Soil Survey in Sweden

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Introduction

The first systematic surveys and mapping undertaken in Sweden with some relevance for soil conditions were undertaken by the Geological Survey of Sweden in the middle of the last century. They were focussed mainly on geological parameters of the parent material (C horizon) and on this basis cannot be classed as real soil surveys.

However, they played an important role in the understanding of soil properties and land use planning, and came later to provide a useful basis for national soil mapping. The geological surveys gave rise to the so called Quaternary and Petrological Maps, the first one being published 1857. The maps show mineralogy and texture and genesis of the parent material, e.g. texture of glacial till and water or wind deposited sediments, and occurrence of peat and gyttja.

Between 1947 and 1966 the most southerly part of the country was surveyed and mapped in a similar way by the Geological Survey of Sweden, but at a more detailed scale, 1:20,000, and limited to small important agricultural regions. These so called Agrogeological Maps include, in addition to texture and mineralogy of parent material, some characterisation of the plough layer (Ap horizon) and an estimate of the market value of land (based on expected production capacities). They may, therefore, justify being designated as the first systematic soil surveys in Sweden, though not national, in view of the relatively small area covered.

Real national soil surveys did not start until the National Survey of Forest Soils was initiated in 1961 by the Department of Forest Soils at the Royal College of Forestry. The organisation was later changed and is now part of the Swedish University of Agricultural Sciences (SLU).

The soil survey was combined with the Swedish National Forest Inventory (ongoing since 1923) in such a way that both forest and soil parameters were recorded on the same plots, thus enabling a better understanding of forest-soil interactions.

These surveys, however, are limited to productive forest land, defined by a stem production exceeding 1m^3 per ha per year. There is some justification for this in that productive forestry is the single most widespread land use in Sweden. Of a total land area of *ca.* 41 million ha, about 23.5 million ha is presently under productive forestry. Other main land categories are peat land, mountainous land without forests, and arable land. As a special task in the inventories, soil samples are collected for chemical analyses and are held in a soil bank for use in future studies.

The nationwide surveys and samplings of forest land were carried out during the periods 1963-1972, 1973-1975 and 1983-1987, and are presently ongoing in the period 1993-2002. The methodology of the inventories has changed slightly with time. The present survey is called the Swedish National Survey of Forest Soils and Vegetation. The aim is, by repeated inventories, to form a base for studies of conditions and changes in soil properties and in vegetation with time.

The first national systematic survey of Swedish arable land was carried out between 1988 and 1995 with random sampling of 3,100 plough-layer horizons (Ap) and 1,700 subsoil samples throughout the agricultural areas in Sweden. The survey was carried out by the Department of Soil Science at SLU and focussed on humus content and the most important soil chemical properties. Reports and maps of arable soil properties have been produced.

Plans for a national mapping of soil units had been drawn up in 1958. Manuscripts were produced for the European Commission at the scale 1:1,000,000 but were never printed, except for being included in the 1:5,000,000 World Soil Map published by FAO-UNESCO. However, new mapping was carried out and eventually published in Sweden.

Soil Mapping

Quaternary and Petrological Maps

Quaternary and Petrological Maps and associated legends have been compiled in a systematic way by the Geological Survey of Sweden since the middle of the 19th century. They were based on topographic reconnaissance maps produced at a scale of 1:50,000 and published in a series from 1862 - 1974. Outcrops were differentiated on rock types, and the Quaternary deposits according to their genetic origin and textural composition. The mapping relates to a depth of 50 cm.

In a more modern series, started in the early 1960s, both methods and mapping were improved. The improvements include interpretation of air photography, both infrared and ortho photos at scales from 1:10,000 to 1:30,000, followed up by field controls and sampling for texture analyses. The maps are generalised regarding both grouping in geological map units and unit contours.

Quaternary and Petrological Maps from the different series are available at a scale of 1:50,000 for approximately 20% of the total area, mainly in the southern part of Sweden. However, these maps are of variable quality because the methodology has changed with time and because some of them, mainly in less densely populated regions in Northern Sweden, are made to give an overview of the geology.

There are also Quaternary and Petrological Maps at scales of 1:100,000 to 1:400,000. In total, the whole country is covered by these geological maps, but with varying degree of precision.

