092	0.034	0.006	0.0014
Härjedalen	2361	0.12	0.24	0.028	0.10	0.018	0.0029

Härjedalen	2361	0.079	0.15	0.016	0.062	0.011	0.0021
Härjedalen	2361	0.16	0.32	0.038	0.14	0.025	0.0043
Ånge	2260	0.081	0.17	0.019	0.069	0.013	0.0023
Timrå	2262	0.16	0.31	0.035	0.12	0.021	0.0037
Berg	2326	0.042	0.082	0.0094	0.035	0.0064	0.0016
Bräcke	2305	0.068	0.13	0.014	0.055	0.0097	0.0022
Ragunda	2303	0.091	0.16	0.019	0.07	0.013	0.0045
Åre	2321	0.043	0.091	0.011	0.041	0.0077	0.0019
Sollefteå	2283	0.049	0.090	0.0093	0.039	0.0067	0.001
Örnsköldsvik	2284	0.11	0.22	0.024	0.095	0.017	0.0026
Krokom	2309	0.083	0.16	0.019	0.071	0.014	0.016
Strömsund	2313	0.095	0.14	0.017	0.064	0.012	0.0035
Åsele	2463	0.11	0.20	0.023	0.083	0.016	0.0032
Nordmaling	2401	0.12	0.24	0.027	0.10	0.018	0.0028
Vindeln	2404	0.19	0.37	0.044	0.16	0.029	0.004
Robertsfors	2409	0.12	0.24	0.028	0.099	0.018	0.0034
Strömsund	2313	0.059	0.11	0.012	0.044	0.0088	0.0018
Skellefteå	2482	0.15	0.27	0.032	0.12	0.021	0.0045
Piteå	2581	0.13	0.27	0.031	0.11	0.019	0.0034
Haparanda	2583	0.12	0.22	0.026	0.095	0.015	0.0030
Boden	2582	0.11	0.18	0.018	0.066	0.010	0.0021
Överkalix	2513	0.10	0.18	0.019	0.070	0.011	0.0021
Övertorneå	2518	0.089	0.17	0.019	0.069	0.012	0.0036
Pajala	2521	0.18	0.33	0.039	0.14	0.023	0.0050
Kristinehamn	1781	0.20	0.38	0.043	0.16	0.030	0.0052
Arvika	1784	0.17	0.34	0.038	0.14	0.025	0.0048
Ludvika	2085	0.14	0.27	0.030	0.11	0.018	0.0034
Malung	2023	0.10	0.20	0.024	0.089	0.016	0.0034
Leksand	2029	0.14	0.25	0.028	0.10	0.019	0.0040
Hedemora	2083	0.24	0.51	0.053	0.20	0.038	0.0058
Torsby	1737	0.10	0.19	0.021	0.078	0.015	0.0037
Älvdalen	2039	0.17	0.34	0.039	0.14	0.025	0.0056
Rättvik	2031	0.12	0.26	0.027	0.10	0.019	0.0037
Ockelbo	2101	0.098	0.19	0.021	0.079	0.015	0.0028
Orsa	2034	0.15	0.31	0.036	0.13	0.026	0.0050
Söderhamn	2182	0.19	0.35	0.042	0.15	0.029	0.0050
Ljusdal	2161	0.12	0.22	0.026	0.095	0.018	0.0031
Hudiksvall	2184	0.56	1.1	0.13	0.49	0.091	0.010
Ljungby	781	0.17	0.32	0.036	0.14	0.024	0.0045
Gislaved	662	0.23	0.43	0.049	0.18	0.032	0.0063
Växjö	780	0.16	0.32	0.037	0.13	0.023	0.0046
Tranemo	1452	0.22	0.45	0.052	0.19	0.035	0.0064
Sävsjö	684	0.14	0.27	0.031	0.12	0.023	0.0047