Geochemical Maps of Soil Parent Material

Soil Geochemical maps at a scale of 1:250,000 and 1:1,000,000 have been made by the Geological Survey of Sweden and relate to the aqua-regia soluble content of *ca.* 30 major and trace elements at a depth of 80 cm in the soil parent material (C horizon), mainly glacial till. The maps are based on *ca.* 32,000 plots with each geographical position set within a precision of better than 50 m. About 30% of the land area is presently covered.

Forest Land Mapping

National maps of site and soil properties of forest land have been compiled based on the national survey by the Swedish National Survey of Forest Soils at the Department of Forest Soils, SLU (the Swedish University of Agricultural Sciences). Most maps are based on the inventory period 1983 to 1987, involving 23,100 plots. The soil samples are from the O or A, E, B, B/C and C horizons. The methodology is described below (see Soil Monitoring).

National or regional maps are made at a scale of *ca.* 1:10 million by interpolation using mainly ordinary kriging (Davis 1986). They are available for a large number of site conditions such as vegetation type, soil unit, groundwater level, humus form, humus-layer thickness, pH, content of C, N and exchangeable ions in O, E, B and C horizons and total elemental composition of C horizons.

Total concentration and amount of heavy metals in humus layers were analysed and mapped by Andersson *et al.* (1989), using samples collected by the Swedish National Survey of Forest Soils and Vegetation.

Mapping of Arable Land

Agrogeological Maps, prepared by the Geological Survey during 1947-1966, are available for the most southerly part of the country (e.g. Ekström, 1953a). It was intended that the maps should be used for the management of arable land. This kind of mapping was restricted to the most productive agricultural districts in Sweden, particularly on carbonate-rich boulder clay.

The maps include information on the texture at a depth of 35 cm, i.e. the texture below the Ap horizon, and humus content of the Ap horizon. Each map also includes a description of the general geology and profile data including a classification of site capacity and estimated market value. Maps are at a scale of 1:20,000 but they cover together not more than *ca.* 0.1 million ha, i.e. about 3 % of the present arable land area or 0.25 % of the total land area in Sweden.

An overview soil map for arable land for the whole of Sweden focussing on plough layer (Ap) conditions was compiled at the beginning of the 1950s at a scale of 1:5 million by Ekström

(1953b), based on geological maps and the author's observations.

Swedish arable soils were also mapped at a scale of *ca.* 1:10 million by Eriksson *et al.* (1997), based on a systematic sampling of arable land from 1988 to 1995. Properties taken into account include humus content and the most important soil chemical properties: pH, total content of C, N and S, carbonate, cation exchange capacity and exchangeable bases, and various trace elements. The methodology is described below (see Soil Monitoring).

Soil Maps

A national soil map at a scale of 1:1,000,000 was made by Troedsson and Wiberg (1986). The map is based on data from the Swedish National Survey of Forest Soils collected in the period 1963-1978. In addition, data from investigations by the authors have been used, together with information from other maps such as Quaternary and Petrological Maps, Agrogeological Maps and topographical maps.

The soils are classified in the Swedish system but translated into the FAO-UNESCO legend and into the Soil Taxonomy system. Podzols are the most dominant soil unit in Sweden, but they are defined differently in the Swedish system compared to the FAO-UNESCO legend. In Sweden, the main criteria for their delimitation is the occurrence of an E horizon. The sub-types are defined by the E horizon thickness, i.e. 0-3cm, 3-6cm and >6cm.

The delineation of map units in Podzol regions of Sweden is mainly based on the occurrence of sub types, i.e. the E horizon thickness. This is particularly the case for the northern part of the country. However, in the FAO-UNESCO system most of these sub types would be classed as Haplic Podzols and they would be considered as more or less one and the same map unit. Therefore, the translation to the FAO-UNESCO legend will result in a loss of important information.

Histosols, Gleysols, Arenosols and Regosols occur in addition to Podzols. In Southern Sweden the pattern is more complex and additional map units are Cambisols and Leptosols.

Soil forming factors and Spodosol properties and occurrence in Sweden were described by Olsson and Troedsson (1990) at a Soil Correlation Meeting (ISCOM) in USA and Canada 1987 concerning characterisation, classification, and utilisation of Spodosols.

A Nordic soil map at a scale of 1:2,000,000 together with a description of units was compiled by Rasmussen *et al.* (1991) as a joint venture between Denmark, Finland, Norway and Sweden. In the case of Sweden, the map is based on the 1:1,000,000 map by Troedsson and Wiberg (1986). The classification scheme used relates to that of the FAO-UNESCO World Soil Map.

However, exceptions occur, e.g. the separation of podzol types is based mainly on E-horizon thickness as previously followed in the Nordic countries. In accordance with definitions of peatland, the Histosols are classified as soils with a peat layer thicker than 30 cm.

Some Quaternary and Petrological Maps, since 1991, have been supplemented by a soil-unit map based on the FAO-UNESCO system at a scale of 1:250,000. Though the maps are published by the Geological Survey of Sweden, the soil map supplement is a cooperative effort with the Swedish University of Agricultural Sciences (T. Troedsson). The delineation of map units is based on the description of the Quaternary geology, the 1:1,000,000 soil map and field observations. The total area presently covered by these soil maps, however, is still only about 0.15% of the total land area.

Soil Monitoring

Systematic soil monitoring in Sweden, at national level, is carried out mainly by:

1. The Swedish National Survey of Forest Soils and Vegetation at the Department of Forest Soils, SLU;
2. Integrated Monitoring (IM) through the Department of Environmental Assessment, SLU;
3. Intensive Monitoring Plots (ICP Forest, Level 2) through the National Board of Forestry;
4. Monitoring of Arable Land, carried out by the Department of Soil Science, SLU.

In addition, soil monitoring is also performed on a regional scale under the responsibility of County Boards but with a common protocol.

The Swedish National Survey of Forest Soils and Vegetation

The survey methods since 1963, when the first survey started, have changed but can generally be described as a stratified random sampling with higher densities in southern Sweden and lower densities in northern Sweden.

The first inventory, during the 10-year period 1963-1972, comprised recording of, e.g. parent material, soil unit, topographical and hydrological conditions, and ground- and field vegetation, in random sampling on almost 76,800 plots.

The country was re-sampled during the 3-year period 1973-1975, with around 23,100 plots and with several investigational pits per plot. The inventory during the 5-year period 1983 to 1987 comprised a total of 23,100 plots on forest land. A new method was implemented for this survey with defined permanent circular plots of a radius between 7 and 10 m. The intention is that the use of permanent plots will improve possibilities for following changes over time. The plots are clustered into "tracts". These are quadratic or rectangular with a side, depending on location in the country, within a range of 300-1800m.

The tracts are located in a *ca.* 5km x 5km to 15km x 15km grid, depending on location in Sweden (denser in the south). In general, soil pits and soil and site descriptions are made at one to two circular plots per tract. At each circular plot, general site properties such as vegetation type and occurrences of different species, type of soil parent material and hydrological conditions are described. Specific variables include thickness of humus layer, humus form and thickness of E horizon. The inventory also records soil type according to the Swedish system and the FAO-UNESCO legend (Figure 1).

The soil is sampled according to O or A, E, B, B/C and C horizons. Samples are stored in a soil bank and analyses include: pH (Figure 2), contents of C, N, exchangeable base cations and aluminium. Parent material (C horizon) from selected plots (*ca.* 3,000) has been analysed for the total elemental composition of major and trace elements. Some plots are included in CCP Forest, level 1 programme. This survey is followed by a new, still ongoing one, covering the 10-year period 1993- 2002.

The results of the measured parameters from The Swedish National Survey of Forest Soils and Vegetation can be related to natural site conditions such as geology and climate and to man-made impacts such as pollution. Using the data, critical loads for acidity and N deposition have been developed.

The geochemical surveys have led not only to a geochemical map but also to assessment of weathering rates in Sweden. The repeated surveys have enabled trends over time to be established, e.g. for acidity and base saturation. It has also been possible to verify that the accumulation of carbon is increasing in humus layers, a fact that is relevant to global climate change and management strategies to reduce net emissions of CO_2.

Most of the material is being presented and free to use as maps or as an interactive database on the world-wide-web (http://www-markinfo.slu.se). Unfortunately the web-material is still in Swedish but a translation to English is being undertaken.