Vetlanda	685	0.19	0.34	0.039	0.15	0.026	0.0057
Borås	1490	0.22	0.47	0.051	0.18	0.035	0.0069
Nässjö	682	0.44	0.82	0.095	0.35	0.062	0.010
Västervik	883	0.14	0.28	0.031	0.12	0.021	0.0038
Lidköping	1494	0.18	0.34	0.040	0.15	0.027	0.0050
Tidaholm	1498	0.16	0.34	0.037	0.14	0.025	0.0046
Karlsborg	1446	0.25	0.50	0.058	0.21	0.037	0.0062
Kinda	513	0.19	0.39	0.045	0.17	0.030	0.0054
Söderköping	582	0.19	0.38	0.045	0.16	0.030	0.0055
Nyköping	480	0.51	0.99	0.12	0.42	0.076	0.012
Bengtstors	1460	0.16	0.29	0.033	0.13	0.023	0.0054
Lekeberg	1814	0.22	0.44	0.051	0.19	0.036	0.0061
Kungsör	1960	0.20	0.38	0.045	0.17	0.033	0.0045
Ljusnarsberg	1864	0.26	0.52	0.058	0.22	0.042	0.0085
Vallentuna	115	0.58	1.2	0.14	0.49	0.092	0.014
Tierp	360	0.2	0.39	0.044	0.16	0.030	0.0051
Tierp	360	0.46	0.92	0.11	0.40	0.076	0.011
Norrtälje	188	0.14	0.26	0.030	0.11	0.022	0.0038
Perstorp	1275	0.20	0.39	0.044	0.16	0.029	0.0054
Hässleholm	1293	0.35	0.56	0.063	0.23	0.039	0.0069
Karlskrona	1080	0.44	0.85	0.10	0.37	0.067	0.012
Kungsbacka	1384	0.15	0.29	0.032	0.12	0.022	0.0042
Tanum	1435	0.23	0.35	0.040	0.14	0.026	0.0043
Strömstad	1486	0.33	0.63	0.069	0.24	0.040	0.0061
Gotland	980	0.28	0.56	0.070	0.26	0.052	0.011
Gotland	980	0.20	0.39	0.045	0.17	0.033	0.0065
Vilhelmina	2462	0.045	0.076	0.0084	0.028	0.0049	0.0013
Östhammar	382	0.51	1.0	0.11	0.38	0.058	0.011
Valdemarsvik	563	0.36	0.77	0.087	0.32	0.058	0.010
Mörbylånga	840	0.34	0.68	0.078	0.30	0.057	0.0092
Mönsterås	861	0.20	0.40	0.046	0.17	0.032	0.0064
Älmhult	765	0.54	1.1	0.12	0.43	0.072	0.011
Höör	1267	0.30	0.63	0.071	0.25	0.047	0.0078
Lund	1281	0.26	0.52	0.06	0.22	0.040	0.0071
Ystad	1286	0.22	0.44	0.05	0.20	0.035	0.0052
Ängelholm	1292	0.35	0.72	0.082	0.30	0.056	0.010
Halmstad	1380	0.19	0.36	0.041	0.16	0.027	0.0033
Varberg	1383	0.58	1.2	0.14	0.52	0.088	0.011
Nora	1884	0.16	0.31	0.036	0.14	0.026	0.0047

Table B. 2. Heavy rare earth elements 2025 (µg/g) TS.

Municipality name	Municipality code	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Åsele	2463	0.0071	0.00095	0.0048	0.00095	0.0021	0.00024	0.0019	0.00024
Lycksele	2481	0.010	0.0014	0.0081	0.0017	0.0043	0.00048	0.0038	0.00048
Vilhelmina	2462	0.0048	0.00069	0.0037	0.00069	0.0018	0.00025	0.0014	0.00022
Vilhelmina	2462	0.0041	0.00064	0.0034	0.00069	0.0019	0.00027	0.0017	0.00025
Sorsele	2422	0.0073	0.0011	0.0055	0.0010	0.0027	0.00042	0.0024	0.00038
Storuman	2421	0.0059	0.00078	0.0046	0.00083	0.0023	0.00024	0.0019	0.00030
Sorsele	2422	0.0099	0.0013	0.0074	0.0014	0.0039	0.00051	0.0031	0.00049
Arvidsjaur	2505	0.021	0.0042	0.019	0.0042	0.010	0.0019	0.0092	0.0015
Arjeplog	2506	0.0041	0.00053	0.0031	0.00055	0.0016	0.00021	0.0014	0.00019
Arjeplog	2506	0.0042	0.00062	0.0035	0.00064	0.0018	0.00023	0.0015	0.00019
Jokkmokk	2510	0.0091	0.0012	0.0066	0.0012	0.0032	0.00043	0.0026	0.00040
Gällivare	2523	0.0059	0.00094	0.0054	0.0011	0.0029	0.00036	0.0024	0.00033
Jokkmokk	2510	0.0072	0.0011	0.0062	0.0012	0.0033	0.00047	0.0028	0.00045
Gällivare	2523	0.013	0.0019	0.011	0.0023	0.0068	0.00092	0.0057	0.00083
Gällivare	2523	0.048	0.0065	0.040	0.0074	0.022	0.0029	0.019	0.0029
Kiruna	2584	0.083	0.011	0.069	0.013	0.042	0.0056	0.038	0.0059
Kiruna	2584	0.0053	0.00068	0.0041	0.00073	0.0021	0.00024	0.0016	0.00025
Älvdalen	2039	0.0053	0.00072	0.0041	0.00072	0.0019	0.00024	0.0017	0.00024
Härjedalen	2361	0.015	0.0023	0.013	0.0027	0.008	0.0011	0.0075	0.0011
Härjedalen	2361	0.0093	0.00079	0.0069	0.00095	0.0035	0.00020	0.0031	0.000095
Härjedalen	2361	0.021	0.0031	0.018	0.0035	0.0098	0.0013	0.0089	0.0012
Ånge	2260	0.011	0.0016	0.0093	0.0017	0.0048	0.0006	0.0040	0.00054
Timrå	2262	0.018	0.0024	0.013	0.0024	0.0062	0.00081	0.0054	0.00069
Berg	2326	0.0054	0.00073	0.0042	0.00076	0.0023	0.00027	0.0018	0.00030
Bräcke	2305	0.0086	0.00080	0.0076	0.0011	0.0040	0.00032	0.0036	0.00025
Ragunda	2303	0.012	0.0015	0.0090	0.0016	0.0045	0.00071	0.0037	0.00055
Åre	2321	0.0071	0.0011	0.0061	0.0013	0.0033	0.00053	0.0029	0.00048
Sollefteå	2283	0.0059	0.00036	0.0045	0.00053	0.0022	0.000045	0.0019	<0.00
Örnsköldsvik	2284	0.015	0.0016	0.012	0.0018	0.0058	0.00045	0.0048	0.00044
Krokom	2309	0.012	0.0015	0.0086	0.0016	0.0046	0.00067	0.0040	0.00067
Strömsund	2313	0.011	0.0014	0.0081	0.0014	0.0040	0.00050	0.0031	0.00043
Åsele	2463	0.013	0.0018	0.010	0.0018	0.0050	0.00069	0.0043	0.00069
Nordmaling	2401	0.015	0.0021	0.011	0.0021	0.0054	0.00071	0.0042	0.00071
Vindeln	2404	0.023	0.0031	0.016	0.0029	0.0078	0.0011	0.0060	0.00089
Robertsfors	2409	0.015	0.0021	0.012	0.0022	0.0062	0.00078	0.0053	0.0007
Strömsund	2313	0.0081	0.0012	0.0074	0.0014	0.0041	0.00053	0.0032	0.00045
Skellefteå	2482	0.018	0.0025	0.014	0.0026	0.0073	0.0011	0.0063	0.00095
Piteå	2581	0.016	0.0022	0.013	0.0025	0.0067	0.00091	0.0056	0.00081