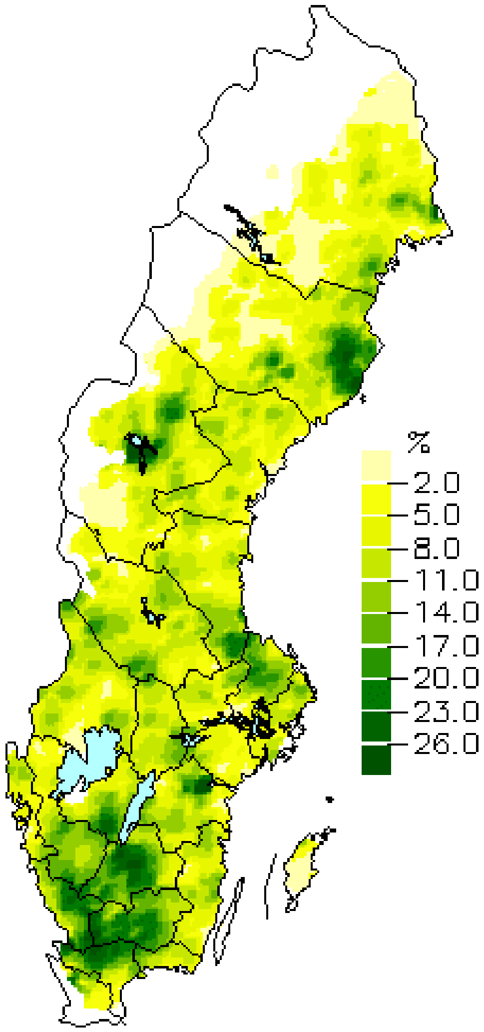

Figure 1: Distribution of Histosols (peatlayer > 30cm) in % of land area.

[Based on data from the Swedish National Survey of Forest Soils and Vegetation.]

Integrated Monitoring (IM)

Integrated Monitoring is presently carried out at four locations in Sweden where there is no or only minor impact from forest management. These sites are: Gårdsjön (F1) - SE04, Aneboda - SE 14, Kindla - SE 15, and Gammtratten - SE 16. The monitoring is carried out in accordance with the UN/ECE LRTAP convention and is part of European-Canadian network.

The monitoring includes water and nutrient budgets for small catchments (50-100 ha) and measurements of climate, hydrology, soil physical and chemical properties, soil unit, soil-water and ground-water chemistry, deposition of e.g. N and acidity, vegetation species, soil respiration, litter decomposition and arginin in needles.

Measurements were initially made in a 50m x 50m grid for each of the catchments. Four horizons of the soils were sampled and analysed. Within each catchment there is a sub-plot for intensive monitoring with renewed sampling and analyses at 5-year intervals.

Thirty six samples are collected and put together to form 6 composite samples for each one of the layers: humus layer, 0-5, 5-10, 10-15 and 15-20 cm. In addition three separate samples are collected from 70 cm depth. Chemical analyses include major and trace elements. The IM activities are described on the world wide web: http://info1.ma.slu.se/IM/.

Intensive Monitoring Plots

The Intensive Monitoring is a national network for managed forests consisting since 1995 of 223 plots of which about 100 plots are part of an international network (ICP Forest, level 2). Of the total number of plots, almost 200 are located in conifer stands, and 30 in deciduous stands. The main aim is to investigate forest vitality and its changes over time. To this end, the measurements on each plot include, apart from a number of tree parameters, soil chemistry and soil-water chemistry.

This monitoring is thus relevant with respect to the soil survey activities carried out in Sweden. The plots are not randomly located but placed in order to cover a range of deposition conditions and to represent commonly occurring site types. The soil measurement programme comprises: initial (just once) determination of contents of N, organic matter and acidity and exchangeable base cations in different horizons.

General site characteristics such as type of parent material, soil unit and hydrological conditions are described.

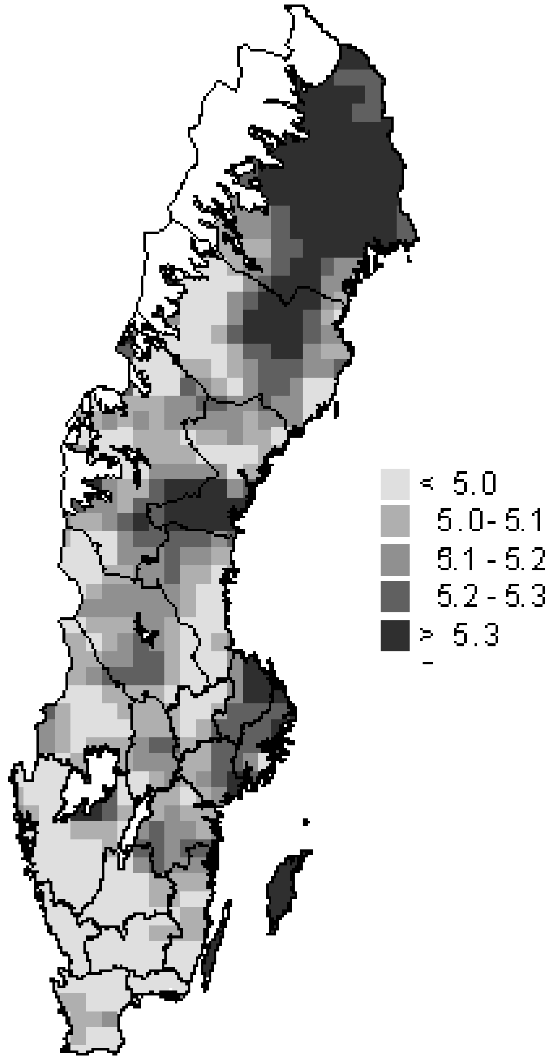

Figure 2: pH (H_2O) in B-horizon in forest soils.

[Data from The Swedish National Survey of Forest Soils and Vegetation 1983-1987.]

Monitoring of Arable Land

The current status of Swedish arable soils was monitored from 1988 to 1995 by the Department of Soil Science at SLU (Eriksson *et al.* 1997), with respect to humus content and the most important soil chemical properties. The data set includes 3,100 plough layer (0-20 cm) samples and 1,700 subsoil samples (40-60 cm) from sites randomly distributed throughout the country.

Chemical variables include: pH, total concentration of C, N and S, carbonate, cation exchange capacity and exchangeable base cations, and various trace elements. At each sampling site the 0-20 cm sample was composed of 6-20 subsamples, and the 40-60 cm sample of 6 subsamples. The area of the sampling site varied between 2 and 20 m^2.

Profiles were analysed in a 100 m grid net, with regard to texture, water retention capacity, pH, humus and calcium carbonate contents and plant available P and K.

The results from the monitoring of arable land identify the link between the investigated variables and general site conditions such as climate and parent material. One example is the distribution of trace elements in the plough layer (Ap), which can be explained mainly by parent material composition, a regional pattern due to influence of the parent materials being clearly visible.

However, anthropogenic depositions also affect the pattern to some extent, particularly with respect to Hg, Cd and Pb. Most of the information is presented and free to use as maps or as an interactive database on the world-wide-web (http://www-umea.slu.se/miljodata/akermark/index.htm). Regretfully the web-material still is in Swedish.

Soil Databases

Soil databases are generally available by the following means:

1. directly and interactively on the world wide web;
2. by order through the web;
3. by contacting the responsible authority.

Applications of Soil Data

Forestry plays an essential role in the Swedish economy, and forestry adaptation to site conditions is important both from a timber production and environmental point of view. The database from the National Survey of Forest Soils and Vegetation has facilitated the development of a method for determining site capacity based on site characteristics (Hägglund & Lundmark, 1976).

This system is generally practised now in Sweden and is particularly useful where site capacities cannot be estimated from stand properties, e.g. damaged stands, clear cut areas and shift in tree species. The database has also been used to estimate acidification (Troedsson, 1985), critical loads for acidity (Sverdrup *et al.*, 1992) and for nitrogen (Rosén *et al.*, 1992), and for the determination of base cation balances (Olsson *et al.*, 1993 and Olsson, 1993).

National strategies for forestry management and environmental protection have been developed by the National Board of Forestry and the Swedish Environmental Protection Agency. These strategies are based on the soil databases described above as well as on soil maps. They deal with measures like site preparation, fertilisation, and lime or ash application to counteract acidification. Several provinces in Sweden have based their selection of relevant or type sites for environmental monitoring on data from databases such as the National Survey of Forest Soils and Vegetation.

Currently a programme has started aimed at developing land use strategies for reducing net greenhouse gas emissions (LUSTRA) in Sweden. A prerequisite for the modelling and upscaling of greenhouse gases to national level is access to a national soil database.

Outlook

It is obvious that access to soil databases is increasingly important in order to understand ongoing changes and to develop guidelines for land use and management. Currently environmental surveys are carried out by different authorities but are partly co-ordinated by the Environmental Data Centre at SLU and the Swedish EnviroNet at the Swedish Environmental Protection Agency. The effectiveness should, however, benefit from a higher degree of co-ordination, e.g. between the surveys carried out the Geological Survey of Sweden (SGU) and the Swedish University of Agricultural Sciences (SLU).