Haparanda	2583	0.012	0.0017	0.010	0.0019	0.0053	0.00072	0.0046	0.00068
Boden	2582	0.0085	0.00071	0.0067	0.00096	0.0036	0.00023	0.0033	0.00027
Övertkalix	2513	0.0085	0.00063	0.0062	0.0008	0.0030	0.00014	0.0026	0.00016
Övertorneå	2518	0.010	0.0015	0.0079	0.0015	0.0043	0.00059	0.0039	0.00055
Pajala	2521	0.018	0.0025	0.014	0.0025	0.0071	0.00098	0.0061	0.00089
Kristinehamn	1781	0.026	0.0036	0.020	0.0038	0.010	0.0013	0.0088	0.0013
Arvika	1784	0.022	0.0032	0.018	0.0034	0.0091	0.0013	0.0079	0.0011
Ludvika	2085	0.015	0.0022	0.012	0.0023	0.0065	0.00083	0.0056	0.00075
Malung	2023	0.014	0.0021	0.011	0.0022	0.0062	0.00080	0.0053	0.0007
Leksand	2029	0.017	0.0023	0.013	0.0026	0.0073	0.00094	0.0059	0.00094
Hedemora	2083	0.034	0.0046	0.029	0.0054	0.016	0.0022	0.015	0.0022
Torsby	1737	0.013	0.0016	0.010	0.0017	0.0054	0.00071	0.0043	0.00065
Älvdalen	2039	0.022	0.0033	0.017	0.0034	0.0092	0.0014	0.0078	0.0012
Rättvik	2031	0.017	0.0023	0.014	0.0028	0.0074	0.00093	0.0065	0.00093
Ockelbo	2101	0.013	0.002	0.011	0.002	0.0060	0.00075	0.0050	0.00075
Orsa	2034	0.023	0.0034	0.018	0.0036	0.0098	0.0013	0.0082	0.0012
Söderhamn	2182	0.026	0.0038	0.021	0.0041	0.011	0.0015	0.0096	0.0014
Ljusdal	2161	0.015	0.0022	0.012	0.0024	0.0067	0.00094	0.0059	0.00084
Hudiksvall	2184	0.074	0.0093	0.055	0.0095	0.029	0.0037	0.027	0.0038
Ljungby	781	0.020	0.0023	0.015	0.0025	0.0077	0.00083	0.0064	0.00089
Gislaved	662	0.027	0.0035	0.023	0.0039	0.012	0.0014	0.011	0.0014
Växjö	780	0.019	0.0027	0.016	0.0031	0.0084	0.0012	0.0075	0.0012
Tranemo	1452	0.030	0.0046	0.027	0.0052	0.015	0.0021	0.013	0.0018
Sävsjö	684	0.019	0.0026	0.015	0.0028	0.008	0.0012	0.0071	0.00094
Vetlanda	685	0.023	0.0029	0.018	0.0031	0.0091	0.0010	0.0072	0.00096
Borås	1490	0.032	0.0048	0.027	0.0053	0.015	0.0021	0.013	0.0019
Nässjö	682	0.053	0.0070	0.039	0.0073	0.020	0.0028	0.017	0.0023
Västervik	883	0.017	0.0022	0.013	0.0024	0.007	0.00089	0.006	0.00081
Lidköping	1494	0.023	0.0032	0.019	0.0035	0.0097	0.0012	0.0085	0.0012
Tidaholm	1498	0.022	0.0032	0.018	0.0035	0.0097	0.0014	0.0085	0.0012
Karlsborg	1446	0.03	0.0042	0.023	0.0044	0.012	0.0016	0.010	0.0014
Kinda	513	0.026	0.0039	0.022	0.0045	0.013	0.0017	0.011	0.0016
Söderköping	582	0.026	0.0036	0.020	0.0039	0.011	0.0014	0.0088	0.0013
Nyköping	480	0.064	0.0094	0.050	0.0095	0.026	0.0036	0.023	0.0034
Bengtstors	1460	0.020	0.0027	0.015	0.0029	0.0078	0.00098	0.0066	0.00098
Lekeberg	1814	0.030	0.0045	0.026	0.0051	0.015	0.0020	0.013	0.0018
Kungsör	1960	0.028	0.0040	0.023	0.0042	0.012	0.0017	0.011	0.0015
Ljusnarsberg	1864	0.036	0.0051	0.030	0.0055	0.016	0.0021	0.014	0.0019
Vallentuna	115	0.078	0.012	0.065	0.013	0.035	0.0049	0.032	0.0046
Tierp	360	0.025	0.0033	0.02	0.0035	0.010	0.0013	0.0083	0.0015
Tierp	360	0.063	0.0079	0.044	0.0076	0.022	0.0026	0.017	0.0023
Norrtälje	188	0.019	0.0029	0.016	0.0031	0.0089	0.0012	0.0077	0.0012
Perstorp	1275	0.025	0.0035	0.021	0.004	0.012	0.0017	0.011	0.0017