It is worthy of note that soil analyses within forestry and agriculture are carried out on < 2mm fine material, whereas geochemical or mineralogical investigations within the geological discipline are often carried out on the < 0.06 mm fraction. This inconsistency restricts the ability to compare results.

It can be foreseen that more emphasis needs to be placed on the rather slow processes but often large pools in B horizons in managed forests, e.g. changes in C pools, acidity, nutrient conditions, etc. The present survey methods are not always sufficient to follow up these new environmental concerns, e.g. slow changes in the soil C-pool relative to the high degree of variability.

Supplementary survey systems need, therefore, to be employed.

Following the recognition of benefits from different land-use forms there is a shift of emphasis from biomass production to water and air quality. This may lead to a more intensive survey of certain critical site types like wet soils with high contents of C and N and with great impact on greenhouse-gas emissions and surrounding waters.

For the same reason the mountainous areas in north-west Sweden should be more intensively surveyed. They have previously been partly forgotten perhaps because of their insignificance for agriculture and forestry. We can also foresee that new parameters in the surveys will successively be introduced, e.g. biological activity, mycorrhiza, soil water in the unsaturated zone, biodiversity.

References

Andersson, A., Nilsson, Å. and Håkansson, L. (1989). Metal concentration of the mor layer. Swedish Environmental Protection Agency, Report 3990.

Davis, J.C. (1986). Statistical Data Analysis in Geology. New York: John Wiley & Sons.

Ekström, G. (1953a). Beskrivning till kartbladet Lund. Sveriges Geologiska Undersökning. Ser. Ad, No 2.

Ekström, G. (1953b). Cultivated soils (surface soils). Atlas över Sverige, nr 63-64. Svenska sällskapet för antropologi och geografi,. Stockholm. (In Swedish with English summary).

Eriksson, J., Andersson, A. and Andersson, R. (1997). Current status of Swedish arable soils. The Swedish Environmental Protection Agency, Report 4778. (In Swedish with English summary).

Hägglund, B. and Lundmark, J.-E. (1976). Site index estimation by means of site properties. Scots pine and Norway spruce in Sweden. Studia Forestalia Suecica, 138.

Olsson, M. (1993). Soils in northern Fennoscandia and Kola Peninsula from an environmental point of view - monitoring and present state. In: Symposium on the State of the Environment and Environmental Monitoring in Northern Fennoscandia and the Kola Peninsula, (Eds.: E.Tikkanen, M.Varmola & T.Katermaa). Arctic Centre Publications 4. Rovaniemi. 51 - 64.

Olsson, M., Melkerud, P.-A. and Rosén, K. (1993). Regional modelling of base cation losses from Swedish forest soils due to whole-tree harvesting. Applied Geochemistry, Suppl. Issue No.2, 189-194.

Olsson, M.T. & Troedsson, T. (1990). Soil forming factors and Spodosol properties in Sweden. In: Proceedings from the Fifth International Soil Correlation Meeting (ISCOM), Characterization, classification, and utilization of Spodosols. Maine, Massachusetts, New Hampshire, New York, Vermont, and New Brunswick, October 1-14 1987, (Eds. J.M. Kimble and R.D. Yeck). 422-432.

Rasmussen, K., Sippola, J., Låg. L., Troredsson, T. and Wiberg, M. (1991). Soil map of Denmark, Finland, Norway and Sweden, scale 1:2,000,000. Landbruksforlaget, Oslo.

Rosén, K., Gundersen, P., Tegnhammar, L., Johansson, M. and Frogner, T. (1992). Nitrogen enrichment of Nordic forest ecosystems - The concept of critical loads. Ambio, 21, 364-368.

Sverdrup, H., Warfvinge, P., Frogner, T., Håoya, A.O., Johansson, M. and Andersen, B. (1992). Critical loads for forest soils in the Nordic countries. Ambio, 21, 348-355.

Troedsson, T. and Wiberg, M. (1986). Soil map of Sweden. The Royal Swedish Academy of Agriculture and Forestry, Stockholm.

Troedsson, T. (1985). Sensitivity of Swedish forest soils to acidification related to site characteristics. National Swedish Environment Protection Board, Report 3001.