Hässleholm	1293	0.034	0.0046	0.027	0.005	0.015	0.0019	0.012	0.0018
Karlskrona	1080	0.056	0.0071	0.044	0.0077	0.023	0.0029	0.020	0.0028
Kungsbacka	1384	0.019	0.0026	0.016	0.0029	0.0083	0.00090	0.0066	0.00088
Tanum	1435	0.023	0.0032	0.018	0.0036	0.0098	0.0013	0.0081	0.0012
Strömstad	1486	0.033	0.0045	0.024	0.0043	0.012	0.0018	0.010	0.0015
Gotland	980	0.049	0.0071	0.040	0.0077	0.021	0.0027	0.017	--
Gotland	980	0.029	0.0039	0.023	0.0041	0.012	0.0016	0.0096	0.0014
Vilhelmina	2462	0.0041	0.00064	0.0034	0.00069	0.0019	0.00027	0.0017	0.00025
Östhammar	382	0.044	0.0058	0.031	0.0062	0.017	0.0025	0.016	0.0023
Valdemarsvik	563	0.050	0.0073	0.040	0.0076	0.021	0.0029	0.018	0.0026
Mörbylånga	840	0.049	0.0063	0.038	0.0065	0.019	0.0018	0.016	0.0015
Mönsterås	861	0.028	0.0041	0.022	0.0043	0.011	0.0016	0.0099	0.0014
Älmhult	765	0.059	0.0072	0.044	0.0077	0.023	0.0024	0.020	0.0021
Höör	1267	0.042	0.0063	0.035	0.0069	0.019	0.0028	0.018	0.0026
Lund	1281	0.036	0.0051	0.028	0.0053	0.015	0.002	0.013	0.0019
Ystad	1286	0.031	0.0036	0.025	0.004	0.013	0.00087	0.011	0.00068
Ängelholm	1292	0.048	0.0067	0.036	0.0067	0.018	0.0024	0.016	0.0021
Halmstad	1380	0.023	0.0023	0.018	0.0025	0.0088	0.00028	0.0076	0.00015
Varberg	1383	0.074	0.0097	0.060	0.011	0.032	0.0036	0.028	0.0032
Nora	1884	0.023	0.0032	0.019	0.0038	0.011	0.0016	0.010	0.0015

Note. -- indicates no data



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